Arcellaceans of several small lakes in southwestern New Brunswick; Their Modern Distribution and Stratigraphic Importance

R. Timothy Patterson
Department of Geology
Dalhousie University
Halifax, Nova Scotia
Canada B3H 3J5

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DALHOUSIE UNIVERSITY
Department of Geology
Halifax, N.S. Canada B3H 3J5 Telephone (902)424-2358 Telex:019-21863

DALHOUSIE UNIVERSITY, DEPARTMENT OF GEOLOGY

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Author: R. Timothy Patterson

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ABSTRACT

Sediment-water interface samples from five small lakes in southwestern New Brunswick (Bonaparte Lake, Bocabec Lake, Gibson Lake, St. Patricks Lake and Big Pond [Deer Island]) were quantitatively examined for the presence of arcellaceans. Two major assemblages, with one assemblage (I), being subdivided into three sub-assemblages, were delineated; all assemblages were dominated by *Difflugia oblonga*. Reduced total and species numbers in the second, assemblage (II), of Bonaparte Lake may be a function of anoxic bottom conditions and/or acid rain pollution. Variations in most Assemblage I sub-assemblages are probably the result of chance colonization events. However, the presence of *Difflugia bidens* in Assemblage Ic seems to be an indicator of increased terrigenous input.

The surface information was also used to perform a first order interpretation of a core from Gibson Lake. Diversity and total numbers generally increased following transition from marine to freshwater conditions, with a decrease in total numbers in the upper part of the core, due to oxidation. *Difflugia oblonga* dominated all core assemblages except in the brackish freshwater transition zone, where *Centropyxis aculeata* dominated.

The results of this study provide further documentation of the value of arcellaceans as paleolimnoloical indicators of the benthic environment.

INTRODUCTION

General Statement

Testate rhizopods, or "thecamoebians", (Loeblich and Tappan, 1964), are a large group of amoeboid protozoa in which the cytoplasm is enclosed within a discrete shell, or test. They are present in large populations in a wide variety of freshwater habitats, from moss, soil, peat, and standing water, to sewage treatment works. They are also found worldwide, from tropical to polar regions (Ogden and Hedley, 1980).

However, although there is a large volume of literature concerning the group, it is scattered and there have been a number of taxonomic difficulties. Medioli and Scott (1983) have prepared a taxonomic review for Arcellacea from selected occurrences in eastern Canada. To date, the only known quantitative distributional study of a modern North American lake, is a study of surficial and fossil arcellacean distribution in Lake Erie (Scott and Medioli, 1983).

Many freshwater microfossils, (e.g. ostracodes and molluscs), tend to dissolve in the low pH sediments of fresh water deposits, hence additional paleolimnological tools are required. Organic and siliceous fossils, (pollen, spores, and diatoms) do not generally reflect conditions at the sediment-water interface. Arcellaceans are agglutinated, and are benthic; hence they resist dissolutin and are representative of bottom conditions. Their high density populations also provide an adequate statistical base under most sampling conditions (Scott and Medioli, 1983).

Sediment-water interface samples from Gibson Lake, Bonaparte Lake, Bocabec Lake, St. Patricks Lake, and Big Pond (Deer Island), in southwestern New Brunswick have been quantitatively examined to determine living arcellacean surficial distributions (Figure 1). This information was then used to perform a first order interpretation of fossil assemblages from Gibson Lake.

These lakes were chosen as a follow up to the Lake Erie study for a number of reasons:

1. To compare the diversity of this inter-lake study of small fresh water bodies with the results obtained from the intra-lake study of Lake Erie; a large fresh water body.
2. These lakes represent raised marine basins. Previous examination and C^{14} dating of core from Gibson Lake has provided an accurate date for the emergence of the lake sill and hence an accurate sea level for that time (Scott and Medioli, 1978, 1980a). In addition, examination of the marine-freshwater transition should provide a history of the appearance and evolution of arcellacean assemblages under continually freshening conditions.
3. Lakes in such close proximity should display very similar distributional assemblages.

There is no previous work on arcellaceans in these lakes except for cursory examination of some marine-fresh water transitions in some cores (Scott and Medioli, 1978, 1980a).

Surficial Sediments of These Five New Brunswick Lakes

Scott and Medioli (1980a) completed a comprehensive examination of cores from some of these lakes, from which the following summary is drawn.

These lakes, on the Fundy Shore of New Brunswick are emerged basins. The maximum marine limit in the area was determined to be approximately 75 meters above present mean sea level, by Gadd and Lee (in Walton et al., 1961; and Lowden and Blake, 1976), and C^{14} dated at 13,000 ybp.

Gibson Lake is at 36 meters above mean sea level. A C^{14} date from the 364-351 cm segment was obtained (7980 ± 120 ybp), but this dates the first freshwater interval. Data from another lake indicates sea level fell below this point at 12,000 ybp (Scott and Medioli, 1980a).

The freshwater portion of all these lakes is comprised of brown organics (gyttja). This is underlain by an organic, grey brown silt, deposited under mildly brackish conditions. This is in turn underlain by a section of dark grey silt with some organics, deposited under marine estuarine conditions. A grey silt with few organics underlies this, while reworked glacial material is found in the base of these cores (Scott and Medioli, 1980a).

Post marine sediment thicknesses vary from 290 cm in Bocabec Lake to 525 cm in Bonaparte Lake. Sedimentation rates have not been determined for any of these lakes.

Vegetational and Climatic Changes Since Deglaciation

Robert Mott (1975) examined and radiocarbon dated lake sediment cores from two small lakes in this area. The pollen profiles they provided reflected vegetational and climatic changes since deglaciation. However, the flora observed probably does not exactly mirror the climate of the time, due to migration lag. This would be particularly true if climatic change was rapid (Bryson and Wendland, 1967).

Following deglaciation, a fauna of herbs and shrubs prevailed, indicating tundra conditions probably caused, in part, by the proximity of the retreating ice sheet. About 11,300 years ago an increase in pollen indicates the presence of more trees, probably climatically similar to that of north central Quebec today.

There was another increase in pollen, particularly pine, about 9,500 years ago. From that time on there was an increase in the hardwood component, a trend which continued until about 1,000 years ago. Since then the climate of southwestern New Brunswick has returned to a cooler and more moist climate, indicated by an increase in spruce pollen, and a decline in hemlock and hardwood pollen.

Thermal and Seasonal Factors

One would expect the temperature curve of a lake to reflect the heat elements of solar radiation absorbed by the lake. However, this is not the case. Direct stratification is portrayed, with dense cold water lying beneath warmer layers, dividing the lake into three regions (Cole, 1979). The upper region, the epilimnion, is thoroughly mixed by wind to a more or less uniform temperature. The hypolimnion, the bottom region, is composed of colder water little affected by wind action and usually termed as stagnant. Separating these two major regions is the metalminion, an intermediate zone where temperature drops rapidly with increasing depth.

Cooper (1942) studied the relationships between area and depth in 118 Maine lakes to determine what type of stratification occurs. He found an average epilimnion depth of 5.5 meters for lake areas of 14 to 40 ha, 9.0 meters for lake areas greater than 810 ha. The bottoms of metalimnia averaged 12.8 meters, and ranged from 10.1 meters to 17.5 meters in a study of 17 lakes carried out by Davis et. al., (1978). This gives a rough estimate of the minimal depths required by lakes for the presence of an often oxygen starved hypolimnion.

Davis et al. (1978) also indicate that summer stratification begins from late April to mid June, with an average occurrence of early May, after a few days to a month of overturn. Stratification then lasts from four to six months with the fall overturn beginning from late October to early November and lasting one to two months. Complete ice cover occurs from late November through early December lasting four to five months. Ice cover disappears in early May. The lakes in the Maine study were from southern to northern Maine, with the lakes of the New Brunswick study being, latitudinally, approximately at the median of Maine. Thus values for the New Brunswick lakes are probably at the median of the range given for the Maine Lakes.

Geological and Geographic Influence on Water Quality of the Lakes

The five lakes are set in a number of geological settings (Figure 1). St. Patricks Lake and Bonaparte Lake are set wholly in granitic bedrock. Big Pond is entirely contained in a volcanic setting, while Bocabec sits astride a sandstone-limestone contact, and Gibson Lake abuts a granitic and limestone unit (Cumming, 1964).

The lakes vary considerably in mean elevation above sea level. Bonaparte Lake is at 49 meters above sea level; Bocabec at 10 meters above sea level; St. Patricks Lake at 75 meters above sea level; Gibson Lake at 35 meters above sea level and Big Pond at 5 meters above sea level (data from Scott and Medioli, 1980a).

Davis et al. (1978) suggest that the chemistry of the bedrock exerts the strongest influence on lake water quality, largely determining the total natural dissolved load, much of the nutrient load, pH and alkalinity. These effects are direct if the bedrock is exposed or near the surface. The local bedrock is still important, even if there is an overburden of glacial till, since most of the tills in New England and the Maritimes are locally derived.

Schindler (1974) states that phosphorous is the most important water quality parameter in determining the water quality of lakes, as Na, K, Mg, Ca, and C are always present in excess. Fixed nitrogen may sometimes be a growth limiting factor, but nitrogen fixing blue green algae thrive under extremely low ambient concentrations. Goldman (1972) and Thurlow et. al. (1975) state that trace elements such as iron may also be a limiting factor. However, the major control of trophic state maybe the rate of input and recycling of phosphorous in the lake water and underlying sediments.

The geological setting of the lakes in the study area ranges from granites to limestone, and are poor to rich respectively, in their supplying of phosphorous for biological uptake. However, studies of lakes in Maine (Davis et al, 1978) also indicate that granite underlain lakes can have relatively high phosphorous levels and trophic state. Other parameters like lake morphology, flushing rate, and the effects of man may be important.

Limestone, which underlies two of the lakes in the study area, yields higher levels of phosphorus, which results from the solution of apatite $(Ca_5)(PO_4)_3(OH)$ and also from the solution of $CaCO_3$ which usually has PO_4 present in solid solution.

Davis et al., (1978) also indicates that the close proximity of lakes to the ocean may also play a considerable role in determining the levels of dissolved solids (Na^+, K^+, Ca^{++}, Mg^{++}, CH_4, SiO_4, etc.). Cyclical salts injected into the atmosphere by sea spray are later precipitated as rain or snow. These salts may then constitute as much as half the dissolved solid load in coastal lake water.

