

# Diatoms in sediment cores in Utah Lake, Utah, U.S.A.

Adchara Javakul, Judith A. Grimes & Samuel R. Rushforth

*Department of Botany and Range Science, Brigham Young University, Provo, Utah 84602, U.S.A.*

Keywords: diatoms, sediment cores

## Abstract

Diatoms from sediment cores taken from Provo Bay, Geneva and midlake sites in Utah Lake, Utah County, Utah were studied. Algal communities from strata at four centimeter intervals of the cores were analyzed. This study has demonstrated that the diatom flora in Utah Lake has changed through time and that the diatom communities of Provo Bay are floristically unique from those of the main body of the lake.

## Introduction

Studies of fossil and subfossil diatoms are commonly used to help assess present and past ecological conditions of a variety of types of waters (Stockner 1972). The siliceous diatom cell wall is often preserved in sediments and can provide valuable evidence of limnologic change through time (Bradbury 1975). Likewise, diatoms are sensitive to and characteristic of their environment and many are narrow in their ecological tolerances. Thus, the identification of species through time as recorded in the sediments and the determination of their sensitivity to various ecological parameters (Palmer 1969) makes it possible to glean significant information concerning earlier environments. Shifts in dominant species through time as determined by examining sediment cores often allow an understanding of lake aging (Patrick 1973, 1977). The historic profile gained by these methods can provide necessary information for making sound management decisions and forecasting future trends in lake development. Such methods have been used to provide evidence of cultural eutrophication (Bolland 1974; Bradbury 1975; Duthie & Sreenivasa 1971) and as a base for management decisions such as those that reversed trends of cultural eutrophica-

tion in Lake Washington (Stockner & Benson 1967).

Significant studies of the sediments of Utah Lake include those by Bingham (1975), Bissell (1942, 1963), Brimhall (1972), Brimhall & Merritt (1981), Bushman (1980), Fuhrman *et al.* (1975), Hunt (1953), Hyatt *et al.* (1969) and Sonnerholm (1974). These studies have been primarily geological and have not involved examination of the biota of the strata. However, they have provided perspective and understanding of the ecological and depositional conditions of the lake.

Diatoms in the sediments of Utah Lake were examined by Grimes & Rushforth (1982) who studied the relationship of recent bottom sediment diatoms to lake trophic status. In Grimes' study recent bottom sediments were taken from various locations in the lake and diatom assemblages were analyzed and compared with those from other lakes and reservoirs in Utah.

Bolland (1974) also examined diatoms in the sediments of Utah Lake. He studied a 500 cm core extracted from a site approximately 2.5 km west of the shoreline adjacent to United States Steel's Geneva Works (latitude 40° 18' 13" North, longitude 111° 47' 43" West). The core was analyzed for chemical profiles and predominant diatom assem-

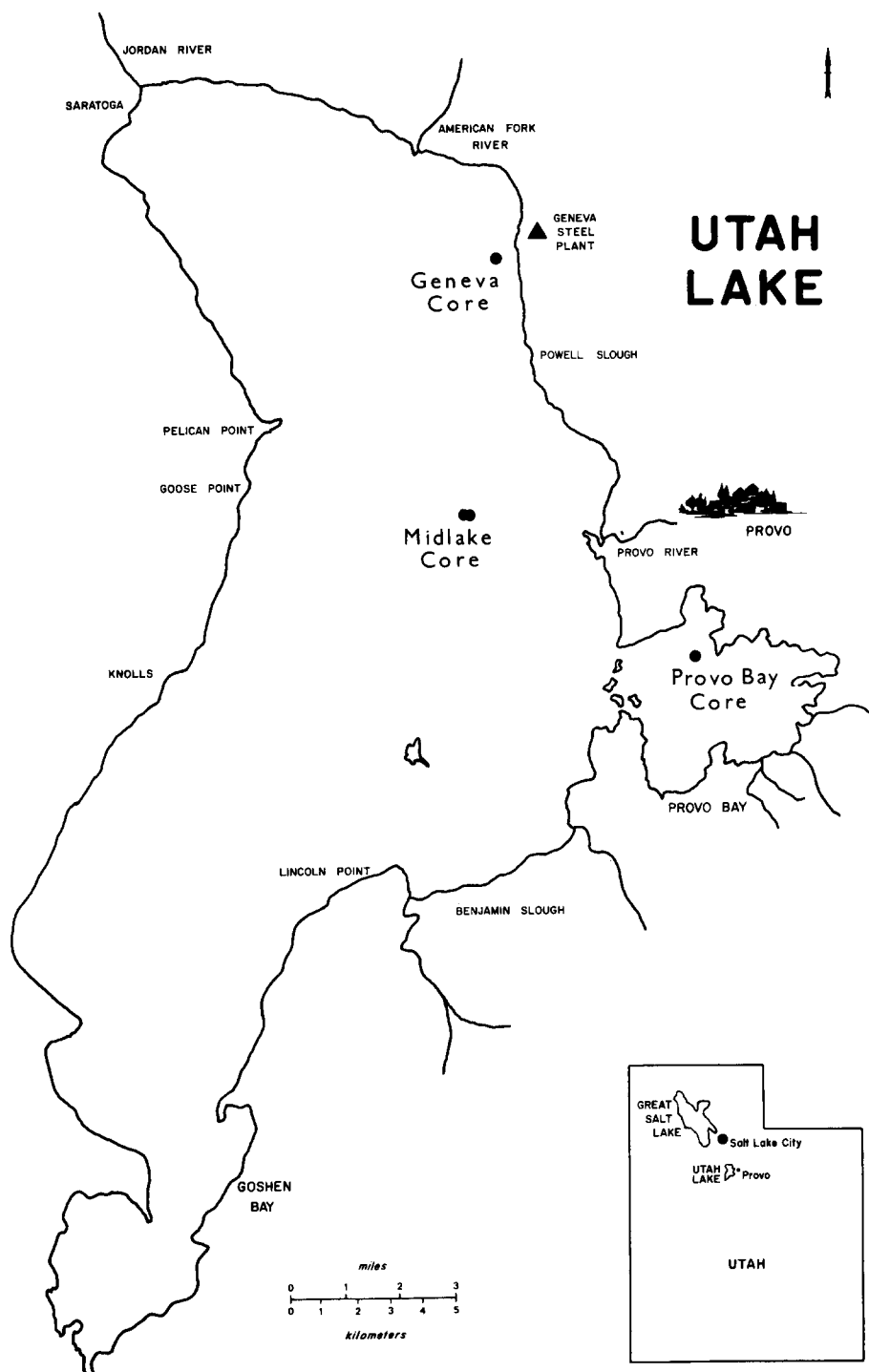


Fig. 1. Reference map of Utah Lake showing the prominent lakeside features and localities where cores were extracted for this study

blages and evaluated for correlations between the two. Both Grimes & Rushforth (1982) and Bolland (1974) concluded that Utah Lake is highly eutrophic and Bolland also illustrated diatom changes through time and concluded that rapid cultural eutrophication had occurred.

