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ABSTRACT

One out of six cores taken from western Lake Erie, south of Point Pelee, and covering almost the entire post-glacial sedimentary sequence, was chosen for detailed biostratigraphic study. The study has brought to light extensive and detailed information on fluctuations in faunal diversity and specimen abundance of molluscan taxa – the most frequent biogenic component of the sediment core. The major objective of this study is to present data on molluscan occurrence within a reliable chronological framework, and at a time resolution deemed most suitable for paleoenvironmental studies.

The most important conclusions achieved by the study are as follows:

(i) Changes in faunal diversity and specimen abundance of mollusca through post-glacial times in the Pelee Shoal area can be linked to a whole array of environmental factors, of which climatic oscillations of more or less regular frequency seem to be of ultimate importance.

(ii) The highest peaks in species abundance and diversity of the Pelee Shoal mollusca are associated with processes of marshland development and natural eutrophication of lake waters and with a high rate of nutrient turnover during most distinctive and contrasting climatic events; these events occurred during the hypsithermal period, namely from 6,250 to 3,000 sidereal years ago. After the hypsithermal events ended, the water level rose and the productivity and diversity of the Pelee Shoal benthic fauna declined.

(iii) The more recent faunistic trends show considerable alteration related to increase in cultural nutrient eutrophication of western Lake Erie.

Moderate increases in diversity and abundance of Pelee Shoal molluscs during the last century appears to affect only those species which are peculiar to the sublitoral, namely the Prosobranchiate snails and Pelecypoda. On the other hand, the increase in abundance of the Pulmonate snails is almost negligible.

The climatic deterioration that begins between 3,000 and 2,500 years before present and cultural nutrient eutrophication (with associated changes in mollusc occurrence) are negatively (inversely) associated.

1. INTRODUCTION

The occurrence of macrobenthic organisms at a particular location and the fluctuations in their specific diversities and specimen abundances with time have intrinsic causes linked to a network of biotic and abiotic factors. When environmental factors act interdependently, change in any one abiotic or biotic parameter may rapidly lead to unsteady modifications of other parameters. Besides seasonal and year-to-year alterations the overall aquatic environment, such as a lake, is changing at a pace of decades and hundreds of years. Much of these longterm and large scale ecological changes are ultimately controlled by complex changes in macroclimate, which itself generally acts independently of other environmental factors with the exception of topography and time.

The challenge that recognizes the role of malacology and paleoclimatology in aquatic ecology of Great Lakes is a discovery and holistic explanation of the obvious and less obvious spatial and temporal patterns and trends as inherited from the geological past within and between bottom dwelling biota of various kinds and their physical and chemical limnological backgrounds. If we are to further our understanding of an aquatic ecosystem makeup and function, and to predict or control its lasting changes, the malacofaunistic and ecological history of any lake and lake habitat come up as an inevitable synopsis of the entire scientific endeavour.

The changes in malacofauna of the Great Lakes within the associated bottom biota of high sensitivity to environmental alterations, except a single attempt made by P. Fritz, T.W. Anderson and F.G.M. Lewis in 1975 did not attract much attention of the mollusc investigators. This paper is the first detailed documented evidence of fluctuations in the Late Quaternary history of the lower Great Lakes that have been trapped by changes in bottom dwelling molluscan fauna. It proves a great value of aquatic molluscs in their ability to reflect an advance of ecological processes in a lake dependent on climatic oscillations.

2. GEOGRAPHIC AND GEOLOGICAL SETTINGS (Fig. 1-2)

A vast inland water belt of the North American mid-continent that extends across Canada to the northern United States and includes large lakes such as Great Bear Lake (18,491 km^2), Great Slave Lake (17,976 km^2), Lake Athabasca (4,964 km^2), Lake Michigan (36.049 km^2) Lake Erie (15, 996 km^2) and Lake Ontario (12,134 km^2) and countless smaller lakes coincides with a climatic and environmental borderland characterized by extensive trajectory, expansion, contraction and dominance of various air masses of contrasting properties. Continuously changing circulation pattern of the air masses is a main cause of the well-defined past and contributing element of present, environmental changes over the area, including changes in trophic state of lakes, and their biotic productivity and diversity.

East-west elongated basin of Lake Erie, extending eastward to the 79th mieridian and westward beyond the 83rd meridian, its mid-latitude position south of the 43rd parallel, relatively small depth (less than 11 m in the Western, about 25 m in the Central and maximum 65 m in the

Eastern sub-basins) is extremely vulnerable to both abrupt as well as gradual, large and small scale environmental changes which do occur frequently but often with lesser contrast and resolution in other similarly-sized or smaller lakes. For this reason, Lake Erie has quite a key position for deciphering the complex history of the Late Quaternary climatic, environmental and trophic state changes not only in the Great Lakes area but also on a continental basis.

The other aspect of the environmental history of Lake Erie is its cultural nutrient eutrophication introduced by man's activities in its fertile watershed with many urban centres which undoubtedly have impact on the lake biota, if not in a fundamental manner as did climate in the past, but certainly to such an extent that it must be considered as an environmental change of very prominent magnitude.

One of the essential requirements of climate-oriented paleolimnological studies is the collection of core samples. Usually the length of most of lake sediment cores for paleoenvironmental studies is not great enough to include the entire depositional record and the earlier parts of the sedimentary sequence may be lacking. The value of such incomplete corings from only the uppermost portion of the sequence is therefore limited. By experience, the short cores with records of environmental changes for only 3-4 thousand years or less in general give rather poor resolution because the periods reflecting most pronounced ecological changes and ecogenesis of the lake biota extend further beyond 4,000 years B.P. on the time scale.

The obtaining of sub-bottom samples for research is usually quite costly. It is natural, therefore, that an investigator without access to proper funding and without possession of grants for carrying out a boring program must depend on cores placed at his disposal by research scientists from related fields, after the cores have been sampled and investigated for other scientific or practical purposes.

The offshore shoals and nearshore zones of Lake Erie attract the attention of investigators and occasionally are subjected to coring operations. Such was the coring operation conducted on the Pelee Shoal in western Lake Erie from which one of the most interesting cores was made available to the author.

Pelee Shoal from which cores, including one chosen for biostratigraphic analysis, were obtained, is a very gentle rise on the lake floor between the Western and Central and Sandusky Basins of Lake Erie. It is an underwater extension of Point Pelee which extends below 42° northern latitude and is thus the southernmost point of the Canadian mainland. The shoal extension runs southward for 12 km and the width averages approximately 4 km. Water depth averages from 6 to less than 9 m and the shallowest depth is only about 5 m.

The western part of Lake Erie was the first of the whole lake to be uncovered from the ice of the last Ice Age. There were reasonable grounds to expect there the oldest and most complete paleoenvironmental records within the present boundaries of Lake Erie.

The slight rise crossing the lake bottom and trending southeast from Point Pelee and including the Pelee Shoal, coincides with geomorphic feature mapped as subaqueous (submerged) blanket moraine (Federal Water Pollution Control Administration, 1968), the Pelee-Loraine moraine (G.D. Hobson, C.E. Henderndorf and C.F.M. Lewis 1969) or the Pelee moraine (P. Sly, 1976). The Pelee moraine, which carries the planar erosional-abrasional surface is uncomfortably covered by postglacial lacustrine sediments, consists of rather fine-grained calcareous clayey till with fewer erratic boulders. According to some authors (A. Zeman, 1980) the till represents so-called lodgement till - basal ice drifted material lodged over becrock deposited during Port Stanley till forming episode some 14,000-13,500 years ago. The late Pleistocene setting shows the Pelee-Loraine moraine, of which the Pelee Shoal is an integrated part, as the oldest of the four moraines which were left behind by retreating, stagnating and re-advancing Erie ice lobe during the Late Wisconsin deglacitation episodes across the Lake Erie basin (within its present boundaries).

The general retreat of the Erie ice lobe was followed by usually vast but short-lived glacier-margin lakes. The stretch of these lakes were reconstructed from studies of their outlets and strand lines, and from investigation of ice laid ground and end moraines in Michigan, Indiana, Ohio and Ontario. A conclusion was made that soon after the Erie ice lobe retreated from the Fort Wayne area, after some 14,500 years before present, the earliest of the ice ponded lakes possibly members of Lake Maumee with outlet to a predecessor of the Wabash River in Indiana, 224 m above the sea level and 51 m above the present Lake Erie level, were formed. It is quite likely that these proglacial lakes set were contemporaneous with the ice crossing responsible for the Pelee Moraine and that the Pelee Moraine was actually constructed at the time of Lake Maumee's submergence. (P. Sly, 1976).

The Pelee-Loraine moraine with adjacent area is underlaid by the Early Paleozoic rock complex emerging from beneath the mostly Middle Paleozoic formations of the Michigan basin and Appalachian geosyncline in the tectonic structural form of so-called Findlay-Algonquin arches. The monoclinal, markedly resistant Lower Devonian limestones and dolomitic limestones underlie the Quaternary deposits of the shallow Western Basin and in the more deeply scoured Central Basin give way to the Upper Devonian less resistant shales for much of the Lake Erie basin length. The eastern margin of the Pelee moraine might concur with this lithological change.

The limestones and dolomitic rocks are generally exhibited along the most accentuated and to the wave action most resistent coastlines of Pelee Island. They also outcrop subaqueously in the form of bedrock notches, underwater hills, between Pelee Island and Pelee shoal, or even as a flat scoured rock bottom, particularly in Pelee Passage (Fig. 1).

There is no evidence of Quaternary sediments older than the Port Stanley till, from the Pelee shoal area, however, the altitudinal differences in bedrock topography might be inscribed to polygenetic erosional alterations that are not only Wisconsinan but most likely older in age and might be subglacial, glaciofluvial and abrasional in origin, related to the processes of penultimate glaciation, de-glaciation and various non-glacial events in the area.

Due to the coincidence of genesis and history, the Pelee Shoal is not completely a flattop, but rather a gently undulating underwater platform. Composed of the early Lake Erie and younger lacustrine sands, silts and silty clays, the rise carries several parallel and transversal sand ridges to about 1-2 m in height and a few rather deep trenches and depressions left after the dredging operations (Fig. 2).

The southern and southwestern end of the Pelee Shoal is somewhat truncated. It drops rather abruptly from 5 m to over 12 m in depth. The truncation runs longitudinally with the Pelee Passage in a northwest-southeastern direction. The Pelee Passage separates the Pelee Shoal from rather irregular bottom relief surrounding the Pelee Island and adjoins at over 11 m depth the northernmost portion of the triangular Sandusky Basin.

The bounding contours of the rise on its western and eastern side are rather gently curved and more regularly spaced. Here the rise is very gradually merging flatbottom Western and Central Basins. The Western Basin of smooth unchanging bottom relief, is in average, only one-tenth of the Lake Erie total area and is only 11 m in depth. In contrast, the Central Basin, on the eastern side of the Pelee Shoal, can be classified as one of the largest lacustrine plains in the world, areally five to six times larger than the Western Basin, with mean water depth of 22 m and 26 m at maximum. Due to a sheltered position from the prevailing western current systems, the gradient (3:10,000) sloping off of the Pelee Shoal to this level is so gradual that the bottom appears practically uniformly flat and smooth.

2.1 DESCRIPTION OF SEDIMENTARY SEQUENCE (Figs. 2-8)

During August 1974, using a barge maneuvered by a tub boat, six cores were collected at various sites on Pelee Shoal. The coring tool was an apparatus suplied by Alpine Geophysics Ltd., Norwood, New York. This corer gave continuous sediment cores of up to 12 m in length and 9 cm in diameter. The main advantage of the corer is the ability to penetrate and sample sand materials with minimal disturbance.

A total of six cores were taken on the shoal, three of which sampled materials down to the basal till. Core 1 was over 4 m long and encountered over-consolidated till under the massive sand and a lag of gravel in depth of 1.2 m. Core 3 was 9 m long and under 2.5 m thick layer of sand a 1.1 m thick layer of laminated sand encountered till in the depth of 3.6 m. Core 4 was 7 m long and penetrated 1.2 m thick layer of massive sand, 1.2 m thick layer of laminated sand, 1.5 m thick layer of laminated silt, then some sand lenses and finally a gravel lag before encountering till in 6.1 m depth.

The other three cores, 5, 6, and 2, were situated further south of Point Pelee and were 9.0 m, 12.0 m and 11.2 m long. They gave a stratal sequence surprisingly similar even if there is a distance of almost 2 km between boring 5 and 6 and 1 km between boring 6 and 2. From top to bottom the sediment in these cores consisted of five distinct stratigraphic subunits (Coakley et al. 1980). The superficial subunit of massive sand was encountered only on site of core 6 and 2 and was 2.1 and 1.5 m thick respectively. At site of core 5 this subunit might have been 2.5 or even 3.0 m thick, but apparently it was dredged out. The superficial subunit of massive sand was underlain by a second subunit of laminated sand identically 2.0 m thick in core 6 and 2 and somewhat thinner at the site of core 5, where its top was removed by dredging operations. The third subunit, transitional in its character, of laminated sand at the top to laminated silt at the base also had the uniform thickness about 2.0 m. The fourth subunit of laminated silt, 4.0 m thick, is the thickest of all the subunits recognized. Finally, the fifth basal subunit of massive clayey silt at core site 5 and 6, and of massive silty clay at core site 2 was at least 1.5 m thick, and probably thicker. None of the cores 5, 6 and 2 encountered the till unit, which obviously forms the base on which the original lacustrine sequence was laid down. Core 2, 11.2 m long was selected for biostratigraphic study and forms the basis of the analysis presented in this report.

3. ANALYTICAL PROCEDURES

The sediment core 2 was subjected first to routine scrutiny. Still being in its protective plastic tubing, the core sections were x-ray photographed for identification of sedimentological changes and cross-correlation. Then the liners were sawn longitudinally and the sediment core was logged and sampled at approximately 30 cm intervals for particle size distribution and other analysis.

The particle size distribution of the sediment samples was obtained using the combined sieve-pipette-settling tube-sedigraph procedure (Rukavina and Lahaie, 1975). The grain size analysis results were presented in the form of the average sand-silt-clay ratio histograms (Figs. 3-7), fence diagram (Fig. 2) and plotted and shaded columnar log diagram to show variation in grain size with reference to sub-bottom depth and major stratal boundaries (Figs. 2 and 8). In addition to the field estimates and the measurement of the penetration rates during the coring operation, the degree of relative density in sand and consistency in soft to stiff cohesive sediments and consolidation of the sediment were tested by Shear Vane Laboratory and one-dimensional consolidation tests respectively (K. Terzaphi and R.B. Peck, 1967). The natural water content of the sediments was estimated as percentage of dry weight. (In case of free draining sands, the values obtained were several times underestimated in comparison with values which they may have in situ). The calcite and dolomite percentages were determined on sediment samples gasometrically by using Chittick apparatus (A. Dreimanis, 1962).

After geotechnical experiments and measurements were completed (Coakley et al. 1980), core 2 was placed at the author's disposal. Since in detailed paleoenvironmental research only continuous and most detailed sampling can provide incontestable results (especially at the zone of transitions) for the malacological examination 33 samples were taken for each 1 m long section of the core. Each sample increment contained approximately 190 cm^3 of sediment material. The samples were individually dried, weighed and stored in plastic bags.

Those samples consisting of sand were dry-sieved through a 20 mesh sieve with openings 0, 84 mm in diameter. The residual material retained on the sieve was stored in vials for sorting, identification and counting.

Clay and silt samples dried into hard and compact lumps. The fossils were separated from the clayey and silty materials by crushing down the lumps into crumbles of about 0.5 cm in size using forceps and specially constructed pliers. Then the shells were extracted manually. Any other separation technique would have either destroyed the sediment matrix or the fragile shells embedded in it.