There is also some evidence that Big Pond may be subject to marine incursion during severe storm conditions.

PREVIOUS WORK

Workers primarily confined themselves to taxonomic studies of lacustrine species of Arcellacea from 1816 to the 1930s. At that time there was a shift in emphasis towards ecological studies and to the taxonomy of soil and mesopsammic forms. Only in the last few years has there been any interest in fossilized and subfossil material, despite their common appearance in Holocene deposits.

BIOLOGY

Deflandre (1953) gave a detailed analysis of the biology of thecamoebians, with an excellent section on Arcellacea. Other authors have reported on the diverse habitats of Arcellacea, which include lakes, ponds, soil moss, treebark, etc., and the distinct assemblages of each habitat (e.g., Lousier, 1974, Heal, 1964, Bonnet, 1964).

Arcellacea are cosmopolitan and Penard (1902) and Decloitre (1953) both have suggested possible means of distribution. Their ability to encyst enabled them, carried by birds feet and wind, to colonize the world. Ehrenberg (1872) reported their presence in muddy rain from Naples, thus they are also able to be transported by winds in the stratosphere.

Ogden and Hedley (1980) report that arcellaceans reproduce every two to eleven days by binary fission. However, Valkanov (1962, a, b, 1966) reports that sexual reproduction occurs rarely as well.

Classification

There are three orders, under the highly artificial Thecamoebian taxanomic umbrella (Deflandre, 1953). Arcellacea species comprise part of one order.

Although Arcellacea species have been described in the literature since 1816 (Leclerc, 1816), it was often done uncritically, and with little regard for previous descriptions, or the rules of nomenclature. An exception was the work done by Joseph Leidy, (1879). His taxonomic units are basically those used by Medioli and Scott (1983) in their taxonomic study. Suprageneric classifications were put forward by de Saedeleer (1934), Deflandre, (1953), Loeblich and Tappan (1964), Bovee and Jahn (1966), Jahn et al., (1974), Ogden and Hedley, (1980), Levine et al., (1980), and Starobogator in Krylov et al., (1980). These classifications are primarily based on pseudopodial characteristics, which are of little use to the fossil record.

Ogden and Hedley's (1980) book, based primarily on traditional taxonomy, is excellent. However, the microclassification is still chaotic.

Medioli and Scott (1983) have prepared a taxonomic review of species occurring in eastern North America. This should alleviate many problems for future workers and facilitate literature surveys of previous work.

Appearances in the Geological Record

Arcellaceans are commonly found in large quantities in Holocene deposits (Scott and Medioli, 1983). There have been many reports of earlier occurrences, however. Deflandre (1953) claimed that Arcellecea species appeared at the base of the Tertiary, and have not evolved since. He did state that they could be useful fossils, but he felt that fresh water deposits are not conducive to preservation. Freugueili (1933) reported seemingly genuine Arcellacea from the Miocene. However, Bradley (1931) suggested the oldest Arcellacea as being mid-Eocene. Vasicek and Ruzicka (1957) as well as Loeblich and Tappan, (1964), disagree and report the presence of Arcellacean species from the Carboniferous. They claim the fossil record of Arcellacea is poor because no one has looked for them. However, there is some controversy over these claims (Loeblich and Tappan, pers. comm. to Scott & Medioli).

Scott and Medioli (1983) have carried out a distributional study of both recent and fossil Arcellacea from Holocene deposits in Lake Erie. This provided firm documentation for the importance of Arcellacea as important tools in paleolimnological studies.

Methods of Collection and Preparation

Sediment-water interface samples were collected at randomly chosen stations in the five lakes. Due to the small size of the lakes, exact station locations were not recorded. Interface samples were collected by D. B. Scott, A. Miller, F. S. Medioli, and P. Lake in June 1979. The Gibson Lake core was obtained by Robert Mott in 1970 using a Livingston cover. An Ekman box corer was used for interface samples with 10 cm^3 replicate samples being obtained at each station and the water depth recorded.

The samples were sieved using a No. 35 mesh (0.5 mm) screen to retain coarse organics and shells and a No. 230 mesh (0.063 mm) screen to retain the arcellaceans. Fine organic material was removed by decantation. Care must be taken during this procedure as processing of arcellaceans is sometimes difficult, due to the fragility of the test. Although arcellacean tests can stand screened water pressure, they cannot survive any mechanical agitation. Since their tests are held together by organic cement, any chemical treatment or oxides will destroy them.

Subsequent to sieving, a mixture of formalin and Rose Bengal stain was added to the samples to detect specimens living at the time of collection. After standing overnight, the samples were rinsed and placed in denatured ethanol.

The samples were then quantitatively examined under a binocular dissecting microscope, usually at 20X.

Scanning electron micrographs were taken using the Cambridge Stereo Scan 180 Scanning electron microscope located at the Bedford Institute of Oceanographic Research in Dartmouth, Nova Scotia, using polaroid NP 55 film.

Results- Interface Samples

Ten species were observed from 90 samples (46 stations); of these, all species had living representatives at the time of collection (Tables 1-5). Subsequent examination revealed the presence of three other species in some samples; Difflugia tricuspis, Difflugia globulus, and Lequereusia spiralis. Living populations were generally small in proportion to total populations, hence total populations were used to define assemblage zones. Total populations include both live and dead specimens; the latter having accumulated over several years. However, they have been shown to be good indicators of long term; as opposed to seasonal conditions (Scott and Medioli, 1980b). Based on total populations, two main assemblages are recognized, which appear to be water depth controlled. Assemblage I is further divided into three subdivisions, which are not controlled by water depth.

Living populations

Living populations were present in significant proportions in most of these lakes. This may have been the result of the collection time of June, 1979. There were 9.4% living populations in Deer Island-Big Pond (Table 1 and 7), 10.9% living in St. Patricks Lake (Table 2 and 7), 5.3% living in Bocabec Lake (Table 3 and 7), 5.7% living in Gibson Lake (Table 4 and 7) and 3.2% living in the Assemblage IA zone of Bonaparte Lake (Table 5 and 7). The Assemblage II zone of Bonaparte Lake is the only area where the living proportion was insignificant (Table 5 and 7). Collection time for this lake was also June 1979, and it is not clear why the living proportion differs so much from the other lakes. Assemblage zones were determined using total populations rather than living populations (Scott & Medioli, 1980b).

Deer Island-Big Pond: Big Pond is dominated by Assemblage IA, found at all water depths, from 3 to 10 meters (Table 1 & 7). The assemblage is characterized by the dominance of Difflugia oblonga, with lesser percentages of Pontigulasia compressa and Lagenodifflugia vas. However, significant proportions of Difflugia urceolata and Centropyxis aculeata are present. A small proportion of Centropyxis constricta is also present.

Total numbers are generally higher in shallow water (73-2358 specimens/10 cc in 3 to 3.5 meters), than in the deeper parts of the lake (39-121 specimens/10 cc at 10 meters).

St. Patricks Lake: This lake is dominated by Assemblage IB, found at all the water depths sampled, from 2 to 5 meters (Table 2 and 7). It differs from Assemblage IA in the significant proportion of Centropyxis constricta present. Difflugia oblonga is dominant with lesser percentages of Pontigulasia compressa, Lagenodifflugia vas, and Difflugia urceolata. Significant proportions of Centropyxis aculeata are also observed.

Total numbers are moderate in this lake, although total counts are generally higher in shallow water (726-753 specimens/10 cc in 2 meters), than deeper water (65-601 specimens/10 cc in 5 meters).

Bocabec Lake: Assemblage IC dominates this lake. This assemblage closely resembles Assemblage IA of Deer Island-Big Pond, differing primarily in the presence of Difflugia bidens (Table 3 and 7). Difflugia bidens is not observed in sediment interface samples from the other lakes. The assemblage also differs from those found in the other lakes, by the presence of a significant proportion of Difflugia corona. The assemblage is dominated by Difflugia oblonga; however several species have significant percentage occurences - Lagenodifflugia vas, Pontigulasia compressa, and Difflugia urceolata. Centropyxis aculeata is also relatively common.

Total numbers are moderate in this lake, and there is no appreciable difference between shallow (324-593 specimens/10 cc in 2 meters) and deeper water (330-457 specimens/10 cc in 9.5 meters).

Gibson Lake: Water depth is fairly constant for all samples (4.5 m to 5 m) and Assemblage IB, as also found in St. Patricks Lake, is present (Table 4 and 7). Difflugia oblonga dominates, followed by Lagenodifflugia vas. Pontigulasia compressa, Difflugia urceolata, and Centropyxis constricta are present in significant proportions. Total populations range from 59 to 1122 specimens/10 cc in 4.5 to 5 meters water depth.

Bonaparte Lake: The lake is dominated by two depth controlled assemblages (Table 5 and 7), Assemblage IA as found in Deer Island-Big Pond, is found in water depths of less that 10 meters. It is dominated by Difflugia oblonga, followed by Pontigulasia compressa and Lagenodifflugia vas.

Assemblage II is found in water depths of 10 to 18 meters. It is similar to Assemblage I A, B, and C, in that it is dominated by Difflugia oblonga, followed by Lagenodifflugia vas, and Pontigulasia compressa. However, diversity is restricted to these three species. Bonaparte Lake is the only lake with water depths greater than 10 meters. Total numbers generally decreased from shallow water 72-361 specimens/10 cc in 8 to 10 meters) to deeper water (25-223 specimens/10 cc in 12 to 18 meters.

Core Results

One core was examined from Gibson lake (Table 6 and Figure 2). This core was sampled at 10 cm. intervals down to 130 cm. Below the 130 cm mark samples were examined at 10 to 40 cm intervals, which were

Total numbers in the upper 50 cm of the core are relatively low (20-122 specimens/10 cc). The upper 50 cm is dominated by Difflugia oblonga (Table 6, Figure 1) with a lesser proportion of Lagenodifflugia vas. All other species occur in percentages less than 16%.