The present study was designed to provide more information concerning diatom distribution both spatially and temporally in Utah Lake. Cores were taken from three different parts of the lake (Provo Bay, midlake and Geneva; Fig. 1) which represent at least two supposedly different ecological habitats. This was done to provide more diverse information concerning floristic and ecological changes through time particularly between Provo Bay and the main body of the lake. Furthermore, we wanted to compare cores from different areas to determine whether diatom sedimentation is localized enough to allow the classification of ecological subunits within Utah Lake.

### Site description

Utah Lake is a turbid, shallow, isothermal, saline-eutrophic lake similar to some found in prairie states of midwestern North America (Grimes & Rushforth 1982). The lake is located in a valley of the Rocky Mountains at the east margin of the Basin and Range Province (Fig. 1). The lake is one of the largest freshwater lakes in western North America covering 38,446 ha and containing roughly 850,000 ac ft of water. It is bordered on the east by the Wasatch Range with peaks rising precipitously from the valley floor at 1,366 m to elevations of more than 3650 m. The Traverse Range bounds the north end of the lake and the Lake Mountains form the western border. These ranges are lower in elevation than the Wasatch but are nevertheless prominent. Utah Lake is a natural lake drained by the Jordan River which runs through a gorge known as the Narrows that forms a break in the Traverse Range at the northwest of the lake. The Jordan River drains into the Great Salt Lake. Utah Lake level is controlled by the Narrows dam at the outlet of the Jordan river (Bissell 1942). Water enters the lake from three major perennial streams (Provo and Spanish Fork Rivers and Hobble Creek) draining the western portion of the Wasatch Range. Other sources of inflow include seepage, return water from irrigated

land, sewage effluent and industrial waste, storm runoff, and spring water discharged at the edge of the lake or through bottom sediments (Hunt 1953).

The average depth of the lake is approximately 240 cm (8 ft) (Brimhall 1972) and due to the large surface area evaporative losses can exceed that taken for irrigation by as much as one third. In all years between 1930 and 1935 water loss by evaporation exceeded that by diversions (Hunt 1953). Bissell (1942) has documented an increase in salinity levels within the lake over the past 50 years. He attributed this increase to the high NaCl content of contributing thermal and cold springs, the dam at the head of the Jordan river which keeps the lake level generally higher thus increasing evaporation, and drainage from saline irrigated land near Goshen, Saratoga and Lehi.

Sedimentation rates in Utah Lake have been a matter of controversy for some time (Bushman 1980). Rates of sedimentation have been estimated using chemical component analyses in cores (Brimhall 1972), acoustical profiles (Brimhall & Merritt 1981), pollen profiles, particularly of species introduced at the time of settlement (Bushman 1980), diatom floristics and radio-carbon dating (Bolland 1974). Brimhall (1972) estimated sedimentation rates for Utah Lake to be 2.4 cm per year from 1885 to 1935 and 3.3 cm per year from 1935 to 1965. This estimate was formed using the high concentration of calcium carbonate in the sediments at 120 cm and the low concentration at 240 cm as possible indicators of known record high and low water levels that occurred in 1885 and 1935 respectively.

Brimhall *et al.* (1976) used an acoustical method (sonar) to estimate sedimentation rates by identifying a layer thought to have been formed in Lake Bonneville approximately 10,000 years ago at 8.5 m. Sedimentation rates associated with this date and depth would be approximately 0.85 mm per year. Bushman (1980) identified pollen of *Taraxacum officinale* (dandelion) at 170 cm in the core studied earlier by Bolland (1974). The earliest date of introduction of this species into Utah Valley is thought to be 1847, which gives an estimated average sedimentation rate of 1.38 cm per year since the middle 1800's. Bolland (1974) collected 1.8 g (dry wt) of peat material at 490–500 cm in this core which was tested using radio-carbon dating methods. This represents the only carbon date performed on Utah Lake sediments. The sample was

dated at 11,400 B. P.  $\pm$  850 years. Assuming that this date is accurate and that the deposition rate has been constant, a sedimentation rate of 0.44 mm per year was calculated. However, Bolland (1974) did not believe his carbon date was accurate. Using the diatom sequence he determined, the sediments and chemical data obtained from his core (analyzed by Brimhall 1972), and known climatological events, he estimated the sedimentation rate to be 2.4 cm per year between 1885 and 1935 and 3.43 cm since 1935.

This discrepancy among these dating methods is alarming and as of yet the dating issue remains unresolved. However, in our opinion the sedimentation rate determined by calcium carbonate analysis (Brimhall 1972) is too great. At rates greater than 3 cm per year the lake would have filled with sediment by the present time unless unusually rapid basin subsidence has been concurrent. Conversely, the rate of 0.44 mm estimated from radio-carbon dating of the peat appears to be too low since it would place Lake Bonneville sediments 4 m higher in the strata than observed using the acoustical method (Brimhall & Merritt 1981). In addition, this estimate is lower than estimates of recent sedimentation rates for other much less eutrophic lakes (Kemp *et al.* 1974) such as Lake Washington (3.1 mm per year), selected Wisconsin Lakes (1.0 to 7.0 mm per year) and Lake Ontario (1.0 to 5.4 mm per year). It is not possible for us to resolve this problem at the present time. However, our data and observations lead us to believe that sedimentation rates are variable both spacially and temporally within the lake. For recent years, the sedimentation rate estimate of Bushman of 14 mm per year (1980) agrees with certain of our diatom depositional data. Further studies to resolve these problems are essential.

