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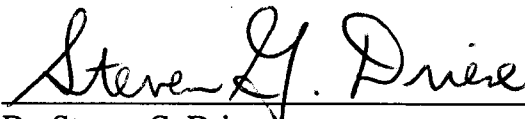
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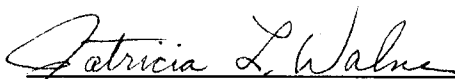
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DIATOM SUCCESSION ACROSS THE LATE PLEISTOCENE/HOLOCENE
INTERVAL: AN EXAMPLE FROM THE SOUTHEASTERN UNITED STATES

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Doctor of Philosophy

Degree

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Abstract

Lacustrine systems are influenced by changes in climate and surrounding vegetation. Changes in vegetation are themselves the result of changes in climate. The objective of this study was to investigate changes in a lacustrine system using fossil diatom assemblages and to compare changes in the diatom assemblages to known changes in aquatic and local terrestrial vegetation in the context of late Quaternary climate change. The study site, Anderson Pond in Middle Tennessee, is a karst sinkhole which has received continuous sedimentation for the last 19,000 years.

The fossil diatom assemblages indicate the presence of five diatom zones during the late Quaternary. The late-Pleistocene interval between 19,000 and 12,750 years Before Present (BP) is dominated by small, benthic species of the genus *Fragilaria*, which are characteristic of alkaline (diatom inferred pH: 6.8 to 7.7), high clarity water, with depths up to 6 meters. Between 12,500 BP and 10,000 BP, a new diatom assemblage establishes that is pH-indifferent (diatom inferred pH: 6.1 to 6.3), shallow-water epiphytic and epipelagic, and dominated by the genera *Eunotia*, *Pinnularia*, and *Stauroneis*. The early to middle Holocene diatom assemblages from 9750 BP through 2250 BP are dominated by the acidophilous, epiphytic genera *Eunotia* and *Gomphonema*, indicating shallow-water levels with acidic water (diatom inferred pH: 5.6 to 5.8). From 2000 BP through 250 BP the diatom assemblages are dominated by planktonic diatoms of the genus *Aulacoseira*, indicating at least seasonal expansion of shallow, open water pools

with continued acidic pH levels (diatom inferred pH: 5.5 to 5.8) and a decrease in water transparency. Modern sediment samples are dominated by the epiphytic genera *Gomphonema*, *Eunotia*, and *Navicula* indicating even shallower water levels and an increase in water pH to neutral conditions (diatom inferred pH: 6.2).

The disappearance of the *Fragilaria*-dominated assemblage between 12,750 BP and 12,500 BP in Anderson Pond coincides with a major change in upland forests from boreal jack pine and spruce to temperate oaks. The following three thousand years represent a period of cumulative changes in aquatic plant communities within the karst basin, associated with the local expansion of a mosaic wet meadow grassland and swamp thicket. *Eunotia* reached dominance by 9750 BP and this diatom assemblage remained relatively stable until 2250 BP. The early Holocene rise in *Eunotia* is linked to the availability of an epiphytic substrate--this is tied to the early Holocene infilling of the basin and the establishment, then expansion of dense alder thickets forming swamps. The rapid increase in *Aulacoseira* between 2250 BP and 2000 BP corresponds with a modest rise in water table and the expansion of open pools within the swamp thicket. The disappearance of *Aulacoseira* and the increase in *Gomphonema*, *Eunotia*, and *Navicula* during the last 250 years resulted from human activity leading to increased sediment influx into the basin.

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CHAPTER I

Introduction

Concern for the apparently enhanced variability in contemporary weather patterns and for near-term projections of major climatic warming (Schneider, 1989) has led the scientific community to look to the past for clues as to how our present climate may respond to potential future changes (Graham & Grimm, 1990; Overpeck et al., 1991; Davis & Zabinski, 1992). The last 19,000 years of geologic history, the late Pleistocene and Holocene, was a time of profound climatic change characterized by the last episode of continental glaciation and the retreat of the Laurentide Ice Sheet across northern North America. Much paleoecological work has been done on this interval of abrupt and major climatic change, particularly based on plant fossil studies of changes in terrestrial vegetation (Delcourt & Delcourt, 1987a, b, 1991). Because the broad-scale migration of plants often lags behind climatic changes and individual species respond differently to climate change depending on their dispersal abilities, other independent geochemical and paleontological data may be useful as alternate proxy monitors of paleoclimate over the last glacial-interglacial cycle (Bradley, 1985; Wright et al., 1993).

Diatom assemblages are useful as proxy indicators of climate change (Warner, 1990). They are generally abundant in freshwater-lake environments and their siliceous tests, readily identified to genus and species, are commonly preserved in lacustrine

deposits. Most species have specific environmental conditions under which they can live, particularly in regard to water chemistry, water clarity, and substrate (Brugam, 1983, 1993; Anderson et al., 1986). They also tell us much about hydrologic conditions, specifically changes in water depth, which cannot be obtained from fossil-pollen studies. Previous studies have shown that diatoms often respond differently to climate changes than does the surrounding upland vegetation (Fritz, 1989; Wolfe & Butler, 1994). Most of the previous studies of Quaternary diatom in eastern North America have concentrated on two regions: north of 40°N latitude primarily in deglaciated terrains of the Great Lakes region (Bradbury, 1975; Brugam, 1980, 1993; Brugam et al., 1988; Bradbury & Dieterich-Rurup, 1993) and New England (Davis, 1987; Winkler, 1988; Whitehead et al., 1989; Charles et al., 1990; Ford, 1990), or, south of 30°N latitude in Peninsular Florida (Sweets et al., 1990; Stoermer et al., 1992). This study will present information on the nature of diatom response to late-Quaternary climate change within the intervening middle latitudes of the unglaciated Southeast.

The Late-Pleistocene/Early-Holocene Interval

The transition from the late Pleistocene to the early Holocene marked an important climatic transition in earth history. In North America a significant factor in this transition from glacial to post-glacial mode was the changing patterns and relationships of the major North American airmasses (Wright et al., 1993). Using fossil-pollen data, Delcourt & Delcourt (1984, 1993) mapped out the broad changes in vegetation within

eastern North America over this period. These changes in vegetation were then used to infer the shifting positions in modal boundaries of major airmasses delimiting climatic regions.

Of particular importance was the spatial displacement of the Polar Frontal Zone separating the cold Pacific airmass to the north from the warmer Maritime Tropical airmass to the south. The Polar Frontal Zone acted as a stable boundary, located at about 33°N, between airmasses during the late glacial interval from 19,000 to 12,500 BP (radiocarbon years Before Present). This Polar Frontal Zone anchored the ecotonal boundary between more-northern boreal conifer forests and southern temperate oak and pine forests (Delcourt & Delcourt, 1984). By 10,000 BP the Polar Frontal Zone had migrated northward to about 41°N along the eastern Atlantic Coast and up to about 45°N in the Great Plains region. This fundamental change is indicated in the fossil-pollen record by a northward migration of mixed conifer-northern hardwood forests and deciduous forests (Wilkins et al., 1991; Delcourt & Delcourt, 1993).

Purpose

The purpose of this dissertation is to investigate how diatom assemblages in the southeastern United States have responded to climatic change during the last 19,000 years, with particular reference to the late Pleistocene period between 14,000 and 10,000 BP and the early Holocene from 10,000 to 9000 BP. The effects of climate changes on lakes, including such factors as hydrologic fluctuation in water depth and seasonal

variation of water-surface temperatures, are reflected by changes in diatom assemblages. Changes in diatom assemblages are also influenced by peripheral changes in the surrounding upland vegetation or in the more local, aquatic macrophyte vegetation. The type of upland vegetation present affects both rates of soil weathering and the chemistry of water flowing into a lake (Whitehead et al., 1973). An important aspect of this study is to investigate the relative influence of climatic, hydrologic, and vegetational change on diatom assemblages at Anderson Pond, Tennessee. Specifically this study addresses three hypotheses:

1. **Do diatom assemblages record prominent late Quaternary climatic events, such as occurred at middle latitudes in eastern North America during the late Pleistocene/early Holocene interval?**

Prediction: As the Polar Frontal Zone migrated northward climatic changes would have led to changes in the composition of diatom assemblages. Diatoms have wide temperature tolerances; however, they are sensitive to length of growing season and the duration of annual ice cover, both of which are dependent on mean annual temperature and seasonality. Consequently, climatic changes, particularly associated with the changing locations of major airmasses, should be recorded as changes in the composition and abundance of species within diatom assemblages.

2. **Do diatom assemblages reflect changes in water depth and sedimentation rates within lacustrine sites, which in turn coincide with regional changes in both climate and upland vegetation?**

Prediction: The decrease in lake depths and sediment accumulation rates across the late Pleistocene/early Holocene interval would have led to changes in diatom assemblages. Decreasing lake levels would have reduced habitats for some diatom species, particularly open water plankton, and increased habitats for other diatoms, such as diatoms epiphytically attached to littoral marsh or swamp vegetation. Decreasing sedimentation rates of inorganic particles should have led to deeper sunlight penetration of near-surface waters allowing diatoms, particularly benthic species, to colonize deeper parts of the lake. Both of these changes in the hydrologic systems should be recorded in the fossil record as changes in species composition and abundance of diatom assemblages.

3. **Do climatically induced changes in diatom assemblages lead or lag changes in the surrounding terrestrial vegetation?**

Prediction: If changes in diatom assemblages *lead* changes in upland vegetation this will be seen in a comparison of both the timing and rates of change in diatom assemblages versus fossil-pollen assemblages using Detrended Correspondence Analysis (DCA). If changes in diatom assemblages lag changes in vegetation, the implication is that diatom assemblages are primarily climate controlled.

Alternate Prediction: If changes in diatom assemblages *lag* behind changes in upland vegetation, as measured by both timing and rates of change in diatom assemblages versus fossil-pollen assemblages using DCA, then the implication is that diatom assemblages are primarily nutrient or substrate controlled.

CHAPTER II

Diatoms as Environmental Indicators

The study of the ecology of diatoms began in the late 19th century, with paleoecological studies as early as the 1920s (references summarized in Battarbee, 1986). Much research has focused upon the role of factors such as habitat, salinity, pH, and nutrients in shaping diatom assemblages (Battarbee, 1986). Patrick & Reimer (1966, 1975) in their taxonomic monographs on the diatoms of the United States included some basic ecological information, such as pH and nutrient preferences. Lowe (1974) compiled an extensive listing of environmental requirements and tolerances of many diatom species that is still a commonly cited reference for diatom studies. Lowe's compilation included information on pH, nutrient, habitat, temperature requirements, as well as other information, such as seasonality of population expansion or "blooms." Most recently diatoms have been used in paleoecological studies as important indicators of historic environmental change, including limnologic changes in pH, salinity, trophic status, and climate (Davis, 1987; Dixit et al., 1992; Fritz, 1996).

Diatoms can be treated as environmental indicators for interpreting some of the important changes that may have occurred in their environment using calibration equations of modern abundance of diatom species correlated with factors such as water depth and pH (Brugam, 1983, 1993; Smol, 1987; Sweets et al., 1990). Autecological data

for representative diatom assemblages and their associated affiliation with water-quality data are broadly available from the western Great Lakes region (Brugam, 1993), New England and the maritime provinces of eastern Canada (Davis, 1987; Whitehead et al., 1989; Charles et al., 1990), as well as in Florida (Sweets et al., 1990). These contemporary data suites bracket the spatial realm of modern-day analogous conditions across eastern North America which are expected to correspond with the temporal succession of late Quaternary diatom assemblages at Anderson Pond, Tennessee.

Acidity/Alkalinity of Lake Water

Diatoms are extensively used as indicators of water pH (Battarbee et al., 1986). Because most diatom taxa have specific, narrow ranges of pH for aquatic conditions in which they live, diatom assemblages can readily be grouped in a pH classification system as shown in Table 1 (Battarbee, 1986; Smol, 1987). This pH classification system of five diatom groups, consisting of two acidic groups or units, one pH-indifferent unit, and two alkaline units, was originally developed by Hustedt from his studies of diatoms in Java, Bali, and Sumatra (Hustedt, 1937-1939) and subsequently modified by others (see summary in Battarbee, 1986; Battarbee et al., 1986). Appropriate calibration equations have been used upon "down-core" assemblages of fossil diatoms in order to document long-term natural and short-term culturally influenced acidification of lake basins (Renberg & Hellberg, 1982; Davis, 1987; Winkler, 1988; Whitehead et al., 1989).

Table 1: Hustedt's pH classification system of diatom assemblages
(Hustedt, 1937-1939; Battarbee, 1986).

pH Group	Symbol	Occurrence
Acidobiontic	AcB	below pH 7; optimum pH 5.5 and below
Acidophilous	Ac	around pH 7, but mainly below pH 7
pH-Indifferent	Ind	equally above and below pH 7
Alkaliphilous	Al	around pH 7, but mainly above pH 7
Alkalibiontic	AlB	above pH 7

Nygaard (1956) developed the first quantitative measure of pH based upon diatoms. Nygaard gave more weight to Hustedt's groups for acidobiontic (AcB) and alkalibiontic (AlB) taxa, weighting them each by a factor of five, and used the collective percentages of the different diatom groupings to create three pH indices for water acidity:

Index α = ratio of acid units to alkaline units

$$= [5(\%AcB) + (\%Ac)] / [5(\%AlB) + (\%Al)]$$

Index ω = acidic units/number of acidic-tolerant species

$$= [5(\%AcB) + (\%Ac)] / (\#AcB + \#Ac)$$

Index ε = alkaline units/number of alkaline-tolerant species

$$= [5(\%AlB) + (\%Al)] / (\#AlB + \#Al)$$

Meriläinen (1967) made a significant modification to Nygaard's system by calibrating the three indices using measurements of the autumn values for pH from fourteen Finnish lakes (Figure 1).

One of the major weaknesses in the Nygaard/Meriläinen system is the relative underweighting for pH-indifferent taxa. This insensitivity for pH-indifferent diatoms was addressed by Renberg & Hellberg (1982) who created an index B which included pH-indifferent taxa:

$$B = \frac{\% Ind + (5 \times \% Ac) + (40 \times \% AcB)}{\% Ind + (3.5 \times \% Al) + (108 \times \% AlB)}$$

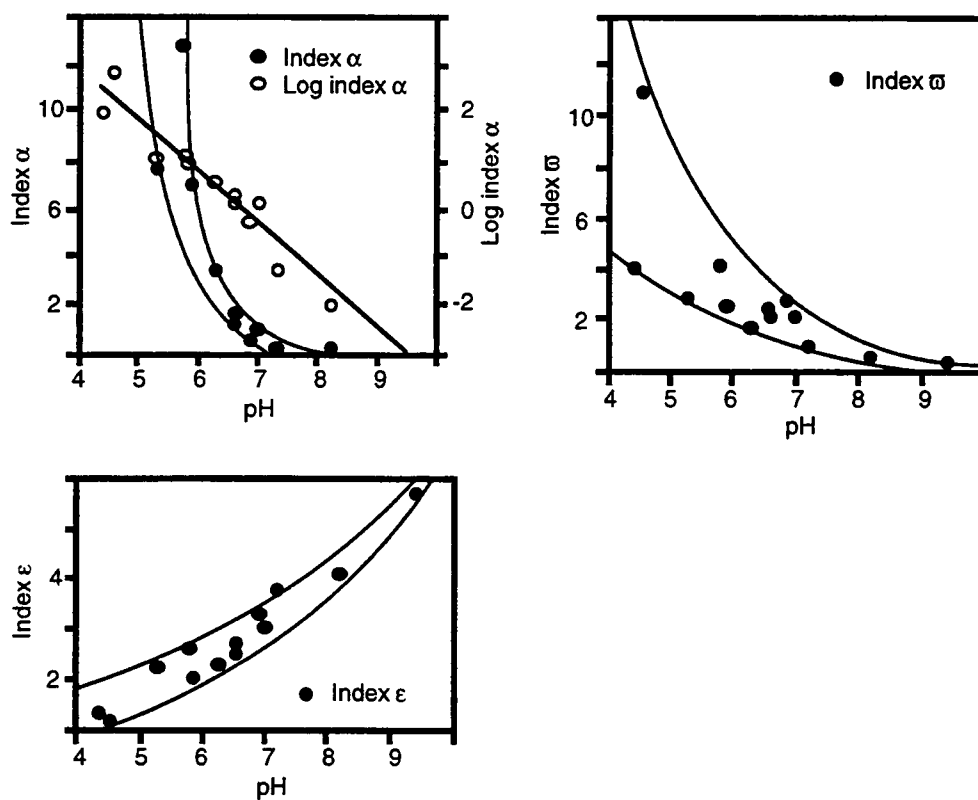


Figure 1. Meriläinen's (1967) calibration of Nygaard's diatom-based indices of water pH graphed against Finnish lake measurements of pH (modified from Battarbee, 1979).

This index was formulated from the analysis of surface-sediment diatom assemblages and water pH from 30 lakes obtained from southwestern Sweden and from the published literature. From this information an equation for pH from log index B (Figure 2) was obtained using linear regression:

$$\text{pH} = 6.40 - 0.85 \log \text{index B}$$

Renberg & Hellberg (1982) then applied this index to paleoecological studies of three lakes in southwestern Sweden to determine pH histories of these lakes (Figure 3). Log index B is still widely used today in paleoecological studies of pH, although the weighting factors for the Hustedt groups must be quantified for regional measures of index B.

More recently multiple regression techniques have been applied to the relationship between modern lakewater pH and diatom assemblages (Charles, 1985; Davis & Anderson, 1985; Charles & Smol, 1988) and the limnologic interpretation of pH histories (Charles & Smol, 1988; Ford, 1990).

Charles (1985) compared surface sediment diatom assemblages to lakewater characteristics in 37 Adirondack Mountain lakes in northern New York. The application of reciprocal averaging ordination (RA) to the data set demonstrated a strong correlation between diatom assemblages and pH-related factors (pH, $r^2 = 0.90$; alkalinity, $r^2 = 0.81$; p(Ca positive charges), $r^2 = 0.67$; pMg, $r^2 = 0.78$; pNa, $r^2 = 0.48$; p-total Al, $r^2 = 0.58$; and conductivity, $r^2 = 0.47$). Existing regression equations (Nygaard, 1956; Renberg & Hellberg, 1982) and equations derived from the data set were then used to test the predictive relationships between lakewater pH and diatom assemblages. All of the

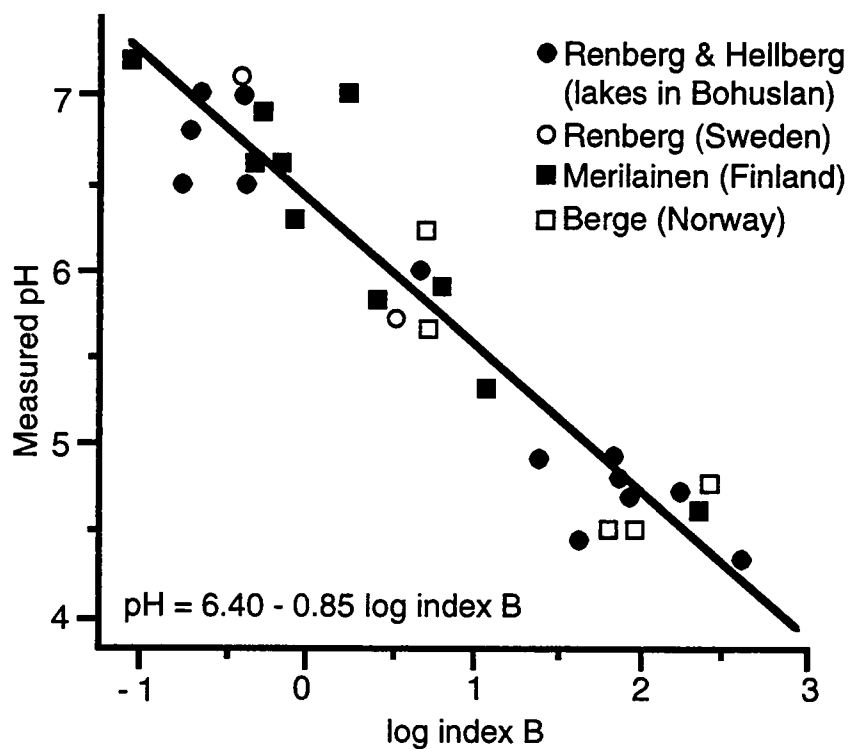


Figure 2. Diatom-based measure of log index B plotted against water pH (modified from Renberg & Hellberg, 1982); calculation including percentages for Hustedt's diatom groups.

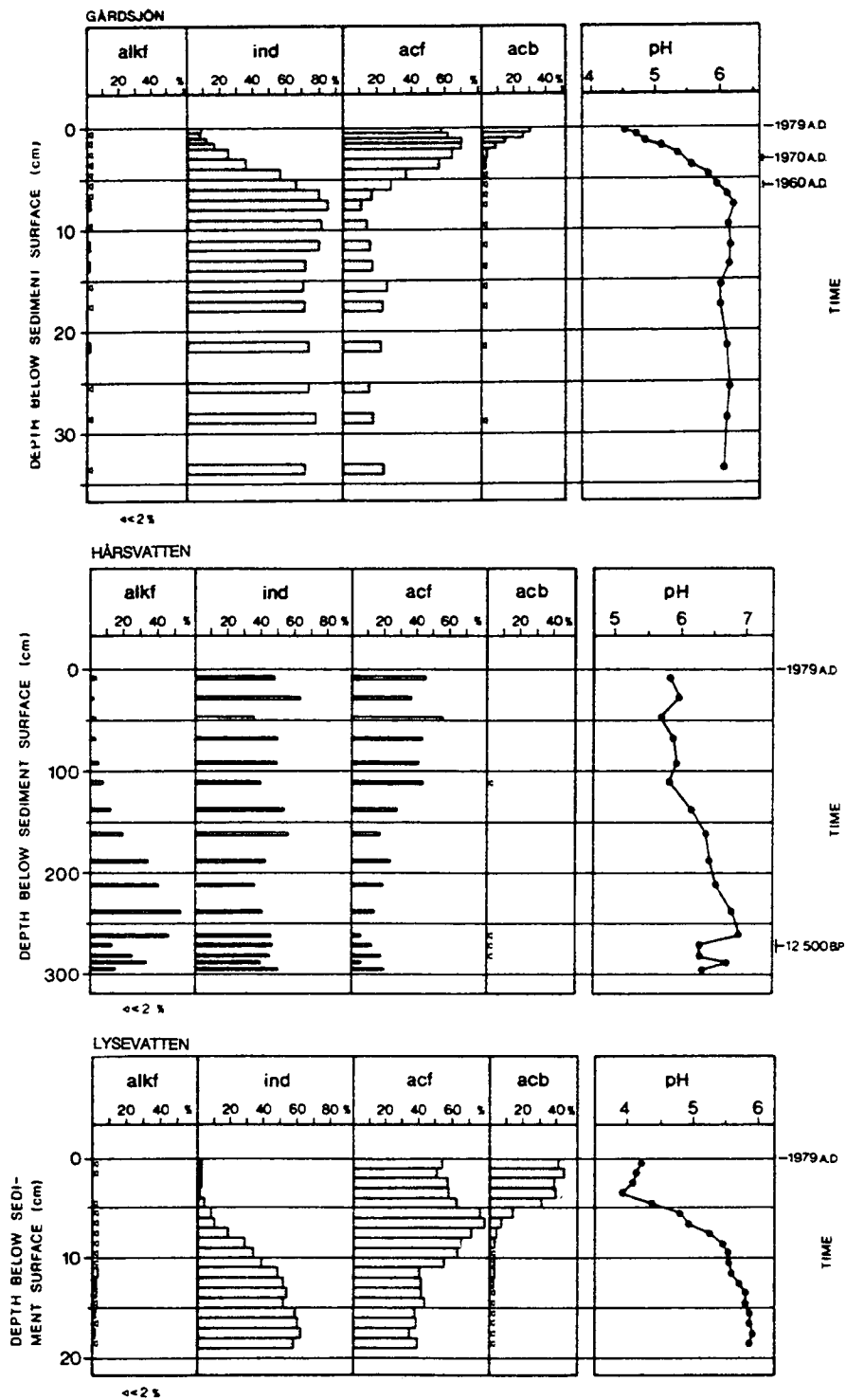


Figure 3. Postglacial changes in water pH from Swedish lakes, inferred from log index B and percentage of major Hustedt diatom groups (modified from Renberg & Hellberg, 1982).

regression equations (Table 2) show a strong correlation between lakewater pH and diatom assemblages (r^2 from 0.61 to 0.94), with strongest correlations for Nygaard's Index α ($r^2 = 0.91$), Renberg & Hellberg's Index B ($r^2 = 0.91$), and Charles' equation derived from diatom pH categories ($r^2 = 0.94$).

Davis & Anderson (1985) studied 31 lakes in New England and 36 lakes in Norway with pH values from 4.4 to 7.1. The authors compared three methods of regression analysis of diatom assemblages and surface water pH: relative frequencies of selected diatom taxa, first principal component (1 PC) of these frequencies, and frequencies of Hustedt pH groups. They found that the best results were obtained using relative frequencies of selected taxa and the first principal component, with r^2 values from 0.69 to 0.91. Regressions based on Hustedt's pH groups had lower r^2 values (0.27 to 0.57). Of the two best techniques, principal components analysis is less susceptible to erratic results due to unusual frequencies of individual taxa.

Ford (1990) compared different quantitative methods and applied these to a study of the 10,000 year record of Cone Pond, New Hampshire (Table 3). She found that the principal components analysis (PCA) method of Davis & Anderson (1985) and the multiple regression calculated by Charles (1985) produced pH values that more closely matched the modern pH of Cone Pond (given this value) than Renberg & Hellberg's Index B, and, therefore, used these two techniques to reconstruct the postglacial pH history of Cone Pond based upon fossil diatom sequences.

Table 2: Regression Equations for Inferring pH From Diatom Assemblages (Charles, 1985). All relationships are highly significant ($p < 0.0001$).

Equations	$r^2 \pm \text{SE (pH units)}$
Assignment of diatom taxa to pH categories based primarily on literature references.	
1) $\text{pH} = 6.81 - 0.70 \log_{10} \text{index } \alpha$	$.91 \pm .33$
2) $\text{pH} = 4.57 + 2.28 \log_{10} \text{index } \epsilon$	$.67 \pm .51$
3) $\text{pH} = 8.44 - 2.33 \log_{10} \text{index } \omega$	$.74 \pm .57$
4) $\text{pH} = 6.91 - 0.85 \log_{10} \text{index B}$	$.91 \pm .34$
5) $\text{pH} = 7.99 - 0.039 \text{ AcB} - 0.035 \text{ Ac} - 0.0087 \text{ Ind} - 0.0013 \text{ Al}$	$.93 \pm .30$
Assignment of idatom taxa to pH categories based primarily on occurrences in Adirondack study lakes.	
6) $\text{pH} = 6.97 - 0.69 \log_{10} \text{index } \alpha$	$.89 \pm .38$
7) $\text{pH} = 5.01 + 1.79 \log_{10} \text{index } \epsilon$	$.61 \pm .60$
8) $\text{pH} = 8.75 - 2.48 \log_{10} \text{index } \omega$	$.83 \pm .46$
9) $\text{pH} = 7.04 - 0.73 \log_{10} \text{index B}$	$.91 \pm .33$
10) $\text{pH} = 8.14 - 0.041 \text{ AcB} - 0.034 \text{ Ac} - 0.0098 \text{ Ind} - 0.0034 \text{ Al}$	$.94 \pm .28$
11) $\text{pH} = 5.30 - 0.033 \text{ Cluster B} + 0.0049 \text{ Cluster C} +$ $0.053 \text{ Cluster E} + 0.019 \text{ Cluster F}$	$.89 \pm .38$

Table 3: Diatom-inferred pH of surface-sediment sample,
Cone Pond, New Hampshire (Ford, 1990).

Source	Equation	Type	Predicted pH
Davis and Anderson, 1985	1	Based on taxa, full range of lakes	4.44
Davis and Anderson, 1985	2	Based on taxa, low-alkalinity lakes	4.27
Davis and Anderson, 1985	3	Based on principal components analysis, full range of lakes	4.58
Davis and Anderson, 1985	4	Based on principal components analysis, low-alkalinity lakes	4.76
Charles, 1985	Multiple regression	Adirondack pH-preference catagories using all taxa	5.36
Charles, 1985	Multiple regression	Adirondack pH-preference catagories; unidentifiable taxa removed	4.87
Charles, 1985	Multiple regression	Literature pH-preference catagories using all taxa	5.33
Charles, 1985	Multiple regression	Literature pH-preference catagories; unidentifiable taxa removed	4.85
Charles, 1985	Renberg & Hellberg's B	Adirondack pH-preference catagories using all catagories	5.14
Charles, 1985	Renberg & Hellberg's B	Adirondack pH-preference catagories; unidentifiable taxa removed	5.14
Charles, 1985	Renberg & Hellberg's B	Literature pH-preference catagories using all taxa	5.13
Charles, 1985	Renberg & Hellberg's B	Literature pH-preference catagories; unidentifiable taxa removed	5.13
Actual lakewater pH			4.48-4.72

Other methods have been applied to the interpretation of pH changes inferred from diatom assemblages. Jones & Flower (1986) used the DECORANA program for Detrended Correspondence Analysis (DCA) to show the relationships for temporal and spatial samples of epipsammic (attached to sediment grains) and epilithic (attached to rock surfaces) diatoms in an acidified lake in Scotland. Their results on DCA Axis 1 indicated a greater spatial variation than temporal variation in species composition (Figure 4), but showed a good correlation between measured lake water pH and reconstructed pH from the surface-sediment diatom assemblages. The authors concluded that surface sediment samples contained a broad and representative mixture of diatoms from different habitats in the lake, sufficient to provide modern-day analogs for interpreting the postglacial changes in diatom composition from this region (Jones & Flower, 1986).

Climate

Diatoms can also be used to infer changes in climatic factors such as mean annual temperature and seasonality, which control the percentage of the year that a lake is free of ice cover and the length of the growing season (Smol, 1987). For example, an episode of climatic cooling may result in a decrease in diatom abundance due to increased ice cover in winter, preventing deep-water diatoms from proliferating (Smol, 1987).

Diatoms thus can be used to study the timing of local hydrologic changes, indirectly driven by the regional passage of the atmospheric Polar Frontal Zone. Because their life histories and dispersal mechanisms differ from those of terrestrial trees, aquatic

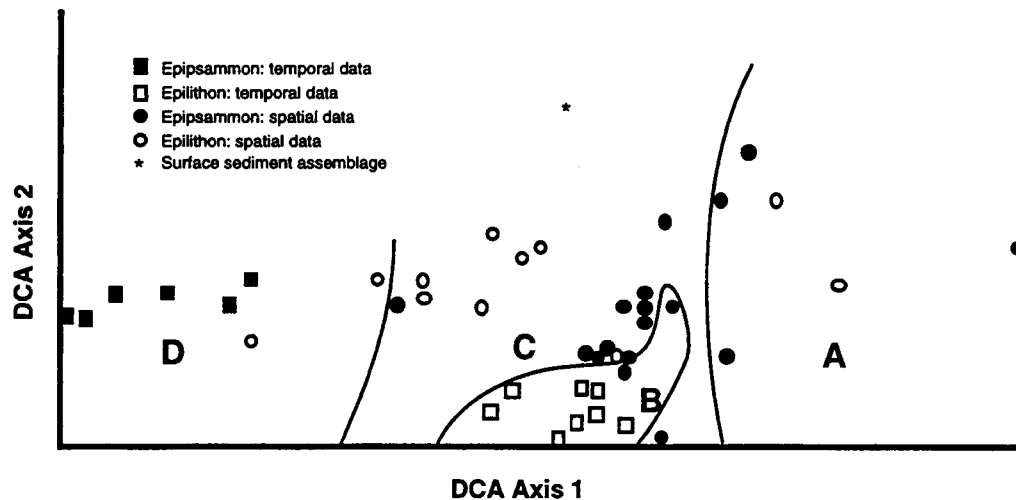


Figure 4. Use of detrended correspondence analysis to characterize contemporary (surface-sediment) and postglacial (sediment core) structure within diatom assemblages from epipsammon and epilithon habitats of a Scottish lake (modified from Jones & Flower, 1986). The epilithon assemblages display broad overlap among fossil (temporal) samples in the sediment core and the spatial array of measurements from seventeen Scottish lakes. However, along Axis 1 of DCA, Assemblage D for epipsammon taxa includes postglacial assemblages *not* adequately paired by contemporary surface-sediment samples. Groups A to D were separately characterized by TWINSpan.

diatoms with their annual life cycles may help in constraining the timing of climatic changes. The importance of seasonality for many diatom species (Smol, 1987) may also be important for studying the timing of airmass movements, because increased seasonality also accompanied the northward migration of the Polar Front.

Hydrology

Because of their sensitivity to water depth and turbidity (Birks & Birks, 1980; Smol, 1987), diatoms are useful for studying the paleohydrology of lacustrine systems. Water level fluctuations are indicated by the relative amounts of planktonic diatoms and benthic diatoms living on lake-bottom muds and plants. A high relative abundance of free-floating, planktonic species is indicative of deeper lakes with sufficient open water, whereas a high relative abundance of benthic species is indicative of clear water or shallower-water depths within the photic zone permitting diatom photosynthesis. Water turbidity is one factor which controls the amount and depth of sunlight that can penetrate into surface waters of a lake (the photic zone) and is therefore important in determining the number and type of diatoms, as well as the habitats they occupy within a lake (Brugam, 1983; Smol, 1987). In late-Quaternary lake records, calculated measures of accumulation rates for mineral sedimentary particles may be used as an index for prehistoric changes in water clarity and turbidity.

Upland Vegetation

Climatic changes lead to changes in vegetation as terrestrial plant species migrate to track, or stay within, their range of environmental tolerance and ability to compete (Wright, 1984). Because a terrestrial plant species can only migrate as rapidly as its seeds (or spores) can be dispersed and successfully colonize available habitats, the migration of taxa into new areas often lags hundreds of years behind the onset of climatic changes that allowed for their initial migration response (Davis & Zabinski, 1992; Webb et al., 1993).

Changing climatic conditions also lead to changes in the taxonomic composition of diatom assemblages and their abundance. The changes in the diatom assemblages may lead or lag behind changes in upland vegetation, depending on whether the diatom species are most strongly influenced either by climate or by their available habitat or nutrient supply, respectively. Differences in the dispersal ability of diatoms relative to upland vegetation should also contribute to differences in their respective rates of migration during periods of climate change. Diatoms appear to be easily dispersed throughout freshwater environments; however, the exact mechanisms are not well known (Round, 1981). Dispersal among non-interconnected water bodies may occur via wind transport or by birds. Diatoms may inadvertently be carried by waterfowl, as clumps of diatom frustules and mud may stick to feathers or webbed feet, or be carried internally within the avian digestive tract (Smith, 1950; Round, 1981).

Some studies have shown that diatoms respond more rapidly than upland vegetation during postglacial climatic changes. In Newfoundland, Wolfe & Butler (1994)

found that, with high frequency temperature fluctuations during the Pleistocene-Holocene transition, diatoms responded to the Younger Dryas cooling event more rapidly than terrestrial-plant assemblages with as much as a 250-year difference. The onset of cooling was recorded in the diatoms by a decrease in their abundance, which the authors attributed to increased thickness of capping ice cover on the lake, blocking sunlight and reducing littoral habitat availability.

Other studies have found that changes in the diatoms lag behind changes in the terrestrial vegetation. Brugam et al. (1988), in a study of the diatom and pollen record from Lily Lake, Minnesota, found that, in some cases, changes in the diatoms occurred after changes in the fossil-pollen assemblages from the same site. The modern diatom assemblages from 255 surface sediment samples in Minnesota, Maine, and eastern Canada (Brugam, 1983, 1993) were compared with water chemistry data to obtain potential modern analogs for fossil diatom assemblages. The positions of modern lakes along DCA Axis 1 and Axis 2 can be compared with environmental variables to determine clusters of lakes with similar environmental variables (clusters numbered 1 through 10 in Figure 5). This information was used to interpret the fossil diatom record from Lily Lake, Minnesota, which contains a record of the last 11,500 radiocarbon years. In their comparison of the diatom and pollen records, Brugam et al. (1988) found that an increase in prairie herbs occurred in the pollen record at about 8000 BP while a shift to alkaline water diatoms, primarily indicated by an increase in abundance of the planktonic diatom *Stephanodiscus hantzschii*, did not occur until 7100 BP. The combination of increased

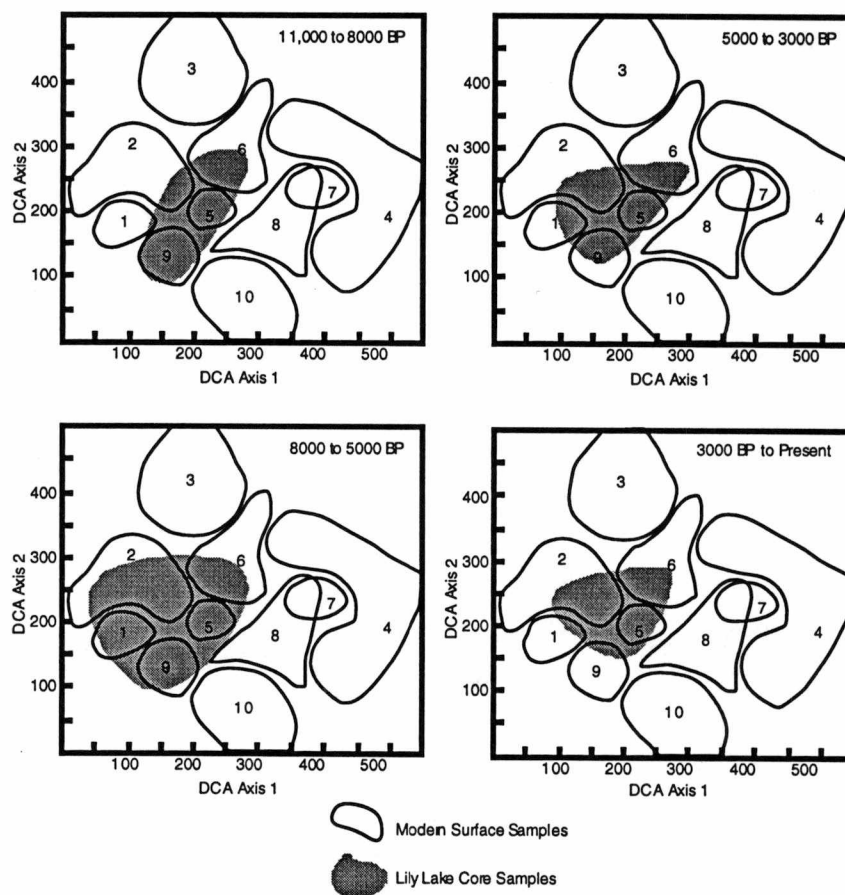


Figure 5. Lily Lake, MN record to compare time and type of terrestrial vegetation and lag of diatom establishment (modified from Brugam et al., 1988).

annual and summer temperatures, reduced and more variable precipitation during the growing season, and increased fire frequency (Wright, 1968) led to the displacement of forest by grassland communities and the eastward shift of the Prairie Peninsula through the western Great Lakes region. This vegetation response tracked the increased zone flow of westerlies and the persistence of the hot dry Pacific Air mass throughout more of each year (Bartlein et al., 1984). Brugam et al. (1988) attributed this mid-Holocene change in the diatom record to climatically induced changes in hydrologic conditions, specifically decreased annual precipitation and increased summertime evaporation of surface waters, and not to vegetationally induced water chemistry changes. The limnologic shift in salinity from permanent fresh water to seasonally fluctuating brine pools triggered changes in both pH and conductivity of the lake waters, in turn driving the major Holocene changes in aquatic diatom assemblages.

Still other studies have shown more complex responses to climatic change with diatom assemblages changing both before and after principal changes in the fossil-pollen record (Brugam, 1980; Fritz, 1989), with responses attributable to both climatic events and vegetationally induced changes in water chemistry.

Fritz's (1989) study of Diss Mere in Norfolk, United Kingdom, spanned the last 10,000 years and recorded both climatic and anthropogenic changes in the fossil-pollen and fossil-diatom assemblages (Figure 6). In the early Holocene interval, changes occurred in the upland vegetation, corresponding with the distinctive pollen assemblages associated with pollen zones 1 through 4, while during the same time span, the diatom assemblages

Time	Vegetation and cultural events	Pollen zone	Pollen zone	Diatom stratigraphical events	Other limnological events
Present	Local tree plantings	8	4	<i>Cyclotella meneghiniana</i> , <i>Stephanodiscus</i> sp. 2, <i>Melosira granulata</i> expand	Increase in iron sulfides
			3d	<i>Stephanodiscus hantzschii</i> dominant	
	Expansion of town in 13th century	7d	3c	<i>Melosira granulata</i> dominant	
			3b	<i>Stephanodiscus</i> cf. <i>oregonica</i> dominant	Increase in mineral matter inwashing
	<i>Cannabis</i> cultivation	7c			
	Founding of town (Anglo-Saxon)	7b			
	Expansion of cereal cultivation				
	Roman	7a	3a	<i>Stephanodiscus parvus</i> dominant	
	Iron Age				
	Widespread forest clearance				
	<i>Hordeum</i> cultivation - Iron Age	6	2c	<i>Stephanodiscus</i> spp. expand	Laminated sediments cease
	<i>Tilia</i> decline			<i>Cyclotella ocellata</i> expands	
	Neolithic	5	2b	<i>Nitzschia</i> spp. and <i>Synedra arcus</i> expand	
	<i>Ulmus</i> decline		2a	<i>Cyclotella comta</i> and <i>C. kuetzingiana</i> dominate	Laminated sediments preserved
		4		Low diatom concentrations	<i>Oscillatoria</i> expansion
	Mixed-deciduous forest expansion		1		
		3		Increased diatom concentrations <i>Cyclotella</i> spp.	Calcareous fine-detrital sediments w/layers of silt and clay
10,000 BP	Spread of <i>Corylus</i>	1		Low diatom concentrations	Minerogenic sediments
	Open <i>Betula</i> woodland				

Figure 6. Holocene limnological changes in diatom assemblages, and terrestrial vegetation impacted by prehistoric cultural land use in Diss Mere, Great Britain (modified from Fritz, 1989).

displayed little compositional change, maintaining diatom zone 1 until 6000 BP. During the middle Holocene, from 6000 BP to 2500 BP, changes occurred in both the upland vegetation and the diatom assemblages. During this period, the changes in the diatom communities generally lagged behind the changes in the upland vegetation. This is particularly noticeable where the onset of diatom zones 2b, 2c, and 3a follows the onset of pollen zones 5, 6, and 7a, respectively (Figure 6). During this time changes in the limnologic system lagged behind changes in the upland vegetation, which were brought about by anthropogenic disturbance of the surrounding forests, and subsequently mineral-sediment and nutrient transport to the lake basin. During the late Holocene, changes occurred to the diatom communities, while the upland vegetation remained relatively stable.

Aquatic Vegetation

The response of diatoms can also be examined relative to aquatic vascular plants occupying the same basin. Aquatic vascular plants act as an important substrate for epiphytic diatoms (Round, 1981; Round et al., 1990), making their presence in the macrophyte communities of shallow-water littoral zones necessary as habitat for the initial colonization and persistence of many diatom species. The species composition of aquatic vascular plants will determine the available structure of aquatic communities (plants that are free-floating or rooted but submerged, rooted and with emergent leaves above the water surface, or even above-water, emergent plants forming bog, marsh, and

swamp communities; Muenscher, 1944; Fassett, 1957). In some Welsh Lakes, Round (1990) found that the epiphytic diatoms *Tabellaria flocculosa* and *Eunotia incisa* (both species are found in present-day Minnesota lakes; Brugam, 1993) maintained a high percentage cover on the aquatic macrophytes of quillwort (*Isoetes*) and of water lily (*Nuphar*), two macrophyte plants prominent in the late-Quaternary record of Anderson Pond, TN. In addition the amount and type of aquatic vegetation will affect the availability of other habitats for epipellic and planktonic diatoms. The lack of extensive mats or marshes of aquatic vegetation will increase the relative abundance of the types of diatoms requiring habitats of more open surface water.

Like aquatic macrophytes, diatom assemblages may depend on lake levels. Lake levels would affect diatom assemblages by influencing the types of habitats available for diatoms. The ratio of planktonic to benthic diatoms has been used to provide a quantitative record of changes in water depth throughout the history of a lake (Brugam, 1980). During high lake levels this ratio tends to increase, whereas during lowered lake levels the ratio decreases.

Nutrient Availability

Changes in the productivity of a lake system, which is dependent on the supply of potentially limiting nutrients such as nitrogen and phosphorous, can also be studied using diatoms (Smol, 1987; Fritz, 1989). Paleoecological studies of Mirror Lake in New

Hampshire show the relationship between upland vegetation, diatom assemblages, and nutrient availability (Davis et al., 1985; see summary Delcourt & Delcourt, 1991).

The post-glacial history of the Mirror Lake Watershed can be divided into 6 periods: late-glacial tundra period, late-glacial spruce period, early-Holocene period, mid- to late-Holocene period, late-Holocene period, and historic settlement period.

The late-glacial tundra period from 14,000 BP to 11,500 BP was an arctic to subarctic climate with tundra vegetation consisting of sedge, grass, and arctic sage. Periglacial solifluction and wind and stream erosion transported mineral grains to the lake, while a lack of humus buildup provided a limited supply of nutrients. These conditions created a lake environment that was clear, alkaline, and oligotrophic with a very low productivity aquatic biota (Davis et al., 1985). Diatoms were absent during this time period (Sherman, 1985).

The late-glacial spruce period from 11,500 BP to 10,000 BP was characterized by the invasion of spruce, with white spruce (*Picea glauca*) invading between 11,500 BP and 11,300 BP, and red spruce (*Picea rubens*) and black spruce (*Picea mariana*) invading around 10,000 BP. The development of forest cover led to the stabilization of hillslopes and increased evapotranspiration and percolation of precipitation, which decreased both runoff and erosion rates, and increased leaching of soluble carbonate. The invasion of green alder (*Alnus crispa*) increased the supply of nitrogen to the watershed. These changes in the upland vegetation did not change the alkaline, low productivity limnologic conditions. During this time the diatom community was dominated by species

characteristic of these conditions, including *Fragilaria pinnata*, *Melosira (Aulacoseira)* spp., and *Cyclotella comta* (Davis et al., 1985; Sherman, 1985).

The early Holocene period from 10,000 BP to 5000 BP saw the development of a mixed coniferous-deciduous forest with increased species richness due to migration of cool-temperate hardwood trees and a decline in boreal spruces. At 10,000 BP, forests included birch, aspen, balsam fir and juniper, and, by 9000 BP, oaks, sugar maple, and red maple. Also during this period, white pine peaked between 9500 BP and 7000 BP and hemlock arrived around 8500 BP and peaked between 7000 BP and 5000 BP. Increased transpiration and decreased supply of water for stream flow, and the development of a soil-humus layer led to decreased rates of sediment loss and increase in organic-rich muds in the lake. These conditions led to an increased supply of nutrients to the lake, increased productivity, a shift to mesotrophic status between 6000 BP and 5000 BP, and a pH shift to slightly acidic water (Davis et al., 1985).

The mid to late Holocene period from 5000 BP to 2000 BP was a time of climatic cooling with a predominance of northern hardwood forest. Eastern hemlock declined around 4800 BP and was replaced first by birch and then sugar maple, beech, pine, and oak. By 3000 BP hemlock reexpanded. During this period the aquatic community, including diatoms, was going through fluctuations; however, these fluctuations appear to be unrelated to changes in upland vegetation (Davis et al., 1985).

During the late Holocene period from 2000 BP to 140 BP, spruce increased with the development of a mixed conifer-hardwood forest. This change was due to increased

climatic cooling and increased annual precipitation to modern levels. This change in the upland vegetation led to increased production of acidic forest litter and accumulation of humus, which caused a change in limnologic conditions in Mirror Lake to higher productivity and slight acidification. These limnologic changes caused a decrease in populations of diatoms (Davis et al., 1985; Sherman, 1985).

The historic settlement period from 140 BP to the present shows the influence of EuroAmerican occupation of the area. Regional forest clearance is reflected in the pollen record by increased levels of herbaceous plants such as ragweed (*Ambrosia*), grass, and dock (*Rumex*). Forest clearance and farming activities led to a minor increase in erosion. This was followed by the development of second growth forests dominated by yellow birch and sugar maple, reduced populations of spruce, beech, and eastern hemlock. These anthropogenic changes in the uplands led to minor cultural eutrophication of Mirror Lake, reflected in the diatom assemblage by an increase in *Melosira* (*Aulacoseira*) spp. and increased species richness of diatoms (Sherman, 1985).

More recently, Huvane & Whitehead (1996) have conducted a similar study of North Pond in western Massachusetts using pollen and diatoms to study watershed-lake interaction. Two important events in the watershed during the last 11,600 years were a local hemlock decline at 7500 ^{14}C yr BP not identified from other lake cores in the region, and a regional hemlock decline beginning at 4800 BP and lasting about 2000 years as previously identified from other lake cores in the region. The first hemlock decline is associated with an increase in sedimentary charcoal particles, indicating that the decline

was the result of fire during a possible dry period (Huvane & Whitehead, 1996). The second hemlock decline occurring on a regional scale may have resulted from the spread of a pathogen (Davis, 1981). Diatom assemblages at North Pond responded differently to each of these hemlock decline events (Huvane & Whitehead, 1996).

Prior to 7500 BP, diatom assemblages at North Pond were characteristic of alkaline water and were dominated by species of the genera *Aulacoseira* and *Cyclotella*, with *Fragilaria pinnata* and its varieties present at low abundances (Huvane & Whitehead, 1996). The local hemlock decline at 7500 BP coincided with sudden changes in the diatoms to a more alkaline assemblage and an increase in the percentage of planktonic diatoms possibly reflecting increased productivity in the open water environment. Also associated with this hemlock decline is a drop in diatom species diversity which is characteristic of a disturbance within the aquatic ecosystem.

The classic, regional hemlock decline beginning at 4800 BP is associated with a slight decline in diatom-inferred pH and a slight increase in diatoms indicative of dystrophic habitats at North Pond (Huvane & Whitehead, 1996). Overall, diatom assemblages at North Pond display only minor responses to the classic, mid-Holocene hemlock decline. The widespread death of hemlock may have lead to a buildup of organic matter, thereby increasing the amount of organic acids reaching the aquatic system, and causing the slight pH decline and increase in dystrophic species.

The comparison of diatom and pollen assemblages at North Pond demonstrates how similar vegetation changes in a watershed, if caused by different mechanisms, will

display different responses in the aquatic environment, as indicated by the diatom assemblages. This study shows the value of using fossils of aquatic organisms in the full interpretation of late Pleistocene environmental changes.

Huttunen & Meriläinen (1986) used DCA to study historical changes at Hännisenlampi, a lake in eastern Finland. They used DCA analysis to relate changes in the diatom assemblages in a 150 cm lake core to the known environmental conditions of modern diatom assemblages from 50 lakes in Finland. Their results are shown in Figure 7, in which they interpreted changes along the horizontal axis as relating to nutrient levels and pH of lake water, with nutrients and pH increasing towards lower values, and changes along the vertical axis as relating to water-turbidity changes in light penetration, with increased light penetration towards higher DCA values.

The diatom assemblages from Hännisenlampi formed five clusters based on the DCA results (Huttunen & Meriläinen, 1986). Cluster 1, containing the four earliest samples beginning in A. D. 900, represents the pre-agricultural period with low nutrient levels, low turbidity, and high light penetration. During this time Hännisenlampi was a bay in a larger water body called Hyypiänjärvi. The onset of agriculture in the area brought an increase in nutrient supply to the lake and a slight increase in turbidity resulting in slightly lower light penetration. This period was followed by a decrease in productivity and light penetration until about A. D. 1750. During the following period, light penetration was at its lowest and nutrient levels increased due to the retting of fiber plants. Retting is the cultural practice of soaking flax plants in shallow-lake water for up

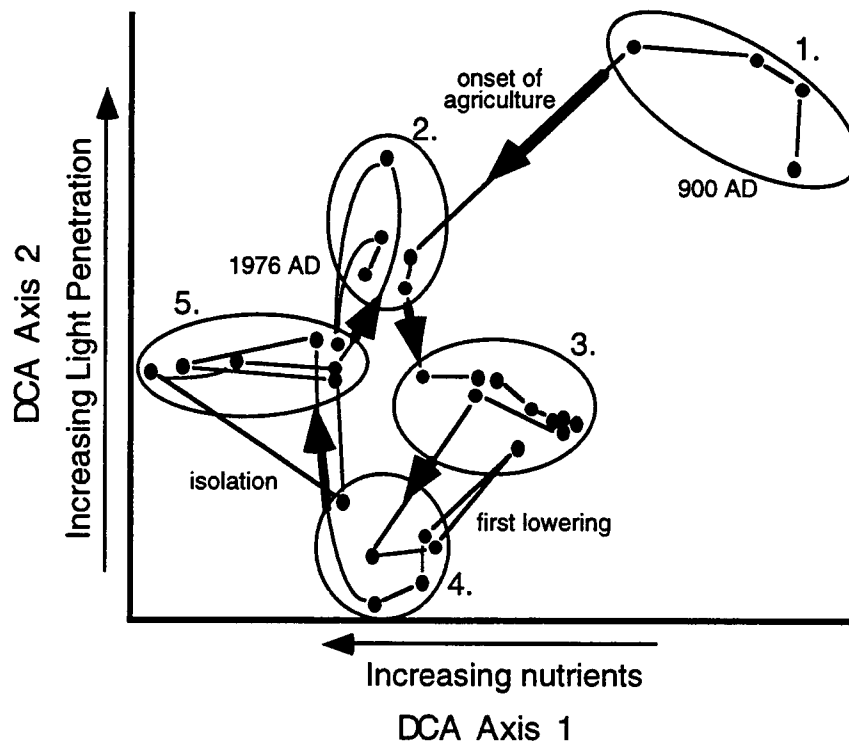


Figure 7. Late-Holocene changes in nutrient availability of lake water (DCA Axis 1) and water turbidity (light penetration) driven by cultural impacts upon upland vegetation (DCA Axis 2) in determining long-term changes of diatom assemblages in Hannisenlampi Bay, Finland (modified from Huttunen & Meriläinen, 1986). Cluster numbers 1 through 5 represent changes in limnological conditions during the past 1000 years.

to several months to speed up the rotting process and to separate the flax fibers for spinning and weaving into linen cloth. The retting will release nutrients and lower oxygen levels available in the lake waters. Lowering of the water level and isolation of Hännisenlampi Bay brought an increase in nutrients and an increase in light penetration, causing a shift in the diatom assemblages from cluster 4 to cluster 5. Following isolation of the bay, agricultural activity decreased in the area, resulting in decreased nutrient levels and increased light penetration, returning the diatom assemblages to cluster 2.

Korhola & Blom (1996) recently used DCA to study the response of diatom assemblages to pollution in Töölö Bay, Helsinki, Finland. They ran DCA on 49 common taxa. Figure 8 shows their DCA results for the diatom taxa and for the sediment-core samples. Using published information on the environmental preferences of the diatom taxa, they determined that DCA Axis 1 represents changing nutrient conditions with the most eutrophic conditions at the highest values. DCA Axis 2 was interpreted as a salinity gradient, with salinity increasing towards higher values. A time line is drawn through the sample data showing how conditions have changed over the last century (Figure 8). Increased nutrient input associated with pollution is indicated by a shift to higher Axis 1 values around A.D. 1930, with a return to lower nutrient conditions following the reduced input of non-treated and partially treated sewage in the 1960s. The general decrease in salinity, indicated by a general drop in Axis 2 values, was interpreted as the result of construction of a railway embankment reducing the input of marine water.

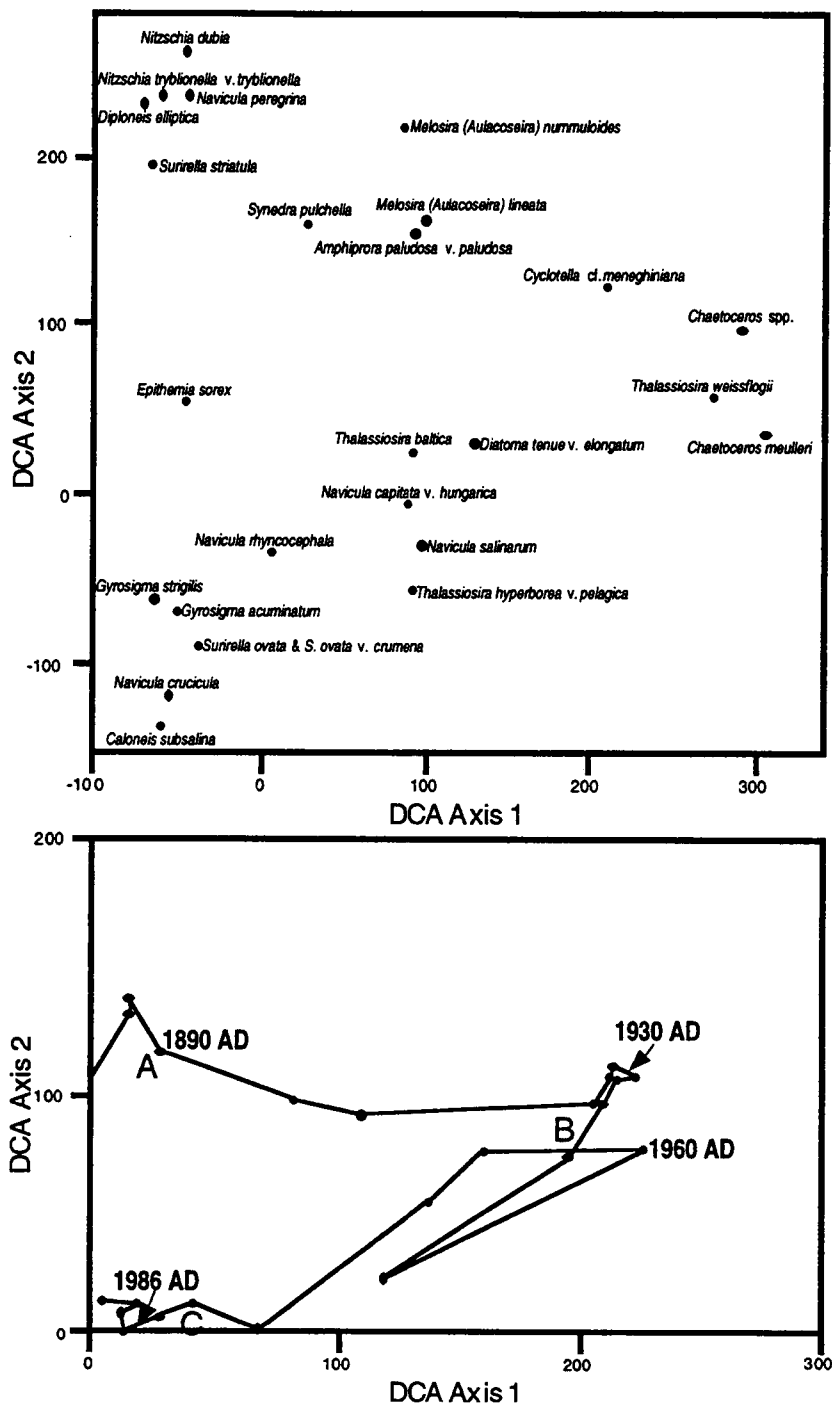


Figure 8. DCA analysis of historic diatom assemblages from sediments of Töölö Bay, Helsinki, Finland, reflecting compositional changes along DCA Axis 1 for increasing nutrient availability and DCA Axis 2 for limnologic shifts from fresh toward saline waters (modified from Korhola & Blom, 1996). The historical sequence records a peak in nutrient loading associated with untreated sewage circa AD 1930 and the reduction of marine waters into the bay following railroad construction after AD 1960.