Below the 50 cm mark down to the 214 cm mark total numbers fluctuated from 90 to 1372/10 cc. The assemblage continues to be dominated by Difflugia oblonga, ranging from 27% to 73% of the total number of individuals per sample. Centropyxis constricta and Lagenodifflugia vas are both significant components. Difflugia bidens appears at the 60 cm mark and is again present from the 203-214 cm mark. However, the species is never more abundant than 3% of the total sample.

From 214 cm to 314 cm, total numbers continually decrease from 819 specimens/10 cc to 24 specimens/10 cc. Difflugia oblonga continues to dominate the assemblage, ranging from 39% to 90% of the samples. Lagenodifflugia vas and Centropyxis constricta continue in significant numbers, but Centropyxis constricta begins to decrease after 226 cm and has disappeared by 293 cm. Its place is taken by Difflugia urceolata. Difflugia protaeiformis, and Difflugia tricuspis both disappear below the 245 cm mark. Difflugia urceolata quickly disappears below the 300 cm mark. Centropyxis aculeata becomes more dominant, comprising 50% of the assemblage by 336 cm and 100% of the assemblage by 356 cm, in the freshwater-marine transition. All rhizopods disappear beneath 386 cm when totally marine sediments appear. Foraminifera are not found until the 416 cm mark and comprise 100% of the assemblage down to 581 cm - the bottom of the core.

DISCUSSION

Surficial Samples Distinctive patterns of arcellacean distribution emerge from the data accumulated from Bocabec Lake, Bonaparte Lake, Gibson Lake, St. Patricks lake and Big Pond (Deer Island). It appears that distributions are controlled by water depth, with all assemblages and subassemblages being dominated by *Difflugia oblonga*. This is reasonable due to the close proximity and similarity of the five lakes. Unfortunately, there have been no known limnological studies of such things as oxygen saturation values, nutrient distribution etc., for any of these lakes. The general characteristics have been assumed from limnological studies carried out on small lakes in Maine (Brooks and Deevey, 1963; Davies et al. 1978) and elsewhere (Kuznetsov, 1970).

No physio-chemical parameters were measured at the time of collection, except for water depth. However, some general remarks on arcellacean distribution are applicable.

In their baseline study of arcellaceans of Lake Erie, Scott and Medioli (1983) determined that temperature variation appears to have no effect, although they found that seasonal stability may be a factor in the eastern basin of the lake. Scott and Medioli (1983) also report that oxygen levels may be a factor for some species while others like *Difflugia oblonga* appear unaffected. This condition appears to be reflected in Assemblage II of Bonaparte Lake, which occurs in water depths of greater than 10 meters. The assemblage is composed almost exclusively of three species, with *Difflugia oblonga* dominating. The lake may exhibit a meromixis type stratification, with the bottom water beneath a 10 meter thermocline being of low oxygen content.

Scott and Medioli (1983) also report that of all the physio-chemical parameters, nutrient values correlate most closely with observed Lake Erie assemblages and total number variations. The data from this new Brunswick study show that there is a general increase in total numbers of arcellacea from deeper to shallower water. This probably reflects a high productivity in the warmer surface waters. However, as no nutrient measurements were taken, any such effects on assemblage variations cannot be determined.

The variations which comprise assemblage I are probably a local response to a specific condition. Difflugia bidens is only found in interface samples from Bocabec Lake. Around 1970 there was a large forest fire in the area which devastated the landscape. The geological setting of the lake is partly made up of sandstone. This combination of conditions has probably resulted in an increase in erosion and clastic terrigenous inflow to the lake. Difflugia bidens was also found in similar proportions in Lake Erie, which also has a high clastic terrigenous input. In the other lakes of the New Brunswick study, sediment is primarily of organic origin.

The reason for the variations in the other assemblage I subdivisions is unknown, but a possible explanation may lie in one these creature's major mode of colonization; transport on birds feet. Thus particular species may have been carried to one lake and not another due to chance conveyance on the feet of water fowl.

Gibson Lake Core

The most marked changes of rhizopod assemblages in the core occurred in the slightly brackish section, suggesting a response to freshening water conditions by the rhizopod populations (Figure 2). The brackish water arcellacean, *Centropyxis aculeata*, dominates the salt/freshwater transition. Significant proportions of *Difflugia urceolata* are present in the lower portion of the freshwater section, but decreases rapidly in importance up core. This is similar to what Scott and Medioli (1983) found in the base of cores are in eastern basin of Lake Erie. They attribute their assemblage to a low level of organics. In these southern New Brunswick Lakes it probably took some time for freshwater communities to develop following transition from marine conditions. This may have meant that organic input was less just after these lakes emerged above sea level.

Total numbers and assemblage diversity increases up core, presumably in response to an increase in organic supply. Oxidizing conditions, in the upper portion of the core, brought on as a result of the core being in storage for many years is probably the reason for the decrease in total numbers found there (Figure 2).

Difflugia bidens, as found in the surficial sediments of Bocabec Lake, is also found in basal freshwater sediment from the core in Gibson Lake. The sparce vegetative cover of the most recently emerged topography may have been very similar to the conditions surrounding Bocabec Lake today, resulting in high clastic supply.

Potential in Acid Rain Research

The Canadian House of Commons sub committee on Acid rain (1981) reports that Canada is facing the greatest environmental threat in its history. The once "cleansing rains and pristine snows" have become a dangerously acidic and destructive. Acid rain, a term unknown a decade ago, has become the most pervasive and feared environmental pollutant in North America.

Acidic precipitation, which includes rain, sleet, hail, and snow is usually defined as having an acidity below pH 5.6 (Graves, 1980). Acid rain, a technically incorrect but acceptable synonym for acid precipitation, is primarily the result of sulphur oxides (SOx) and Nitrogen oxides (NOx) which are transformed into sulphuric acid ($H_2 SO_4$) and nitric acid, HNO_3 (Likens, et al., 1979) respectively, as they are transported by the atomosphere over distances up to thousands of kilometers (Bryson, and Hare eds., 1974).

Research carried out over many years indicates that much of eastern Canada is sensitive to acid rain due to a lack of natural buffering or neutralizing capacity in the rocks and soil. However, buffering capacity is present in areas rich in carbonate material like limestone (Kelly, 1981). In areas of little buffering capacity, as occurs in granitic and volcanic terrains, and particularly in the Precambrian Shield areas, acid loading will eventually strip away the buffering capacity and runoff water entering lakes and streams will directly reflect the acidity of the rainfall. Water bodies also have a buffering capacity. As would be expected, the buffering capacity of these bodies generally reflects the alkalinity of the geological setting. Over time, continued acid loading can exhaust the buffering capacities of sensitive geological zones, both on land and in the water. The water bodies are then assaulted not only by the acid rain directly, but by the acidic runoff water from the de-buffered soils and rocks in the watershed. These lakes become more and more acidic over time, deleteriously affecting the floras and faunas of these lakes. For example, most fish populations disappear when pH falls below 4.5 (Watt, 1981). The average precipitation falling on New Brunswick has a pH of 4.6 while the average for Nova Scotia is marginally higher at pH 4.7.

An important component of the overall research program on acid rain is the continuous and systematic monitoring of acid depostion. The subcommittee on acid rain (1981) received evidence from several witnesses that monitoring of acidic deposition and of subsequent environmental damage in Canada needs to be improved. There is no substantial disagreement among reputable scientists that the Canadian environment is being damaged by acid rain. Amongst the missing information is a detailed body of data on historical trends in acid deposition and a precise quantitative assessment of acid rain damage and rates of acidification in areas of differing sensitivity.

A single pH sensitive limnological tool capable of determining present lake conditions as well as those over a period of time in a single sampling would be very useful. Traditional tools like water samples are unacceptable since they provide no historical information. However, arcellaceans, which have already been shown to be useful as an organic content indicator in Lake Erie, (Scott and Medioli, 1983) may fill the above prerequisites.

The lakes in the study area are in a variety of geological settings (Figure 1). St. Patricks Lake and Bonparte Lake are both located in a highly acid rain sensitive acidic granitic terrain. Big Pond (Deer Island) is located in a volcanic setting of unknown alkalinity, while most of Gibson and Bocabec Lakes are located in a highly buffering limestone setting of probably normal alkalinity. A clear dichotomy exists between the restricted assemblage of rhizopods found in Bonaparte Lake and the assemblages found in Gibson Lake and Bocabec Lake which may partially be a response to a low pH value. However, St Patricks Lake located in the same acidic setting as Bonaparte Lake has an assemblage closer to that of the limestone cloistered lakes. A possible explaination may lie in the small size of these lakes and the proportionately small drainage basins (Figure 1) which results in their effective isolation. The assemblage in St. Patricks Lake may be the result of very local conditions, e.g., local Pleistocene or organic overburden with a high buffering capacity (Davis et al., 1978). However, at this point an equally plausible possibility is that arcellaceans are indifferent to pH variations, with the assemblage diversity a function of some other factor(s).

Until actual pH and Eh measurements have been made in these lakes a true determination of the effects of pH on rhizopod assemblages cannot be determined. Nonetheless, if a link can be established between a lake's level of alkalinity, and the rhizopod assemblage(s) found there, a detailed analysis of historical acid deposition will be possible through quantitative analysis of core for arcellaceans.

CONCLUSIONS

Definite spatial assemblages occur in Bocabec Lake, Gibson Lake, Bonaparte Lake, St. Patricks Lake, and Big Pond (Deer Island). In Gibson Lake these assemblages have been traced temporarily. The simple preparation techniques, relatively high abundance and good preservation facilitates their use. This study complements Scott and Medioli's (1983) baseline Lake Erie effort, and provides further evidence of the value of arcellaceans as paleolimnological indicators of the benthic environment.

ABBREVIATED TAXONOMY

This paper is not taxonomic in nature. Medioli and Scott (1983) have completed a major taxonomic study of Arcellacea from eastern Canada. Only the original species reference is presented; where taxonomic problems have been particularly severe, some common species names have been listed.

Generic names are in accordance with Loeblich and Tappan (1964) and most species are similar to those used by Leidy (1879). Illustrations have been included but they do not cover the total variability spectrum present in the taxa.

Centropyxis aculeata (Ehrenberg, 1832)

ab Ehrenberg, 1830.

Pl. 4, figs. 1-7

Arcella aculeata Ehrenberg 1832, ab. Ehrenberg, 1830, p. 60,
Centropyxis aculeata (Ehrenberg 1832). Stein, 1859, p. 43.