## Methods

### *Field and laboratory*

Core samples were collected from several sites in Utah Lake in July, 1975. Cores were obtained with a polyvinylchloride tube 4.5 cm in diameter that had been sharpened on one end for penetration. The tube was forced into the lake sediments as deeply as possible and then stoppered. The tube was then removed from the lake bottom together with

the sediment core and returned to the laboratory.

Three cores were selected for analyses. The first was obtained from Provo Bay 1.2 km off the radio towers in the northeast part of the bay (T7SR2ES15). It was only 28 cm long due to difficulty in coring the sediments typical of Provo Bay. The second was recovered approximately 0.3 km west of the wastewater settling ponds of United States Steel Geneva Works (T6SR2ES07). This core was 116 cm long. The third core was recovered east of midlake approximately 2.5 km west of Provo Boat Harbor (T7SR2ES06) (Fig. 1). This core was 124 cm long.

Subsamples were extracted from each core at 4 cm intervals using a sharp cork borer which was washed between extracting each sample. Subsamples were transferred into 250 ml beakers for laboratory processing. Permanent diatom slides were prepared following standard nitric acid oxidation methods (St. Clair & Rushforth 1977) and were mounted in Naphrax diatom mountant. Slides were examined and diatom species identified and counted at 1000x using Zeiss RA microscopes with Nomarski interference phase contrast and bright field objectives.

### *Data analysis*

Quantitative data were obtained by counting a minimum of 400 diatoms per slide. Figures obtained in this manner were converted to percent relative densities for each species identified.

Importance values for all species encountered in the study were computed by multiplying average percent relative density times percent frequency (Ross & Rushforth 1980). Importance values were also determined in the same manner for each core separately.

Relative densities of all diatoms per sample were used to compute similarity indices for each level in the three cores relative to those of all other levels in the three cores following the methods of Ruzicka (1958). These indices were then used to perform cluster analyses of species following Sneath & Sokal (1973) to determine if patterns of similarity existed in depth and/or core locations.

Spearman rank correlation analysis was performed on ranked average importance values from the three cores in three different combinations for comparison of important species in the three cores (Snedecor & Cochran 1968). This analysis was li-

Table 1. List of diatom species observed in cores studied from Utah Lake.

Family Coscinodiscaceae	
Cyclotella kuetzingiana var. planetophora Fricke	Cyclotella meneghiniana Kützing
Cyclotella ocellata Pantocsek	Melosira granulata (Ehr.) Ralfs
Melosira granulata var. angustissima Mueller	Melosira islandica Mueller
Melosira italica (Ehr.) Kützing	Melosira varians Agardh
Stephanodiscus dubius Thwaites	Stephanodiscus invisitatus Hohn and Hellerman
Stephanodiscus niagarae Ehrenberg	Stephanodiscus subtilis van Goor
Stephanodiscus species 1	Stephanodiscus species 2
Family Fragilariaceae	
Tabellaria fenestrata (Lyngb.) Kützing	Diatoma tenue Agardh
Diatoma vulgare Bory	Opephora martyi Heribaud
Fragilaria brevistriata var. inflata (Pant.) Hustedt	Fragilaria construens (Ehr.) Grunow
Fragilaria construens var. binodis (Ehr.) Grunow	Fragilaria construens var. pumila Grunow
Fragilaria construens var. venter (Ehr.) Grunow	Fragilaria crotonensis Kitton
Fragilaria lapponica Grunow	Fragilaria leptostauron (Ehr.) Hustedt
Fragilaria leptostauron var. dubia (Grun.) Hustedt	Fragilaria pinnata Ehrenberg
Fragilaria similis Krasske	Fragilaria vaucheriae (Kütz.) Peterson
Fragilaria virescens Ralfs	Synedra acus Kützing
Synedra amphicephala var. austriaca (Grun.) Hustedt	Synedra capitata Ehrenberg
Synedra delicatissima var. angustissima Grunow	Synedra parasitica (Smith) Hustedt
Synedra rumpens var. meneghiniana Grunow	Synedra ulna (Nitz.) Ehrenberg
Synedra ulna var. oxyrhynchus f. mediocontracta (Forti) Hustedt	
Asterionella formosa Hassall	
Family Eunotiaceae	
Eunotia pectinalis (Muell.) Rabenhorst	
Family Achnanthaceae	
Cocconeis diminuta Pantocsek	Cocconeis disculus (Schum.) Cleve
Cocconeis pediculus Ehrenberg	Cocconeis placentula var. lineata (Ehr.) van Heurck
Achnanthes chilensis var. subaequalis Reimer	Achnanthes clevei Grunow
Achnanthes clevei var. rostrata Hustedt	Achnanthes exigua Grunow
Achnanthes hauckiana Grunow	Achnanthes hauckiana var. rostrata Schultz
Achnanthes lanceolata (Breb.) Grunow	Achnanthes lanceolata var. dubia Grunow
Achnanthes lewisiana Patrick	Achnanthes linearis f. curta H. Smith
Achnanthes minutissima Kützing	Achnanthes pinnata Hustedt
Rhoicosphenia curvata (Kütz.) Grunow ex Rabenhorst	
Family Naviculaceae	
Mastogloia elliptica var. danseii (Thwaites) Cleve	Mastogloia smithii Grunow
Mastogloia smithii var. lacustris Grunow	Gyrosigma acuminatum (Kütz.) Rabenhorst
Gyrosigma spencerii (Queck.) Griffith	Gyrosigma strigilis (W. Smith) Cleve
Stauroneis phoenicenteron (Nitz.) Ehrenberg	Stauroneis species
Anomoeoneis sphaerophora (Ehr.) Pfister	Anomoeoneis vitrea (Grun.) Ross
Neidium dubium (Ehr.) Cleve	Neidium iridis (Ehr.) Cleve
Diploneis elliptica (Kütz.) Cleve	Diploneis marginestriata Hustedt
Diploneis oblongella (Naeg. ex Kütz.) Ross	Diploneis oculata (Breb.) Cleve
Diploneis pseudovalis Hustedt	Diploneis puella (Schum.) Cleve
Diploneis smithii var. dilatata (Breb. ex. W. Smith) Cleve	Diploneis species
Navicula abiskoensis Hustedt	Navicula accomoda Hustedt
Navicula anglica Ralfs	Navicula arvensis Hustedt
Navicula bacillum Ehrenberg	Navicula capitata var. hungarica (Grun.) Ross