After the shell separation procedure was over, each of the 369 samples was examined and specimens identified to a species tank. The direct counting of shells was made under a low-powered stereomicroscope with possibility of magnification: x6, x12, x25 or x50, respectively. Representative well-preserved specimens were picked out and drawn with the help of camera lucida (Fig. 10-39). Reference material is presently stored in the author's collection at the Canada Centre for Inland Waters, Burlington, Ontario, Canada.

3.1 BIOSTRATIGRAPHIC DATA DISPLAY (Table 1-2, Fig. 9)

The existing variety of paleoenvironmental data sources from the Great Lakes area and elsewhere ranging from lithostratigraphic, biostratigraphic, chronostratigraphic, paleoclimatic, geolimnologic, geochemical, magnetrostratigraphic to lake levels and sedimentation rate histories is in discord and incompatible.

Some of the reasons why interpretations in paleoenvironmental studies up to now are rarely feasible particularly on a quantitative basis are:

(i) absence of consistent reference data,

(ii) lack of proper understanding of the resolution limits of the paleoenvironmental record,

(iii) inappropriate approaches to problems concerning chronological adjustment of the vertical core records because of the unavailability of reliable detailed chronological scales based on continuous biostratigraphic sequences.

All the examined sediment samples from core 2 contained organic detritus. The biogenic detritus was composed mostly of well-preserved molluscan skeletal remains, at some horizons markedly diverse and prolific. The skeletal remains were belonging to several ecological and taxonomic categories with a dominance of prosobranchiate gastropods, followed by sphaeriacean clams. Other taxonomic groups such as pulmonate gastropods and unionacean clams were minor. Most of the identified species are paleoenvironmentally indigeneous and still inhabit either present-day Pelee Shoal sublitoral or live in the shallower nearshore zone of Lake Erie and its coastal marshes.

The high resolution of the molluscan records and its completeness provide rather unique opportunity to significantly elucidate the chronological details of the faunal genesis and ecological conditions under which the Lake Erie bottom biota originated and evolved over the succeeding millenia.

The Pelee Shoal molluscan sequence with its very pronounced fluctuations in faunal composition and in the specimen abundance of various taxanomic categories is also very attractive for studies on detailed paleoenvironmental reconstruction, intercalibrations between physical, chemical and climatological parameters based on known environmental requirements of selected species, and on intersite correlations.

My objective in this report is to outline and employ the most simple but effective procedure of dealing with core data to explore possible interpretation improvements of quantitative data that might result in bringing forth a relatively consistent and chronologically well-adjusted paleoenvironmental record not only for western Lake Erie, but usable for reference and correlation purposes elsewhere.

To simplify this task, it was decided to reduce the extensive data on faunal diversity (number of species per sample increment) and specimen abundance available per each 3 cm sample interval and depress somewhat the high resolution of the original data set to a level that is currently most preferred in paleoenvironmental studies. In other words, the data from sets of three 3 cm intervals were combined together and plotted stratigraphically as data from 123 sample increments, thus yielding approximately 11 data sets per 1 m of core length.

The 9 cm sediment core samples which provided the data on mollusc diversities and abundances were (because of differences in specific weight) not of equal mass. For example, sediment samples of sand averaged only 570 g per sample while clayey and silty samples were 100-130 g heavier. Also at 36 horizons, the core samples had been half split and half sections had been removed before the stratigraphic analysis proceeded. This meant that only meager subsamples were available at these positions for paleontological investigations. For the sake of consistency, in order to have proportionally balanced frequency abundance data continuously throughout the whole length of the core, we normalized abundance data and plotted the tallies against sub-bottom depth as macrofossil concentrations: number of specimens in 100 g of dry sediment per 9 cm core increment.

The graphic representation of the downcore data, after being consistently combined and considerably reduced, formed the continuous sawtooth curves with pronounced in-phase segments and shouldered, symmetrical or skewed peak groupings of various amplitude. The smoothened curves neither under-emphasized nor over-emphasized the basic fluctuation pattern, but retaining the number of most pronounced peaks and troughs eliminated the obscure random oscillations charactizing the use of the 3 cm sample increment record. They also facilitated the establishment of the composite charts to highlight the relationship between and among the mollusc species content and abundance data for various collective taxonomic categories. This is shown by the close coincidence in peaks and troughs position in curves representing the downcore variation in faunal diversity and specimen abundance. Side by side, the faunal taxonomic diversity and specimen abundance curves can be considered a generalized downcore response diagram of the whole molluscan community.

3.2 TIME SCALE CORRECTIONS (Table 1, Fig. 8)

To interpret the downcore record of faunal diversity and specimen abundance in terms of environmental change, especially climatic change, including changing patterns of local immigration, extinction and productivity, one must consider the fossil record in an appropriate chronological reference frame.

For conversion of the trends in species diversity and specimen abundance downcore to an absolute chronology, the two standard time scales which are most often used in the modern paleoenvironmental studies were chosen: one expressing time in sidereal years before present (B.P.) and the other allowing conversion of the radiocarbon dates to absolute chronology. (N.A. Mörner, 1980.).

The transforming device employed was a sedimentation rate curve of core 2 supplemented by ^{14}C dating (Fig. 8). The radiocarbon date 10,250 ± 350 years B.P. was determined on plant detritus, believed to be autochthonous, at 5, 6 m core depth (160.7 a.s.l.), below the horizon of the transitional sediment subunit sandwiched between clayey silt and sand dominated subunits. The radiocarbon dated 10,250 ± 350 years B.P. core level chronostratigraphically thus corresponds with major changes in Pelee

Shoal depositional environment, at the end of the Lake Wisconsin and at the beginning of the Holocene.

3.3 SEDIMENTATION RATES (Fig. 8)

According to the sedimentological and paleontological record, the earliest limnic clayey silt deposition, we assume, to have started before or around 12,500 sidereal years B.P. after rather shortlasting subaerial consolidation of lake bottom sediments (Coakley _et_ _al_. 1976). The sediment record we think does not extend further back to substantiate a reliable conclusion on Late Wisconsinan events earlier than 12,500 years B.P. No traces of terrestrial molluscs or other fossils, suggesting the subaerial exposure of the bottom of the lake prior to early Lake Erie limnic sedimentation were found. The earliest limnic depositional regime was apparently rather stagnant, tranquil and resulted in very rapid, monotonously fine-grained sedimentation associated with turbid water entering or originating within the lake basin. This could have occurred until the permafrost and dead ice buried under sediments of various origin was completely razed off and dismantled and while the main body of the Laurentide glacier broke up, disintegrated and with its periglacial zone retreated toward the northeast.

Exact rates at which the clayey silts and silty clays were accumulated on the lake bottom is not easy to estimate because of the multitude of processes which controls them. The flux of fine sediment particles through the water column, the preservation and solubility of the minerogenic components, the stability of the sediments once they were resting on the lake floor, their differential compaction after burial, are all factors which makes estimation of sedimentation rates uncertain and disputable. The estimated value of the linear sedimentation rate, 3 mm/yr for clay and silt dominated strata at the site of core 2, obtained by dividing the measured length of core section by the estimated time of sediment accumulation endpoints, seems to represent only one-half (or more likely one-quarter) of the initial sediment thickness (A.J. Zeman, 1980).

A soft lake bottom with rapid accumulation of clay and silt does not represent a very favourable environment for diversity of molluscan life. But certain species tolerate and even require such habitat, particularly when the lake floor is sparsely or densely vegetated with a growth of submerged aquatic plants. The concentration of *Probithinella lacustris* a prosobranchiate snail, and *Sphaerium striatinum*, a sphaeriacean clam in rapidly accumulated clayey silt strata comprising the interval 6,50-11,08 m in effect indicates a high reproduction rate per area and time unit for the populations, with boreal affinities, between 11,000 and 12,500 years ago. Consequently, in the time series bar diagram (Fig. 8) established by conversion of the counts of skeletal remains from the vertical depth scale to a horizontal time scale via a sedimentation rate graph, the data control points of low counts are consistent with productivity bars of the medium height at the beginning of the chronologically adjusted paleoenvironmental record and indicate medium to high eutrophic productivity.

The steep, rapidly rising Lake Wisconsinan portion of sedimentation rate curve, after passing at the Early Holocene-Late Wisconsinan level an abrupt inflection turns to rather straight course sloping gradually towards the top. This trend is an indication of the steady and gradual depositional environment.

As the calm and placid boreal limnic depositional conditions ceased to exist so did physical properties of the low energy Late Wisconsinan sedimentary environment. With the dawn of more tempestuous Holocene climatic conditions over the tranquil mudflat platform of Pelee Shoal encroached gradually a little at a time, but at steady rate, high energy sandflats. Upon the depositional environment change were superimposed limnological changes in the lake metabolism, its biotic diversity, and productivity regimes including oscillations in mollusc assemblage compositon and specimen densities controlled by climate.

As a result of the different network of interactions between time, sediment supply, winnowing and accumulation, the sedimentation rates slowed down. The estimated gross linear sedimentation rate for predominantly sand subunits of the lithological column is less than 0,6 mm per year. This value, if it is corrected for compaction and loss of porosity with depth and time can be higher. But if such factors are taken into account as postdepositional solution of the discrete calcareous particulate components, winnowing of sand of fine particles and episodic removal of noncohesive loose material by bottom currents the steady initial sediment accumulation could slow down and nondepositional hiatuses interrupt the sedimentary record.

The temporal distribution of sediment depriving episodes and hiatuses is an important variable in the broad sedimentation rate pattern. The sediment depriving, non-depositional or extremely low sedimentation rate episodes occur either near or at those chronological levels, which show very dramatic increase in faunal diversity and specimen abundances throughout the paleontological record.

For example, the anomalously high specimen abundance peaks such as one which occurs at depth interval 317-326 m shows that this episode of non-deposition and high organic productivity must be quite lengthy causing enormous increase of concentration of shells in the sediment matrix. To adjust the abnormal peak in amplitude and make it congruent with general patterns of the lake productivity during the Holocene it was compulsory to split a single increment concentration value and equalize it over two 250-year increments (6,000 ± 250 years B.P.). The expanded timespan changed amplitude of the peak and modulated through the control points the sedimentation rate curve and made its particular portion flat. At other intervals where processes generating hiatuses were most intensively at work, the sedimentation curve might have such notable flat portions with little or no slope at the various depth-time intervals.

Low sedimentation and non-sedimentation intervals particularly if combined with increases in water temperature, eutrophication and rapid nutrient turnover, represent most favourable and fertile conditons for optimal diversification of molluscan limnic communities and for increasing the molluscan reproductive potential to a maximal possible level.

With exception of a few easily detectable irregularities as those mentioned, the plotting procedure of data control points thoughtfully scattered on sedimentation rate line have inferred indirect dates to all major peaks and troughs of molluscan record without much adjustments in amplitude or phase.

Because of slight variation in the net sedimentation rate all 50 interpolated ages established from 123 investigated levels are inferred approximations and subject to errors which might be corrected by minor rearrangements usually within error bound of the radiocarbon dating (about ± 250 years).

To sum up the illustrated molluscan record of faunal diversity and productivity change (after being segment after segment triffle chronolgically adjusted) in phase to compensate differences in sedimentation rates dates the megascopically and granulometrically recognized markers of the lacustrine sequence of the Pelee Shoal are as follows: (i) the conventional Holocene-Late Wisconsin chronostratigraphic boundary (10,000 years B.P.) falls very close to the mid-point of the transitional subunit. (ii) the Early-Mid Holocene boundary set arond 6,250 years B.P. is about one-third above the base of laminated sand and sand with silt lenses subunit. (iii) Finally, the Mid-Holocene and Early Holocene boundary set around 3,000 years B.P. is near the bottom of the surficial massive sand subunit. It should be noted that excessive concern to detailed boundaries placement, whether stratigraphical or chronolgical on this scale of resolution is a circumlocution, perhaps an unjustified and unimportant pettiness with regard to the whole record perspective.

4. MOLLUSCAN FAUNAL CHARACTERISTICS

The number of specimens present in 9 cm sediment core increments and their average concentrations: number of specimens per 100 g of sediment, according to the major taxonomic groupins: Unionacea, Sphaeriacea, Prosobranchia and freshwater, terrestrial and total Pulmonata are presented in Table 1. The names of all recognized species according to their allegiance to different dominance groups and major taxonomic categories are inserted in Table 2. The abundance data on occurences of twenty-five most significant species and taxonomic groups are indicated in the time range malacodiagram in Fig. 9. Original illustrations of most of the species are shown in Fig. 10-43.

4.1 DOMINANT AND SUBORDINATE TAXA (Table 2)

In the mixture of taxonomic entities present in organic detritus of the Pelee Shoal limnic sediments, on the basis of frequency distribution, two categories can be recognized: dominant and subordinate, (Table 2).

The dominant taxa are those forms or groups of forms which in quantitative terms (particularly by their biomass, abundance and density) are prevalent components of the mollusc assemblage which occur continuously throughout the entire, or almost entire, sediment sequence. The abundance fluctuations of each group of species or individual dominant species may be utilized to establish the paleoenvironmental trends. In this study, however, the use of the entire faunal assemblage is prefereable to any one of eleven indicator species, recognized among the total of sixty-one identified taxa, since ecological adaptations through time may influence the paleoenvironmental message delivered by single taxon. In addition to the indicator species as collective taxa of the dominant group may be considered the entire Pisidiid clam population, a group which in their ecological requirements represent closely related species. The Unionacean clams in terms of their biomass dominate the benthic biota, but in terms of the abundance counts, they must be categorized as rare forms. Except Sphaeriacean clams in capacity of the collective indicator taxa stand subtotals of Prosobranchian and Pulmonate Gastropods and a total of entire Molluscan population. All dominant forms are paleoenvironmentally autochthonous.

In the dominant species group (Table 2) the ratio of the Pelecypods, (including Unionacean and Pisidiid clams as units) - Prosobranchiate gastropod species - Freshwater Pulmonate gastropods is 4(2):8:1. The terrestrial pulmonates are not represented in dominant groups.

In addition to dominant group the molluscan assemblage of the core samples is marked by the presence of subordinate forms. These are either confined to certain horizons only, or their distribution throughout the sediment core is semicontinuous, and interrupted or their cumulative frequencies, abundance, densities and biomass is extremely low. This is probably because the environmental conditions of the site did not fully satisfy their common needs. They may be indigenous and semipermanent as most of the species of Pisidiids are or they may be only evanescent intruders from the neighbouring communities, where they occurred more abundantly, as in the case of the Pulmonate snails. Finally, they may be allochthonous as most of the land snails. The subordinates including rare species contribute greatly to faunal diversity counts. As such they are very useful in paleoenvironmental analysis as good indicators of the spatial and temporal transition from one set of environmental conditions to another.

The ratio of the Pelecypods-Prosobranchiate gastropods-Pulmonate gastropods belonging to category of subordinate species is 13:7:30.

4.2 OCCURRENCE AND EVALUATION OF TAXONOMIC ENTITIES (Table 2, Fig. 10-43)

In this paper we do not intend to analyse the problems of conchological taxonomy, malacological nomenclature, or search after interesting but seldom-seen rarities. The preference in the molluscan material analysis had been given to reliability of the interpretation of the paleoenvironmental record which in the long run is based on easily identified, well-known and routinely counted ubiquitous forms. But by handling over 25,000 specimens from the core samples we run inevitably into several taxonomic and ecozoogeographical problems which require at least very short coverage and commentary.

To overcome complications which arise with identification of fossil material at subgeneric levels, we imposed a few standard limitations on treatment of certain taxonomic entities. Taxonomically hard to deal with but consistent fragmentary material particularly material consisted of almost specifically unrecognizable immature juveniles and coroded shells were preferred to list whenever possible as a potentially single specific taxon. If we observed within a population of a polymorphic taxon either regular or erratic unconformity with the typical form throughout a portion of the core we tried to retain the earliest nominal designation.