Description: The test is yellow or brown, ovoid or circular, and depressed. The largely organic test is usually rough and covered with sand grains, while the apertural region is smooth. The anterior slope is large with a small anterior angle, which Medioli and Scott (1983) report to be 15 to 40 degrees from material they examined. The posterior slope is poorly defined and practically absent, fusing into the fundus at the posterior. The height to length ratio is quite low. Medioli and Scott (1983) reported a ratio of 0.4 to 0.5 from material they examined. The aperture is invaginated, subcentral and slightly anterior. Spines may, or may not be present, and are usually concentrated along the posterior margin.

Centropyxis constricta (Ehrenberg, 1842)

pl. 4, figs. 8-14

Arcella constricta Ehrenberg 1843, p. 410, pl. 4, fig. 35, pl. 5, fig. 1.

Difflugia constricta (Ehrenberg 1843). Leidy, 1879, p. 120, pl. 18, figs. 8-55 (not 1-7)

Centropyxis constricta (Ehrenberg 1843), Deflandre, 1929, p. 340, text figs. 60-67.

Urnulina compressa Cushman, 1930, p. 15, pl. 1, figs. 2a, b.

Description: The test is yellow and usually elliptical in dorsal view, and much less depressed than C. aculeata. The test is usually smooth on the apertural surface and rough at the aboral region. The aperture has a variable degree of tilt, from almost horizontal to, a ventral configuration, very similar to that found in C. aculeata. The apertural rim is semicircular with varying degrees of invagination. There are usually three spines extending from the fundus although there is some variation in this number.

Difflugia bidens Penard, 1902

pl. 2, figs. 13, 14.

Difflugia bidens Penard, 1902, p. 264, text-figs. 1-8 on p. 265.

Description: The test is opaque, regularly ovoid and laterally compressed. The fundus is rounded with two to three blunt spines. Medioli and Scott (1983) report that the shell is composed of well sorted quartz grains giving specimens a very smooth appearance. The aperture is round and well defined, and there is no external neck.

Difflugia corona Wallich, 1804

pl. 2., figs. 1-6.

Difflugia corona Wallich 1864, p. 244, pl. 15, figs. 4b, ?4a, ?4c, pl. 16, figs. 19, 20 [binomen D. corona used for a var of D. globularis, itself sub sp. of D. protaeiformis (misspelled proteiformis)

Description: The test is yellow and was observed to be very smooth, despite being composed of angular quartz grains. The aperture truncates the shell, with an apertural lip which is crenulated. These range in number from 4, in my material, to 16 reported by Medioli and Scott (1983). The fundus is rounded with a variable number of spines. A diaphragm may be present in the aperture (pl. 1, fig. 6).

Difflugia globulus (Ehrenbergh), 1848

pl 1., figs. 1-3

Difflugia globulus (Ehrenberg 1848) Cash & Hopkinson, 1909, p. 33, text-figs. 52-54, pl. 21, figs. 5-9.

Difflugia globularis Wallich, 1864 [as subspecies of species D. protaeiformis Lamarck 1818, misspelled D. proteiformis], p. 241, p 1, 15, fig. 4h, pl. 16, figs. 1, 2, 2a, 17, 21.

Description: The test is brown, spherical or hemispherical, and usually composed of large quartz fragments. There are reports in the literature (Medioli and Scott, 1983) that diatom frustules may occasionally be present. The aperture in observed specimens is usually large although Medioli and Scott (1983) report that it can be as little as 1/4 of the maximum width. It is readily distinguished from D. urceolata by the lack of a pronounced collar and by its rough appearance.

Difflugia oblonga (Ehrenberg) 1832

pl 1., figs. 4-12

Difflugia oblonga Ehrenberg, 1832 b, p. 90.

Difflugia pyriformis Perty, 1849 b, p. 168.

Difflugia capreolata Penard, 1902, p. 222, text-figs. 1-6, p. 223, tex-fig. 6, p. 213.

Difflugia longicollis Gassowsky, 1936, Ogden & Hedley, 1980, p. 144, pl. 61.

Description: In my samples the test is yellow, and composed of fine quartz grains. The test is extremely variable in shape and size, from pyriform to compressed and flask shaped. The fundus is rounded or expanded into one or more blunt processes; some individuals in the material I examined had upwards of 20 processes. The subcylindrical neck tapers to a round and clearly defined aperture. In my material it is noteworthy that of *D. oblonga* specimens from Bocabec Lake and Gibson Lake, most display a single blunt, rounded conical process protruding from the fundus. The extreme variability observed in this species makes it easy to understand the taxonomic confusion in the literature.

Difflugia protaeiformis Lamarck, 1816

pl. 3, figs. 3,4.

Difflugia protaeiformis Lamarck 1816, p 95, figured in Leclerc 1816, pl. 17 figs. 1-5.

Difflugia acuminata Ehrenberg, 1830, p 95.

Difflugia curvicaulis Penard 1899, p 36, pl. 3, figs 2-6.

Description: The test is brown, and composed of quartz particles in my material. There are reports in the literature (Medioli & Scott, 1983) that diatom fragments may also occasionally be part of the shell. The shape of specimens observed is extremely variable, from amphora-like, pyriform to cylindroconical; however, the latter configuration was most common. The fundus is rounded to tapering, and although not observed in my material, Medioli and Scott (1983) report that one or more blunt processes may protrude. The neck usually tapers but D. protaeiformis is readily distinguished from D. oblonga by the higher aperture to maximum diameter ratio.

Difflugia tricuspis Carter, 1856

pl, 2 , figs. 15, 16, pl. 3 figs. 1,2.

Difflugia tricuspis Carter, 1856, p. 221, pl. 7, fig. 80.

Difflugia tuberculata Wallich, 1864, p. 241, pl. 15, fig. 4g, pl. 16, fig. 18 [binomen D. tuberculata used for a var. of D.

globularis, itself subsp. of D. protaeiformis (misspelled proteiformis)]

Difflugia lobostoma Leidy, 1874b, p. 79

Difflugia labiosa Walles, 1919, p. 39, pl. 51, fig. 11.

Description: The test is opaque to yellow. Specimens in my material are oval in shape with no neck. The aperture is deeply indented and is trilopated in my samples although Medioli and Scott (1983) reported more variability in the number of lobes (up to 6). The surface of the test is smooth and composed of quartz grains although the literature (Medioli and Scott, 1983) claims that the test is rough and covered with sand grains.

Difflugia urceolata (Carter 1864)

pl, 2 , figs. 11, 12

Difflugia urceolata Carter, 1864, p. 27, pl. 1, fig. 7

Lagunculina sp(??) Parker et al., 1953, p. 10, pl. 1, fig. 2.

Description: The test is opaque to brown, ovoid to spherical, with a general amphora to cauldron-like appearance. The fundus is rounded with a short neck terminating in a pronounced apical rim or collar, which may be straight or recurved, and is of variable shape and size. The test is composed of sand grains of varying coarseness. Encysted forms are very common in some samples.

Difflugia urnula (Gruber 1884)

pl. 3, figs. 5-14

Ovulina urnula Gruber 1884, p. 497-499, pl. 2, fig. 19, 20.

Description: The test is brown and composed of quartz fragments. The shape is subspherical, with a narrow circular aperture, bordered by an outward expanded flanged collar of variable width. A complete or partial diaphragm across the aperture may, or may not, be present.

Gruber based his generic name on the type of pseudopodia present in the species. However, Medioli and Scott (1983) have proven that pseudopodia type is not a valid taxonomic variable. In fact, several types of pseudopodia have been observed in the same species (Medioli and Scott, 1983). The characteristics of the species indicate that the species should be placed in the genus Difflugia and the genus name Ovulina discarded. Medioli and Scott (1983) did not figure this species in their taxonomic study.

Lagenodifflugia vas (Leidy 1874)

pl. 1., figs. 13-16.

Difflugia vas Leidy 1874, p. 155

Pontigulasia vas (Leidy) Schouteden, 1906, p. 338, footnote.

Difflugia pyriformis Perty 1849. Edmonson, 1906, p. 12 (partim), pl. 2, fig. 12 not figs. 8-9.

Lagenodifflugia vas (Leidy). Medioli and Scott, 1983, p. 58-60, p. 2, fig. 18-23, 27-28.

Description: The test is yellow and composed of fine quartz grains. The shell is generally pyriform, divided into a bulbous main part and a neck. Medioli and Scott (1983) report that these sections are separated by an internal diaphragm, pierced by a single, central, usually large orifice. The surface of the test generally denotes the diaphragm, by the presence of a constriction at the base of the neck. In my material there is an integration between L. vas and D. oblonga.

Lecquereusia spiralis (Ehrenberg 1840)

pl. 2., figs. 9, 10.

Difflugia spiralis Ehrenberg 1840, p. 199.

Lecquereusia spiralis Rhumbler 1895, pl. 4 no. 1. Lageheim 1901, p. 514, pars (?)

Description: The test is yellow, and ovoid to pyriform in shape. L. spiralis is similar to P. compressa in that there is a constriction at the base of the neck which, according to Medioli and Scott (1983) corresponds to an internal diaphragm with two or more openings. The neck is asymmetrical, presumably in relation to the asymmetrical internal positioning of the diaphragm. Medioli and Scott (1983) report a morphological integration between L. spiralis and P. compressa forms. This was not observed in my material, possibly due to the scarcity of L. spiralis specimens.

Pontigulasia compressa (Carter 1864)

pl. 2., figs. 7, 8.

Difflugia compressa Carter, 1864, p. 22, pl. 1, figs. 5-6.

Pontigulasia compressa (Carter 1864) Averintsev, 1906, p. 169.

Proteonina hancocki Cushman & McCulloch, 1948, p. 76.

Description: The test is yellow, and ovoid to pyriform in shape, with a short neck that joins the body in a v-shaped wedge. Medioli and Scott (1983) report that the constiction delineated by this wedge, is a doubly perforated internal diaphragm. The aperture at the end of the well defined tapering neck is generally narrow and elliptical in cross section. The neck has a smoother appearance than the rest of the test, due to the arrangement of the constituent fine quartz grains.