*Navicula capitata* var. *luneburgensis* (Grun.) Patrick  
*Navicula circumtexta* Meister ex Hustedt  
*Navicula cryptocephala* var. *veneta* (Kutz.) Rabenhorst  
*Navicula cuspidata* var. *heribaudi* Peragallo  
*Navicula exigua* Greg. ex Grunow  
*Navicula gastrum* (Ehr.) Kützing  
*Navicula graciloides* A. Mayer  
*Navicula heufleri* Grunow  
*Navicula inflexa* (Greg.) Ralfs  
*Navicula menisculus* var. *upsaliensis* (Grun.) Grunow  
*Navicula mutica* Kützing  
*Navicula mutica* var. *nivalis* (Ehr.) Hustedt  
*Navicula pelliculosa* (Breb. ex Kutz.) Hilse  
*Navicula placentula* (Ehr.) Kützing  
*Navicula pupula* Kützing  
*Navicula radiosa* Kützing  
*Navicula radiosa* var. *tenella* (Breb. ex Kützing) Grunow  
*Navicula reinhardtii* var. *elliptica* Heribaud  
*Navicula rhynchocephala* var. *amphiceros* (Kutz.) Grunow  
*Navicula scutelloides* W. Smith ex Gregory  
*Navicula secura* Patrick  
*Navicula tenelloides* Hustedt  
*Navicula tripunctata* var. *schizonemoides* (v.H.) Patrick  
*Navicula viridula* (Kutz.) Ehrenberg  
*Caloneis bacillum* (Grun.) Cleve  
*Caloneis lewisii* Patrick  
*Caloneis schumanniana* var. *fasciata* Hustedt  
*Caloneis silicula* var. *limosa* (Kutz.) van Landingham  
*Pinnularia borealis* Ehrenberg  
*Pinnularia maior* (Kutz.) Rabenhorst  
*Pinnularia obscura* Krasske  
*Pinnularia viridis* var. *minor* Cleve

*Navicula cincta* (Ehr.) Ralfs  
*Navicula cryptocephala* Kützing  
*Navicula cuspidata* (Kutz.) Kützing  
*Navicula cuspidata* var. *major* Meister  
*Navicula festiva* Krasske  
*Navicula gottlandica* Grunow  
*Navicula halophila* (Grun.) Cleve  
*Navicula heufleri* var. *leptocephala* (Breb. ex Gr.) Patrick  
*Navicula lanceolata* (Ag.) Kützing  
*Navicula minima* Grunow  
*Navicula mutica* var. *cohnii* (Hilse) Grunow  
*Navicula oblonga* (Kutz.) Kützing  
*Navicula peregrina* (Ehr.) Kützing  
*Navicula protracta* Grunow  
*Navicula pupula* var. *rectangularis* (Greg.) Grunow  
*Navicula radiosa* var. *parva* Wallace  
*Navicula reinhardtii* (Grunow) Grunow  
*Navicula rhynchocephala* Kützing  
*Navicula salinarum* Grunow  
*Navicula secreta* var. *apiculata* Patrick  
*Navicula subhamulata* Grunow  
*Navicula tripunctata* (O. Muell.) Bory  
*Navicula tuscula* Ehrenberg  
*Navicula wardii* Patrick  
*Caloneis amphisbaena* (Bory) Cleve  
*Caloneis fenzioides* Cleve-Euler  
*Caloneis permagna* (Bail.) Cleve  
*Caloneis silicula* (Ehr.) Cleve  
*Caloneis ventricosa* var. *truncatula* (Grun.) Meister  
*Pinnularia burkii* Patrick  
*Pinnularia microstauron* (Ehr.) Cleve  
*Pinnularia viridis* (Nitz.) Ehrenberg  
*Scoliopleura peisonis* Grunow

#### Family Entomoneidaceae

*Entomoneis paludosa* (W. Sm.) Reimer

#### Family Cymbellaceae

*Cymbella affinis* Kützing  
*Cymbella cymbiformis* Agardh  
*Cymbella mexicana* (Ehr.) Cleve  
*Cymbella muelleri* Hustedt  
*Cymbella prostrata* var. *auerswaldii* (Rabh.) Reimer  
*Amphora coffeiformis* (Ag.) Kützing  
*Amphora ovalis* var. *affinis* (Kutz.) v. Heurck ex deToni  
*Amphora veneta* Kützing

*Cymbella cistula* (Ehr.) Kirchner  
*Cymbella inaequalis* (Ehr.) Rabenhorst  
*Cymbella minuta* var. *silesiaca* (Bleisch ex Rabh.) Reimer  
*Cymbella muelleri* var. *ventricosa* (Temp. & Perag.) Reimer  
*Cymbella tumida* (Breb. ex Kützing) v. Heurck  
*Amphora ovalis* (Kutz.) Kützing  
*Amphora perpusilla* (Grun.) Grunow

#### Family Gomphonemaceae

*Gomphonema angustatum* (Kutz.) Rabenhorst  
*Gomphonema intricatum* Kützing  
*Gomphonema olivaceum* var. *calcareum* (Cl.) Cleve  
*Gomphonema truncatum* var. *capitatum* Ehrenberg

*Gomphonema dichotomum* Kützing  
*Gomphonema olivaceum* (Lingb.) Desmazieres  
*Gomphonema parvulum* (Kutz.) Kützing  
*Gomphonema ventricosum* Gregory

#### Family Epithemiaceae

*Denticula elegans* Kützing  
*Epithemia adnata* var. *minor* (Perag. & Herib.) Patrick

*Epithemia adnata* (Kutz.) Brebisson  
*Epithemia argus* (Ehr.) Kützing

*Epithemia argus* var. *longicornus* (Ehr.) Grunow  
*Epithemia intermedia* Fricke  
*Epithemia turgida* (Ehr.) Kutzing  
*Rhopalodia gibba* var. *ventricosa* (Kutz.) Peragallo  
*Rhopalodia musculus* (Kutz.) Mueller