Korhola & Blom (1996) also plotted DCA Axis 1 scores relative to surface-water calcium content, phosphorus content, and Shannon-Weaver diversity index for diatoms. Increases in calcium content and phosphorus content and decrease in diatom diversity are correlated with increased scores along DCA Axis 1 (Figure 8), indicating an environmental relationship between water chemistry and taxonomic composition in the diatom assemblage. For example, the diatom assemblage circa A.D. 1930 is dominated by *Cyclotella cf. meneghiniana*, and displays the low value of less than 2.5 for the Shannon-Weaver diversity index, indicating the eutrophic status associated with high nutrient loading of polluted waters. Korhola & Blom interpret Figure 8 to indicate a rapid decadal response of the diatoms to pollution, but a slower, sixty-year recovery after the reduction of pollutants entering the bay.

Smol (1985) used another group of algae, the chrysophytes, to study trophic status in lakes. Chrysophytes are a predominantly planktonic group of algae that produce a siliceous resting stage called a cyst or stratospore (Bold & Wynne, 1985; Smol, 1985). Smol (1985) found that the relative abundance of chrysophyte cysts, or stratospores, and diatom frustules was a useful indicator of trophic status. During eutrophic phases, when nutrients are abundant, few chrysophyte cysts are recorded in sediments. During oligotrophic phases, when nutrients are less abundant, the relative abundance of chrysophyte cysts increases.

CHAPTER III

Environmental History of Anderson Pond

Site Description

Anderson Pond is located on the eastern Highland Rim of Middle Tennessee (36°02'N, 85°30'W) in White County, and covers an area of approximately 34.8 ha (Figure 9). The lacustrine basin originated as a sinkhole which developed in the underlying Mississippian age St. Louis Formation, a dolomitic limestone. This site is at an elevation of 300 to 310 m above mean sea level (Hardeman, 1966; Garman, 1971). The Cumberland Plateau, 0.8 km to the southeast, is approximately 300 m higher in elevation and is capped by sandstones and conglomerates of the Mississippian-age Pennington Formation and the Pennsylvanian-age Gizzard and Crab Orchard Mountain Groups.

The current mean annual precipitation for the Highland Rim is 130 cm and the adjacent Cumberland Plateau, serving as an orographic barrier to moisture-bearing storms, has a slightly higher mean annual precipitation of about 140 cm. Average temperatures in this region include a January maximum of 10°C, January minimum of 0°C, July maximum of 29-33°C, and July minimum of 18°C (Delcourt, 1979). Surface run-off and springs both serve as sources of water (Ellis & Chester, 1989). The water level fluctuates as much as 1.8 m annually between late-winter highstands and the lowest levels of late-summer and fall (Delcourt, 1979), and isolated open-water pools within the central basin have not

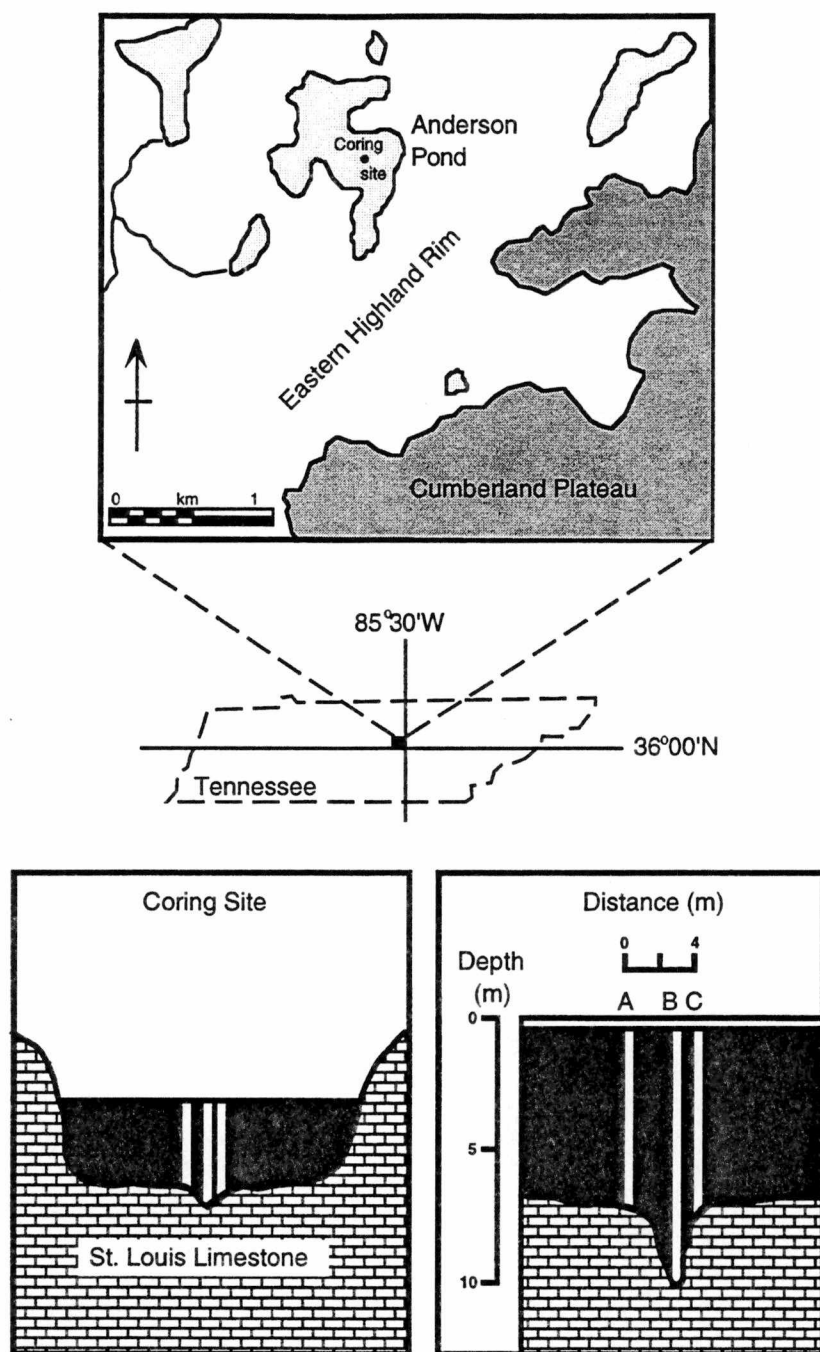


Figure 9. Geologic setting of Anderson Pond, TN (modified from Delcourt, 1979).

dried out completely within historic times (Ellis & Chester, 1989). The present pH is 2.6, as measured on March 30, 1998 using an ATI Orion model 250A portable meter and a Corning High Performance Combination probe (Cat. No. 476390).

Modern Vegetation

Ellis & Chester (1989) surveyed the vegetation present in the Anderson Pond basin. They found three main community types distributed within the karst sinkhole basin, and an additional community type, sedge meadow, on the west side of the basin which was disturbed and infilled with soil in the spring of 1982 during construction of an adjacent housing development (Figure 10). Most of the steep hillsides delineating the basin are occupied by a 15-30 m band of mesic rim forest dominated by oaks (*Quercus* spp.). Seasonally inundated swamp forest forms a peripheral belt around the basin. The swamp forest consists primarily of red maple (*Acer rubrum*), blackgum (*Nyssa sylvatica*), willow oak (*Quercus phellos*), sweetgum (*Liquidambar styraciflua*), river birch (*Betula nigra*), and sycamore (*Platanus occidentalis*) with a dense thicket understory of alder (*Alnus serrulata*), buttonbush (*Cephalanthus occidentalis*), Virginia willow (*Itea virginica*), swamp rose (*Rosa palustris*), American holly (*Ilex opaca*), and blueberry (*Vaccinium* spp.), as well as a herbaceous layer including sedges (*Carex*) and smartweeds (*Polygonum*). The shallow-water, inner basin is occupied by a swamp thicket community type with shrubs of buttonbush, Virginia willow, swamp rose, black willow (*Salix nigra*), water willow (*Decodon verticillatus*), emergent macrophytes of bur-weed (*Sparganium*

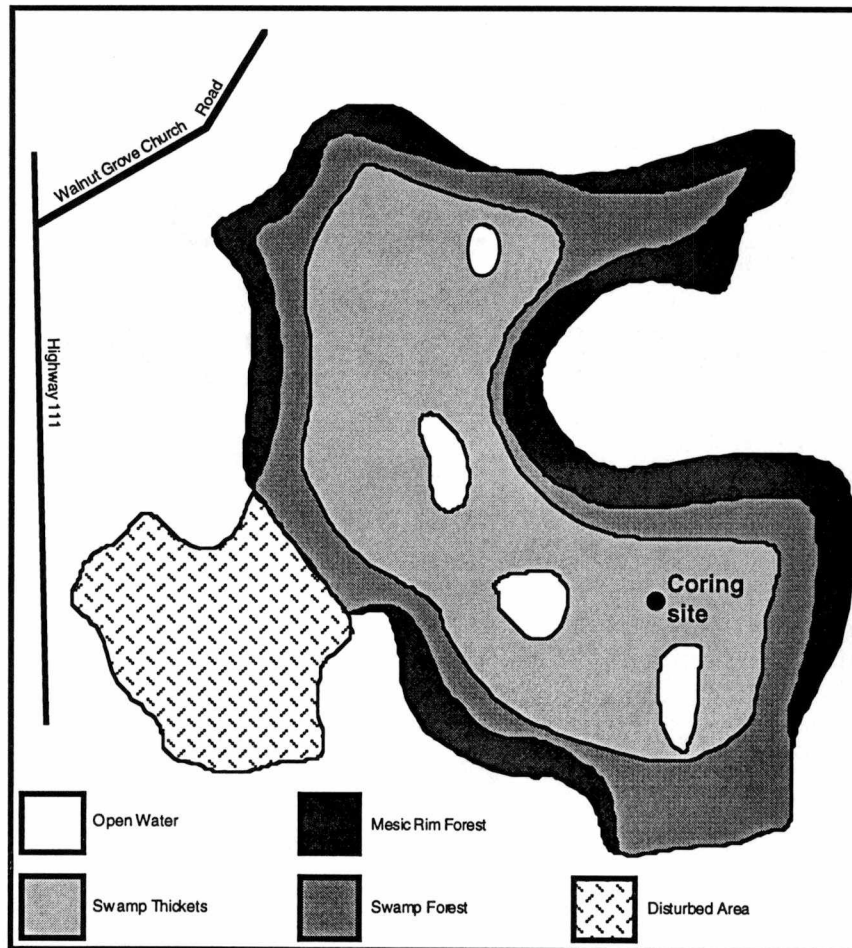


Figure 10. Major plant communities of Anderson Pond, TN (modified from Ellis & Chester, 1989).

americanum), and many graminoids. In the interior of the sinkhole basin, permanent pools of open water contain aquatic vegetation, including floating populations of hornwood (*Ceratophyllum echinatum*), duckweeds (*Lemna* spp.), and *Spirodela* spp. (Delcourt, 1979).

Core Lithology and Chronology

Delcourt (1979) obtained and described three cores from the deepest part of the basin (Figure 9). Two of the cores made contact with the limestone bedrock at approximately 7 m depth and contained 6 to 7 m of silty clay sediment. The longest core, reaching a depth of 10.05 m beneath the mud-water interface, penetrated a collapse chute in the bedrock (Figures 9, 11). The core penetrating the chute contained basal layers of dark grayish brown sand and silt with chert granules dispersed throughout (10.05 m to approximately 6.70 m in depth). A brown sandy, silty clay was present between 6.70 and 5.34 m and typically brown silty clay was present between 5.34 and 0.43 m. A very dark brown fibrous, slightly silty clay with leaf and wood matter was present between 0.43 m and 0.25 m. Unconsolidated sediment and leaf mat was present between 0.25 m and the mud-water interface (0.0 m). Above the mud-water interface was a thin (0.07 m) leaf and root mat beneath 0.18 m of water.

Ten radiocarbon dates on the longest core date the lowermost sediment at 25,000 BP and approximately the 7 m depth, where the two adjacent cores begin, at 18,760 BP. The sedimentation record and the radiocarbon dates indicate that continuous lacustrine

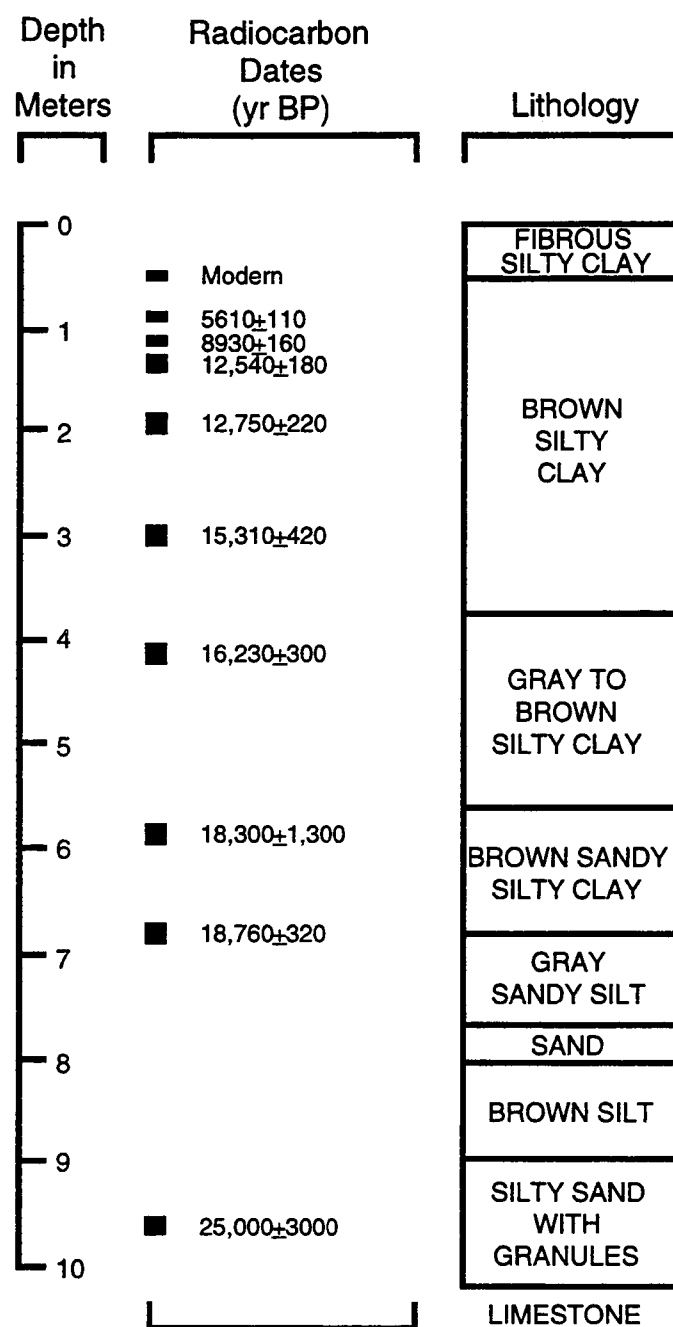


Figure 11. Core lithology from Anderson Pond, TN (modified from Delcourt, 1979).

sedimentation was been occurring for approximately the last 19,000 years. The sediments deposited in the lowest portion of the core represent the initial formation of the sinkhole with intermittent sedimentation prior to the development of a permanent lake. A plot of the radiocarbon dates showing age versus depth (Figure 12) indicates that late Pleistocene sedimentation rates were high until approximately 12,500 BP, and then latest-glacial and early Holocene sedimentation rates dropped off significantly until the last few hundred years of the historic interval (Delcourt, 1985; Mills & Delcourt, 1991).

Upland Vegetation History

Arboreal pollen distribution (Delcourt, 1979) shows the major changes in vegetation at Anderson Pond over the last 19,000 years (Figure 13). From 19,000 BP until approximately 16,300 BP, northern pine (*Diploxylon Pinus*) and spruce (*Picea*) are the dominant arboreal taxa, with a gradual increase in oak (*Quercus*) and modest values for fir (*Abies*) and ash (*Fraxinus*). The presence of jack pine (*Pinus banksiana*) needle fragments in the plant macrofossils, along with a mean internal cap diameter of 37.4 μm for the *Diploxylon Pinus* pollen, indicates that the pine present at Anderson Pond at this peak-glacial time was predominantly jack pine (*P. banksiana*), a species with a northern, Canadian distribution today (Delcourt, 1979). The record of arboreal vegetation present around Anderson Pond between 19,000 BP and 16,300 BP indicates a full-glacial boreal coniferous forest in middle Tennessee.

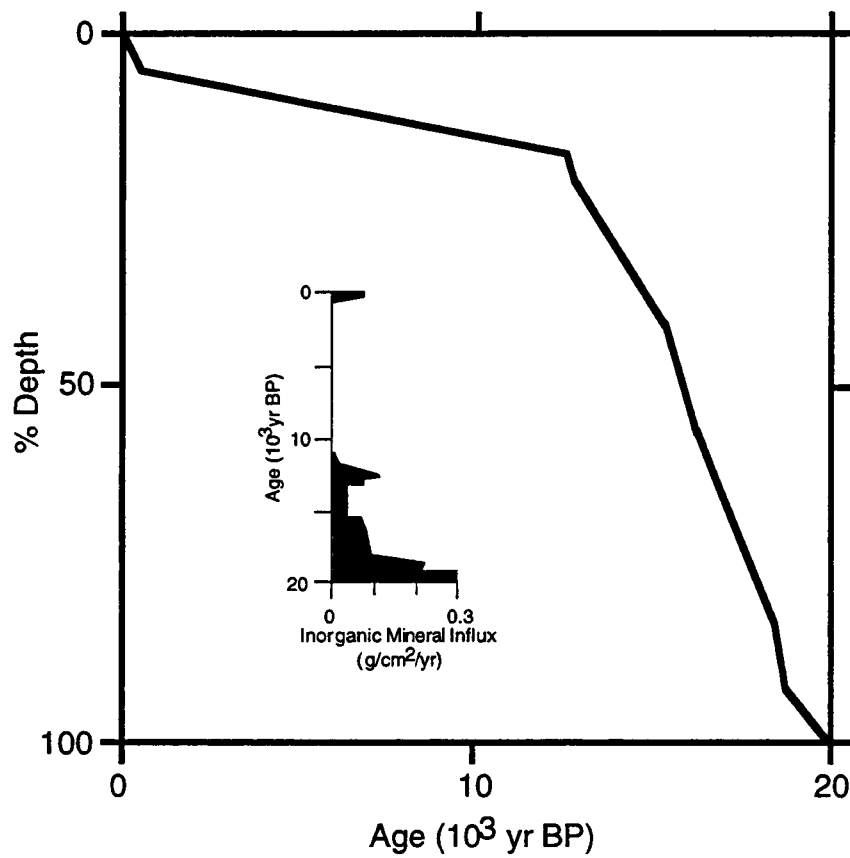


Figure 12. Core chronology from Anderson Pond, TN with mineral sediment influx (modified from Mills & Delcourt, 1991).

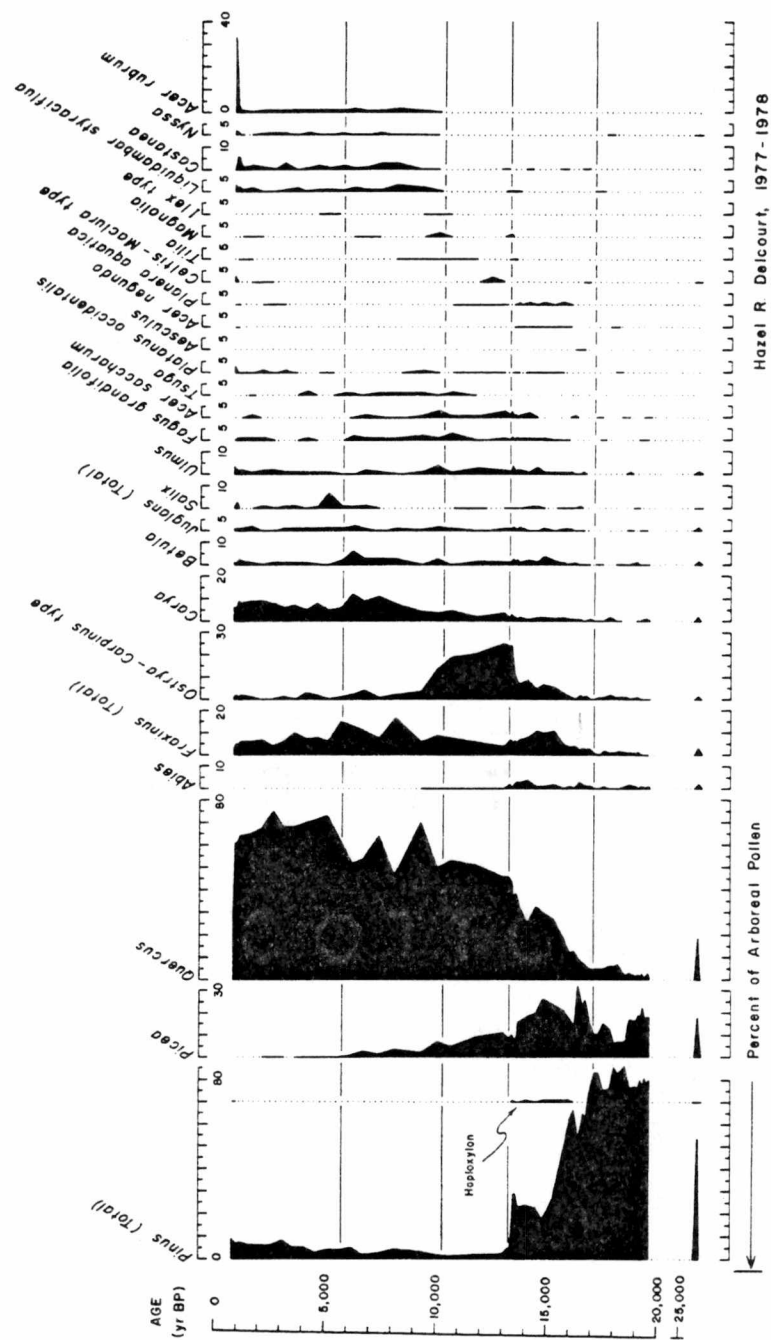


Figure 13. Arboreal pollen diagram for Anderson Pond, TN (modified from Delcourt, 1979).

In late-glacial times starting at approximately 16,300 BP, populations of Diploxylon pine (*Pinus*) declined, and populations of Haploxylon pine established locally, represented by eastern white pine (*Pinus strobus*). Pollen values rose in abundance for oak, spruce, fir, ash, and ironwood (*Ostrya-Carpinus* type). Represented by continuous curves and low percentage values, populations were established by immigrating species of hickory (*Carya*), birch (*Betula*), walnut (*Juglans*), willow (*Salix*), and elm (*Ulmus*). The upland vegetation at this time was a mixed conifer-hardwood forest, indicating less severe winters and a longer growing season (Delcourt, 1979).

The most significant change in the fossil-pollen record occurred at approximately 12,500 BP (Figure 13), with an almost complete loss of jack pine and fir, a decrease in abundance of spruce, continued increase in oak, and a large increase in ironwood. This pronounced change in vegetation indicates a rapid, pronounced change from a boreal regional climate to a temperate climate.

Since 12,500 BP, the upland forest surrounding Anderson Pond have been dominated by deciduous trees (Delcourt, 1979). The dominant upland tree from 12,500 BP to the present has been oak. In the early Holocene from 12,500 BP to 9500 BP, establishment of peak populations for ironwood, American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), and hemlock (*Tsuga canadensis*) indicate a mixed mesophytic forest associated with cool, mesic climate conditions (Delcourt, 1979; Delcourt & Delcourt, 1994). The regional phenomenon of the ironwood rise at mid latitudes is interpreted as a species response to enhanced Milankovitch seasonality, with

colder winters and variable, but warmer springs and summers (Delcourt & Delcourt, 1994). The ability of ironwood to bend without breaking would also help them withstand increased disturbance due to enhanced storm activity during this time accompanying the northward migration of the Polar Frontal Zone (Delcourt & Delcourt, 1984, 1994).

The middle Holocene interval from 9500 to 5000 BP represents closed, deciduous forest dominated by oak, hickory, ash, and birch. Warm-temperate conditions permitted the immigration of tree populations for upland species of chestnut (*Castanea*) and mesic, lowland species such as sweetgum (*Liquidamber styraciflua*), tupelo gum or black gum (*Nyssa*), and red maple (*Acer rubrum*) (Delcourt, 1979).

The late Holocene interval from 5000 to 160 BP corresponded with the persistence of oak-hickory-dominated upland forests, supplemented with the arrival of southern pines (Diploxylon *Pinus*) such as shortleaf pine (*Pinus echinata*). Late Holocene increases in additional mesic-to-hydric taxa such as willow, sycamore (*Platanus occidentalis*), and planer tree (*Planera aquatica*) indicate increased precipitation levels and more substantive water ponding within the lowland, swamp forests of the sinkhole basin, particularly after 3000 to 2000 BP.

The historic interval is highlighted by the abrupt increases in red maple pollen values, reflecting historic forest clearance and erosion of upland soils and subsequent sediment infilling of the basin, expanding lowland habitat suitable for red maple.

Delcourt (1979) presented qualitative criteria for identifying the position of modern analogs for the vegetation at Anderson Pond over its 25,000 year record. The

modern analogs and reconstructed temperature and precipitation records (Figure 14) show the general warming trend from the boreal full-glacial period to the warm-temperate climate of the post-glacial period.

The fossil pollen record from 25,000 BP to 23,000 BP, representing the Farmdalian interstadial, has a modern analog location in the western Great Lakes region. Central Minnesota has the modern pollen assemblage that is most similar to the Anderson Pond fossil pollen assemblage at this time (Figure 14). The climate at this time was cool with enough moisture to support temperate deciduous tree species and northern pines, spruce, and fir (Delcourt, 1979).

The fossil pollen record from 23,000 BP to 16,500 BP, representing full glacial, has its closest modern analog in southern Manitoba (Figure 14). The climate at this time was significantly colder and drier than at present with a short growing season, as indicated by the predominance of 'boreal' conifers (Delcourt, 1979).

The fossil pollen record from 16,500 BP to 12,500 BP, representing the late-glacial period, has its closest modern analog in northeastern Minnesota (around 16,000 BP) and northeastern Wisconsin (around 13,000 BP) (Figure 14). The climate during this time became warmer with a longer growing season, causing a decrease in the abundance of jack pine and the development of a mixed spruce, fir, and deciduous forest (Delcourt, 1979).

The interval between 12,750 BP and 12,500 BP marked a major change in the environment at Anderson Pond, with significant changes in arboreal pollen, aquatic pollen,

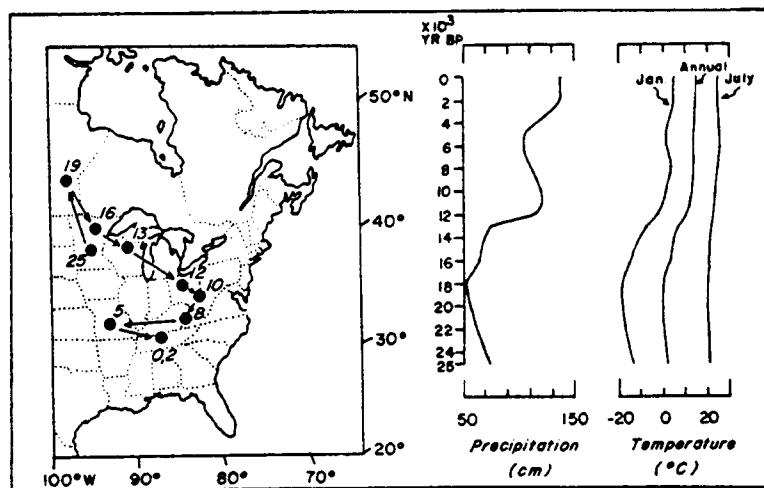


Figure 14. Modern pollen analogs and paleoclimatic curves reconstructed for Anderson Pond, TN from 25,000 BP to the Present (from Delcourt, 1979).

and sediment accumulation rates (Delcourt, 1979). A change from coniferous to deciduous forests and rapid infilling of the basin, as indicated by changes in aquatic vegetation and increased sedimentation, indicate a short period of accelerated change to higher temperature and increased precipitation, causing significant ecosystem change and landscape instability during the latest-Pleistocene around 12,500 BP at Anderson Pond (Delcourt, 1979).

The fossil-pollen record from 12,500 BP to 9500 BP, representing the early Holocene, has its closest modern analog in the Allegheny Plateau region of Ohio (around 12,000 BP) and West Virginia (around 10,000 BP) (Figure 14). The climate during this time was cool and wet (mesic) as indicated, particularly, by the abundance of ironwood (Delcourt, 1979).

The fossil pollen record from 9500 BP to 5000 BP, representing the middle-Holocene, has its closest modern analog in eastern Kentucky (around 8000 BP) and the Ozark Mountains of eastern Missouri (around 5000 BP)(Figure 14). The changes in vegetation during the mid-Holocene interval, particularly increases in percentages of oak, ash, hickory, birch, alder, buttonbush, and Virginia willow, indicate Hypsithermal warming and drying through this time period (Delcourt, 1979).

The fossil pollen record from 5000 BP to the present, representing the late Holocene, corresponds with a geographic shift in modern analog locations towards the modern pollen assemblage at Anderson Pond (Figure 14). This change in the fossil-pollen

record reflects forest changes responding to increased precipitation in the late Holocene (Delcourt, 1979).

Delcourt & Delcourt (1985) compared different quantitative methods for reconstructing the vegetation history of Anderson Pond (Figures 15, 16). One of these methods, the use of modern analogs, is particularly relevant to the present study. Three different methods were used to determine the coefficient of dissimilarity between the fossil pollen assemblages from Anderson Pond and potential modern analog sites (Figure 16). The dissimilarity between the fossil pollen and the modern analogs is lowest from 19,000 BP to 15,000 BP, and is also generally low after 9000 BP to the present (Delcourt & Delcourt, 1985). This means that good modern analogs exist for the fossil pollen assemblages during these times. From 15,000 BP to 9000 BP the match between the fossil pollen record and modern analogues is poor. Thus, during the late Pleistocene transition to early Holocene, species extinctions and immigrations created dynamically changing forest communities that are not well represented by a modern forest type.

Aquatic Vegetation History

The history of the aquatic environment at Anderson Pond can be inferred from the fossil records of aquatic pollen (Figure 17) and plant macrofossils (Figure 18). This paleoecological data provides information on long-term changes in local climate and water depth of the basin.

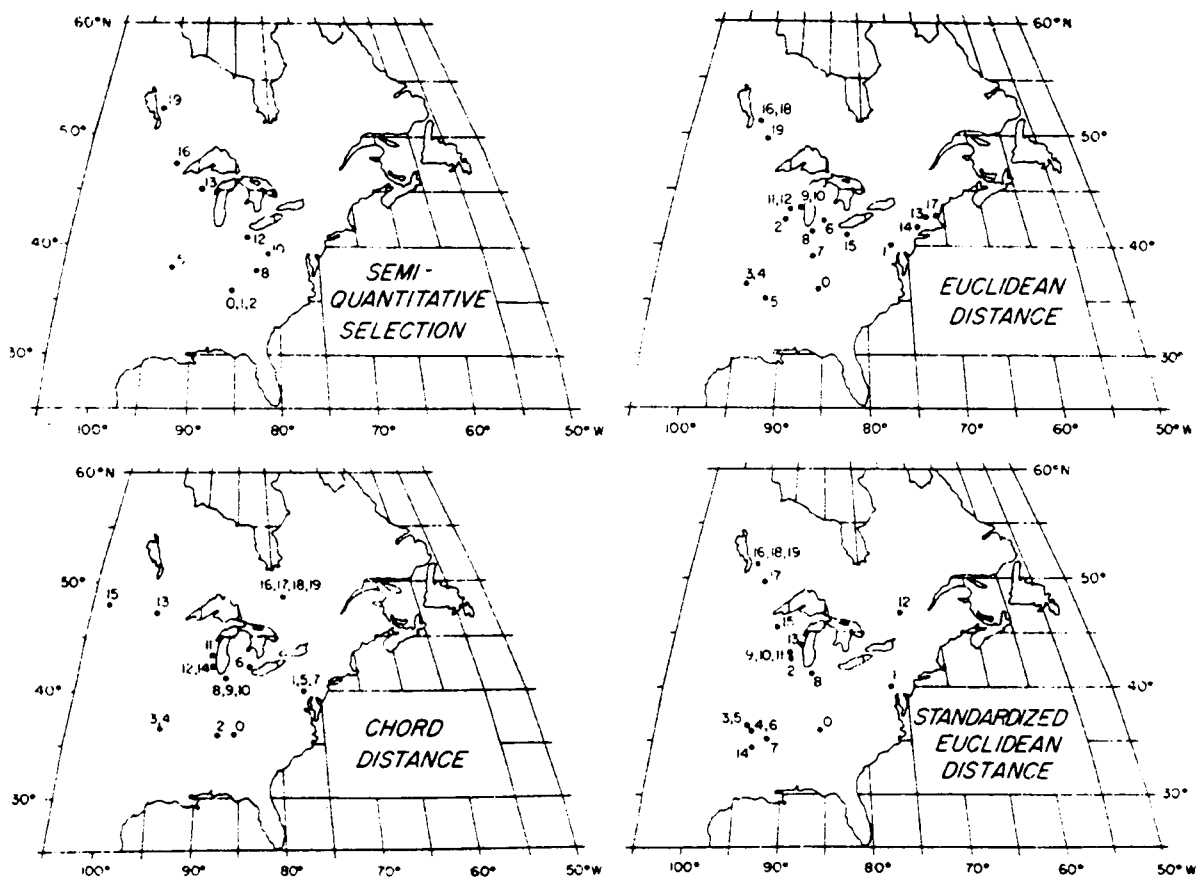


Figure 15. Geographic locations for best modern analogues for fossil-pollen spectra at 1000 year intervals from 19,000 BP to the present at Anderson Pond, TN. Numbers represent age ($\times 10^3$ yr BP) (from Delcourt & Delcourt, 1985).

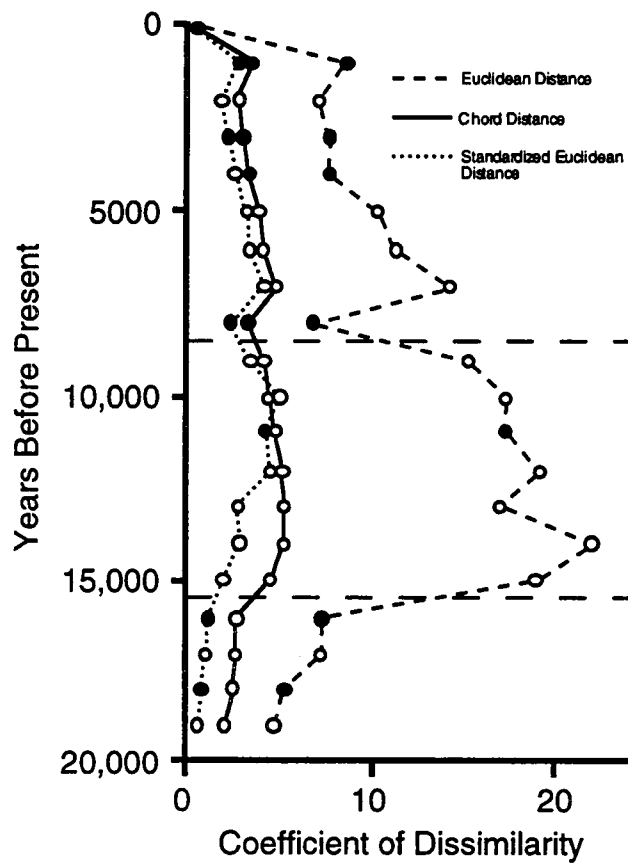
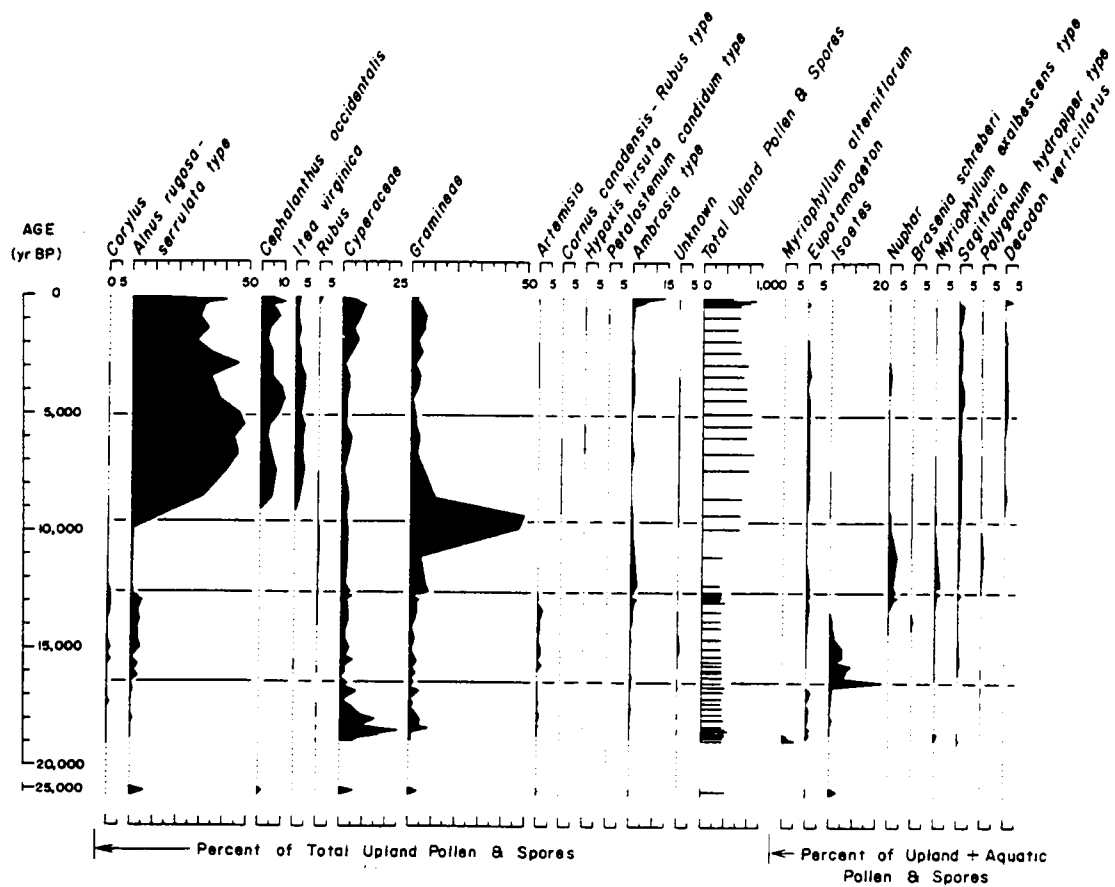


Figure 16. Coefficients of dissimilarity calculated for best modern analogues based upon three dissimilarity measures from 19,000 BP through the Present (modified from Delcourt & Delcourt, 1985). Solid dots portrayed for a given time represent selection of the same modern pollen spectrum as the best modern analogue by two or more coefficients of dissimilarity.

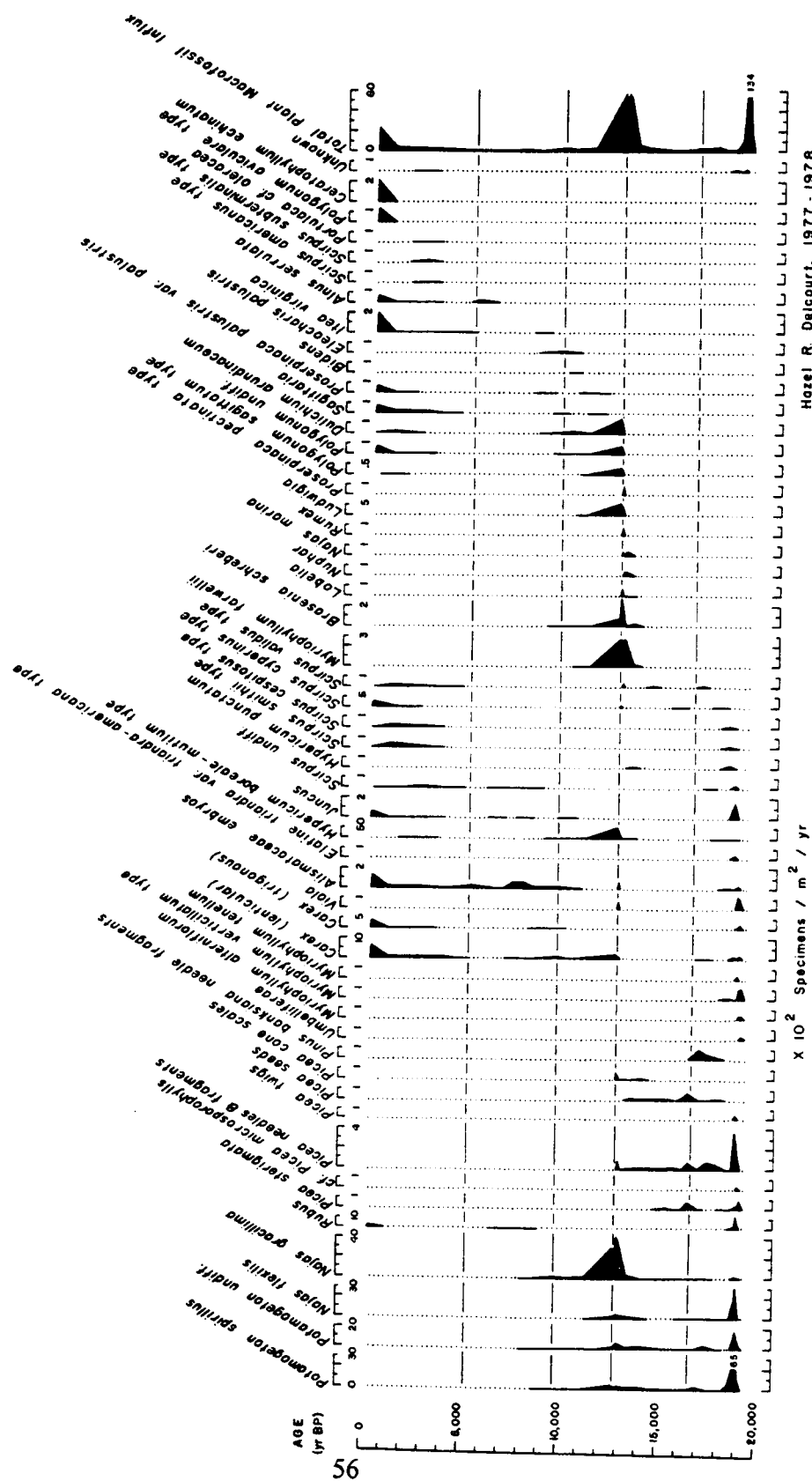
Important pond-shore and aquatic communities between 19,000 BP and 12,500 BP included plants from the sedge and rush family (Cyperaceae), grass family (Gramineae), benthic rooted plants, *Potamogeton spirillus*, *Najas flexilus* and *N. gracillima*, and shrub alder (*Alnus rugosa-serrulata* type). *Myriophyllum* species such as *M. alterniflorum*, *M. verticillatum* type, and *M. tenellum*, aquatic species found only at northern latitudes today (Muenscher, 1944), are present between 19,000 BP and 18,000 BP. *Potamogeton spirillus*, another aquatic species characteristic of northern latitudes of the Great Lakes region today and found at water depths of up to 5 m (Muenscher, 1944), was most abundant between 19,000 BP and 18,000 BP. Quillwort (*Isoetes*) microspores increased between 16,500 BP and 12,500 BP, indicating moderate water depths up to 5 m, high conductivity levels, and a silty mud lake bottom as habitat for these benthic-rooted plants (Muenscher, 1944). The development of a silt-mineral bottom in the late glacial may be linked with seasonal influx of colluvium into the lake basin (Figure 12). The aquatic macrophyte vegetation present at Anderson Pond between 19,000 BP and 12,500 BP indicates a cool glacial-age climate in Middle Tennessee and a permanent lake with a depth of up to 5 m.

At approximately 12,500 BP, a time of significant change in the upland forest, the aquatic vegetation also underwent changes, with initial increases in pollen values for Gramineae, water lily (*Nuphar*), *Myriophyllum exalbescens* type (characteristic of 1-4 m deep water; Muenscher, 1944), and *Polygonum hydropiper* type (Figure 17). The plant-macrofossil influx data (Figure 18) show peaks in *Najas gracillima*, *Proserpinaca*



Hazel R. Delcourt, 1977-1978

Figure 17. Aquatic pollen diagram for Anderson Pond, TN (modified from Delcourt, 1979).



pectinata type, and *Myriophyllum farwellii*, all species of floating aquatic plants characteristic of acidic water and northern latitudes (Muenscher, 1944), which only lasted 1000 to 2000 years. These two species marked the onset of acidification of Anderson Pond with cool temperatures remaining into the earliest post-glacial period. The corresponding macrofossil peaks for groups of benthic rooted aquatics, such as water shield (*Brasenia schreberi*) and water lily (*Nuphar*), and shallow-water, emergent marsh species, such as sedge (lenticular *Carex*), *Ludwigia*, *Polygonum sagittatum* type, and three-cornered sedge (*Dulichium arundinaceum*), arrowhead (*Sagittaria*), and bullrush (*Scirpus cyperinus* type and *S. validus* type), reflect the abrupt shallowing of water levels and the conversion of open-water pools to shallow wet-meadows and marsh throughout much of the basin.

Another significant change occurred in the lowland vegetation at approximately 9500 BP with a significant increase in alder (*Alnus serrulata*), and increases in buttonbush (*Cephalanthus occidentalis*), Virginia willow (*Itea virginica*), *Eupotamogeton*, *Sagittaria*, and swamp loosestrife (*Decodon verticillatus*). These changes in vegetation in the early post-glacial from herbaceous marsh to woody shrub thicket reflect sediment infilling of the basin and lowered (although seasonally fluctuating) water depths, which allowed for the spread of swamp shrub thickets out into the wet meadows and pools of the central basin (Delcourt, 1979). The nonarboreal pollen (Figure 17) and macrofossil (Figure 18) records show the persistence of this mosaic of marsh and swamp-thicket communities up to the historic time of settlement around A.D. 1790 (Delcourt, 1979). In this historic

interval, sediment accumulation rates increased (Figure 12) along with the increased representation of aquatic pollen (Figure 17) and increased influx of plant macrofossils (Figure 18). These paleoecological changes resulted from soil erosion due to EuroAmerican clearance of forest and cultivation of nearby upland slopes (Delcourt, 1979).

Sedimentation

Delcourt (1985) and Mills & Delcourt (1991) discussed the effects of vegetation and climate change upon lacustrine and alluvial paleohydrology in midlatitudes (35° to 40°N) of eastern North America (Figure 19). For upland lakes, they suggested that high rates of accumulation for inorganic, mineral particles occurred prior to 12,500 BP. The high accumulation rates of particulate matter, colluvially transported from uplands and deposited within lakes, coincided with a glacial-age, pluvial period of high water tables and relatively deep, permanent lakes. They proposed the regional, northward shift in the Polar Frontal Zone about 12,500 BP coincided with the changeover from a boreal-like zonal climate flow pattern to a temperate, meridional flow pattern of predominant airmasses. Webb et al. (1993) also found higher lake levels across the East, indicating higher effective moisture, prior to the Pleistocene/Holocene transition; they found, however, a difference in the interval of the Holocene period of maximum aridity between the northeast and the midwest, occurring at about 9,000 BP and at about 6,000 BP, respectively. The use of diatoms may more accurately constrain the timing of these late-

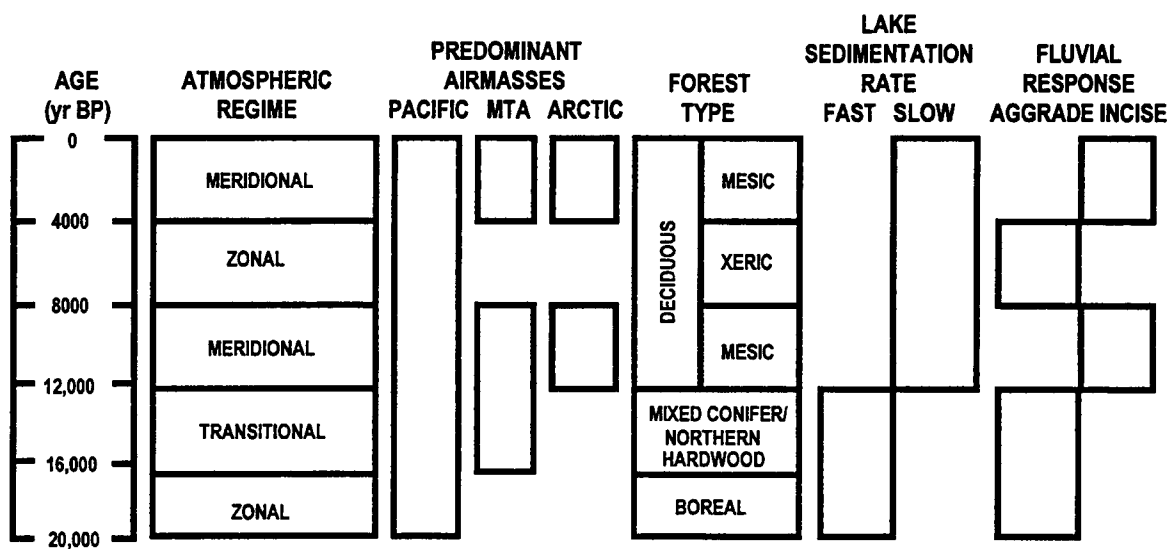


Figure 19. Influence of climate and vegetation upon lacustrine and alluvial paleohydrology in the unglaciated region of eastern North America between approximately 35° and 40° N (modified from Delcourt, 1985).

Quaternary changes in lake levels and determine how closely the local lake level changes correlate with the model of limnologic sedimentation rates proposed by Mills & Delcourt (1991).

The increased rates of Pleistocene sediment accumulation may have directly affected diatom assemblages due to the increased turbidity which would have blocked sunlight in surface waters and, at least seasonally, vertically constricted the available photic zone. The late glacial peak in quillwort populations records the shift to shallower water depths (less than 5 m) and development of a silt-mineral mud bottom in the lake. If sediment accumulation rates of inorganic mineral particles were higher prior to 12,500 BP, then the turbidity should be reflected as differences in the diatom assemblages in terms of species composition and in their preservation.

The late Pleistocene change in upland vegetation from open coniferous to closed deciduous forest could be a major control on sedimentation. Conifer-dominated forests produce thin, easily-eroded litter, readily moved down slope by colluvium in water-saturated soils with high groundwater tables (Delcourt, 1985). The denser structure of Holocene deciduous forests, with their corresponding buildup of thick, decay-resistant, organic litter capping the well-drained mineral soil horizons, together with dropping groundwater tables, would limit the effect of sheet wash flow by meteoric precipitation and would reduce the amount of erosion of mineral particles from land-surface soils. Holocene establishment of lowland thickets would serve as filter barriers to trap sediments from hill slopes. This late Pleistocene change in erosion rates is indicated in

Figure 12 by an abrupt decrease in the rate of influx of inorganic minerals into Anderson Pond at 12,500 BP (Mills & Delcourt, 1991). Diatom analysis should help determine the regional importance of climatic moisture regime versus upland vegetation in controlling erosion rates of upland soils as well as the limnologic significance of changing water turbidity regimes.

CHAPTER IV

Methods

Based upon the core chronology determined by ten radiocarbon dates (Figure 12; Delcourt, 1979), samples for diatom analysis, each approximately 0.5 cc in volume, were taken at approximately 1000-year intervals, with finer 250-year resolution during intervals of diatom floristic and compositional change. Processing of samples for diatom analysis followed the method of Stoermer et al. (1995). The samples were first boiled for 30 minutes in 30% H_2O_2 , followed by fuming for one hour in 25 ml of concentrated HNO_3 . Samples of siliceous diatom frustules were then settled in distilled water for a minimum of 6 hours and then decanted. This step was repeated six times to bring the samples to neutral pH. Samples were then settled onto cover slips, dried, and mounted on microscope slides using Naphrax.

Slides were examined by light microscopy under oil immersion at 1000X, numerical aperture 1.32, with a Leitz Laborlux 12 microscope. At least 500 valves were counted for each of 24 stratigraphic levels, except for one with a count of only 337 valves (121.0 cm below mud-water surface), corresponding to the age 12,000 BP. Sparse valve concentration of poorly preserved diatoms prohibited counts from three additional depth levels of 374.6, 467.4, and 551.0 cm below mud-water surface, corresponding with ages of 16,000, 17,000, and 18,000 BP. In cases of broken frustules, only valves containing the

taxonomically diagnostic central area or over 50% of the valve surface area were counted. The identification of diatoms was based upon the standard taxonomic manuals of Foged (1974, 1981), Hustedt (1928-1966), Krammer & Lange-Bertalot (1986-1991), Patrick & Reimer (1966, 1975), and Round et al. (1990). The identification of diatom genera and species was verified by comparison with reference diatom slides at Iowa Lakeside Lab and the University of Michigan and by consultation with Dr. Gene Stoermer. Siliceous cysts of chrysophytes were also tabulated, but not classified at the generic or species level, to quantify the ratio of chrysophyte cysts to diatom valves, which has been found to be a useful paleolimnological index of trophic status in temperate lakes (Smol, 1985).

The multivariate statistical technique of Detrended Correspondence Analysis (DCA) was applied to the diatom data using the program DECORANA (Hill, 1979) from the statistical package PC-ORD (McCune, 1987). DCA is an eigenvector ordination technique which is based on reciprocal averaging (Gauch, 1982). This technique is used in this study to interpret factors controlling diatom assemblages, to group samples into similar assemblages, and to quantitatively compare diatom assemblages with both the nature and timing of change (Delcourt & Delcourt, 1987b, 1992) for the arboreal pollen and aquatic pollen assemblages obtained by Delcourt (1979).

The question of whether diatoms lead or lag behind changes in upland vegetation is examined by looking at differences in the quantitative rate of change of vegetation and the rate of change in diatoms from Anderson Pond using the DCA Axis 1 results. The difference between DCA Axis 1 scores for adjacent samples are determined and then

adjusted for differences in time span between samples. The resulting value is a rate of change between two sample points. The value obtained is a measure of change in beta diversity per unit of time (Jacobson et al., 1987; Delcourt & Delcourt, 1987b, 1992). For comparison, a change of 4 units (SD) of beta diversity corresponds with complete turnover (100% change) in species composition. This same technique can be applied to the diatoms to determine how they respond in relation to the terrestrial vegetational changes.

Detrended Correspondence Analysis (DCA) has been a commonly used statistical technique for paleoecological studies using diatoms since the mid-1980s (Huttunen & Meriläinen, 1986; Jones & Flower, 1986). Studies using DCA have been particularly useful in interpreting the relationship between diatom assemblages and such environmental variables as acidity/alkalinity (Jones & Flower, 1986; Brugam, 1988, 1993) and nutrients (Huttunen & Meriläinen, 1986; Brugam 1988; Korhola & Blom, 1996).

The interpretation of pH history of Anderson Pond is obtained using the pH categories of Hustedt (1937-1939) and the log index B equation of Renberg & Hellberg (1982). A modern pH measurement was obtained from Anderson Pond using an ATI Orion model 250A portable meter and a Corning High Performance Combination probe (Cat. No. 476390).

CHAPTER V

Results

Taxonomy of Anderson Pond Diatoms

Diatom taxonomy is based primarily on the structure and shape of the frustule (Round et al., 1990). Because the frustule is the part that is readily preserved as a fossil within lake sediments, this makes the identification and classification of fossil diatoms at the species level directly comparable to the classification of modern diatoms.

Incorporating the substantial revision of diatom taxonomy over the last decade, contemporary taxonomic treatments at both the generic and species levels are presented by Krammer & Lange-Bertalot (1986-1991) and by Round et al. (1990).

Diatoms Identified at Anderson Pond

Late Quaternary diatoms identified from Anderson Pond core included 30 genera with at least 164 species and varieties. The classification of diatom taxonomy and photographic plates of these taxa are included in Appendices A and B, respectively. Data tallies are presented in Appendix C. In cases where diatoms were not identified to species, this was typically due to differential preservation and breakage of the valves. Identification to varietal level was used for some taxa that were readily identifiable. Certain genera were significantly affected by breakage, making identification below the

generic level impossible for most valves. This was particularly true for the genus *Pinnularia*.

The classification for this study follows that of Round et al. (1990) for taxonomic levels down to genus. The exception is the small, benthic *Fragilaria* species which Round et al. (1990) have split into different genera. The subtle characteristics (typically seen under SEM) used to differentiate these taxa are difficult to distinguish under a light microscope, and many authors of ecological and paleoecological studies still group these species into the broader taxon *Fragilaria* (Rawlence, 1992; Pienitz & Smol, 1993; Wolfe & Butler, 1994). Alternatively, I report eleven taxa of *Fragilaria* in this study. Appendix A lists the contemporary taxonomic classification and systematics for diatom genera found in this study.

Table 4 list the species and varieties of diatoms identified from the Anderson Pond core. Some genera, such as *Eunotia*, *Gomphonema*, and *Pinnularia*, have a large number of species occurring throughout the late-Pleistocene and Holocene sedimentary sequence. The genera *Aulacoseira*, *Cymbella* and *Navicula* have a high number of species in part of the core, corresponding to a restricted time interval, but only one or two species present in the rest of the core. Many genera, such as *Amphora*, *Neidium*, *Sellaphora* and *Stauroneis*, occur throughout the core but are only represented by one or a few species in any sample. Other genera, such as *Cocconeis*, *Epithemia*, *Fragilaria*, *Frustulia*, and *Gyrosigma*, have only a limited stratigraphic range of occurrence in the core.

Table 4. Alphabetical listing of late-Quaternary diatom taxa reported from Anderson Pond, TN.