ACKNOWLEDGEMENTS

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Plate 1

Figures 1-3 Difflugia globulus (Ehrenberg), 1848

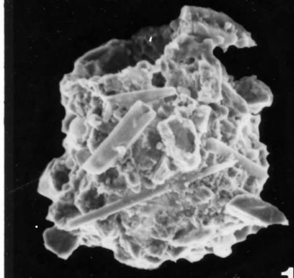
1. Side view of typical specimen x 270; 2 . Side view x 305; 3. Apertural view of specimen of figure 2. x 260.

Figures 4-12 Difflugia oblonga Ehrenberg, 1832

4. Side view of specimen displaying a bifurcated neck x 133; 5. side view of laterally flattened specimen with many small spines x 134; 6. side view of specimen with wide neck and coarse agglutination x 223; 7. Apertural view of specimen of figure 6 x 223; 8. side view of laterally compressed specimen x 155; 9. side view of laterally compressed specimen with lateral spines x 250; 10. side view of typical specimen with spine x 223; 11. side view of typical specimen x 160; 12. side view of specimen with coarse agglutination in neck, tending towards Lagenodifflugia vas x 143.

Figures 13-16 Lagenodifflugia vas (Leidy, 1874)

13. side view of specimen with prominent constriction x 133; 14. side view of typical specimen x 154; 15. side view of specimen with narrow neck x 184; 16. side view of specimen with pronounced constriction and narrow neck x 167.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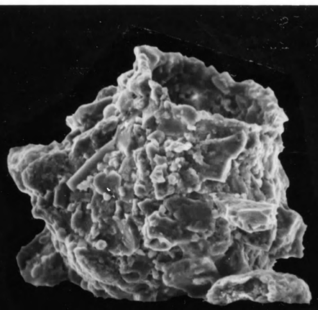
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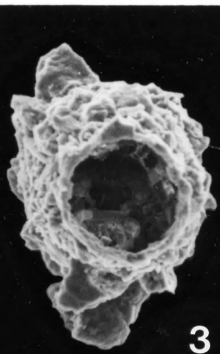
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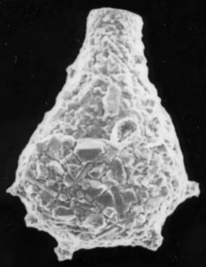
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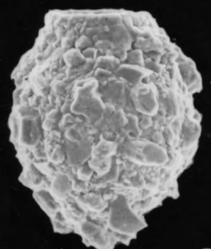
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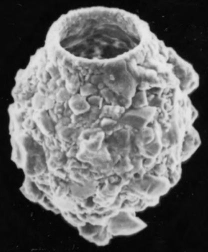
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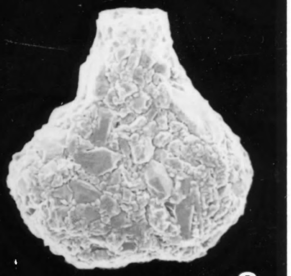
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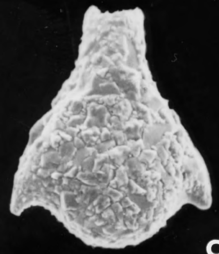
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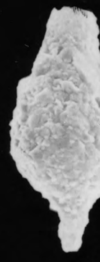
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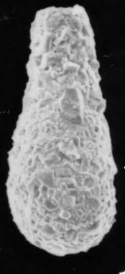
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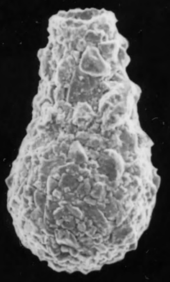
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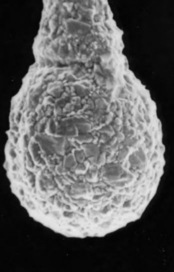
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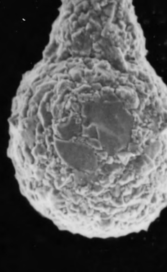
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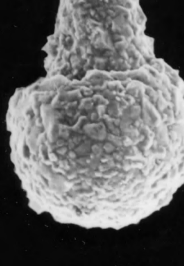
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Plate 2

Figures 1-6 Difflugia corona Wallich, 1864

1. Side view of specimen with several spines x 266; 2. apertural view of specimen from figure 1 with 3 crenulations x 227; 3. apertural view of specimen with 4 crenulations x 265; 4. apertural view of specimen with 5 crenulations x 220; 5. apertural view of specimen with 13 crenulations x 330; 6. apertural view of specimen with 13 crenulations and diaphragm x 270.

Figures 7, 8 Pontigulasia compressa (Carter, 1864)

7. side view of specimen with typical v-constriction at base of neck x 198; 8. apertural view of specimen from figure 7 x 243.

Figures 9,10 Lecquereusia spiralis (Ehrenberg, 1840)

9. side view of specimen with short neck x 336; 10. side view of typical specimen x 520.

Figures 11, 12 Difflugia urceolata Carter, 1864

11. side view of specimen with well developed apertural lip x 152; 12. side view of encysted specimen (test broken open) x 135.

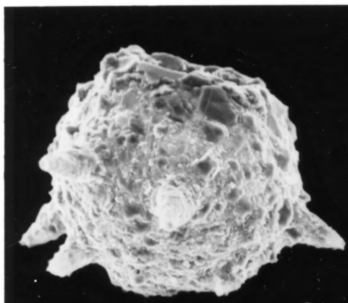
Plate 2

Figures 13, 14 *Difflugia bidens* Penard, 1902

13. side view of typical specimen x 167; 14. side view of specimen with slightly developed neck x 170.

Figures 15, 16 *Difflugia tricuspis* Carter, 1856

15. side view of typical specimen x 510; 16. apertural view of specimen from figure 15 x 620.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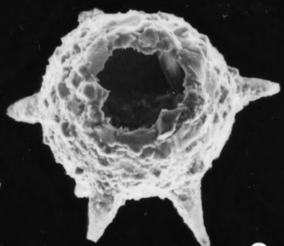
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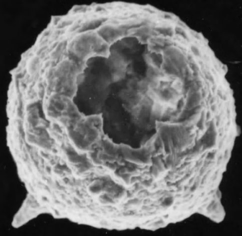
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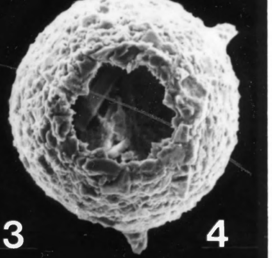
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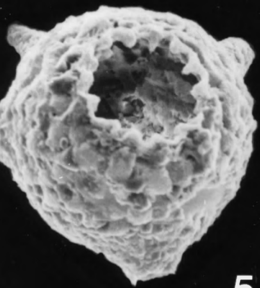
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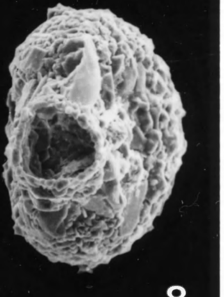
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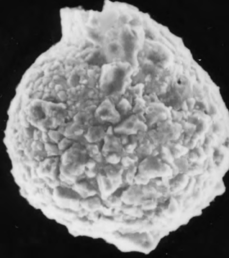
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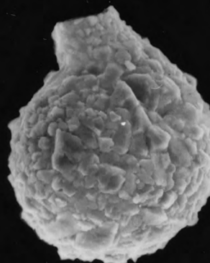
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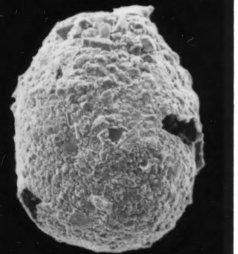
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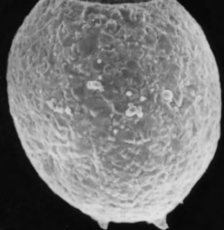
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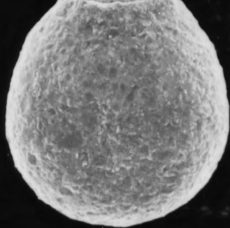
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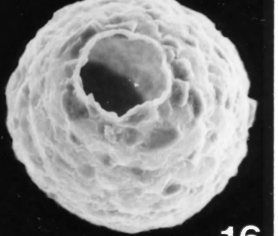
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Plate 3

Figures 1, 2 Difflugia tricuspis Carter, 1856

1. side view of specimen with slightly developed apertural lip x 460; 2. apertural view of specimen with well developed apertural lip x 520.

Figures 3,4 Difflugia protaeiformis Lamarck, 1816

3. side view of specimen with coarse agglutination x 184; 4. side view of autogenous (Scott and Medioli, 1983) specimen x 252.

Figures 5-14 Difflugia urnula Gruber, 1884

5. side view of specimen with coarse agglutination x 249; 6. apertural view of specimen from figure 5 showing apertural lip development x 265; 7. side view of specimen with diaphragm x 255; 8. apertural view of specimen from figure 7 x 277; 9. side view of specimen with well developed apertural lip x 201; 10. side view of specimen x 235; 11. apertural view of specimen from figure 10 with diaphragm partly blocking aperture x 206; 12. apertural view of specimen x 263; 13. side view of specimen from figure 12 with thickened apertural lip x 194; 14. side view of specimen with wide neck tending towards Difflugia urceolata x 236.