*Epithemia argus* var. *protracta* A. Mayer  
*Epithemia ocellata* (Ehr.) Kutzing  
*Rhopalodia gibba* (Ehr.) Mueller  
*Rhopalodia gibberula* var. *vanheurckii* Mueller

#### Family Nitzschiaceae

*Hantzschia amphioxys* (Ehr.) Grunow  
*Nitzschia acicularis* W. Smith  
*Nitzschia angustata* (W. Sm.) Grunow  
*Nitzschia apiculata* (Greg.) Grunow  
*Nitzschia gracilis* Hantzsch  
*Nitzschia hantzschiana* Rabenhorst  
*Nitzschia inconspicua* Grunow  
*Nitzschia linearis* W. Smith  
*Nitzschia punctata* (W. Sm.) Grunow  
*Nitzschia sigma* (Kutz.) W. Smith  
*Nitzschia subtilis* (Kutz.) Grunow  
*Nitzschia tryblionella* var. *debilis* (Arnott) Mayer  
*Nitzschia tryblionella* var. *victoriae* Grunow

*Bacillaria paxillifer* (Muell.) Hendey  
*Nitzschia amphibia* Grunow  
*Nitzschia angusta* var. *acuta* Grunow  
*Nitzschia frustulum* (Kutz.) Grunow  
*Nitzschia granulata* A. Schmidt  
*Nitzschia hungarica* Grunow  
*Nitzschia intermedia* Grunow  
*Nitzschia palea* (Kutz.) W. Smith  
*Nitzschia romana* Grunow  
*Nitzschia sigmoidea* (Ehr.) W. Smith  
*Nitzschia tryblionella* Hantzsch  
*Nitzschia tryblionella* var. *levidensis* (W. Sm.) Grunow

#### Family Surirellaceae

*Cymatopleura elliptica* (Breb.) W. Smith  
*Surirella angusta* Kutzing  
*Surirella linearis* W. Smith  
*Surirella ovalis* var. *brightwellii* (W. Sm.) Cleve  
*Surirella robusta* var. *splendida* (Ehr.) van Heurck  
*Campylodiscus noricus* var. *hibernicus* (Ehr.) Grunow

*Cymatopleura solea* (Breb.) W. Smith  
*Surirella biseriata* Brebisson  
*Surirella ovalis* Brebisson  
*Surirella ovata* Kutzing  
*Surirella striatula* Turpin

mitted to samples from the surface to 28 cm deep in order to eliminate bias from deeper samples in the Geneva and midlake cores since the Provo Bay core was only 28 cm in length.

## Results and discussion

### *Description of the cores*

The Geneva and midlake cores were physically very similar to the core taken by Bolland (1974). Bolland's core was described by Brimhall (1972) as generally composed of monotoned gray, fine grained sediment consisting mainly of calcite diluted by clay and minor amounts of quartz and other materials. The Provo Bay core differed in that it had a generally coarser grain size intermixed with silt, clay and fragmented mollusk shells. The color tone of this core varied from the light gray of the Geneva and midlake cores in the middle portion to a darker gray at the upper and lower portion of the core. This core additionally contained more organic de-

bris and was less compacted in the upper portion than either the Geneva or midlake cores.

### *Taxonomic section*

Two hundred and thirty-five taxa were identified in this study. These species are listed in Table 1.

### *Importance values and rank correlation analysis*

An importance value was determined for each taxon for all seventy samples in the study as well as for each taxon in each individual core (Table 2). Thirty-five species had importance values exceeding 3 in the overall analysis. The most prominent of these were *Stephanodiscus dubius* (16.73), *Melosira granulata* (8.87), *Amphora ovalis* var. *affinis* (5.60), *Fragilaria construens* var. *venter* (4.67), *Fragilaria construens* (4.25) and *Diploneis smithii* var. *dilatata* (3.48). The most important taxon in the Geneva and midlake cores was *Stephanodiscus dubius* at 18.15 and 17.3 respectively. Important species in the Geneva and midlake cores were most-

Table 2. Species with importance values (Ross & Rushforth 1978) exceeding 0.5 in any one of the three cores of all cores combined. The right four columns contain importance values only for the first 28 cm. of each core.

Species	Importance values for entire cores				Importance values for first 28 cm			
	Overall	Provo Bay	Geneva	Midlake	Overall	Provo Bay	Geneva	Midlake
<i>Stephanodiscus dubius</i>	16.98		18.15	17.37	8.13		12.13	18.31
<i>Melosira granulata</i>	8.87	2.53	8.52	10.84	6.62	2.53	9.24	9.56
<i>Amphora ovalis</i> var. <i>affinis</i>	5.60		6.05	6.42	4.69		6.33	9.06
<i>Fragilaria construens</i> var. <i>venter</i>	4.67	6.98	2.03	6.42	3.98	6.98	0.94	4.04
<i>Fragilaria construens</i>	4.25	12.39	3.30	2.97	5.13	12.39	1.50	1.50
<i>Diploneis smithii</i> var. <i>dilatata</i>	3.64		3.69	4.50			0.60	0.68
<i>Amphora ovalis</i>	2.52		4.18	3.05	1.76		3.29	3.33
<i>Fragilaria pinnata</i>	2.52	5.09	2.76	1.75	2.72	5.09	1.95	1.11
<i>Cyclotella ocellata</i>	2.52	6.01	1.24	1.63	3.34	6.01	0.53	0.63
<i>Amphora perpusilla</i>	2.40	0.74	3.12	2.26	3.69	0.69	4.16	6.63
<i>Stephanodiscus species</i> <sup>1</sup>	2.39		4.48	0.73	1.93		9.91	
<i>Navicula cryptocephala</i> var. <i>veneta</i>	2.25		2.41	2.19	0.83		1.27	1.35
<i>Melosira granulata</i> var. <i>angustissima</i>	2.20	1.18	1.44	2.77	4.62	1.80	6.66	6.35
<i>Melosira italica</i>	2.10	10.33		2.09	6.17	10.33	0.63	8.60
<i>Navicula rhynchocephala</i> var. <i>amphiceros</i>	1.45		0.98	0.79			0.85	1.85
<i>Cyclotella meneghiniana</i>	1.42	5.57	1.69		5.20	5.57	7.80	2.61
<i>Diploneis elliptica</i>	1.17		1.76	1.06			0.67	
<i>Diploneis marginistriata</i>	0.96		1.39	1.17			0.55	
<i>Caloneis limosa</i>	0.77		1.12	0.80			0.88	0.95
<i>Fragilaria brevistriata</i> var. <i>inflata</i>	0.35	1.16			0.53	1.16		
<i>Nitzschia amphibia</i>	0.19	1.79				1.79		
<i>Nitzschia frustulum</i>	0.13	0.69				0.88		
<i>Cymbella inaequalis</i>	0.07	2.87				2.87		
<i>Cocconeis placentula</i> var. <i>lineata</i>	0.91	4.54	0.55	0.98	1.84	4.54		0.92
<i>Gyrosigma acuminatum</i>	0.86		0.62	1.43			1.14	
<i>Fragilaria brevistriata</i>	0.84	2.10	0.64	0.66	0.67	2.10		
<i>Navicula capitata</i> var. <i>hungarica</i>	0.52		0.65	0.56	0.75		0.73	2.41
<i>Navicula anglica</i>	0.52		0.65	0.53				
<i>Nitzschia palea</i>	0.35		0.80				1.97	
<i>Navicula minima</i>	0.35		0.66				0.63	
<i>Navicula capitata</i> var. <i>luneburgensis</i>	0.17		0.70				1.23	
<i>Cocconeis disculus</i>	0.62			1.22				
<i>Ophephora martyi</i>	0.41			0.63				
<i>Stephanodiscus invisitatus</i>	0.09						1.43	
<i>Surirella ovalis</i> var. <i>brightwellii</i>	0.30						1.26	0.81
<i>Pleurosigma delicatulum</i>	0.02						0.73	