Neglected taxonomic features of the malacological record will require separate study, particularly whether the clusters of taxonomically related ecophenotypic entities are a local population response to environmental change or an immigrative extension of the particular ecophenotype geographic range.

The Pelee Shoal limnic sediment sequence is characterized by a frequent occurrence of Pelecypoda (Fig. 10-13). The Unionocean clams occur as mother-of-pearl flakes and periostracal ligament fragments mixed with early juveniles and whole shells of adults. The Unionscean fragments are easily distinguishable from non-nacreous mostly unfragmented shells of Pisidiids.

For unusually large dimensions from 3 cm to over 10 cm in length the value of the freshwater mussels in stratigraphic context of a sediment core sequence is rather limited. Undoubtedly, the Pelee Shoal from its earliest time of existence was a spawning ground for naiads which most largely contributed to its benthic faunal biomass. Of the more than dozen species which could inhabit the Pelee Shoal mussel beds, only three forms were identified down to species level and entered the diversity and specimen count charts. These are: <u>Lampsilis</u> <u>radiata</u> <u>siliquoidea</u>

(Fig. 10) *Fusconaia flava* and *Anodonta grndis grandis*. (Note: For author's name in the species mentioned above see Table 2). The other forms which could occur in Pelee Shoal deposit sequences are *Amblema plicata* (Say 1817), *Quadrula pustulosa* (Lea 1831), *Q. quadrula* (Rafinesque 1820), *Elliptio dilatata* (Rafinesque 1920), *Pleurobema cordatum* (Rafinesque 1820), *Lampsilis ovata* (Say 1817), *Leptodea fragilis* (Rafinesque 1820), *Ligumia nasuta* (Say 1817), *L. recta* (Lamarck 1819), *Obovaria subrotunda* (Rafinesque 1920), *Proptera alata* (Say 1817), *Truncilla donaciformis* (Lea 1928), *T. truncata* (Rafinesque 1820) and *Obliquaria reflexa* (Rafinesque 1820).

The abundance of Sphaeriacean clams in the core assemblage is quantitatively second in importance to the Prosobranchiate gastropods. Among several hundreds of Pisidiid clams as many as nine species were distinguished. Rather than showing the individual species range patterns at present, we have grouped the species together as Pisidium spp. to include immature shells into the total sum. These are difficult to identify and sort out on specific level. This step has increased the resolution of the clam record and provides better paleoenvironmental evidence than the information provided by individual species. The recovered species of Pisidiids however have entered the faunal diversity counts on each of 123 core levels. The fingernail clams' names are listed among subordinate forms in Table 2 and one characteristic species, *Pisidium lilljeborgi* is illustrated in Fig. 11. The members of the genera *Sphaerium* and *Musculium* do not cause taxonomical problems. The downcore and time range distribution of *Sphaerium striatinum* (Fig. 12) covers the entire Holocene and is consistent with general response pattern shown by the entire molluscan community. Within the population characterized by well-marked growth rests, there are specimens with weaker and barely discernible external striae, and specimens which could be regarded as intermediates between the extreme forms. Neither Sphaerium nitidum (Westerlund 1876), a predominatly subarctic and arctic form, nor its relative Sphaerium corneum (Linne 1758) a common alien introduced from Europe and naturalized in Lake Erie waters were found. Musculum lacustre (Fig. 13) is confined mostly to Late Wisconsinan lower portion of the sediment core and to few Early, Mid and Late Holocene incidental occurrences in the mid and upper core sections. Depaupterate and capped morphs of Musculium lacustre from the core samples suggest consistency with the high latitude cool water sublittoral and littoral forms. In a crude way, this form might indicate episodes of temperature drops of the Pelee Shoal waters. Subordinate form Musculium transverse was found only in fragments and in only three chronologically widely spread occurrences at the top (9-18 cm; 0=250 years B.P.), at the middle (561-570 cm; 10,250-10,000 years B.P. and at the bottom (842-852 cm; 11,750-12,000 years B.P.) of the sediment sequence.

The numerical predominance of Prosobranchiate gastropods (Fig. 14-27) and the relative high number of their species and specimens, represent the most striking aspect about the molluscan fauna of the Pelee Shoal limnic sediment sequence. Eight or eleven dominant species and seven of fifty subordinate species which occur in the Pelee Shoal sediments belong to this subclass.

First appearance of Valvata perdepressa (Fig. 16) at 7,250 years B.P. and its rapid abundance increase at 6,250 years B.P. provides important datum level for intra-Holocene biochronology. The co-occurrence of Prosobranchiate species since the earliest existence of limnic conditions at the Pelee Shoal makes them most outstanding and responsive indicator of paleoenvironmental trends throughout the entire Late Wisconsinan and Holocene time.

Prosobranchiate mollusca belonging to category of dominant forms show a fluctuating abundance pattern which might indiacte the operation of environmental periodic factors. The most important primary environmental factors seems to be temperature, trophic state of the lake waters and nutrient turnover rates. Most of the operculate molluscs reach highest abundances during climatic interludes as warm as, or warmer than at present, corresponding to a relatively high state of eutrophicity and rapid nutrient turnover.

An apparent exception to this rule is Valvata sincera helicoidea (Fig. 17). Its morphs identical with those which occur at present in the Canadian northland lakes, tend to occupy, but never abundantly those intervals with intermediate climate more or less similar to or strikingly cooler than that at present. A variant of the same species with a slightly modified shell sculpture (most likely a morph ecologically induced and attributable to Great Lakes), is sporadically present even in warmest Holocene intervals perhaps as a relic population. Occurrence of Valvata sincera helicoidea and associated ecophenotypes is an example of a taxon with low population counts which with climatic ingression adjust its shell morphology and ecological valencies without reducing greatly its densities. It is also an example of a species which once established in the lake is never completely eradicated.

The adult specimens of Campeloma decisum (Fig. 14) carry very distinct characters sufficient for correct determination. However, the immature specimens could be confused with adult forms of Somatogyrus subglobosus. We did not reliably identify Somatogyrus subglobosus previously reported to be a common species in Western Lake Erie (K.G. Wood, 1963) in any of the Pelee Shoal sediment, but we did identify Campeloma decisum in Late Holocene samples.

Valvata tricarinata (Fig. 15) shells from the Great Lakes are often characterized by the loss of carination to such a degree, that they become often convergent with Valvata perdepressa (Fig. 16). On the other hand, some Valvata perdepressa forms show slight angulation discernible on the last body whorl. In this study we consider Valvata perdepressa within the narrow rank of its most discriminating characters and all carinated or distinctly angulated morphs we assigned to intra-population variations of Valvata tricarinata.

The correct identification of minute, (in their general shell characteristics) converging species of Hydrobiid operatulate gastropods from the sediment core samples is difficult for a variety of reasons. Apart from the sexual differences (Fig. 18, 20-22) and exceeding variability in their shell morphology (Fig. 21) there is a lack of distinctive shell differences compatible with features of internal anatomy. The shape of male reproductive organ (-the verge) is a feature on which the specific taxonomic categories in Hydrobiids are almost entirely based, yet the shell characters represent the only feature that can be consistently employed in the identification of fossil material. To confront the taxonomic confusions and associated score of nomenclature alterations and different names attached to often only phenotypically aberant or sexually distinct shells we consider Hydrobiids present in our samples as cluster of forms centered around three dominant species: *Cincinnatia cincinnatiensis* (Fig. 18), *Probithinella lacustris* (Fig. 20), *Pyrgulopsis letsoni* (Fig. 21) and three subordinate species *Marstonia decepta* (Fig. 19), *Amnicola limosa* (Fig. 22) and *A. walkeri* (Fig. 23).

There is a great deal of overlap in conchological characters between male shells and relatively longer and narrower shells of females in conispiral *Cincinnatia cincinnatiensis*. In the counts, the shells were not differentiated according to sexual dimorphism, but shells of both sexes are illustrated. The very common Hydrobiids with a truncated apex and nuclear whorl sunken below following whorl we refer to *Probythinella lacustris*. It seems that relationships between shell morphology and ecogenesis are not consistent enough to give rank of separate taxonomic status to various *Probythinella* morphs which were seen in our material. Also extremely prone to variation in shell morphology is *Pyrgulopsis letsoni*, a characteristic species inhabiting crevices and cavities in calcium carbonate encrustations on rocks and rocky substrates. It is rarely seen alive, but is common as a Late Quaternary fossil. The taxonomic status of *Pyrgulopsis letsoni* and related forms require taxonomical re-evaluation particularly on fresh material with soft parts preserved which will be quite unlikely to be obtained without special sampling techniques and diving.

Subordinate Hydrobiid species, namely Marstonia decepta, Amnicola limosa and Amnicola walkeri, were found in Pelee Shoal samples in much lower numbers than one would expect. This is perhaps a result of their failure to establish themselves and reproduce successfully in competitive relationships with other tiny Amnicolids.

Large turreted, thickwalled, often variously multi-carinated Pleurocerid operculates (Fig. 24-27) were found for the first time as accessory specimens as early as Late Wisconsinan of the Pelee Shoal sediment sequence. They regularly occurred in Early Holocene sections and their presence became overwhelming (particularly in terms of mass of shell material) in the Mid and Late Holocene sections. Two Pleuroceriid species Oxytrema livescens (Fig. 25) and Pleurocera acuta (Fig. 24) are superior in abundance of shells to forms Oxytrema haldemani (Fig. 26) and Spirodon carinata (Fig. 27). The proportion of Oxytrema livescens to Pleurocera acuta specimens in the counted samples seems to be somewhat underestimated, because all ambiguities in identification and counting of the Pleuroceriid species were resolved in favour of most abundant form Pleurocera acuta. The shells of Oxytrema livescens were counted but only when recognized with certainty.We have selected a single specimen for illustration (Fig. 26), but otherwise no attempt was made to separate specimens of Oxytrema haldemani from slightly wider shells of Oxytrema livescens. It seems that shells of both forms strongly converge and their separation in paleoenvironmental studies is not much relevant. Spirodon *carinata* known also under the name *Oxytrema livescens niagarensis* (Lea, 1841) is poorly recognized inhabitant of rocks washed by waves. It was found at depth-time intervals 126-172 cm (2,500-3,250 years B.P.) and 308-317 cm (5,500-5,750 years B.P.) but never abundantly. Both intervals are associated with changes in water levels noted early in the Mid Holocene and in the transition from Mid to Late Holocene.

Two species *Valvata tricarinata* and *Probithinella lacustris* out of the total of fifteen operculate snails present in the Pelee Shoal malacofauna are ecogeographically widespread, inhabiting various freshwater habitats along the gradient ranging from southern to northern latitudes across the North American continent. One species *Valvata sincera helicoidea* belongs to groups which have more or less northern boreal ecozoogeographical affinities. Four species *Pleurocere acuta*, *Campeloma decisum*, *Amnicola limosa* and *Somatogyrus subglobosus* might be regarded as species with geographic range descending from the Great Lakes basin toward very southern latitudes. Eight species are characteristic of mid-latitude North America, in general and may be regarded the endemics of Great Lakes-St. Lawrence River watershed, including adjacent segments of neighbouring interior basins: *Valvata perdepressa*, *Pyrgulopsis letsoni*, *Cincinnatia cincinnatiensis*, *Oxytrema livescens*, *Marstonia decepta*, *Amnicola walkeri*, *Oxytrema haldemani* and *Spirodon carinata*.

Finally, it remains to say that no shells of *Bithynia tentaculata* (Linné 1758) an accidentally imported Prosobranchiate snail brought to Great Lakes from Europe and during last 100 years rapidly became widespread were found in the Pelee Shoal mollusc samples. The species have infested the most molluscan biotopes in western Lake Erie and engage the native mollusc population in direct competition for available resources.

The rather exclusive ecotaxonomical group found in molluscan fauna of the pelee Shoal sediment sequence are Pulmonate gastropods (Fig. 28-43). The main characteristic which distinguishes Pulmonate gastropods from clams and Prosobranchiate operculates is the replacement of the gills with a mantle sack as an organ of respiration. Gaseous exchange by means of the mantle cavity makes pulmonate snails more or less less independent on aquatic environment since respiration may take place largely or totally out of the water depending on species specific adaptation. For convenience of paleoenvironmental analysis the aquatic and land Pulmonate snails are treated separately (Fig. 28-39 and Fig. 40-43, respectively).

Because the presence of Pulmonate snails is bound up with tolerance to environmental instability, their ability to maintain a population above a certain size in a widely fluctuating environment often fails. In Pelee Shoal malacofauna only one pulmonate snail Gyraulus parvus (Fig. 34) falls into the category of prevalent forms. But even this form occurs often in low amounts and did not achieve continuous downcore distribution. All other Pulmonate species belong to subordinate groups.

Because they are so markedly numerous specifically, Pulmonate molluscs have a signficant effect on the faunal diversity counts, but (insofar as the specimen abundance in the Pelee Shoal malacological record is concerned) they are relatively unimportant.

From a total of thirty-one Pulmonate species, eighteen species are freshwater and twelve are terrestrial. The latter includes two more or less semiterrestrial inhabitants of near water mudflats - Catinella vermeta and Zonitoideus nitidus.

In the paleoenvironmental analysis of the Pelee Shoal Late Quaternary molluscan sequence, the terrestrial Pulmonates either indicates the intervals associated with environmental extremities semicontinuously through the whole record in contrast to accentuated faunal diversity peaks established by freshwater forms. The assessing of the occurrence of the Pulmonate snails was done with awareness of the possibility of long range accidental transport of shells from the surrounding mainland. Low counts of terrestrial specimens in the Pelee Shoal Late Quaternary section thanatocenosis prevents the use as a paleoenvironmental tool the malacospectral analysis.

Where identification of a Pulmonate snail was possible to the species level either on the basis of the well preserved or only partially damaged shells), the selected representative specimen is figured and the horizons from which it has been taken indicated in figure captions. Illustrated freshwater Pulmonates are: Gyraulus parvus (Fig. 34), Fossaria decampi (Fig. 28), Lymnaea stagnalis appressa (Fig. 29) Acella haldemani (Fig. 30), Stagnicola elodes (Fig. 31) Physa gyrina (Fig. 32), Physa skinneri (Fig. 33), Promenetus exacuous (Fig. 35) Planorbula armigera (Fig. 36) Helisoma anceps (Fig. 37), Helisoma campanulatum (Fig. 38) and Ferrissia rivularis (Fig. 39). Illustrated Terrestrial Pulmonates are: Gastrocopta holzingeri (Fig. 40), Gastropoda

Terrestrial Pulmonates are: *Gastrocopta holzingeri* (Fig. 40), *Gastropoda pentodon* (Fig. 41) *Strobilops labyrinthica* (Fig. 42) and *Helicodiscus parallelus* (Fig. 43). Where an attempt has been made to identify specimens from fragmented material only and identification is regarded as approximate the illustrations are not given. The names of taxa with uncertain identification and the depth/time intervals at which they occur are as follows:

Freshwater species:

Fossaria modicella

1039-1048 cm (12,500-12,250 years B.P.)

Fossaria parva

317-326 cm (5,250-5,750 years B.P.)

Stagnicola reflexa

181-190 cm (3,750-3,500 years B.P.)

Physa integra

18-27 cm (0-250 years B.P.)

117-126 cm (2,250-2,000 B.P.)

Gyraulus deflectus

190-200 cm (4,000-3,750 years B.P.)

Menetus opercularis

227-236 cm (4,500-4,750 years B.P.)

Helisoma trivolvis

144-153 cm (3,000-2,750 years B.P.)