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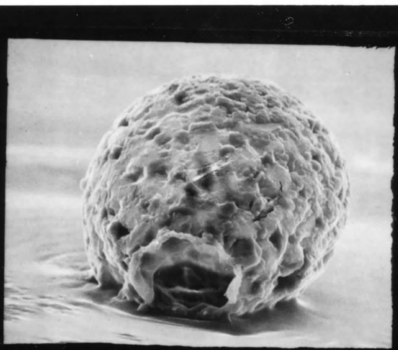
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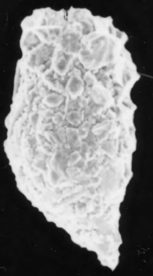
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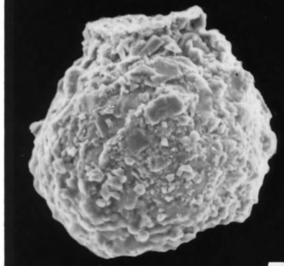
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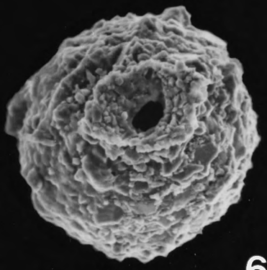
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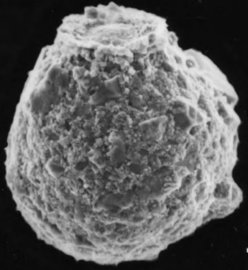
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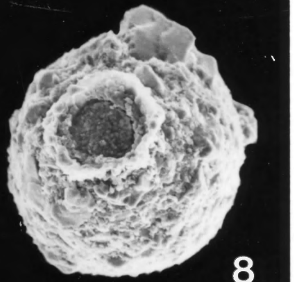
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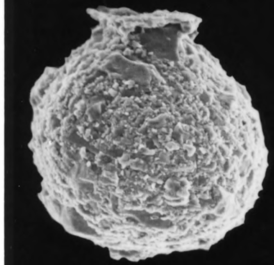
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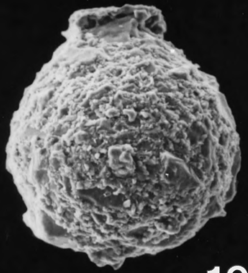
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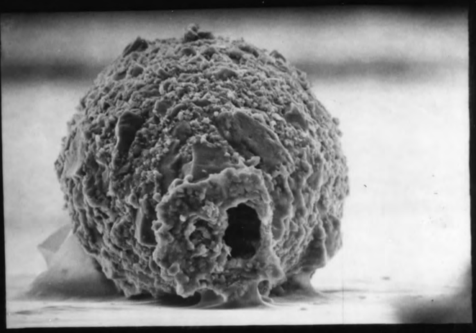
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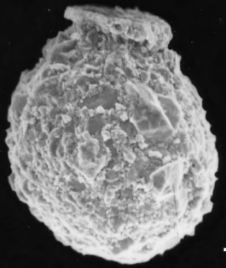
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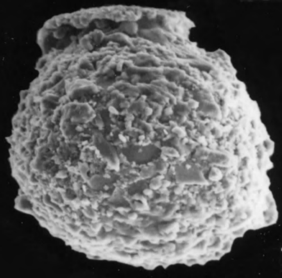
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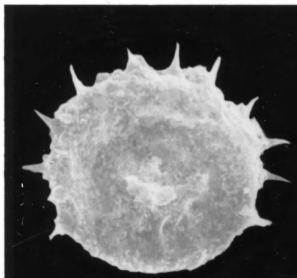
Plate 4

Figures 1-7 *Centropyxis aculeata* (Ehrenberg, 1832)

1. dorsal view of specimen with a number of spines extending farther anteriorly than usual, x 181; 2. dorsal view of specimen with 6 spines and little agglutination x 205; 3. anterior view of specimen in figure 2 showing the high angle of the spines to the horizontal x 303; 4. anterial- ventral view of broken specimen x 310; 5. ventral view of broken specimen in figure 6 showing broken spines x 272; 6. side view of agglutinated specimen with an anterior depression x 263; 7. dorsal view of specimen in figure 6, which is almost circular x 217.

Figures 8-14 *Centropyxis constricta* (Ehrenberg, 1843)

8. ventral view of specimen with broken spines, x 291; 9. ventral view of multispined specimen x 256; 10. ventral view of specimen with 7 spines x 290; 11. apertural view of specimen in figure 10, not invaginated aperture x 440; 12. anterior view of specimen in figure 8, x 410; 13. ventral view of specimen with 5 spines and slightly inclined aperture, x 237; 14. apertural view of specimen in figure 13, showing a ventral flattening more pronounced than usual x 302.



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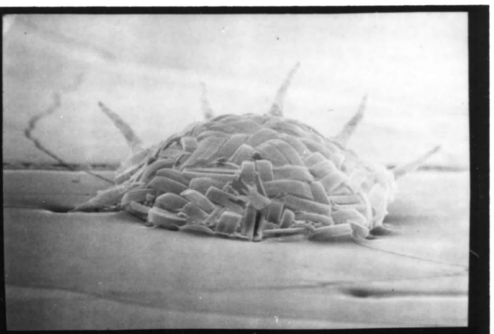

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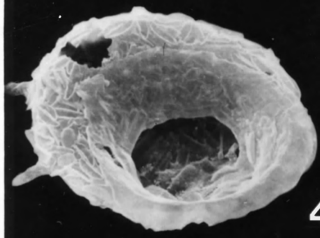

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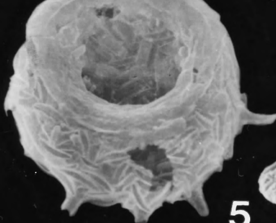

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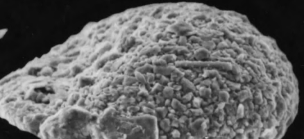

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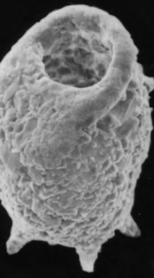

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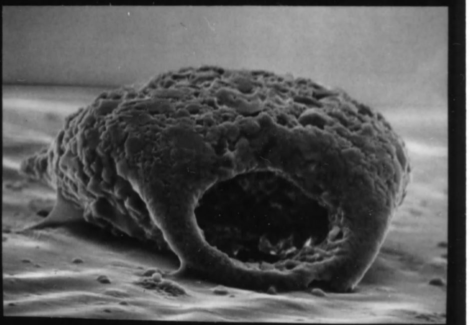

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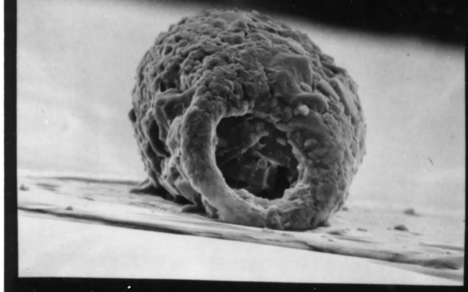

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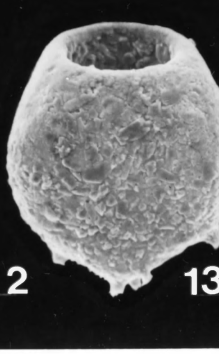

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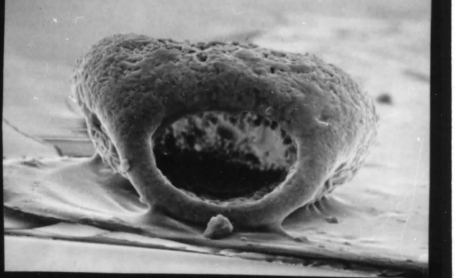

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Table 1. Percentage occurrences of Arcellacean species from BIG POND surface stations. L = Living, T = Total, X = 1%. All total numbers are per unit sample. (i.e. 10 cm^3)

STATION NUMBER		1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B
WATER DEPTH (M)		5	5	10	10	4.5.	4.5	3.5	3.5	3	3	10	10
TOTAL NUMBER OF SPECIES	L	8	6	2	3	7	4	3	3	6	4	3	5
	T	9	9	5	7	9	6	7	5	9	9	8	8
TOTAL NUMBER OF INDIVIDUALS/10ML	L	46	42	4	6	186	49	12	8	192	32	9	10
	T	465	686	39	121	1138	200	144	73	2358	976	72	78
Centropyxis aculeata	L												
	T	2	X	7	22	X		1		X	X	21	2
C. constricta	L	20				8							67
	T	2	2		3	X	X	1		2	2	1	4
Difflugia bidens	L												
	T												
D. corona	L	50	100			13				6	25		
	T	X	X			X			1	1	X	3	1
D. oblonga	L	10	7	10	10	13	16	6	10	8	5	19	8
	T	34	46	51	35	35	41	63	58	58	56	44	46
D. protaeiformis	L	11	17		8	22				9			33
	T	2	X		10	2	2	X		X	X	1	4
D. urceolata	L	11	11		7	27	60			22		25	
	T	8	7	3	12	4	3	1	4	10	10	6	9
D. urnula	L	33								50			
	T	X	X			X				X	1		
Lagenodifflugia vas	L	7	17	40		10	23	14	25	5	2		23
	T	13	8	13	7	10	7	10	5	24	27	11	17
Pontigulasia compressa	L	10	2			9	32	15	13		3	22	8
	T	39	36	26	11	46	47	23	32	3	3	13	17

Table 2. Percentage occurrences of Arcellacean species from ST. PATRICKS LAKE surface stations.
L = Living, T = Total, X = 1%. All total numbers are per unit sample. (i.e. 10 cm^3)

STATION NUMBER		1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B
WATER DEPTH (M)		2	2	4.5	4.5	5	5	4.5	4.5	5	5	4.5	4.5	4.5	4.5	4	4	4	4	4	4
TOTAL NUMBER OF SPECIES	L	7	7	6	5	8	5	2	3	3	1	1		2	5	7	6	3	3	3	6
	T	8	8	8	8	9	8	8	8	7	8	9	6	7	9	9	8	8	8	9	8
TOTAL NUMBER OF INDIVIDUALS/10ML	L	230	120	49	16	97	12	5	5	13	2	2		2	15	48	23	6	3	6	25
	T	753	726	247	270	509	601	343	119	107	65	201	69	215	310	332	234	226	224	414	253
Centropyxis aculeata	L	45	12	30											17		100				22
	T	1	7	4	3	2	2	X	3	X	8	2	6	3	2	2	X	6	2	5	4
C. constricta	L	25	38		25	22	4								6		6	6			15
	T	1	7	4	3	4	5	6	14	13	9	4	2	8	10	11	7	14	11	8	16
Difflugia bidens	L																				
	T																				
D. corona	L		43	33		50															
	T	X	2	1		X	X	X	X		2	X			X	2		X		3	
D. oblonga	L	30	7	21	7	16	2	3	3	18	9	3		X	5		11	2	2	2	12
	T	36	27	34	45	47	42	42	49	41	35	39	33	50	49	27	41	36	43	32	37
D. protaeiformis	L					33															
	T			1	X	X	X	1	X	3	3	4		1	3	1	2	2	3	2	2
D. urceolata	L	11	19	20	2	28	4	2	13	18							9		3	2	6
	T	35	25	18	19	17	17	19	13	10	6	14	22	9	7	18	20	13	16	24	20
D. urnula	L	89				67															
	T	1	X		X	X						X			X	X	X		X	X	X
Lagenodifflugia vas	L	21	16	20	3	19	X		46	12					4		9		4	5	4
	T	11	16	19	13	13	19	14	11	23	34	9	20	15	9	14	9	10	11	10	9
Pontigulasia compressa	L	36	21	20	7	17	1		9					3	5		9	5			6
	T	14	16	19	17	15	14	16	9	9	3	26	17	14	19	24	20	18	9	15	12