ly similar and their corresponding importance values were approximately the same. Exceptions to this included *Fragilaria construens* var. *venter* (2.03 in Geneva and 6.42 in midlake) and *Stephanodiscus species*<sup>1</sup> (4.48 in Geneva and 0.73 in midlake) as well as *Cyclotella meneghiniana*, *Cocconeis disculus* and *Melosira italica* which were present only in midlake.

In order to accurately compare the Provo Bay to the Geneva and midlake cores it was necessary to compute importance values for species that occurred in the first 28 cm of all cores together and each core separately (Table 2). *Stephanodiscus du-*

*bis* continued to be the most prominent species in the combined analysis of the 28 cm cores. However, there was a significant drop in its value in comparison with that from the analysis of all 70 samples. Species with an importance value greater than 1 were basically the same as those in the over all list. However, *Cocconeis placentula* var. *lineata* was included in the important species of the 28 cm analysis and *Navicula cryptocephala* var. *veneta*, *Navicula rhynchocephala* var. *amphiceros*, *Diploneis elliptica*, and *Diploneis smithii* var. *dilatata* were excluded.

The most prominent species in the upper 28 cm of

the Geneva and midlake cores were again *Stephanodiscus dubius* and *Melosira granulata*. Species important only in the Provo Bay core were *Fragilaria brevistriata*, *Fragilaria brevistriata* var. *inflata*, *Cymbella inaequalis*, *Nitzschia amphibia* and *Nitzschia frustulum*. Conversely, *Stephanodiscus dubius* and *Amphora ovalis* var. *affinis* were important in Geneva and midlake cores but not important in Provo Bay. Nine species with importance values greater than 0.5 were restricted to the Geneva core. *Stephanodiscus* species<sup>1</sup> was the highest of these with a value of 9.9.

Spearman rank correlation analysis was performed on species with importance values in excess of 3.0 which were present in the upper 28 cm of each core. This analysis showed that the Provo Bay and Geneva cores were significantly negatively correlated ( $P \leq .025$ ), the Provo Bay and midlake cores were not significantly correlated and the Geneva and midlake cores were positively correlated ( $P \leq .10$ ).

Pearson's correlation analysis was also performed on the same data set. This analysis showed that the Geneva and midlake cores were significantly correlated ( $P \leq .10$ ). Conversely, the Provo Bay and Geneva cores and Provo Bay and midlake cores were not significantly correlated.

#### Cluster analysis

The eight samples of the Provo Bay core clustered into three distinct groups each dominated by a separate centric euplankter. Group I (0–4 cm) was dominated by *Cyclotella meneghiniana* with an average relative density of 25%, group II at 8–12 cm was dominated by *Cyclotella ocellata* with an average relative density of 48%, and group III (16–28 cm) was dominated by *Melosira italica* with an average relative density of 35%. Figure 2 illustrates the species important in all three cores at all depths and reflects the trends obtained from cluster analysis.

The 30 samples of the Geneva core segregated upon analysis into five major groups at different depths. These groups were largely determined by changes through time in relative density of the euplankters *Cyclotella meneghiniana*, *Melosira granulata*, *Melosira granulata* var. *angustissima*, *Stephanodiscus dubius*, and *Stephanodiscus* species<sup>1</sup>. Other species important in causing separation of

the sediments into groups were *Amphora ovalis*, *Amphora ovalis* var. *affinis*, *Cyclotella kutzingiana*, *Diploneis smithii* var. *dilatata*, *Navicula capitata* var. *hungarica*, *Navicula cryptocephala* var. *veneta* and *Stephanodiscus* species<sup>1</sup>. Figure 2 illustrates the changes in density of the most abundant of these species at various depths in this core. Not all species are illustrated in Figure 2 since some only occurred in moderate numbers in narrow depth ranges but still influenced the cluster analysis.

Analysis of the midlake core samples showed that three major cluster groups could be delineated. These groups were largely formed based upon changes in the same euplankters as for the Geneva core. However, *Amphora perpusilla*, *Fragilaria construens*, and *Fragilaria construens* var. *venter* were important delineators in this core. *Melosira italica* and *Navicula rhyncocephala* var. *amphicerus* were also important at different levels.