212-254 cm (5,000-4,500 years B.P.)

272-290 cm (5,500-5,250 years B.P.)

299-317 cm (5,750-5,500 years B.P.)

389-398 cm (8,000-7,750 years B.P.)

479-584 cm (9,000-8,750 years B.P.)

497-507 cm (9,250-9,000 years B.P.)

561-570 cm (10,250-10,000 years B.P.)

Terrestrial species:

Cochlicopa lubrica

209-218 cxm (4,250-4,000 years B.P.)

525-534 cm (9,750-9,500 years B.P.)

Succinea ovalis

90-99 cm (2,000-1,750 years B.P.)

153-163 cm (3,250-3,000 years B.P.)

Catinella vermeta

126-135 cm (2,500-2,250 years B.P.)

290-299 cm (5,500-5,250 years B.P.)

344-353 cm (7,250-7,000 years B.P.)

461-479 cm (8,750-8,500 years B.P.)

552-561 cm (10,250-10,000 years B.P.)

Discus cronkhitei

425-434 cm (8,500-8,250 years B.P.)

Punctum minutissimum

163-172 cm (3,250-3,000 years B.P.)

190-200 cm (4,000-3,750 years B.P.)

218-227 cm (4,750-4,500 years B.P.)

Zonitoideus arboreus

181-200 cm (4,000-3,750 years B.P.)

190 200 cm (4,000-3,750 years B.P.)

Zonitoideus nitidus

181-200 cm (4,000-3,750 years B.P.)

218-236 cm (4,750-4,500 years B.P.)

245-254 cm (5,000-4.750 years B.P.)

317-326 cm (6,250-5,750 years B.P.)

Striatura milium

534-543 cm (9,750-8,500 years B.P.).

Species whose identification is questionable respresent only a small percentage of the total fauna. In spite of uncertainty in their identification they still represent taxonomic entities valid enough to enter the faunal diversity counts.

Most of the Pulmonate species that occur in the Pelee Shoal sequence have rather broad ecological valencies and ecozoogeographical characteristics. Eight species out of the total of nineteen aquatic Pulmonates identified from the Pelee Shoal sequence have ecogeogeographic ranges which cover almost the entire or greater part of the North American continent (Fossaria modicella, Fossaria parva, Stagnicola elodes, Gyraulus parvus, Planorbula armigera, Helisoma anceps, Helisoma trivolvis, Ferrissia rivularis). In seven Pulmonate species that occur in Pelee Shoal assemblage the distributional range is limited to North American mid and northern latitudes. (Lymnaea stagnalis appressa, Physa integra, Physa gyrina, Physa skinneri, Gyraulus deflectus, Promenetus exacuous and Helisoma campanulatum). The occurence of these widespread species correlates directly with moderate climatic and environmental conditions.

The remaining four Pulmonate species are restricted in their adaptational range and have primary importance in establishing the more specific faunististic affinities.

Fossaria decampi is a common inhabitant of mostly marl lakes in mid latitude zone of North America since the Late Wisconsinan time. With establishment of the northern coniferous forest zone, within its present boundaries, the ecogeographic range of Fossaria decampi seems to shift toward more northern latitudes leaving behind in the deciduous forest a belt of few rather tenuous relic populations. Occurrence of Fossaria decampi in lower the portion of the Pelee Shoal sequence indicates an environment with northern affinities which deteriorated with climatic amelioration at the Lake Wisconsinan-Holocene boundary. With the disappearance of coniferous forest from the Lake Erie area about 10,000 sidereal years B.P. Fossaria decampi became extinct at Pelee Shoal until the last millenium when with modern deterioration of climate the species seems to be attempting to re-establish its population at Pelee Shoal again.

Acella heldemani is endemic and rather rare species of Lower Great Lakes and St. Lawrence River watershed with a few localities beyond its southern boundaries. Evolutionary processes which brought to existence this gracile lymnaeid species might have taken place in Late Quaternary. The species has been reported from Late Wisconsinan deposits,but in context of this study it seems to be a fossil of the altithermal, rather than the harsh climatic condition of the Pleistocene.

Menetus opercularis is species of southern affinities. A few localities known from Great Lakes basin are on the northernmost periphery of its geographic range. Its occurrence as fossil in Pelee Shoal sequence indicates the climatic conditions warmer than those at present.

The Occurrence of Stagnicola reflexa which has the densiest populations in lakes or ponds with luxuriant overgrowth of hydro and hygrophytes particularly in the ecotone between prairie and broad-leafed temperate deciduous forest seems to be also an indicator of warmer and drier climate 3,750-3,500 years B.P.

Among terrestrial snails in the Pelee shoal malacofauna there are two ecozoogeographically different groups. Five species out of the total of twelve terrestrial Pulmonate snails determined in the Pelee Shoal molluscan fauna have ecogeographical range which covers almost all of mid-latitude North America. These are: Catinella vermeta, Cochlicopa lubrica, Discus cronkhitei, Zonitoideus arboreus and Zonitoideus nitidus). In the remaining seven species of land snails the geographical range is limited to North American mid and southern latitudes: Succinea ovalis, Gastrocopta holzingeri, Gastrocopta pentodon, Strobilops *labyrinthica*, *Helicodiscus parallelus*, *Punctum minutissimum* and *Striatura milium*).

The results show that the occurrence of Pulmonate snails in the Pelee Shoal sequence is transitional. It is apparent that Pulmonate occurences are in direct relationship with availability of more diversified and more fluctuating environmental resources during the Mid and Early Holocene, and Late Wisconsinan. In more persistent Late Holocene environments Pulmonate snails, both preadapted toward warmer or cooler climatic conditions fail to survive the termination of marshland conditions in Pelee Shoal area and most of them after a rise of water levels over the shoal 3,000 years ago (J.P. Coakley 1976) became locally extinct.

5. DISCUSSION

The appearance and elimination of various populations with time, in the lacustrine ecosystem, is considered a continuous process. The progressive changes apparent in the community detailed faunistic and ecogeographic structure represent simple effective and important measure of the ecological and climatic history of the environment involved.

5.1 DIVERSITY PATTERN (Fig. 3 and 44)

The faunal diversity of the molluscan fauna downcore, and the time range records were obtained by direct counting of the number of species per sample increment and sample depth/inferred age intervals respectively.

The Pelee Shoal molluscan record shows that massive immigration of freshwater mollusc species into the study area started very early after deglaciation, with refilling the early Lake Erie basin following rather shortlasting subaerial exposure and consolidation of lake bottom sediments (Coakley et al. 1977). No molluscs or other macro fossils are yet known from the interval represented by sediments older than 12,500 years.

The pioneering development of the molluscan community between 12,500 and 10,000 years ago is marked by progressively increasing diversity from very low, about 3-6 freshwater species to medium level of 11 species between 11,500 and 11,250 years B.P. After subsequent drop in number of species inhabiting the area, the faunal diversity increases to its Late Wisconsinan maximum of 15 species, about 11,000-10,750 years B.P. and then drops again to about 10-12 species.

In the Early Holocene deposits of the Pelee Shoal, the molluscan diversity rarely drops below its mature medium level of 12 species per 60 cm^2 per 250 years. The maximum peak diversity as high as 20 species per 60 cm^2 per 250 years is synchronous with an Early Holocene altithermal episode 8,000 to 7,500 years ago. But this relatively high level of diversity is only a transitional phenomenon in the Early Holocene faunal diversity pattern.

In contrast to the Early Holocene, the counts of various species per 60 cm^2 unit area and 250 year unit time in the Mid Holocene taxocene increases and averages 20 or more species per area and time unit. This high level of diversity is maintained during the earlier two thirds of the Mid Holocene time. During the remainder of the Mid Holocene time the faunal diversity increases to well over 25 species per area and time unit. The highest diversity peak according to our investigations is reached at the end of the hypsithermal period about 4,000 years ago, when diversity is almost three times higher than at average mature diversity level (Fig. 8).

In Late Holocene the diversity decreases to medium or only slightly higher than medium levels approaching resemblance with Early Holocene times. After pronounced man-made environmental changes were introduced into lake bottom environments the faunal diversity rapidly increases up at 20 species.

The maintenance of the averaged diversity level is accomplished and possible by the almost continuous presence of dominant species, mostly Prosobranchiate gastropods and clams throughout the examined stratigraphic sequence. The faunal diversity of dominant species community forms a plateau from which emerge accentuated peaks and troughs of various amplitudes marking down climatic and other environmental extremities. The significance of the coincidence of the environmental change with the peaks and troughs of faunal diversity is conveyed by immigration and displacement of the subordinate species, mainly freshwater and terrestrial Pulmonates and in lesser degree by the dominant, branchiate (gills equipped) mollusca.

The Mid Holocene increased in diversity of freshwater fauna results mostly from mixing sublittoral and littoral taxa with deep to shallow marsh forms during repeated but relatively brief declines in water levels, ensuing the nearshore increase in water temperatures, paludification, natural eutrophication and rapid nutrient turnover rates. The return to a steady diversity state was associated with reversible environmental trends.

The terrestrial species which accentuated some of the diversity peaks such as one formed 4,000 years ago might be washed into the lake from nearby forested mainland and major islands, or from sand and mudflats temporarily emerged from the lake and covered by a fen herb-graminoid and low shrub vegetation.

5.2 ABUNDANCE FLUCTUATIONS (Table 1, Fig. 8, 9 and 44)

The rate of reproduction in molluscs is not constant and varies (according to species particular environmental requirements) spatially and with time and initial conditions. The specimen abundances as affected by particular environmental conditions per unit area and unit time, in addition to faunal diversity represent an important paleoenvironmental index.

In gross vague patterns of the first approximation the abundance series of the dominant molluscan taxa seems to fluctuate over different sedimentary environments and habitats in phase with each other and apparently with a network of factors governing and controlling their occurrence and productivity. This perceptible synchronous rhythm in abundance of individual species demonstrate strong mutual resemblance of dominant species to one another in their ecological valencies, tolerances and environmental requirements.

The time range malacodiagram which depict the Late Quaternary distribution of the major species and groups of species in core 2 (Fig. 9) shows that in the early phase of the molluscan sequence two dominant species (Probithinella lacustris and Spharium striatinum both with strong boreal afinities) attained significantly massive densities in the Early Lake Erie benthic community. Only at the most detail scale of resolution, (i.e., curves constructed from 3 cm sample interval tallies in the lower segment of the core with very high sedimentation rates) Probithinella lacustris and Sphaerium striatinum fluctuate in their productivity in the manner displaying slightly inverse relationship. This inverse relationship on the onset of molluscan community development, might be a response to relatively rigorous environmental pressures during the pioneering and early mature phase in development of the benthic biota marked by intense competition for structural niche. In simplistic terms, inverse correlation in distribution of tiny operculate snail Probithinella lacustris and fingernail bivalve clam Sphaerium striatinum may be explained by fluctuations in the spatial pattern of submerged vegetation growing on the lake bottom. Sparse vegetation might serve to provide a greater amount of ground space for spawnng and burrowing activities in substrate for clams, while dense and close vegetation cover provide more opportunity for population expansion of operculate snails which uses leaves of aquatic herbs as substrates of colonization. By using the environmental resource in the most optimal way, *Probithinella lacustris* with *Sphaerium striatinum* two basically competing opportunistic species, continue to stay as the principal species of the molluscan assemblage during the whole early buildup of the benthic community.

With exception of *Sphaerium striatinum* the initial bivalve abundances of early inhabitants of the Pelee Shoal are very low. Neither highly variable populations of clams *Pisidium* spp., nor *Musculium lacustre*, a characteristic Late Wisconsinan bivalve, nor Unionacean clams (represented most likely by *Anodonta grandis grandis*) reach the reproductive potential and biomass of *Sphaerium striatinum*. In comparison with *Probithinella lacustris*, the other operculate species are noteworthy in the Late Wisconsinan only by a dearth of counts. Freshwater Pulmonate snails occur on the very beginning of the record (*Fossaria decampi*) then they are absent and appear again towards the end of Late Wisconsinan in a rather diversified way being at the Late Wisconsinan-Holocene boundary for the first time in company of a terrestrial species (*Catinella vermeta*). The low specimen counts suggest that the Late Wisconinan environment only very poorly satisfied the molluscan needs.

There are several interesting points in the Early Holocene development of the Pelee Shoal malacofauna. In comparison with Late Wisconsinan, the milder climatic ameliorations of the Early Holocene had stimulating effect on higher fecundity of aquatic molluscs. At certain points in time with an amazing regularity occur in the record rather brief events, during which aquatic mollusc populations were eliminated and decimated and at the same time brought about the occurrences of terrestrial snails. The events of successive decimation of aquatic species are either about 1,150 or 575 years apart with major turning points (minima) centered around 9,550 and 8,450 years B.P. and to a lesser degree around 7,350-7,300 and 6,200 years B.P. and with minor turning points centered around 7,000, 7,800 and 6,750 years B.P. The refereed events represent for aquatic molluscs the periods of habitat and life deprivation. Consequently the empty valves of large bivalves accumulates on lake bottom. In each of the intervals, particularly in that one of around 8,450 years B.P. concentrations of nacreous (mother of pearl) flakes were found. In samples from around 8,450, 7,350-7,500 and 6,200 years B.P. there are not occurrences of Sphaeriacean clams. A few leached fragments of Pisidiids were found in sediment samples with inferred age, 9,250-9,750 years B.P. In samples which match the major cyclic points (minima) the prosobranchiate mollusca are on the lowest diversity and abundance values. It seems that the operculates have been diminished always somewhat prior of decimation of bivalves.

Less destructive impact on aquatic mollusca had environmental changes indicated as a cleft in abundance peaks around 7,800 and less prominent one around 9,000 years B.P. (minima in Probithinella lacustris, Pyrgulopsis letsoni, Valvata tricarinata, Pisidiids and Pleurocera acuta). Hemicycle event around 6,750 years B.P. is hardly discernible, but its presence is evident in finer scale of resolution, particularly from gaps between position of rather anomalous maxima shown by Oxytrema livescens and Pleurocera acuta.

Even more convincing marker of the periodic cyclic pattern of full 1,150 year stadial cycle within Early Holocene aquatic sequence of Point Pelee is recurrence of land gastropod shells or shell fragments at all four recognized turning points. The terrestrial mollusca seems to be completely absent from the 575 years hemicycle minima.

The productivity of mollusca in terms of specimen abundances and biomass of Middle Holocene is several times higher than that of periods following or preceeding it. (The Mid Holocene occupy length of time as Late Holocene and is about a millenium longer than Early Holocene.) The occurrence of Mid Holocene mollusca give some idea how far a peuplement of individual or ecotaxonomically related species can depend on maintenance of optimal conditions, deterioration, recovery and extreme fertility in the lacustrine system.

Changes in abundance of mollusca triggered by Mid Holocene altithermal shows the periodic cyclic pattern consistent in phase with similar cyclicity revealed in the Early Holocene record but with much more extensive amplitude. The major Mid Holocene turning points are somewhat obscurred by extreme contrast and detailed richness of the record on scale presented. The minima in molluscan productivity are clearly centered around 5,050, 3,900 and 2,800 years B.P., and are marked down by presence of terrestrial forms particulary about 3,900 years B.P. The 570 year hemicycle is apparent at 3,350 and 4,450 years B.P. levels.

The hemicycle event at 5,600 years B.P. is abstruse and hidden by anomalously high and massive specimen abundance peaks and hiatus in sedimentary record.

The episode between 6,200-5,000 years B.P. shows most stimulating and favourable setting of variables for molluscan life than any other Holocene or Late Wisconsinan interval of equal time span.