No.	Taxa
1	<i>Achnanthes exigua</i> Grunow
2	<i>Achnanthes lanceolata</i> Brebisson ex Kützing
3	<i>Amphora ovalis</i> (Kützing) Kützing
4	<i>Amphora ovalis</i> var. <i>affinis</i> (Kützing) Van Heurck
5	<i>Aulacoseira ambigua</i> (Grunow) Simonsen
6	<i>Aulacoseira distans</i> (Ehrenberg) Simonsen
7	<i>Aulacoseira granulata</i> (Ehrenberg) Simonsen
8	<i>Aulacoseira herzogii</i> (Lemmermann) Simonsen
9	<i>Aulacoseira islandica</i> (O. Müller) Simonsen
10	<i>Aulacoseira lirata</i> f. <i>biseriata</i> (Grunow) Haworth
11	<i>Aulacoseira nygaardii</i> Camburn in Camburn & Kingston
12	<i>Aulacoseira subarctica</i> f. <i>recta</i> (O. Müller) Krammer
13	<i>Caloneis bacillum</i> (Grunow) Cleve
14	<i>Caloneis ventricosa</i> var. <i>minuta</i> (Grunow) Mills
15	<i>Cocconeis placentula</i> var. <i>lineata</i> (Ehrenberg) Van Heurck
16	<i>Craticula ambigua</i> (Ehrenberg) Mann in Round et al.
17	<i>Craticula cuspidata</i> (Kützing) Mann in Round et al.
18	<i>Cymbella acutiuscula</i> Cleve
19	<i>Cymbella amphicephala</i> Naegahrd ex Kützing
20	<i>Cymbella aspera</i> (Ehrenberg) H. Peragallo
21	<i>Cymbella cistula</i> (Ehrenberg) Kirchner
22	<i>Cymbella cuspidata</i> Kützing
23	<i>Cymbella hauckii</i> Van Heurck
24	<i>Cymbella heteropluera</i> var. <i>subrostrata</i> Cleve
25	<i>Cymbella inaequalis</i> (Ehrenberg) Rabenhorst
26	<i>Cymbella lanceolata</i> (Aghard) Aghard
27	<i>Cymbella naviculiformis</i> Auerswald
28	<i>Cymbella proxima</i> Reimer in Patrick & Reimer
29	<i>Cymbella subcuspidata</i> Krammer
30	<i>Denticula lauta</i> J. W. Bailey
31	<i>Diatoma</i> sp.
32	<i>Diploneis elliptica</i> (Kützing) Cleve
33	<i>Encyonema lunatum</i> (W. Smith in Greville) Van Heurck
34	<i>Encyonema mesiana</i> (Cholnoky) Mann in Round et al.
35	<i>Encyonema minutum</i> (Hilse in Rabenhorst) Mann in Round et al.
36	<i>Encyonema muelleri</i> (Hustedt) Mann in Round et al.
37	<i>Encyonema silesiacum</i> (Bleisch in Rabenhorst) Mann in Round et al.
38	<i>Epithemia adnata</i> var. <i>proboscidea</i> (Kützing) Patrick in Patrick & Reimer
39	<i>Epithemia turgida</i> (Ehrenberg) Kützing
40	<i>Epithemia turgida</i> var. <i>granulata</i> (Ehrenberg) Brun
41	<i>Epithemia turgida</i> var. <i>westermanni</i> (Ehrenberg) Grunow
42	<i>Eunotia arcus</i> Ehrenberg
43	<i>Eunotia bilunaris</i> (Ehrenberg) Mills
44	<i>Eunotia circumborealis</i> Lange-Bertalot & Nörpel
45	<i>Eunotia clevei</i> Grunow in Cleve & Möller
46	<i>Eunotia diodon</i> Ehrenberg
47	<i>Eunotia faba</i> Ehrenberg

Table 4 (continued)

Alphabetical listing of late-Quaternary diatom taxa reported from Anderson Pond, TN

No.	Taxa
48	<i>Eunotia flexuosa</i> (Brebisson) Kützing
49	<i>Eunotia formica</i> Ehrenberg
50	<i>Eunotia glacialis</i> Meister
51	<i>Eunotia implicata</i> Nörpel et al.
52	<i>Eunotia incisa</i> Gregory
53	<i>Eunotia intermedia</i> (Krasske ex Hustedt) Nörpel & Lange-Bertalot
54	<i>Eunotia minor</i> (Kützing) Grunow in Van Heurck
55	<i>Eunotia monodon</i> Ehrenberg
56	<i>Eunotia monodon</i> var. <i>bidens</i> (Gregory) Hustedt
57	<i>Eunotia naegelii</i> Migula in Thomé
58	<i>Eunotia pectinalis</i> (O. F. Müller?) Rabenhorst
59	<i>Eunotia pectinalis</i> var. <i>undulata</i> (Ralfs) Rabenhorst
60	<i>Eunotia praerupta</i> Ehrenberg
61	<i>Eunotia praerupta</i> var. <i>bidens</i> (Ehrenberg) Grunow
62	<i>Eunotia rhomboidea</i> Hustedt
63	<i>Eunotia rostellata</i> Hustedt ex Patrick
64	<i>Eunotia serra</i> Ehrenberg
65	<i>Eunotia serra</i> var. <i>tetraodon</i> (Ehrenberg) Nörpel
66	<i>Eunotia soleirolii</i> (Kützing) Rabenhorst
67	<i>Eunotia subarcutoides</i> Alles et al.
68	<i>Eunotia sudetica</i> O. Müller
69	<i>Eunotia tenella</i> (Grunow) Cleve
70	<i>Eunotia triodon</i> Ehrenberg
71	<i>Eunotia veneris</i> (Kützing) De Toni
72	<i>Fragilaria brevistriata</i> Grunow
73	<i>Fragilaria constricta</i> Ehrenberg
74	<i>Fragilaria construens</i> (Ehrenberg) Grunow
75	<i>Fragilaria construens</i> var. <i>venter</i> (Ehrenberg) Grunow
76	<i>Fragilaria lapponica</i> Grunow
77	<i>Fragilaria leptostauron</i> (Ehrenberg) Hustedt
78	<i>Fragilaria nitzschioides</i> Grunow
79	<i>Fragilaria pinnata</i> Ehrenberg
80	<i>Fragilaria pinnata</i> var. <i>intercedens</i> (Grunow) Hustedt
81	<i>Fragilaria subsalina</i> (Grunow) Lange-Bertalot
82	<i>Frustulia rhomboides</i> (Ehrenberg) De Toni
83	<i>Gomphonema acuminatum</i> Ehrenberg
84	<i>Gomphonema affine</i> Kützing
85	<i>Gomphonema angustatum</i> (Kützing) Rabenhorst
86	<i>Gomphonema apicatum</i> Ehrenberg
87	<i>Gomphonema brasiliense</i> Grunow
88	<i>Gomphonema gracile</i> Ehrenberg
89	<i>Gomphonema grunowii</i> Patrick in Patrick & Reimer
90	<i>Gomphonema intricatum</i> Kützing
91	<i>Gomphonema parvulum</i> (Kützing) Kützing
92	<i>Gomphonema sarcophagus</i> Gregory

Table 4 (continued)

Alphabetical listing of late-Quaternary diatom taxa reported from Anderson Pond, TN

No.	Taxa
93	<i>Gomphonema sphaerophorum</i> Ehrenberg
94	<i>Gomphonema subclavatum</i> (Grunow) Grunow
95	<i>Gomphonema truncatum</i> Ehrenberg
96	<i>Gomphonema truncatum</i> var. <i>capitatum</i> (Ehrenberg) Patrick in Patrick & Reimer
97	<i>Gomphonema turris</i> Ehrenberg
98	<i>Gyrosigma acuminatum</i> (Kützing) Rabenhorst
99	<i>Hantzschia amphioxys</i> (Ehrenberg) Grunow in Cleve & Grunow
100	<i>Hantzschia elongata</i> (Hantzsch) Grunow
101	<i>Luticola mutica</i> (Kützing) Mann in Round et al.
102	<i>Meridion circulare</i> (Greville) Agardh
103	<i>Navicula americana</i> Ehrenberg
104	<i>Navicula exigua</i> Gregory ex Grunow
105	<i>Navicula explanata</i> Hustedt
106	<i>Navicula gregaria</i> Donkin
107	<i>Navicula ignota</i> var. <i>acceptata</i> (Hustedt) Lange-Bertalot
108	<i>Navicula ignota</i> var. <i>palustris</i> (Hustedt) Lund
109	<i>Navicula minima</i> Grunow
110	<i>Navicula mouri</i> Patrick
111	<i>Navicula muralis</i> Grunow
112	<i>Navicula oblonga</i> (Kützing) Kützing
113	<i>Navicula placenta</i> Ehrenberg
114	<i>Navicula protracta</i> Grunow
115	<i>Navicula pseudoscutiformis</i> Hustedt
116	<i>Navicula radiosa</i> Kützing
117	<i>Navicula rhyncocephala</i> Kützing
118	<i>Navicula viridula</i> (Kützing) Kützing emend. Van Heurck
119	<i>Neidium affine</i> (Ehrenberg) Pfitzer
120	<i>Neidium iridis</i> (Ehrenberg) Cleve
121	<i>Nitzschia filiformis</i> (W. Smith) Van Heurck
122	<i>Nitzschia frustulum</i> (Kützing) Grunow in Cleve & Grunow
123	<i>Nitzschia linearis</i> (Agardh) W. Smith
124	<i>Nitzschia palea</i> (Kützing) W. Smith
125	<i>Nitzschia sinuata</i> var. <i>delognei</i> (Grunow) Lange-Bertalot
126	<i>Orthoseira dendroteres</i> (Ehrenberg) Crawford
127	<i>Pinnularia acrosphaeria</i> W. Smith
128	<i>Pinnularia angusta</i> (Cleve) Krammer
129	<i>Pinnularia borealis</i> Ehrenberg
130	<i>Pinnularia braunii</i> (Grunow) Cleve
131	<i>Pinnularia brebissonii</i> (Kützing) Rabenhorst
132	<i>Pinnularia divergens</i> W. Smith
133	<i>Pinnularia formica</i> (Ehrenberg) Patrick in Patrick & Reimer
134	<i>Pinnularia gibba</i> Ehrenberg
135	<i>Pinnularia gigas</i> Ehrenberg
136	<i>Pinnularia legumen</i> (Ehrenberg) Ehrenberg
137	<i>Pinnularia maior</i> (Kützing) Rabenhorst

Table 4 (continued)

Alphabetical listing of late-Quaternary diatom taxa reported from Anderson Pond, TN

No. Taxa
138 <i>Pinnularia mesolepta</i> (Ehrenberg) W. Smith
139 <i>Pinnularia microstauron</i> (Ehrenberg) Cleve
140 <i>Pinnularia neomajor</i> Krammer
141 <i>Pinnularia nobilis</i> (Ehrenberg) Ehrenberg
142 <i>Pinnularia nodosa</i> (Ehrenberg) W. Smith
143 <i>Pinnularia rupestris</i> Hantzsch
144 <i>Pinnularia streptoraphe</i> Cleve
145 <i>Pinnularia viridiformis</i> Krammer
146 <i>Pinnularia viridis</i> (Nitzsch) Ehrenberg
147 <i>Pinnularia viridoides</i> Krammer
148 <i>Sellaphora pupula</i> var. <i>rectangularis</i> (Gregory) Mereschowsky
149 <i>Stauroneis anceps</i> Ehrenberg
150 <i>Stauroneis anceps</i> f. <i>gracilis</i> Rabenhorst
151 <i>Stauroneis anceps</i> f. <i>linearis</i> (Ehrenberg) Hustedt
152 <i>Stauroneis fluminea</i> Patrick & Freese
153 <i>Stauroneis kriegeri</i> Patrick
154 <i>Stauroneis phoenicenteron</i> (Nitzsch) Ehrenberg
155 <i>Surirella bifrons</i> Ehrenberg
156 <i>Surirella brebissonii</i> Krammer & Lange-Bertalot
157 <i>Surirella linearis</i> W. Smith
158 <i>Surirella ovalis</i> Brebisson
159 <i>Synedra parasitica</i> (W. Smith) Hustedt
160 <i>Synedra radians</i> Kützing
161 <i>Synedra rumpens</i> Kützing
162 <i>Synedra ulna</i> (Nitzsch) Ehrenberg
163 <i>Tabellaria fenestrata</i> (Lyngbye) Kützing
164 <i>Tabellaria flocculosa</i> (Roth) Kützing

The most diverse genus at Anderson Pond is *Eunotia* with 30 species and varieties identified. Many of these occur throughout the core, with the most abundant being *E. bilunaris*, *E. implicata*, *E. incisa*, *E. minor*, and *E. monodon*. *Eunotia monodon* is the most abundant taxon in the Anderson pond core, followed by *E. bilunaris*.

The next most diverse genus is *Pinnularia* with 21 species identified. This genus was generally very poorly preserved due to breakage of valves, making identification to the species level challenging. However, individual valves of some species, such as *P. gibba*, *P. gigas*, *P. microstauron*, *P. streptoraphe*, and *P. viridis*, have been identified commonly throughout the core.

Diatom Stratigraphy

The Anderson Pond core can be divided into five diatom assemblage zones based on percent values in the dominant and subdominant diatom genera present and the results of DCA on the diatom genera. These data were chosen to delineate diatom assemblage zones because this level of data summary included all taxa present, including rare taxa with distinct ecological preferences, particularly in the late glacial portion of the core. Figure 20 shows all genera counted as a percent of total diatoms present at each sample depth with diatom zones shown on the right. Also included are undifferentiated diatoms that were not identifiable to the generic level due to poor preservation because of valve breakage or dissolution. For comparison, Figure 21 presents the stratigraphic curves of

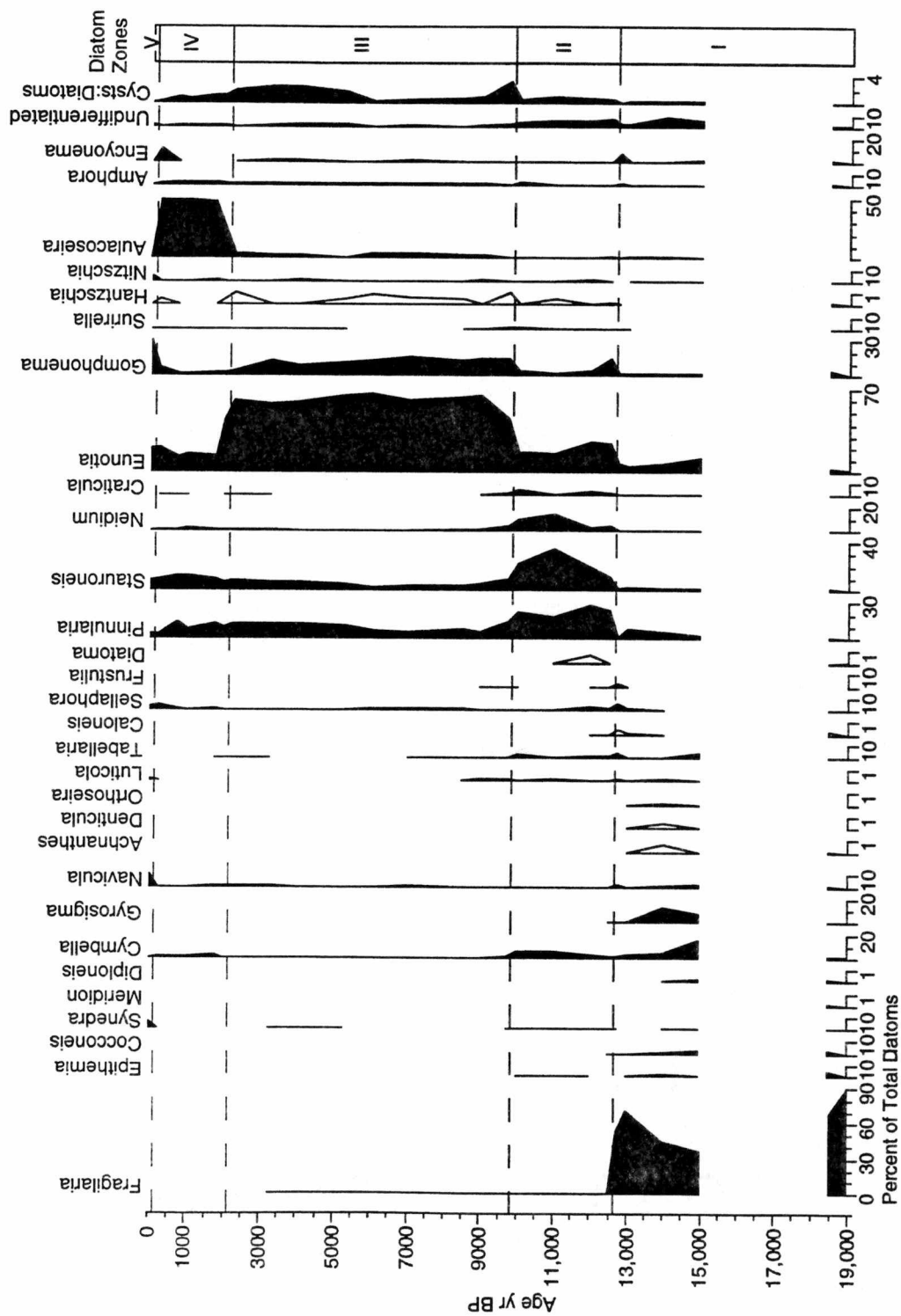


Figure 20. Diatom genera diagram for 30 genera through time. Black curves are plotted at a scale of 10 percent per grid mark; open curves are plotted at a scale of 1 percent per grid mark.

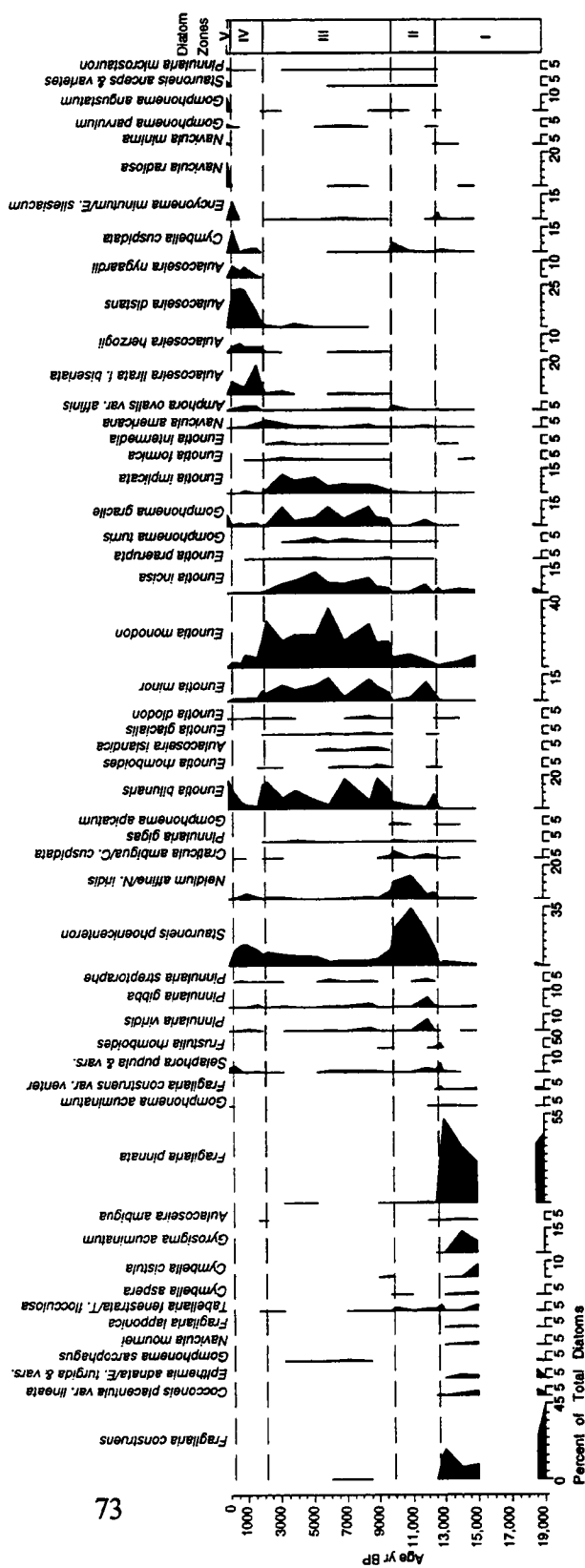


Figure 21. Diatom species diagram for 52 species through time.

percentages for the 52 diatom species; the diatom-zone boundaries for diatom assemblages are based upon the genus-level DCA.

Diatom Assemblage Zone 1

Zone 1 includes the stratigraphic levels from 19,000 BP through 12,750 BP and is dominated by the genus *Fragilaria* (Figure 20). This genus accounted for between 37 and 90 percent of the total diatom valves per level counted in this zone, with peaks in abundance at 19,000 BP and 13,000 BP. The species present are all small, benthic taxa, primarily *F. construens* and *F. pinnata* (Figure 21). Also identified in at least two samples were *F. brevistriata*, *F. subsalina*, *F. construens* f. *venter*, *F. lapponica*, and *F. leptostauron*.

Between 18,000 BP and 16,000 BP diatom valves, as well as chrysophyte cysts and freshwater-sponge spicules, are extremely sparse and poorly preserved when present. Slides made from samples within this sample range may contain only 2 or 3 fragments of diatom valves on an entire coverslip (see occurrences of diatom taxa as noted in Appendix C).

In the earliest portion of the core, representing peak-glacial times from 19,000 BP to 18,500 BP, important accessory genera include *Epithemia*, *Gomphonema*, *Cocconeis*, *Eunotia*, *Cymbella*, and *Navicula*. Each of these genera reach an abundance of more than 2 percent in at least one full-glacial sample. Typically, genera exhibit low species-level diversity at 19,000 BP and then display enhanced taxonomic richness with at least four

species and varieties by 18,500 BP. In contrast, the genus *Cocconeis* is represented by only one species, *Cocconeis placentula* var. *lineata*.

The genera *Cymbella* (16.0%), *Eunotia* (11.5%), *Gyrosigma* (7.4%), and *Navicula* (6.4%) increase in importance by late-glacial times at 15,000 BP, which is also the lowest abundance of *Fragilaria* (37.2%) in Zone 1. *Gyrosigma acuminatum* reaches 13.2% at 14,000 BP. The genus *Pinnularia* (3 species) reaches 7.9% at 13,000 BP. At 12,750 BP, 11 species of *Eunotia* (7.6%), 2 species of *Encyonema* (6.8%), 5 species of *Navicula* (6.7%), and *Sellaphora pupula* (6.3%) are important taxa.

There are also a number of minor taxa that occur only in Zone 1 and never reach an abundance of 1.0 percent. These include *Meridion circulare*, *Caloneis bacillum*, *C. placentula* var. *lineata*, *C. ventricosa* var. *minuta*, *Diploneis elliptica*, *Achnanthes exigua*, *A. lanceolata*, *Denticula lauta*, and *Orthoseira dendroteres*.

Near the end of the late-glacial at 12,750 BP, the Pleistocene assemblage is still dominated by *Fragilaria* (52.5%), but an increase in diversity with small, short-lived peaks in many taxa, including *Navicula*, *Sellaphora*, *Frustulia*, *Encyonema*, *Tabellaria*, and *Caloneis*.

Chrysophyte cysts are relatively rare throughout Diatom Assemblage Zone 1. The chrysophyte cyst to diatom valve ratio (C:D) ranged between 0.01 and 0.19 (Figure 20). During this zone chrysophyte cysts were at their most abundant with C:D ratios of 0.14 at 15,000 BP and 0.19 at 14,000 BP. This coincides with the lowest abundance of *Fragilaria* (37.2 and 45.4%, respectively) in Zone 1.

Diatom Assemblage Zone 2

Zone 2 includes the late Pleistocene samples from 12,500 BP through 10,000 BP and is dominated by the genera *Eunotia*, *Pinnularia*, and *Stauroneis*. These three genera each maintain an abundance of between 11% and 35% throughout this zone. Through 12,000 BP, *Eunotia* and *Pinnularia* are nearly equal in abundance, at about 25% each. After 12,000 BP *Stauroneis* is most abundant in the early Holocene transition through 10,000 BP.

Both *Eunotia* and *Pinnularia* are very diverse genera in this zone, typically with from 4 to 8 species each in most samples. The most common species of *Eunotia* are *E. bilunaris*, *E. minor*, and *E. monodon* (Figure 21). Valves of the genus *Pinnularia* are broken in most cases, often allowing for identification only to the generic level. Consequently, in most samples few *Pinnularia* have been identified to the species level. However, species identified in more than one sample in Zone 2 include *P. braunii*, *P. gibba*, *P. gigas*, *P. microstauron*, and *P. viridis*. The genus *Stauroneis* is represented primarily by *S. phoenicenteron* in all samples. *S. anceps* occurs in two samples in Zone 2 with only one or two valves counted.

A few other taxa are important in Zone 2. The genus *Gomphonema* accounts for up to 14 percent of the total diatoms in the first two samples, when *Eunotia* and *Pinnularia* are most abundant. These three genera, as well as the genus *Craticula*, display a similar pattern of higher abundance early in Zone 2, followed by a decrease in abundance around 11,000 BP, and then an increase in abundance around 10,000 BP. Also important

in Zone 2 is the genus *Neidium*, whose pattern of abundance parallels that of *Stauroneis* with a peak (14.1%) at around 11,000 BP.

During Diatom-Assemblage Zone 2 the C:D ratio increases to between 0.38 and 0.92 (Figure 20), indicating that chrysophytes have increased in relative abundance during this late-glacial period. Abundance of chrysophyte cysts relative to diatoms is greatest at 11,000 BP.

Diatom Assemblage Zone 3

Zone 3 includes the early through middle Holocene samples from 9750 BP through 2250 BP and is dominated by the genus *Eunotia* which accounts for between 45 and 67% of the total diatom valves counted. At 9750 BP, *Eunotia* is 45.7%, whereas the subsequent samples remain consistently above 57%. *Eunotia* maintains high species richness throughout Zone 3, with from 7 to 16 species identified per sample and an average diversity of 11.6 species per sample. The five most common species of *Eunotia* are *E. bilunaris*, *E. implicata*, *E. incisa*, *E. minor*, and *E. monodon* (Figure 21). *E. monodon* is the most abundant species in most samples accounting for 36 percent of the total diatom valves counted in the peak-interglacial level at 6000 BP.

The second most abundant diatom genus in Zone 3 is *Gomphonema*, accounting for 11.4 to 15.7% of the diatom valves counted throughout most of this zone. Valves for this genus drop off to 8.6% at 4000 BP, rebound to 12.3% at 3250 BP, and by 2250 BP drop below 5%. The most abundant species, occurring in all samples, is *G. gracile*. Other

common species include *G. affine*, *G. angustatum*, *G. parvulum*, *G. sarcophagus*, and *G. turris*.

The other two dominant genera from Zone 2, *Pinnularia* and *Stauroneis*, remain important in Zone 3. Their relative abundance drops off in the first part of Zone 3 but then begins to rise again at 5250 BP, remaining at moderate levels (typically 6.0 to 12.7%) through the end of this zone. Comparably, another codominant in Zone 2, the genus *Neidium*, drops off at the beginning of Zone 3 but shows a minor increase in relative abundance (1.6%) during the last part of this zone.

Several additional genera also show minor increases in Zone 3. The genus *Navicula* increases in abundance during this zone, with *N. americana* identified as the only species in all but one of the samples from this zone. The genera *Aulacoseira* and *Sellaphora* increase in abundance in the first part of this zone. Species of *Aulacoseira* include *A. distans*, *A. granulata*, *A. herzogii*, *A. islandica*, *A. lirata* f. *biseriata*, and *A. subarctica* f. *recta*. *Sellaphora pupula* var. *rectangularis* is present in all but one sample.

Chrysophyte cysts continue to be abundant during diatom Zone 3. The C:D ratio is quite variable, ranging from 0.16 to 2.54 (Figure 20). From 9750 BP through 7000 BP, the C:D ratio is relatively consistent with values ranging from 0.55 to 0.88. The sample at 6000 BP has the lowest C:D ratio of Zone 3 at 0.16, indicating a substantial drop in the relative abundance of chrysophyte cysts. From 5250 BP through 2250 BP, C:D ratio increases to values of 1.76 to 2.54. This is the time of greatest abundance of chrysophyte cysts in the Anderson Pond core, with the peak in abundance occurring at 3250 BP.

Diatom Assemblage Zone 4

Zone 4, including late Holocene samples from 2000 BP through 250 BP, is dominated by the genus *Aulacoseira* which accounts for 27 to 49% of the total diatom valves counted. Species of *Aulacoseira* are present at an abundance of less than 5% throughout most of the late-Quaternary sequence, but rise in abundance at around 2000 BP (26.9%) and reach maximum abundance of 49.0% by 750 BP. Although the genus *Eunotia* is still codominant at 2000 BP, accounting for 43.5% of the valves counted, the large increase in *Aulacoseira* distinguishes this sample from zone 3. Four species, *A. distans*, *A. herzogii*, *A. lirata* f. *biseriata*, and *A. nygaardii*, are present throughout Zone 4 (Figure 21). *Aulacoseira distans* is the most abundant species in all but the 1750 BP sample, accounting for 22.9% of the total diatom valves counted.

The genera *Eunotia*, *Pinnularia*, and *Stauroneis* remain important, each with an abundance generally above 10%. *Eunotia* and *Pinnularia* remain diverse with generally 4 to 9 species identified per sample, while *Stauroneis phoenicenteron* is the only species represented by this genus. The genera *Amphora*, *Cymbella*, and *Neidium* increase slightly in this zone, but remain below 5% of the total. The sample at 250 BP displays a noticeable increase in abundance of the genera *Encyonema*, *Eunotia*, *Gomphonema*, and *Sellaphora*, with a co-occurring drop in the abundance of the genera *Pinnularia*, *Stauroneis*, and *Neidium*.

During Diatom Assemblage Zone 4 chrysophyte cysts remain abundant, with C:D ratios of 0.31 to 1.33 (Figure 20). In the late-Holocene interval from 2000 BP through 750

BP, the C:D ratio is highest at 2000 BP, decreases to less than 1.0 between from 1000 BP through 750 BP (0.74 and 0.94 respectively), and decreases substantially, to 0.31, by 250 BP. This marked shift coincides with an increase in the diatoms *Eunotia*, *Gomphonema*, and *Encyonema*, and a decrease in both *Pinnularia* and *Stauroneis*.

Diatom Assemblage Zone 5

Zone 5 is represented by the one historic, or modern, sample corresponding with landscape modification following settlement by EuroAmerican pioneers. This sample is dominated by the genus *Gomphonema* which accounts for 30.6% of the total diatom valves counted (Figure 20). Five species of *Gomphonema* were identified in this sample: *G. acuminatum*, *G. angustatum*, *G. gracile*, *G. grunowii*, and *G. parvulum* (Figure 21). The genus *Eunotia* (20%) continues to be important in this sample with six species identified. *Eunotia bilunaris* is the most common species in this sample accounting for 17.6% of the diatom valves counted. The genera *Pinnularia* (5%) and *Stauroneis* (8.2%) remain near their previous levels of abundance.

There were some important compositional changes between Zone 4 and Zone 5. The dominant genus from Zone 4, *Aulacoseira*, almost completely disappears, with only one valve counted in the modern-day surface muds. The genera *Amphora*, *Cymbella*, and *Neidium* completely disappear from historic sediments. Also, the genus *Navicula* (with five species) became an important component of the diatom assemblage, accounting for 20% of the valves counted. Within *Navicula*, *N. americana* completely disappears and *N. radiosa* becomes the most abundant historic species for this genus.

During Diatom Assemblage Zone 5 the relative chrysophyte cyst abundance continues to drop significantly. The C:D ratio decreases to 0.03 (Figure 20), its lowest value since the oldest sample at 19,000 BP.

Statistical Analyses of Diatom Assemblages

Detrended Correspondence Analysis (DCA) was used to analyze the diatom assemblages in the Anderson Pond core. DCA was run on several taxonomic levels of resolution for the fossil diatom data (genera data in Appendices D, E; species data in Appendices F, G). This analysis will objectively permit the quantitative identification of informal diatom assemblage zones based on the dissimilarity among diatom assemblages and to help clarify the factors controlling the temporal distribution of diatoms throughout the sedimentary sequence.

Diatom Genera

DCA on the thirty diatom genera (Appendix E) showed a strong correlation with DCA Axis 1 having an eigenvalue of 0.73. In other words, DCA Axis 1 accounts for over the majority of the compositional variation in the data set. DCA Axis 2 had an eigenvalue of 0.20, and DCA Axis 3 has an eigenvalue of 0.10. The scores for Axis 1 and Axis 2 are plotted on Figure 22.

In considering DCA Axis 1, an important feature is the broad clustering of some genera between 2.3 and 3.0 Beta SD. Within this cluster, nine genera occur at values between 2.9 and 3.0 Beta SD. All of these genera occur in the late Pleistocene interval, and

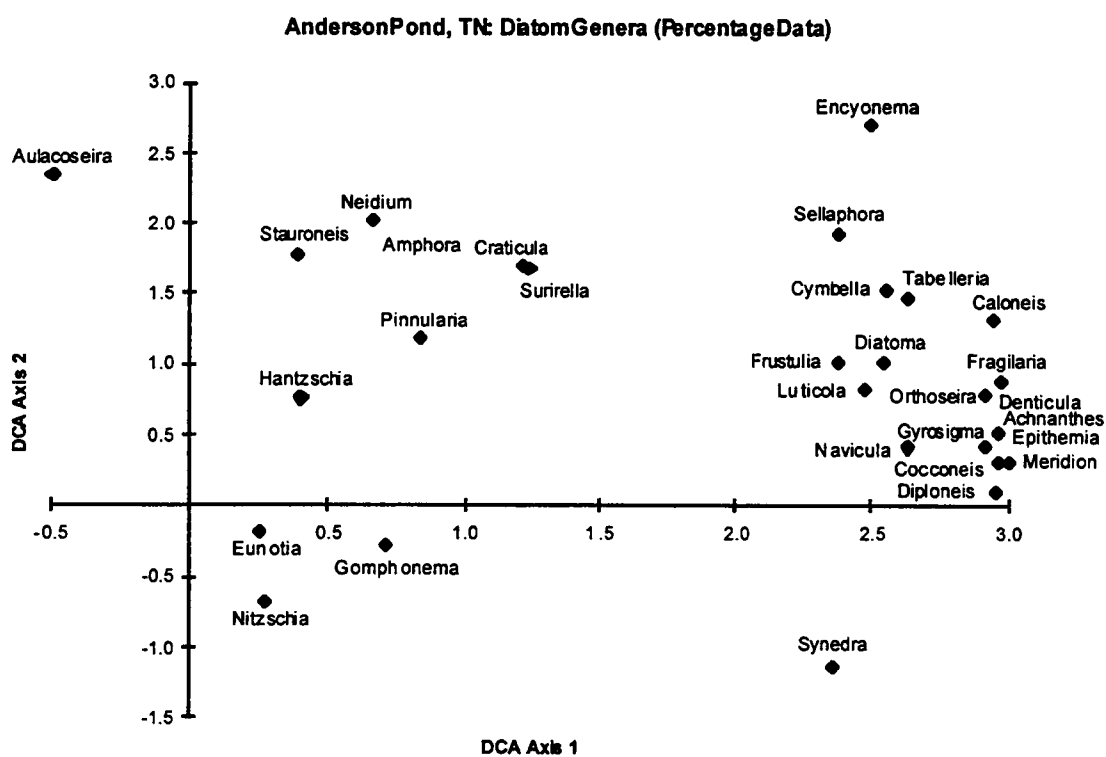


Figure 22. DCA taxon scores for 30 diatom genera at Anderson Pond, TN.

either disappear after 12,750 BP or recur only at very low abundance in one or two stratigraphic levels. Plotting between +0.3 and +1.5 are mostly genera that reach their greatest stratigraphic abundance in the earliest post-glacial or within the last 250 years, such as *Gomphonema*, *Neidium*, *Pinnularia*, and *Stauroneis*. Then the most abundant genus between 9750 BP and 2250 BP, *Eunotia*, plots between +0.2 and +0.3 on DCA Axis 1. *Aulacoseira*, the dominant genus from 2000 BP through 250 BP, plots at the lowest axis 1 value of -0.5 on DCA Axis 1. The genus *Synedra* is distinctive as a modern-day (0 BP) codominant, plotting at 2.4 on DCA Axis 1 and -1.0 on DCA Axis 2.

For the ordination space of $<+1.5$ on DCA Axis 1, the value of +0.5 on DCA Axis 2 separates genera by time interval, with values $<+0.5$ for genera that are dominant in the earliest post-glacial and the late Holocene, and values of $>+0.5$ for middle Holocene and modern-day assemblages. Genera that reach their greatest abundance in the late-glacial or historic intervals (>2.3 on DCA Axis 1) span the full range of values across DCA Axis 2. These taxon peaks are associated with intervals of high mineral-sediment accumulation rates in the basin (Figure 12). Genera that are present throughout the past 19,000 years and that have little correlation in abundance to a particular time interval, or that have a high abundance in more than one time interval, generally plot towards the middle of DCA Axis 2.

Sample scores (corresponding with stratigraphic levels in the core) for the genera (Figure 23) display a strong clustering of five time intervals characterized by diagnostic diatom assemblage zones. Stratigraphic samples for Diatom Zone 1 plot >1.5 Beta SD on

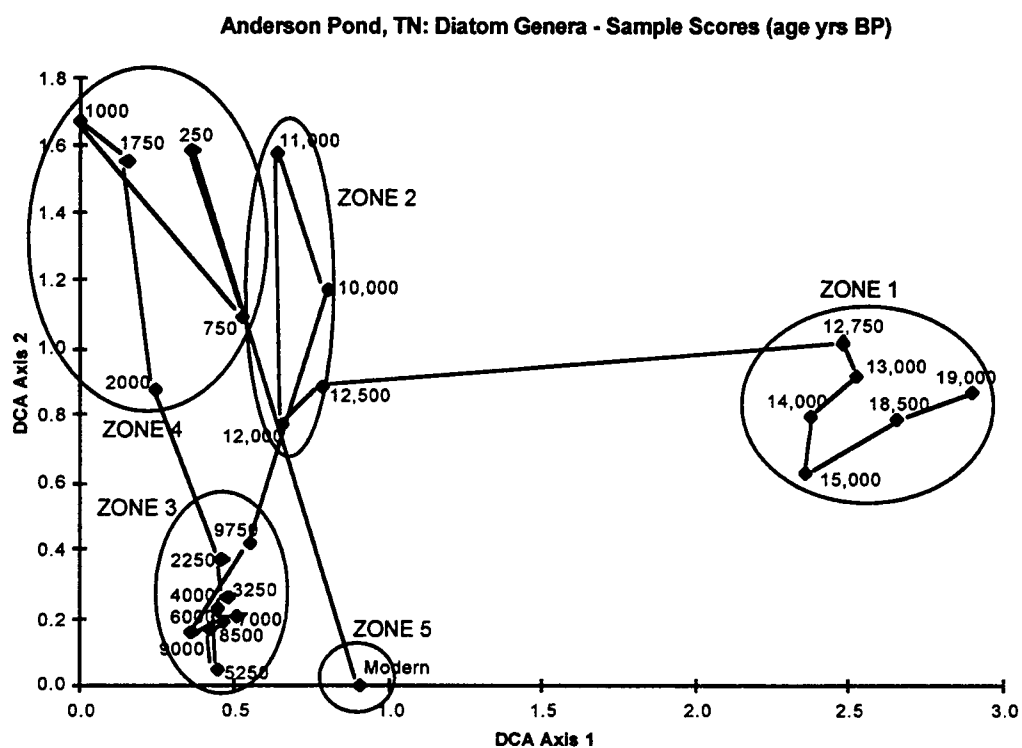


Figure 23. DCA sample scores for 30 diatom genera at Anderson Pond, TN. Line connects successive ages in sequence.

DCA Axis 1 and display a relative narrow range of variation on DCA Axis 2, with values between +0.6 and 1.1 Beta SD. Zones 2 through 5 (Holocene) all plot below a Beta SD value of 1.5 on DCA Axis 1, indicating a distinct separation between these zones and Zone 1 (Pleistocene). Zone 2 clusters tightly in ordination space >0.5 to 1.0 on DCA Axis 1 and from 0.6 to 1.8 along DCA Axis 2; Zone 3 occurs from 0.3 to 0.6 along DCA Axis 1 and <0.5 along DCA Axis 2; Zone 4 from 0.0 to 0.6 along DCA Axis 1 and 0.8 to 1.8 along DCA Axis 2. The lone sample (0 BP) for Zone 5 occurs at a value of 0.9 on DCA Axis 1 and at a value of 0.0 on DCA Axis 2. This value for DCA Axis 1 is larger than any of the other post-glacial samples and the value for DCA Axis 2 is lower than any other sample, but Zone 5 still clusters within the Holocene ordination region.

Diatom Species

Fifty-two diatom species were chosen for additional analysis using DCA (Appendices F, G). The species selected were present in at least three stratigraphic levels and had a percent abundance of $\geq 1.00\%$ in at least one sample (Pienitz & Smol, 1993). In the species analysis there is a strong loading along DCA Axis 1, with an eigenvalue of 0.82. DCA Axis 2 also had a moderate loading with an eigenvalue of 0.41, and DCA Axis 3 has an eigenvalue of 0.23.

Figure 24 shows a plot of the DCA Axis 1 and Axis 2 scores for the species scores data. Similar to the DCA results for the diatom genera results (Figure 22), there is a strong clustering of species that are at their greatest abundance or only found in Pleistocene times prior to 12,500 BP. These species occur at values of greater than 2.5

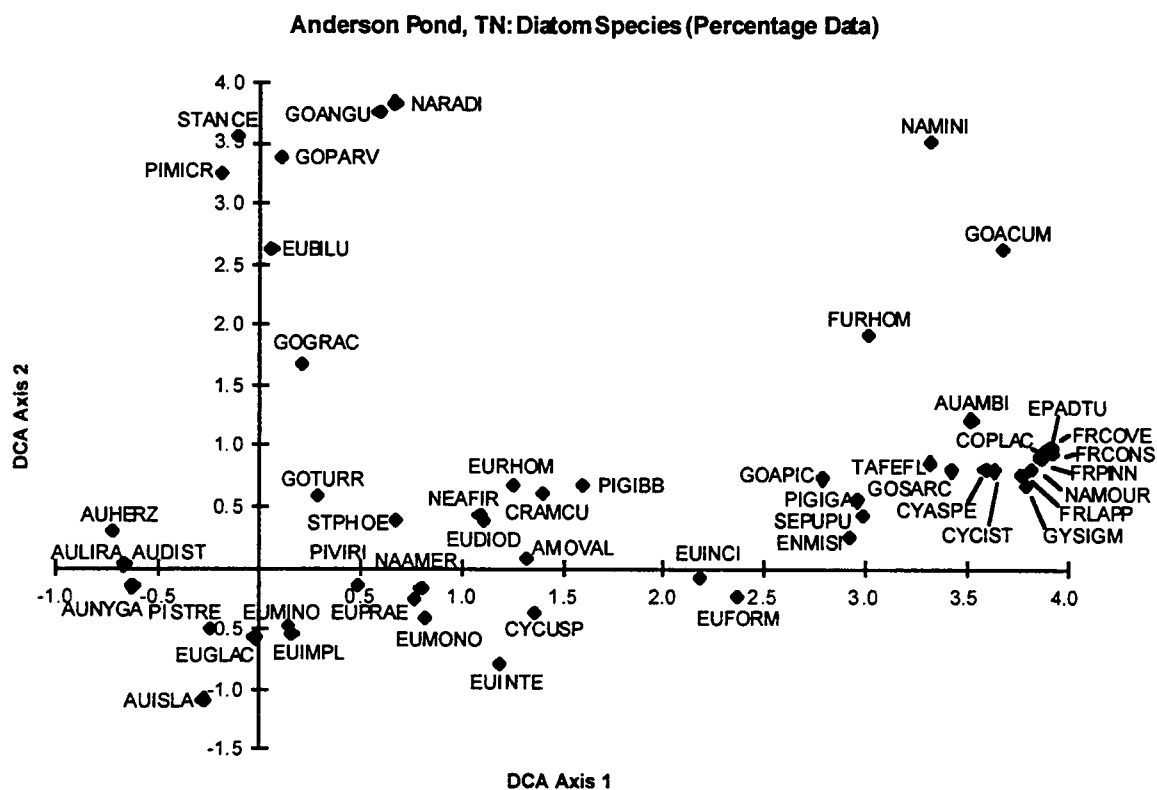


Figure 24. DCA taxon scores for 52 diatom species at Anderson Pond, TN (taxon > 1.00% at one level and at least three stratigraphic occurrences). Species codes are listed with species names in Appendix G.

along DCA Axis 1. There is a general trend of lower values (<2.5 in DCA Axis 1) as species reach their peak abundance in the latest Pleistocene and Holocene times. Relative to the plot of genus taxon scores (Figure 22), there does not appear to be as strong of a separation of species along Axis 2 (Figure 24).

The DCA Axis 1 and Axis 2 species sample scores are plotted in Figure 25. In the species sample data, only Pleistocene Zone 1 and Historic Zone 5 (compare with Figure 23) are separated out clearly, whereas, late-glacial Zone 2 and Holocene Zones 3 and 4 overlap. Pleistocene Zone 1 plots at values >3.0 Beta SD along DCA Axis 1, while all other Zones plot below 1.1 Beta SD. Along Axis 2, the modern-day Zone 5 plots at a value of 2.9 while all other Holocene samples plot at values of ≤ 1.0 Beta SD. Within Zone 4, all but the most recent sample, at 250 BP, separates out from Zones 2 and 3, with the lowest Axis 1 values typically <0.2 Beta SD.

Comparison Between Diatom and Pollen Assemblages

Quantitative changes in the diatom assemblages and changes in the fossil-pollen record were compared using the diatom data from this study (Figures 20, 21) and the pollen data of Delcourt (1979) (Figures 13, 17). The data for arboreal pollen and for aquatic pollen were used separately for these DCA analysis. The aquatic pollen included taxa of hydric habitats which expanded into the Anderson Pond basin, such as shrubs of *Alnus serrulata* and *Cephalanthus occidentalis*, and the herbaceous plants in the Cyperaceae and the Gramineae. In conjunction with the plant macrofossil data

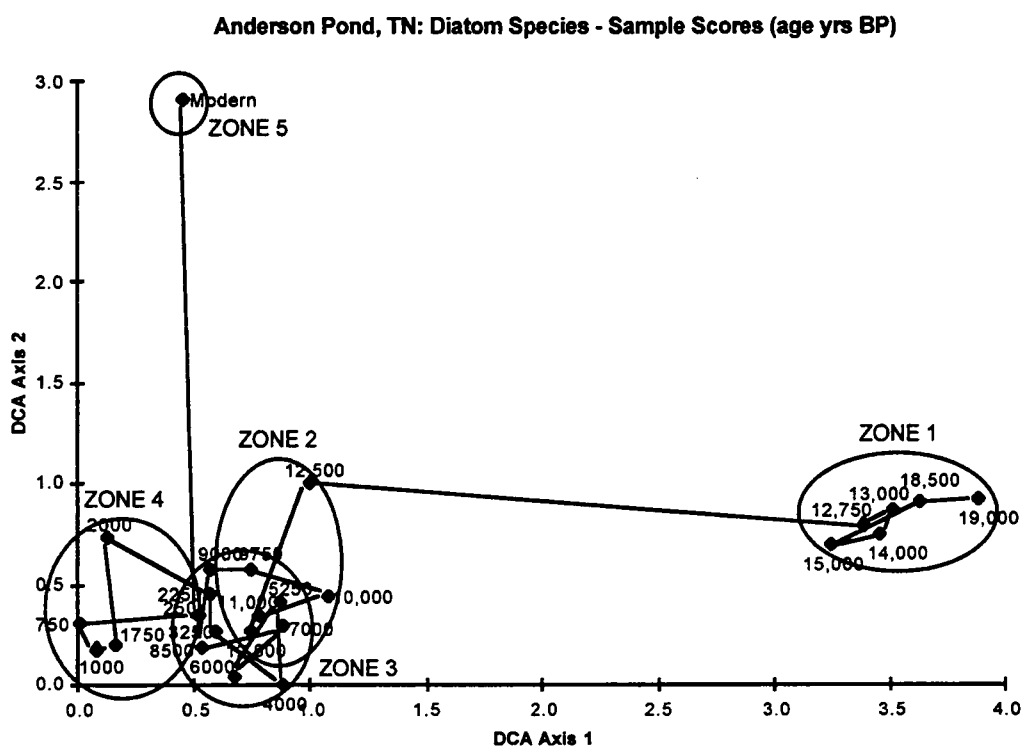


Figure 25. DCA sample scores for 52 diatom species at Anderson Pond, TN. Line connects successive ages in sequence.

(Figure 18), the fossil-pollen abundance of these taxa all provide information on the type, depth, and size of aquatic habitat available to diatom assemblages.

The comparison among the diatoms (Appendices H, I), arboreal pollen (Appendix J), and aquatic pollen (Appendix K) was done using the scores for DCA Axis 1 from each data set (Appendix L). The score along the DCA Axis is a measure of the average standard deviation (SD) of turnover in the data set (Gauch, 1982), where a value of 4 SD would be a complete turnover in composition. To compare the data sets, the difference in values for DCA Axis 1 from temporally successive samples was determined, and this value was then corrected for differences in the amount of radiocarbon time between samples and adjusted to 250-year increments. The result is a rate of change curve, measuring change in SD per radiocarbon time, with peaks in the curve representing comparable times of greatest change in that data (Delcourt & Delcourt, 1987b; Delcourt & Delcourt, 1992). For each data set, DCA was run on percent dominance (D) data and on floristic (F) data, which is the presence or absence of taxa.

Arboreal Pollen

Figure 26 shows the DCA results of the dominance (D, based upon % data) and floristic (F, based upon taxon presence/absence) data for arboreal pollen at Anderson Pond. Beta D and beta F are both highest in the first sample at 19,000 BP (Appendix J). Beta D values display a relatively consistent drop in values to a low of 0.00 between approximately 7500 BP and 6000 BP. For beta F there is a more erratic drop off to a

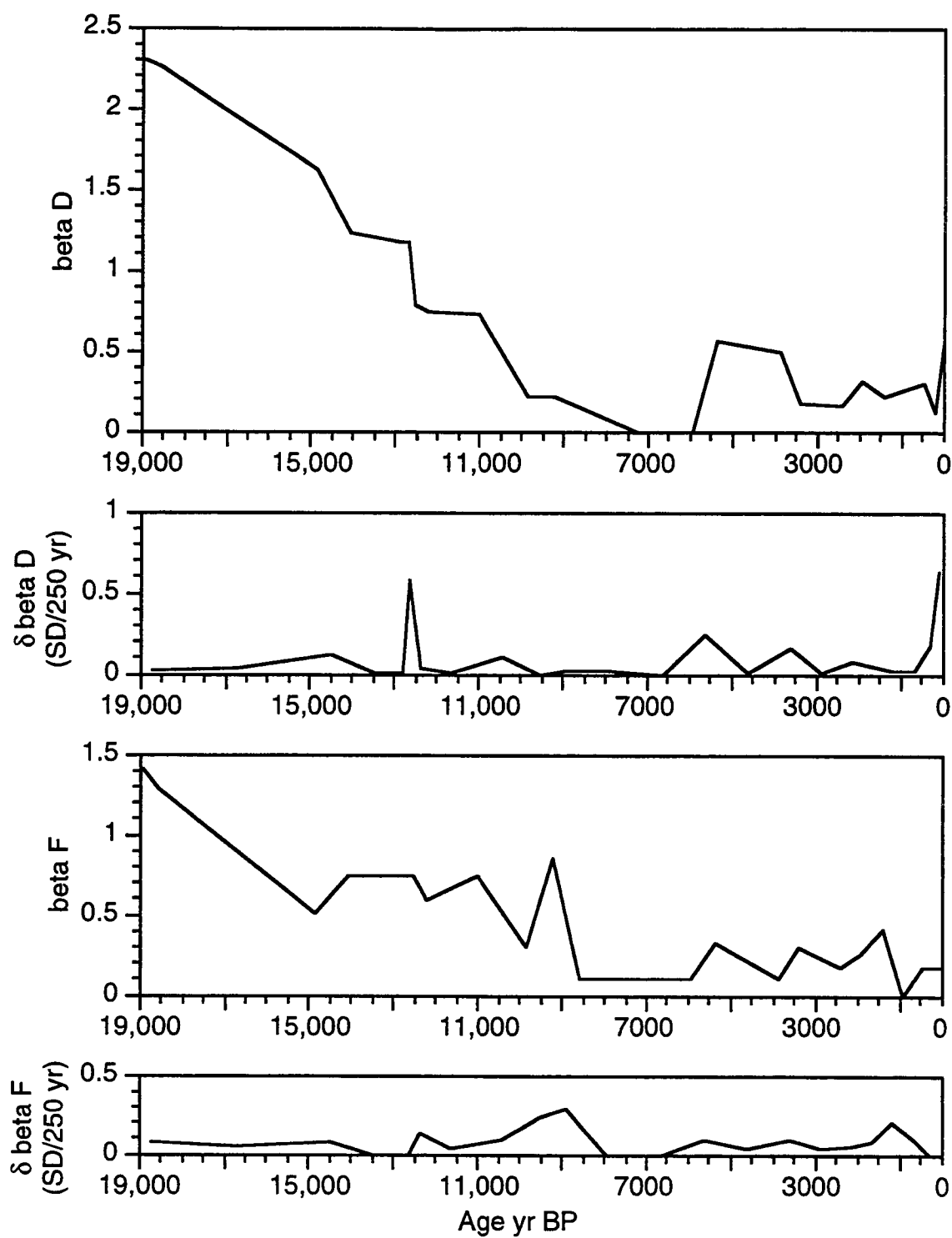


Figure 26. DCA results for arboreal pollen at Anderson Pond, TN.

value of 0.11 around 8500 BP and stabilization at this value through 6000 BP. After 6000 BP both beta D and beta F show fluctuating, but relatively low values.

Plots of rates of change (δ beta D and δ beta F) show low rates of change for both dominance and floristic data during the late-glacial up to 12,750 BP. The dominance data displayed a large peak (0.58 Beta SD/250 BP) between 12,630 BP and 12,390 BP, while the floristic data displayed no apparent change (0.00 Beta SD). This represents a major changeover in forest-canopy dominance but persistence of the same mix of plant species throughout the forest region. Driven by plant extinctions and immigration, the more substantive floristic change (0.13 Beta SD) followed, between about 12,400 and 11,600 BP (Figure 26, Appendix J). Throughout the post-glacial time, rates of change were quite variable. The floristic data displayed their largest rates of change (>0.23 Beta SD) between 9500 BP and 7900 BP. A secondary floristic peak in rate of change (0.21 Beta SD) occurred between 1200 BP and 700 BP. A prominent dominance peak of 0.63 Beta SD occurred in the last 100 years.

Aquatic Pollen

Figure 27 shows the DCA results of the dominance (D) and floristic (F) data for aquatic pollen at Anderson Pond (Appendix K). Both beta D and beta F commenced with high values at about 19,000 BP and drop off significantly by 18,500 BP, and continued to drop in value through 15,000 BP. The beta F value rose significantly at 14,000 BP and stayed between 1.0 and 1.6 Beta SD through 9000 BP. The beta D value does not make

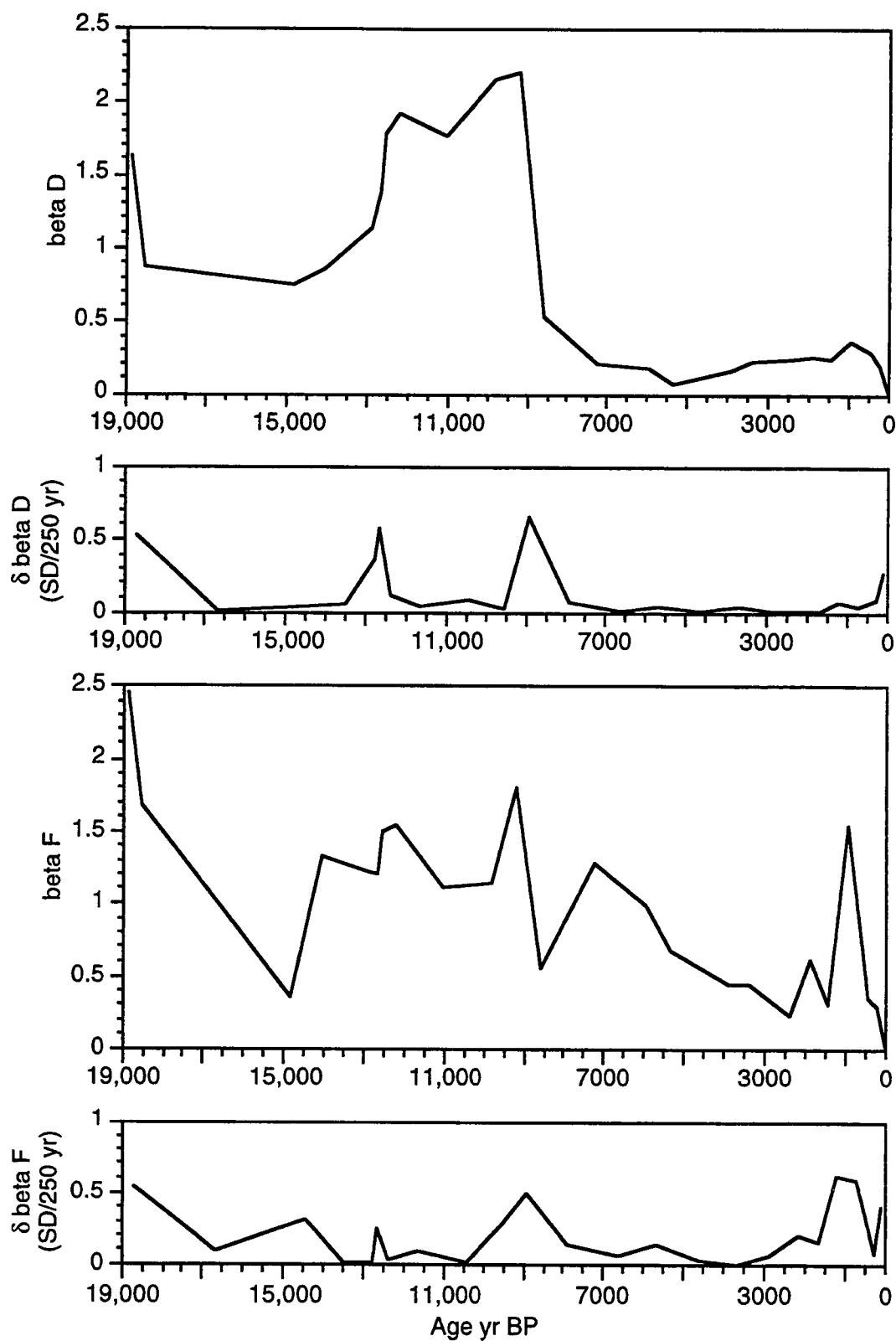


Figure 27. DCA results for aquatic pollen at Anderson Pond, TN.

an abrupt, marked rise until about 12,900 BP, and then remains around values >1.75 from 12,500 BP through 8600 BP. After 8600 BP, the beta D values remained relatively stable at values typically below 0.30. During the same period, the beta F values fluctuated between 0.00 and 1.54 (Figure 27).