Table 3. Percentage occurrences of Arcellacean species from BOCABEC LAKE surface stations.
L = Living, T = Total, X = 1%. All total numbers are per unit sample. (i.e. 10 cm^3)

STATION NUMBER		1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B
WATER DEPTH (M)		2	2	3.5	3.5	6	6	9.5	9.5	8.5	8.5	3	3	4	4	2.5	2.5	2	2	3.5	3.5
TOTAL NUMBER OF SPECIES	L	4	7	4	5	5	7	6	6	4	6	3	5	2	2	7	3	2	5	3	3
	T	9	9	10	9	10	10	9	9	9	10	9	9	9	10	10	8	10	8	9	9
TOTAL NUMBER OF INDIVIDUALS/10ML	L	7	54	21	11	41	65	54	39	6	50	10	52	2	4	21	3	2	18	5	13
	T	324	420	454	381	975	682	330	457	511	917	396	327	135	208	638	114	593	340	376	318
Centropyxis aculeata	L		6																		
	T	12	8	3	7	2	3	1		X	3	8	3	8	3	32	12	8	7	3	3
C. constricta	L		1		20			25		X		10				20	100				
	T	1	3	3	3	2	2	2	3	2	X	5	6	1	3	X	X	2	X	6	3
Difflugia bidens	L						64	17			17										
	T			1		X	2	2	3	5	4				4	X					X
D. corona	L				11						25					3					
	T	5	3	4	2	X	X		X	X	X	X	X	4	2	32	24	12	9	5	3
D. oblonga	L		9	3	4	1	12	18		X	5	3	13	2	2	2	6	X	6	X	7
	T	30	27	37	19	15	11	43	44	39	32	38	43	38	41	9	14	39	37	33	38
D. protaeiformis	L	40	13			5	6									13			25		
	T	1	2	X	1	2	2	X	2	X	X	X	X	4	2	1	X	X	1	X	X
D. urceolata	L	3	11	9	1	6	15	17		X	5	2	9	4	12	6			7	2	3
	T	31	42	26	38	7	15	18	12	23	25	16	17	20	9	10	24	13	20	24	25
D. urnula	L	17	42				8						43								
	T	2	1	4	X	X	2	1	3		2	3	7	1	4	X		X		X	
Lagenodifflugia vas	L			10		3	5	3		X	8		26			5		X	7		4
	T	11	2	9	14	64	58	19	16	17	9	14	8	11	16	6	14	18	17	17	17
Pontigulasia compressa	L	X	35	3	5	2	39	36			5		24			9	8		4	5	
	T	7	12	13	16	6	5	13	18	14	23	15	15	13	16	10	11	8	8	10	11

Table 4. Percentage occurrences of Arcellacean species from GIBSON LAKE surface stations.
L = Living, T = Total, X = 1%. All total numbers are per unit sample. (i.e. 10 cm^3)

STATION NUMBER		1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	8A	8B	9A	9B	10A	10B
WATER DEPTH (M)		5	5	5	5	5	5	4.5	4.5	4	4	5	5	5	5	5	5	5	4.5	4.5
TOTAL NUMBER OF SPECIES	L	3	3	2	3	5	1	3	2	7	6	5	6	4	3	5	5	5	2	2
	T	8	7	9	9	9	9	8	7	8	8	9	9	8	8	9	9	9	8	4
TOTAL NUMBER OF INDIVIDUALS/10ML	L	11	14	6	10	16	14	8	2	124	88	32	44	17	4	54	74	20	32	16
	T	388	343	283	658	724	544	219	54	1122	546	968	546	258	280	1550	718	858	105	59
Centropyxis aculeata	L					6				7	6	7								
	T	2		5	2	2	1	4	2	5	12	6	2	2	4	4	3	3	4	
C. constricta	L					3				20	10		10			X	4		33	
	T	5	6	17	13	10	7	8	2	3	7	18	7	9	9	13	8	12	6	
D. bidens	L																			
	T																			
D. corona	L														100				100	
	T			X	X	X	2				X	X	X		X	1	1	1	2	
D. oblonga	L	4	4	4	2	3	4	5	4	5	16	3	8	8	2	5	14	5	35	29
	T	50	47	48	56	46	57	36	50	47	44	43	48	54	48	45	50	46	38	58
D. protaeiformis	L				33					100							11			
	T	X	X	2	X	2	X	X		X		2	X	X	X	2	3	2	X	
D. urceolata	L	8	38					5		22	22	14	16	4	5	5	14		16	
	T	3	5	5	6	5	7	9	11	31	19	5	9	11	7	6	11	12	11	14
D. urnula	L								50				50			50			100	
	T	X	X	X	X	X	X	X	4	X	X	X	2	X		X	X		2	
Lagenodifflugia vas	L	2			2	2		4		2	18	3	2	8		4	8	2	33	50
	T	31	32	10	14	23	22	32	22	10	8	15	21	15	19	14	11	11	23	20
Pontigulasia compressa	L		6	3		1				10	23	4	7	5		3			14	
	T	8	9	12	7	11	3	11	9	4	10	11	10	9	12	14	13	12	13	8

Table 5. Percentage occurrences of Arcellacean species from BONAPARTE LAKE surface stations. L = Living, T = Total, X = 1%. All total numbers are per unit sample. (i.e. 10 cm^3)

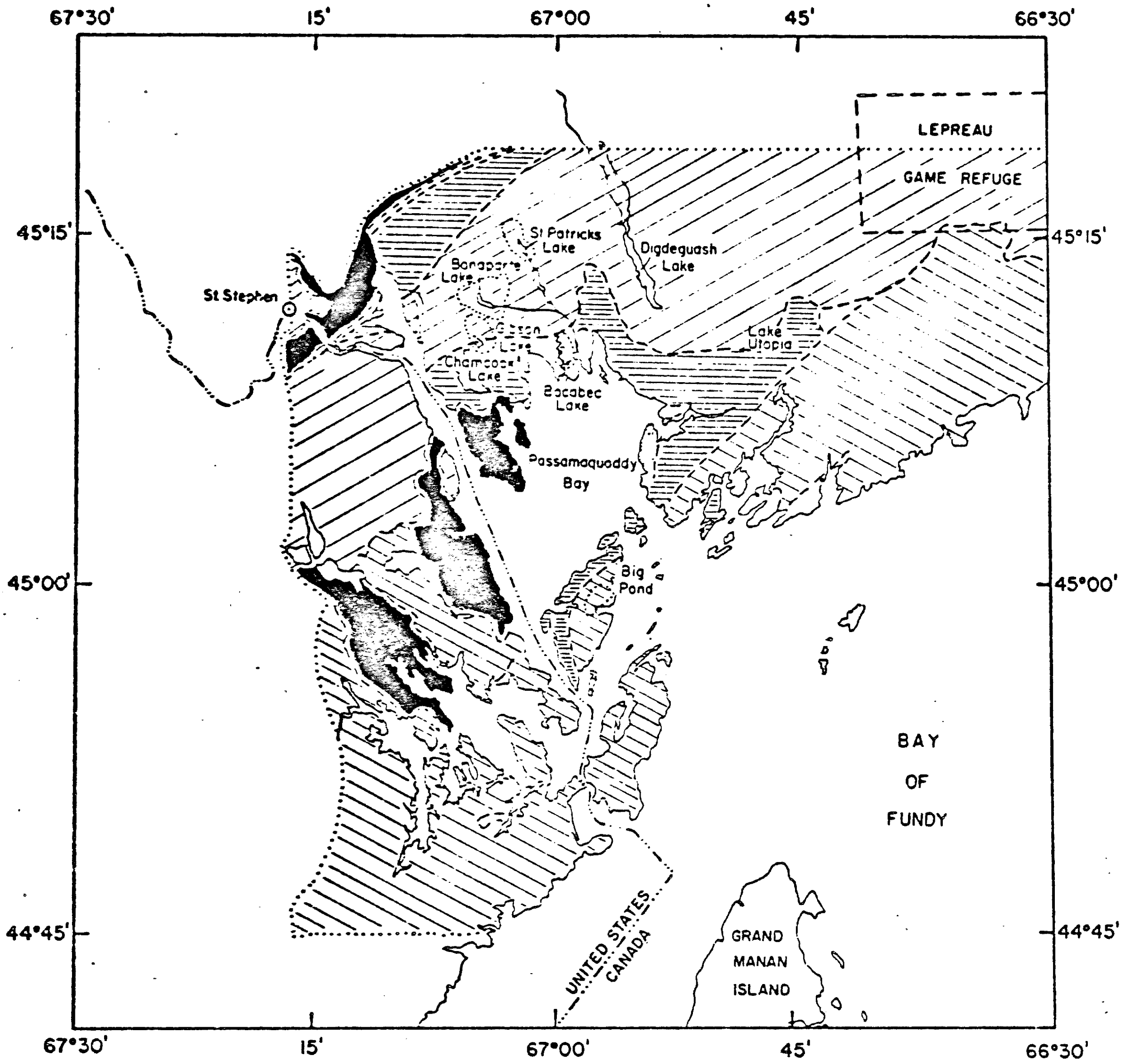
STATION NUMBER		1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	10A	10B
WATER DEPTH (M)		8	8	10	10	13	13	15	15	12	12	18	18	13	13	8	8	10	13	13
TOTAL NUMBER OF SPECIES	L	1	4	3	3			2			1					3		3		2
	T	7	6	5	4	4	3	3	3	3	3	3	3	3	4	5	5	3	3	4
TOTAL NUMBER OF INDIVIDUALS/10ML	L	1	15	25	6			3			1									2
	T	361	233	128	227	223	183	98	60	67	33	25	34	78	68	322	88	77	68	63
Centropyxis constricta	L																			
	T	X																		1
C. aculeata	L																			
	T	X	X	2												X	1			
D. bidens	L																			
	T																			
D. corona	L																			
	T		X																	
D. oblonga	L		8	20	2						5					8				4
	T	57	43	66	75	61	53	46	52	46	61	48	47	52	49	59	64	59	46	41
D. protaeiformis	L																			
	T	1				X														
D. urceolata	L		8																	
	T	4	5	X	X										1	1	3			
D. urnula	L																			
	T																			
Lagenodifflugia vas	L	1	4	26	3			7								16				
	T	20	31	21	14	19	23	15	13	12	6	12	29	22	11	20	22	14	9	8
Pontigulasia compressa	L		7	8	4			5								11				3
	T	17	19	10	10	20	24	39	35	42	33	40	24	26	39	20	10	27	45	50