Comparisons of the Mid Holocene mollusca specimen abundance peaks enables us to depict the directional process in abundance performance in different phases of Mid Holocene and categorize species according to their environmental requirements and response to environmental change into five groups:

(i) Species with more or less even productivity through most of the favourable conditions of Mid Holocene. These are further divisible into two subgroups: a) species with the mediocre peak at the very beginning of the Mid Holocene e.g., *Oxytrema livescens*; b) species with the mediocre peak at the very end of the Mid Holocene, e.g., *Pyrgulopsis letsoni*.

(ii) Species achieving maximum fecundity performance and biomass in the middle of the Mid Holocene, e.g., *Pleurocera acuta*, *Valvata tricarinata* and *Sphaerium striatinum*.

(iii) Species attaining the maximum specimen counts at the very beginning and end of the Mid Holocene and waned in the middle of the Mid Holocene, e.g., *Cincinnatia cincinnatiensis*.

(iv) Species which underwent a major increase in population increase at the beginning of Mid Holocene and their productivity from peak to peak declined gradually toward the end of Mid Holocene, e.g., *Valvata perdepressa* and *Probithinella lacustris*.

(v) Species which major increase and highest rank of abundance occurred approximately 4,000 years B.P., e.g., Gyraulus parvus and Pisidium spp.

The Mid Holocene specimen abundance record for subordinate species of mollusca is too erratic to show the exclusive pattern similar to those displayed by dominant species, however, there are indications that some subordinate species might share responsiveness with above mentioned groups, e.g., Helisoma campanulata with species of the first group, Planorbula armigera with the second, Promenetus exacuous with the third, Ferrissia rivularis with the fourth and remainder of species, namely terrestrial snails with the fifth group.

The last three millenia of the paleoenvironmental history of the Pelee Shoal are characterized by a decline in the molluscan specimen abundances in general, and around the Late Holocene turning point in particular. The turning points, which in Late Holocene paleoclimatic terminology are known under vernacular name of Little Ice Ages are centered around 2,785, 1,651-1,750 and 517 years B.P. The hemicycles are present, but in a rather vague way due to assymetricity or indistinctiveness of the specimen abundance peaks. At least in two species, namely in Pleurocera acuta and Valvata perdepressa the high altithermal productivity trend did not fade away suddenly and is responsible for bulky peaks between 2,750-2,500 years B.P.

Despite the adverse effect of worsening climatic conditions the molluscan record of modern times is characterized by extensive buildup of specimen abundance particularly among sublittoral Prosobranchiate species and bivalves as a consequence of cultural nutrient eutrophication of Lake Erie waters.

5.3 RESPONSE OF MOLLUSCS TO CLIMATIC CHANGE (Fig. 44)

To document resemblance of the molluscan faunal diversity and specimen abundance record produced in this study with well-known and accepted paleoenvironmental records we choose three different indicators of climatic change: (i) the rate of sea level rise and fall during last 8,000 sidereal years as determined by M. Claud-Hillaire (1976) from eastern coast of Hudson Bay, Quebec, Canada. (ii) Late Quaternary water temperature record obtained by N.A. Mörner from marl deposits of a lake on the Island of Götland in the Baltic Sea, Sweden. (iii) R.W. Fairbridge's eustatic curve of global oceanic transgression and regression maxima.

Comparison of molluscan records with independently obtained paleoclimatic indicators suggest that the complexity of climatic history in Lake Erie is similar to that in the other parts of the northern hemisphere.

6. FINAL REMARKS

Six vibratory sediment cores, 9 cm in diameter and ranging in length up to twelve metres were taken from the floor of Lake Erie, at Pelee Shoal, south of Point Pelee. One of them, 11.2 m long was chosen for the detailed biostratigraphic investigation to work out the history of the climatic impact on lake bottom biota. The shell and fragmented shells of gastropod and bivalved molluscs present as biogeneic detritus throughout the entire length of the core were used at a paleoenvironmental tool.

The analysis and enumeration of the shell material has brought out large amounts of data on the mollusc taxacene composition, fluctuation in faunal diversity and specimen abundances. The continuous set of more than 370 core increments yielded over 25,000 specimens belonging to 40 genera and up to 65 species. All major taxonomic groups of freshwater and terrestrial fauna were represented. The identified taxa in the molluscan sequence involve species which are almost all living on Pelee Shoal or with the Lake Erie associated coastal marshes at the present time. The assemblage was greatly dominated by Prosobranchiate Gastopods. Pulmonate freshwater Gastropods and Pelecypods were minor. The smallest in numbers but high in the rank of importance (as indicators of the paleoenvironmental extremes) were shells of terrestrial snails.

Associated with the molluscan material there was a trifle of other organic, remains. Of the animal remains, crustacean carapaces, coleopteran calyptras, headcapsules of chironomid larvae and fish scales prevailed but not in amounts which, if counted will result in the continuous quantitative record through a segment or the entire sediment core.

The recovered floristic remains included charcoal, needle-shaped coniferous leaves and their casts in silty clay, twigs of deciduous trees, a hazel nut (Coryllus americana), Potamogeton seeds and seeds of various other non-arboreal plants, as well as some Nitella and Chara oogonias. In comparison with overall mollusc abundance, the plant remains were rather obscure.

The malacofauna therefore holds the key to understanding of the historical development of the Pelee Shoal lake bottom biota.

In this paper I made an attempt to identify response of the Pelee Shoal mollusca to environmental changes ultimately controlled by variation in climatic conditions on Late Quaternary time scale. Within this time scale signficant changes in ecological processes in lake bottom biota were identified and dated. The Pelee Shoal molluscan record can be considered to be more detailed and better dated than any other freshwater faunal diversity and specimen abundance record known to date covering the last 12,500 sidereal years. The Late Quaternary molluscan sequence from the Pelee Shoal proves that climatic change is a driving mechanism of the ecological processes and that longterm and large-scale ecological change within lake bottom biota cannot be pictures apart from understanding past patterns and trends in climatic environment.

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TABLES

Table 1. Sample sequence from the Late Quaternary fossiliferous limnic sediments of the Pelee Shoal, Lake Erie. (Core 2).

Table

Sample Number	Interval Range (cm)	Dry Mass of sediment sample (g)	Inferred Age (sidereal years B.P.)	BIVALVIA		GASTROPODA				Total Mollusca
				Unionacea	Sphaeriacea	Total Proso-branchia	Fresh-water	Terres-trial	Total Pulmonata	
1	0-9	553	Present	-	73*	183	4	1	5	262
					13.2**	33.0			0.9	47.3
2	9-18	794		1	140	448	6	-	6	597
					17.2	56.7			0.7	75.1
3	18-27	749	250	3	67	206	2	-	2	276
					9.0	27.8			0.2	36.8
4	27-36	692	500	1	35	136	1	-	1	173
					5.0	19.7			0.1	25.0
5	36-45	887	750	1	58	141	-	-	-	200
					6.5	16.0			-	22.5
6	45-54	909		2	42	165	1	-	1	209
					4.6	18.3			0.1	22.9
7	54-63	749		1	45	143	2	-	2	190
					6.2	19.7			0.2	26.3
8	63-72	880	1000	-	30	56	-	-	-	87
					3.4	6.3			-	9.8
9	72-81	477	1500	1	16	65	-	-	-	81
					3.4	13.8			-	17.2
10	81-90	659	1750	-	70	162	-	-	-	232
					10.9	25.3			-	36.2
11	90-99	720	2000	1	57	61	-	1	1	119
					7.9	8.4			0.1	16.5
12	99-108	853		-	43	58	1	-	1	102
					5.1	6.9			0.1	11.9

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* Number of specimens present in a 9 cm sediment increment

** Average concentration of specimens per 100 g of sediment

Table [illegible] (continued)

13	108–117	840		1	15	21	–	–	–	37
					1.8	2.5				4.5
14	117–126	682	2250	–	15	49	2	–	2	66
					2.2	7.4			0.3	10.0
15	126–135	526	2500	2	75	329	1	1	2	507
					14.7	64.5			0.3	79.8
16	135–144	327	2750	2	23	168	–	–	–	193
					7.1	52.5			–	60.3
17	144–153	695	3000	1	104	130	1	–	1	236
					15.0	18.8			0.1	34.2
18	153–163	1006		2	77	145	2	1	3	227
					7.7	14.5			0.3	22.7
19	163–172	525	3250	2	94	367	1	–	1	464
					18.4	71.9			0.1	90.9
20	172–181	234	3500	1	7	58	1	–	1	112
					3.3	27.6			0.4	63.3
21	181–190	496	3750	3	253	403	32	4	36	695
					50.6	80.6			7.2	139.0
22	190–200	854	4000	2	1230	1344	76	14	90	2667
					148.1	161.9			10.8	321.3
23	200–209	696	4250	–	237	189	13	3	16	442
					33.8	27.0			2.2	63.1
24	209–218	679	4500	2	192	256	5	2	7	457
					29.0	38.7			1.0	69.2
25	218–227	800		2	505	616	17	3	20	1143
					63.1	77.0			2.5	142.8
26	227–236	744	4750	1	806	606	19	3	22	1435
					108.3	81.4			3.0	192.8

Table continued

27	236-245	576		1	223	171	6	-	6	401
					40.5	31.0			1.0	72.9
28	245-254	748		1	214	82	9	1	10	407
					28.9	11.0			1.3	55.0
29	254-263	762	5000	-	145	98	2	-	2	245
					19.0	12.8			0.2	32.2
30	263-272	651		2	126	158	-	-	-	286
					20.3	25.4			-	46.1
31	272-281	819	5250	-	124	111	4	-	4	240
					15.3	13.7		-	0.4	29.6
32	281-290	822		-	197	136	4	-	4	337
					24.0	16.5			0.4	41.0
33	290-299	710	5500	-	139	173	4	1	5	317
					19.8	24.7			0.7	45.2
34	299-308	636		1	134	299	12	-	12	446
					21.2	47.4			1.9	70.7
35	308-317	813	5750	2	228	446	4	-	4	680
					28.1	55.0			0.4	83.9
36	317-326	612	6250	3	802	2833	26	2	28	3666
					133.6	472.1			4.6	611
37	326-335	660	6500	1	38	68	3	-	3	110
					5.8	10.4			0.4	16.7
38	335-344	751	7000	5	197	437	16	-	16	653
					26.9	59.8			2.1	89.4
39	344-353	876		3	161	176	-	1	1	341
					18.2	20.0			0.1	38.7
40	353-362	641	7250	1	124	112	1	-	1	238
					20.0	18.0			0.1	38.3

Table 1 (continued

41	362-371	793	7500	-	70	51	-	-	-	211
					8.7	6.3			-	15.1
42	371-380	800		-	91	172	1	-	1	264
					11.3	21.5			0.1	33.0
43	380-389	700	7750	2	239	386	6	-	6	633
					34.1	55.1			0.8	90.4
44	389-398	640		-	229	245	5	1	6	480
					35.7	38.2			0.9	75.0
45	398-407	680	8000	-	33	58	1	-	1	92
					4.8	8.5			1.4	13.5
46	407-416	610		-	21	28	1	-	1	50
					3.4	4.5			0.1	8.1
47	416-425	600	8250	-	8	87	1	-	1	96
					1.3	14.5			0.1	16.0
48	425-434	720		-	18	81	-	1	1	100
					2.5	11.2			0.1	13.8
49	434-443	810		-	71	208	-	-	-	279
					8.7	25.6			-	34.4
50	443-452	620	8500	2	24	110	-	-	-	136
					3.8	17.7			-	21.9
51	452-461	620		3	45	96	-	-	-	144
					7.2	15.4			-	23.2
52	461-470	720	8750	1	44	62	-	1	1	109
					6.1	8.6			0.1	15.1
53	470-479	610		-	25	39	-	-	-	64
					4.0	6.3			-	10.4
54	479-488	610		-	39	47	1	-	1	87
					6.3	7.7			0.1	14.2

Table 1 (continued

55	488-497	720	9000	-	20	27	-	-	-	47
					2.7	3.7				6.5
56	497-507	800	9250	-	51	44	3	2	5	100
					7.0	5.5			0.6	12.5
57	507-516	710		-	26	49	-	-	-	75
					3.6	6.9			-	10.5
58	516-525	740	9500	-	12	54	1	1	2	68
					1.6	7.2			0.2	9.1
59	525-534	810		-	46	74	1	1	2	122
					8.1	9.1			0.2	15.0
60	534-543	550	9750	2	48	109	2	2	4	135
					3.2	19.8			0.7	24.5
61	543-552	840	10.000	-	24	79	-	-	-	103
					2.8	9.4			-	12.2
62	552-561	820		-	20	48	1	1	2	70
					2.4	5.8			0.2	8.5
63	561-570	720	10.250 (^{14}C)	-	15	30	1	1	2	47
					2.0	4.1			0.2	6.5
64	570-579	630		-	29	39	-	-	-	68
					4.6	6.1			-	10.7
65	579-588	600	10.500	-	30	43	-	1	1	74
					5.0	7.1			0.1	12.3
66	588-598	550		-	7	13	-	-	-	20
					1.2	2.3			-	3.6
67	598-607	400	10.750	-	18	34	1	-	1	53
					4.5	8.5			0.2	13.2
68	607-616	700			26	27	-	-	-	53
					3.7	3.8			-	7.5

Table 1 (continued)

69	616-625	730		-	47	42	2	-	2	91
					6.4	5.7			0.2	12.4
70	625-634	500		-	24	13	-	-	-	37
					4.8	2.6			-	7.4
71	634-643	620		-	26	29	-	-	-	55
					4.1	4.6			-	8.8
72	643-652	600	11.000	-	24	19	-	-	-	43
					4.0	3.1			-	7.1
73	652-661	600		-	33	16	-	-	-	49
					5.5	2.6			-	8.1
74	661-670	510		-	8	10	-	-	-	18
					1.5	1.9			-	3.5
75	670-679	600	11.250	-	12	16	-	-	-	28
					2.0	2.6	-	-	-	4.6
76	679-688	550		-	60	51	2	-	2	111
					10.9	9.2			0.3	20.1
77	688-697	420		1	23	19	-	-	-	43
					5.4	4.5			-	10.2
78	697-706	700		-	12	30	1	-	1	42
					1.7	4.2			0.1	6.0
79	706-715	630		-	9	60	-	-	-	69
					1.4	9.5			-	10.9
80	715-724	400		-	5	6	-	-	-	9
					1.2	1.5			-	2.2
81	724-733	550		-	6	16	-	-	-	22
					1.0	2.9			-	4.0
82	733-742	650	11.500	-	4	9	-	-	-	13
					0.6	1.4			-	2.0

Table 1 (continued)

83	742-751	420		-	9	12	-	-	-	21
					2.1	2.8			-	5.0
84	751-760	560		-	14	41	-	-	-	55
					2.5	7.3			-	9.8
85	760-769	600		-	25	20	-	-	-	45
					4.1	3.3			-	7.5
86	769-778	560		-	24	30	-	-	-	54
					4.2	5.3			-	9.6
87	778-788	320		-	20	32	-	-	-	52
					6.2	10.0			-	16.2
88	788-796	600	11.750	1	19	13	-	-	-	33
					3.1	2.1			-	5.5
89	796-805	700		-	17	12	-	-	-	29
					2.4	1.7	-	-	-	4.1
90	805-815	550		-	14	15	-	-	-	29
					2.4	2.7			-	5.2
91	815-824	640		-	19	42	-	-	-	61
					2.9	6.5			-	9.5
92	824-833	620		-	14	44	-	-	-	58
					2.2	7.0			-	9.3
93	833-842	450		-	19	24	-	-	-	43
					2.1	5.3			-	9.5
94	842-851	500		-	13	59	-	-	-	72
					2.6	11.8			-	14.4
95	851-860	520		-	7	22	-	-	-	29
					1.3	4.2			-	5.5
96	860-869	510		2	10	57	-	-	-	68
					1.9	11.1			-	13.3