Rates of change for percent dominance and floristic (δ beta D and δ beta F, respectively) data were both high between 19,000 BP and 18,500 BP (Figure 27), and then dropped off to values near 0.0. The dominance data displayed low values for rate of change during most of the rest of the late Quaternary, with relatively large, but narrow peaks near 12,600 BP and 8900 BP, and increased values occurred particularly after 100 BP. The floristic data show continual fluctuations in rates of change throughout the full interval, with high values near 14,500 BP, 12,600 BP, between 9500 BP to 7900 BP, between 1200 BP and 700 BP, and 100 BP (Figure 27).

Diatom Genera and Species

The DCA results for 30 diatom genera (Figure 28) and 52 species (Figure 29) were broadly comparable (Appendices H, I). Beta D values for both genera and species were high in the Pleistocene from 19,000 BP through 12,750 BP, and then dropped off sharply in the latest glacial and Holocene. Beta F values began to drop off at 14,000 BP and continued dropping through the late-glacial interval to 12,750 BP. The beta D values displayed a small rise between 11,000 BP and 10,000 BP, a modest drop after 10,000 BP, and consistent levels through 2250 BP. During this same period, the beta F values

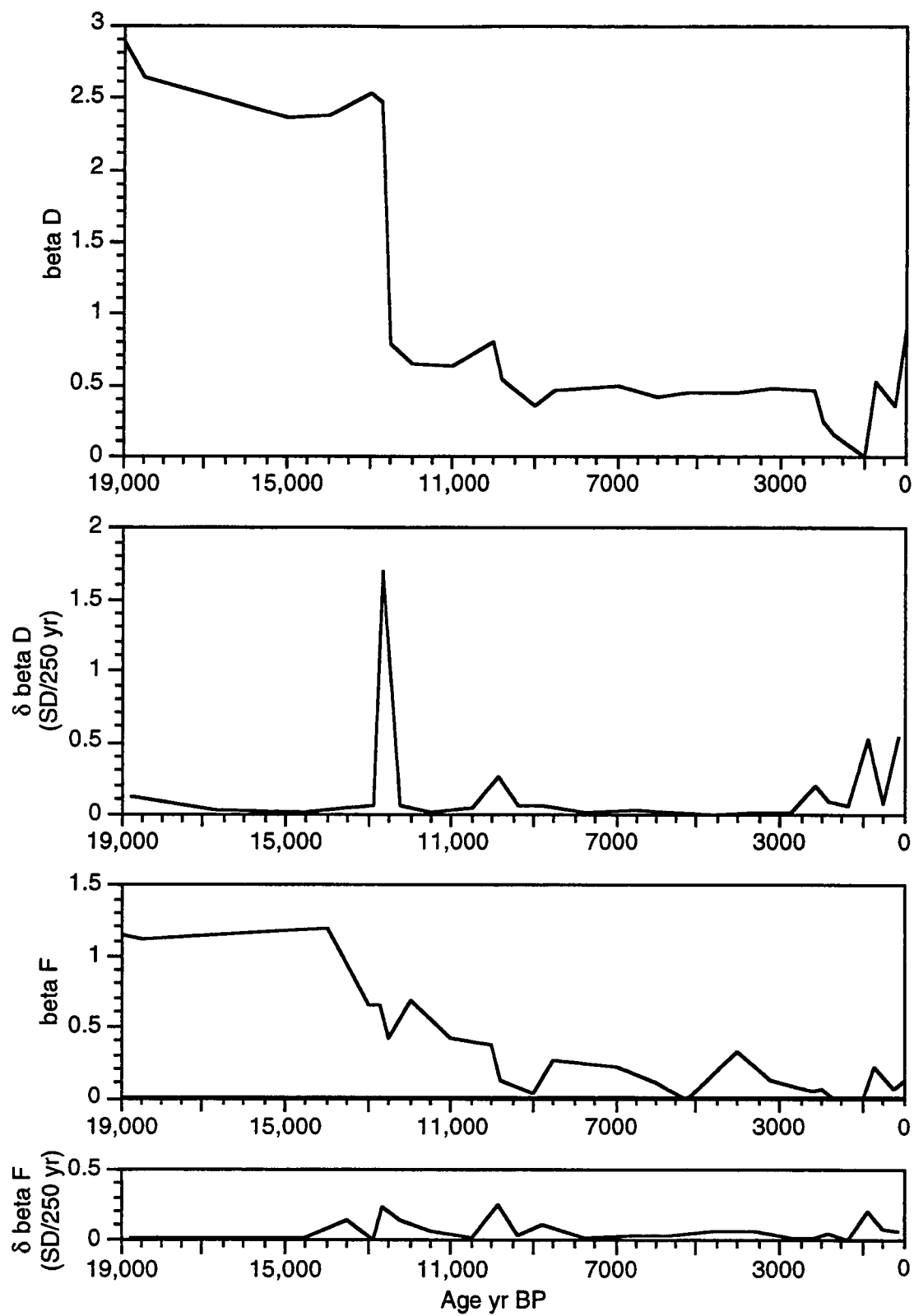


Figure 28. DCA results for diatom genera at Anderson Pond, TN.

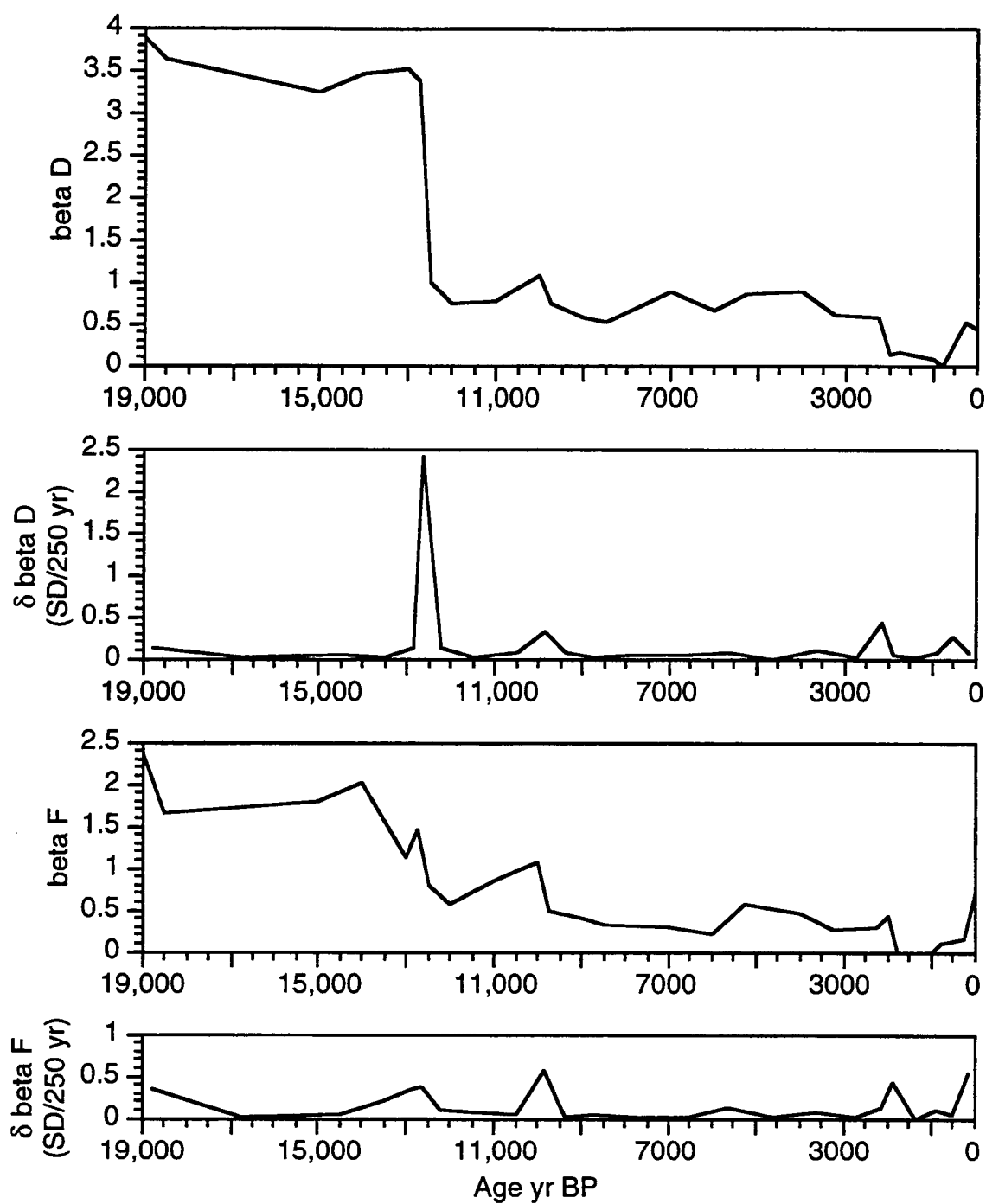


Figure 29. DCA results for diatom species at Anderson pond, TN.

displayed a similar drop in values between 10,000 BP and 9750 BP, but displayed much less consistency than the beta D values. All four curves showed a drop in values after 2000 BP and increased values after 1000 BP.

The change in percent dominance (δ beta D) and floristic (δ beta F) curves also showed similarities in timing between the genera and species data. The δ beta D curves were low during the late-glacial interval and showed a large peak between 12,750 BP and 12,500 BP. A δ beta D value of 2.4 for the species data indicates a change in percent dominance of over 50 %. Both curves then showed a smaller peak between 10,000 BP and 9750 BP, then remained at values below 0.1 through 3000 BP, and finally displayed fluctuating rates of change to the present. The δ beta F curves displayed a similar overall pattern, but peak values remained below 0.6 Beta SD.

Vegetation and Diatom Genera

For comparison the DCA results for the dominance (D) data for arboreal pollen, aquatic pollen, and diatom genera are shown in Figure 30 (Appendix L). All three graphs displayed a strong, synchronous peak, in the late Pleistocene dated between 12,750 BP and 12,500 BP. For both the arboreal pollen and the diatom taxa this is the largest peak, indicating that the arboreal vegetation and the diatoms went through their greatest changes in community dominance for any time in the past 19,000 years. For the arboreal pollen, this marks the change in forest canopy from a boreal jack pine- and spruce-dominated, conifer forest to a temperate oak-dominated, deciduous forest. For the diatoms, this

RATES OF TAXONOMIC TURNOVER

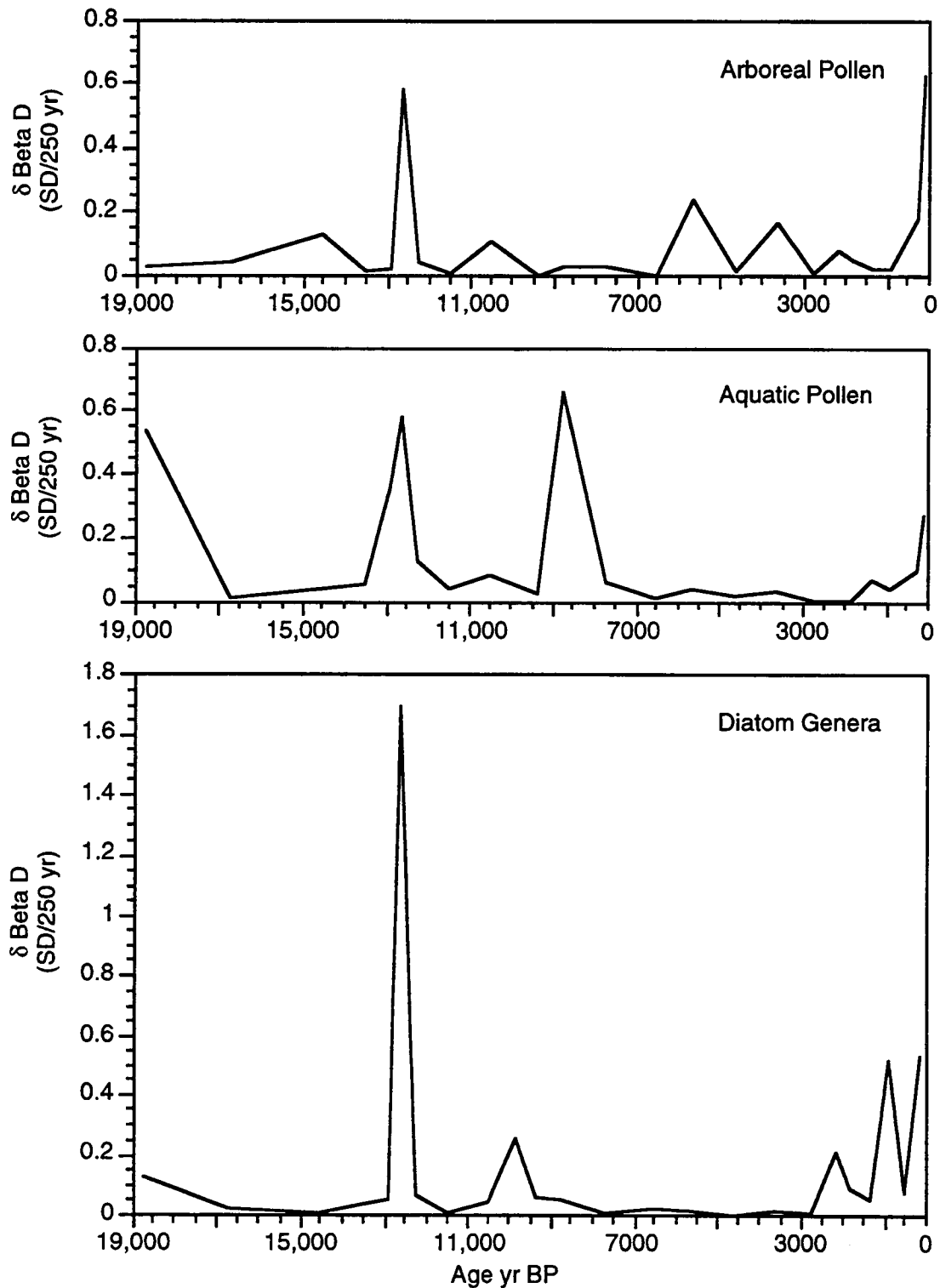


Figure 30. Summary of DCA-determined rates of taxon turnover at Anderson Pond, TN.

marks the change from a *Fragilaria*-dominated assemblage to a *Pinnularia/Eunotia/Stauroneis*-dominated assemblage.

Except for the historic interval, changes after 12,500 BP in the arboreal pollen appear to be largely uncorrelated with changes in the aquatic pollen and the diatom assemblages. This suggests a partial decoupling of the upland environment from the aquatic environment, with different factors controlling the biotic changes in the two environments.

Within the aquatic environment, changes occurred in both the aquatic pollen and the diatoms between 12,500 BP and about 8000 BP. The aquatic pollen actually displays its greatest change between 9000 BP and 8500 BP. Between 8000 BP and 2250 BP there is relative stability in both the aquatic pollen and the diatom assemblages. From 2250 BP to the present the diatom assemblages have been undergoing continual change while the aquatic pollen has been undergoing relatively low levels of change. The change between the prehistoric sample at 250 BP and the modern, post-settlement sample shows a strong peak in both the diatoms and arboreal pollen, with less change occurring in the aquatic pollen.

Diatom-inferred pH History of Anderson Pond

The reconstructed pH history of Anderson Pond (Figure 31) was obtained using the pH classification scheme of Hustedt (1937-1939) and the index B method of Renberg & Hellberg (1982) (Appendix M). With Renberg & Hellberg's method, species classified as

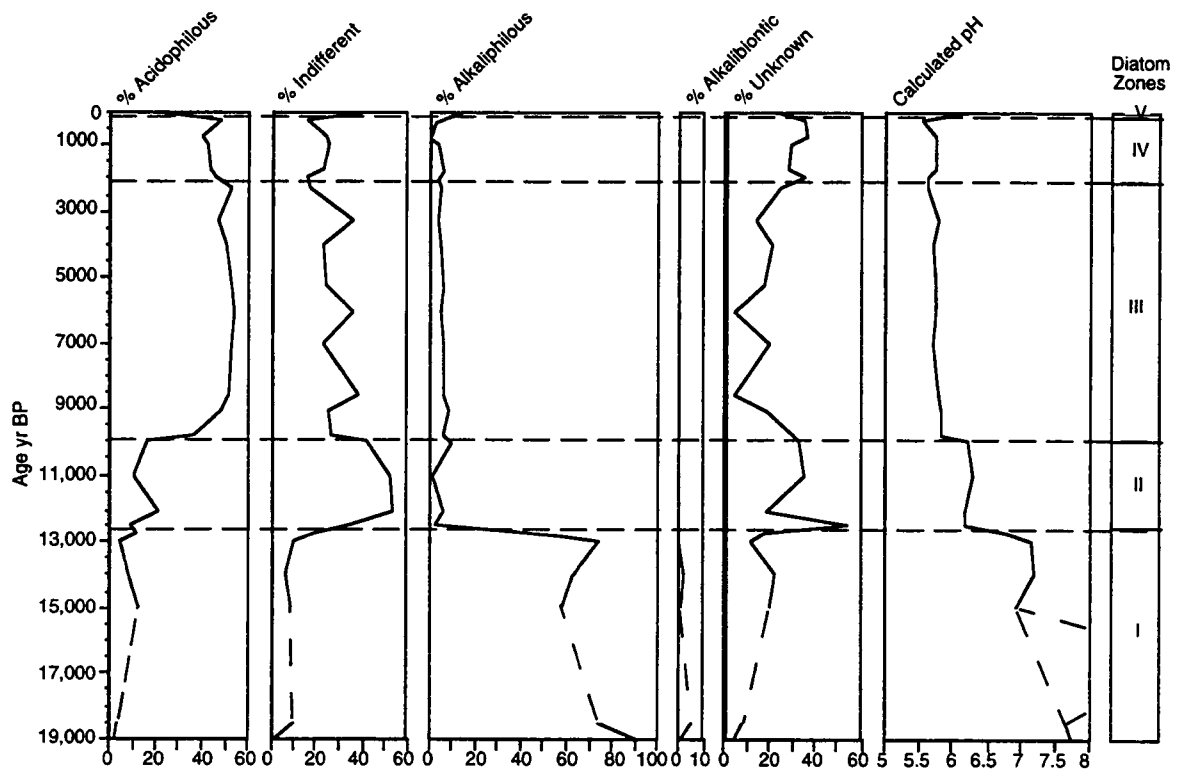


Figure 31. Hustedt groupings of pH preference for late-Quaternary diatoms and diatom-inferred pH reconstruction at Anderson Pond, TN.

pH indifferent are included in the analysis, as well as acidobiontic, acidophilous, alkaliphilous, and alkalibiontic species (Figure 31). The pH classification for species used in this analysis is based on various literature sources as indicated in Appendix A. No acidobiontic species were found in this study. The relative abundance of the different pH categories and the results of the pH analysis are shown in Figure 31. I used the equation:

$$\text{pH} = 6.40 - 0.85 \log \text{index B}$$

from Renberg & Hellberg (1982).

In Diatom Zone 1, pH values are high (Figure 31, Appendix M). The highest calculated value for pH (7.7) is found in the oldest sample, at 19,000 BP, and at 18,500 BP the pH value is very similar (7.7). The calculated pH drops somewhat by 15,000 BP (6.9) and fluctuates near neutral (between 7.2 at 14,000 BP and 6.8 at 12,750 BP) through the end of zone 1. These values reflect the dominance throughout Zone 1 of alkaliphilous and alkalibiontic species in the genera *Fragilaria*, *Epithemia*, *Cocconeis*, and *Gyrosigma*.

From 13,000 BP to 12,750 BP, the pH dropped from 7.2 to 6.8, and the pH continued to drop to 6.2 by the beginning of zone 2 at 12,500 BP. This large drop in pH corresponds to the prominent shift in the diatom flora, from the alkaliphilous, *Fragilaria*-dominated assemblages of Zone 1 to the acidophilous to pH-indifferent assemblages of *Pinnularia*, *Stauroneis*, and *Neidium* that dominate Zone 2. During Zone 2 the pH stayed relatively constant with values ranging from 6.1 to 6.3.

Another drop in pH occurred at the boundary between Diatom Zone 2 and Zone 3, from a pH value of 6.2 at 10,000 BP to a pH of 5.8 at 9750 BP. This is interpreted

from a major increase in the predominantly acidophilous genus *Eunotia*, and a corresponding drop in the predominantly pH-indifferent species with the genera *Neidium*, *Pinnularia*, and *Stauroneis*. The calculated pH values then stayed between 5.6 and 5.8 through Zone 3 and all but the last sample of Zone 4. There is a general trend towards decreasing pH values through Zone 3, with pH rising back up to 5.8 during the *Aulacoseira*-dominated Zone 4. At the end of zone 4, the pH dropped from 5.8 at 750 BP to the lowest pH value recorded in the core of 5.5 for the time of 250 BP.

The modern sample of Zone 5 marks a return to higher pH with a calculated value of 6.2. This value is similar to the typical pH values calculated for Zone 2. This Zone 5 is characterized by the disappearance of the acidophilous species of *Aulacoseira* found in Zone 4 and an increase in pH-indifferent and alkaliphilous species in the genera *Gomphonema*, *Navicula*, and *Synedra*. This pH value of 6.2 calculated for contemporary diatom assemblages in modern sediments (circa 1982) is consistent with the water pH measurements of 6.5 to 6.6 taken March 30, 1998 at the coring location.

Figure 32 shows the results of DCA on 52 diatom species with pH category listed for each species (superimposed over their taxon scores in Figure 24). There is a predominance of alkaliphilous and alkalibiontic species toward higher positive values for DCA Axis 1 on the diagram, and an increasing percentage of pH-indifferent and acidophilous species toward lower values for DCA Axis 1. Species with <0.00 values are entirely acidophilous or acidophilous/pH-indifferent. Figure 33 shows the calculated pH values, based upon the sample scores for the same species analysis (Figure 25). The

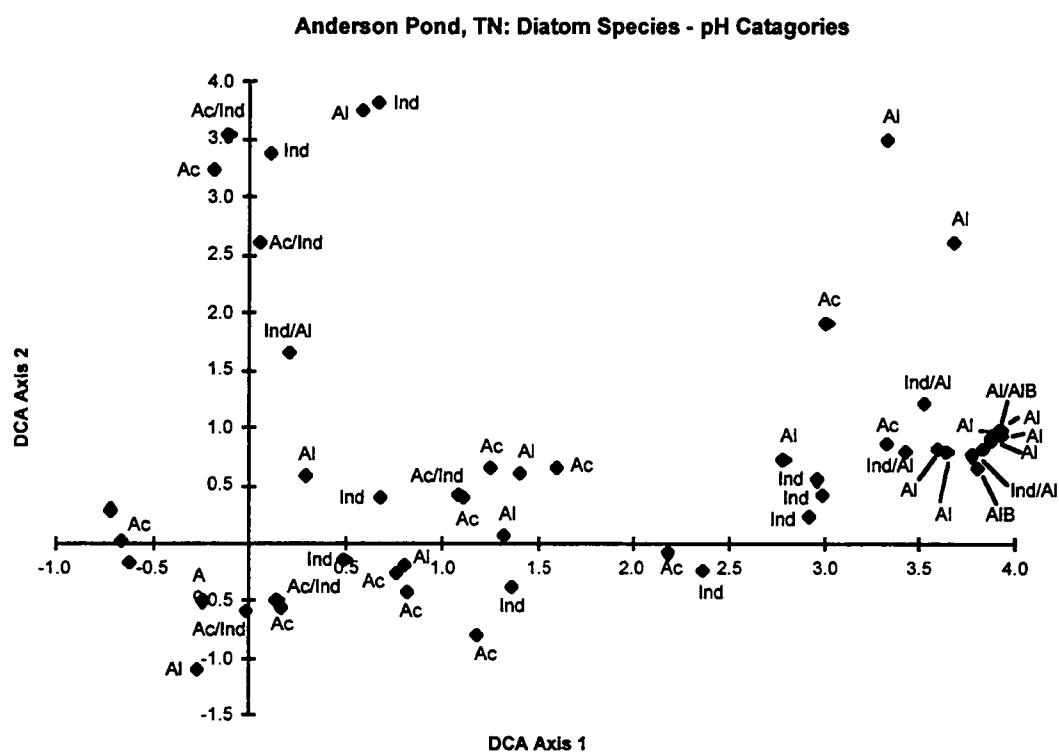


Figure 32. Hustedt pH categories superimposed over corresponding diatom species DCA scores.

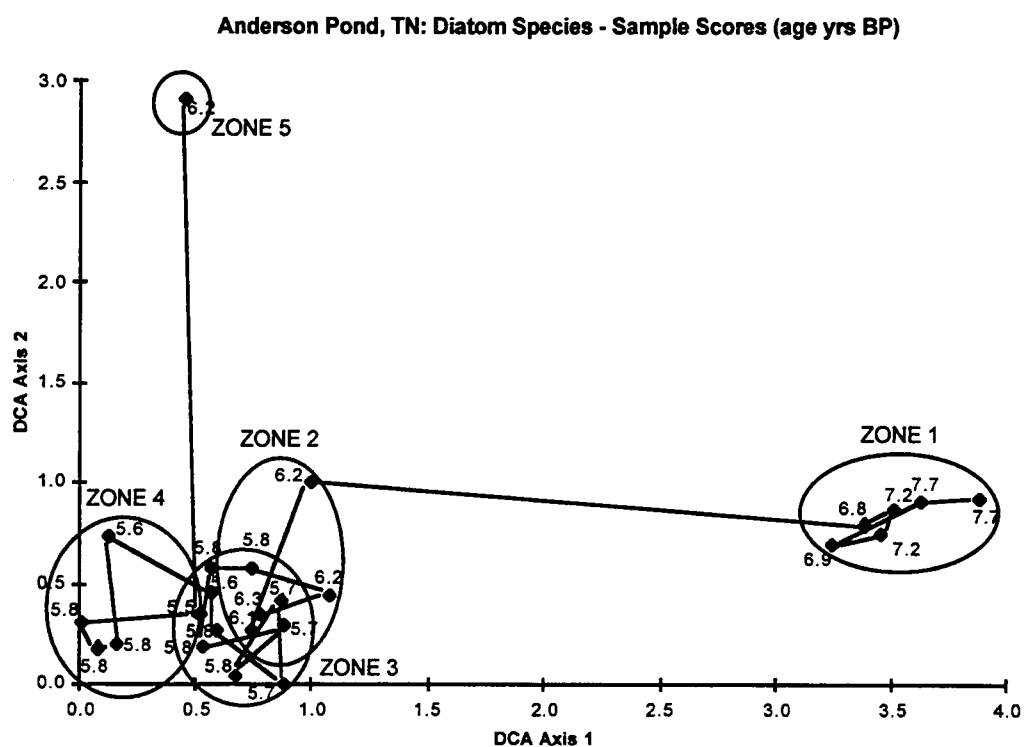


Figure 33. Calculated pH values superimposed over sample scores for diatom species (ages in BP).

relationship between pH and diatom zones can be seen here with large separation between Zone 1 on the right (see Figure 25) and all other zones toward the left, indicating a shift from alkaline pH conditions of the Pleistocene limnic habitat. There is a less clear separation between Holocene Zones 2 through 5 indicating that they exhibit a broad overlapping range of pH values.

Paleoecology of Diatoms at Anderson Pond

Table 5 and Appendix A summarize modern relationships for ecological requirements and preferences for late Quaternary diatom species and varieties reported at Anderson Pond. Primary reference literature includes Lowe (1974), Patrick and Reimer (1966, 1975), Foged (1974, 1981), Charles (1985), and Anderson et al. (1986). The pH preferences are available for most of the taxa (classified in Hustedt's five groups of Table 1: acidobiontic (AcB), acidophilous (Ac), pH-indifferent (Ind), alkaliphilous (Al), and alkalibiontic (AlB)) included in Table 5, but syntheses of other ecological information are less readily available from published literature.

The diatoms present at Anderson Pond represent all major habitat types for freshwater diatoms, but are predominantly haptobenthic (capable of living on more than one type of substrate) in habitat (Figure 34). The diatom haptobenthos may occupy habitats that are epiphytic (attached to aquatic plants and macroalgae), epilithic (attached to rocks), epipelic (unattached within sediment), or epipsammic (attached to sediment grains) (Round, 1981). Many of the diatoms at Anderson Pond are strictly epipelic or

Table 5. Contemporary ecological characterization of diatom preferences based on taxa reported from late-Quaternary assemblages at Anderson Pond, TN. Primary references include (1) Lowe (1974), (2) Foged (1981), (3) Charles (1985), (4) Anderson, Davis, & Berge (1986), and (5) Patrick & Reimer (1966, 1975).

Species	Habitat	Water pH	Trophic Status	Seasonality	Comments	Reference
<i>Achnanthes exigua</i>	benthic	Al			springs; euryphotic	1
<i>Achnanthes lanceolata</i>	benthic	Al		Spring/Fall max.	springs; high O conc.	1
<i>Amphora ovalis</i>	benthic	Al			calciophilous	1
<i>Aulacoseira ambigua</i>	euplanktonic	Ind-Al	eutrophic		mesoosymbiotic	1
<i>Aulacoseira distans</i>	benthic	Ac	oligo-/dystrophic		pools/ditches	1
<i>Aulacoseira granulata</i>	euplanktonic	Al	eutrophic	Summer form		1
<i>Aulacoseira islandica</i>		Al	eu-/oligotrophic	Spring/Fall max.		1
<i>Aulacoseira lirata</i>		Ac				1
<i>Aulacoseira subarctica</i>		Ind-Al				2
<i>Caloneis bacillum</i>	benthic	Al			springs (crenophilous)	1
<i>Cocconeis palecentula</i> v. <i>lineata</i>	epiphytic	Al		Fall maxima		1, 5
<i>Craticula ambigua</i>	benthic	Al		Fall maxima	euryoxybiontic	1
<i>Craticula cuspidata</i>	benthic	Al	eutrophic		euryoxybiontic	1
<i>Cymbella acutiuscula</i>		Al				2
<i>Cymbella amphicephala</i>		Ind				2
<i>Cymbella aspera</i>	benthic	Al		Spring maxima	O saturation is optimal	1
<i>Cymbella cistula</i>	epiphytic	Al			O saturation is optimal	1, 5
<i>Cymbella cuspidata</i>		Ind				2
<i>Cymbella hauckii</i>		Al				2
<i>Cymbella heteropleura</i> v. <i>subrostrata</i>		Ind				2
<i>Cymbella lanceolata</i>		Al				2
<i>Cymbella naviculiformis</i>	benthic	Ind		weak Fall maxima	O saturation is optimal	1
<i>Diploneis elliptica</i>	benthic	Ind-Al			deep water form	1
<i>Encyonema mesiana</i>		Al				5
<i>Encyonema minuta</i>		Ind				3
<i>Encyonema muelleri</i>		Al				5
<i>Encyonema silesiacum</i>		Ind				5
<i>Epithemia adnata</i> (zebra)	epiphytic	Al-AIB			15-30+ degrees C	1,5
<i>Epithemia turgida</i>	benthic	Al-AIB			calciophilous	1

Table. 5 (continued)
Contemporary ecological characterization of diatom preferences based on taxa reported from late-Quaternary assemblages at Anderson Pond, TN.

Species	Habitat	Water pH	Trophic Status	Seasonality	Comments	Reference
<i>Epithemia turgida</i> v. <i>granulata</i>		AIB				2
<i>Epithemia turgida</i> v. <i>westermanni</i>		AIB				2
<i>Eunotia arcus</i>		Ac			calcium tolerant	2, 5
<i>Eunotia bilunaris</i> (<i>curvata</i>)	benthic/tychoplank.	Ac-Ind	eu-/oligotrophic		(un)attached; low miner.	1
<i>Eunotia diodon</i>		Ac			cool water	2, 5
<i>Eunotia faba</i>		Ac				2
<i>Eunotia flexuosa</i>		Ac				2
<i>Eunotia formica</i>	benthic	Ind				1
<i>Eunotia glacialis</i>		Ac-Ind				2
<i>Eunotia incisa</i>		AcB-Ac			Ca tolerant, cool water	3, 5
<i>Eunotia intermedia</i> (<i>vanheurckii</i>)		Ac	oligotrophic			3, 5
<i>Eunotia minor</i>	benthic	Ac-Ind			aerophilous, Ca tolerant	1, 5
<i>Eunotia monodon</i>		Ac				2
<i>Eunotia monodon</i> var. <i>bidens</i>		Ac				2
<i>Eunotia naegeli</i>		Ac				3
<i>Eunotia pectinalis</i>		Ac	eu-/oligotrophic		mostly cooler regions	1
<i>Eunotia pectinalis</i> var. <i>undulata</i>		Ac-Ind			low mineral content	1
<i>Eunotia praerupta</i>		Ac				2
<i>Eunotia praerupta</i> var. <i>bidens</i>		Ac				2
<i>Eunotia rhomboidea</i>		Ac				2
<i>Eunotia rostellata</i>		Ac			cool water	5
<i>Eunotia serra</i>		Ac	oligo-/dystrophic			3, 5
<i>Eunotia sudetica</i>		Ac				2
<i>Eunotia tenella</i>		Ac				2
<i>Eunotia triodon</i>		Ac	oligotrophic			4, 5
<i>Eunotia veneris</i>		Ac				2
<i>Fragilaria brevistriata</i>	benthic	AI	eutrophic			1
<i>Fragilaria constricta</i>		Ind	slightly dystrophic			2, 5
<i>Fragilaria construens</i>	benthic/tychoplank.	AI	eutrophic	Fall maxima	springs; O-rich water	1

Table. 5 (continued)

Contemporary ecological characterization of diatom preferences based on taxa reported from late-Quaternary assemblages at Anderson Pond, TN.

Species	Habitat	Water pH	Trophic Status	Seasonality	Comments	Reference
<i>Fragilaria construens</i> var. <i>venter</i>	benthic/tychoplank.	Al	oligo-/mesotrophic	Spring form		1
<i>Fragilaria lapponica</i>	epipelagic	Ind-Al				2
<i>Fragilaria leptostauron</i>	benthic	Ind-Al			oxygen-rich water	1
<i>Fragilaria pinnata</i>	benthic	Al	eutrophic		oxygen-rich water	1
<i>Fragilaria subsalina</i> (<i>construens</i>)	benthic/tychoplank.	Al				1
<i>Frustulia rhomboides</i>	benthic	Ac	oligo-/dystrophic			1
<i>Gomphonema acuminatum</i>	benthic	Ind	oligo-/mesotrophic		temperate	1, 5
<i>Gomphonema angustatum</i>	benthic	Al	eutrophic	Spring/Fall max.	springs; 0-30 degrees C	1
<i>Gomphonema apicatum</i>		Al				2
<i>Gomphonema brasiliense</i>		Ind			warm water	5
<i>Gomphonema gracile</i>	benthic	Ind-Al				1
<i>Gomphonema grunowii</i>		Ind				5
<i>Gomphonema intricatum</i>	benthic	Al	eutrophic			1
<i>Gomphonema parvulum</i>	benthic	Ind	eutrophic			1, 5
<i>Gomphonema sarcophagus</i>		Ind-Al	mesotrophic		facult N heterotro; 15-30	1, 5
<i>Gomphonema sphaerophorum</i>			meso-/eutrophic			5
<i>Gomphonema subclavatum</i>		Ind				5
<i>Gomphonema truncatum</i>		Ind				5
<i>Gomphonema turris</i>		Ind	oligo-/mesotrophic			5
<i>Gyrodigma acuminatum</i>	benthic	Al	eutrophic	Spring/Fall max.	calciphilous	1
<i>Hantzschia amphioxys</i>	benthic	Al		Spring maxima		1
<i>Luticola mulica</i>	benthic/tychoplank.	Ind-Al		Fall maxima	Springs, aerophilous	1
<i>Meridion circulare</i>	benthic/tychoplank.	Al	eutrophic	Spring maxima	Springs; 0-30	1
<i>Navicula americana</i>	benthic	Al				1
<i>Navicula exigua</i>		Ind				5
<i>Navicula explanata</i>		Ind				2
<i>Navicula gragaria</i>		Al				2
<i>Navicula ignota</i> (<i>paludosa</i>) var. <i>palustris</i>		Ind				2
<i>Navicula minima</i>	benthic	Al	eutrophic		Springs	1

Table 5 (continued)

Contemporary ecological characterization of diatom preferences based on taxa reported from late-Quaternary assemblages at Anderson Pond, TN.

Species	Habitat	Water pH	Trophic Status	Seasonality	Comments	Reference
<i>Navicula muralis</i>					aerophilous	5
<i>Navicula oblonga</i>		Al				5
<i>Navicula placenta</i>					aerophilous	5
<i>Navicula protracta</i>		Ind				2
<i>Navicula pseudoscutiformis</i>		Ind			0-15	1
<i>Navicula radiosa</i>	benthic	Ind			0-30	1
<i>Navicula rhynchocephala</i>	benthic	Al	eutrophic	Spring/Fall max.	mesooxybiontic	1
<i>Navicula viridula</i>	benthic	Al	eutrophic	Summer form	mesooxybiontic	1
<i>Neidium affine</i>		Ind-Al				1
<i>Neidium iridis</i>		Ind				1
<i>Nitzschia filiformis</i>		Ind			not full autotr; euryoxybi	1
<i>Nitzschia frustulum</i>	benth/eu-/tychoplank.	Al	eutrophic		oblig N hetero; mesoxybi	1
<i>Nitzschia linearis</i>	benthic	Al	eutrophic	Summer form	Springs; O-rich	1
<i>Nitzschia palea</i>	benthic/tychoplank.	Ind	eutrophic	Spr/Sum/Fall max.	oblig N hetero; 0-30	1
<i>Nitzschia sinuata (denticula) var. delognei</i>		Al			high oxygen conc.	1
<i>Pinnularia acrosphaeria</i>		Al				2
<i>Pinnularia borealis</i>	benthic	Ind	eutrophic		0-15; low min; aerophil.	1
<i>Pinnularia braunii</i>		Ind			cool water	2, 5
<i>Pinnularia brebissonii</i>		Ind			cool water	2, 5
<i>Pinnularia divergens</i>		Ind			cool water	2, 5
<i>Pinnularia gibba</i>		Ac	eu-/oligotrophic		springs (crenoph.); MOB	1
<i>Pinnularia legumen</i>	benthic	Ind	oligo-/mesotrophic			2, 5
<i>Pinnularia maior</i>		Ind				2
<i>Pinnularia mesolepta</i>		Ind				2
<i>Pinnularia microstauron</i>		Ind	oligotrophic			2, 5
<i>Pinnularia neomajor (flexuosa)</i>		Ind			cool water	2, 5
<i>Pinnularia nobilis</i>		Ac				2
<i>Pinnularia nodosa</i>		Ind			cool water	2, 5
<i>Pinnularia rupestris</i>					cool water	5

Table 5 (continued)

Contemporary ecological characterization of diatom preferences based on taxa reported from late-Quaternary assemblages at Anderson Pond, TN.

Species	Habitat	Water pH	Trophic Status	Seasonality	Comments	Reference
<i>Pinnularia streptoraphe</i>		Ac				2
<i>Pinnularia viridis</i>	benthic	Ind		Spring/Fall max.	mesooxybiontic	1
<i>Sellophora pupula</i> var. <i>rectangularis</i>	benthic	Ind	eutrophic		mesooxybiontic	1
<i>Stauroneis anceps</i>	benthic	Ind	eu-/oligotrophic	Spring/Fall max.	mesooxybiontic	1
<i>Stauroneis anceps</i> f. <i>gracilis</i>	benthic	Ac-Ind			MOB, low chloride conc.	1
<i>Stauroneis fluminea</i>		Ind				2
<i>Stauroneis kriegeri</i>		Ind				2
<i>Stauroneis phoenicenteron</i>	benthic	Ind	eu-/oligotrophic		euryoxybiontic	1
<i>Surirella bifrons</i>		Al				2
<i>Surirella linearis</i>		Ind				2
<i>Surirella ovalis</i>		Al				1
<i>Surirella brevissonii</i> (ovata)		Al		Winter maxima	0-24	1
<i>Synedra parasitica</i>	epiphytic on diatoms	Ind-Al	meso-/eutrophic			1, 5
<i>Synedra radians</i>	euplanktonic	Al	eutrophic		high mineral content	1
<i>Synedra rumpens</i>	benthic	Ind				1
<i>Synedra ulna</i>	euplanktonic	Al	eutrophic			1
<i>Tabellaria fenestrata</i>	benthic	Ac	all trophic levels	Spr/Sum/Fall max. 0-30; dirty wat		1
<i>Tabellaria flocculosa</i>	benthic/tychoplank.	Ac	meso-/oligo-/dys-	Spring/Fall max. attached		1

Key for water pH: AcB = acidobiontic; Ac = acidophilous; Ind = pH-indifferent; Al = alkaliphilous; AIB = alkalibiontic.

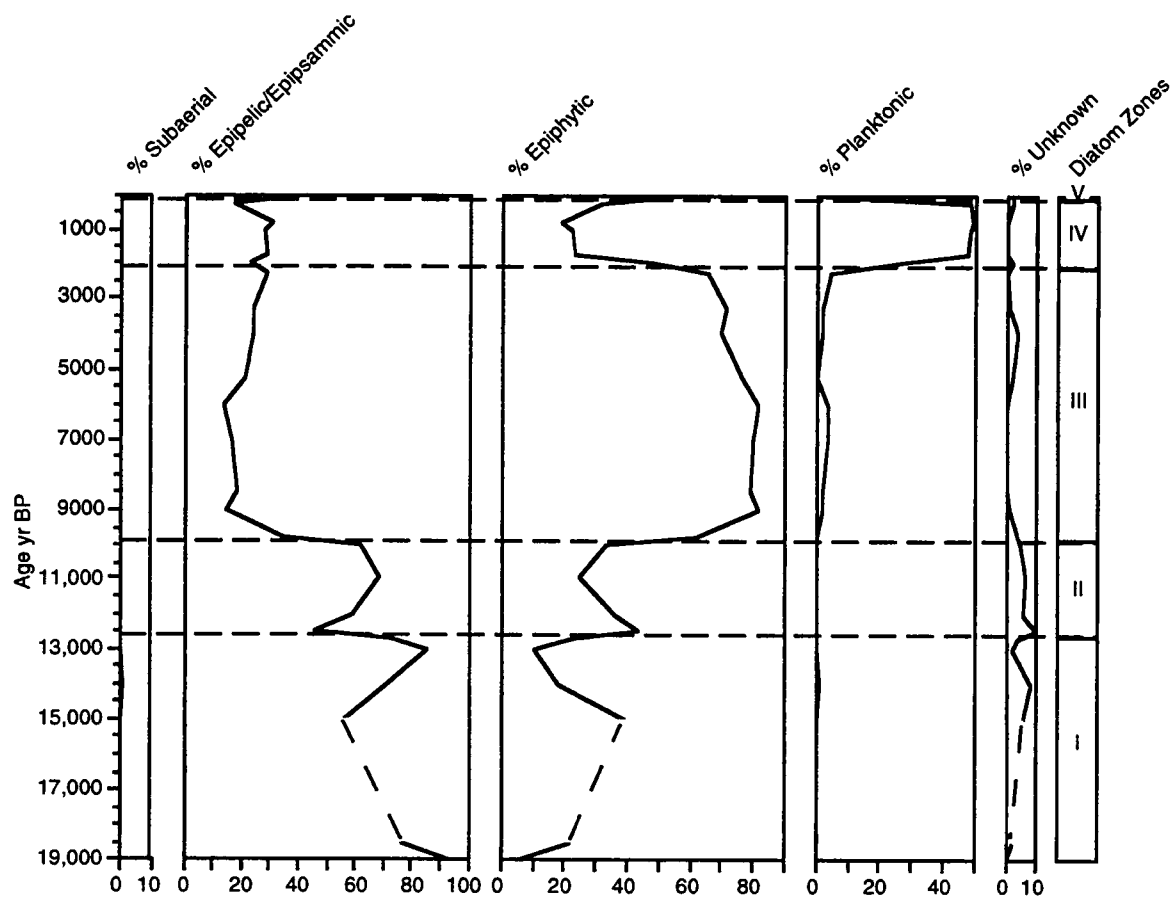


Figure 34. Habitat groupings for late-Quaternary diatoms at Anderson Pond, TN. Benthic forms of epipellic and epipsammic habitats are grouped together.

epipsammic and are grouped together as epipelagic taxa in Figure 34. Diatoms that live in more than one type of these four habitats, commonly termed haptobenthic or as periphytic by some authors (Lowe, 1974), are grouped together here as epiphytic (Figure 34) because most of the species present in this study are commonly found attached to vegetation. Planktonic diatoms can be separated into two categories: euplanktonic diatoms, which are normally suspended in the water, and tychoplanktonic diatoms, which are normally on or in a substrate, but are often suspended in the water. Subaerial, or aerophilous, diatoms are found on substrates that are damp but not submerged in water, such as moss.

Epipelagic/epipsammic diatoms were the dominant habitat group from 19,000 BP through 10,000 BP. Epiphytic diatoms were dominant between 10,000 BP and 2250 BP. Planktonic diatoms were either absent or rare throughout most of the record until after 2250 BP, when they became the co-dominants through 250 BP. The modern sample is once again dominated by epiphytic diatoms. Subaerial diatoms are also present at low abundance in the oldest portion of the core (19,000 BP through 18,500 BP) and from 15,000 BP through the latest Pleistocene, disappearing by the middle Holocene.

The diatoms at Anderson Pond cover a broad range of pH preference (Figure 31). Based on Hustedt's pH classification (Table 1), the categories of alkaliphile (Al), pH-indifferent (Ind), and acidophile (Ac) are well represented, with a few alkalibionts (AlB) present in the oldest part of the core (Figure 31). Known acidobionts (AcB) are generally absent, indicating that pH levels did not typically drop below 5.5. Alkaliphilous taxa are

dominant prior from 19,000 BP through 12,750 BP, pH-indifferent taxa are dominant from 12,500 BP to 9750 BP, and acidophilous taxa are dominant from 9000 BP to the present (Figure 31). The transition between 12,750 BP and 12,500 BP thus marks a major change in water pH from neutral alkaline to pH-neutral conditions at Anderson Pond.

The diatoms present at Anderson Pond cover a range of trophic conditions (Figure 35). Trophic conditions are divided into four categories: eutrophic (high nutrient concentrations), mesotrophic (moderate nutrient concentrations), oligotrophic (low nutrient concentrations), and dystrophic (high humus concentrations with strong acidic conditions). Diatoms characteristic of eutrophic waters are most abundant prior to 12,500 BP, whereas intermediate conditions of mesotrophic status are present from 12,000 BP to the present. The only important dystrophic diatom species found at Anderson Pond, *Frustulia rhomboides*, occurs at 12,750 BP and at a lower abundance at 12,500 BP (Figures 20, 21, Appendix A), that I interpret represents a brief but substantial influx of humic acids during the latest glacial.

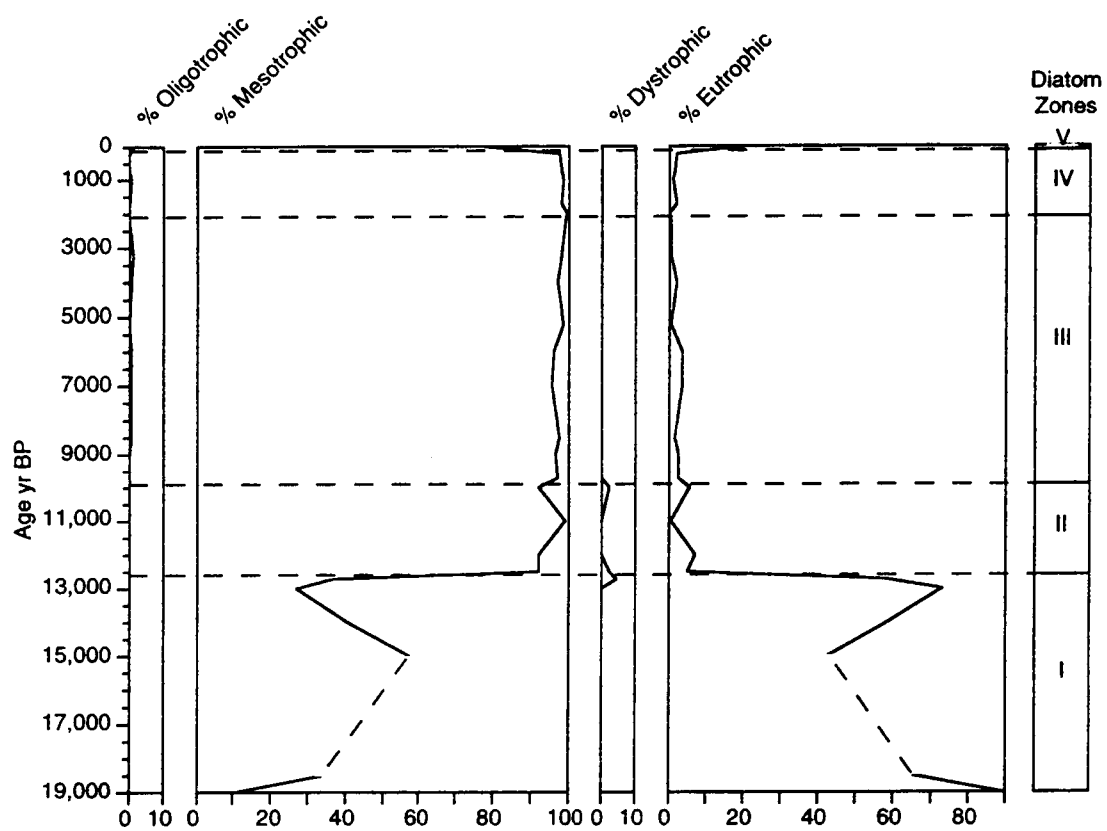


Figure 35. Trophic status groups for late-Quaternary diatoms at Anderson Pond, TN.

There are additional environmental preferences that may be important for many diatom species present at Anderson Pond (Table 5, Appendix A). Prior to 12,500 BP, many species are characteristic of springs, cool to temperate water temperatures (0 to 30°C), high oxygen contents, and/or high calcium (Ca) levels (calciphilous). From 12,500 to the present, diatom species characteristic of these environmental conditions are absent or only present at very low abundance.

CHAPTER VI

Late Quaternary Limnologic Changes at Anderson Pond

Diatom Assemblage Zones and Diatom Ecology

The ecological preferences and tolerances of modern diatoms can be used to interpret the environmental conditions in which fossil diatom assemblages may have existed (Brugam et al., 1988; Dixit et al., 1992). Diatoms respond quickly to dynamically changing environments (Dixit et al., 1992) and so they are particularly useful in studies of lake water acidity (Charles, 1985; Battarbee, 1986). Most of the diatom taxa found in the Anderson Pond sediments have persisted for the entire period of this study, covering the last 19,000 years; within this time range, I speculate that the ecological preferences of these diatom taxa have not changed. In this section I will use the known ecology of modern diatoms (Table 5, Appendix A) to interpret the fossil assemblages at Anderson Pond.

The Zone 1 diatom assemblage is composed of predominantly alkaliphilous species, based on pH studies of modern diatoms (Lowe, 1974; Charles, 1985; Brugam, 1993) (Figures 31, 36). The dominant genus in this zone, *Fragilaria*, is composed entirely of small, benthic species, such as *F. brevistriata*, *F. construens*, *F. lapponica*, and *F. pinnata*. Some of the rare species, which occur either solely or predominantly in this

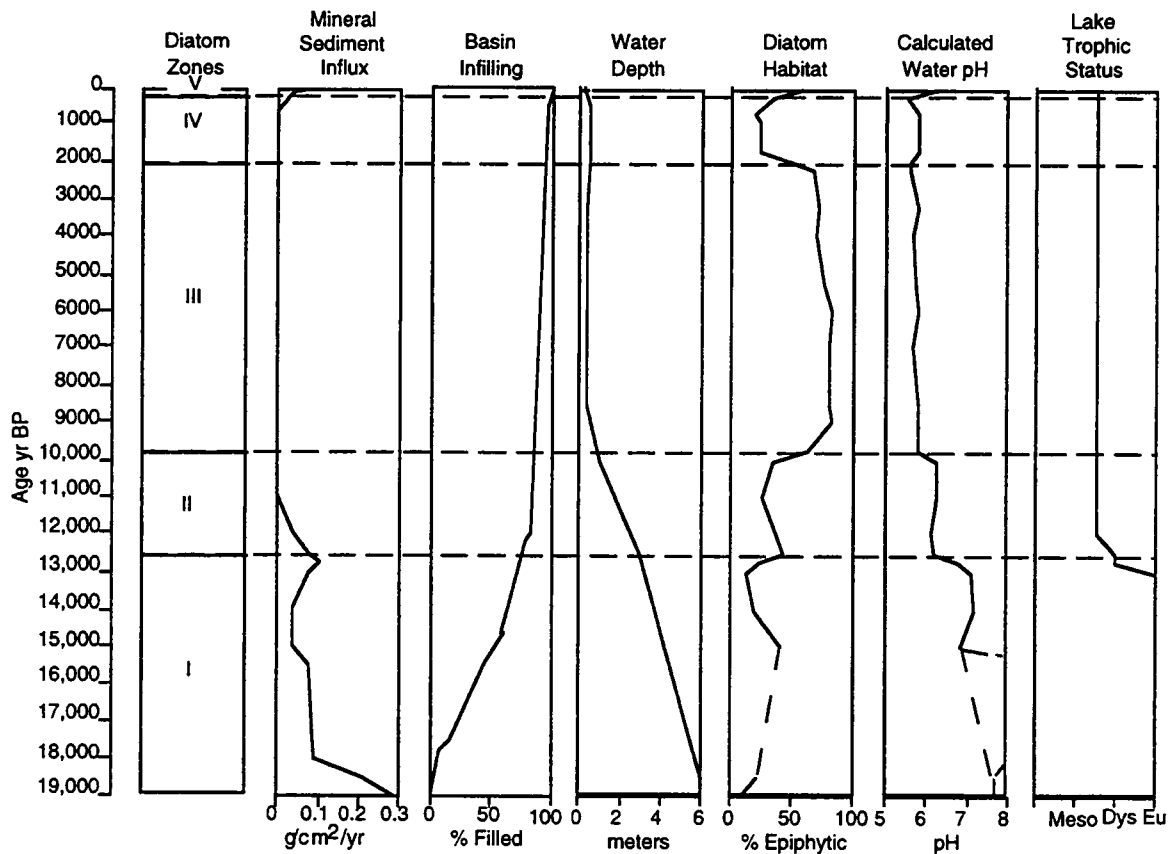


Figure 36. Summary chart for late-Quaternary changes in diatom assemblage zones, mineral sediment influx, basin infilling, water depth, diatom habitat, calculated water pH, and lake trophic status (mesotrophic, dystrophic, or eutrophic) within the Anderson Pond basin.

zone, are also alkaliphiles, such as *Aulacoseira ambigua*, *Cocconeis placentula* var. *lineata*, and *Navicula radiosa*.

Another important feature of Zone 1 diatom assemblages is the predominance of epipelagic and epiphytic diatoms, with an almost complete lack of planktonic diatoms (Figure 34). Important epipelagic/epiphytic diatoms include species of the genera *Fragilaria*, *Epithemia*, *Eunotia*, *Gomphonema*, and *Navicula*, as well as *Cocconeis placentula* var. *lineata* and *Gyrosigma acuminatum*. A few diatoms characteristic of subaerial environments were also present, including *Hantzschia amphioxys*, *Luticola mutica*, *Orthoseira dendroteres*, and *Pinnularia borealis* (Round, 1981).

The *Fragilaria* species present at Anderson Pond are common in the deep-water environments of northern lakes, formed in deglaciated environments, and persisting through the late-glacial to early post-glacial interval as basins gradually infilled with mineral sediment (Haworth, 1972; Haworth, 1976; Wolfe & Butler, 1994).

The conspicuous lack of siliceous microfossils between 18,000 BP and 15,000 BP (Figures 27, 36) is difficult to explain. One possibility is that high sedimentation rates of detrital grains may have diluted the apparent concentration of microfossils. However, during Pleistocene times of colluvial transport from uplands, lake sedimentation rates were high during the entire period between 19,000 BP and 12,750 BP (Delcourt, 1985). Figure 12 documents the interval of peak mineral influx in the full glacial between 18,000 BP and 16,500 BP, perhaps increasing levels of water and decreasing light penetration through surface waters. This causal mechanism for collapsing diatom populations might

account for poor valve preservation due to their mechanical breakage. Alternatively, an interval of high alkalinity (>8.0 pH) may have dissolved most siliceous diatom valves, as well as chrysophyte cysts and freshwater sponge spicules, leaving no apparent diatom record as an artifact of dissolution. The geochemistry of opaline silica in freshwater systems is dictated by pH conditions. Blatt et al. (1972, pp. 354-360) documented that natural solid silica (such as in diatom valves) will experience initial dissolution at pH 8.0 and accelerated dissolution at pH levels above 9.0. When isolated valves were preserved in stratigraphic levels for this span, only large robust taxa such as *Cymbella aspera* were represented. In contrast, small, thin, or delicate valves, such as the small benthic *Fragilaria* species, were characteristically absent. I consider this evidence to support the interpretation of substantive dissolution of siliceous microfossils, rather than turbidity shading of the photic zone, to account for sparse diatom representation.

During this late Pleistocene interval at Anderson Pond, the limnological conditions represent alkaline water with pH levels approaching or exceeding 8.0. This is indicated by the high percentages (50 to 90%) of diatom valves represented by the alkaliphilous group (Figure 31), a group with pH levels mainly above pH 7.0. More convincing is the consistent representation of up to 5 percent alkalibionts with pH tolerance restricted to alkaline waters greater than pH 7.0 (Table 1). These alkalibiontic taxa include: *Epithemia turgida*, *E. turgida* var. *granulata*, *E. turgida* var. *westermannii*, and *E. zebra*.

The transition between Zone 1 and Zone 2 is primarily a transition from alkaliphilous-dominated diatom assemblages to acidophilous-dominated diatom

assemblages. In Zone 1, the dominant genus *Fragilaria* almost completely disappears between 12,750 BP and 12,500 BP, while mostly acidophilous taxa, such as *Eunotia*, *Neidium*, and *Pinnularia*, become more abundant, along with pH-indifferent taxa such as species of *Gomphonema* and *Stauroneis phoenicenteron*.

Zone 2 marks the late-glacial beginning of an acidic aquatic environment that remains acidic through Zones 3 and 4. It is distinguished from the later zones by a higher diatom ratio of epipellic plus epipsammic taxa compared to epiphytic taxa (Figure 34). The most abundant epipellic diatoms in Zone 2 are *Pinnularia* spp., *Stauroneis phoenicenteron*, *Neidium* spp., and *Craticula* spp. Within Zone 2 there are more epiphytic diatoms early in the zone than later, with more *Eunotia* and *Gomphonema* present from 12,500 BP to 12,000 BP, followed by decreases in these genera and increases in *Stauroneis* and *Neidium* by 11,000 BP.