An examination of the cluster analysis for all three cores combined illustrated several prominent association patterns. The upper samples of the three cores, Provo Bay (surface – 4 cm), Geneva (surface – 16 cm) and midlake (surface – 4 cm), comprised a group distinct from the remaining strata of these cores. This can be attributed to the prevalence of *Cyclotella meneghiniana* and *Melosira granulata* var. *angustissima* in these samples. Their congruity and uniqueness suggest similar ecological conditions in their respective localities during recent years in Utah Lake.

Provo Bay samples (8–28 cm) were floristically unique enough to separate them from all strata in the Geneva and midlake cores. The diatoms which distinguishing these sediments from those of core *Fragilaria construens*, *Cyclotella ocellata* (8–12 cm), *Cymbella inaequalis* (20–28 cm), *Nitzschia amphibia* (surface – 4 cm) and *Nitzschia frustulum* (surface – 4 cm).

The absence of *Stephanodiscus dubius* in the Provo Bay core provided possibly the best means of distinguishing these sediments from those of corresponding depths in either the Geneva or midlake cores. Other species diagnostic of Provo Bay (Table 1) such as *Cyclotella ocellata* (8–12 cm) were present in the other two cores but only infrequently.

The mid portions of the Geneva (20–96 cm) and midlake (8–80 cm) cores were floristically similar and distinguished by the prominence of *Stephanodiscus dubius*. This taxon peaked in both of these

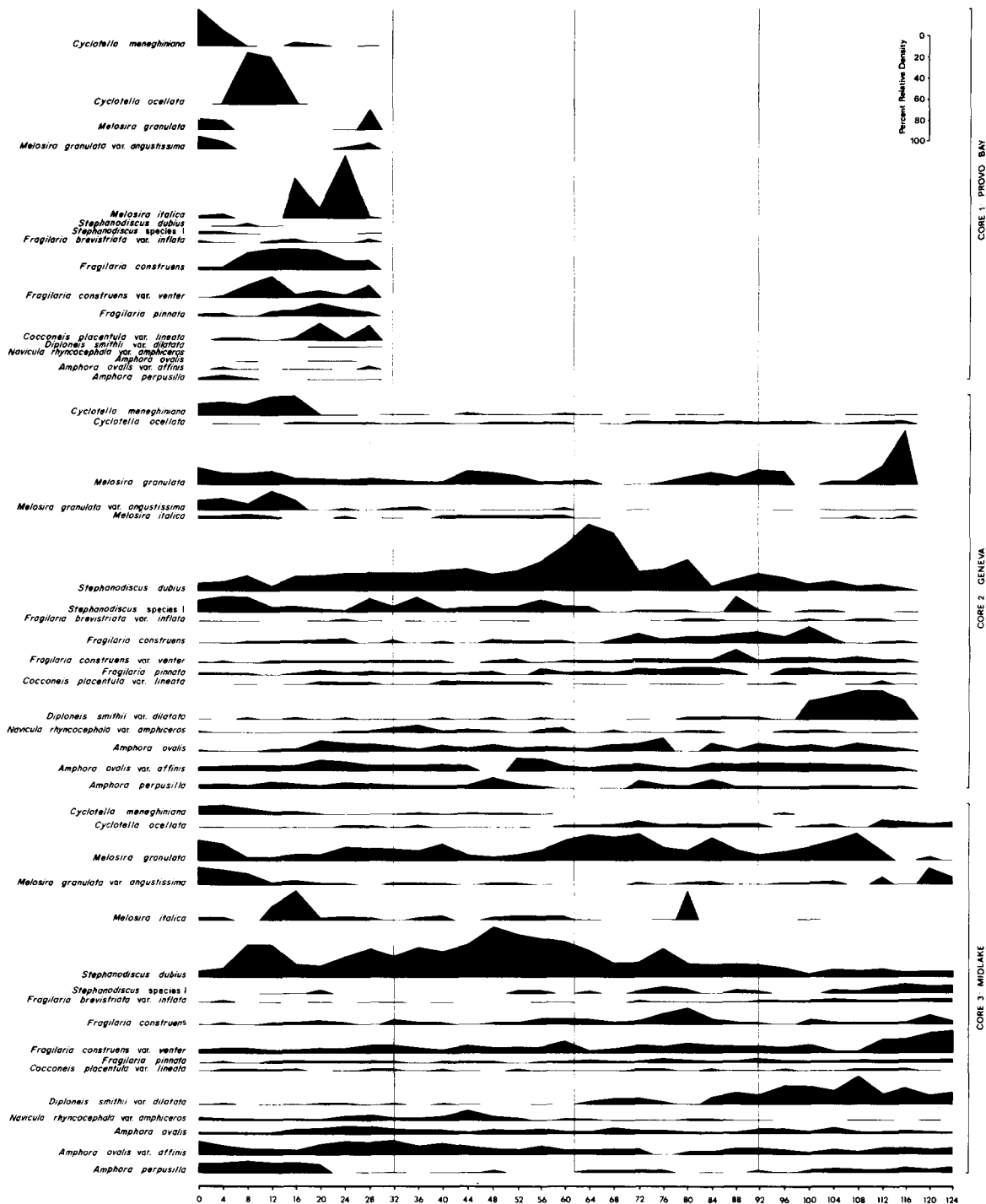


Fig. 2. Graph of relative densities of diatom species in three cores taken from Utah Lake, Utah. Centimeters of depth of the cores are printed along the bottom of the graph. The scale for relative density is printed in the upper right corner of the figure.

cores within this zone (Geneva at 60–68 cm and midlake at 48–52 cm). It was largely the varying percentages of this taxon together with certain others that identified unique relationships within and between the Geneva and midlake cores.

The deep strata of both the Geneva and midlake cores formed a distinct group which can be attributed to the presence of *Diploneis smithii* var. *dilatata* in every sample. In addition, *Melosira granulata* and *Fragilaria construens* were also important in these strata averaging 30% and 15% respectively.

A peak of *Stephanodiscus dubius* at 55% density in the 60–68 cm levels in the Geneva core mirrored a similar occurrence of 50% density at the 44–64 cm levels in the midlake core. There was a difference of 16 cm in this occurrence between the peaks in the two cores. In addition to this, a sudden occurrence of *Diploneis smithii* var. *dilatata* in the Geneva core at 100–116 cm and the midlake core at 68–124 cm was noted. In this case there was a difference of 30 cm between the two. One explanation for these discrepancies is different sedimentation rates at the two sites.