Table [illegible] (continued)

97	869-878	500		-	6	35	-	-	-	41
					1.2	7.0			-	8.2
98	878-887	610	12.000	-	8	18	-	-	-	26
					1.3	2.9			-	4.2
99	887-895	600		-	8	8	-	-	-	16
					1.3	1.3			-	2.6
100	895-905	600		-	4	32	-	-	-	36
					0.6	5.3			-	6.0
101	905-914	550		-	5.0	30	-	-	-	35
					0.9	5.4			-	6.3
102	914-923	600		-	6	67	-	-	-	73
					1.0	11.1			-	12.1
103	923-932	500		-	7	43	-	-	-	50
					1.4	8.6			-	10.0
104	932-941	1220		-	6	20	-	-	-	26
					0.4	1.6			-	2.1
105	941-950	640		-	-	21	-	-	-	21
					-	3.2			-	3.2
106	950-958	640		-	5	12	-	-	-	17
					0.7	1.8			-	2.6
107	958-967	390		-	15	18	-	-	-	33
					3.8	4.6			-	8.4
108	967-976	620		-	7	11	-	-	-	18
					1.1	1.7			-	2.9
109	976-985	610		-	11	29	-	-	-	40
					1.8	4.7			-	6.5
110	985-994	400	12.250	-	15	27	1	-	1	44
					3.7	6.7			0.2	11.0

Table 1 (continued)

111	994-1003	520		-	18	28	-	-	-	46
					3.4	5.3			-	8.8
112	1003-1012	620		-	10	24	-	-	-	34
					1.6	3.8			-	5.4
113	1012-1021	480		-	8	25	-	-	-	33
					1.6	5.2			-	6.8
114	1021-1030	520		-	9	21	-	-	-	30
					1.7	4.0			-	5.7
115	1030-1039	640		-	18	15	-	-	-	33
					2.8	2.3			-	5.1
116	1039-1048	620		-	23	18	1	-	1	42
					3.7	2.9			0.1	6.9
117	1048-1057	400		-	6	8	-	-	-	14
					1.5	2.0			-	3.5
118	1057-1066	620		-	8	19	-	-	-	27
					1.2	3.0			-	4.3
119	1066-1075	580		-	7	13	-	-	-	20
					1.2	2.2			-	3.4
120	1075-1084	320		-	9	18	-	-	-	27
					2.8	5.6			-	8.4
121	1084-1093	620		-	16		-	-	-	26
					2.5				-	4.1
122	1093-1102	620		-	15		-	-	-	32
					2.4				-	5.1
123	1102-1108	440	∼12.500	-	18				-	23
					4.0				-	5.2

TABLE 2.— Molluscan assemblage from Late Quaternary Sediments at the Pelee Shoal, Lake Erie (Core 2)

DOMINANT FORMS

Pelecypoda (Unionacean and Sphaeriacean clams):

- Unionacea (various species)
- Pisidium spp.
- Sphaerium striatinum (Lamarck, 1818)
- Musculium lacustre (Müller, 1774)

Prosobranchiate Gastropods:

- Valvata tricarinata (Say, 1817)
- Valvata perdepressa (Walker, 1906)
- Valvata sincera helicoidea (Dall, 1905)
- Cincinnatia cincinnatiensis (Anthony, 1840)
- Probythinella lacustris (Baker, 1928)
- Pyrgulopsis letsoni (Walker, 1901)
- Pleurocera acuta (Rafinesque, 1831)
- Oxytrema livescens (Menke, 1830)

Freshwater Pulmonate Gastropods:

- Gyraulus parvus (Say, 1817)

Succinea ovalis (Say, 1817)*

Catinella vermeta (Say, 1829)*

Discus cronkhitei (Newcomb, 1865)*

Helicodiscus parallelus (Say, 1821)

Punctum minutissimum (Lea, 1841)*

Zonitoides arboreus (Say, 1816)*

Zonitoides nitidus (Müller, 1774)*

Striatura milium (Morse, 1859)*

Note: Data on the species designated with an asterisk were not used in construction of the time range malacodiagram (Fig. 8), but were included and accounted for in the faunal diversity chart (Fig. 7).

Fig. 1. Location, bathymetry and physiography of the study area. The left corner insert shows the Point Pelee area in the western part of Lake Erie enclosed by a cross-hatched box. In the enlarged view of the area, the core locations and bottom contours (in metres) are shown. The location of analysed core 2 is indicated by an arrow.

FIGURES

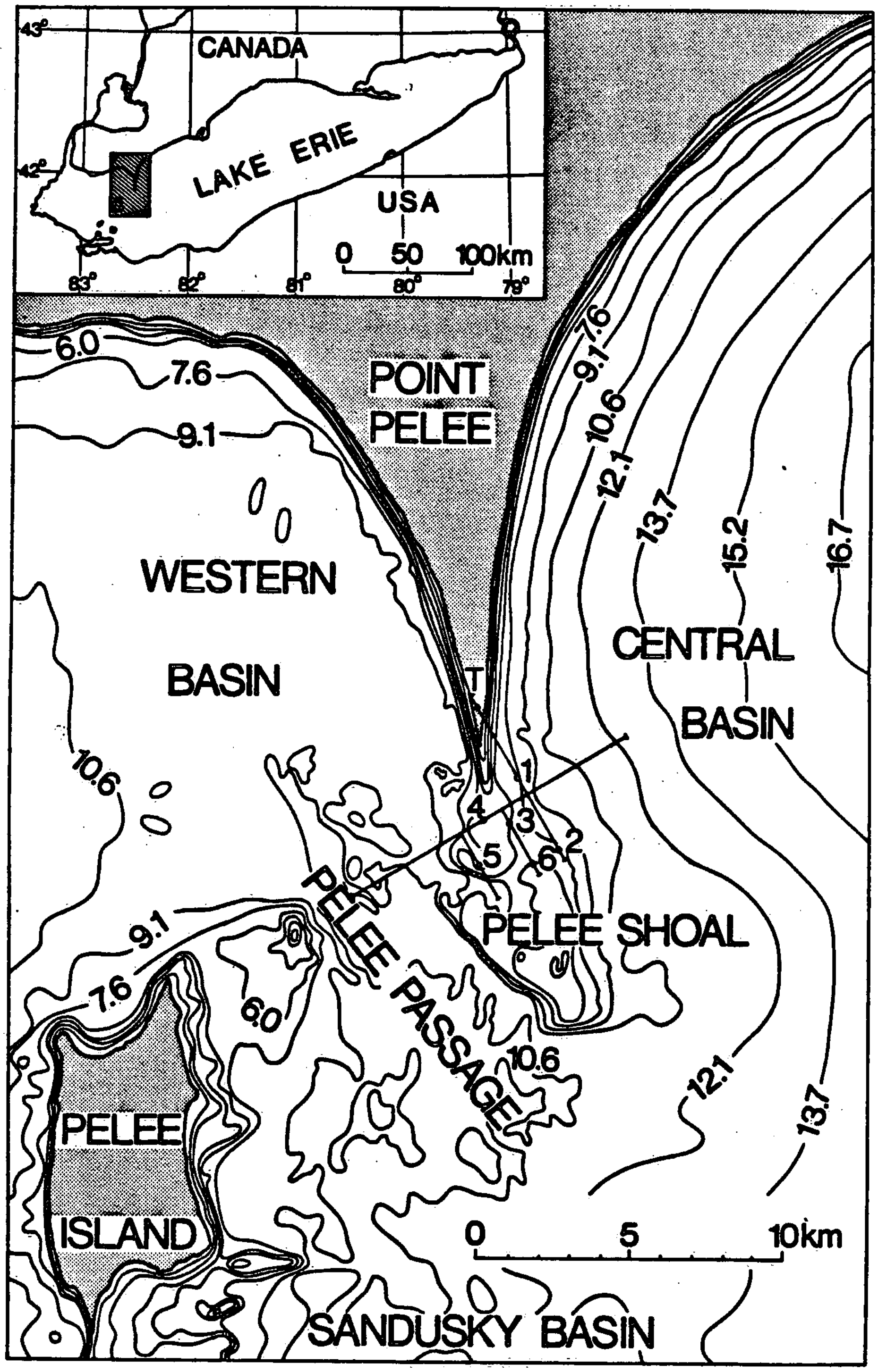

CANADA
LAKE ERIE
USA
43°
42°
83°
82°
81°
80°
79°
0 50 100km
POINT PELEE
WESTERN BASIN
CENTRAL BASIN
PELEE SHOAL
PELEE PASSAGE
PELEE ISLAND
SANDUSKY BASIN
6.0
7.6
9.1
10.6
12.1
13.7
15.2
16.7
T
1
2
3
4
5
6
0 5 10km

Figure 2.

A. The fence diagram showing distribution of the erosional and abrasional surface and in cross-section thickness and character of layers in the depositional environment of the Pelee Shoal south of Point Pelee as reconstructed from logs of six sediment cores (1-6) and a sediment core (T) from the Nature Centre area of the Point Pelee National Park coring site (J. Terasmae, 1969).

B. Location of the stratigraphic cross sections and sites of the cores used in the construction of the fence diagram. The bathymetric contours are given in metres. The core 2, studied in detail, is the core most easterly situated (water depth 6.8 m).

LEGEND. Bedrock: 1. Lower Devonian carbonate formation, mostly limestone and dolomitic limestone. Glacial deposits: 2. Port Stanley lodgement till. Lacustrine unit: Late Wisconsinan basal subunits: 3. Massive clay (core 2). 4. Massive clayey silt (core 5 and 6).
5. Laminated clayey silt. Early Holocene-Late Wisconsinan transitional subunit: 6. Transition from laminated silt at the bottom to laminated sand at the top, pebbly and gravelly intercalations. Early to Mid Holocene subunits: 7. Laminated sand and sand with silt lenses. Mid Holocene-Late Holocene surficial subunits: 8. Massive sand.

Note: The sand cover at the Point Pele site (T) might include sand facies that are the product of eolian dune migration particularly at the top.

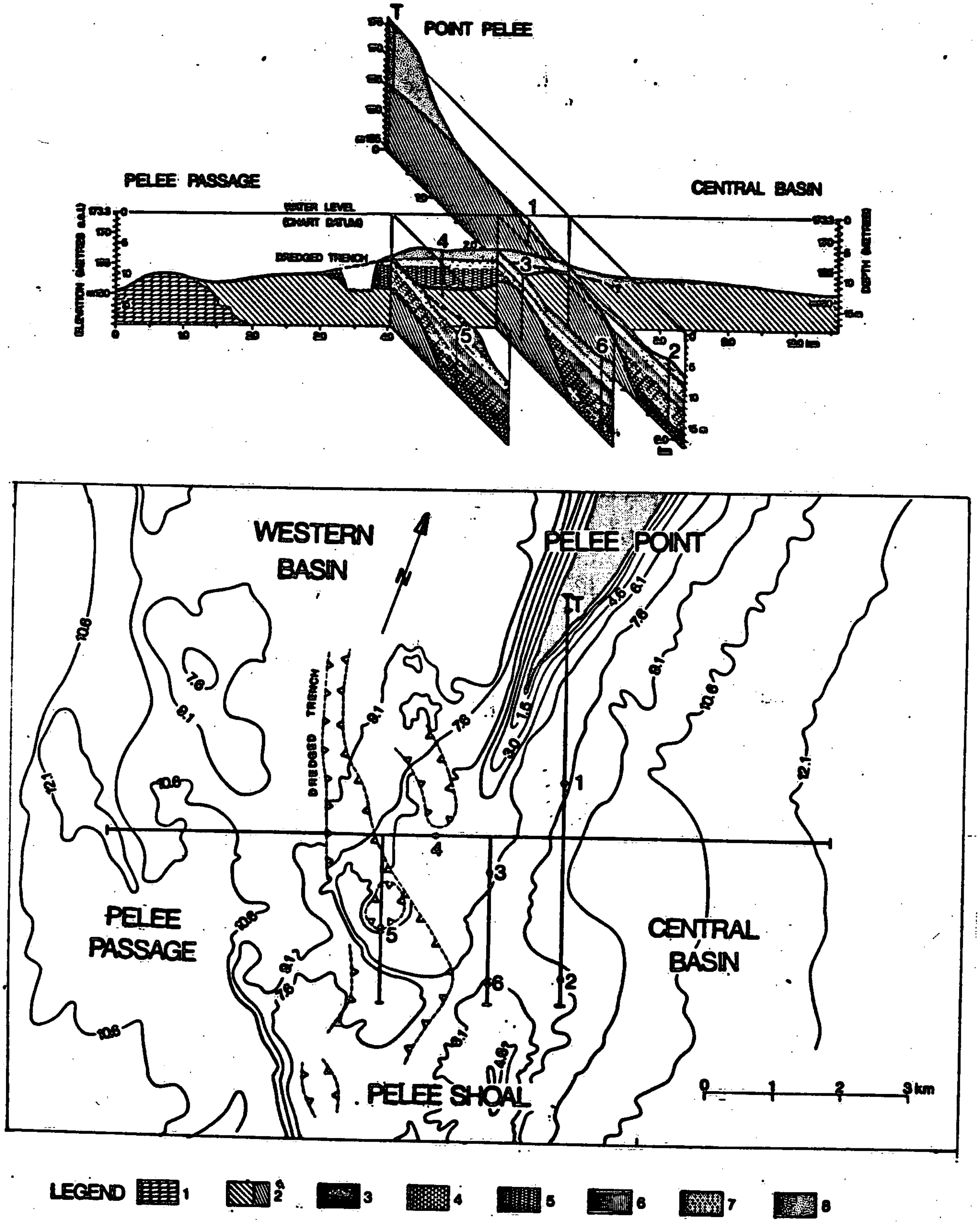

POINT PELEE
PELEE PASSAGE
CENTRAL BASIN
WATER LEVEL
(CHART DATUM)
DREDGED TRENCH
ELEVATION (METRES G.S.L)
DEPTH (METRES)
173.3
1
2
3
4
5
6
T
0
10
20
30
40
120 km
15 m
WESTERN BASIN
PELEE POINT
N
DREDGED TRENCH
PELEE PASSAGE
CENTRAL BASIN
PELEE SHOAL
1.5
3.0
4.6
6.1
7.6
9.1
10.6
12.1
0
1
2
3 km
LEGEND
1
2
3
4
5
6
7
8

Figure 3. Average sand-silt-clay ratio in Port Stanley lodgement till samples from the Pelee Shoal (Core 1 and 4). The intercalations and other textural changes in the till consist of 10 to 20% increase in sand and silt content. The till typically contains uniformly distributed limestone and quarzite pebbles. It isstiff to very stiff in consistency and has low natural water content ca 18-23%. Due to transient subaerial exposure and subsequent dessication the top of the till deposit was overconsolidated and for subsequently deposited lacustrine sediments represented very little or practically incompactible substrate. The till encountered in the cores has relatively high content of carbonates up to 20%; calcite-dolomite ratio is 3:1. No animal or plant fossils were found in the grey to olive grey till samples.