Early Holocene Zone 3 is distinguished by the high ratio of epiphytic diatoms relative to the group of epipellic plus epipsammic diatoms (Figure 34). The onset of Zone 3 is marked by an increase in abundance of the epiphytic diatoms *Eunotia* and *Gomphonema*, and by the decrease in the epipellic diatoms *Pinnularia*, *Stauroneis*, *Neidium*, and *Craticula*. However, there is no significant change in the genera and species present as measured by floristic rates of turnover in beta F/250 years (Figure 29). This zone is also characterized by the greatest stability of any zone in terms of its composition.

The transition from Zone 3 to Zone 4 is characterized by the rise to dominance by the planktonic genus *Aulacoseira*. Zone 4 is the only diatom zone in this core with a significant planktonic component. *Aulacoseira* increases from less than 5% of the total diatoms at 2250 BP, to almost 27% by 2000 BP, and reaches dominance with over 47% by 1750 BP. During this same time period, the dominant genus in Zone 3, the epiphytic *Eunotia* (presumably attached to plant surfaces of swamp-thicket shrubs), goes from over 60%, to 43.5%, to less than 15% over the span of this 500 year interval.

Zone 4 maintains a relatively stable abundance of the dominant genus *Aulacoseira* but the abundance of other taxa fluctuates significantly. The high abundance of *Aulacoseira* throughout Zone 4 indicates a continuous availability of open-water habitat of shallow pools available for planktonic diatoms, but changes in the habitat available for epipelagic and epiphytic diatoms and/or changes in water chemistry. This may reflect a late-Holocene climatic shift towards more precipitation and greater seasonal fluctuation of pond water levels.

The transition from Zone 4 to Zone 5 is characterized by the almost complete loss of *Aulacoseira* and an increase in abundance for *Gomphonema* and *Navicula*. The loss of *Aulacoseira* correlates with the historic infilling of the basin with sediment eroded from EuroAmerican agricultural fields and the dramatic loss of open water in the reduced pool areas available to planktonic diatoms (Figure 10). The increase in *Navicula* spp., particularly *N. radiosa*, may also indicate changes in water chemistry, such as an increase water pH toward more alkaline conditions.

Zone 1 Fragilaria-Dominated Assemblages

Diatom assemblages dominated by small, benthic species of the genus *Fragilaria*, similar to the Zone 1 assemblages of this study, are common in the late Pleistocene portion of many lakes in deglaciated terrains of the Temperate Zone of the Northern Hemisphere (Haworth, 1972; Haworth, 1976; Brugam, 1980; Rawlence, 1988; Rawlence & Senior, 1988; Rawlence, 1992; Wolfe & Butler, 1994). Other researchers have found *Fragilaria*-dominated assemblages in more recent stratigraphic levels of Holocene lake cores (Brugam, 1988; Winkler, 1988). Despite the common occurrence of this diatom genus in post-glacial lake sediments, there is as yet no clear consensus in the factors controlling the occurrence of these *Fragilaria*-dominated assemblages.

Brugam (1980, 1983, 1988) studied diatom assemblages from modern lakes, primarily in Minnesota, to determine the ecological preferences of many diatom species and assemblages, and used this information to infer the modern analogs of fossil diatom assemblages (Brugam, 1980, 1988). In these studies, Brugam found that in modern lakes the small, benthic *Fragilaria* species, *F. brevistriata*, *F. construens*, *F. construens* var. *venter*, and *F. pinnata*, were not strongly correlated with any environmental factors. There was a correlation with deeper water (>1 m water depth)(Brugam, 1980), which would be similar to the late-Pleistocene environments interpreted in this study; however, Brugam's subsequent studies did not reaffirm this apparent correlation, indicating that depth may not be the primary factor determining *Fragilaria* occurrence. These epipelagic species do require clear water conditions (Brugam, 1980). Rawlence (1992) summarized

some of the variety of limnologic conditions under which similar *Fragilaria*-dominated assemblages may thrive.

Both Haworth (1976) and Brugam (1980) found that the *Fragilaria*-dominated assemblages were also low in planktonic diatoms. Haworth (1976) suggested that this relationship indicated poor nutrient conditions and a greater ability of the *Fragilaria* species to extract nutrients from the bottom sediment. Wolfe & Butler (1994) found that *Fragilaria* increased in abundance with the onset of organic sedimentation.

In the present study, the paleoecological setting of the *Fragilaria*-dominated zone is one of a deep lake (perhaps exceeding 6 meters water depth), with a large supply of base cations in surface waters, during a time of high influx of mineral particulate sediment (Figure 12) from a periglacial landscape of boreal forests and a cold late-Pleistocene climate. The presence of the *Fragilaria* species themselves supports a limnic interpretation of clear, alkaline water. The setting of Anderson Pond within a broad, flat karst sinkhole (Figure 9) may help to account for the lack of planktonic diatoms. If the water level was not sufficiently close to the topographic surface of the sinkhole rim, a lack of wind-driven turbulence may have prevented the development of an abundant planktonic fauna. This mechanism has been suggested for the modern-day lack of planktonic diatoms in an arctic thaw lake near Cape Herschel, Ellesmere Island by Smol (1983). Without the planktonic component and with a lack of consensus from the modern ecological data, the dominance by *Fragilaria* may be best accounted for by its ability to outcompete other diatom taxa (Haworth, 1976; Wolfe & Butler, 1994).

Zone 1 to Zone 2 Transition

The transition from Zone 1 to Zone 2 (Figures 20, 36) was the most significant change in the fossil diatom record at Anderson Pond. This late-glacial transition, occurring between 12,750 BP and 12,500 BP, corresponds with the general replacement of alkaliphilous diatoms by pH-indifferent and acidophilous diatoms. Chrysophyte cysts increased in relative abundance during this interval as well. This interval also marks a major change in the arboreal pollen (Figure 13) and in the aquatic pollen record (Figure 17). The major reorganization of upland plant communities involved the replacement of late-glacial, boreal jack pine- and spruce-dominated forests by post-glacial, temperate oak-dominated forests (Delcourt, 1979).

This late Pleistocene transition in all components of the ecosystem examined in this study results from a change in climate regimes in middle Tennessee, marking the end of glacial-age conditions in this mid-latitudinal region (Figure 14). Climatic change at this time was brought about by the migration of the atmospheric position of the Polar Frontal Zone across Tennessee (Delcourt & Delcourt, 1984; Delcourt, 1985) allowing the Maritime Tropical Air mass to influence the climate in this region, leading to the northward expansion of warm-temperate forests (Delcourt & Delcourt, 1984) (Figure 37).

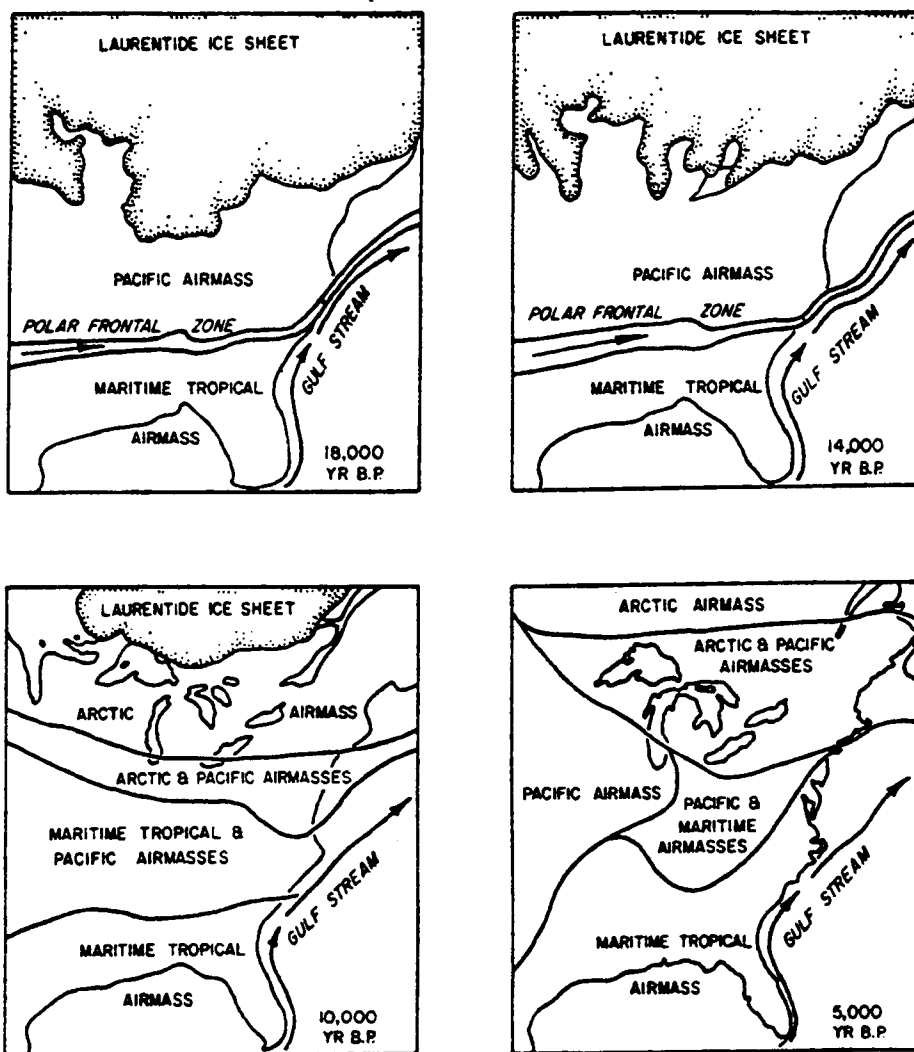


Figure 37. Paleoclimatic reconstructions for eastern North America indicating the northward migration of major airmasses during the late-Quaternary time range recorded at Anderson Pond, TN (modified from Delcourt, 1985).

Late-Glacial/Early Holocene Diatom Zones and Aquatic Vegetation

The DCA results showed a correlation between the timing of response for the diatoms and the aquatic pollen during the post-glacial portion of the record at Anderson Pond (Figure 30). During this same interval the arboreal pollen record showed many periods of change in the upland vegetation that were not correlated with changes in the aquatic environment (Figure 30). I consider this evidence that the changes in the diatom assemblages during this time were influenced by factors that affected only their immediate aquatic system.

During the late-glacial and early Holocene interval, from 12,500 BP to 9750 BP, both the diatoms and aquatic pollen were undergoing change (Figure 30). Initially the aquatic pollen showed a small peak between 11,000 BP and 10,000 BP. This is followed by a slightly larger peak in the diatom record between 10,000 BP and 9750 BP. Then between 9000 BP and 8500 BP the aquatic pollen record displayed its largest peak in rate of change of assemblages.

In the aquatic pollen record (Figure 17), the first post-glacial peak corresponds to an increase in the percentage of Gramineae pollen, indicating the spread of the littoral zone of wet-meadow grasses towards the basin interior. As the basin filled with sediment and became shallower, grasses colonized much of the expanded littoral area of Anderson Pond and created a habitat with much exposed sediment for epipellic diatoms such as

Pinnularia, *Stauroneis*, *Neidium*, and *Craticula*, with less suitable epiphytic habitat for *Eunotia* and *Gomphonema*.

The second peak in the aquatic pollen record, between 9000 BP and 8500 BP, marks this decrease in Gramineae (grasses) and increases in the percentages for *Alnus rugosa-serrulata* pollen type (alder), *Cephalanthus occidentalis* (buttonbush), and *Itea virginica* (Virginia willow). This establishment of wetland shrubs is corroborated by their presence as macrofossils (Figure 18). During this Holocene interval, alder thickets were spreading out into the site, effectively outshading and replacing the grasses. This led to an aquatic habitat with less open-pool surface area, and therefore less muddy pool bottom for epipellic diatoms to colonize, and more suitable meadow/thicket vegetation providing critical substrate for epiphytic diatoms. This change in habitat structure facilitated the increased dominance of the genera *Eunotia* and *Gomphonema*, and the decreased abundance of *Pinnularia*, *Stauroneis*, *Neidium*, and *Craticula*.

Within Zone 2, there is a change in the ratio of epipellic diatoms to epiphytic diatoms, with an increase in the epipellics around 11,000 BP (Figure 34). Based upon the aquatic pollen relative-frequency diagram (Figure 17), the increase in percentages of Gramineae (grasses) occurs synchronously with the increase in relative frequency of epipellic diatoms, and marks the spread of grasses into the central portion of the Anderson Pond basin (at the coring site) and marks the infilling of the basin and shallowing of the water to within 1 meter of the present-day sediment surface, creating a suitable wet-meadow habitat for grasses throughout most of the geographic extent of the karst basin.

The change in the diatoms from an epipellic-dominated assemblage to an epiphytic-dominated assemblage occurs, *lagging* behind the initial aquatic vegetation response, between the two peaks of change in the aquatic pollen record (Figure 30). For the diatoms the change in assemblage composition occurs sometime between 10,000 BP and 9750 BP. Although this does not correlate with the peak change in the aquatic pollen record, it does correlate with the timing of around 9500 BP for the initial post-glacial spread of alder thickets into the basin perimeter (Figures 17, 18). Also, the diatom genus *Eunotia* does not reach its peak abundance until the concomitant peak in the aquatic pollen record between 9000 BP and 8500 BP.

Diatom Zone 3 is a period of relative stability for both the diatoms and the aquatic vegetation in an environment with water depths less than 1 meter and swamp thickets of alder, buttonbush, and Virginia willow spreading throughout the central basin. The competitive displacement of grasses and closing in of taller, thicket-type vegetation, with seasonally fluctuating water levels, created a vertical zone of habitat more suitable to epiphytic diatoms and less favorable to epipellic diatoms.

The late Holocene environment of Anderson Pond began to change after 2250 BP. By 2000 BP, *Eunotia*, although still the dominant genus, had dropped from around 60% of the total diatoms to around 45%, and by 1750 BP it accounted for less than 15%. During the same interval, *Aulacoseira* rose from less than 5% at 2250 BP to around 27% at 2000 BP, and finally to over 47%, where it stayed throughout Zone 4. This change, from an epiphytic-dominated diatom assemblage to a planktonic-dominated diatom

assemblage, the expansion of open pools and displacement of alder thicket at the coring site (Figure 10) correlates with an increase in late-Holocene regional precipitation (Figure 14) (Delcourt, 1979). The increase in precipitation led to a higher water table, possibly a greater seasonal range with vertical fluctuation of surface water up to 1.8 m observed today, and the lateral recession of thicket vegetation, expanding pools of open water more suitable for seasonal blooms of planktonic diatoms. The large variation in the DCA sample results for Zone 4 (Figure 30) may indicate a great deal of hydrologic variability during the late Holocene, which is reflected in broad compositional variability of the diatom assemblages during Zone 4. This also may reflect changes in water chemistry, such as pH or nutrient levels, possibly due to the initial impact of prehistoric human activity.

Diatom Assemblage Zone 5 and the Impact of Human Activity

Between 250 BP and the present, significant change has occurred in the diatom assemblage. I interpret the loss of the planktonic *Aulacoseira* to indicate an effective loss of open water within permanent pools of standing water. During this historic time approximately 30 cm of silty clay and 20 cm of fibrous, silty clay have been accumulating within the basin sediment surface. This input of sediment has resulted largely from alteration of the landscape due to EuroAmerican human activity, such as forest clearing and agricultural practices in nearby uplands, which has caused rapid basinal infilling in the last 200 years, allowing for the readvance of thicket-type vegetation into the basin, as seen by the increased influx of nonarboreal pollen (Figure 17) and swamp trees such as

red maple (*Acer rubrum*, Figure 13). The increase in abundance of the diatom genus *Navicula*, particularly *N. radiosa*, may reflect changes in water chemistry, toward an increase in pH, though still acidic conditions. The effective loss of chrysophyte cysts during this time may also indicate a small increase in pH and/or decrease in water depth.

CHAPTER VII

Late Quaternary Diatom Changes Across Eastern North America

This is the first paleoecological study of diatoms in the southeastern United States covering the full-glacial to post-glacial period, for the unglaciated region north of the Florida Peninsula. As such, it offers an opportunity to compare the response of diatom assemblages within a latitudinal context: to contrast mid latitudes in the southeast with those of more northern diatom assemblages in the Great Lakes and New England areas of the United States and sites in southeastern Canada. Most eastern North American lakes for which diatom records have been obtained are located in now-deglaciated regions that were covered with ice during the last glacial maxima. Therefore, they did not begin to form a sedimentary diatom record until deglaciation and exposure to sediment input.

Anderson Pond formed beyond the southernmost extent of the Laurentide Ice Sheet and was never covered with glacial ice. Its formation, due to the collapse of a karst sinkhole, occurred prior to 20,000 BP, but it did not become permanently filled with water, and therefore, did not receive continuous sedimentation, until approximately 19,000 BP to 20,000 BP. This coincided with the period of peak glaciation so that this diatom record records the climatic peak of the last glacial maximum and the full glacial succession to full interglacial conditions, making Anderson Pond a suitable site for

comparison to the onset of glaciation and formation of post-glacial lakes in northeastern North America.

The most distinctive similarity between the Anderson Pond diatom record and other diatom records from eastern North America is the presence of a pioneering *Fragilaria*-dominated assemblage (Figure 38). This is a feature common to many post-glacial lakes in both North America (Brugam, 1980; Rawlence, 1988) and Europe (Haworth, 1976). At many sites with an initially high relative abundance of small, benthic *Fragilaria* species, those species either disappear or decrease significantly in relative abundance after approximately 2000 years or less (Haworth, 1972; Ritchie & Koivo, 1975; Smol, 1983; Rawlence, 1988; Rawlence & Senior, 1988; Ford, 1990; Wolfe & Butler, 1994). A few sites, including Anderson Pond, have *Fragilaria*-dominated assemblages lasting for longer periods of time (Brugam, 1980; Wolfe, 1994; Huvane & Whitehead, 1996).

For those sites that display a significant decrease in relative abundance of *Fragilaria* species, there may be a climate-related pattern to this decrease. Anderson Pond is the first site to undergo this transformation, between 12,750 BP and 12,500 BP, associated with the northward passage of the Polar Frontal Zone (Figure 37 and 38). This is followed by changes at near-coastal Canadian sites impacted by dramatic shifts in position of this Polar Front, reflected in the Younger Dryas climatic oscillation in New Brunswick (Rawlence, 1988; Rawlence & Senior, 1988), Newfoundland (Wolfe & Butler, 1994), and Baffin Island (Wolfe, 1994) between approximately 11,500 BP and 10,000

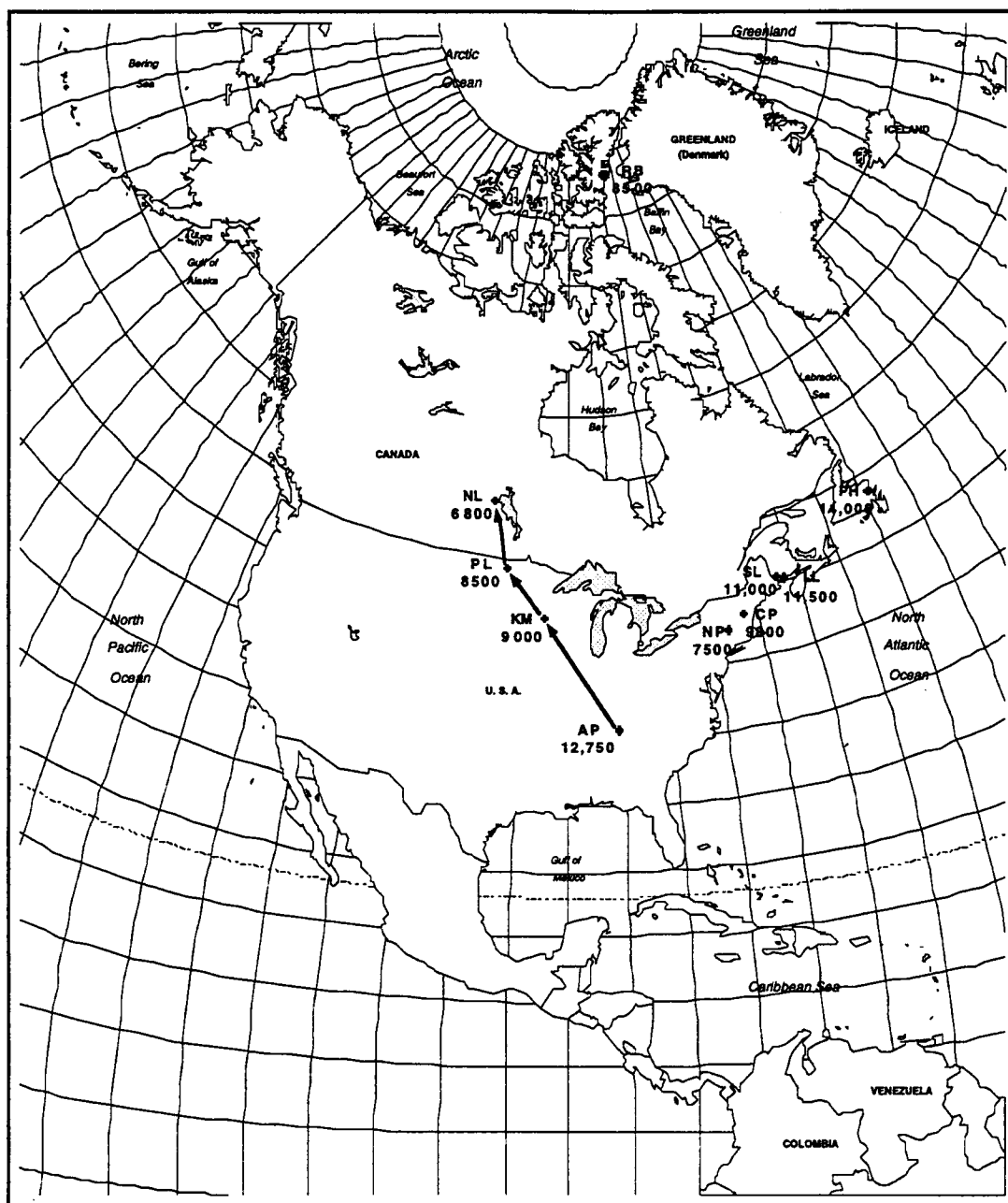


Figure 38. Latitudinal transect across eastern North America comparing the timing of collapse of *Fragilaria*-dominated diatom assemblages during the late-Quaternary. Site codes, locations, and references are listed below.

AP	Anderson Pond, Tennessee (Tolliver, 1998)
CP	Cone Pond, New Hampshire (Ford, 1990)
KM	Kirchner Marsh, Minnesota (Brugam, 1980)
LL	Little Lake, New Brunswick (Rawlence & Senoir, 1988)
NL	nameless lake, Manitoba (Ritchie & Koivo, 1975)
NP	North Pond, Massachusetts (Huvane & Whitehead, 1996)
PH	Pine Hill Pond, Newfoundland (Wolfe & Butler, 1994)
PL	Pickeral Lake, South Dakota (Haworth, 1972)
RB	Rock Basin Lake, Ellesmere Island (Smol, 1983)
SL	Splan Lake, New Brunswick (Rawlence, 1988)

BP. Comparable climatic changes occur between approximately 9750 BP and 7500 BP in three areas: New England (Ford, 1990; Huvane & Whitehead, 1996), the western Great Lakes/northeastern Great Plains (Haworth, 1972; Brugam, 1980; Bradbury & Dietrich-Rurup, 1993), and Ellesmere Island (Smol, 1983). This most recent change of 6800 BP occurred at the most northcentral continental site in Manitoba (Ritchie & Koivo, 1975).

The general pattern of more recent Holocene dates for the decrease in abundance of small, benthic *Fragilaria* species closely mimics the shrinkage of the Laurentide Ice Sheet (Figure 38). This similar pattern of change from late-glacial to post-glacial diatom assemblages appears to reflect the continued influence of the receding Laurentide Ice Sheet on regional weather patterns as well as an overall amelioration of global climate (Wright et al., 1993).

The overall pattern of change in the diatom assemblages at Anderson Pond shows a strong similarity to Kirchner Marsh, MN (Brugam, 1980) (Figure 38). There is an initial period dominated by small, benthic *Fragilaria* species that lasts for a few thousand years, followed by another long interval with a number of epipelagic and epiphytic taxa at similar relative abundance, with some shifting of dominance, and a recent interval dominated by acidophilous species of the genus *Aulacoseira*, especially *A. distans*. Although the specific taxa differ between Kirchner Marsh and Anderson Pond, there is a close similarity in limnologic history, with shallowing and acidification of the site. The major change from a *Fragilaria*-dominated assemblage to other dominant taxa occurs

approximately 3000 years later at Kirchner Marsh, reflecting the later passage of the Polar Front and interglacial warming of this more northern site.

In a regional context, Anderson Pond displays a similar limnologic development to many other sites of eastern North America, with infilling of the basin, replacement of open-water by bog/marsh/swamp communities, and natural acidification leading to changes in diatom assemblages. Differences in the timing of these changes reflect differences in the timing of initial exposure and sedimentation of the basin, timing of local climate changes, and local geology and morphology of the sedimentary basin.

CHAPTER VIII

Conclusions

Diatoms at Anderson Pond, Tennessee, responded to late-Quaternary changes in climate, aquatic vegetation, lake depth, and to historic human activity. Changes in the diatom assemblages at Anderson Pond provide information on the late Pleistocene through Holocene development of this site that is not available from the pollen record, as well as confirm the paleoecological results of the fossil-pollen studies. Important events and developments recorded in the fossil-diatom record are:

1. The late-Pleistocene diatom record, from 19,000 BP to 12,750 BP, contains predominantly alkaliphilous, epipelagic taxa, dominated by small, benthic species of the genus *Fragilaria*. This is a boreal-climate diatom assemblage, commonly found colonizing many late Pleistocene to early Holocene sites throughout temperate and boreal regions of the northern hemisphere. This assemblage indicates clear, alkaline waters up to 6 m in depth throughout the late Pleistocene interval. The poor preservation of siliceous microfossils may reflect their accelerated dissolution with pH conditions ≥ 8.0 in peak glacial times from 18,000 to 16,000 BP.
2. The most significant change in the diatom record occurs between 12,750 BP and 12,500 BP, and represents a late-glacial change from predominantly alkaline-water taxa to

predominantly acidic-water taxa. This is the most significant change in water chemistry recorded in the diatom record. This change coincides with the most significant climatic event in the history of Anderson Pond: the northward migration of the atmospheric Polar Frontal Zone across middle Tennessee. Recorded in the arboreal pollen record, this climatic event marks the change from a jack pine and spruce-dominated boreal forest to an oak-dominated temperate forest. Also recorded in the aquatic pollen and plant macrofossil assemblages, this climatic event is associated with the loss of cold-tolerant, floating aquatic plants and their replacement by more temperate, shallow-water, rooted and emergent aquatic macrophytes. This fundamental climatic change triggered *synchronous responses* in the upland forests, the aquatic macrophyte communities, and in the open-water diatom assemblages.

3. The late-glacial/Holocene diatom record from 12,500 BP to 2250 BP is primarily a record of shallowing water and changes in available substrate under relatively consistent, interglacial climatic conditions. This record of Anderson Pond was initially, from 12,500 BP through 10,000 BP, dominated by the epipelagic genera *Pinnularia* and *Stauroneis*, as well as the epiphytic genus *Eunotia*, and, by 9750 BP, changed to an epiphytic *Eunotia/Gomphonema*-dominated assemblage. This epiphytic diatom response results from physical changes in the lake environment: the infilling of the lake basin, shallowing of the water level and spread of surrounding grasses into the basin. Thus, between 12,500 and 10,000 BP, the response of epiphytic diatoms *leads* the response of aquatic

vegetation—the displaced of littoral sedge meadows by a shrub thicket consisting of southern alder, buttonbush, and Virginia willow.

4. In the later post-glacial period, from 2000 BP through 250 BP, the diatom record indicates increased precipitation in the late Holocene as a rise to dominance by the planktonic genus *Aulacoseira*. This change in the diatom record indicates an increase in open water in shallow pools, at least seasonally available for planktonic diatoms. This environmental change is recorded in the aquatic pollen as a decrease in pollen influx, but no significant change is seen in the relative abundance of vascular-plant taxa.

5. The modern diatom assemblage records the influence of human activity on Anderson Pond in the last 200 hundred years. The almost complete disappearance of the planktonic genus *Aulacoseira* and the increase in relative abundance of the epiphytic genus *Gomphonema* indicate a loss of open-water habitat, corresponding with an increase in sedimentation rate associated with land clearance by humans as EuroAmerican population in the surrounding area grew. There may also have been an increase in the pH (calculated pH = 6.2) to the highest level of the post-glacial period, which is indicated by a decrease in relative abundance of acidophilous taxa and an increase in pH-indifferent taxa such as *Navicula radiosa*.

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APPENDICES

Appendix A. Contemporary taxonomic/systematic characterization of diatoms found at Anderson Pond, as modified from Round, Crawford, & Mann (1990).

Division BACILLARIOPHYTA

Class COSCINODISCOPHYCEAE Round & Crawford 1990

Subclass COSCINODISCOPHYCIDAE Round & Crawford 1990

Order AULACOSEIRALES Crawford 1990

Family AULACOSEIRACEAE Crawford 1990

Aulacoseira Thwaites 1848

Aulacoseira ambigua (Grunow) Simonson 1979

(Plate 1, Figure 1)

Krammer & Lange-Bertalot, 1991, p. 25, pl. 21, fig. 1-16

diameter 4-17 μm ; height 5-13 μm ; striae 16-25/10 μm ; puncta 17-22/10 μm

Ecology: Alkaliphilous to pH-indifferent, eutrophic, euplanktonic, cosmopolitan (Lowe, 1974).

Remarks: Common only during Diatom Zone 1 and Zone 2. Only one valve counted during the Holocene.

Aulacoseira distans (Ehrenberg) Simonsen 1979

(Plate 1, Figure 2)

Krammer & Lange-Bertalot, 1991, p. 32, pl. 29, fig. 1-23

diameter 4-20 μm ; height 3.5-8.5 μm ; striae 10-16/10 μm ; puncta 13-22/10 μm

Ecology: Acidophilous, oligotrophic to dystrophic, periphytic (Lowe, 1974).

Remarks: Most common *Aulacoseira* species during Diatom Zone 4. Also found in Diatom Zone 3.

Aulacoseira granulata (Ehrenberg) Simonsen 1979

Krammer & Lange-Bertalot, 1979, p. 22, pl. 17, fig. 1-10

diameter 4-30 μm ; height 5-24 μm ; striae 7-15/10 μm ; puncta 5-12/10 μm

Ecology: Alkaliphilous, eutrophic, euplanktonic, Summer form, cosmopolitan (Lowe, 1974).

Remarks: Uncommon *Aulacoseira* species at Anderson Pond. Found in only four samples.

Aulacoseira herzogii (Lemmermann) Simonsen 1979

(Plate 1, Figure 3)

Dodd, 1987, p. 19, fig. 1e

diameter around 6.5 μm ; height around 17 μm ; striae around 32/10 μm

Ecology: Insufficiently known. Characteristic of the southeastern United States; not found in the northern Great Lakes states (Camburn & Kingston, 1986).

Remarks: One of four *Aulacoseira* species commonly found in Diatom Zone 3 and Zone 4.

Aulacoseira islandica (O. Müller) Simonsen 1979

Krammer & Lange-Bertalot, 1991, p. 26, pl. 22, fig. 1-12

diameter 3-28 μm ; height 4-21 μm ; striae 11-16/10 μm ; puncta 12-18/10 μm

Ecology: Alkaliphilous, eutrophic to oligotrophic, Spring and Fall maxima (Lowe, 1974).

Remarks: Only found in Diatom Zone 3.

Aulacoseira lirata f. *biseriata* (Grunow) Haworth 1988

(Plate 1, Figure 4)

Krammer & Lange-Bertalot, 1991, p. 37, pl. 34, fig. 1-12

diameter 7-27 μm ; height 3-8 μm ; striae 8-12/10 μm ; puncta 9-10/10 μm

Ecology: Acidophilous (Lowe, 1974). Benthic form, cosmopolitan (Krammer & Lange-Bertalot, 1991)

Remarks: Second most common *Aulacoseira* species in Diatom Zone 4. Also found in Diatom Zone 3.

Aulacoseira nygaardii Camburn in Camburn & Kingston 1986

(Plate 1, Figure 5)

Camburn & Kingston, 1986, p. 26, pl. 3, fig. 48, 52-54

diameter 6.9-11 μm ; height 7-17 μm ; striae 20-22/10 μm ; puncta 25-30/10 μm

Ecology: Insufficiently known.

Remarks: One of four *Aulacoseira* species commonly found in Diatom Zone 3 and Zone 4.

Aulacoseira subarctica f. *recta* (O. Müller) Krammer 1990

Krammer & Lange-Bertalot, 1991, p. 28, pl. 23, fig. 3

diameter 3-5 μm ; height 2.5-18 μm ; striae 17-21/10 μm ; puncta 17-22/10 μm

Ecology: Acidophilous, oligotrophic to mesotrophic, planktonic, cosmopolitan (Krammer and Lange-Bertalot, 1991).

Remarks: Only found in one sample at 5250 BP.

Order ORTHOSEIRALES Crawford 1990

Family ORTHOSEIRACEAE Crawford 1990

Orthoseira Thwaites 1848

Orthoseira dendroteres (Ehrenberg) Crawford 1990

Krammer & Lange-Bertalot, 1991, p. 14, pl. 11, fig. 6-9

diameter 17-65 μm ; height 14-27 μm ; striae 11-14/10 μm

Ecology: Insufficiently known.

Remarks: Only found in one sample at 14,000 BP.

Class FRAGILARIOPHYCEAE Round 1990

Subclass FRAGILARIOPHYCIDAE Round 1990

Order FRAGILARIALES Silva 1962

Family FRAGILARIACEAE Greville 1833

Fragilaria Lyngbye 1819

Fragilaria brevistriata Grunow 1885

(Plate 1, Figure 6)

Patrick & Reimer, 1966, p. 128, pl. 4., fig. 14

length 12-28 μm ; width 3-5 μm ; striae 13-17/10 μm

Ecology: alkaliphilous, eutrophic, periphytic, cosmopolitan (Lowe, 1974).

Remarks: Found at low abundance in most Diatom Zone 1 samples.

Fragilaria constricta Ehrenberg 1841

Patrick & Reimer, 1966, p. 122, pl. 3, fig. 17
length 20-70 μm ; width 6-16 μm ; striae 13-18 μm

Ecology: Prefers water of low mineral content and usually slightly dystrophic (Patrick & Reimer, 1966).
Remarks: Present in only one sample (14,000 BP) in Diatom Zone 1.

Fragilaria construens (Ehrenberg) Grunow 1862

(Plate 1, Figure 7)

Patrick & Reimer, 1966, p. 125, pl. 4, fig. 4
length 7-25 μm ; width 5-12 μm ; striae 14-18/10 μm

Ecology: alkaliphilous, eutrophic, periphytic/tychoplanktonic, Fall maximum, an indicator of oxygenated waters (Lowe, 1974).

Remarks: Along with *Fragilaria pinnata*, the most common species from 19,000 BP through 12,750 BP at Anderson Pond. Found in all Diatom Zone 1 samples. Found at low abundance in one Diatom Zone 3 sample at 7000 BP.

Fragilaria construens var. *venter* (Ehrenberg) Grunow 1881

Patrick & Reimer, 1966, p. 126, pl. 4, fig. 8-9
length 5-9 μm ; width 3-6 μm ; striae 14-16/10 μm

Ecology: Alkaliphilous, oligotrophic to mesotrophic, periphytic/tychoplanktonic, cosmopolitan (Lowe, 1974).

Remarks: Present in most Diatom Zone 1 samples. Less abundant than *Fragilaria construens* and *F. pinnata*.

Fragilaria lapponica Grunow 1881

Patrick & Reimer, 1966, p. 130, pl. 4, fig. 17
length 12-40 μm ; width 4-6 μm ; striae 6-9/10 μm

Ecology: Seems to prefer circumneutral water of low mineral content and indifferent to small amounts of NaCl (Patrick & Reimer, 1966).

Remarks: Present in three Diatom Zone 1 samples.

Fragilaria leptostauron (Ehrenberg) Hustedt 1931

(Plate 1, Figure 8)

Patrick & Reimer, 1966, p. 124, pl. 4, fig. 2
length 15-36 μm ; width 10-23 μm ; 5-9/10 μm

Ecology: pH indifferent (Lowe, 1974). Common in freshwater, usually in shallow water, often on mud surfaces (Patrick & Reimer, 1966).

Remarks: Present in two Diatom Zone 1 samples.

Fragilaria nitzschoides Grunow 1881

Patrick & Reimer, 1966, p. 123, pl. 4, fig. 1
length 15-52 μm ; width 3-5 μm ; striae 16-20/10 μm

Ecology: Insufficiently known.

Remarks: Present in only one Diatom Zone 1 sample (13,000 BP).

Fragilaria pinnata Ehrenberg 1843

(Plate 1, Figure 9)

Patrick & Reimer, 1966, p. 127, pl. 4, fig. 10
length 3-35 μm ; width 2-6 μm ; striae 7-12/10 μm

Ecology: Alkaliphilous, eutrophic, periphytic, oxygen-rich water (Lowe, 1974).

Remarks: Along with *Fragilaria construens*, the most common species from 19,000 BP through 12,750 BP at Anderson Pond. Found in all Diatom Zone 1 samples and occasionally in other samples.

Fragilaria pinnata var. *intercedens* (Grunow) Hustedt 1931

Patrick & Reimer, 1966, p. 127, pl. 4, fig. 11
length 15-34 μm ; width 4-6 μm ; striae 6-8/10 μm

Ecology: A tolerant fresh-water taxon (Patrick and Reimer, 1966).

Remarks: Present in only one Diatom Zone 1 sample (12,750 BP).

Fragilaria subsalina (Grunow) Lange-Bertalot 1991

Krammer & Lange-Bertalot, 1991, p. 138, pl. 127, fig. 9-15
length 7-20 μm ; width 2-5 μm ; striae 19-24/10 μm

Ecology: alkaliphilous, periphytic/tychoplanktonic (Lowe, 1974).

Remarks: Present in Diatom Zone 1 from 18,500 BP through 14,000 BP.

Diatoma Bory 1824

Note: No valves of *Diatoma* were identifiable to species.

Meridion Agardh 1824

Meridion circulare (Greville) Agardh 1831

Patrick & Reimer, 1966, p. 113, pl. 2, fig. 15
length 12-80 μm ; width 4-8 μm ; striae 15-16/10 μm ; costae 3-5/10 μm

Ecology: Alkaliphilous, eutrophic, periphytic/tychoplanktonic, Spring form, indicator of high oxygen concentration (Lowe, 1974). Seems to prefer flowing water (Patrick & Reimer, 1966).

Remarks: Only found in one Diatom Zone 1 sample (18,500 BP).

Synedra Ehrenberg 1830

Synedra parasitica (W. Smith) Hustedt 1930

Patrick & Reimer, 1966, p. 140, pl. 5, fig. 12
length 10-25 μm ; width 3-5 μm ; striae 16-19/10 μm

Ecology: pH-circumneutral, slightly alkaline, mesotrophic to eutrophic, epiphytic on other diatoms (Patrick & Reimer, 1966).

Remarks: Identified in only one Diatom Zone 1 sample (18,500 BP).

Synedra radians Kützing 1844

Patrick & Reimer, 1966, p. 137, pl. 5, fig. 4
length 40-120 μm ; width 2.5-4 μm ; striae 15-18/10 μm

Ecology: Alkaliphilous, eutrophic, euplanktonic, cosmopolitan (Lowe, 1974).

Remarks: Identified only in Diatom Zone 5.

Synedra rumpens Kützing 1844

(Plate 1, Figure 10)

Patrick & Reimer, 1966, p. 143, pl. 5, fig. 19
length 27-70 μm ; width 2-4 μm ; striae 18-20/10 μm

Ecology: pH-indifferent, periphytic, probably cosmopolitan (Lowe, 1974).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP) and in Diatom Zone 5.

Synedra ulna (Nitzsch) Ehrenberg 1836

Patrick & Reimer, 1966, p. 148, pl. 7, fig. 1-2
length 50-350 μm ; width 5-9 μm ; striae 8-12/10 μm

Ecology: Alkaliphilous, eutrophic, euplanktonic, Spring, Summer, and Fall form, cosmopolitan, unsuitable as an ecological indicator (Lowe, 1974).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP) and in one Diatom Zone 3 sample (4000 BP).

Order TABELLARIALES Round 1990

Family TABELLARIACEAE Kützing 1844

Tabellaria Ehrenberg 1940

Tabellaria fenestrata (Lyngbye) Kützing 1844

(Plate 1, Figure 11)

Patrick & Reimer, 1966, p. 103, pl. 1, fig. 1-2
length 25-116 μm ; width 5-10 μm ; striae 14-18/10 μm

Ecology: Acidophilous, all nutrient conditions, periphytic and attached, Spring and Fall maxima, cosmopolitan (Lowe, 1974).

Remarks: Most commonly identified in Diatom Zone 1 despite its classification as acidophilous. Always more abundant than *Tabellaria flocculosa* in Diatom Zone 1.

Tabellaria flocculosa (Roth) Kützing 1844

(Plate 1, Figure 12)

Krammer & Lange-Bertalot, 1991, p. 108, pl. 106, fig. 1-13
length 6-130 μm ; width 3.8-8.5 μm ; striae 13-20/10 μm

Ecology: Acidophilous, mesotrophic/oligotrophic/dystrophic, periphytic and tychoplanktonic, Spring and Fall maxima, cosmopolitan (Lowe, 1974).

Remarks: Identified in Diatom Zones 1 through 3. Highest abundance reached during Diatom Zone 2.

Class BACILLARIOPHYCIDAE Haeckel 1878

Subclass EUNOTIOPHYCIDAE Mann 1990

Order EUNOTIALES Silva 1962

Family EUNOTIACEAE Kützing 1844

Eunotia Ehrenberg 1837

Eunotia arcus Ehrenberg 1837

Krammer & Lange-Bertalot, 1991, p. 184, pl. 147
length 17-90 μm ; width 3-9 μm ; Striae 8-14/10 μm

Ecology: Acidophilous.

Remarks: Present at low abundance in Diatom Zones 3 and 4.

Eunotia bilunaris (Ehrenberg) Mills 1934

(Plate 1, Figure 13)

Krammer & Lange-Bertalot, 1991, p. 179, pl. 137
length 10-150 μm ; width 1.9-6 μm ; striae 11-28/10 μm

Ecology: Tycoplanktonic/periphytic; acidophilic/pH-indifferent; eutrophic/oligotrophic.

Remarks: *Eunotia bilunaris* is one of the most abundant taxa at Anderson Pond, occurring in all but 1 sample and being the most abundant taxon in 3 samples.

Eunotia circumborealis Lange-Bertalot & Nörpel 1991

Krammer & Lange-Bertalot, 1991, p. 197, pl. 143, fig. 16-23
length 13-45 μm ; width 6-8 μm ; striae 13-17/10 μm

Ecology: Oligotrophic/dystrophic.

Remarks: Present at low abundance in most Diatom Zone 3 samples and in one Diatom Zone 1 sample (18,500 BP).

Eunotia clevei Grunow in Cleve & Möller 1878

Krammer & Lange-Bertalot, p. 211, pl. 158, fig. 7,8
length 100-340 μm ; width 22-40 μm ; striae 12-18/10 μm

Ecology: Fossil species, modern occurrences uncertain (Patrick and Reimer, 1966).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP).

Eunotia diodon Ehrenberg 1837

(Plate 1, Figure 14)

Krammer & Lange-Bertalot, 1991, p. 191, pl. 149, fig. 8-19
length 10-65 μm ; width 5-14 μm ; striae 12-16/10 μm

Ecology: Acidophilous.

Remarks: Present at generally low abundance in all Diatom Zones.

Eunotia faba Ehrenberg 1838

Krammer & Lange-Bertalot, 1991, p. 225, pl. 164, fig. 1-10
length 16-60 μm ; width 5-9 μm ; striae 13-15/10 μm

Ecology: Acidophilous, oligotrophic.

Remarks: Present at low abundance in Diatom Zones 1 through 3.

Eunotia flexuosa (Brebisson) Kützing 1849

Krammer & Lange-Bertalot, 1991, p. 182, pl. 140, fig. 8-18
length 90-300 μm ; width 2-7 μm ; striae 11-20/10 μm

Ecology: Acidophilic.

Remarks: Identified at low abundance in Diatom Zones 1 through 4.

Eunotia formica Ehrenberg 1843

(Plate 1, Figure 16)

Krammer & Lange-Bertalot, 1991, p. 209, pl. 152, fig. 8-12A
length 35-200 μm ; width 7-14 μm ; striae 6-12/10 μm

Ecology: Periphytic; pH-indifferent, oligotrophic/dystrophic.

Remarks: Present in most Diatom Zone 3 samples. Also identified in Diatom Zones 1, 2, and 4.

Distinguished from *Eunotia monodon* by central swelling, particularly on the ventral margin.

Eunotia glacialis Meister 1912

Krammer & Lange-Bertalot, 1991, p. 207, pl. 151, fig. 1-10A
length 30-200 μm ; width 3-7.5 μm ; striae 9-15 μm

Ecology: Acidophilic.

Remarks: Present in most Diatom Zone 3 samples. Also identified in two Diatom Zone 2 samples.

Eunotia implicata Nörpel, Lange-Bertalot, & Alles 1991

(Plate 1, Figure 15)

Krammer & Lange-Bertalot, 1991, p. 197, pl. 143, fig. 1-9A
length 20-40 μm ; width 3-6 μm ; striae 14-22 μm

Ecology: pH-indifferent; oligotrophic/dystrophic.

Remarks: Important species of *Eunotia* present in all Diatom Zone 2 through 5 samples. Most abundant in Diatom Zone 3. Also identified in some Diatom Zone 1 samples with first appearance at 15,000 BP.

Eunotia incisa Gregory 1854

(Plate 2, Figure 1)

Krammer & Lange-Bertalot, 1991, p. 221, pl. 161, fig. 8-19
length 13-50 μm ; width 4-6 μm ; striae 12-17/10 μm

Ecology: Acidobiontic/acidophilic, oligotrophic.

Remarks: Found in all samples except the modern sample. Important *Eunotia* species in Diatom Zones 1 through 4. Reaches greatest abundance in Diatom Zone 3, but is the most abundant *Eunotia* species in the two oldest samples (19,000 BP and 18,500 BP) despite being classified as an acidobiont/acidophile. Only *Eunotia* species identified in oldest sample.

Eunotia intermedia (Krasske ex Hustedt) Nörpel & Lange-Bertalot 1991

Krammer and Lange-Bertalot, 1991, p. 215, pl. 143, fig. 10-15
length 14-45 μm ; width 3.5-5 μm ; striae 14-19/10 μm

Ecology: Acidophilic/pH-indifferent, oligotrophic.

Remarks: Present in Diatom Zones 1 and 3.

Eunotia minor (Kützting) Grunow in Van Heurck 1881

(Plate 2, Figure 2)

Krammer & Lange-Bertalot, 1991, p. 196, pl. 142, fig. 7-15
length 20-60 µm; width 4.5-8 µm; striae 9-15/10 µm

Ecology: Periphytic; acidophilic/pH-indifferent; aerophilous.

Remarks: One of the most common taxa in this genus at Anderson Pond. Present in all samples except two (19,000 BP and 15,000 BP). Most important in Diatom Zones 2 through 4.

Eunotia monodon Ehrenberg 1843

(Plate 2, Figure 3)

Krammer & Lange-Bertalot, 1991, p. 210, pl. 158, fig. 1-6
length 35-220 µm; width 6-15 µm; striae 8-12/10 µm

Ecology: acidophilic.

Remarks: *Eunotia monodon* is the most abundant taxon in the Anderson Pond core, occurring in all but 2 samples (19,000 BP and 18,500 BP) and being the most abundant taxon in 8 samples.

Eunotia monodon var. *bidens* (Gregory) Hustedt 1932

Krammer & Lange-Bertalot, 1991, p. 210, pl. 158, fig. 4-6
length 35-220 µm; width 6-15 µm; striae 8-12/10 µm

Ecology: Acidophilous, oligotrophic/dystrophic.

Remarks: Identified in one Diatom Zone 3 sample (6000 BP). Differs from the nominate variety by the presence of two undulations on the dorsal margin. Patrick & Reimer (1966) indicate that this variety prefers warm water, identifying specimens from Florida and Georgia.

Eunotia naegeli Migula in Thomé 1907

Krammer & Lange-Bertalot, 1991, p. 182, pl. 140, fig. 1-6
length 10-150 µm; width 1.5-3.5 µm; striae 14-20/10 µm

Ecology: acidophilic.

Remarks: Identified in one Diatom Zone 4 sample (2000 BP).

Eunotia pectinalis (O. F. Müller?) Rabenhorst 1864

Krammer & Lange-Bertalot, 1991, p. 193, pl. 141, fig. 6
length 10-140 µm; width 5-10 µm; striae 7-15/10 µm

Ecology: Acidophilous, eutrophic/oligotrophic, most common in cooler regions.

Remarks: Identified in one Diatom Zone 3 sample (9000 BP).

Eunotia pectinalis var. *undulata* (Ralfs) Rabenhorst 1864

Krammer & Lange-Bertalot, 1991, p. 193, pl. 141, fig. 1-5, 7
length 10-140 µm; width 5-10 µm; striae 7-15/10 µm

Ecology: Acidophilous/pH-indifferent.

Remarks: Identified in one Diatom Zone 1 sample (12,750 BP). Differs from nominate variety by presence of undulations along dorsal margin and a central swelling of the ventral margin.

Eunotia praerupta Ehrenberg 1843

Krammer & Lange-Bertalot, 1991, p. 186, pl. 148
length 20-100 μm ; width 6-17 μm ; striae 7-13/10 μm

Ecology: Acidophilous.

Remarks: Identified in two samples (12,000 BP and 3250 BP).

Eunotia praerupta var. *bidens* (Ehrenberg) Grunow 1880

(Plate 2, Figure 4)

Krammer & Lange-Bertalot, 1991, p. 187, pl. 148, fig. 11,12
length 20-100 μm ; 6-17 μm ; Striae 7-13/10 μm

Ecology: Acidophilous.

Remarks: Present in most samples from 9750 BP through 1750 BP. Also identified at 18,500 BP. Same as nominate variety except for the presence of two undulations along the dorsal margin.

Eunotia rhomboidea Hustedt 1950

(Plate 2, Figure 5)

Krammer & Lange-Bertalot, 1991, p. 223, pl. 164, fig. 11-20
length 10-25 μm ; width 2-4 μm ; striae 15-19/10 μm

Ecology: Acidophilous, oligotrophic.

Remarks: Present in low abundance in Diatom Zones 1 through 4.

Eunotia rostellata Hustedt ex Patrick in Patrick & Reimer 1966

(Plate 2, Figure 6)

Patrick & Reimer, 1966, p. 191, pl. 10, fig. 9
length 46 μm ; width 4-5 μm ; central striae 14-16/10 μm ;
terminal striae 17-18/10 μm

Ecology: Found in cool, acid water (Patrick & Reimer, 1966)

Remarks: Identified in one Diatom Zone 1 sample (12,750 BP).

Eunotia serra Ehrenberg 1837

(Plate 2, Figure 7)

Krammer & Lange-Bertalot, 1991, p. 219, pl. 146, fig. 1, 2
length 30-160 μm ; width 12-17 μm ; striae 9-12/10 μm

Ecology: Acidophilous, oligotrophic-dystrophic, cold water.

Remarks: Identified in one Diatom Zone 3 sample (5250 BP).

Eunotia serra var. *tetraodon* (Ehrenberg) Nörpel 1991

Krammer & Lange-Bertalot, 1991, p. 220, pl. 146, fig. 5
length 30-50 μm ; width 12-17 μm ; striae 9-12/10 μm

Ecology: Acidophilous, oligotrophic-dystrophic, cold water.

Remarks: Identified in two samples (13,000 BP and 12,000 BP). Differs from nominate variety in its shorter length (<50 μm) and in having only four undulations (Krammer & Lange-Bertalot, 1991).

Eunotia soleirolii (Kützing) Rabenhorst 1864

Krammer & Lange-Bertalot, 1991, p. 194, pl. 142, fig. 2-6
length 10-100+ μm ; width 5-8 μm ; 7-14/10 μm

Ecology: pH indifferent; oligotrophic.

Remarks: Identified in only one Diatom Zone 3 sample (9000 BP)

Eunotia subarcutoides Alles, Nörpel, & Lange-Bertalot 1991

Krammer & Lange-Bertalot, 1991, p. 214, pl. 138, fig. 1-9
length 6-35 μm ; width 2.7-4.5 μm ; striae 18-23/10 μm

Ecology: Acidobiontic, oligotrophic.

Remarks: Identified in only one Diatom Zone 3 sample (4000 BP).

Eunotia sudetica O. Müller 1898

Krammer & Lange-Bertalot, 1991, p. 224, pl. 161, fig. 1-7
length 12-60 μm ; width 5.5-9 μm ; striae 8-13/10 μm

Ecology: Acidophilous.

Remarks: Identified in only one Diatom Zone 3 sample (5250 BP).

Eunotia tenella (Grunow) Cleve 1895

Patrick & Reimer, 1966, p. 210, pl. 13, fig. 6
length 6-37 μm ; width 2-4 μm ; striae 14-20 μm

Ecology: Prefers somewhat acid, soft waters (Patrick & Reimer, 1966).

Remarks: Identified in only one Diatom Zone 1 sample (18,500 BP).

Eunotia triodon Ehrenberg 1837

Krammer & Lange-Bertalot, 1991, p. 220, pl. 146, fig. 6-9
length 30-120 μm ; width 10-26 μm ; striae 15-20 μm

Ecology: Acidophilous, oligotrophic.

Remarks: Identified in only one Diatom Zone 1 sample (12,750 BP).

Eunotia veneris (Kützing) De Toni 1892

(Plate 2, Figure 8)

Krammer & Lange-Bertalot, 1991, p. 222, pl. 163, fig. 14-19
length 13-50 μm ; width 4-6 μm ; striae 12-17 μm

Ecology: Acidobiontic-acidophilous, dystrophic.

Remarks: Identified from samples in Diatom Zones 2 through 4.

Subclass BACILLARIOPHYCIDAE Mann 1990
Order CYMBELLALES Mann 1990
Family CYMBELLACEAE Greville 1833

Cymbella Agardh 1830

Cymbella acutiuscula Cleve 1894

(Plate 2, Figure 10)

Patrick & Reimer, 1974, p. 35, pl. 5, fig. 2
length 70-105 μm ; width 20-25.5 μm ; central striae 8-11/10 μm ;
terminal striae 12-13/10 μm ; puncta 14-20/10 μm

Ecology: Insufficiently known (Patrick & Reimer, 1975).

Remarks: Present only in Diatom Zone 1.

Cymbella amphicephala Naegahrd ex Kützing 1849

Patrick & Reimer, 1975, p. 33, pl. 4, fig. 11
length 20-40 μm ; width 6-8 μm ; central striae 12-16/10 μm ;
terminal striae 18-20/10 μm

Ecology: Found frequently under conditions of high O_2 content and at a pH above 7 (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (8500 BP).

Cymbella aspera (Ehrenberg) H. Peragallo 1889

Patrick & Reimer, 1975, p. 53, pl. 10, fig. 2
length 70-265 μm ; width 20-48 μm ; striae 7-12/10 μm ; puncta 11-15/10 μm

Ecology: Alkaliphilous, periphytic, Spring form, cosmopolitan, oxygen saturation is optimal (Lowe, 1974). Often reported from seeps and springs, but also found in streams and lakes in shallower water (Patrick & Reimer, 1975).

Remarks: Present in most Diatom Zone 1 samples and in one Diatom Zone 2 sample (10,000 BP).

Cymbella cistula (Ehrenberg) Kirchner 1878

(Plate 2, Figure 9)

Patrick & Reimer, 1975, p. 62, pl. 11, fig. 3-4
length 35-180 μm ; width 15-36 μm ; central striae 7-9/10 μm ;
terminal striae 12-13/10 μm ; puncta (lineae) 18-22/10 μm

Ecology: Alkaliphilous, periphytic, cosmopolitan, oxygen saturation is optimal (Lowe, 1974). Most often noted in the United States as an epiphyte in lakes and streams with some flow (Patrick & Reimer, 1975).

Remarks: Identified in Diatom Zone 1 from 15,000 BP through 14,000 BP. Third most abundant diatom species at 15,000 BP after *Fragilaria pinnata* and *F. construens*.

Cymbella cuspidata Kützing 1844

(Plate 3, Figure 1)

Patrick & Reimer, 1975, p. 39, pl. 6, fig. 2-3
length 35-100 μm ; width 14-28 μm ; central striae 8-11.5/10 μm ;
terminal striae 12-15/10 μm ; puncta 20-22/10 μm

Ecology: pH indifferent, but larger forms found more often at neutral to slightly acid pH (Patrick & Reimer, 1975).

Remarks: Most common species of *Cymbella* at Anderson Pond. Found in all diatom zones except Diatom Zone 5.

Cymbella hauckii Van Heurck 1887

(Plate 4, Figure 1)

Patrick & Reimer, 1975, p. 37, pl. 5, fig. 5-7

length 39-80 μm ; width 13-20 μm ; central striae 10-12/10 μm ; terminal striae 16-17/10 μm ; central puncta 16/10 μm ; terminal puncta 20-22/10 μm

Ecology: Insufficiently known (Patrick & Reimer, 1975).

Remarks: Identified in Diatom Zones 1 and 3.

Cymbella heteropleura var. *subrostrata* Cleve 1894

(Plate 3, Figure 2)

Patrick & Reimer, 1975, p. 38, pl. 6, fig. 1

length 135-270 μm ; width 37-52 μm ; central striae 8-10/10 μm ; terminal striae 14-15/10 μm ; puncta 12-16/10 μm

Ecology: Insufficiently known, but mostly recorded from lake and pond sediments in the northern parts of the U. S. (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (13,000 BP) and one Diatom Zone 2 sample (12,000 BP).

Cymbella inaequalis (Ehrenberg) Rabenhorst 1847

Patrick & Reimer, 1975, p. 36, pl. 5, fig. 3

length 55-220 μm ; width 19-50 μm ; central striae 6-9/10 μm ; terminal striae 10-12/10 μm ; puncta 16-20/10 μm

Ecology: Often reported from lakes (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP).

Cymbella lanceolata (Aghard) Aghard 1830

Patrick & Reimer, 1975, p. 52, pl. 10, fig. 1

length 70-210 μm ; width 20-34 μm ; central striae 9-10/10 μm ; terminal striae 12-14/10 μm ; cross bars 12-15/10 μm

Ecology: Alkaliphilous, most common in shallow water littoral habitats associated with submerged aquatic plants and sometimes partially decaying vegetation (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (14,000 BP).

Cymbella naviculiformis Auerswald 1863

Patrick & Reimer, 1975, p. 31, pl. 4, fig. 9

length 30-50 μm ; width 9-16 μm ; central striae 12-14/10 μm ; terminal striae 18/10 μm ; puncta 27-29/10 μm

Ecology: pH indifferent, periphytic, weak Fall maximum, cosmopolitan, oxygen saturation is optimal (Lowe, 1974).

Remarks: Identified in the most recent Diatom Zone 4 sample (750 BP).