Table 6. Percentage occurrences of Arcellacean species down GIBSON LAKE CORE
x = 1% - All total numbers are per unit sample (i.e., 10 cm³)

DEPTH IN CORE (CM)	10	20	30	40	50	60	70	80	90	100	110	120	130	144 145	154 155	193 194	203 204	213 214	223 234	22 5 22 6	240 245	273 274	283 284	293 294	313 314
TOTAL # OF SAMPLES	6	6	9	8	8	9	8	9	10	9	7	9	8	8	9	10	10	7	7	8	8	6	4	4	5
TOTAL # OF INDIVIDUALS /10ml	115	20	74	122	103	386	394	418	317	471	556	463	498	90	699	411	1372	819	180	140	105	102	30	18	24
Centropyxis aculeata	3	10	8	2		3	4	X	8	3	2	4	1		X	X	X		1	3	X	X			4
C. constricta	12	15	18	25	22	36	22	27	24	23	30	22	23	3	10	8	15	17	14	15	10	X	2		
Difflugia bidens						X										3	3	X							
D. corona					3					X					X										
D. globulus									X								X							6	0
D. oblonga	37	35	22	36	51	38	52	27	39	42	46	44	32	73	65	65	52	43	51	44	34	87	90	39	80
D. protaeiformis	12	5	3	X	X	4	3	5	1	3	3	3	3	1	1	5	3	4	X	6	2				
D. tricuspis	12	5	5	X	2		X	4	2	X		1	1	2	X	2				5	5				
D. urceolata			4	4	3	1	1	3	3	X	X	1	5	2	X	X	3	3	9		15	3		22	8
D. urnula																X	X								
Lagenodifflugia vas	24	30	27	14	9	8	13	27	12	23	12	15	23	12	10	6	15	27	21	23	31	5	8	33	4
Lesquereusia spiralis			5			X			X					1						2					
Pontigulasia compressa			8	16	9	8	4	8	11	6	7	10	12	6	11	9	8	6	3	2	2	3			4

Table 7. Mean total occurrences of Arcellacean species in five lakes of southwestern New Brunswick. L = living, T = Total, X = 1%

LAKE		Bocabec Lake	Bonaparte Lake	Gibson Lake	St. Patricks Lake	Big Pond
Percent living of total Number of Individuals		5.3	3.2	5.7	10.9	9.4
Mean Total Number of Individuals/Samples	L	24	5	31	34	50
	T	448	129	538	311	529
Centrophyxis aculeata	L	X		1.4	11.3	
	T	6.3	X	3.3	3.2	4.8
Centrophyxis constricta	L	8.9		4.5	7.4	7.9
	T	2.7	X	7.4	7.9	1.5
Difflugia bidens	L	9.8				
	T	1.1				
Difflugia corona	L	2.1		16.7	9.7	24.3
	T	5.7	X	X	X	X
Difflugia oblonga	L	4.8	2.5	7.9	7.7	10.2
	T	31.4	53.9	47.9	39.5	47.3
Difflugia protaeiformis'	L	5.1		9.0	1.9	10.0
	T	2.4	X	2.3	1.5	1.9
Difflugia urceolata	L	5.6	1.1	8.4	5.6	15.7
	T	18.3	X	7.8	17.1	6.4
Difflugia urnula	L	6.5		15.6	14.2	16.6
	T	2.1		1.8	X	X
Lagenodifflugia vas	L	3.7	3.0	6.9	8.2	13.8
	T	17.9	16.9	17.5	11.5	12.7
Pontigulasia compressa	L	8.8	2.0	4.0	9.2	9.5
	T	11.7	27.9	8.2	15.3	24.7



Base-map cartography with revisions by the Geographical Survey of Canada, 1966, from maps published at 1:250,000 scale by the Army Survey Establishment, R.C.E., 1953, 1955-57

Mean magnetic declination 21°01' West, decreasing 0.6' annually.

Readings vary from 20°39', in the SW corner to 21°37' in the NE corner of the map-area.

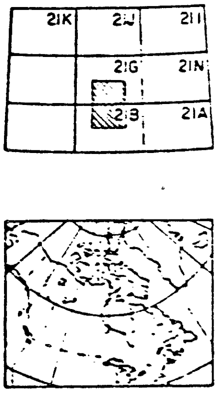


Figure 1.

Geology of the Passamaquoddy Bay region, Charlotte county, New Brunswick, Canada, and Washington county, Maine, USA.

Scale 1:253,440

(1 inch to 4 miles)

4 0 4 8 Miles

6 0 6 12 Kilometers

▨ Instrusive Rocks

▧ Volcanic Rocks

☐ Sandstone

▤ Limestone

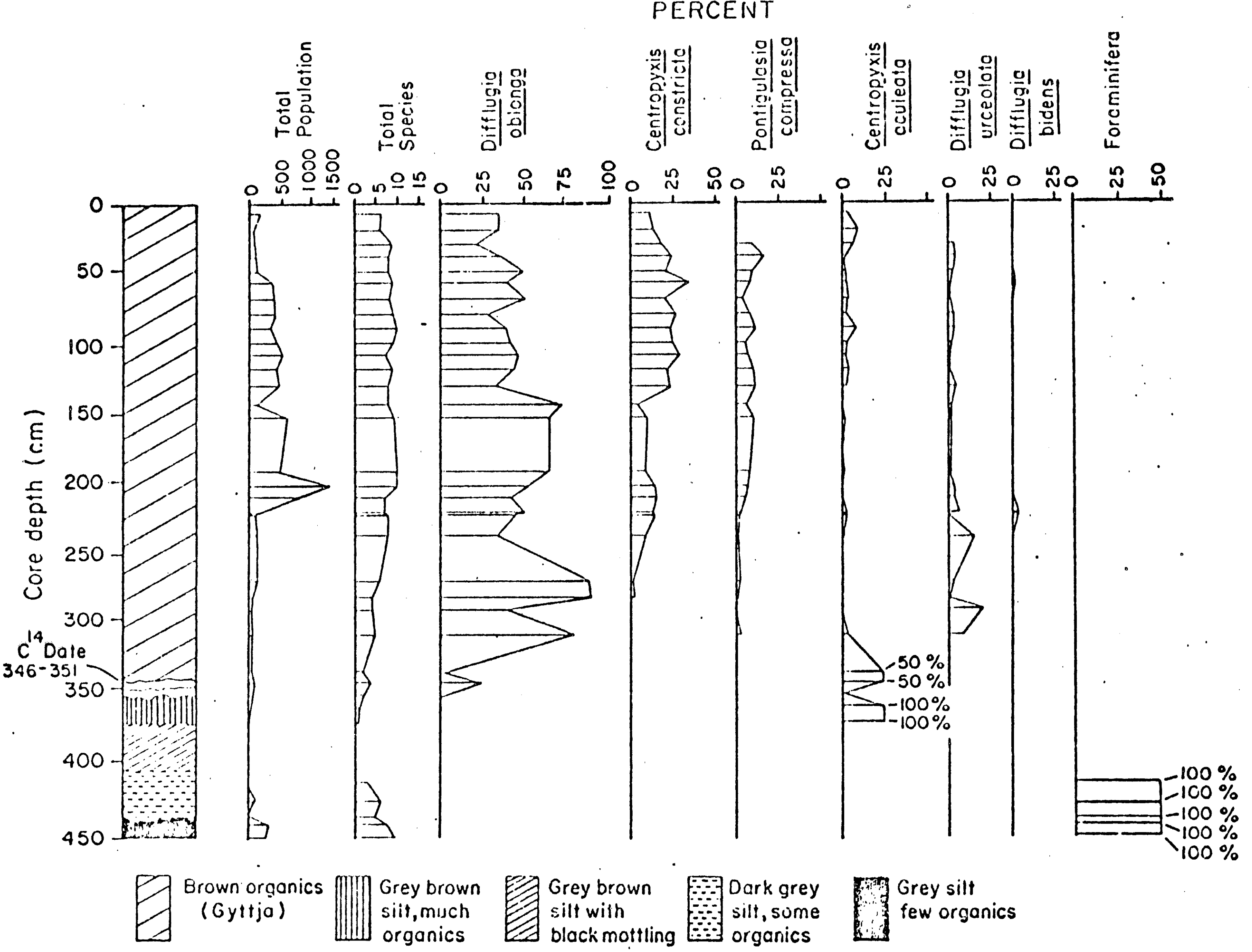
■ Slate

〰 Fault

– – – – – Rock Type Boundary

.... Drainage Basin Boundary

Figure 2. Lithology and biostratigraphy of Gibson Lake core. Horizontal lines represent number and percentage values at corresponding levels; vertical lines are subjective averaging.



The following is a breakdown of the approximate time spent in the preparation of this thesis.

Item	Time Spent (Hrs.)
Arcellacean Identification and Counting.	130
Sample Preparation	2
Tables and Diagrams	30
Preparation of Photographic Plates	12
Research and Writing	55
Total Time	229

Figure 1. Basemap cartography by the Geographical Survey (1966), which has been rearranged, with additions, by the author. Drafting was executed professionally.

Figure 2. Diagram was prepared by the author and drafted professionally.

Tables 1-7. These were prepared by the author and typed professionally on a word processor.

SEM photography was carried out by Frank Thomas with assistance by David Smith, David Scott, and the author in developing prints.

Photographic plates were compiled by the author and Tracy McKenzie, but were reproduced professionally.