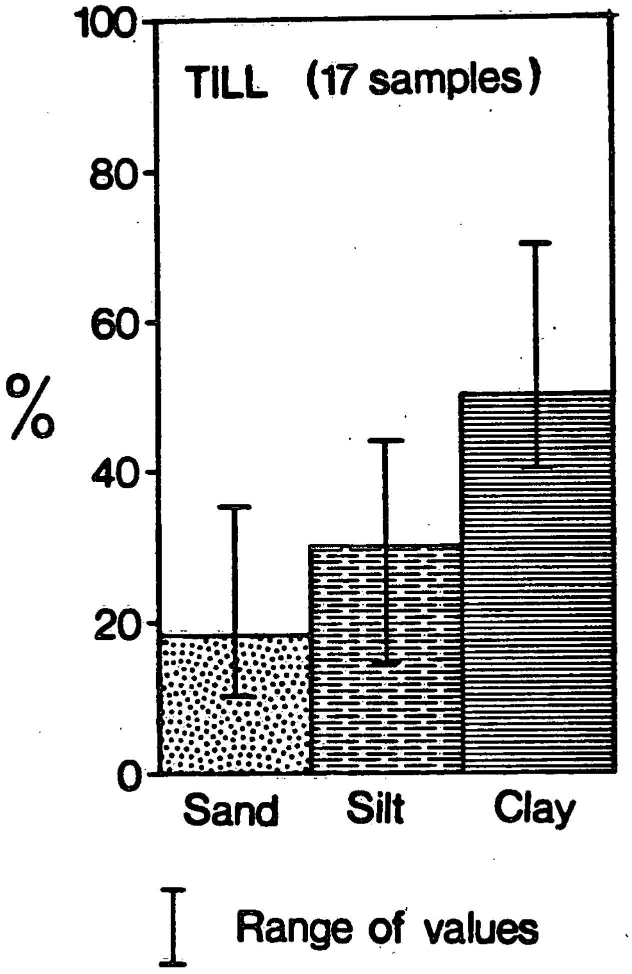

TILL (17 samples)
100
80
60
40
20
0
%
Sand
Silt
Clay
Range of values

Figure 4. Average sand-silt-clay ratio in clayey sediment samples from the lower part of the Pelee Shoal lacustrine Late Wisconsinan basal subunit. (Core 2,9.9-11.2 m). The distinction of silty clay from clayey silt in designation of the particle size analysis results is at large semantic: the difference between silt and clay content varies only slightly (less than 3%). Vibracore penetration rates measured during the coring operation were much lower, ca 33 cm/20 sec than in the till ca 33 cm/20-170 sec. The natural water content was higher, ca 35-40%. The consolidation tests on sediment samples from the silty clay shows that the sediment is least consolidated of all sediment samples tested from the Pelee Shoal. The carbonate content is approximately the same as in the till samples, about 25%; calcite-dolomite ratio 1:1. The silty clay grey and olive grey in colour contains depauperate mollusc fauna consisting of 15-30 specimens for 9 cm sediment core sample increment.

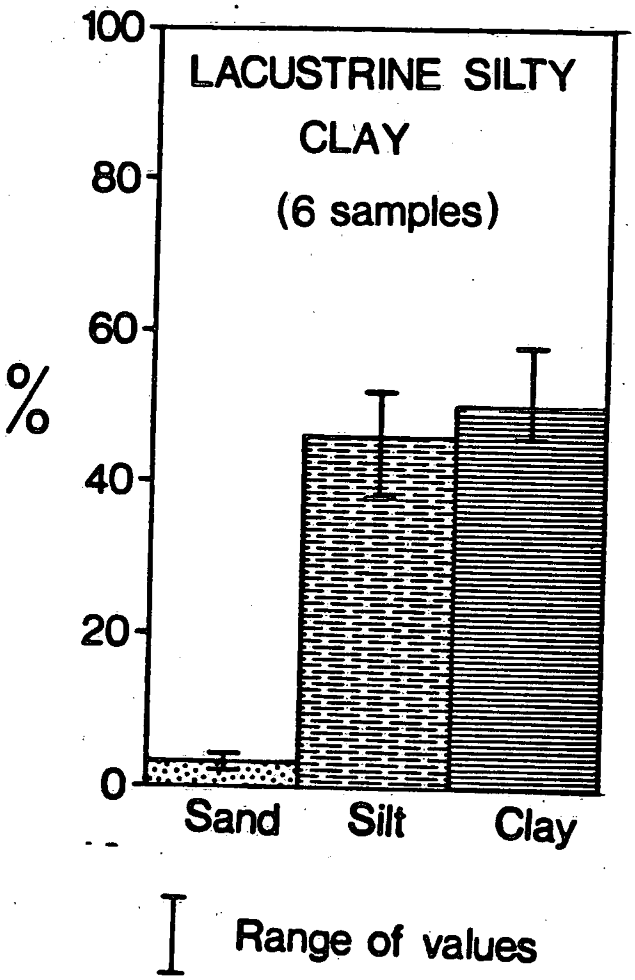
100
80
60
40
20
0
%
LACUSTRINE SILTY CLAY
(6 samples)
Sand
Silt
Clay
Range of values

Figure 5. Average sand-silt-clay ratio in silt dominated sediment samples from the Pelee Shoal lacustrine Late Wisconsinan upper basal subunit, (Core 2, 4, 5 and 6). Textural variations throughout the silt complex are common and involves mostly increasing in sand content at the expense of the clay fraction. Water content of the silt-dominated sediment is characteristically highest of all sediments encountered in cores, up to 50%. Results of consolidation tests indicate progression from underconsolidated soft, rapidly accumulated, massive, lower part of the basal unit to normally consolidated and less rapidly deposited laminated upper part. The carbonate content irregularly varies from 20 to 30% and is characterized by reversals of calcite-dolomite ratio 1:2. In the grey and olive grey silt dominated sediments are characteristically present dark grey and black bands of iron sulphide, casts of coniferous free leaves, plant detritus, wood chips and mollusc shells consisting of 15-110 specimens per 9 cm sediment core interval.

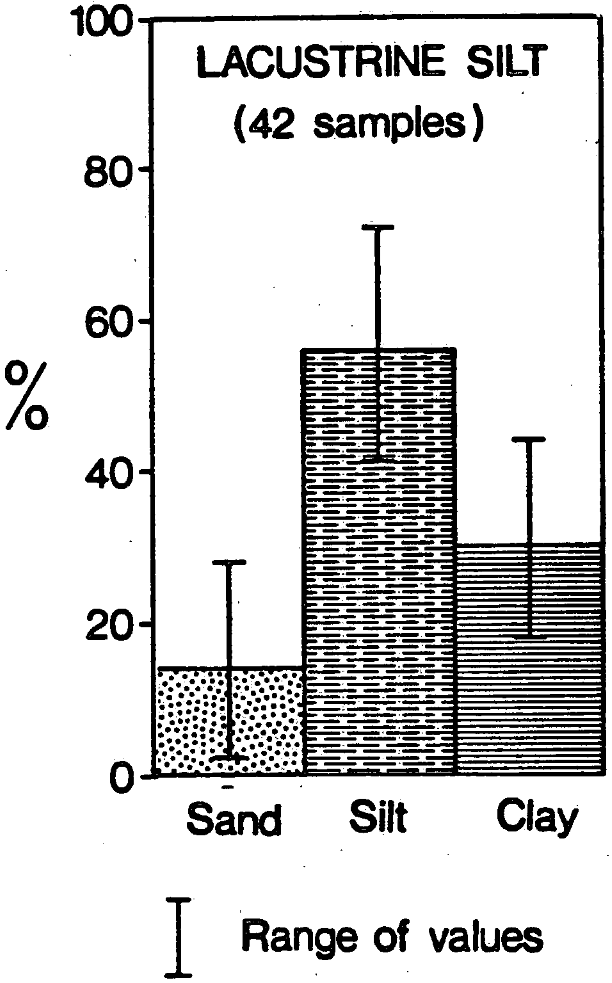

LACUSTRINE SILT
(42 samples)
100
80
60
40
20
0
%
Sand
Silt
Clay
Range of values

Figure 6. Average sand-silt-clay ratio in the Late Wisconsinan-Early Holocene transitional subunit at the site of cores 2, 5 and 6. The transition between basal silt- and overlying sand-dominated comples is gradual. The consistent trend from silt to sand-dominated layers is lacking on core site 4, where boundary between silt and conformably overlying sand complex is sharply bounded. The unit with upward decreasing amount of fine particles also shows a decreasing trend in water content from 35% to about 20%. The samples from the upper portion of the transitional unit yielded the consolidation test values which indicate slight overconsolidation rather than characteristics of normal consolidation. Carbonate content of the layer was up to 30% and calcite-dolomite ratio varied from 1:1 to 1:2. In the olive grey to dark greyish-brown transitional layer there is also a progressively increase in concentrates of both fossil plant and animal material content. The number of the mollusc shells per increment is, in average, more than twice as high at the top (30-220 specimens) as at the bottom of the transitional unit (15-110 specimens).

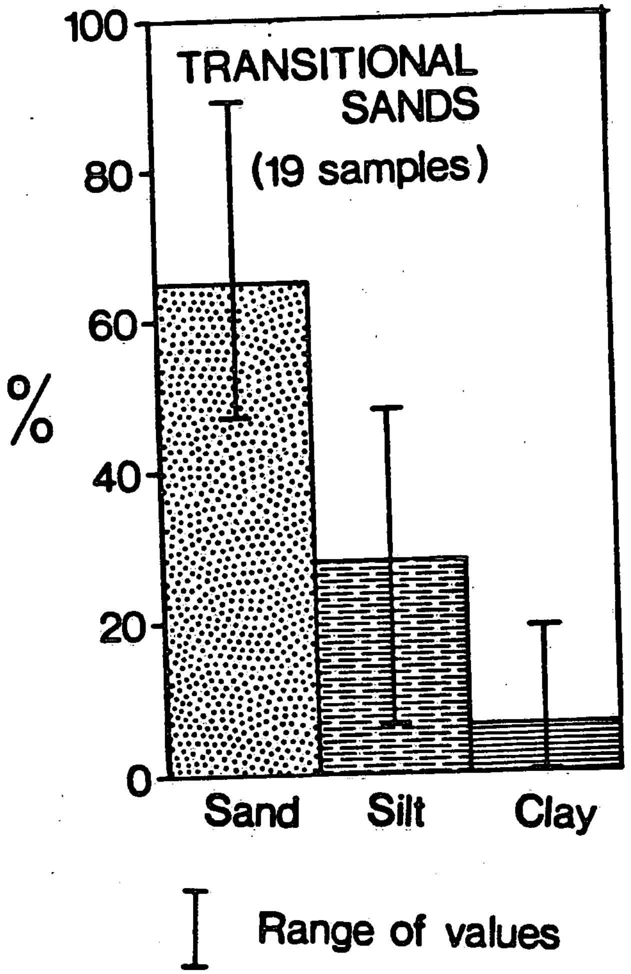

TRANSITIONAL SANDS
(19 samples)
100
80
60
40
20
0
%
Sand
Silt
Clay
Range of values

Figure 7. Average sand-silt-clay ratio in superficial subunits ranging from Early through Mid to Late Holocene. On some sites only Mid to Late Holocene or only Late Holocene occur. The subunits as a whole are thickest on the site of cores 6 and 2, reaching 4.1 and 3.8 m respectively. The lower Early to Mid Holocene 1.5-2.0 m thick subunit is composed of dark greyish-brown sediment which show a moderate to high degree of segregation into beds with random interfingering of sand and olive-grey silty lenses. Laminae of dark coloured grains, rich in heavy minerals and coarse-grained sand are common. Most of the bedding and lamination tend to disappear in the Mid to Late Holocene subunit 1,3-2,0 m thick which forms an internally structureless, massive bed. Two facies of sand have similar geotechnical properties: penetration rates are either less than 10 or between 10 and 20 sec/33 cm. Natural water content is 5-10% of dry weight. Layers are slightly overconsolidated. The carbonate content reaches maximum about 20% and calcite-dolomite ratio varies from sample to sample. The Early Mid and late Holocene strata also vary significantly in mollusc shell content. The fossils are extremely abundant and diversified in Mid-Holocene subunit, medium species rich and abundant in Early and in Late Holocene subunit. The most prolific 9 cm Mid Holocene core increment contained as many as 3,700 specimens belonging to 30 different molluscan species.

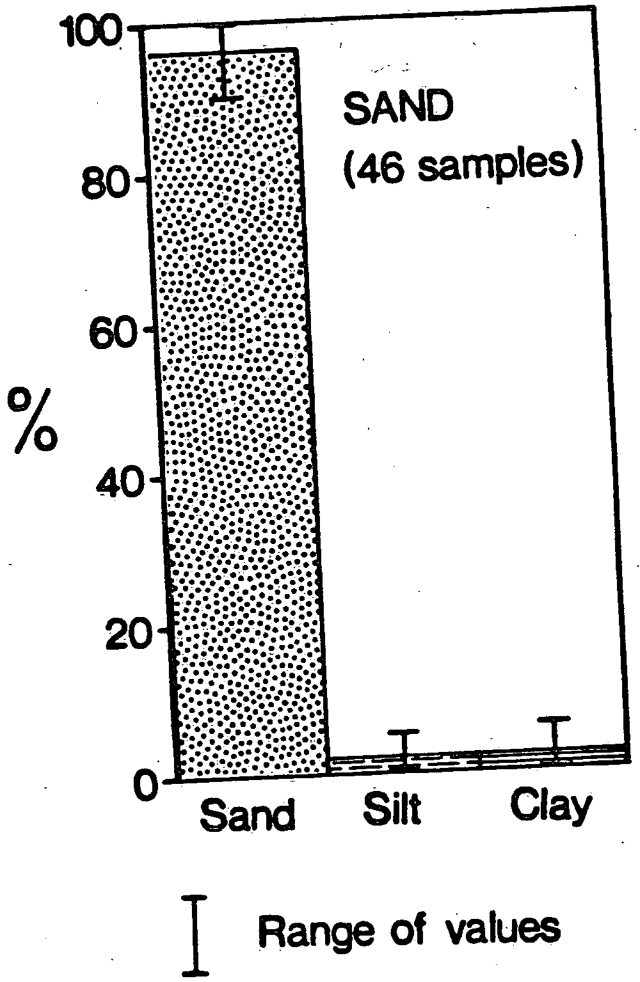

100
80
60
40
20
0
%
SAND
(46 samples)
Sand
Silt
Clay
Range of values

Figure 8. The depth/inferred age graph for Pelee Shoal core 2.

TOP: FROM LEFT TO RIGHT.

Stratigraphy: Simplified lithology and granulometry record of the core 2. Rasters illustrating the lithology of stratal subunits are the same as those used in fence diagram in Fig. 2.

Mollusca: Downcore fluctuations in faunal (taxonomic) diversity and specimen abundance of the total molluscan population. The counts were made for each 9 cm core increment.

Accumulation rate graph: Conversion of the subbottom depth of the molluscan record levels to inferred age via a curve pointing out the sedimentation rates. Curve knobs indicate the downcore levels and time on which the transformation was made.

BOTTOM:

Time series bar diagrams of faunal diversity and specimen abundance fluctuations of total population of molluscs during the last 12,500 years before present at Pelee Shoal. Each bar width represents a time block of approximately 250 years.