Cymbella proxima Reimer in Patrick & Reimer 1975

Patrick & Reimer, 1975, p. 61, pl. 11, fig. 1

length 45-120 μm ; width 18-24 μm ; central striae 7-8/10 μm ; terminal striae 11/10 μm ; puncta 14-15/10 μm

Ecology: Not found, so far, in streams or rivers (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP).

Cymbella subcuspidata Krammer 1982

Krammer & Lange-Bertalot, 1986, p. 339, pl. 146, fig. 6-7
length 54-100 μm ; width 19-31 μm ; central striae 8-11/10 μm ;
terminal striae 15/10 μm ; puncta 18-23/10 μm

Ecology: Insufficiently known.

Remarks: Identified in the most recent Diatom Zone 4 sample (750 BP).

Encyonema Kützting 1833

Encyonema lunatum (W. Smith in Greville) Van Heurck 1896

(Plate 4, Figure 2)

Patrick & Reimer, 1975, p. 46, pl. 7, fig. 11-14
length 20-51 μm ; width 4.5-7 μm ; central striae 9-12/10 μm ;
terminal striae 16-18/10 μm ; lineae 25-28/10 μm

Ecology: Insufficiently known (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (12,750 BP).

Encyonema mesiana (Cholnoky) Mann in Round, Crawford, & Mann 1990

Krammer & Lange-Bertalot, 1986, p. 304, pl. 118, fig. 1-8
length 30-70 μm ; width 9-14 μm ; central striae 7-9(11)/10 μm ;
terminal striae 15-18/10 μm ; puncta 18-22/10 μm

Ecology: Found in Weakly acid to moderately alkaline waters (Patrick & Reimer, 1975)

Remarks: Identified in one Diatom Zone 1 sample (13,000 BP).

Encyonema minutum (Hilse in Rabenhorst) Mann in Round, Crawford, & Mann 1990

Krammer & Lange-Bertalot, 1986, p. 305, pl. 119, fig. 1-13
length 7-32 μm ; width 3.9-7 μm ; central striae 10.5-15/10 μm ;
terminal striae 14-20/10 μm ; puncta 30-38/10 μm

Ecology: Cosmopolitan, oligotrophic (Krammer & Lange-Bertalot, 1986). pH indifferent (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (14,000 BP).

Encyonema muelleri (Hustedt) Mann in Round, Crawford, & Mann 1990

Krammer & Lange-Bertalot, 1986, p. 311, pl. 122, fig. 10-15
length 30-150 μm ; width 7-30 μm ; central striae 6.5-10/10 μm ;
terminal striae 10-11/10 μm ; puncta 13-20/10 μm

Ecology: Alkaliphilous (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (19,000 BP).

Encyonema silesiacum (Bleisch in Rabenhorst) Mann in Round, Crawford, & Mann 1990
(Plate 4, Figure 3)

Krammer & Lange-Bertalot, 1986, p. 304, pl. 117, fig., 1-24
length 15-46 μm ; width 6.5-14.2 μm ; central striae 10.5-15/10 μm ;
terminal striae 14-20/10 μm ; puncta 24-30/10 μm

Ecology: Cosmopolitan, oligotrophic to eutrophic (Krammer & Lange-Bertalot, 1986). pH indifferent (Patrick & Reimer, 1975).

Remarks: Most common species of *Encyonema* at Anderson Pond. Identified in Diatom Zones 1, 3, and 5.

Family GOMPHONEMATACEAE Kützing 1844

Gomphonema Ehrenberg 1832

Gomphonema acuminatum Ehrenberg 1832 (Plate 4, Figure 4)

Patrick & Reimer, 1975, p. 112, pl. 15, fig. 2, 4, 7
length 30-85 μm ; width 7-11 μm ; striae 8-11/10 μm

Ecology: Alkaliphilous, periphytic, cosmopolitan (Lowe, 1974).

Remarks: Identified in most Diatom Zone 1 samples, the first Diatom Zone 2 sample and the Diatom Zone 5 sample.

Gomphonema affine Kützing 1844

Patrick & Reimer, 1975, p. 133, pl. 17, fig. 5
length 30-75 μm ; width 7-11 μm ; striae 10-13/10 μm

Ecology: Tolerant of a wide range of conductivity in fresh water (Patrick & Reimer, 1975).

Remarks: Present in Diatom Zones 2 and 3.

Gomphonema angustatum (Kützing) Rabenhorst 1864 (Plate 4, Figure 5)

Patrick & Reimer, 1975, p. 133, pl. 17, fig. 17-19
length 12-45 μm ; width 5-9 μm ; striae 9-12/10 μm

Ecology: Alkaliphilous, eutrophic, periphytic, Fall and Winter maxima (Lowe, 1974). Patrick & Reimer (1975) indicate a preference for oligotrophic to somewhat mesotrophic water.

Remarks: Present in Diatom Zones 1, 2, 3, and 5. Most common *Gomphonema* species in Diatom Zone 5.

Gomphonema apicatum Ehrenberg 1854

Patrick & Reimer, 1975, p. 110, pl. 15, fig. 1
length 45-50 μm ; width 13-14 μm ; striae 10-12/10 μm

Ecology: Not well known (Patrick & Reimer, 1975).

Remarks: Identified in Diatom Zones 1 and 2.

Gomphonema brasiliense Grunow 1878

Patrick & Reimer, 1975, p. 143, pl. 18, fig. 15-17
length 25-65 μm ; width 5-10 μm ; striae 16-18/10 μm

Ecology: Seems to prefer circumneutral, warm water with moderate conductivity (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (15,000 BP).

Gomphonema gracile Ehrenberg 1838

(Plate 4, Figure 6)

Patrick & Reimer, 1975, p. 131, pl. 17, fig. 1-3
length 24-90 μm ; width 3-11 μm ; striae 8-16/10 μm

Ecology: Alkaliphilous to pH-indifferent, periphytic, cosmopolitan (Lowe, 1974). Prefers water of low nutrient content (Patrick and Reimer, 1975).

Remarks: The most common species of *Gomphonema* at Anderson Pond. Present in all diatom zones. Most abundant in Diatom Zone 3.

Gomphonema grunowii Patrick in Patrick & Reimer 1975

(Plate 4, Figure 7)

Patrick & Reimer, 1975, p. 131, pl. 17, fig. 6
length 33-56 μm ; width 7-10 μm ; central striae 12-13/10 μm ;
terminal striae 16/10 μm

Ecology: Seems to prefer circumneutral water of moderate conductivity (Patrick & Reimer, 1975).

Remarks: Identified in Diatom Zone 5:

Gomphonema intricatum Kützing 1844

Patrick & Reimer, 1975, p. 134, pl. 18, fig. 1
length 30-70 μm ; width 5-9 μm ; striae 9-11/10 μm

Ecology: Alkaliphilous, eutrophic, periphytic, cosmopolitan (Lowe, 1974).

Gomphonema parvulum (Kützing) Kützing 1849

(Plate 4, Figure 8)

Patrick & Reimer, 1975, p. 122, pl. 17, fig. 7-12
length 15-30 μm ; width 4-8 μm ; striae 13-16/10 μm

Ecology: pH-indifferent, periphytic, cosmopolitan, a facultative nitrogen heterotroph and may be a pollution indicator (Lowe, 1974).

Remarks: Identified in Diatom Zones 2 through 5.

Gomphonema sarcophagus Gregory 1856

(Plate 4, Figure 9)

Ecology: Alkaliphilous to pH-indifferent (Lowe, 1974). Seems to prefer water of moderate conductivity and mesotrophic nutrient level (Patrick & Reimer, 1975).

Remarks: Identified in Diatom Zones 1 and 3.

Gomphonema sphaerophorum Ehrenberg 1845

Patrick & Reimer, 1966, p. 115, pl. 15, fig. 11
length 30-47 μm ; width 7-10 μm ; striae 11-16/10 μm

Ecology: Seems to prefer medium to fairly hard water, and mesotrophic to eutrophic in nutrient level (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (14,000 BP).

Gomphonema subclavatum (Grunow) Grunow 1880

Patrick & Reimer, 1975, p. 129, pl. 16, fig. 10
length 35-70 µm; width 8-10 µm; 9-13/10 µm

Ecology: pH-indifferent (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP) and one Diatom Zone 3 sample (12,500 BP).

Gomphonema truncatum Ehrenberg 1832

Patrick & Reimer, 1975, p. 118, pl. 16, fig. 3
length 26-65 µm; width 6-14 µm; striae 10-12/10 µm

Ecology: pH-indifferent, moderate hardness, cool to moderately warm temperature, low to moderate nutrient content (Patrick and Reimer, 1975).

Remarks: Present in Diatom Zones 1 and 2 in most samples from 13,000 BP through 12,000 BP.

Gomphonema truncatum var. *capitatum* (Ehrenberg) Patrick in Patrick & Reimer 1975

Patrick & Reimer, 1975, p. 119, pl. 16, fig. 4
length 16-65 µm; width 6-13 µm; striae 10-12/10 µm

Ecology: Shallow, fresh water (Patrick & Reimer, 1975).

Remarks: Differs from the nominate variety in its less capitate apex and the striae usually being slightly less radiate (Patrick & Reimer, 1975).

Remarks: Identified in Diatom Zone 1.

Gomphonema turris Ehrenberg 1854

(Plate 4, Figure 10)

Patrick & Reimer, 1975, p. 114, pl. 16, fig. 6
length 40-60 µm; width 13 µm; central striae 8-10/10 µm;
terminal striae 12/10 µm

Ecology: Circumneutral (Patrick & Reimer, 1975).

Remarks: Present in many Diatom Zone 2 and 3 samples. Most abundant in the middle of Diatom Zone 3.

Order ACHNANTHALES Silva 1962

Family ACHNANTHACEAE Kützinger 1844

Achnanthes Bory 1822

Achnanthes exigua Grunow 1880

Patrick & Reimer, 1966, p. 257, pl. 16, fig. 21-22
length 7-17 µm; width 4.5-6 µm; striae (raphe valve) 24-25/10 µm;
striae (pseudoraphe valve) 20-22/10 µm

Ecology: Alkaliphilous, periphytic, eurythermal, euryphotic, cosmopolitan (Lowe, 1974).

Remarks: Identified in one Diatom Zone 1 sample (14,000 BP).

Achnanthes lanceolata Brebisson ex Kützing 1846

Patrick & Reimer, 1966, p. 269, pl. 18, fig. 1-10
length 12-31 μm ; width 4.5-8 μm ; striae 11-14/10 μm

Ecology: Alkaliphilous, found in springs and streams, periphytic, Spring and Fall maxima, cosmopolitan, requires high oxygen concentrations, one of the first to colonize a new stream (Lowe, 1974). Observed especially in rather well-aerated flowing waters of neutral to alkaline pH (Patrick & Reimer, 1966).
Remarks: Identified in one Diatom Zone 1 sample (15,000 BP).

Family COCCONEIDACEAE Kützing 1844

Cocconeis Ehrenberg 1837

Cocconeis placentula var. *lineata* (Ehrenberg) Van Heurck 1885 (Plate 4, Figure 11a, b)

Patrick & Reimer, 1966, p. 242, pl. 15, fig. 5-6
length 10-70 μm ; width 8-40 μm ; striae (raphe valve) 19-23/10 μm ;
striae (pseudoraphe valve) 19-20/10 μm

Ecology: Alkaliphilous, periphytic, Fall maximum, cosmopolitan (Lowe, 1974).
Remarks: Present in all Diatom Zone 1 samples except one.

Order NAVICULALES Bessey 1907

Suborder NEIDIINEAE Mann 1990

Family DIADESMIDACEAE Mann 1990

Luticola Mann 1990

Luticola mutica (Kützing) Mann in Round, Crawford, and Mann 1990 (Plate 4, Figure 12)

Patrick & Reimer, 1966, p. 454, pl. 42, fig. 2
length 10-40 μm ; width 7-12 μm ; striae 14-20/10 μm

Ecology: Round in fresh, brackish, and alkaline water; often an aerophile (Patrick & Reimer, 1966).
Remarks: Present in Diatom Zones 1, 2, and 3 from 14,000 BP through 9000 BP, and again in Diatom Zone 5.

Family AMPHIPLEURACEAE Grunow 1862

Frustulia Rabenhorst 1853

Frustulia rhomboides (Ehrenberg) De Toni 1891 (Plate 4, Figure 13)

Patrick & Reimer, 1966, p. 306, pl. 21, fig. 5
length 70-160 μm ; width 15-30 μm ; transverse striae 20-30/10 μm ;
longitudinal striae 20-30/10 μm

Ecology: Acidophilous, oligotrophic to dystrophic, periphytic, cosmopolitan (Lowe, 1974).
Remarks: Identified in the last Diatom Zone 1 sample and in Diatom Zone 2. A common indicator species of dystrophic conditions.

Family NEIDIACEAE Mereschowsky 1903

Neidium Pfitzer 1871

Neidium affine (Ehrenberg) Pfitzer 1871

(Plate 5, Figure 2)

Patrick & Reimer, 1966, p. 390, pl. 35, fig. 2
length 30-65 μm ; width 8-13 μm ; striae 22-24/10 μm ; puncta about 24/10 μm

Ecology: Alkaliphilous to pH-indifferent, cosmopolitan (Lowe, 1974).

Remarks: Identified in Diatom Zones 1 and 3. May be present in Diatom Zones 3 and 4, but breakage of valves made it often difficult to identify *Neidium* valves to species level.

Neidium iridis (Ehrenberg) Cleve 1894

(Plate 5, Figure 1)

Patrick & Reimer, 1966, p. 386, pl. 34, fig. 1
length 50-190 μm ; width 16-40 μm ; striae 14-18/10 μm ; puncta 13-18/10 μm

Ecology: pH-indifferent, cosmopolitan (Lowe, 1974). Appears to prefer standing or only slightly moving water (Patrick & Reimer, 1966).

Remarks: Present in Diatom Zones 1 through 4. Most abundant in Diatom Zone 3 from 11,000 BP through 10,000 BP.

Suborder SELLAPHORINEAE Mann 1990

Family SELLAPHORACEAE Mereschowsky 1902

Sellaphora Mereschowsky 1902

Sellaphora pupula var. *rectangularis* (Gregory) Mereschowsky 1902

(Plate 5, Figure 3)

Patrick & Reimer, 1966, p. 497, pl. 47, fig. 12
length 20-40 μm ; width 7-11 μm ; central striae 13-17/10 μm ; terminal striae 26/10 μm

Ecology: pH-indifferent, eutrophic, periphytic (Lowe, 1974) Prefers water of high mineral content (Patrick & Reimer, 1966).

Remarks: Present in all diatom zones and most samples. Never reaches an abundance of more than 3 percent of total diatom valves.

Family PINNULARIACEAE Mann 1990

Caloneis Cleve 1894

Caloneis bacillum (Grunow) Cleve 1894

Patrick & Reimer, 1966, p. 586, pl. 54, fig. 8
length 15-45 μm ; width 4-9 μm ; striae (22)24-30/10 μm

Ecology: Soft, hard, or slightly brackish waters. Often found in standing, alkaline waters (Patrick & Reimer, 1966).

Remarks: Identified in two Diatom Zone 1 samples (18,500 BP and 12,750 BP).

Caloneis ventricosa var. *minuta* (Grunow) Mills 1934

Patrick & Reimer, 1966, p. 584, pl. 54, fig. 2
length 22-33 μm ; width 6-7 μm ; striae 21-22/10 μm

Ecology: Insufficiently known.

Remarks: Identified in one Diatom Zone 1 sample (13,000 BP).

Pinnularia Ehrenberg 1843

Pinnularia acrosphaeria W. Smith 1853

(Plate 5, Figure 4)

Patrick & Reimer, 1966, p. 623, pl. 60, fig. 2-3
length 30-180 μm ; width 8-20 μm ; striae 6-14/10 μm

Ecology: Seems to prefer littoral areas of circumneutral lakes and ponds (Patrick & Reimer, 1966).

Remarks: Identified in Diatom Zone 1.

Pinnularia angusta (Cleve) Krammer 1992

Krammer, 1992, p. 122, pl. 44, fig. 16-20
length 33-62 μm ; width 5.4-8.1 μm ; striae 10-13/10 μm

Ecology: Oligotrophic (Krammer, 1992).

Remarks: Identified in one Diatom Zone 3 sample (3250 BP).

Pinnularia borealis Ehrenberg 1843

Patrick & Reimer, 1966, p. 618, pl. 58, fig. 13
length 28-110 μm ; width 7-18 μm ; striae 4-6/10 μm

Ecology: pH-indifferent, eutrophic, may be aerophilous, periphytic (Lowe, 1974). Prefers cool water of low mineral content (Patrick & Reimer, 1966).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP) and in one Diatom Zone 3 sample (5250 BP).

Pinnularia braunii (Grunow) Cleve 1895

(Plate 5, Figure 5)

Patrick and Reimer, 1966, p. 594, pl. 55, fig. 3
length 30-60 μm ; width 8-12 μm ; striae 10-12/10 μm

Ecology: Seems to prefer cool water of low mineral content (Patrick and Reimer, 1966).

Remarks: Identified in the two earliest Diatom Zone 2 samples (12,500 BP and 12,000 BP).

Pinnularia brebissonii (Kützing) Rabenhorst 1864

Patrick & Reimer, 1966, p. 614, pl. 58, fig. 6
length 40-60 μm ; width 9-11 μm ; striae 10-14/10 μm

Ecology: Seems to prefer cool water of low mineral content (Patrick & Reimer, 1966).

Remarks: Present in Diatom Zone 3 from 9000 BP through 6000 BP.

Pinnularia divergens W. Smith 1853

(Plate 5, Figure 7)

Patrick & Reimer, 1966, p. 603, pl. 56, fig. 1
length 50-140 μm ; width 13-20 μm ; striae 9-12/10 μm

Ecology: Cool water of low mineral content (Patrick & Reimer, 1966).
Remarks: Identified in one Diatom Zone 2 sample (12,000 BP).

Pinnularia formica (Ehrenberg) Patrick in Patrick & Reimer 1966

Patrick & Reimer, 1966, p. 627, pl. 61, fig. 1-2
length 75-105 μm ; width 11-14 μm ; striae 9-12/10 μm

Ecology: Seems to prefer fresh water of low mineral content (Patrick and Reimer, 1966).
Remarks: Identified in the two earliest Diatom Zone 2 samples.

Pinnularia gibba Ehrenberg 1843

(Plate 5, Figure 6)

Krammer, 1992, p. 124, pl. 45, fig. 1-11
length 50-122 μm ; width 9.3-14(16) μm ; striae 8-10/10 μm

Ecology: Acidophilous, eutrophic to oligotrophic, springs and streams, periphytic, cosmopolitan, can live in oxygen poor water (Lowe, 1974).
Remarks: Present in all diatom zones. The most commonly identified *Pinnularia* species along with *Pinnularia viridis*.

Pinnularia gigas Ehrenberg 1843

(Plate 6, Figure 1)

Krammer, 1992, p. 154, pl. 64, fig. 1-5
length 160-320 μm ; width 30-50 μm ; striae 4-5/10 μm

Ecology: Cosmopolitan, oligotrophic, optimum under pH of 6 (Krammer, 1992).
Remarks: Commonly identified *Pinnularia* species in Diatom Zones 1 through 3.

Pinnularia legumen (Ehrenberg) Ehrenberg 1843

(Plate 7, Figure 1)

Patrick & Reimer, 1966, p. 608, pl. 57, fig. 2
length 60-130 μm ; width 15-23 μm ; striae 8-12/10 μm

Ecology: Seems to prefer water of low nutrient content (Patrick and Reimer, 1966).
Remarks: Identified in one Diatom Zone 1 sample (18,500 BP).

Pinnularia maior (Kützinger) Rabenhorst 1853

Patrick & Reimer, 1966, p. 629, pl. 61, fig. 4
length 140-200 μm ; width 25-40 μm ; striae 5-7/10 μm

Ecology: Widely distributed in water of fairly low mineral content (Patrick & Reimer, 1966).
Remarks: Identified in two Diatom Zone 4 samples (1000 BP and 750 BP).

Pinnularia mesolepta (Ehrenberg) W. Smith 1853

Patrick & Reimer, 1966, p. 600, pl. 55, fig. 17-18
length 30-65 μm ; width 9-12 μm ; striae 10-14/10 μm

Ecology: pH-indifferent to acidophilous, prefers water of low mineral content (Patrick & Reimer, 1966).
Remarks: Identified in Diatom Zones 3 and 5.

Pinnularia microstauron (Ehrenberg) Cleve 1891

(Plate 8, Figure 1)

Patrick & Reimer, 1966, p. 597, pl. 55, fig. 12
length 25-90 μm ; width 7-11 μm ; striae 10-13/10 μm

Ecology: Tolerates a wide range of pH and mineral content, but seems to prefer oligotrophic, slightly acid water (Patrick & Reimer, 1966).

Remarks: Present in Diatom Zones 2 through 5.

Pinnularia neomajor Krammer 1992

(Plate 7, Figure 2)

Krammer, 1992, p. 150, pl. 62, fig. 1-5
length 125-270 μm ; width 18-32 μm ; striae 6-8/10 μm

Ecology: Cosmopolitan, oligotrophic to dystrophic (Krammer, 1992).

Remarks: Present in Diatom Zones 2 through 4.

Pinnularia nobilis (Ehrenberg) Ehrenberg 1843

Patrick & Reimer, 1966, p. 638, pl. 64, fig. 2
length 200-350 μm ; width 34-50 μm ; striae 4-5/10 μm

Ecology: Seems to prefer slightly acid to circumneutral fresh water of low mineral content (Patrick & Reimer, 1966).

Remark: Identified in Diatom Zones 3 and 4.

Pinnularia nodosa (Ehrenberg) W. Smith 1856

(Plate 8, Figure 2)

Patrick & Reimer, 1966, p. 601, pl. 55, fig. 20-21
length 35-75 μm ; width 9-18 μm ; striae 7-11/10 μm

Ecology: Seems to prefer cool water and water of low mineral content although sometimes found in other types of water (Patrick & Reimer, 1966).

Remarks: Identified in Diatom Zones 2, 3, and 5.

Pinnularia rupestris Hantzsch 1861

(Plate 8, Figure 3)

Patrick & Reimer, 1966, p. 630, pl. 61, fig. 7
length 47-75 μm ; Width 8-10 μm ; striae 14-15/10 μm

Ecology: Seems to prefer cool water of low mineral content (Patrick & Reimer, 1966).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP).

Pinnularia streptoraphe Cleve 1891

(Plate 6, Figure 2)

Patrick & Reimer, 1966, p. 639, pl. 64, fig. 4
length 135-260 μm ; width 20-35 μm ; striae 5/10 μm

Ecology: Lakes, ponds, and bogs in water of low mineral content; seems to prefer acid water (Patrick & Reimer, 1966).

Remarks: Identified in Diatom Zones 2 through 4.

Pinnularia viridiformis Krammer 1992

Krammer, 1992, p. 160, pl. 69, fig. 1-5
length 80-165 μm ; width 14-22 μm ; striae 7-9/10 μm

Ecology: Oligotrophic, cosmopolitan (Krammer, 1992).

Remarks: Identified in two Diatom Zone 3 samples (9000 BP and 7000 BP).

Pinnularia viridis (Nitzsch) Ehrenberg 1843

(Plate 7, Figure 3)

Patrick & Reimer, 1966, p. 639, pl. 64, fig. 5
length 50-170 μm ; width 10-30 μm ; striae 6-9/10 μm

Ecology: pH-indifferent, periphytic, Spring and Fall maxima, cosmopolitan, found in water of higher mineral content than many of the species belonging to *Pinnularia* (Lowe, 1974).

Remarks: Present in all diatom zones. The most commonly identified *Pinnularia* species along with *Pinnularia gibba*.

Pinnularia viridoides Krammer, 1992

(Plate 8, Figure 4)

Krammer, 1992, p. 154, pl. 65, fig. 2
length 65-145 μm ; width 18-25 μm ; 7-10(11)/10 μm

Ecology: Cosmopolitan (Krammer, 1992).

Remarks: Identified in one Diatom Zone 3 sample (6000 BP).

Suborder DIPLONEIDINEAE Mann 1990

Family DIPLONEIDACEAE Mann 1990

Diploneis Ehrenberg ex Cleve 1894

Diploneis elliptica (Kützinger) Cleve 1891

(Plate 8, Figure 9)

Patrick & Reimer, 1966, p. 414, pl. 38, fig. 10
length 20-130 μm ; width 10-60 μm ; costae 8-14/10 μm ; alveoli 12-14/10 μm

Ecology: Alkaliphilous to pH-indifferent, periphytic, deep water form, cosmopolitan (Lowe, 1974). Found in bogs, lakes, and springs (Patrick & Reimer, 1966).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP).

Suborder NAVICULINEAE Hendey 1937

Family NAVICULACEAE Kützinger 1844

Navicula Bory 1822

Navicula americana Ehrenberg 1843

(Plate 8, Figure 7)

Patrick & Reimer, 1966, p. 493, pl. 47, fig. 3
length 30-120 μm ; width 10-30 μm ; striae 15-18/10 μm

Ecology: Alkaliphilous, periphytic, cosmopolitan (Lowe, 1974).

Remarks: Present in all diatom zones except Diatom Zone 5. Identified in all but 3 samples. Reaches highest abundance around the boundary of Diatom Zones 2 and 3, but never exceeds 4.30 percent of the total diatom valves counted.

Navicula exigua Gregory ex Grunow 1880

Patrick & Reimer, 1966, p. 522, pl. 49, fig. 23
length 17-30 μm ; width 9-12 μm ; striae 12-14/10 μm

Ecology: Alkaliphilous, periphytic, cosmopolitan (Lowe, 1974).
Remarks: Identified in one Diatom Zone 1 sample (15,000 BP).

Navicula explanata Hustedt 1948

Patrick & Reimer, 1966, p. 526, pl. 50, fig. 7
length 28-40 μm ; width 9-12 μm ; center striae 10/10 μm ; terminal striae 20/10 μm

Ecology: Insufficiently known.
Remarks: Identified in one Diatom Zone 1 sample (18,500 BP).

Navicula gregaria Donkin 1861

Patrick & Reimer, 1966, p. 467, pl. 44, fig. 6
length 15-35 μm ; width 5-9 μm ; striae 16-22/10 μm

Ecology: Prefers brackish water and fresh water with high mineral content (Patrick & Reimer, 1966).
Remarks: Identified in Diatom Zone 5.

Navicula ignota var. *acceptata* (Hustedt) Lange-Bertalot 1985

Krammer & Lange-Bertalot, 1986, p. 179, pl. 64, fig. 22-25
length 6-14 μm ; width 4-6 μm ; striae 13-18/10 μm

Ecology: Cosmopolitan (Krammer & Lange-Bertalot, 1986).
Remarks: Identified in one Diatom Zone 1 sample (15,000 BP).

Navicula ignota var. *palustris* (Hustedt) Lund 1948

Krammer & Lange-Bertalot, 1986, p. 179, pl. 64, fig. 16-21
length (10?) 16-24 μm ; width 4-6 μm ; striae 13-18/10 μm

Ecology: pH-indifferent, cosmopolitan (Foged, 1981).
Remarks: Identified in one Diatom Zone 1 sample (15,000 BP).

Navicula minima Grunow 1880

(Plate 8, Figure 5)

Patrick & Reimer, 1966, p. 488, pl. 46, fig. 17-18
length 6-17 μm ; width 2.5-5 μm ; striae 26/10 μm

Ecology: Alkaliphilous, eutrophic, periphytic especially among fallen leaves, cosmopolitan (Lowe, 1974).
Remarks: Identified in Diatom Zones 1 and 5.

Navicula mournei Patrick 1959

Patrick & Reimer, 1966, p. 461, pl. 43, fig. 5
length 20-30 μm ; width 5-9 μm ; striae 17-21/10 μm ; puncta 25-30/10 μm

Ecology: Fresh water, sometimes found in slightly brackish water (Patrick & Reimer, 1966).
Remarks: Identified in Diatom Zone 1 in all samples from 19,000 BP through 14,000 BP.

Navicula muralis Grunow 1880

Patrick & Reimer, 1966, p. 488, pl. 46, fig. 15
length 5-12 μm ; width 4-5 μm ; striae 30-36/10 μm

Ecology: Fresh water, often an aerophile (Patrick & Reimer, 1966).
Remarks: Identified in Diatom Zone 5.

Navicula oblonga (Kützing) Kützing 1844

Patrick & Reimer, 1966, p. 534, pl. 51, fig. 6
length 70-220 μm ; width 13-24 μm ; striae 6-9/10 μm

Ecology: Alkaliphilous, eutrophic, periphytic, cosmopolitan, seems to prefer water of high mineral content (Lowe, 1974).
Remarks: Identified in one Diatom Zone 1 sample (12,750 BP).

Navicula placenta Ehrenberg 1854

Patrick & Reimer, 1966, p. 462, pl. 43, fig. 8
length 35-44 μm ; width 14-17 μm ; striae 22-27/10 μm

Ecology: Fresh water, often associated with moss as an aerophile (Patrick & Reimer, 1966).
Remarks: Identified in one Diatom Zone 1 sample (18,500 BP).

Navicula protracta Grunow 1880

Patrick & Reimer, 1966, p. 471, pl. 45, fig. 3
length 17-55 μm ; width 5-10 μm ; center striae 12/10 μm ; terminal striae 24/10 μm

Ecology: Seems to prefer fresh water with high mineral content or slightly brackish water; often found in polluted water (Lowe, 1974).
Remarks: Identified in one Diatom Zone 1 sample (15,000 BP).

Navicula pseudoscutiformis Hustedt 1930

Patrick & Reimer, 1966, p. 451, pl. 41, fig. 4
length 8-25 μm ; width 7-17 μm ; striae 26/10 μm

Ecology: pH indifferent (Lowe, 1974). Oligohalobe to salinity indifferent, sometimes found in water of high mineral content; seems to prefer cool water (Patrick & Reimer, 1966).
Remarks: Present in Diatom Zone 1.

Navicula radiosa Kützing 1844

(Plate 8, Figure 6)

Patrick & Reimer, 1966, p. 509, pl. 48, fig. 15
length 40-120 μm ; width 10-19 μm ; striae 10-12/10 μm

Ecology: pH-indifferent, periphytic, cosmopolitan (Lowe, 1974).
Remarks: Identified in Diatom Zones 1, 3, and 5. Second most commonly identified diatom species in Diatom Zone 5 after *Eunotia bilunaris*.

Navicula rhyncocephala Kützing 1844

Patrick & Reimer, 1966, p. 505, pl. 48, fig. 6

length 35-60 μm ; width 10-13 μm ; central striae 8/10 μm ; terminal striae 12/10 μm

Ecology: Alkaliphilous, eutrophic, periphytic, Spring and Fall maxima, cosmopolitan, seems to prefer water of high mineral content (Lowe, 1974).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP).

Navicula viridula (Kützing) Kützing emend. Van Heurck 1880

(Plate 8, Figure 8)

Patrick & Reimer, 1966, p. 506, pl. 48, fig. 9

length 35-80 μm ; width 10-15 μm ; striae 8-10/10 μm

Ecology: Alkaliphilous, eutrophic, periphytic, Summer form, cosmopolitan (Lowe, 1974).

Remarks: Identified in two Diatom Zone 1 samples (18,500 BP and 12,750 BP).

Family PLEUROSIGMATACEAE Mereschkowsky 1903

Gyrosigma Hassall 1845

Gyrosigma acuminatum (Kützing) Rabenhorst 1853

Patrick & Reimer, 1966, p. 314, pl. 23, fig. 1-3

length 60-125 μm ; width 12-16 μm ; transverse striae 16-18/10 μm ;
longitudinal striae 17-20/10 μm

Ecology: Alkaliphilous, eutrophic, periphytic, Spring and Fall maxima, cosmopolitan (Lowe, 1974).

Remarks: Identified in most Diatom Zone 1 samples.

Family STAURONEIDACEAE Mann 1990

Stauroneis Ehrenberg 1843

Stauroneis anceps Ehrenberg 1843

(Plate 8, Figure 11)

Patrick & Reimer, 1966, p. 361, pl. 30, fig. 1

length 24-75 μm ; width 9-15 μm ; striae 20-25/10 μm ; puncta fine

Ecology: pH-indifferent, eutrophic to oligotrophic, periphytic, Spring and Fall maxima, cosmopolitan (Lowe, 1974).

Remarks: Identified in Diatom Zones 2 and 3.

Stauroneis anceps f. *gracilis* Rabenhorst 1864

(Plate 8, Figure 10)

Patrick & Reimer, 1966, p. 361, pl. 30, fig. 2

length 40-55 μm ; width 8-10 μm ; striae 26/10 μm

Ecology: Acidophilous to pH-indifferent, periphytic (Lowe, 1974).

Remarks: Identified in Diatom Zones 3 and 5. Differs from the nominate variety in its more elongate, elliptical-lanceolate valve with extremely narrowed capitate ends (Patrick & Reimer, 1966).

Stauroneis anceps f. *linearis* (Ehrenberg) Hustedt 1930

Patrick & Reimer, 1966, p. 362, pl. 30, fig. 3
length 24-75 μm ; width 9-15 μm ; striae 20-25/10 μm ; puncta fine

Ecology: A widespread eurytopic species, pH-indifferent (Patrick & Reimer, 1966).

Remarks: Identified in Diatom Zone 5. Distinguished from the nominate variety by valves with parallel sides and distinctly capitate ends (Patrick & Reimer, 1966).

Stauroneis fluminea Patrick & Freese 1961

Patrick & Reimer, 1966, p. 360, pl. 29, fig. 6
length 60-90 μm ; width 12-18 μm ; striae 18-24/10 μm

Ecology: So far found in soft, slightly acid to neutral waters (Patrick & Reimer, 1966).

Remarks: Identified in one Diatom Zone 3 sample (9000 BP).

Stauroneis kriegei Patrick 1945

(Plate 8, Figure 12)

Patrick & Reimer, 1966, p. 362, pl. 30, fig. 5
length 20-23 μm ; width 4-6 μm ; striae 26/10 μm

Ecology: Appears to be pH-indifferent, oligohalob; more characteristic of headwater areas (Patrick & Reimer, 1966).

Remarks: Identified in Diatom Zones 3 and 5.

Stauroneis phoenicenteron (Nitzsch) Ehrenberg 1843

(Plate 9, Figure 1)

Patrick & Reimer, 1966, p. 359, pl. 29, fig. 1-2
length 70-380 μm ; width 16-53 μm ; striae 12-17/10 μm

Ecology: pH-indifferent, eutrophic to oligotrophic, periphytic, cosmopolitan, apparently has a wide range of ecological tolerance (Lowe, 1974).

Remarks: Present in all diatom zones and all samples. One of the most common diatom species in Anderson Pond, with an abundance of over 3 percent of the total diatom valves counted in all samples in Diatom Zones 2 through 4. Reaches greatest abundance in Diatom Zone 2.

Craticula Grunow 1868

Craticula ambigua (Ehrenberg) Mann in Round, Crawford, and Mann 1990

Patrick & Reimer, 1966, p. 464, pl. 43, fig. 10
length 30-120 μm ; width 15-25 μm ; transverse striae 14-24/10 μm ;
longitudinal lines 22-26/10 μm

Ecology: Tolerant of a wide range of fresh water conditions (Patrick & Reimer, 1966).

Remarks: Identified in Diatom Zones 1, 2, and 4.

Craticula cuspidata (Kützing) Mann in Round, Crawford, and Mann 1990

(Plate 9, Figure 2).

Patrick & Reimer, 1966, p. 464, pl.43, fig. 9

length 30-120 μm ; width 15-25 μm ; transverse striae 14-24/10 μm ;

longitudinal lines 22-26/10 μm

Ecology: Tolerant of a wide range of fresh water conditions (Patrick & Reimer, 1966).

Remarks: Identified in Diatom Zone 1. May also present in Diatom Zone 2, but valves of this genus are badly broken and often not identifiable to species.

Order THALASSIOPHYSALES Mann 1990

Family CATENULACEAE Mereschkowsky 1902

Amphora Ehrenberg ex Kützing 1844

Amphora ovalis (Kützing) Kützing 1844

Patrick & Reimer, 1975, p. 68, pl. 13, fig. 1-2

length 35-85 μm ; valve width 9-17 μm ; frustule width 18-38 μm ; striae 10-12/10 μm

Ecology: Alkaliphilous, periphytic, comopolitan (Lowe, 1974). Seems to be characteristic of standing or slowly flowing waters (Patrick & Reimer, 1975).

Remarks: Identified in Diatom Zones 2 through 4.

Amphora ovalis var. *affinis* (Kützing) Van Heurck 1885

(Plate 9, Figure 3)

Patrick & Reimer, 1975, p. 69, pl. 13, fig. 3-4

length 28-80 μm ; valve width 7-12 μm ; frustule width 16-35 μm ;

central striae 11-12/10 μm ; apical striae 13-15/10 μm

Ecology: As the nominate variety (Patrick & Reimer, 1975).

Remarks: Present in Diatom Zones 1 through 4. Identified in all but five samples.

Order BACILLARIALES Hendey 1837

Family BACILLARIACEAE Ehrenberg 1831

Hantzschia Grunow 1877

Hantzschia amphioxys (Ehrenberg) Grunow in Cleve & Grunow 1880

(Plate 9, Figure 7)

Krammer & Lange-Bertalot, 1997, p. 128, pl. 88, fig. 1-7

length 20-210(300) μm ; width 5-15(25) μm ; striae 11-28/10 μm ; fibulae 4-11/10 μm

Ecology: Alkaliphilous, may be aerophilous, periphytic, spring maximum, very broad ecological tolerance (Lowe, 1974).

Remarks: Identified in Diatom Zones 1 and 3.

Hantzschia elongata (Hantzsch) Grunow 1880

Krammer & Lange-Bertalot, 1997, p. 128, pl. 89, fig. 1-2a

length 230-430 μm , width 10-14 μm , striae 12-19/10 μm , fibulae 7-8(10)/10 μm

Ecology: Cosmopolitan, low conductivity water (Krammer & Lange-Bertalot, 1997).

Remarks: Identified in Diatom Zones 2 and 3.

Nitzschia Hassall 1845

Nitzschia filiformis (W. Smith) Van Heurck 1896

Krammer & Lange-Bertalot, 1997, p. 27, pl. 19, fig. 7-13
length 20-100 μm ; width 4-6 μm ; striae 27-36/10 μm ; fibulae 7-11/10 μm

Ecology: pH-indifferent, cosmopolitan, not fully autotrophic (Lowe, 1975).

Remarks: Identified in one Diatom Zone 3 sample (4000 BP).

Nitzschia frustulum (Kützting) Grunow in Cleve & Grunow 1880

Krammer & Lange-Bertalot, 1997, p. 94, pl. 68, fig. 1-19
length 5-60 μm , width 2-4.5 μm , striae 19-30/10 μm , fibulae 10-16/10 μm

Ecology: Alkaliphilous, eutrophic, cosmopolitan, obligate nitrogen heterotroph, euplanktonic, tycho planktonic, and periphytic (Lowe, 1974).

Remarks: Identified in one Diatom Zone 3 sample (9000 BP).

Nitzschia linearis (Agardh) W. Smith 1853

Krammer & Lange-Bertalot, 1997, p. 69, pl. 55, fig. 1-10
length 34-228 μm ; width 2.5-7.5 μm ; striae 28-41/10 μm ; fibulae 8-17/10 μm

Ecology: Alkaliphilous, eutrophic, found in springs and streams, living only in oxygen rich water (Lowe, 1974).

Remarks: Identified at low abundance in Diatom Zones 1 through 4.

Nitzschia palea (Kützting) W. Smith 1856

(Plate 9, Figure 8)

Krammer & Lange-Bertalot, 1997, p. 85, pl. 59, fig. 1-24
length 15-70 μm ; width 2.5-5 μm ; striae 28-40/10 μm ; fibulae 9-17/10 μm

Ecology: pH-indifferent, eutrophic, tycho planktonic or periphytic, spring, summer, and fall maxima, very good indicator of pollution, obligate nitrogen heterotroph, wide ecological tolerance (Lowe, 1974)

Remarks: Present in Diatom Zone 5.

Nitzschia sinuata var. *delognei* (Grunow) Lange-Bertalot 1980

Krammer & Lange-Bertalot, 1997, p. 52, pl. 40, fig. 7-8
length 10-50 μm ; width 3-8 μm ; striae 18-25/10 μm ; fibulae 5-8/10 μm

Ecology: Alkaliphilous; found in water with high oxygen concentration (Lowe, 1974).

Remarks: Identified in Diatom Zones 1 and 2.

Denticula Kützting 1844

Denticula lauta J. W. Bailey 1854

Patrick & Reimer, 1975, p. 171, pl. 22, fig. 6-9
length 18-67 μm ; width 5-10 μm ; striae 20/10 μm ; long costae 2-4/10 μm ;
short costae 3-4/10 μm

Ecology: Data are limited but this taxon seems to prefer water of high conductivity (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (14,000 BP).

Order RHOPALODIALES Mann 1990

Family RHOPALODIACEAE (Karsten) Topachevs'kyj & Oksiyuk 1960

Epithemia Kützing 1844

Epithemia adnata var. *proboscidea* (Kützing) Patrick in Patrick & Reimer 1975

(Plate 9, Figure 4)

Patrick & Reimer, 1975, p. 181, pl. 24, fig. 5

length 40-50 μm ; width 8-10 μm ; costae 2.5-4/10 μm ; alveoli 11-12/10 μm ,
in rows 11-14/10 μm , rows 3-7 between costae

Ecology: Seems to prefer alkaline water in littoral; epiphytic on aquatic plants (Patrick & Reimer, 1975).

Remarks: Identified in two Diatom Zone 1 samples (18,500 BP and 14,000 BP).

Epithemia turgida (Ehrenberg) Kützing 1844

(Plate 9, Figure 5)

Patrick & Reimer, 1975, p. 182, pl. 25, fig. 1a-b

length 60-150 μm ; width 15-20 μm ; costae 3-5/10 μm ; alveoli in rows,
rows 7-9/10 μm , 2-3 rows between costae

Ecology: Alkalibiontic to alkaliphilous, periphytic, cosmopolitan (Lowe, 1974). A littoral species which prefers alkaline water (Patrick & Reimer, 1975).

Remarks: Identified in two Diatom Zone 1 samples (18,500 BP and 15,000 BP).

Epithemia turgida var. *granulata* (Ehrenberg) Brun 1880

Patrick & Reimer, 1975, p. 183, pl. 25, fig. 3

length 130-200 μm ; width 13-20 μm ; costae 3-4(5)/10 μm ; alveoli 8-10/10 μm ,
in rows 7-10/10 μm , 2-3 rows between costae

Ecology: Prefers alkaline water (Patrick & Reimer).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP).

Epithemia turgida var. *westermanni* (Ehrenberg) Grunow 1862

(Plate 9, Figure 6)

Patrick & Reimer, 1975, p. 184, pl. 25, fig. 2a-b

length 40-120 μm ; width 16-34 μm ; costae 3-5/10 μm ; alveoli in rows,
rows 8/10 μm , 2-3 rows between costae

Ecology: Fresh water (Patrick & Reimer, 1975).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP).

Order SURIRELLALES Mann 1990

Family SURIRELLACEAE Kützing 1844

Surirella Turpin 1828

Surirella bifrons Ehrenberg 1843

Krammer & Lange-Bertalot, 1997, p. 196, pl. 147, fig. 1-5

length 76-150 μm ; width 30-60 μm ; wing canals 12-22/10 μm

Ecology: Cosmopolitan, oligotrophic (Krammer & Lange-Bertalot, 1997).

Remarks: Identified in one Diatom Zone 1 sample (18,500 BP).

Surirella brebissonii Krammer & Lange-Bertalot 1987

Krammer & Lange-Bertalot, 1997, p. 179, pl. 126, fig. 2-11
length 8-70 μm ; width 8-30 μm ; striae (16)17-19(20)/10 μm ;
wing canals and costae 3.5-6(7)/10 μm

Ecology: Alkaliphilous, winter maximum (Lowe, 1974).

Remarks: Identified in Diatom Zones 1 through 4.

Surirella linearis W. Smith 1853

Krammer & Lange-Bertalot, 1997, p. 198, pl. 149, fig. 1-9
length 20-120 μm ; width 9-25 μm ; wing canals 2-3/10 μm

Ecology: Cosmopolitan (Krammer & Lange-Bertalot, 1997).

Remarks: Identified in Diatom Zone 4.

Surirella ovalis Brebisson 1838

Krammer & Lange-Bertalot, 1997, p. 178, pl. 125, fig. 1-7
length 16-120 μm ; width 12-45 μm ; striae (16)17-19/10 μm ; wing canals 1.5-4.5/10 μm

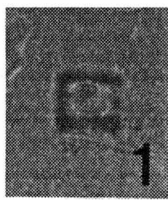
Ecology: Alkaliphilous (Lowe, 1974).

Remarks: Identified in Diatom Zones 1 and 2.

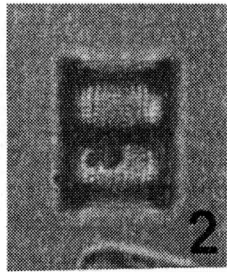
Appendix B. Photographic plates of diatom taxa.

PLATE 1

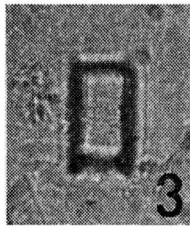
- Fig. 1. *Aulacoseira ambigua*
Fig. 2. *Aulacoseira distans*
Fig. 3. *Aulacoseira herzogii*
Fig. 4. *Aulacoseira lirata* f. *biseriata*
Fig. 5. *Aulacoseira nygaardii*
Fig. 6. *Fragilaria brevistriata*
Fig. 7. *Fragilaria construens*
Fig. 8. *Fragilaria leptostauron*
Fig. 9. *Fragilaria pinnata*
Fig. 10. *Synedra rumpens*
Fig. 11. *Tabellaria fenestrata*
Fig. 12. *Tabellaria flocculosa*
Fig. 13. *Eunotia bilunaris*
Fig. 14. *Eunotia diodon*
Fig. 15. *Eunotia implicata*
Fig. 16. *Eunotia formica*



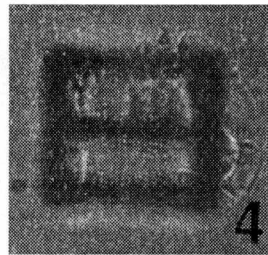
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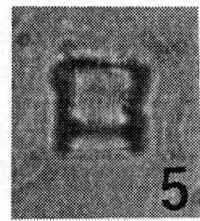
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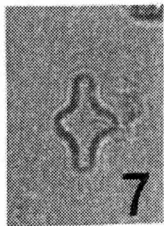
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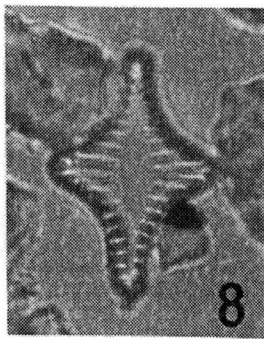
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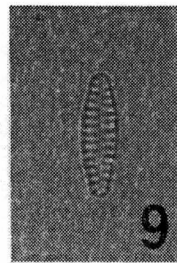
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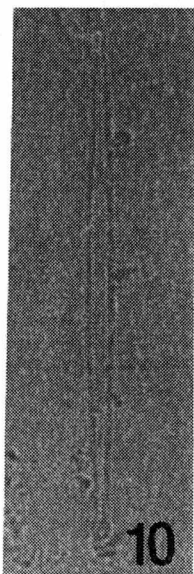
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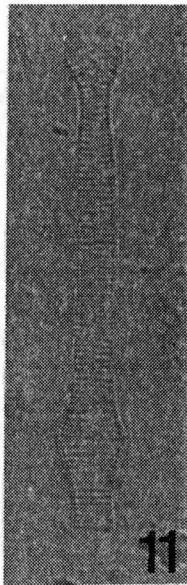
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9



10

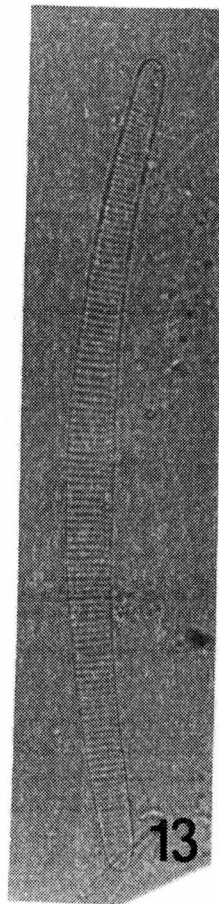


11

10 μm



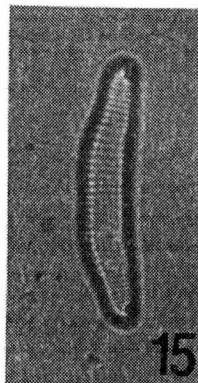
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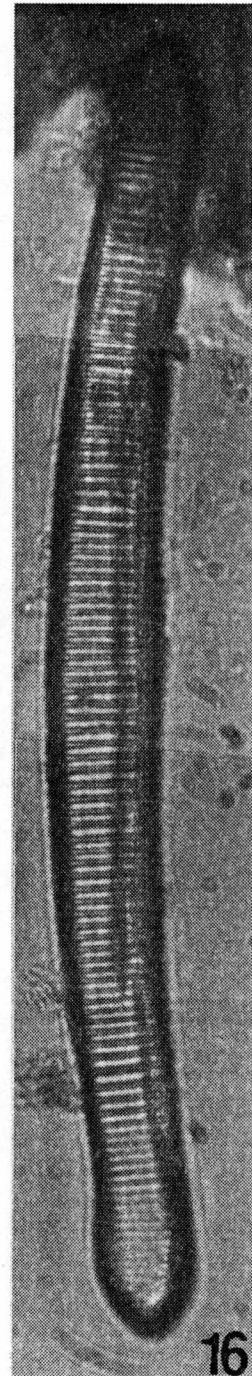
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14



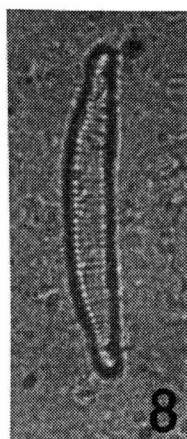
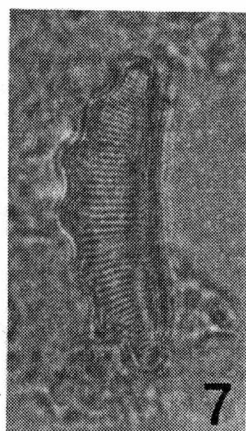
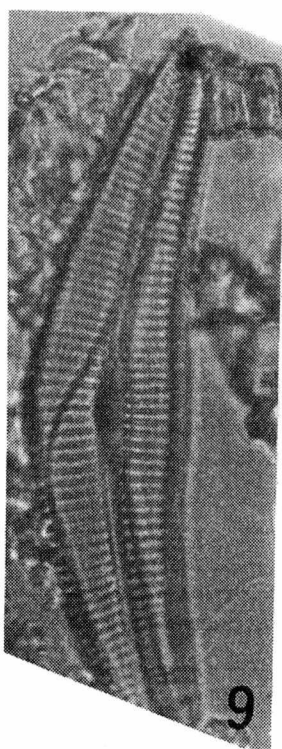
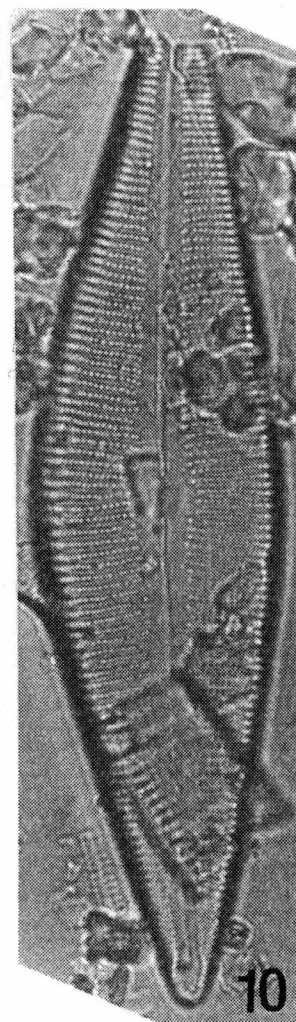
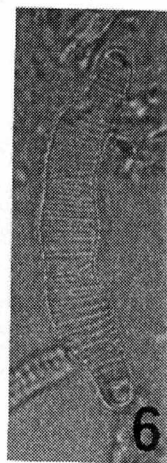
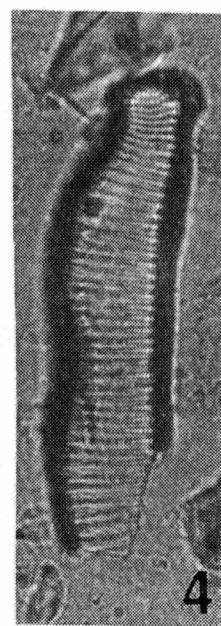
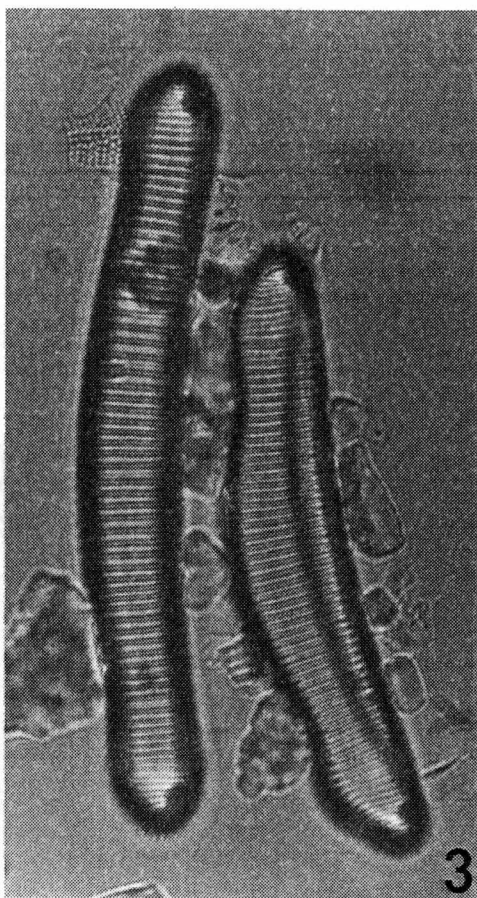
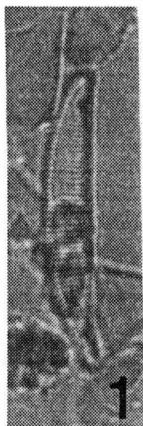
15



16

PLATE 2

- Fig. 1. *Eunotia incisa*
Fig. 2. *Eunotia minor*
Fig. 3. *Eunotia monodon*
Fig. 4. *Eunotia praerupta* var. *bidens*
Fig. 5. *Eunotia rhomboidea*
Fig. 6. *Eunotia rostellata*
Fig. 7. *Eunotia serra*
Fig. 8. *Eunotia veneris*
Fig. 9. *Cymbella cistula*
Fig. 10. *Cymbella acutiuscula*

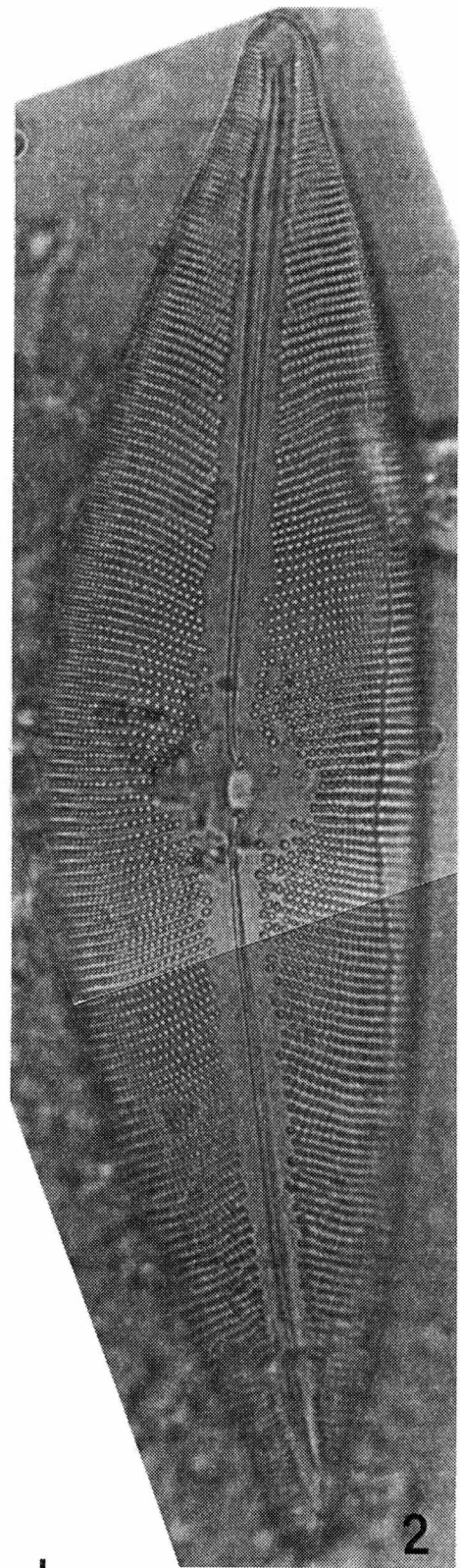
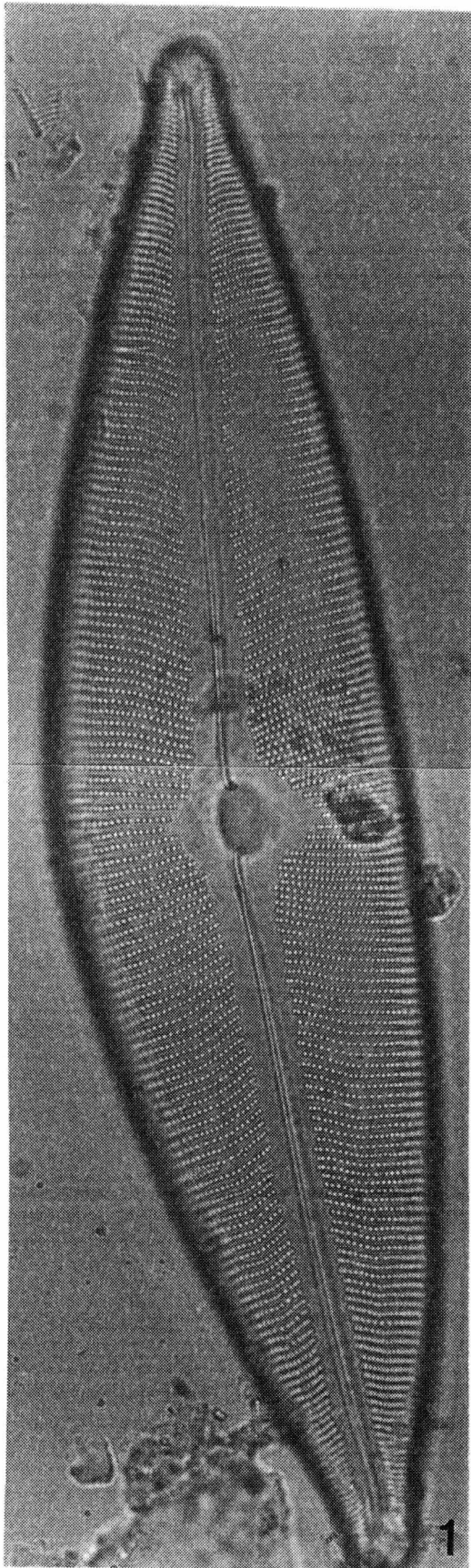