## Conclusions

1) Provo Bay sediments are floristically unique and distinct from those of either Geneva or midlake cores. 2) The upper sediments of all three cores are similar floristically and different from other sediments which suggests some change in the recent history of the lake at all three sites. 3) The occurrence of peaks of *Diploneis smithii* var. *dilatata* and *Stephanodiscus dubius* in both the Geneva and midlake cores but at different levels in the sediments suggests a possible differential sedimentation rate at the two sites. 4) The presence of *Melosira italica* at approximately the same depths in the Provo Bay and midlake cores suggest similar sedimentation rates at these two sites. 5) The deeper portions of the Geneva and midlake cores are floristically similar to each other and distinct from other strata.

## Acknowledgements

We wish to thank William E. Evenson, Dennis K. Shiozawa, J. Vaun Mc Arthur and C. Selby Herrin

for their assistance in statistical analyses of our data.

## References

- Bingham, C. C., 1975. Recent sedimentation trends in Utah Lake. Brigham Young Univ. Geol. Stud. 22: 105–140.
- Bissell, H. J., 1942. Preliminary study of the bottom sediments of Utah Lake. Div. of Geology, Committee on Sedimentation. Nat. Res. Council, Ann. Rep. 1940–1941, Exhibit H: 62–69.
- Bissell, H. J., 1963. Lake Bonneville: geology of southern Utah Valley, Utah. U.S. Geol. Surv. prof. Pap. 257-B: 101–130.
- Bolland, R. F., 1974. Paleocological interpretation of the diatom succession in recent sediments of Utah Lake, Utah. Ph.D. Thesis, University of Utah, Salt Lake City. 100 pp.
- Bradbury, J. P., 1975. Diatom stratigraphy and human settlement in Minnesota. Geol. Soc. Am. spec. Pap. 171. 74 pp.
- Brimhall, W. H., 1972. Recent history of Utah Lake as reflected in its sediments: a first report. Brigham Young Univ. Geol. Stud. 19: 121–126.
- Brimhall, W. H., Bassett, I. G. & Merritt, L. B., 1976. Reconnaissance study of deep water springs and strata of Utah Lake. Mountainlands Ass. Govt. Tech. Rep. Eyring Research Inst., Provo, Utah. 21 pp.
- Brimhall, W. H. & Merritt, L. B., 1981. The geology of Utah Lake: implications for resource management. Gt. Basin Nat. 5: 24–42.
- Bushman, J. R., 1980. The rate of sedimentation in Utah Lake and the use of pollen as an indicator of time in the sediments. Brigham Young Univ. Geol. Stud. 27: 35–43.
- Duthie, H. C. & Sreenivasa, M. R., 1971. Evidence for eutrophication of Lake Ontario from the sedimentary diatom succession. Proc. 14th Conf. Int. Ass. Gt. Lakes Res.: 1–13.
- Fuhrman, D. K., Merritt, L. B., Bradshaw, J. S. & Barton, J. R., 1975. Water quality effect of diking a shallow arid-region lake. EPA Tech. Ser. EPA-660/2-75-007. 234 pp.
- Grimes, J. A. & Rushforth, S. R., 1982. Diatoms of recent bottom sediments of Utah Lake, Utah, U.S.A. Bibliotheca Phycologica 55: 1–179.
- Hunt, C. B., 1953. Lake Bonneville-geology of northern Utah Valley, Utah. U.S. Geol. Surv. prof. Pap. 257-A: 1–99.
- Hyatt, M. L., Skogerboe, G. V., Haws, F. W. & Austin, L. H., 1969. Hydrologic Inventory of Utah Lake drainage area. Utah Div. Water. Res., Utah Wat. Res. Lab., Rept. PR WG 40-3. Utah State Univ., Utah.
- Kemp, A. L. W., Anderson, T. W., Thomas, R. L. & Mudrochova, A., 1974. Sedimentation rates and recent sedimentary history of Lakes Ontario, Erie, and Huron. J. Sedimentary Petrol. 44(1): 207–218.
- Palmer, C. M., 1969. A composite rating of algae tolerating organic pollution. J. Phycol. 5: 78–82.
- Patrick, R., 1973. Use of algae, especially diatoms, in the assessment of water quality. In: Cairns, J. & Dickson, K. L. (Eds.) Biological Methods for the Assessment of Water Quality. Am. Soc. Test. Mat. Pub. 528: 76–95.

- Patrick, R., 1977. The ecology of freshwater diatoms and diatom communities. In: Werner, D. (Ed.), *The Biology of Diatoms*, Univ. Cal. press, Berkeley, pp. 284–332.
- Ross, L. E. & Rushforth, S. R., 1980. The effects of a new reservoir on the attached diatom communities in Huntington Creek, Utah, U.S.A. *Hydrobiologia* 68: 157–165.
- Ruzicka, M., 1958. Anwendung mathematisch-statistischer Methoden in der Geobotanik. (Synthetische Bearbeitung von Aufnahmen). *Biologia Batisl.* 13: 647–661.
- Sneath, P. H. A. & Sokal, R. R., 1973. *Numerical Taxonomy*. W. H. Freeman and Co., San Francisco. 573 pp.
- Snedecor, G. W. & Cochran, W. G., 1968. *Statistical Methods*, 6th ed. Iowa State Univ. Press. Ames, Iowa.
- Sonerholm, P. A., 1974. Normative mineral distributions in Utah Lake sediments: a statistical analysis. *Brigham Young Univ. Geol. Stud.* 21: 97–118.
- St. Clair, L. L. & Rushforth, S. R., 1977. The diatom flora of the Goshen warm springs ponds and wet meadows, Goshen, Utah. *Nova Hedwigia* 23: 353–425.
- Stockner, J. G., 1972. Paleolimnology as a means of assessing eutrophication. *Verh. int. Verein. Limnol.* 13: 1018–1030.
- Stockner, J. G. & Benson, W. W., 1967. The succession of diatom assemblages in the recent sediments of Lake Washington. *Limnol. Oceanogr.* 21: 513–532.

Received 18 November 1981; in revised form 2 April 1982.