10 μm

PLATE 3

Fig. 1. *Cymbella cuspidata*

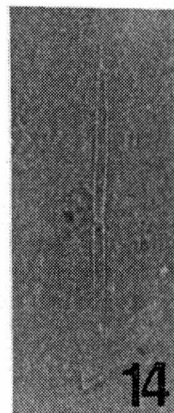
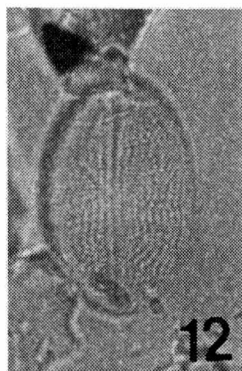
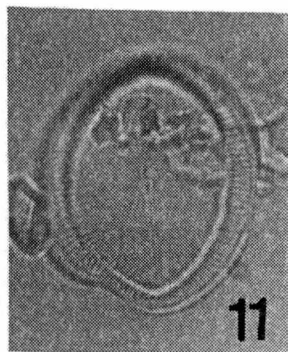
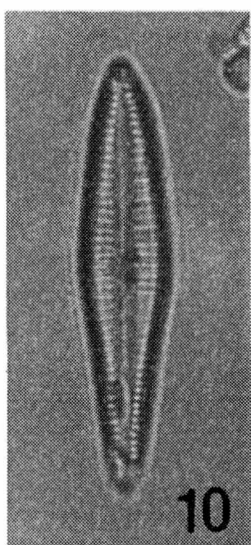
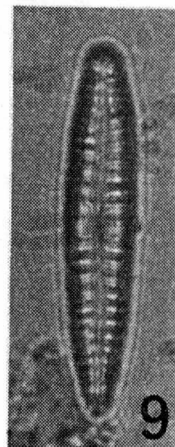
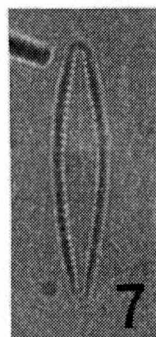
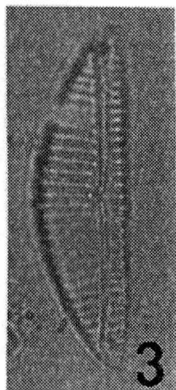
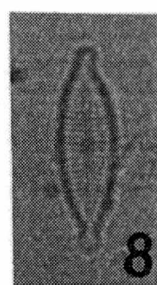
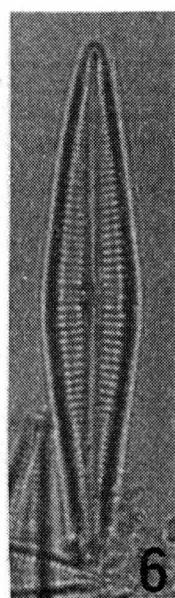
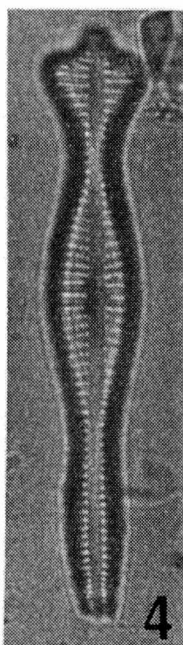
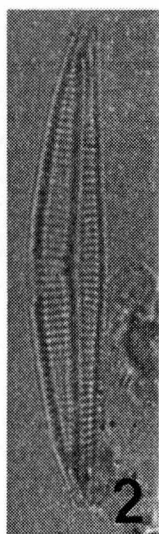
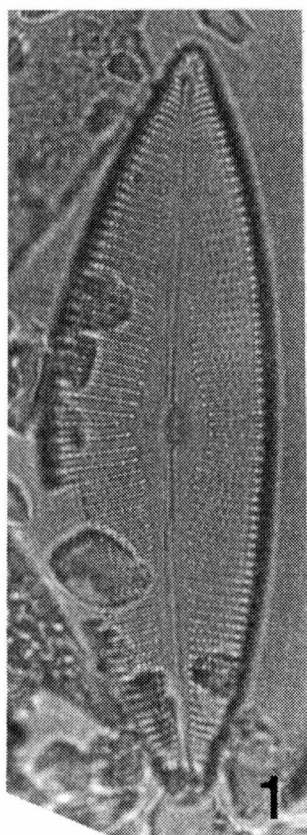
Fig. 2. *Cymbella heteropleura* var. *subrostrata*



10 μ m

PLATE 4

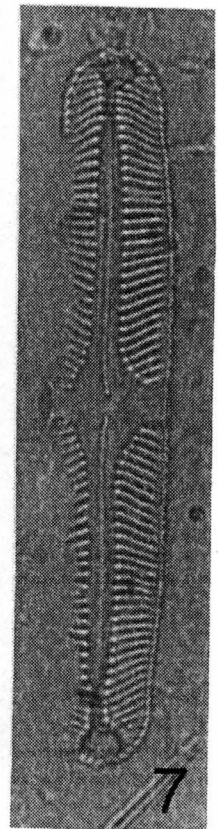
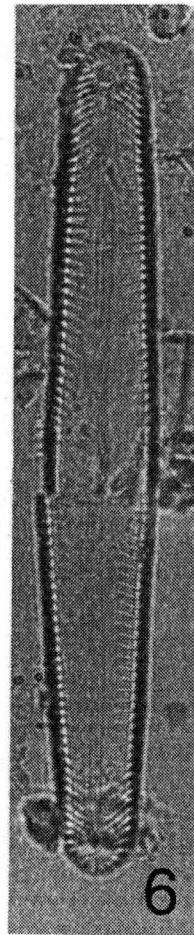
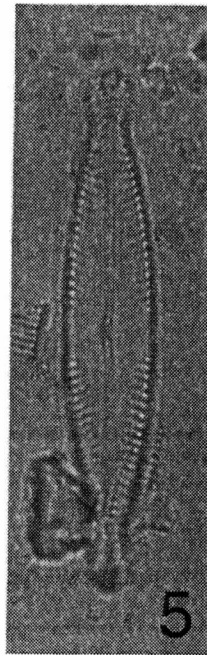
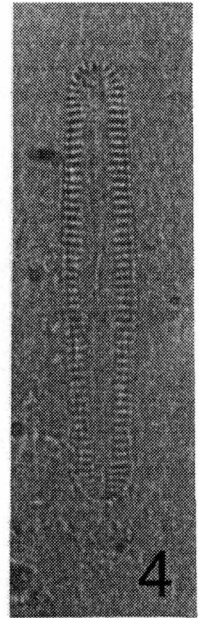
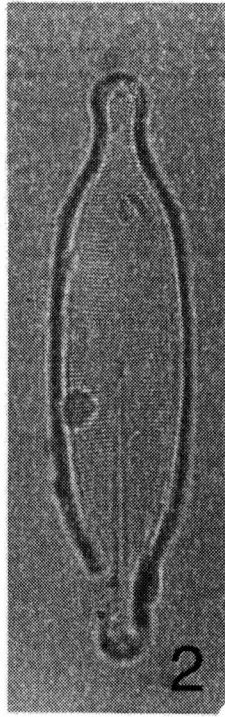
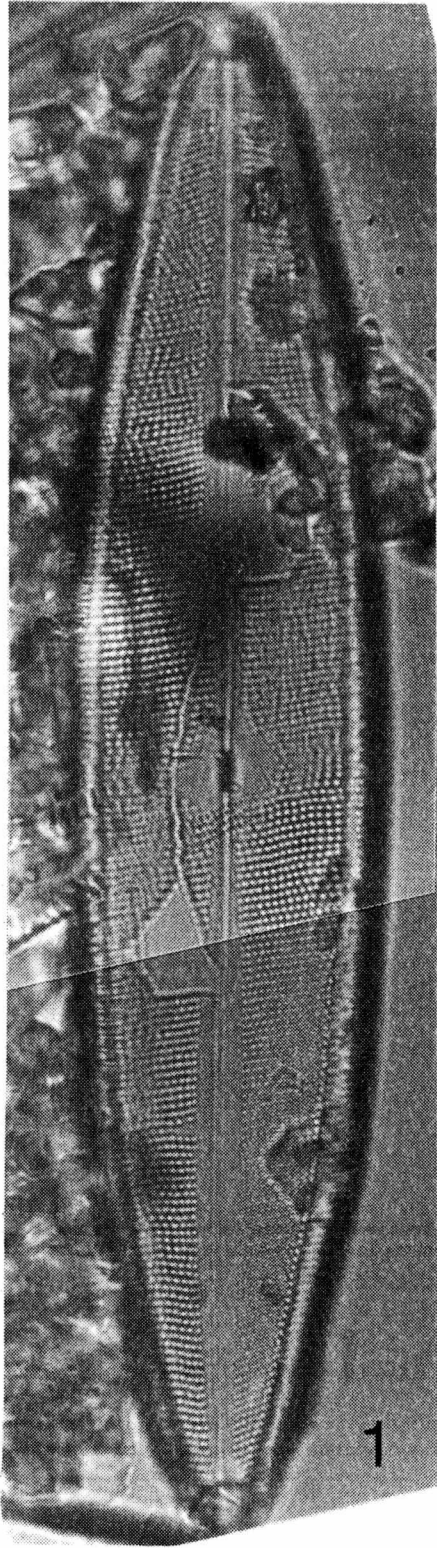
- Fig. 1. *Cymbella hauckii*
- Fig. 2. *Encyonema lunatum*
- Fig. 3. *Encyonema silesiacum*
- Fig. 4. *Gomphonema acuminatum*
- Fig. 5. *Gomphonema angustatum*
- Fig. 6. *Gomphonema gracile*
- Fig. 7. *Gomphonema grunowii*
- Fig. 8. *Gomphonema parvulum*
- Fig. 9. *Gomphonema sarcophagus*
- Fig. 10. *Gomphonema turris*
- Fig. 11-12. *Cocconeis placentula* var. *lineata*
11. Raphid valve.
12. Araphid valve.
- Fig. 13. *Luticola mutica*
- Fig. 14. *Frustulia rhomboides*



10 μm

PLATE 5

- Fig. 1. *Neidium iridis*
- Fig. 2. *Neidium affine*
- Fig. 3. *Sellaphora pupula* var. *rectangularis*
- Fig. 4. *Pinnularia acrosphaeria*
- Fig. 5. *Pinnularia braunii*
- Fig. 6. *Pinnularia gibba*
- Fig. 7. *Pinnularia divergens*

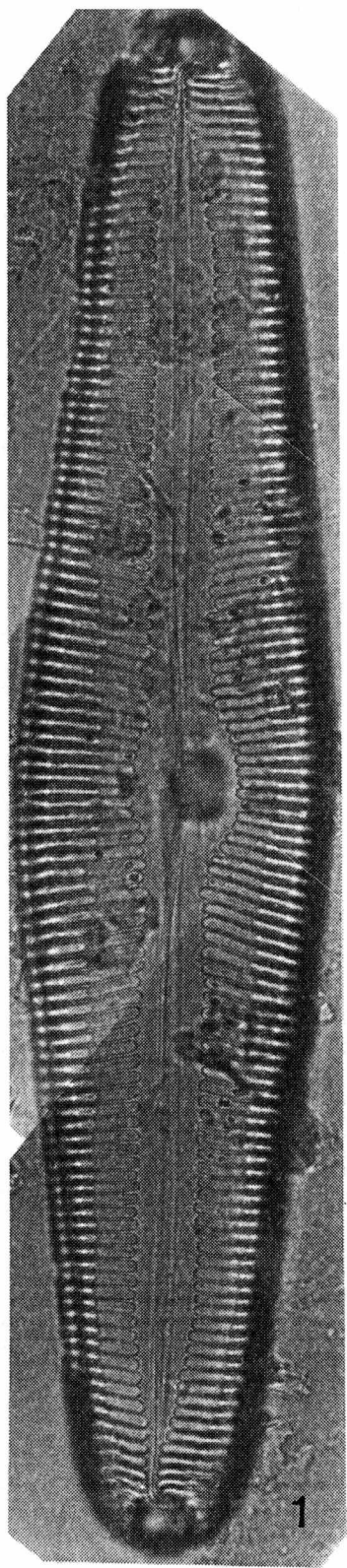


10 μ m

PLATE 6

Fig. 1. *Pinnularia gigas*

Fig. 2. *Pinnularia streptoraphe*



10 μ m

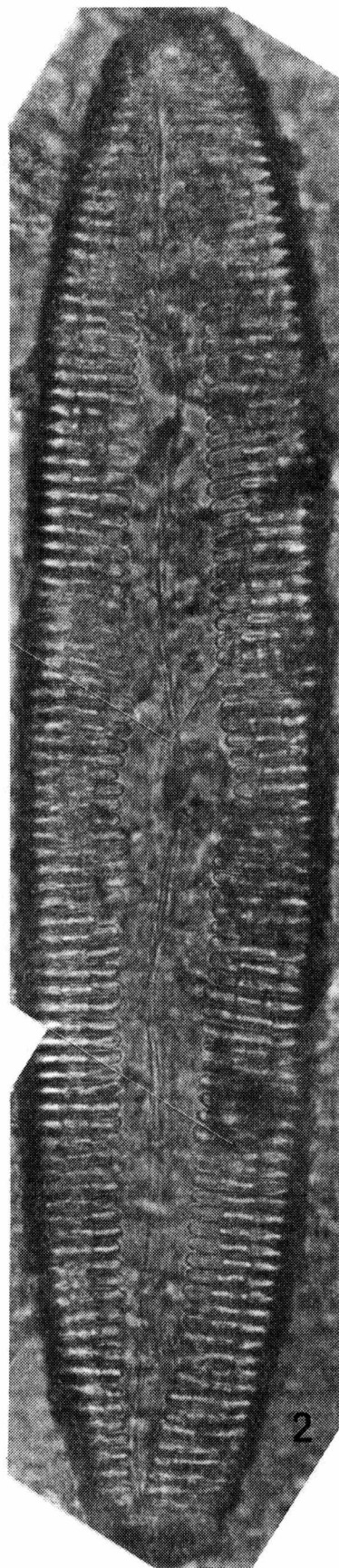
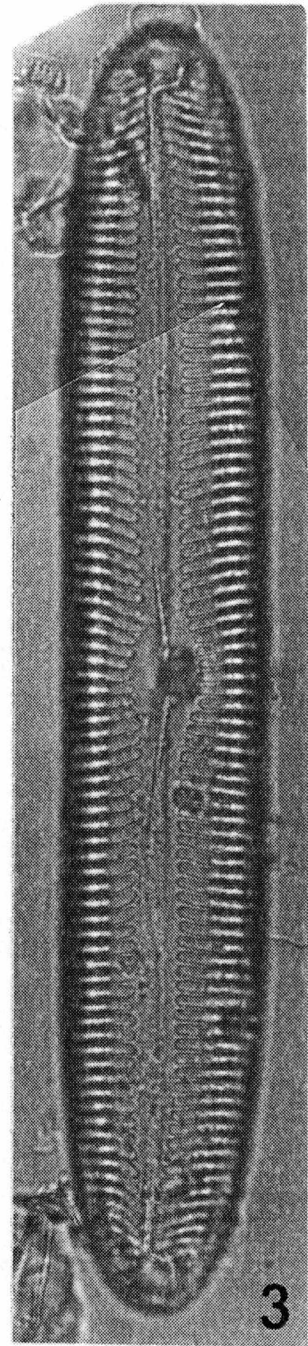
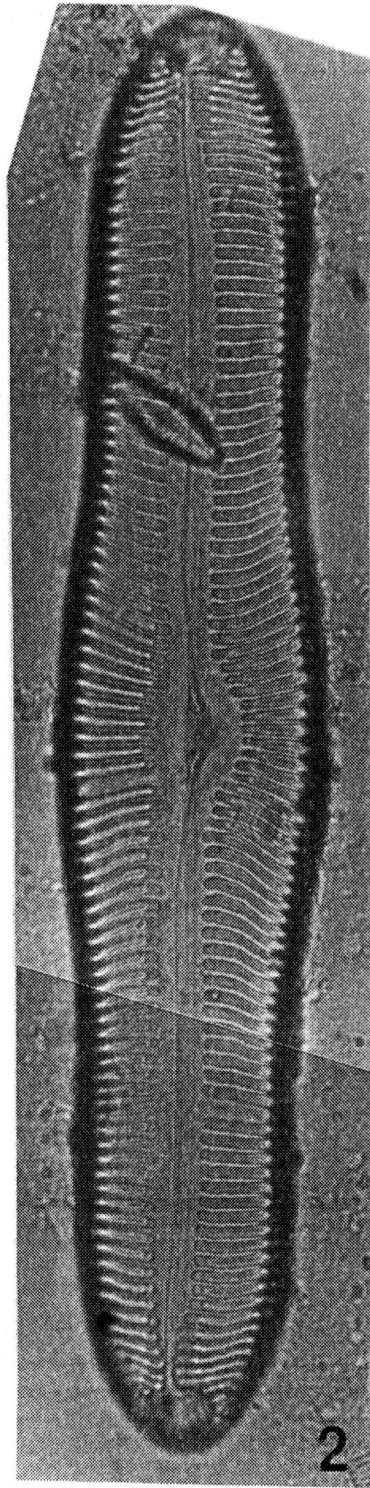
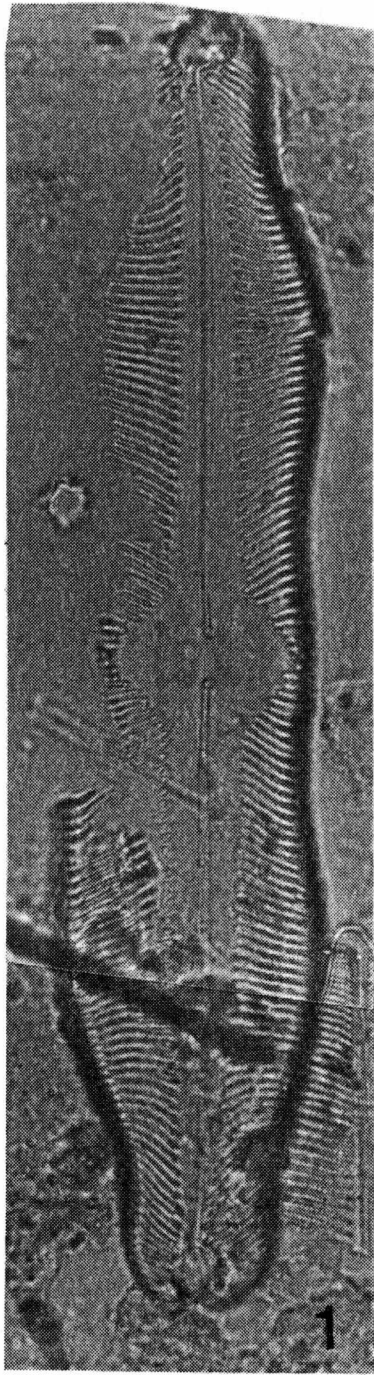


PLATE 7

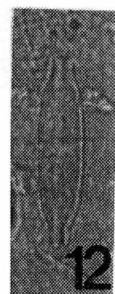
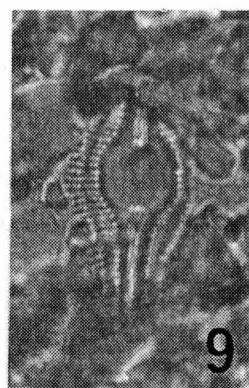
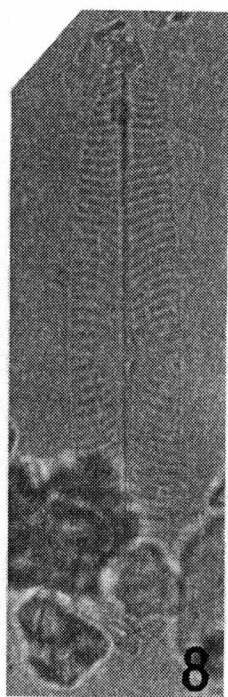
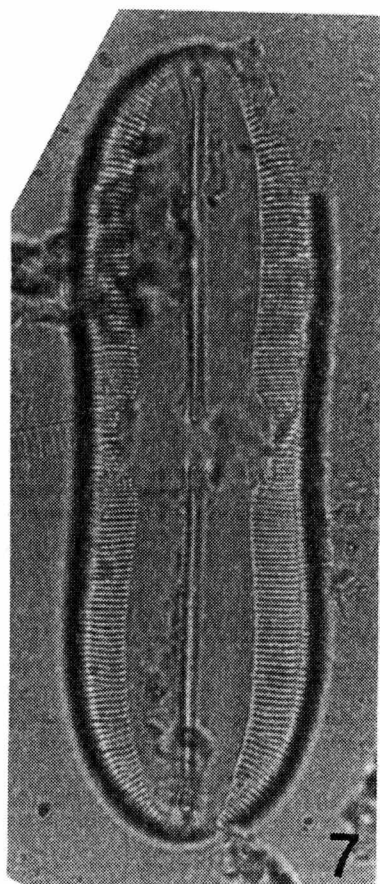
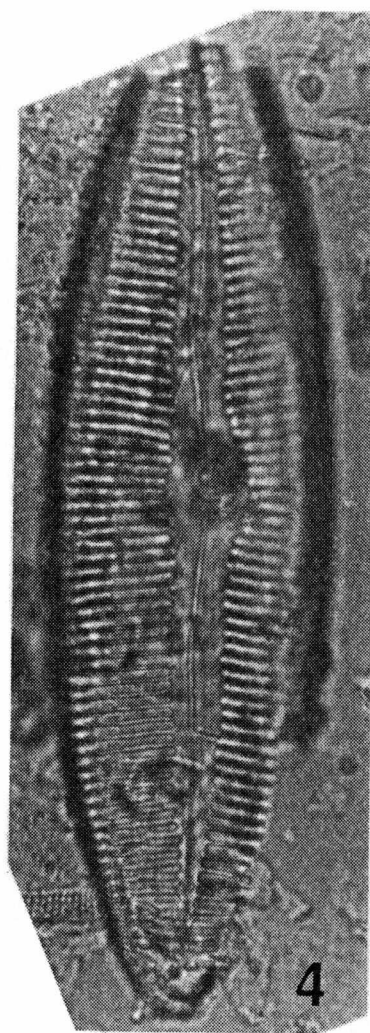
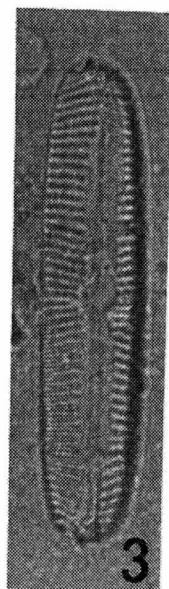
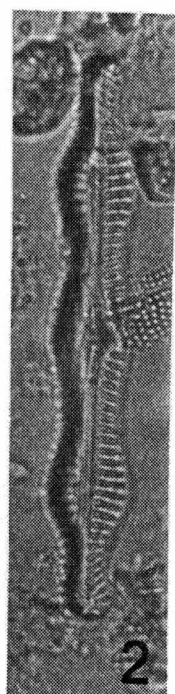
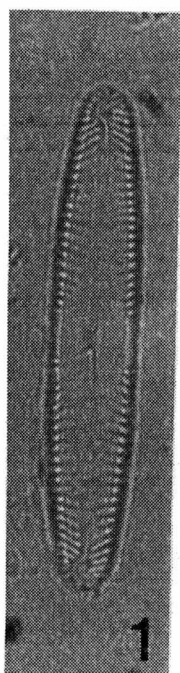
- Fig. 1. *Pinnularia legumen*
Fig. 2. *Pinnularia neomajor*
Fig. 3. *Pinnularia viridis*



10 μ m

PLATE 8

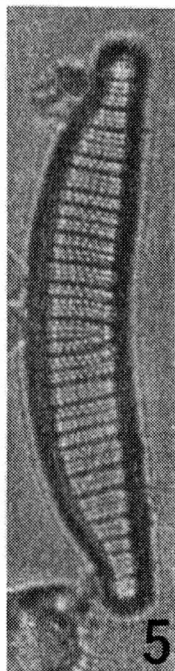
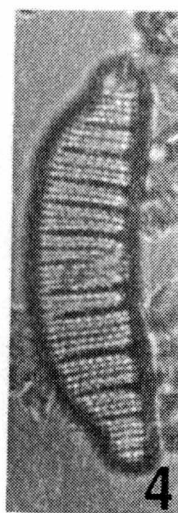
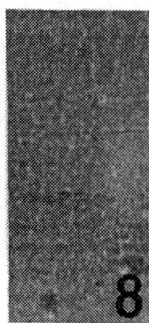
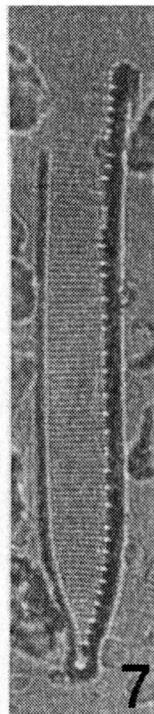
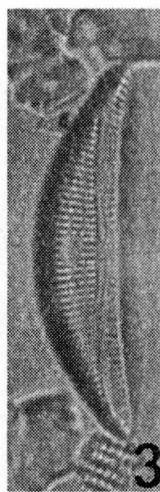
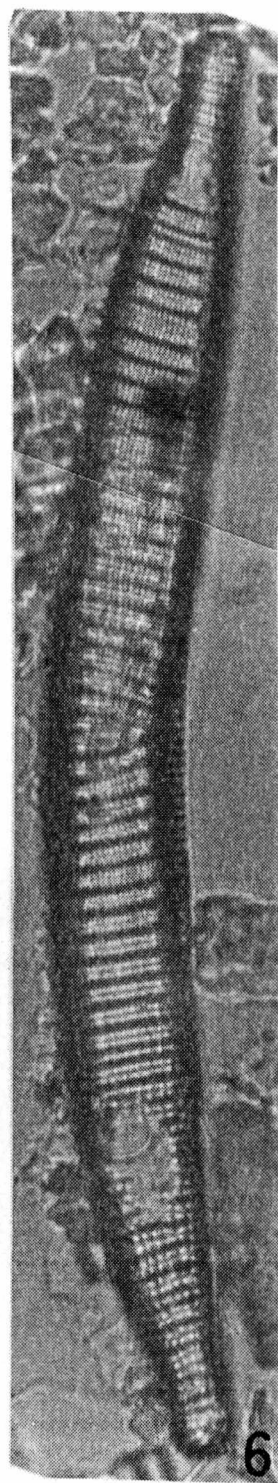
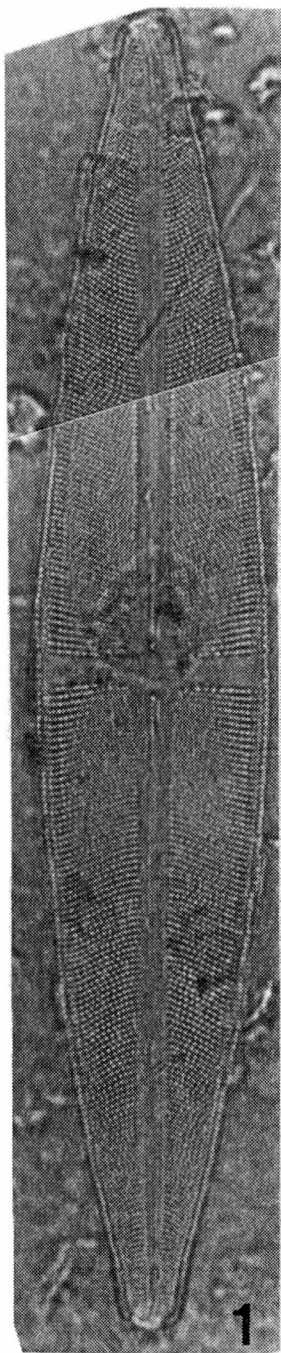
- Fig. 1. *Pinnularia microstauron*
Fig. 2. *Pinnularia nodosa*
Fig. 3. *Pinnularia rupestris*
Fig. 4. *Pinnularia viridoides*
Fig. 5. *Navicula minima*
Fig. 6. *Navicula radiosa*
Fig. 7. *Navicula americana*
Fig. 8. *Navicula viridula*
Fig. 9. *Diploneis elliptica*
Fig. 10. *Stauroneis anceps*. f. *gracilis*
Fig. 11. *Stauroneis anceps*
Fig. 12. *Stauroneis kriegeri*



10 μm

PLATE 9

- Fig. 1. *Stauroneis phoenicenteron*
- Fig. 2. *Craticula cuspidata*
- Fig. 3. *Amphora ovalis* var. *affinis*
- Fig. 4. *Epithemia adnata* var. *proboscidea*
- Fig. 5. *Epithemia turgida*
- Fig. 6. *Epithemia turgida* var. *westermanni*
- Fig. 7. *Hantzschia amphioxys*
- Fig. 8. *Nitzschia palea*



└──┘
10 μ m

Appendix C. Fossil-diatom data, arranged by increasing core depth (cm below mud-water surface, cm bms) and by radiocarbon age (radiocarbon years before present, BP).

Depth 0-5 cm bms Age 0 BP (Surface Sample)	Total No. Valves	Diatom Percent
<i>Aulacoseira</i> undifferentiated	1	0.2
<i>Encyonema silesiacum</i>	3	0.6
<i>Eunotia bilunaris</i>	88	17.6
<i>Eunotia diodon</i>	1	0.2
<i>Eunotia implicata</i>	1	0.2
<i>Eunotia minor</i>	1	0.2
<i>Eunotia monodon</i>	4	0.8
<i>Eunotia veneris</i>	1	0.2
<i>Eunotia</i> undifferentiated	4	0.8
<i>Gomphonema acuminatum</i>	1	0.2
<i>Gomphonema angustatum</i>	44	8.8
<i>Gomphonema gracile</i>	36	7.2
<i>Gomphonema grunowii</i>	6	1.2
<i>Gomphonema parvulum</i>	13	2.6
<i>Gomphonema</i> undifferentiated	53	10.6
<i>Luticola mutica</i>	1	0.2
<i>Navicula gregaria</i>	1	0.2
<i>Navicula minima</i>	7	1.4
<i>Navicula muralis</i>	1	0.2
<i>Navicula radiosa</i>	74	14.8
<i>Navicula</i> undifferentiated	17	3.4
<i>Nitzschia palea</i>	12	2.4
<i>Nitzschia</i> undifferentiated	9	1.8
<i>Pinnularia acrosphaeria</i>	3	0.6
<i>Pinnularia gibba</i>	2	0.4
<i>Pinnularia mesolepta</i>	1	0.2
<i>Pinnularia microstauron</i>	7	1.4
<i>Pinnularia nodosa</i>	1	0.2
<i>Pinnularia viridis</i>	1	0.2
<i>Pinnularia</i> undifferentiated	10	2.0
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	15	3.0
<i>Stauroneis anceps</i> f. <i>gracilis</i>	10	2.0
<i>Stauroneis anceps</i> f. <i>linearis</i>	4	0.8
<i>Stauroneis kriegeri</i>	19	3.8
<i>Stauroneis phoenicenteron</i>	6	1.2
<i>Stauroneis</i> undifferentiated	2	0.4
<i>Synedra radians</i>	16	3.2
<i>Synedra rumpens</i>	8	1.6
<i>Synedra</i> undifferentiated	8	1.6
Undifferentiated valves	8	1.6
Total Diatoms	500	
Chrysophyte Cysts	17	
Chrysophyte:Diatom Ratio	0.03	

Depth 37.5 cm bms Age 250 BP	Total No. Valves	Diatom Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	9	1.8
<i>Aulacoseira distans</i>	113	22.2
<i>Aulacoseira herzogii</i>	18	3.5
<i>Aulacoseira lirata</i> f. <i>biseriata</i>	40	7.8
<i>Aulacoseira nygaardii</i>	38	7.5
<i>Aulacoseira undifferentiated</i>	39	7.6
<i>Cymbella cuspidata</i>	7	1.4
<i>Encyonema undifferentiated</i>	1	0.2
<i>Eunotia bilunaris</i>	58	11.4
<i>Eunotia implicata</i>	3	0.6
<i>Eunotia incisa</i>	4	0.8
<i>Eunotia minor</i>	9	1.8
<i>Eunotia monodon</i>	21	4.1
<i>Eunotia undifferentiated</i>	15	2.9
<i>Gomphonema gracile</i>	6	1.2
<i>Gomphonema parvulum</i>	4	0.8
<i>Gomphonema undifferentiated</i>	26	5.1
<i>Hantzschia undifferentiated</i>	2	0.4
<i>Navicula americana</i>	2	0.4
<i>Neidium iridis</i>	6	1.2
<i>Pinnularia gibba</i>	1	0.2
<i>Pinnularia undifferentiated</i>	19	3.7
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	5	1.0
<i>Sellaphora pupula</i> var. <i>undifferent.</i>	3	0.6
<i>Stauroneis phoenicenteron</i>	46	9.0
<i>Stauroneis undifferentiated</i>	2	0.4
<i>Surirella undifferentiated</i>	2	0.4
Undifferentiated valves	11	2.2
Total Diatoms	510	
Chrysophyte Cysts	158	
Chrysophyte:Diatom Ratio	0.31	

41.6 cm	Total No.	Diatoms
750 BP	Valves	Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	12	2.4
<i>Aulacoseira distans</i>	116	22.9
<i>Aulacoseira herzogii</i>	30	5.9
<i>Aulacoseira lirata</i> f. <i>biseriata</i>	28	5.5
<i>Aulacoseira nygaardii</i>	22	4.3
<i>Aulacoseira</i> undifferentiated	52	10.3
<i>Craticula ambigua</i>	1	0.2
<i>Cymbella cuspidata</i>	3	0.6
<i>Cymbella naviculiformis</i>	1	0.2
<i>Cymbella subcuspidata</i>	6	1.2
<i>Eunotia arcus</i>	2	0.4
<i>Eunotia bilunaris</i>	26	5.1
<i>Eunotia diodon</i>	2	0.4
<i>Eunotia flexuosa</i>	2	0.4
<i>Eunotia implicata</i>	2	0.4
<i>Eunotia incisa</i>	6	1.2
<i>Eunotia minor</i>	9	1.8
<i>Eunotia monodon</i>	14	2.8
<i>Gomphonema gracile</i>	11	2.2
<i>Navicula americana</i>	4	0.8
<i>Neidium iridis</i>	11	2.2
<i>Nitzschia linearis</i>	2	0.4
<i>Pinnularia gibba</i>	1	0.2
<i>Pinnularia maior</i>	8	1.6
<i>Pinnularia streptoraphe</i>	4	0.8
<i>Pinnularia viridis</i>	4	0.8
<i>Pinnularia</i> undifferentiated	52	10.3
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	6	1.2
<i>Stauroneis phoenicenteron</i>	65	12.8
Undifferentiated valves	4	0.8
Total Diatoms	506	
Chrysophyte cysts	474	
Chrysophyte:Diatom Ratio	0.94	

Depth 43.6 cm bms Age 1000 BP	Total No. Valves	Diatom Percent
<i>Amphora ovalis</i>	1	0.2
<i>Amphora ovalis</i> var. <i>affinis</i>	15	2.9
<i>Aulacoseira distans</i>	114	22.2
<i>Aulacoseira herzogii</i>	18	3.5
<i>Aulacoseira lirata</i> f. <i>biseriata</i>	24	4.7
<i>Aulacoseira nygaardii</i>	36	7.0
<i>Aulacoseira</i> undifferentiated	58	11.3
<i>Cymbella cuspidata</i>	9	1.8
<i>Eunotia bilunaris</i>	16	3.1
<i>Eunotia diodon</i>	1	0.2
<i>Eunotia implicata</i>	9	1.8
<i>Eunotia incisa</i>	3	0.6
<i>Eunotia minor</i>	11	2.1
<i>Eunotia monodon</i>	41	8.0
<i>Gomphonema gracile</i>	9	1.8
<i>Navicula americana</i>	2	0.4
<i>Neidium iridis</i>	18	3.5
<i>Nitzschia linearis</i>	3	0.6
<i>Pinnularia maior</i>	1	0.2
<i>Pinnularia microstauron</i>	3	0.6
<i>Pinnularia streptoraphe</i>	2	0.4
<i>Pinnularia viridis</i>	9	1.8
<i>Pinnularia</i> undifferentiated	31	6.0
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	3	0.6
<i>Stauroneis phoenicenteron</i>	68	13.3
<i>Surirella brebissonii</i>	1	0.2
<i>Surirella linearis</i>	2	0.4
Undifferentiated valves	5	1.0
Total Diatoms	513	
Chrysophyte Cysts	380	
Chrysophyte:Diatom Ratio	0.74	

Depth 49.7 cm bms Age 1750 BP	Total No. Valves	Diatom Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	16	3.2
<i>Aulacoseira distans</i>	58	11.6
<i>Aulacoseira herzogii</i>	19	3.8
<i>Aulacoseira lirata</i> f. <i>biseriata</i>	95	19.0
<i>Aulacoseira nygaardii</i>	9	1.8
<i>Aulacoseira</i> undifferentiated	56	11.2
<i>Cymbella cuspidata</i>	14	2.8
<i>Eunotia arcus</i>	1	0.2
<i>Eunotia bilunaris</i>	13	2.6
<i>Eunotia diodon</i>	3	0.6
<i>Eunotia formica</i>	3	0.6
<i>Eunotia implicata</i>	2	0.4
<i>Eunotia incisa</i>	6	1.2
<i>Eunotia minor</i>	10	2.0
<i>Eunotia monodon</i>	32	6.4
<i>Eunotia praerupta</i> var. <i>bidens</i>	1	0.2
<i>Eunotia veneris</i>	1	0.2
<i>Gomphonema gracile</i>	13	2.6
<i>Navicula americana</i>	13	2.6
<i>Neidium iridis</i>	7	1.4
<i>Nitzschia linearis</i>	4	0.8
<i>Pinnularia gibba</i>	7	1.4
<i>Pinnularia neomajor</i>	2	0.4
<i>Pinnularia nobilis</i>	1	0.2
<i>Pinnularia streptoraphe</i>	1	0.2
<i>Pinnularia viridis</i>	4	0.8
<i>Pinnularia</i> undifferentiated	48	9.6
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	6	1.2
<i>Stauroneis phoenicenteron</i>	50	10.0
<i>Surirella linearis</i>	1	0.2
Undifferentiated valves	5	1.0
Total Diatoms	501	
Chrysophyte Cysts	645	
Chrysophyte:Diatom Ratio	1.29	

Depth 51.7 cm bms Age 2000 BP	Total No. Valves	Diatom Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	6	1.2
<i>Aulacoseira ambigua</i>	1	0.2
<i>Aulacoseira distans</i>	24	4.7
<i>Aulacoseira herzogii</i>	19	3.8
<i>Aulacoseira lirata</i> f. <i>biseriata</i>	39	7.7
<i>Aulacoseira</i> undifferentiated	53	10.5
<i>Cymbella</i> undifferentiated	2	0.4
<i>Eunotia bilunaris</i>	73	14.4
<i>Eunotia formica</i>	1	0.2
<i>Eunotia implicata</i>	1	0.2
<i>Eunotia incisa</i>	5	1.0
<i>Eunotia minor</i>	31	6.1
<i>Eunotia monodon</i>	86	17.0
<i>Eunotia naegellii</i>	2	0.4
<i>Eunotia rhomboidea</i>	2	0.4
<i>Eunotia</i> undifferentiated	20	4.0
<i>Gomphonema</i> undifferentiated	14	2.8
<i>Hantzschia</i> undifferentiated	2	0.4
<i>Navicula americana</i>	17	3.4
<i>Neidium iridis</i>	5	1.0
<i>Pinnularia</i> undifferentiated	50	9.9
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	1	0.2
<i>Stauroneis phoenicenteron</i>	37	7.3
<i>Stauroneis</i> undifferentiated	2	0.4
<i>Surirella linearis</i>	1	0.2
<i>Surirella</i> undifferentiated	1	0.2
<i>Tabellaria</i> undifferentiated	1	0.2
Undifferentiated valves	10	2.0
Total Diatoms	506	
Chrysophyte Cysts	672	
Chrysophyte:Diatom Ratio	1.33	

Depth 53.7 cm bms	Total No.	Diatom
Age 2250 BP	Valves	Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	4	0.8
<i>Anomoneis</i> undifferentiated	1	0.2
<i>Aulacoseira distans</i>	7	1.4
<i>Aulacoseira herzogii</i>	4	0.8
<i>Aulacoseira lirata</i> f. <i>biseriata</i>	5	1.0
<i>Aulacoseira</i> undifferentiated	7	1.4
<i>Craticula</i> undifferentiated	1	0.2
<i>Encyonema silesiacum</i>	1	0.2
<i>Eunotia bilunaris</i>	86	16.8
<i>Eunotia circumborealis</i>	4	0.8
<i>Eunotia diodon</i>	1	0.2
<i>Eunotia glacialis</i>	1	0.2
<i>Eunotia implicata</i>	11	2.1
<i>Eunotia incisa</i>	7	1.4
<i>Eunotia minor</i>	27	5.3
<i>Eunotia monodon</i>	146	28.5
<i>Eunotia praerupta</i> var. <i>bidens</i>	4	0.8
<i>Eunotia rhomboidea</i>	1	0.2
<i>Eunotia</i> undifferentiated	23	4.5
<i>Gomphonema angustatum</i>	1	0.2
<i>Gomphonema gracile</i>	3	0.6
<i>Gomphonema</i> undifferentiated	16	3.1
<i>Hantzschia elongata</i>	5	1.0
<i>Navicula americana</i>	22	4.3
<i>Neidium iridis</i>	7	1.4
<i>Pinnularia gigas</i>	1	0.2
<i>Pinnularia streptoraphe</i>	1	0.2
<i>Pinnularia</i> undifferentiated	63	12.3
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	2	0.4
<i>Stauroneis phoenicenteron</i>	42	8.2
<i>Stauroneis</i> undifferentiated	3	0.6
<i>Surirella</i> undifferentiated	2	0.4
<i>Tabellaria flocculosa</i>	1	0.2
Undifferentiated valves	2	0.4
Total Diatoms	512	
Chrysophyte Cysts	956	
Chrysophyte:Diatom Ratio	1.87	

Depth 61.8 cm bms	Total No.	Diatom
Age 3250 BP	Valves	Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	6	1.2
<i>Aulacoseira lirata</i> f. <i>biseriata</i>	11	2.2
<i>Encyonema silesiacum</i>	4	0.8
<i>Eunotia arcus</i>	2	0.4
<i>Eunotia bilunaris</i>	35	6.9
<i>Eunotia circumborealis</i>	3	0.6
<i>Eunotia diodon</i>	4	0.8
<i>Eunotia faba</i>	1	0.2
<i>Eunotia formica</i>	7	1.4
<i>Eunotia glacialis</i>	2	0.4
<i>Eunotia implicata</i>	59	11.7
<i>Eunotia incisa</i>	28	5.5
<i>Eunotia intermedia</i>	7	1.4
<i>Eunotia minor</i>	50	9.9
<i>Eunotia monodon</i>	82	16.2
<i>Eunotia praerupta</i>	5	1.0
<i>Eunotia</i> undifferentiated	6	1.2
<i>Gomphonema affine</i>	1	0.2
<i>Gomphonema gracile</i>	61	12.1
<i>Navicula americana</i>	13	2.6
<i>Neidium</i> undifferentiated	8	1.6
<i>Nitzschia linearis</i>	3	0.6
<i>Pinnularia angusta</i>	2	0.4
<i>Pinnularia gibba</i>	3	0.6
<i>Pinnularia neomajor</i>	3	0.6
<i>Pinnularia nobilis</i>	1	0.2
<i>Pinnularia</i> undifferentiated	51	10.1
<i>Stauroneis phoenicenteron</i>	37	7.3
<i>Surirella</i> undifferentiated	2	0.4
Undifferentiated valves	8	1.6
Total Diatoms	505	
Chrysophyte Cysts	1281	
Chrysophyte:Diatom Ratio	2.54	

Depth 67.9 cm bms Age 4000 BP	Total No. Valves	Diatom Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	5	1.0
<i>Aulacoseira distans</i>	12	2.3
<i>Cymbella cuspidata</i>	1	0.2
<i>Encyonema silesiacum</i>	5	1.0
<i>Eunotia bilunaris</i>	56	11.0
<i>Eunotia circumborealis</i>	1	0.2
<i>Eunotia flexuosa</i>	1	0.2
<i>Eunotia formica</i>	6	1.2
<i>Eunotia glacialis</i>	2	0.4
<i>Eunotia implicata</i>	41	8.0
<i>Eunotia incisa</i>	39	7.6
<i>Eunotia intermedia</i>	2	0.4
<i>Eunotia minor</i>	37	7.2
<i>Eunotia monodon</i>	101	19.8
<i>Eunotia praerupta</i> var. <i>bidens</i>	6	1.2
<i>Eunotia subarcuatoides</i>	2	0.4
<i>Eunotia undifferentiated</i>	7	1.4
<i>Fragilaria pinnata</i>	1	0.2
<i>Gomphonema gracile</i>	18	3.5
<i>Gomphonema sarcophagus</i>	2	0.4
<i>Gomphonema turris</i>	5	1.0
<i>Gomphonema undifferentiated</i>	19	3.7
<i>Navicula americana</i>	8	1.6
<i>Neidium undifferentiated</i>	3	0.6
<i>Nitzschia filiformis</i>	4	0.8
<i>Nitzschia linearis</i>	5	1.0
<i>Pinnularia gigas</i>	6	1.2
<i>Pinnularia microstauron</i>	1	0.2
<i>Pinnularia nodosa</i>	2	0.4
<i>Pinnularia viridis</i>	1	0.2
<i>Pinnularia undifferentiated</i>	54	10.6
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	4	0.8
<i>Stauroneis phoenicenteron</i>	34	6.7
<i>Suirella undifferentiated</i>	1	0.2
<i>Synedra ulna</i>	1	0.2
Undifferentiated valves	18	3.5
Total Diatoms	511	
Chrysophyte Cysts	1253	
Chrysophyte:Diatom Ratio	2.45	

Depth 78.0 cm bms	Total No.	Diatom
Age 5250 BP	Valves	Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	4	0.8
<i>Aulacoseira subarctica</i> f. <i>recta</i>	1	0.2
<i>Cymbella</i> undifferentiated	2	0.4
<i>Eunotia arcus</i>	1	0.2
<i>Eunotia bilunaris</i>	30	5.8
<i>Eunotia circumborealis</i>	2	0.4
<i>Eunotia faba</i>	4	0.8
<i>Eunotia flexuosa</i>	2	0.4
<i>Eunotia formica</i>	4	0.8
<i>Eunotia implicata</i>	51	9.9
<i>Eunotia incisa</i>	65	12.6
<i>Eunotia minor</i>	50	9.7
<i>Eunotia monodon</i>	101	19.5
<i>Eunotia praerupta</i> var. <i>bidens</i>	9	1.7
<i>Eunotia serra</i>	2	0.4
<i>Eunotia sudetica</i>	4	0.8
<i>Eunotia</i> undifferentiated	7	1.4
<i>Gomphonema gracile</i>	28	5.4
<i>Gomphonema sarcophagus</i>	1	0.2
<i>Gomphonema turis</i>	15	2.9
<i>Gomphonema</i> undifferentiated	15	2.9
<i>Hantzschia elongata</i>	2	0.4
<i>Navicula americana</i>	9	1.7
<i>Neidium iridis</i>	3	0.6
<i>Nitzschia linearis</i>	3	0.6
<i>Pinnularia borealis</i>	1	0.2
<i>Pinnularia gigas</i>	2	0.4
<i>Pinnularia</i> undifferentiated	53	10.3
<i>Stauroneis phoenicenteron</i>	31	6.0
Undifferentiated valves	15	2.9
Total Diatoms	517	
Chrysophyte Cysts	910	
Chrysophyte:Diatom Ratio	1.76	

Depth 83.0 cm bms	Total No.	Diatom
Age 6000 yr BP	Valves	Percent
<i>Amphora ovalis</i>	7	1.3
<i>Aulacoseira granulata</i>	5	1.0
<i>Aulacoseira islandica</i>	9	1.7
<i>Aulacoseira</i> spore	8	1.5
<i>Cymbella haukii</i>	2	0.4
<i>Encyonema silesiacum</i>	3	0.6
<i>Eunotia bilunaris</i>	16	3.1
<i>Eunotia formica</i>	2	0.4
<i>Eunotia glacialis</i>	6	1.2
<i>Eunotia implicata</i>	25	4.8
<i>Eunotia incisa</i>	33	6.3
<i>Eunotia minor</i>	71	13.7
<i>Eunotia monodon</i>	187	36.0
<i>Eunotia monodon</i> var. <i>bidens</i>	2	0.4
<i>Eunotia praerupta</i> var. <i>bidens</i>	2	0.4
<i>Eunotia</i> undifferentiated	2	0.4
<i>Gomphonema gracile</i>	59	11.3
<i>Gomphonema gracile</i> (multi-stigma)	2	0.4
<i>Gomphonema parvulum</i>	5	1.0
<i>Gomphonema</i> undifferentiated	1	0.2
<i>Hantzschia elongata</i>	2	0.4
<i>Hantzschia</i> undifferentiated	2	0.4
<i>Navicula americana</i>	4	0.8
<i>Navicula</i> undifferentiated	2	0.4
<i>Neidium affine</i>	2	0.4
<i>Nitzschia</i> undifferentiated	2	0.4
<i>Pinnularia brebissonii</i>	3	0.6
<i>Pinnularia gibba</i>	4	0.8
<i>Pinnularia microstauron</i>	3	0.6
<i>Pinnularia streptoraphe</i>	8	1.5
<i>Pinnularia viridis</i>	5	1.0
<i>Pinnularia viridoides</i>	1	0.2
<i>Pinnularia</i> undifferentiated	10	1.9
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	8	1.5
<i>Stauroneis kriegeri</i>	1	0.2
<i>Stauroneis phoenicenteron</i>	16	3.1
Total Diatoms	520	
Chrysophyte Cysts	81	
Chrysophyte:Diatom Ratio	0.16	

Depth 89.3 cm bms Age 7000 BP	Total No. Valves	Diatom Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	7	1.4
<i>Aulacoseira distans</i>	2	0.4
<i>Aulacoseira herzogii</i>	5	1.0
<i>Aulacoseira lirata</i> f. <i>biseriata</i>	6	1.2
<i>Aulacoseira</i> undifferentiated	6	1.2
<i>Cymbella cuspidata</i>	1	0.2
<i>Cymbella</i> undifferentiated	2	0.4
<i>Encyonema silesiacum</i>	8	1.6
<i>Eunotia arcus</i>	2	0.4
<i>Eunotia bilunaris</i>	92	18.0
<i>Eunotia circumborealis</i>	1	0.2
<i>Eunotia faba</i>	2	0.4
<i>Eunotia flexuosa</i>	1	0.2
<i>Eunotia formica</i>	3	0.6
<i>Eunotia glacialis</i>	3	0.6
<i>Eunotia implicata</i>	29	5.7
<i>Eunotia incisa</i>	30	5.9
<i>Eunotia intermedia</i>	2	0.4
<i>Eunotia minor</i>	17	3.3
<i>Eunotia monodon</i>	85	16.7
<i>Eunotia praerupta</i> var. <i>bidens</i>	2	0.4
<i>Eunotia rhomboidea</i>	6	1.2
<i>Eunotia veneris</i>	4	0.8
<i>Eunotia</i> undifferentiated	30	5.9
<i>Fragilaria construens</i>	2	0.4
<i>Gomphonema affine</i>	2	0.4
<i>Gomphonema gracile</i>	26	5.1
<i>Gomphonema parvulum</i>	7	1.4
<i>Gomphonema sarcophagus</i>	4	0.8
<i>Gomphonema turis</i>	14	2.7
<i>Gomphonema</i> undifferentiated	27	5.3
<i>Hantzschia amphioxys</i>	1	0.2
<i>Hantzschia elongata</i>	2	0.4
<i>Navicula americana</i>	5	1.0
<i>Navicula radiosa</i>	4	0.8
<i>Navicula</i> undifferentiated	2	0.4
<i>Neidium iridis</i>	4	0.8
<i>Nitzschia linearis</i>	1	0.2
<i>Pinnularia gibba</i>	3	0.6
<i>Pinnularia gigas</i>	1	0.2
<i>Pinnularia mesolepta</i>	1	0.2
<i>Pinnularia microstauron</i>	1	0.2
<i>Pinnularia neomajor</i>	1	0.2
<i>Pinnularia nodosa</i>	1	0.2
<i>Pinnularia streptoraphe</i>	1	0.2
<i>Pinnularia viridiformis</i>	1	0.2
<i>Pinnularia</i> undifferentiated	20	3.9
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	7	1.4
<i>Stauroneis anceps</i>	3	0.6
<i>Stauroneis phoenicenteron</i>	18	3.5
Undifferentiated valves	5	1.0
Total Diatoms	510	
Chrysophyte Cysts	293	
Chrysophyte:Diatom Ratio	0.57	

Depth 99.0 cm bms Age 8500 BP	Total No. Valves	Diatom Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	7	1.4
<i>Aulacoseira islandica</i>	12	2.4
<i>Cymbella amphicephala</i>	1	0.2
<i>Cymbella hauckii</i>	1	0.2
<i>Encyonema silesiacum</i>	1	0.2
<i>Eunotia bilunaris</i>	28	5.6
<i>Eunotia circumborealis</i>	2	0.4
<i>Eunotia diodon</i>	6	1.2
<i>Eunotia glacialis</i>	9	1.8
<i>Eunotia implicata</i>	28	5.6
<i>Eunotia incisa</i>	45	9.0
<i>Eunotia minor</i>	67	13.4
<i>Eunotia monodon</i>	131	26.2
<i>Eunotia undifferentiated</i>	1	0.2
<i>Gomphonema gracile</i>	58	11.6
<i>Gomphonema undifferentiated</i>	9	1.8
<i>Hantzschia elongata</i>	2	0.4
<i>Navicula americana</i>	9	1.8
<i>Neidium affine</i>	3	0.6
<i>Neidium iridis</i>	2	0.4
<i>Neidium</i> spp.	2	0.4
<i>Pinnularia brebissonii</i>	1	0.2
<i>Pinnularia gibba</i>	10	2.0
<i>Pinnularia microstauron</i>	3	0.6
<i>Pinnularia streptoraphe</i>	5	1.0
<i>Pinnularia viridis</i>	12	2.4
<i>Pinnularia</i> spp.	12	2.4
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	7	1.4
<i>Sellaphora pupula</i> var. <i>undifferentiated</i>	1	0.2
<i>Stauroneis anceps</i> f. <i>gracilis</i>	2	0.4
<i>Stauroneis phoenicenteron</i>	20	4.0
<i>Stauroneis undifferentiated</i>	2	0.4
<i>Tabellaria undifferentiated</i>	1	0.2
Total Diatoms	500	
Chrysophyte Cysts	322	
Chrysophyte:Diatom Ratio	0.64	

Depth 101.5 cm bms Age 9000 BP	Total No. Valves	Diatom Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	4	0.8
<i>Amphora</i> undifferentiated	1	0.2
<i>Aulacoseira islandica</i>	13	2.5
<i>Cymbella cuspidata</i>	1	0.2
<i>Cymbella</i> undifferentiated	2	0.4
<i>Encyonema</i> undifferentiated	3	0.6
<i>Eunotia bilunaris</i>	97	18.8
<i>Eunotia circumborealis</i>	1	0.2
<i>Eunotia diodon</i>	1	0.2
<i>Eunotia faba</i>	1	0.2
<i>Eunotia formica</i>	2	0.4
<i>Eunotia glacialis</i>	3	0.6
<i>Eunotia implicata</i>	25	4.8
<i>Eunotia incisa</i>	22	4.3
<i>Eunotia intermedia</i>	2	0.4
<i>Eunotia minor</i>	46	8.9
<i>Eunotia monodon</i>	81	15.7
<i>Eunotia pectinalis</i>	1	0.2
<i>Eunotia praerupta</i> var. <i>bidens</i>	2	0.4
<i>Eunotia rhomboidea</i>	10	1.9
<i>Eunotia soleirolii</i>	3	0.6
<i>Eunotia veneris</i>	4	0.8
<i>Eunotia</i> undifferentiated	35	6.8
<i>Gomphonema affine</i>	3	0.6
<i>Gomphonema angustatum</i>	3	0.6
<i>Gomphonema gracile</i>	31	6.0
<i>Gomphonema intricatum</i>	1	0.2
<i>Gomphonema turris</i>	5	1.0
<i>Gomphonema</i> undifferentiated	29	5.6
<i>Luticula mutica</i>	1	0.2
<i>Navicula americana</i>	4	0.8
<i>Neidium iridis</i>	5	1.0
<i>Nitzschia frustulum</i>	1	0.2
<i>Nitzschia linearis</i>	5	1.0
<i>Pinnularia brebissonii</i>	2	0.4
<i>Pinnularia gigas</i>	1	0.2
<i>Pinnularia mesolepta</i>	2	0.4
<i>Pinnularia viridiformis</i>	2	0.4
<i>Pinnularia viridis</i>	1	0.2
<i>Pinnularia</i> undifferentiated	21	4.1
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	4	0.8
<i>Stauroneis anceps</i> f. <i>gracilis</i>	1	0.2
<i>Stauroneis fluminea</i>	3	0.6
<i>Stauroneis phoenicenteron</i>	23	4.5
<i>Surirella brebissonii</i>	1	0.2
Undifferentiated valves	7	1.4
Total Diatoms	516	
Chrysophyte Cysts	454	
Chrysophyte:Diatom Ratio	0.88	

Depth 105.9 cm bms	Total No.	Diatom
Age 9750 BP	Valves	Percent
<i>Aulacoseira herzogii</i>	1	0.2
<i>Aulacoseira lirata</i> f. <i>biseriata</i>	1	0.2
<i>Craticula</i> undifferentiated	10	2.0
<i>Cymbella</i> undifferentiated	9	1.8
<i>Eunotia bilunaris</i>	62	12.3
<i>Eunotia diodon</i>	1	0.2
<i>Eunotia formica</i>	1	0.2
<i>Eunotia glacialis</i>	4	0.8
<i>Eunotia implicata</i>	8	1.6
<i>Eunotia incisa</i>	16	3.2
<i>Eunotia minor</i>	26	5.1
<i>Eunotia monodon</i>	80	15.8
<i>Eunotia praerupta</i> var. <i>bidens</i>	8	1.6
<i>Eunotia rhomboidea</i>	5	1.0
<i>Eunotia veneris</i>	1	0.2
<i>Eunotia</i> undifferentiated	19	3.8
<i>Fragilaria pinnata</i>	2	0.4
<i>Frustulia rhomboides</i>	1	0.2
<i>Gomphonema affine</i>	1	0.2
<i>Gomphonema gracile</i>	22	4.3
<i>Gomphonema turris</i>	3	0.6
<i>Gomphonema</i> undifferentiated	44	8.7
<i>Hantzschia elongata</i>	5	1.0
<i>Luticula mutica</i>	1	0.2
<i>Navicula americana</i>	4	0.8
<i>Navicula</i> undifferentiated	1	0.2
<i>Neidium iridis</i>	1	0.2
<i>Neidium</i> undifferentiated	25	4.9
<i>Nitzschia</i> undifferentiated	1	0.2
<i>Pinnularia gibba</i>	2	0.4
<i>Pinnularia nodosa</i>	1	0.2
<i>Pinnularia viridis</i>	2	0.4
<i>Pinnularia</i> undifferentiated	62	12.3
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	2	0.4
<i>Stauroneis phoenicenteron</i>	50	9.9
<i>Surirella</i> undifferentiated	4	0.8
<i>Tabellaria</i> undifferentiated	3	0.6
Undifferentiated valves	17	3.4
Total Diatoms	506	
Chrysophyte Cysts	278	
Chrysophyte:Diatom Ratio	0.55	

Depth 108.0 cm bms	Total No.	Diatom
Age 10,000 BP	Valves	Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	14	2.8
<i>Aulacoseira granulata</i>	1	0.2
<i>Craticula</i> undifferentiated	22	4.3
<i>Cymbella aspera</i>	2	0.4
<i>Cymbella cuspidata</i>	31	6.1
<i>Cymbella</i> undifferentiated	2	0.4
<i>Eunotia bilunaris</i>	23	4.5
<i>Eunotia implicata</i>	6	1.2
<i>Eunotia incisa</i>	6	1.2
<i>Eunotia minor</i>	1	0.2
<i>Eunotia monodon</i>	32	6.3
<i>Eunotia veneris</i>	3	0.6
<i>Eunotia</i> undifferentiated	14	2.8
<i>Gomphonema angustatum</i>	3	0.6
<i>Gomphonema apicatum</i>	8	1.6
<i>Gomphonema</i> undifferentiated	12	2.4
<i>Navicula americana</i>	5	1.0
<i>Neidium iridis</i>	53	10.4
<i>Pinnularia gigas</i>	7	1.4
<i>Pinnularia microstauron</i>	1	0.2
<i>Pinnularia nodosa</i>	2	0.4
<i>Pinnularia viridis</i>	2	0.4
<i>Pinnularia</i> undifferentiated	98	19.3
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	2	0.4
<i>Stauroneis phoenicenteron</i>	111	21.9
<i>Stauroneis</i> undifferentiated	3	0.6
<i>Surirella</i> undifferentiated	9	1.8
<i>Synedra</i> undifferentiated	1	0.2
<i>Tabellaria flocculosa</i>	11	2.2
Undifferentiated valves	23	4.5
Total Diatoms	508	
Chrysophyte Cysts	250	
Chrysophyte:Diatom Ratio	0.49	

Depth 114.7 cm bms	Total No.	Diatom
Age 11,000 BP	Valves	Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	3	0.6
<i>Craticula</i> undifferentiated	3	0.6
<i>Cymbella cuspidata</i>	5	1.0
<i>Cymbella</i> undifferentiated	26	5.0
<i>Encyonema</i> undifferentiated	2	0.4
<i>Epithemia</i> undifferentiated	1	0.2
<i>Eunotia bilunaris</i>	11	2.1
<i>Eunotia implicata</i>	2	0.4
<i>Eunotia incisa</i>	3	0.6
<i>Eunotia minor</i>	11	2.1
<i>Eunotia monodon</i>	40	7.7
<i>Eunotia</i> undifferentiated	16	3.1
<i>Gomphonema affine</i>	1	0.2
<i>Gomphonema</i> undifferentiated	6	1.2
<i>Hantzschia elongata</i>	2	0.4
<i>Luticola mutica</i>	1	0.2
<i>Navicula americana</i>	2	0.4
<i>Neidium iridis</i>	2	0.4
<i>Neidium</i> undifferentiated	71	13.7
<i>Pinnularia</i> undifferentiated	94	18.1
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	1	0.2
<i>Stauroneis anceps</i>	1	0.2
<i>Stauroneis</i> undifferentiated	179	34.6
<i>Surirella</i> undifferentiated	2	0.4
<i>Tabellaria</i> undifferentiated	1	0.2
Undifferentiated valves	32	6.2
Total Diatoms	518	
Chrysophyte Cysts	475	
Chrysophyte:Diatom Ratio	0.92	

Depth 121.0 cm bms	Total No.	Diatom
Age 12,000 BP	Valves	Percent
<i>Amphora ovalis</i>	1	0.3
<i>Craticula ambigua</i>	8	2.4
<i>Cymbella cuspidata</i>	2	0.6
<i>Cymbella heteropluera</i> var. <i>subrostrata</i>	7	2.1
<i>Diatoma</i> undifferentiated	2	0.6
<i>Eunotia bilunaris</i>	6	1.8
<i>Eunotia faba</i>	3	0.9
<i>Eunotia implicata</i>	2	0.6
<i>Eunotia incisa</i>	17	5.0
<i>Eunotia minor</i>	38	11.3
<i>Eunotia monodon</i>	15	4.5
<i>Eunotia praerupta</i>	1	0.3
<i>Eunotia serra</i> var. <i>tetraodon</i>	1	0.3
<i>Eunotia</i> undifferentiated	5	1.5
<i>Fragilaria pinnata</i>	3	0.9
<i>Gomphonema affine</i>	2	0.6
<i>Gomphonema gracile</i>	12	3.6
<i>Gomphonema truncatum</i>	1	0.3
<i>Gomphonema turris</i>	2	0.6
<i>Navicula americana</i>	4	1.2
<i>Neidium</i> undifferentiated	10	3.0
<i>Nitzschia linearis</i>	2	0.6
<i>Nitzschia sinuata</i> var. <i>delognei</i>	1	0.3
<i>Pinnularia braunii</i>	2	0.6
<i>Pinnularia divergens</i>	1	0.3
<i>Pinnularia formica</i>	3	0.9
<i>Pinnularia gibba</i>	19	5.6
<i>Pinnularia microstauron</i>	1	0.3
<i>Pinnularia streptoraphe</i>	5	1.5
<i>Pinnularia viridis</i>	25	7.4
<i>Pinnularia</i> undifferentiated	35	10.4
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	10	3.0
<i>Stauroneis phoenicenteron</i>	68	20.2
<i>Tabellaria fenestrata</i>	5	1.5
Undifferentiated valves	18	5.3
Total Diatoms	337	
Chrysophyte Cysts	223	
Chrysophyte:Diatom Ratio	0.66	

Depth 124.6 cm bms	Total No.	Diatom
Age 12,500 BP	Valves	Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	2	0.4
<i>Aulacoseira ambigua</i>	3	0.6
<i>Aulacoseira</i> undifferentiated	2	0.4
<i>Craticula</i> undifferentiated	8	1.6
<i>Cymbella cuspidata</i>	2	0.4
<i>Cymbella</i> undifferentiated	8	1.6
<i>Encyonema</i> undifferentiated	3	0.6
<i>Eunotia bilunaris</i>	46	8.9
<i>Eunotia glacialis</i>	2	0.4
<i>Eunotia implicata</i>	2	0.4
<i>Eunotia incisa</i>	2	0.4
<i>Eunotia minor</i>	31	6.0
<i>Eunotia monodon</i>	13	2.5
<i>Eunotia rhomboidea</i>	3	0.6
<i>Eunotia veneris</i>	8	1.6
<i>Eunotia</i> undifferentiated	18	3.5
<i>Fragilaria pinnata</i>	1	0.2
<i>Frustulia</i> undifferentiated	3	0.6
<i>Gomphonema acuminatum</i>	1	0.2
<i>Gomphonema gracile</i>	10	1.9
<i>Gomphonema parvulum</i>	6	1.2
<i>Gomphonema subclavatum</i>	1	0.2
<i>Gomphonema truncatum</i>	1	0.2
<i>Gomphonema turris</i>	1	0.2
<i>Gomphonema</i> undifferentiated	52	10.1
<i>Hantzschia</i> undifferentiated	1	0.2
<i>Navicula americana</i>	4	0.8
<i>Navicula</i> undifferentiated	4	0.8
<i>Neidium</i> undifferentiated	22	4.3
<i>Pinnularia braunii</i>	4	0.8
<i>Pinnularia formica</i>	3	0.6
<i>Pinnularia gibba</i>	6	1.2
<i>Pinnularia gigas</i>	4	0.8
<i>Pinnularia microstauron</i>	1	0.2
<i>Pinnularia neomajor</i>	1	0.2
<i>Pinnularia viridis</i>	3	0.6
<i>Pinnularia</i> undifferentiated	100	19.5
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	9	1.8
<i>Stauroneis anceps</i>	2	0.4
<i>Stauroneis phoenicenteron</i>	58	11.3
<i>Stauroneis</i> undifferentiated	15	2.9
<i>Sunrella ovalis</i>	1	0.2
<i>Synedra</i> undifferentiated	2	0.4
<i>Tabellaria flocculosa</i>	10	1.9
Undifferentiated valves	35	6.8
Total diatoms	514	
Chrysophyte Cysts	194	
Chrysophyte:Diatom Ratio	0.38	

Depth 185.0 cm bms	Total No.	Diatom
Age 12,750 BP	Valves	Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	4	0.7
<i>Aulacoseira ambigua</i>	3	0.6
<i>Caloneis bacillum</i>	2	0.4
<i>Cocconeis placentula</i> var. <i>lineata</i>	1	0.2
<i>Craticula cuspidata</i>	1	0.2
<i>Cymbella cuspidata</i>	6	1.1
<i>Cymbella</i> undifferentiated	2	0.4
<i>Encyonema lunatum</i>	14	2.6
<i>Encyonema silesiacum</i>	4	0.7
<i>Encyonema</i> undifferentiated	19	3.5
<i>Epithemia</i> undifferentiated	1	0.2
<i>Eunotia bilunaris</i>	4	0.7
<i>Eunotia diodon</i>	1	0.2
<i>Eunotia flexuosa</i>	1	0.2
<i>Eunotia implicata</i>	1	0.2
<i>Eunotia incisa</i>	15	2.8
<i>Eunotia minor</i>	3	0.6
<i>Eunotia monodon</i>	4	0.7
<i>Eunotia pectinalis</i> var. <i>undulata</i>	1	0.2
<i>Eunotia rhomboidea</i>	2	0.4
<i>Eunotia rostellata</i>	1	0.2
<i>Eunotia triodon</i>	1	0.2
<i>Eunotia</i> undifferentiated	7	1.3
<i>Fragilaria construens</i>	78	14.4
<i>Fragilaria construens</i> var. <i>venter</i>	11	2.0
<i>Fragilaria pinnata</i>	194	35.9
<i>Fragilaria pinnata</i> var. <i>intercedens</i>	1	0.2
<i>Frustulia rhomboides</i>	16	3.0
<i>Gomphonema acuminatum</i>	2	0.4
<i>Gomphonema angustatum</i>	1	0.2
<i>Gomphonema apicatum</i>	1	0.2
<i>Gomphonema gracile</i>	1	0.2
<i>Gomphonema</i> undifferentiated	7	1.3
<i>Gyrosigma</i> undifferentiated	1	0.2
<i>Luticola mutica</i>	1	0.2
<i>Navicula americana</i>	1	0.2
<i>Navicula minima</i>	3	0.6
<i>Navicula oblonga</i>	2	0.4
<i>Navicula pseudoscutiformis</i>	4	0.7
<i>Navicula viridula</i>	2	0.4
<i>Navicula</i> undifferentiated	24	4.4
<i>Neidium</i> undifferentiated	3	0.6
<i>Pinnularia</i> undifferentiated	11	2.0
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	16	3.0
<i>Sellaphora pupula</i> var. undifferentiated	18	3.3
<i>Stauroneis phoenicenteron</i>	4	0.7
<i>Stauroneis</i> undifferentiated	2	0.4
<i>Surirella</i> undifferentiated	1	0.2
<i>Tabellaria fenestrata</i>	10	1.8
<i>Tabellaria flocculosa</i>	9	1.7
Undifferentiated valves	19	3.5
Total Valves	541	
Chrysophyte Cysts	31	
Chrysophyte:Diatom Ratio	0.06	

Depth 195.2 cm bms	Total No.	Diatom
Age 13,000 BP	Valves	Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	3	0.6
<i>Aulacoseira granulata</i>	5	1.0
<i>Caloneis ventricosa</i> var. <i>minuta</i>	1	0.2
<i>Craticula ambigua</i>	1	0.2
<i>Cymbella acutiuscula</i>	1	0.2
<i>Cymbella cuspidata</i>	10	2.0
<i>Cymbella heteropleura</i> var. <i>subrostrata</i>	4	0.8
<i>Encyonema mesiana</i>	3	0.6
<i>Eunotia bilunaris</i>	1	0.2
<i>Eunotia diodon</i>	1	0.2
<i>Eunotia implicata</i>	1	0.2
<i>Eunotia incisa</i>	5	1.0
<i>Eunotia intermedia</i>	1	0.2
<i>Eunotia minor</i>	2	0.4
<i>Eunotia monodon</i>	9	1.8
<i>Eunotia serra</i> var. <i>tetraodon</i>	1	0.2
<i>Fragilaria brevistriata</i>	1	0.2
<i>Fragilaria construens</i>	93	18.4
<i>Fragilaria nitzschioides</i>	1	0.2
<i>Fragilaria pinnata</i>	262	51.8
<i>Gomphonema acuminatum</i>	6	1.2
<i>Gomphonema apicatum</i>	1	0.2
<i>Gomphonema gracile</i>	2	0.4
<i>Gomphonema truncatum</i>	1	0.2
<i>Navicula americana</i>	4	0.8
<i>Navicula minima</i>	2	0.4
<i>Navicula pseudoscutiformis</i>	1	0.2
<i>Navicula undifferentiated</i>	2	0.4
<i>Neidium iridis</i>	4	0.8
<i>Pinnularia gibba</i>	2	0.4
<i>Pinnularia gigas</i>	3	0.6
<i>Pinnularia undifferentiated</i>	35	6.9
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	5	1.0
<i>Stauroneis phoenicenteron</i>	14	2.8
<i>Tabellaria fenestrata</i>	3	0.6
Undifferentiated valves	15	3.0
Total Valves	506	
Chrysophyte Cysts	36	
Chrysophyte:Diatom Ratio	0.07	

Depth 236.0 cm bms Age 14,000 BP	Total No. Valves	Diatom Percent
<i>Achnanthes exigua</i>	3	0.6
<i>Amphora ovalis</i> var. <i>affinis</i>	3	0.6
<i>Aulacoseira ambigua</i>	7	1.3
<i>Aulacoseira granulata</i>	1	0.2
<i>Cocconeis placentula</i> var. <i>lineata</i>	7	1.3
<i>Cymbella aspera</i>	3	0.6
<i>Cymbella cistula</i>	3	0.6
<i>Cymbella cuspidata</i>	3	0.6
<i>Cymbella lanceolata</i>	5	1.0
<i>Cymbella</i> undifferentiated	10	1.9
<i>Denticula lauta</i>	2	0.4
<i>Encyonema minutum</i>	2	0.4
<i>Epithemia adnata</i> var. <i>proboscidea</i>	7	1.3
<i>Epithemia</i> undifferentiated (2 humps)	1	0.2
<i>Eunotia bilunaris</i>	1	0.2
<i>Eunotia faba</i>	3	0.6
<i>Eunotia incisa</i>	13	2.5
<i>Eunotia minor</i>	2	0.4
<i>Eunotia monodon</i>	19	3.6
<i>Fragilaria brevistriata</i>	1	0.2
<i>Fragilaria constricta</i>	2	0.4
<i>Fragilaria construens</i>	43	8.2
<i>Fragilaria lapponica</i>	4	0.8
<i>Fragilaria leptostauron</i>	1	0.2
<i>Fragilaria pinnata</i>	185	35.4
<i>Fragilaria subsalina</i>	1	0.2
<i>Gomphonema acuminatum</i>	1	0.2
<i>Gomphonema sphaerophorum</i>	2	0.4
<i>Gomphonema</i> undifferentiated	7	1.3
<i>Gyrosigma acuminatum</i>	69	13.2
<i>Luticola mutica</i>	1	0.2
<i>Navicula mournei</i>	4	0.8
<i>Navicula</i> undifferentiated	14	2.7
<i>Neidium</i> undifferentiated	4	0.8
<i>Nitzschia linearis</i>	1	0.2
<i>Orthoseira dendroteres</i>	1	0.2
<i>Pinnularia gigas</i>	3	0.6
<i>Pinnularia</i> undifferentiated	30	5.7
<i>Stauroneis phoenicenteron</i>	10	1.9
<i>Tabellaria fenestrata</i>	2	0.4
Undifferentiated valves	41	7.9
Total Valves	522	
Chrysophyte Cysts	98	
Chrysophyte:Diatom Ratio	0.19	

Depth 276.8 cm bms Age 15,000 BP	Total No. Valves	Diatom Percent
<i>Amphora ovalis</i> var. <i>affinis</i>	3	0.6
<i>Cocconeis placentula</i> var. <i>lineata</i>	14	2.6
<i>Craticula</i> undifferentiated	1	0.2
<i>Cymbella acutiuscula</i>	2	0.4
<i>Cymbella aspera</i>	7	1.3
<i>Cymbella cistula</i>	43	8.1
<i>Cymbella hauckii</i>	2	0.4
<i>Cymbella</i> undifferentiated	31	5.8
<i>Diploneis</i> undifferentiated	1	0.2
<i>Encyonema</i> undifferentiated	5	0.9
<i>Epithemia turgida</i>	1	0.2
<i>Epithemia</i> undifferentiated	4	0.8
<i>Eunotia bilunaris</i>	3	0.6
<i>Eunotia formica</i>	7	1.3
<i>Eunotia implicata</i>	2	0.4
<i>Eunotia incisa</i>	9	1.7
<i>Eunotia monodon</i>	38	7.2
<i>Eunotia</i> undifferentiated	2	0.4
<i>Fragilaria brevistriata</i>	3	0.6
<i>Fragilaria construens</i>	48	9.1
<i>Fragilaria construens</i> var. <i>venter</i>	4	0.8
<i>Fragilaria lapponica</i>	6	1.1
<i>Fragilaria pinnata</i>	134	25.3
<i>Fragilaria subsalina</i>	2	0.4
<i>Gomphonema brasiliense</i>	3	0.6
<i>Gomphonema truncatum</i> var. <i>capitatum</i>	1	0.2
<i>Gomphonema</i> undifferentiated	6	1.1
<i>Gyrosigma acuminatum</i>	39	7.4
<i>Navicula americana</i>	2	0.4
<i>Navicula exigua</i>	1	0.2
<i>Navicula ignota</i> var. <i>acceptata</i>	2	0.4
<i>Navicula ignota</i> var. <i>palustris</i>	8	1.5
<i>Navicula mournei</i>	8	1.5
<i>Navicula protracta</i>	1	0.2
<i>Navicula radiosa</i>	2	0.6
<i>Navicula</i> undifferentiated	10	1.9
<i>Neidium</i> undifferentiated	1	0.2
<i>Nitzschia sinuata</i> var. <i>delognei</i>	1	0.2
<i>Pinnularia gibba</i>	4	0.8
<i>Pinnularia gigas</i>	1	0.2
<i>Pinnularia viridis</i>	2	0.4
<i>Pinnularia</i> undifferentiated	9	1.7
<i>Stauroneis</i> undifferentiated	6	1.1
<i>Synedra</i> undifferentiated	3	0.6
<i>Tabellaria fenestrata</i>	19	3.6
<i>Tabellaria flocculosa</i>	2	0.4
Undifferentiated valves	27	5.1
Total Diatoms	530	
Chrysophyte Cysts	72	
Chrysophyte:Diatom Ratio	0.14	

Depth 374.6 cm bms
Age 16,000 BP

Total No.
Valves Diatom
 Percent

Very few diatom valves or chrysophyte cysts present.
The following genera and species were identified.
All valve fragments were from large, robust species.

<i>Aulacoseira</i> undifferentiated	1	
<i>Cymbella cistula</i>	1	
<i>Cymbella</i> unidentified	2	
<i>Epithemia turgida</i>	1	
<i>Eunotia</i> unidentified	5	
<i>Pinnularia</i> unidentified	4	
Total Diatoms	14	
Chrysophyte cysts	8.00	

Depth 467.4 cm bms
Age 17,000 BP

Total No.
Valves

Diatom
Percent

No diatom valves or chrysophyte cysts were identified from this sample.
No siliceous fossils of any kind present.

Depth 551.0 cm bms
Age 18,000 BP

Total No. Valves	Diatom Percent
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No diatom valves or chrysophyte cysts were identified from this sample.
No siliceous fossils of any kind present.

Depth 616.2 cm bms Age 18,500 BP	Total No. Valves	Diatom Percent
<i>Acnantes lanceolata</i>	1	0.2
<i>Amphora ovalis</i> var. <i>affinis</i>	6	1.0
<i>Caloneis bacillum</i>	2	0.3
<i>Cocconeis placentula</i> var. <i>lineata</i>	22	3.5
<i>Craticula cuspidata</i>	1	0.2
<i>Cymbella acutiuscula</i>	1	0.2
<i>Cymbella aspera</i>	2	0.3
<i>Cymbella cuspidata</i>	4	0.6
<i>Cymbella hauckii</i>	2	0.3
<i>Cymbella inaequalis</i>	1	0.2
<i>Cymbella proxima</i>	3	0.5
<i>Cymbella undifferentiated</i>	3	0.5
<i>Diploneis elliptica</i>	1	0.2
<i>Encyonema silesiacum</i>	3	0.5
<i>Encyonema undifferentiated</i>	3	0.5
<i>Epithemia adnata</i> var. <i>probiscidea</i>	10	1.6
<i>Epithemia turgida</i>	5	0.8
<i>Epithemia turgida</i> var. <i>granulata</i>	7	1.1
<i>Epithemia turgida</i> var. <i>westermanni</i>	1	0.2
<i>Epithemia undifferentiated</i>	6	1.0
<i>Eunotia bilunaris</i>	2	0.3
<i>Eunotia circumborealis</i>	1	0.2
<i>Eunotia clevei</i>	1	0.2
<i>Eunotia incisa</i>	14	2.2
<i>Eunotia minor</i>	1	0.2
<i>Eunotia praerupta</i> var. <i>bidens</i>	2	0.3
<i>Eunotia tenella</i>	1	0.2
<i>Fragilaria brevistriata</i>	5	0.8
<i>Fragilaria construens</i>	164	26.2
<i>Fragilaria construens</i> var. <i>venter</i>	8	1.3
<i>Fragilaria lapponica</i>	1	0.2
<i>Fragilaria leptostauron</i>	5	0.8
<i>Fragilaria pinnata</i>	228	36.4
<i>Fragilaria subsalina</i>	2	0.3
<i>Fragilaria undifferentiated</i>	18	2.9
<i>Gomphonema acuminatum</i>	2	0.3
<i>Gomphonema angustatum</i>	2	0.3
<i>Gomphonema gracile</i>	5	0.8
<i>Gomphonema sarcophagus</i>	8	1.3
<i>Gomphonema subclavatum</i>	2	0.3
<i>Gomphonema truncatum</i> var. <i>capitatum</i>	2	0.3
<i>Gomphonema undifferentiated</i>	5	0.8
<i>Gyrosigma acuminatum</i>	3	0.5
<i>Hantzschia amphioxys</i>	1	0.2
<i>Meridion circulare</i>	1	0.2
<i>Navicula explanata</i>	3	0.5
<i>Navicula mournei</i>	2	0.3
<i>Navicula placenta</i>	1	0.2
<i>Navicula radiosa</i>	2	0.3
<i>Navicula rhyncocephala</i>	2	0.3
<i>Navicula viridula</i>	3	0.5
<i>Navicula undifferentiated</i>	1	0.2
<i>Neidium affine</i>	1	0.2
<i>Neidium undifferentiated</i>	3	0.5
<i>Pinnularia borealis</i>	1	0.2
<i>Pinnularia legumen</i>	1	0.2

<i>Pinnularia rupestris</i>	1	0.2
<i>Pinnularia viridis</i>	1	0.2
<i>Pinnularia</i> undifferentiated	8	1.3
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	2	0.3
<i>Stauroneis phoenicenteron</i>	8	1.3
<i>Surirella bifrons</i>	1	0.2
<i>Surirella brebissonii</i>	1	0.2
<i>Surirella ovalis</i>	1	0.2
<i>Synedra parasitica</i>	1	0.2
<i>Synedra rumpens</i>	2	0.3
<i>Synedra ulna</i>	1	0.2
Undifferentiated valves	12	1.9
Total Diatoms	627	
Chrysophyte Cysts	31	
Chrysophyte:Diatom Ratio	0.05	

Depth 679.3 cm bms	Total No.	Diatom
Age 19,000 BP	Valves	Percent
<i>Cocconeis placentula</i> var. <i>lineata</i>	4	0.8
<i>Cymbella naviculiformis</i>	1	0.2
<i>Cymbella</i> undifferentiated	8	1.5
<i>Diatoma</i> undifferentiated	1	0.2
<i>Encyonema muelleri</i>	1	0.2
<i>Encyonema</i> undifferentiated	1	0.2
<i>Epithemia</i> undifferentiated	3	0.6
<i>Eunotia incisa</i>	5	1.0
<i>Eunotia</i> undifferentiated	1	0.2
<i>Fragilaria brevistriata</i>	4	0.8
<i>Fragilaria construens</i>	231	44.7
<i>Fragilaria construens</i> f. <i>venter</i>	6	1.2
<i>Fragilaria parasitica</i>	2	0.4
<i>Fragilaria pinnata</i>	221	42.7
<i>Gomphonema</i> undifferentiated	2	0.4
<i>Gyrosigma acuminatum</i>	1	0.2
<i>Navicula americana</i>	1	0.2
<i>Navicula minima</i>	5	1.0
<i>Navicula mournei</i>	3	0.6
<i>Navicula pseudoscutiformis</i>	2	0.4
<i>Neidium</i> undifferentiated	1	0.2
<i>Pinnularia</i> undifferentiated	1	0.2
<i>Sellaphora pupula</i> var. undifferentiated	2	0.4
<i>Stauroneis</i> undifferentiated	1	0.2
<i>Synedra</i> undifferentiated	3	0.6
<i>Tabellaria fenestrata</i>	2	0.4
Undifferentiated valves	4	0.8
Total Diatoms	517	
Chrysophyte Cysts	6	
Chrysophyte:Diatom Ratio	0.01	

Appendix D. Summary percentage data for diatom genera from Anderson Pond, TN.
Order of genera based on greatest peak in relative abundance.

Depth	Age BP	Aulacoseira	Eunotia	Stauroneis	Pinnularia	Fragilaria	Gomphonema	Cymbella	Encyonema	Amphora
0.0	0	0.2	20.0	8.2	5.0	0.0	30.6	0.0	0.6	0.0
37.5	250	48.6	21.6	9.4	3.9	0.0	7.1	1.4	11.4	1.8
41.6	750	49.0	12.5	12.8	13.6	0.0	2.2	2.0	0.0	2.4
43.6	1000	48.7	15.8	13.3	9.0	0.0	1.8	1.8	0.0	3.1
49.7	1750	47.3	14.4	10	12.6	0.0	2.6	27.9	0.0	3.2
51.7	2000	26.9	43.5	7.7	9.9	0.0	2.8	0.4	0.0	1.2
53.7	2250	4.5	60.7	8.8	12.7	0.0	3.9	0.0	0.0	0.8
61.8	3250	2.2	57.6	7.3	11.9	0.0	12.3	0.0	0.8	1.2
67.9	4000	2.3	58.9	6.7	12.5	0.2	8.6	0.2	1.0	1.0
78.0	5250	0.2	64.2	6.0	11.8	0.0	11.4	0.4	0.0	0.8
83.0	6000	4.2	66.5	3.3	6.5	0.0	12.9	0.4	0.6	1.3
89.3	7000	3.7	60.6	4.1	5.9	0.4	15.7	0.6	1.6	1.4
99.0	8500	2.4	63.4	4.8	8.6	0.0	13.4	0.4	0.2	1.4
101.5	9000	2.5	65.1	5.2	5.6	0.0	14.0	0.6	0.6	1.0
105.9	9750	0.4	45.7	9.9	13.2	0.4	13.8	1.8	0.0	0.0
108.0	10,000	0.2	16.7	22.4	21.7	0.0	4.5	6.9	0.0	2.8
114.7	11,000	0.0	16.0	34.7	18.1	0.0	1.4	6.0	0.4	0.6
121.0	12,000	0.0	26.1	20.2	27.0	0.9	5.0	2.7	0.0	0.3
124.6	12,500	1.0	24.3	11.7	23.7	0.2	14.0	1.9	0.6	0.4
185.0	12,750	0.6	7.6	1.1	2.0	52.5	2.2	1.5	6.8	0.7
195.2	13,000	1.0	4.2	2.8	7.9	70.6	2.0	3.0	0.6	0.6
236.0	14,000	1.5	7.3	1.9	6.3	45.4	1.9	4.6	0.4	0.6
276.8	15,000	0.0	11.5	1.1	3.0	37.2	1.9	16.0	0.9	0.6
616.2	18,500	0.0	3.5	1.3	1.9	68.7	4.1	2.6	1.0	1.0
679.3	19,000	0.0	1.2	0.2	0.2	89.7	0.4	1.7	0.2	0.0

Appendix D (continued)
Summary percentage data for diatom genera from Anderson Pond, TN.

Neidium	Navicula	Sellophora	Hantzschia	Nitzschia	Surirella	Meridion	Epithemia	Cocconeis	Synedra	Gyrosigma
0.0	20.0	3.0	0.0	4.2	0.0	0.0	0.0	0.0	6.4	0.0
1.2	0.4	4.7	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0
2.2	0.8	1.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
3.5	0.4	0.6	0.0	0.6	0.6	0.0	0.0	0.0	0.0	0.0
1.4	2.6	1.2	0.0	0.8	0.2	0.0	0.0	0.0	0.0	0.0
1.0	3.4	0.2	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0
1.4	4.3	0.4	1.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
1.6	2.6	0.0	0.0	0.6	0.4	0.0	0.0	0.0	0.0	0.0
0.6	1.6	0.8	0.0	1.8	0.2	0.0	0.0	0.0	0.2	0.0
0.6	1.7	0.0	0.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0
0.4	1.2	1.5	0.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0
0.8	2.6	1.4	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0
1.4	1.8	1.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0	0.8	0.8	0.0	1.2	0.2	0.0	0.0	0.0	0.0	0.0
5.1	1.0	0.4	1.0	0.2	0.8	0.0	0.0	0.0	0.0	0.0
10.4	1.0	0.4	0.0	0.0	1.8	0.0	0.0	0.0	0.2	0.0
14.1	0.4	0.2	0.4	0.0	0.4	0.0	0.2	0.0	0.0	0.0
3.0	1.2	3.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0
4.3	1.6	1.8	0.2	0.0	0.2	0.0	0.0	0.0	0.4	0.0
0.6	6.7	6.3	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.2
0.8	1.8	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.8	3.4	0.0	0.0	0.2	0.0	0.0	1.5	1.3	0.0	13.2
0.2	6.4	0.0	0.0	0.2	0.0	0.0	0.9	2.6	0.6	7.4
0.6	2.2	0.3	0.2	0.0	0.5	0.2	4.6	3.5	0.6	0.5
0.2	2.1	0.4	0.0	0.0	0.0	0.0	0.6	0.8	0.6	0.2

Appendix D (continued)
Summary percentage data for diatom genera from Anderson Pond, TN.

Caloneis	Craticula	Diploneis	Achnanthes	Tabellaria	Denticula	Luticola	Orthoseira	Diatoma	Frustulia	Undifferentiated
0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	1.6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	2.0
0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.4
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4
0.0	2.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	3.4
0.0	4.3	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	4.5
0.0	0.6	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	6.2
0.0	2.4	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0	5.3
0.0	1.5	0.0	0.0	1.5	0.0	0.0	0.0	0.6	0.0	6.8
0.4	0.2	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.6	3.5
0.2	0.2	0.0	0.0	3.5	0.0	0.2	0.0	0.0	3.0	3.0
0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	7.9
0.0	0.0	0.0	0.6	0.4	0.4	0.2	0.2	0.0	0.0	5.1
0.0	0.2	0.2	0.0	4.0	0.0	0.0	0.0	0.0	0.0	1.9
0.3	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.2	0.0	0.8

Appendix E. Detrended Correspondence Analyses (DCA) of diatom genera data.

Genera	Axis 1	Axis 2	Years BP	Axis 1	Axis 2
Achnanthes	2.93	0.66	19,000	2.89	0.87
Amphora	0.89	1.71	18,500	2.64	0.79
Aulacoseira	-0.50	2.35	15,000	2.35	0.63
Caloneis	2.94	1.33	14,000	2.37	0.80
Cocconeis	2.96	0.32	13,000	2.52	0.92
Craticula	1.21	1.70	12,750	2.47	1.02
Cymbella	2.55	1.54	12,500	0.78	0.89
Denticula	2.91	0.79	12,000	0.65	0.78
Diatoma	2.54	1.02	11,000	0.63	1.58
Diploneis	2.95	0.10	10,000	0.80	1.18
Encyonema	2.49	2.71	9750	0.54	0.42
Epithemia	2.96	0.53	9000	0.36	0.16
Eunotia	0.25	-0.17	8500	0.46	0.20
Fragilaria	2.97	0.89	7000	0.50	0.21
Frustulia	2.38	1.02	6000	0.41	0.17
Gomphonema	0.71	-0.27	5250	0.44	0.05
Gyrosigma	2.91	0.43	4000	0.44	0.23
Hantzschia	0.40	0.76	3250	0.47	0.27
Luticola	2.47	0.83	2250	0.45	0.38
Meridion	3.00	0.32	2000	0.24	0.88
Navicula	2.63	0.42	1750	0.15	1.56
Neidium	0.66	2.02	1000	0.00	1.68
Nitzschia	0.27	-0.67	750	0.52	1.10
Orthoseira	2.91	0.79	250	0.36	1.59
Pinnularia	0.84	1.18	0	0.90	0.00
Sellaphora	2.37	1.93			
Stauroneis	0.39	1.77			
Surirella	1.23	1.68			
Synedra	2.36	-1.13			
Tabellaria	2.63	1.48			

Appendix F. Diatom species - % dominance data for 52 species for DCA analysis.

Age BP	AMOVAL	AUDIST	AUHEPZ	AULIRA	AUNYGA	COPLAC	CRAMCU	CYOUSP	ENMSI	EUBILU	EUFORM	EUMPL	EUNQ
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	17.6	0.0	0.2	0.0
250	1.8	22.2	3.5	7.8	7.5	0.0	0.0	13.7	11.4	11.4	0.0	0.6	0.8
750	2.4	22.9	5.6	5.5	4.3	0.0	0.2	0.6	0.0	5.1	0.0	0.4	1.2
1000	3.1	22.2	3.5	4.7	7.0	0.0	0.0	1.8	0.0	3.1	0.0	1.8	0.6
1750	3.2	10.8	3.8	17.8	1.6	0.0	0.0	2.8	0.0	2.6	0.6	0.4	1.2
2000	1.2	4.7	3.4	7.7	0.0	0.0	0.0	0.0	0.0	14.4	0.2	0.2	0.8
2250	0.8	1.4	0.8	1.0	0.0	0.0	0.2	0.0	0.0	16.8	0.0	2.1	1.4
3250	1.2	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.8	6.9	1.4	11.7	5.5
4000	1.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0	11.0	1.2	8.0	7.6
5250	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	0.8	10.0	12.6
6000	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	3.1	0.4	4.8	6.3
7000	1.4	0.4	1.0	1.2	0.0	0.0	0.0	0.2	1.6	18.0	0.6	5.7	5.9
8500	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	5.6	0.0	5.6	9.0
9000	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	18.8	0.4	4.8	4.3
9750	0.0	0.0	0.2	0.2	0.0	0.0	2.0	0.0	0.0	12.3	0.2	1.6	3.2
10,000	2.8	0.0	0.0	0.0	0.0	0.0	4.3	6.1	0.0	4.5	0.0	1.2	1.2
11,000	0.6	0.0	0.0	0.0	0.0	0.0	0.6	1.0	0.0	2.1	0.0	0.4	0.6
12,000	0.2	0.0	0.0	0.0	0.0	0.0	2.4	0.6	0.0	1.8	0.0	0.6	5.0
12,500	0.4	0.0	0.0	0.0	0.0	0.0	1.6	0.4	0.6	8.9	0.0	0.4	0.4
12,750	0.7	0.0	0.0	0.0	0.0	0.2	0.2	1.1	4.3	0.7	0.0	0.2	2.8
13,000	0.6	0.0	0.0	0.0	0.0	0.0	0.2	2.0	0.6	0.2	0.0	0.2	1.0
14,000	0.6	0.0	0.0	0.0	0.0	1.3	0.0	0.6	0.4	0.2	0.0	0.0	2.5
15,000	0.6	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.9	0.6	1.3	0.4	1.7
18,500	1.0	0.0	0.0	0.0	0.0	3.5	0.2	0.6	1.0	0.3	0.0	0.0	2.2
19,000	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Appendix F (continued)

Diatom species - % dominance data for 52 species for DCA analysis.

	EUMINO	EUMONO	EURAE	FROONS	FROOVE	FRINN	FURHOM	GOGFAC	GOPARV	NAAMER	NEAFIR	GYSIGM	FIGBB	PISTRE
0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	7.2	2.6	0.0	0.0	0.0	0.4	0.0
1.8	4.1	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.8	0.4	1.2	0.0	0.2	0.0
1.8	2.8	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.8	2.2	0.0	0.2	0.8
2.1	8.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.6	3.5	0.0	0.0	0.4
2.0	6.4	0.2	0.0	0.0	0.0	0.0	0.0	2.6	0.0	2.6	1.4	0.0	1.4	0.2
6.1	17.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	1.0	0.0	0.0	0.0
5.3	28.5	0.8	0.0	0.0	0.0	0.0	0.0	0.6	0.0	4.3	1.4	0.0	0.0	0.2
9.9	16.2	1.0	0.0	0.0	0.0	0.0	0.0	12.1	0.0	2.6	1.6	0.0	0.6	0.0
7.2	19.8	1.2	0.0	0.0	0.0	0.2	0.0	3.5	0.0	1.6	0.6	0.0	0.0	0.0
9.7	20.0	1.7	0.0	0.0	0.0	0.0	0.0	5.4	0.0	1.7	0.6	0.0	0.0	0.0
13.7	36.3	0.4	0.0	0.0	0.0	0.0	0.0	11.7	1.0	0.8	0.4	0.0	1.0	1.5
3.3	16.7	0.4	0.4	0.4	0.0	0.0	0.0	5.1	1.4	1.0	0.8	0.0	0.6	0.2
13.4	26.2	0.0	0.0	0.0	0.0	0.0	0.0	11.6	0.0	1.8	1.4	0.0	2.0	1.0
8.9	15.7	0.4	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.8	1.0	0.0	0.0	0.0
5.1	15.8	1.6	0.0	0.0	0.0	0.4	0.2	4.3	0.0	0.8	5.1	0.0	0.4	0.0
0.2	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	10.4	0.0	0.0	0.0
2.1	7.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	14.1	0.0	0.0	0.0
11.3	4.5	0.3	0.0	0.0	0.0	0.9	0.0	3.6	0.0	1.2	3.0	0.0	5.6	1.5
6.0	2.5	0.0	0.0	0.0	0.0	0.2	0.6	1.9	1.2	0.8	4.3	0.0	1.2	0.0
0.6	0.7	0.0	14.4	0.0	2.0	35.9	3.0	0.2	0.0	0.2	0.6	0.2	0.0	0.0
0.4	1.8	0.0	18.6	0.0	0.0	51.8	0.0	0.4	0.0	0.8	0.8	0.0	0.4	0.0
0.4	3.6	0.0	8.2	0.0	0.0	35.4	0.0	0.0	0.0	0.0	0.8	13.2	0.0	0.0
0.0	7.2	0.0	9.1	0.0	0.8	25.3	0.0	0.0	0.0	0.4	0.2	7.4	0.8	0.0
0.2	0.0	0.3	26.2	0.0	1.3	36.4	0.0	0.8	0.0	0.0	0.6	0.5	0.0	0.0
0.0	0.0	0.0	44.7	0.0	1.2	42.7	0.0	0.0	0.0	0.2	0.2	0.4	0.0	0.0

Appendix F (continued)
Diatom species - % dominance data for 52 species for DCA analysis.

FVIRI	SERUFU	STPHOE	TAFEEI	EPADTU	AUAMBI	AUISLA	CYASFE	CYCIST	EUDIOD	EUGLAC	EUINTE	EURHOM	FRLAPP
0.2	3.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
0.0	4.7	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.8	1.2	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
1.8	0.6	13.3	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
0.8	1.2	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
0.0	0.2	7.3	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
0.0	0.4	8.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.2	0.0
0.0	0.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.4	1.4	0.0	0.0
0.2	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0
0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.2	1.5	3.1	0.0	0.0	0.0	1.7	0.0	0.0	0.0	1.2	0.0	0.0	0.0
0.2	1.4	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.4	1.2	0.0
2.4	1.6	4.0	0.2	0.0	0.0	2.4	0.0	0.0	1.2	1.8	0.0	0.0	0.0
0.6	0.8	4.5	0.0	0.0	0.0	2.5	0.0	0.0	0.2	0.6	0.4	1.9	0.0
0.4	0.4	9.9	0.6	0.0	0.0	0.0	0.0	1.8	0.2	0.8	0.0	1.0	0.0
0.4	0.4	21.9	2.2	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.2	34.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.4	3.0	20.2	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.6	1.8	11.3	1.9	0.0	0.6	0.0	0.0	0.0	0.0	0.4	0.0	0.6	0.0
0.0	6.3	0.8	3.5	0.0	0.6	0.0	0.0	0.0	0.2	0.0	0.0	0.4	0.0
0.0	1.0	2.8	0.6	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.0
0.0	0.0	1.9	0.4	1.5	1.3	0.0	0.6	0.6	0.0	0.0	0.0	0.0	0.8
0.4	0.0	1.1	4.0	0.9	0.0	0.0	1.3	8.1	0.0	0.0	0.0	0.0	1.1
0.2	0.3	1.3	0.0	4.6	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.2
0.0	0.4	0.0	0.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix F (continued)
Diatom species - % dominance data for 52 species for DCA analysis.

GOACUM	GOANGU	GOAPIC	GOSARC	GOTUPR	NAMINI	NAMOUR	NARADI	FIGGA	FIGOR	STANCE
0.2	8.8	0.0	0.0	0.0	1.4	0.0	14.8	0.0	1.4	2.8
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0	1.2	0.2	0.0
0.0	0.0	0.0	0.2	2.9	0.0	0.0	0.0	0.4	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
0.0	0.0	0.0	0.8	2.7	0.0	0.0	0.8	0.2	0.2	0.6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.4
0.0	0.6	0.0	0.0	1.0	0.0	0.0	0.0	0.2	0.0	0.2
0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.6	1.6	0.0	0.0	0.0	0.0	0.0	1.4	0.2	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.3	0.0
0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.8	0.2	0.4
0.4	0.2	0.2	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
1.2	0.0	0.2	0.0	0.0	0.4	0.0	0.0	0.6	0.0	0.0
0.2	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.6	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.6	0.2	0.0	0.0
0.3	0.3	0.0	1.3	0.0	0.0	0.3	0.3	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	1.0	0.6	0.0	0.0	0.0	0.0

Appendix G. Detrended Correspondence Analyses (DCA) of diatom species data.

Species	Code	Axis 1	Axis 2
<i>Amphora ovalis</i> & varieties	AMOVAL	1.31	0.08
<i>Aulacoseira ambigua</i>	AUAMBI	3.52	1.23
<i>Aulacoseira distans</i>	AUDIST	-0.67	0.03
<i>Aulacoseira herzogii</i>	AUHERZ	-0.73	0.30
<i>Aulacoseira islandica</i>	AUISLA	-0.28	-1.08
<i>Aulacoseira lirata</i> f. <i>biseriata</i>	AULIRA	-0.67	0.04
<i>Aulacoseira nygaardii</i>	AUNYGA	-0.63	-0.15
<i>Cocconeis placentula</i> var. <i>lineata</i>	COPLAC	3.86	0.94
<i>Craticula ambigua</i> & <i>C. cuspidata</i>	CRAMCU	1.39	0.62
<i>Cymbella aspera</i>	CYASPE	3.63	0.80
<i>Cymbella cistula</i>	CYCIST	3.58	0.82
<i>Cymbella cuspidata</i>	CYCUSP	1.35	-0.35
<i>Encyonema minutum</i> & <i>E. silesiacum</i>	ENMISI	2.92	0.26
<i>Epithemia adnata</i> , <i>E. turgida</i> & varieties	EPADTU	3.90	0.98
<i>Eunotia bilunaris</i>	EUBILU	0.04	2.63
<i>Eunotia diodon</i>	EUDIOD	1.10	0.40
<i>Eunotia formica</i>	EUFORM	2.36	-0.23
<i>Eunotia glacialis</i>	EUGLAC	-0.03	-0.56
<i>Eunotia implicata</i>	EUI MPL	0.15	-0.53
<i>Eunotia incisa</i>	EUINCI	2.17	-0.06
<i>Eunotia intermedia</i>	EUI NTE	1.18	-0.77
<i>Eunotia minor</i>	EUMINO	0.13	-0.46
<i>Eunotia monodon</i>	EUMONO	0.81	-0.40
<i>Eunotia praerupta</i> & varieties	EUPRAE	0.75	-0.24
<i>Eunotia rhomboidea</i>	EURHOM	1.24	0.68
<i>Fragilaria construens</i>	FRCONS	3.92	0.95
<i>Fragilaria construens</i> var. <i>venter</i>	FRCOVE	3.92	0.99
<i>Fragilaria lapponica</i>	FRLAPP	3.77	0.77
<i>Fragilaria pinnata</i>	FRPINN	3.86	0.91
<i>Frustulia rhomboides</i>	FURHOM	3.00	1.92
<i>Gomphonema acuminatum</i>	GOACUM	3.67	2.63
<i>Gomphonema angustatum</i>	GOANGU	0.58	3.76
<i>Gomphonema apicatum</i>	GOAPIC	2.78	0.75
<i>Gomphonema gracile</i>	GOGRAC	0.20	1.68
<i>Gomphonema parvulum</i>	GOPARV	0.09	3.39
<i>Gomphonema sarcophagus</i>	GOSARC	3.42	0.80
<i>Gomphonema turris</i>	GOTURR	0.28	0.59
<i>Gyrosigma acuminatum</i>	GYSIGM	3.79	0.68
<i>Navicula americana</i>	NAAMER	0.79	-0.16
<i>Navicula minima</i>	NAMINI	3.31	3.52
<i>Navicula mournei</i>	NAMOUR	3.82	0.82
<i>Navicula radiosa</i>	NARADI	0.65	3.84
<i>Neidium affine</i> & <i>N. iridis</i>	NEAFIR	1.08	0.44
<i>Pinnularia gibba</i>	PIGIBB	1.59	0.68
<i>Pinnularia gigas</i>	PIGIGA	2.96	0.56
<i>Pinnularia microstauron</i>	PIMICR	-0.20	3.26
<i>Pinnularia streptoraphe</i>	PISTRE	-0.26	-0.48
<i>Pinnularia viridis</i>	PIVIRI	0.48	-0.13
<i>Sellaphora pupula</i> var. <i>rectangularis</i>	SEPUPU	2.98	0.44
<i>Stauroneis anceps</i> & varieties	STANCE	-0.12	3.56
<i>Stauroneis phoenicenteron</i>	STPHOE	0.66	0.40
<i>Tabellaria fenestrata</i> & <i>T. flocculosa</i>	TAFEFL	3.31	0.87

Appendix G (continued)

Detrended Correspondence Analyses (DCA) of diatom species data.

Years BP	Axis 1	Axis 2
0	0.44	2.92
250	0.51	0.35
750	0.00	0.31
1000	0.07	0.18
1750	0.16	0.20
2000	0.12	0.74
2250	0.56	0.46
3250	0.59	0.27
4000	0.87	0.00
5250	0.86	0.41
6000	0.66	0.05
7000	0.87	0.29
8500	0.52	0.19
9000	0.56	0.58
9750	0.74	0.58
10,000	1.07	0.45
11,000	0.77	0.35
12,000	0.73	0.27
12,500	0.98	1.00
12,750	3.38	0.80
13,000	3.51	0.87
14,000	3.45	0.75
15,000	3.24	0.70
18,500	3.62	0.91
19,000	3.87	0.93

Appendix H. Diatom genera scores based upon percentage abundance (%) and upon presence/absence (P/A) presented along DCA Axis 1.

Years BP	DCA Axis 1 (%)	DCA Axis 1 (P/A)	Midpoint	Years BP	SD/250	yr (%)	SD/250	yr (P/A)
19,000	2.89	1.15		18,750		0.125		0.015
18,500	2.64	1.12		16,750		0.020		0.004
15,000	2.35	1.18		14,500		0.005		0.003
14,000	2.37	1.19		13,500		0.038		0.135
13,000	2.52	0.65		12,875		0.050		0.000
12,750	2.47	0.65		12,625		1.690		0.230
12,500	0.78	0.42		12,250		0.065		0.130
12,000	0.65	0.68		11,500		0.005		0.065
11,000	0.63	0.42		10,500		0.043		0.013
10,000	0.80	0.37		9875		0.260		0.240
9750	0.54	0.13		9375		0.060		0.030
9000	0.36	0.04		8750		0.050		0.110
8500	0.46	0.26		7750		0.007		0.007
7000	0.50	0.22		6500		0.023		0.030
6000	0.41	0.10		5625		0.010		0.033
5250	0.44	0.00		4625		0.000		0.066
4000	0.44	0.33		3625		0.010		0.070
3250	0.47	0.12		2750		0.005		0.018
2250	0.45	0.05		2125		0.210		0.010
2000	0.24	0.06		1875		0.090		0.050
1750	0.15	0.01		1375		0.050		0.000
1000	0.00	0.01		875		0.520		0.210
750	0.52	0.22		500		0.080		0.080
250	0.36	0.06		125		0.540		0.060
0	0.90	0.12						

Appendix I. Diatom species scores based upon percent age abundance (%) and upon presence/ absence (P/A) presented along DCA Axis 1.

Years BP	DCA Axis 1 (%)	DCA Axis 1 (P/A)	Midpoint	Years BP	SD/250 yr (%)	SD/250 yr (P/A)
19,000	3.87	2.34		18,750	0.125	0.345
18,500	3.62	1.65		16,750	0.027	0.010
15,000	3.24	1.79		14,500	0.053	0.058
14,000	3.45	2.02		13,500	0.015	0.225
13,000	3.51	1.12		12,875	0.130	0.350
12,750	3.38	1.47		12,625	2.400	0.370
12,500	0.98	0.79		12,250	0.125	0.105
12,000	0.73	0.58		11,500	0.010	0.068
11,000	0.77	0.85		10,500	0.075	0.058
10,000	1.07	1.08		9875	0.330	0.580
9750	0.74	0.50		9375	0.060	0.030
9000	0.56	0.41		8750	0.020	0.045
8500	0.52	0.32		7750	0.058	0.005
7000	0.87	0.29		6500	0.053	0.023
6000	0.66	0.20		5625	0.067	0.123
5250	0.86	0.57		4625	0.002	0.024
4000	0.87	0.45		3625	0.093	0.063
3250	0.59	0.26		2750	0.008	0.010
2250	0.56	0.30		2125	0.440	0.130
2000	0.12	0.43		1875	0.040	0.430
1750	0.16	0.00		1375	0.030	0.000
1000	0.07	0.00		875	0.070	0.090
750	0.00	0.09		500	0.255	0.035
250	0.51	0.16		125	0.070	0.540
0	0.44	0.07				

Appendix J. Arboreal pollen scores based upon percentage abundance (%) and upon presence/ absence (P/A) presented along DCA Axis 1.

Years BP	DCA Axis 1 (%)	DCA Axis 1 (P/A)	Midpoint	Years BP	SD/250 yr (%)	SD/250 yr (P/A)
18,903	2.30	1.41		18,724	0.028	0.084
18,544	2.26	1.29		16,705	0.043	0.053
14,866	1.62	0.51		14,473	0.124	0.076
14,079	1.23	0.75		13,488	0.013	0.000
12,897	1.17	0.75		12,806	0.014	0.000
12,714	1.18	0.75		12,630	0.580	0.000
12,546	0.79	0.75		12,393	0.041	0.130
12,239	0.74	0.59		11,637	0.002	0.033
11,035	0.73	0.75		10,434	0.106	0.094
9832	0.22	0.30		9531	0.000	0.228
9230	0.22	0.85		8914	0.028	0.292
8597	0.15	0.11		7934	0.028	0.000
7270	0.00	0.11		6606	0.000	0.000
5941	0.00	0.11		5652	0.242	0.095
5363	0.56	0.33		4624	0.010	0.037
3884	0.50	0.11		3638	0.162	0.096
3391	0.18	0.30		2898	0.005	0.033
2404	0.16	0.17		2158	0.081	0.046
1911	0.32	0.26		1665	0.050	0.076
1418	0.22	0.41		1172	0.020	0.208
925	0.26	0.00		679	0.020	0.086
432	0.30	0.17		304	0.175	0.000
175	0.12	0.17		88	0.629	0.000
0	0.56	0.17				

Appendix K. Aquatic pollen scores based upon percentage abundance (%) and upon presence/absence (P/A) presented along DCA Axis 1.

Years BP	DCA Axis 1 (%)	DCA Axis 1 (P/A)	Midpoint	Years BP	SD/250 yr (%)	SD/250 yr (P/A)
18,903	1.64	2.45	18,724	0.536	0.543	
18,544	0.87	1.67	16,705	0.009	0.090	
14,866	0.74	0.35	14,473	0.038	0.311	
14,079	0.86	1.33	13,488	0.057	0.023	
12,897	1.13	1.22	12,806	0.355	0.014	
12,714	1.39	1.21	12,630	0.580	0.238	
12,546	1.78	1.50	12,393	0.122	0.033	
12,239	1.93	1.54	11,637	0.033	0.089	
11,035	1.77	1.11	10,434	0.079	0.004	
9832	2.15	1.13	9531	0.020	0.278	
9230	2.20	1.80	8914	0.656	0.494	
8597	0.54	0.55	7934	0.062	0.139	
7270	0.21	1.29	6606	0.008	0.058	
5941	0.17	0.98	5652	0.043	0.134	
5363	0.07	0.67	4624	0.015	0.035	
3884	0.16	0.46	3638	0.030	0.000	
3391	0.22	0.46	2898	0.003	0.058	
2404	0.23	0.23	2158	0.005	0.198	
1911	0.24	0.62	1665	0.005	0.152	
1418	0.23	0.32	1172	0.066	0.619	
925	0.36	1.54	679	0.035	0.598	
432	0.29	0.36	304	0.097	0.078	
175	0.19	0.28	88	0.270	0.400	
0	0.00	0.00				

Appendix L. Overall comparison of DCA Scores for rates of change of Beta SD values per 250 year intervals (SD/250 yr) as measured from DCA Axis 1 scores.

Years BP	Arboreal	Pollen	Aquatic Pollen	Years BP	Diatoms
18,724		0.028	0.536	18,750	0.125
16,705		0.043	0.009	16,750	0.020
14,473		0.124	0.038	14,500	0.005
13,488		0.013	0.057	13,500	0.038
12,806		0.014	0.355	12,875	0.050
12,630		0.580	0.580	12,625	1.690
12,393		0.041	0.122	12,250	0.065
11,637		0.002	0.033	11,500	0.005
10,434		0.106	0.079	10,500	0.043
9531		0.000	0.020	9875	0.260
8914		0.028	0.656	9375	0.060
7934		0.028	0.062	8750	0.050
6606		0.000	0.008	7750	0.007
5652		0.242	0.043	6500	0.023
4624		0.010	0.015	5625	0.010
3638		0.162	0.030	4625	0.000
2898		0.005	0.003	3625	0.010
2158		0.081	0.005	2750	0.005
1665		0.050	0.005	2125	0.210
1172		0.020	0.066	1875	0.090
679		0.020	0.035	1375	0.050
304		0.175	0.097	875	0.520
88		0.629	0.270	500	0.080
				125	0.540

Appendix M. pH indices for Hustedt diatom groups and calculated pH values based on Renberg & Hellberg's log index B.

Years BP	Acidophilous	pH-Indifferent	Alkaliphilous	Alkalibiontic	Unknown	Calculated pH
0	20.8 %	42.4 %	14.2 %	0.0 %	22.6 %	6.2
250	47.1	16.4	2.2	0.0	34.3	5.5
750	39.5	23.8	0.5	0.0	36.2	5.8
1000	41.6	25.5	4.3	0.0	28.6	5.8
1750	44.0	22.0	6.6	0.0	27.4	5.8
2000	45.8	15.2	4.6	0.0	34.4	5.6
2250	52.8	17.1	5.3	0.0	24.8	5.6
3250	46.7	35.5	4.4	0.0	13.4	5.8
4000	50.9	23.6	5.0	0.0	20.5	5.7
5250	52.4	24.0	6.0	0.0	17.6	5.7
6000	53.9	35.6	5.2	0.0	5.3	5.8
7000	52.3	21.9	5.9	0.0	19.9	5.7
8500	51.2	38.0	5.8	0.0	5.0	5.8
9000	47.7	25.6	8.1	0.0	18.6	5.8
9750	36.7	26.4	5.6	0.0	31.3	5.8
10,000	16.2	40.4	10.9	0.0	32.5	6.2
11,000	10.8	52.8	1.6	0.2	34.6	6.3
12,000	20.9	53.9	6.3	0.0	18.9	6.1
12,500	9.4	33.8	3.4	0.0	53.4	6.2
12,750	12.2	18.8	56.0	0.2	16.8	6.8
13,000	4.8	10.4	74.0	0.0	10.8	7.2
14,000	7.7	6.6	62.1	1.5	22.1	7.2
15,000	13.0	8.1	57.8	1.0	20.1	6.9
18,500	3.0	10.2	74.2	4.7	7.9	7.7
19,000	1.8	1.4	91.6	0.6	4.6	7.7

Vita

Robert L. Tolliver was born in Columbus, Ohio, on May 16, 1962. He grew up in Taylor, Michigan, and Moddersville, Michigan. He graduated from high school in 1980 and then went to Michigan State University, East Lansing, Michigan. In 1988, he graduated with a BS degree in Geology.

In 1988, Robert began work on his MS in Geology at Western Michigan University. His areas of concentration there were sedimentary geology, hydrogeology, and Quaternary geology. It was at Western Michigan University that Robert developed an interest in paleontology. He graduated in 1992 with an MS in Geology.

In 1992, Robert began work on his PhD in Geology, where he researched the paleoecology of diatoms in late-Quaternary lake sediments and their use in re-constructing paleoclimates. It was here that he met his wife, Christina Gayle Orr, a graduate student in the English department. They were married in 1995.