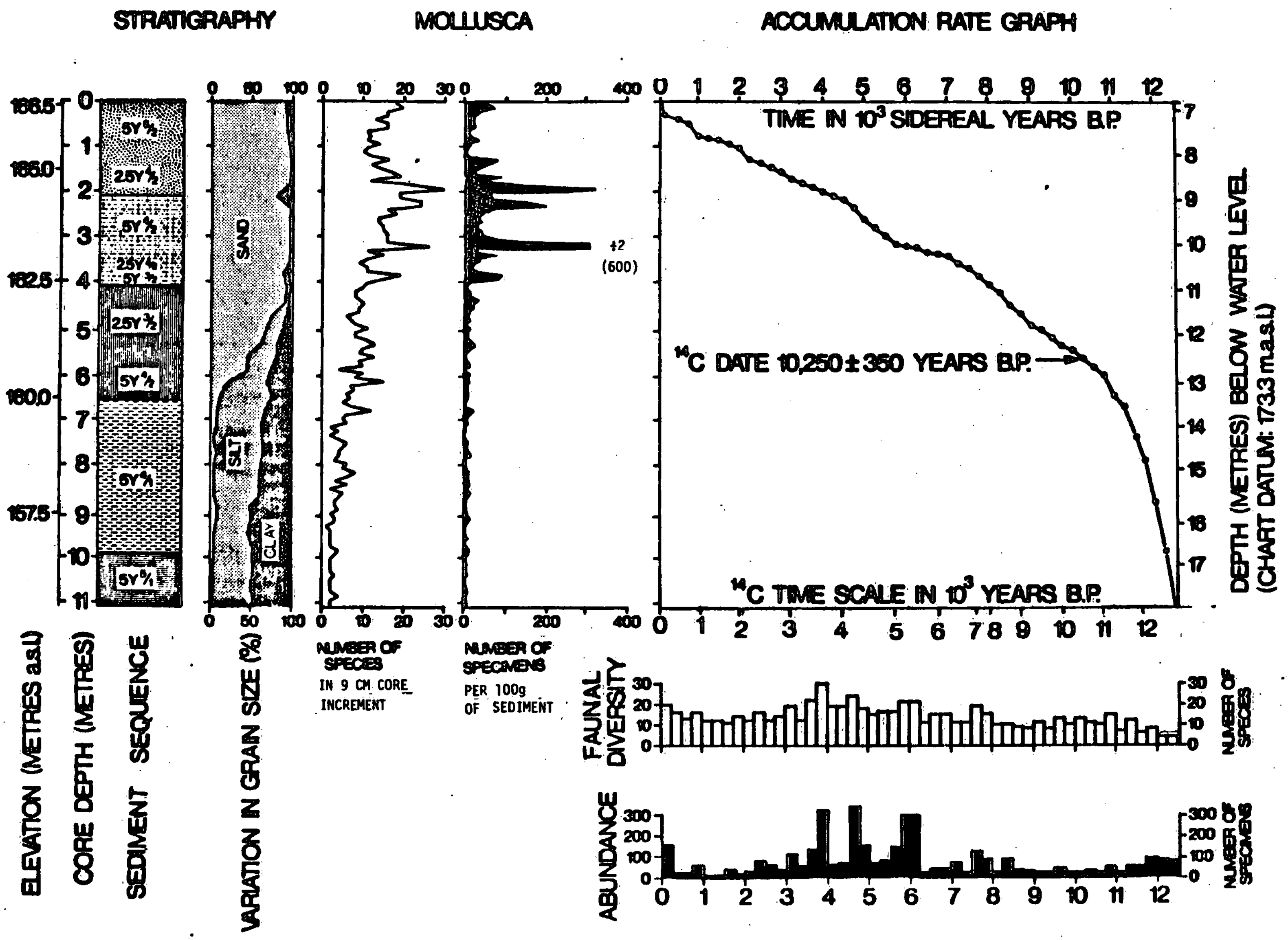
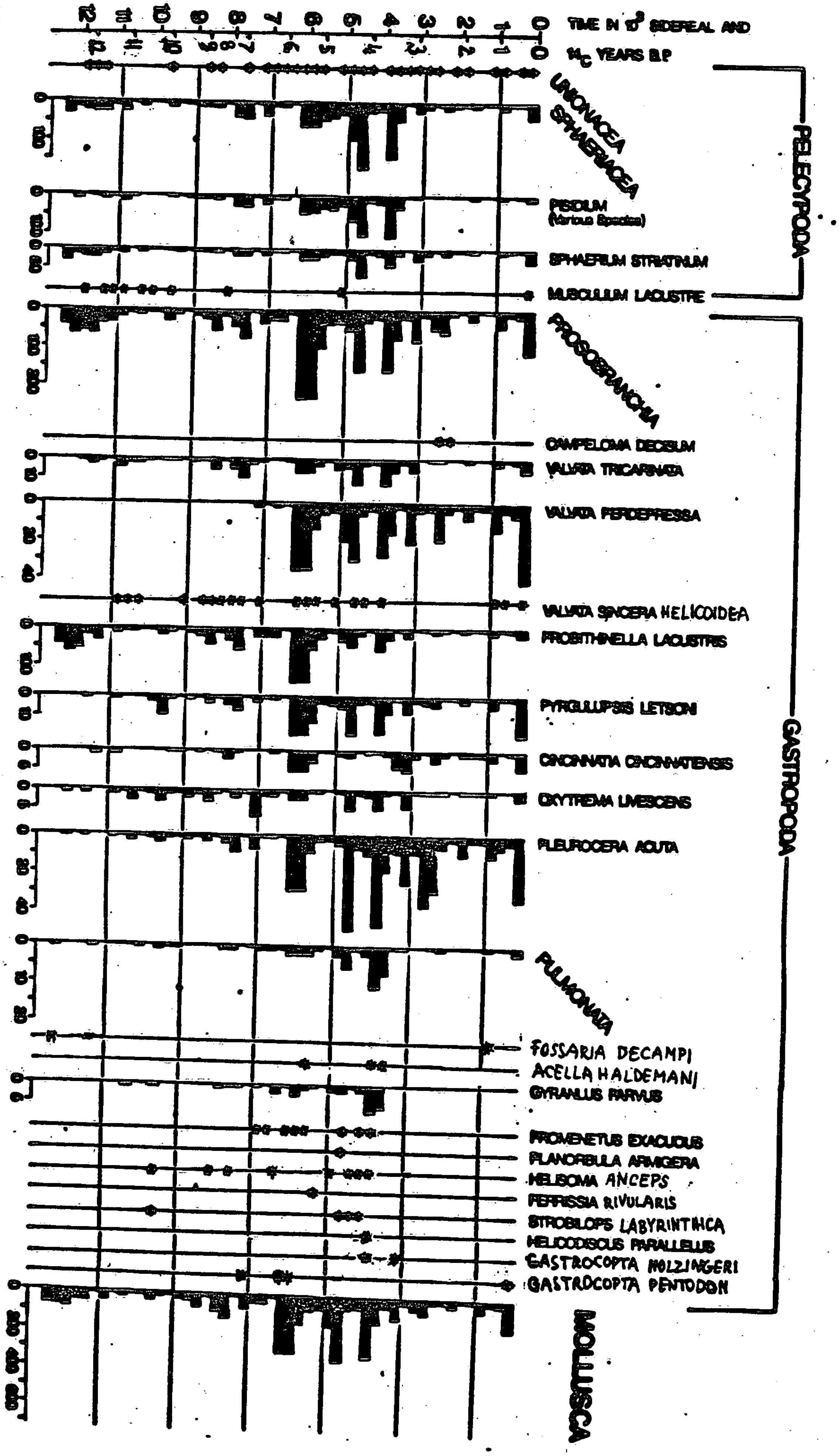

STRATIGRAPHY
MOLLUSCA
ACCUMULATION RATE GRAPH
ELEVATION (METRES a.s.l)
166.5
165.0
162.5
160.0
157.5
CORE DEPTH (METRES)
SEDIMENT SEQUENCE
5Y 6/2
2.5Y 4/2
5Y 6/2
2.5Y 4/2
5Y 3/2
2.5Y 3/2
5Y 4/2
5Y 4/1
5Y 5/1
VARIATION IN GRAIN SIZE (%)
SAND
SILT
CLAY
NUMBER OF SPECIES
IN 9 CM CORE INCREMENT
NUMBER OF SPECIMENS
PER 100g OF SEDIMENT
±2 (600)
TIME IN 10³ SIDEREAL YEARS B.P.
¹⁴C DATE 10,250 ± 350 YEARS B.P.
¹⁴C TIME SCALE IN 10³ YEARS B.P.
DEPTH (METRES) BELOW WATER LEVEL
(CHART DATUM: 173.3 m.a.s.l)
FAUNAL DIVERSITY
NUMBER OF SPECIES
ABUNDANCE
NUMBER OF SPECIMENS

Figure 9. Time-range malacodiagram summarizing changes in abundances of the main taxonomic entities occurring during the last 12,500 sidereal years in the Pelee Shoal of Lake Erie. Each bar represents productivity of the mollusc populations in terms of concentration-number, of specimens in 100 g of sediment per unit area 60 cm^2, per unit time block 250 years.



NOTES: ⊕ 1–10; ▮ >10 Valves (Unionacea and Sphaeriacea) or Individuals (Gastropoda)

PELECYPODA:

Figures 10-13

Figure 10. Lampsilis radiata siliquoidea (Barnes, 1823).

Exterior of the left valve showing coarse double-looped beak sculpture of a juvenile shell. A specimen from the Pelee Shoal, Mid Holocene sediment: core 2, sample interval 227-236 cm, the inferred age 4,750-4,000 years B.P. Lampsilis radiata siliquoidea is an example of a unionacean clam. It is one of the three Unionacean clam species identified from the Pelee Shoal lacustrine sediments.

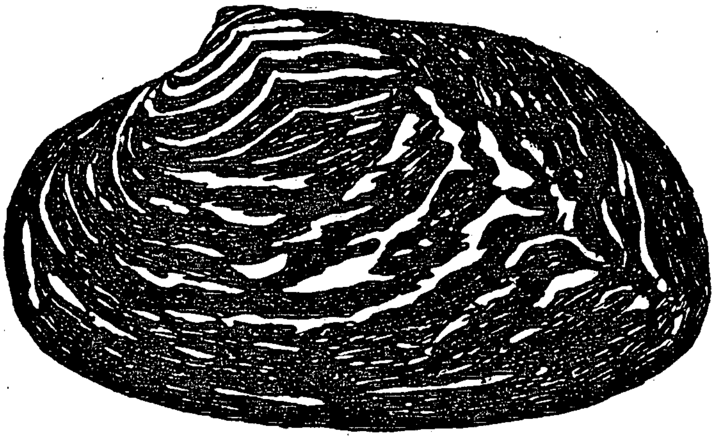


Figure 11. _Pisidium lilljeborgi_ (Esmarck and Hoyer, 1886). Exterior view of the left valve of an adult specimen from the Pelee Shoal Mid Holocene sediment: core 2, depth interval 181-190 cm, inferred age 3,750-3,500 years B.P. _Pisidium lilljeborgi_ is an example of a sphaeriacean clam. It is one of the nine _Pisidium_ species occurring throughout the Pelee Shoal limnic sediment.

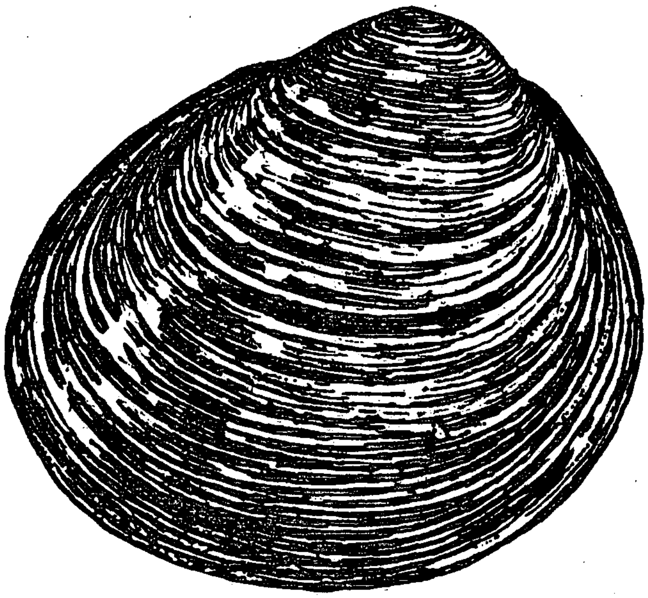


Figure 12. Sphaerium striatinum (Lamarck, 1818).

Exterior view of the left valve of a specimen from the Pelee Shoal Late Wisconsinan sediment: core 2, depth interval 1102-1108 cm, inferred age 12,500-12,250 years B.P. The chronostratigraphical distribution of this sphaeriacean clam covers entire Late Quaternary of the Pelee Shoal. At fine record gradation, its abundance is in inverse relationship with the pattern revealed by Prosobranchiate snails.

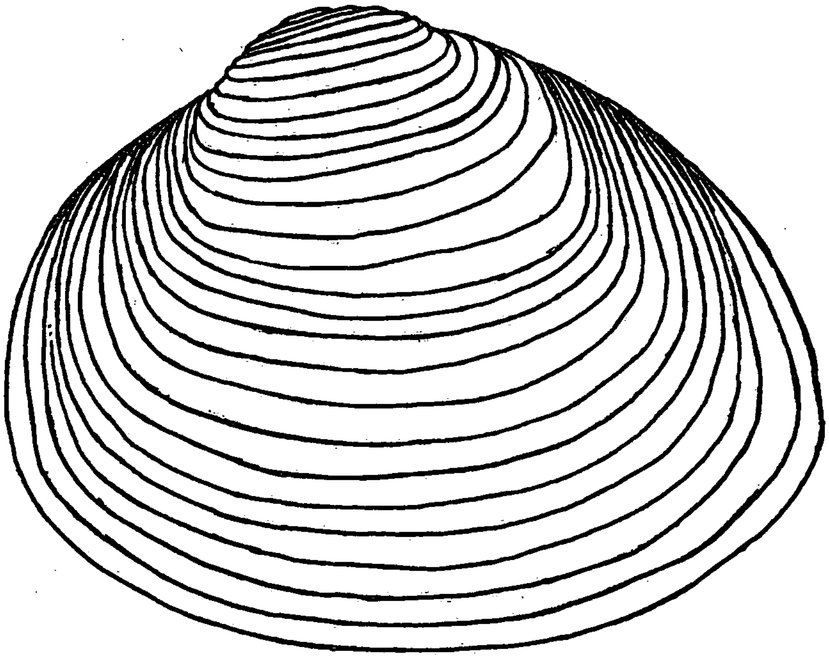
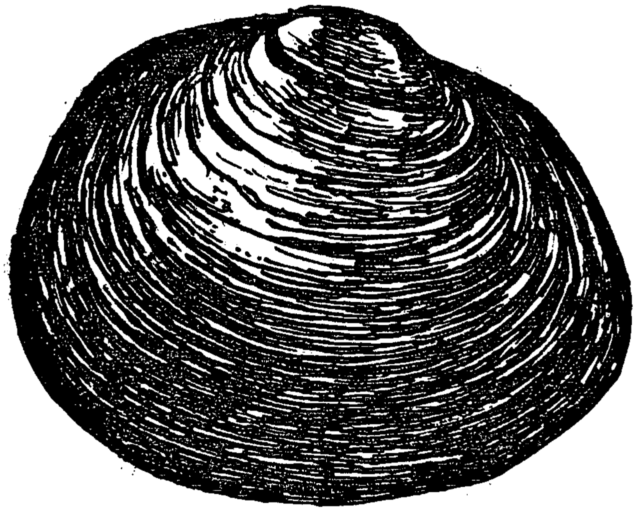


Figure 13. Musculium lacustre (Müller, 1774).

Exterior view of the left valve of a capped and depauperate specimen from the Pelee Shoal Late Wisconsinan sediment: core 2, depth interval 842-851 cm, inferred age 12,000-11,750 years B.P. The characteristic Sphaeriacean clam of Late Wisconsinan with a few accidental occurrences in Early, Mid and Late Holocene.



PROSOBRANCHIATE GASTROPODS:

Figures 14–27

Figure 14. Campeloma decisum (Say, 1816).

A front view of a large adult specimen from the Pelee Shoal Late Holocene sediment: core 2, depth interval 117-126 cm, inferred age 2,250-2,000 years B.P. In addition to the figured specimen, another was found at depth interval 126-135 cm, inferred age 2,500-2,250 years B.P. The occurrence of Campeloma decisum infers with termination of the Pelee Shoal marshland interval prior to establishment of the sublittoral benthic environment with water depth near the present one.

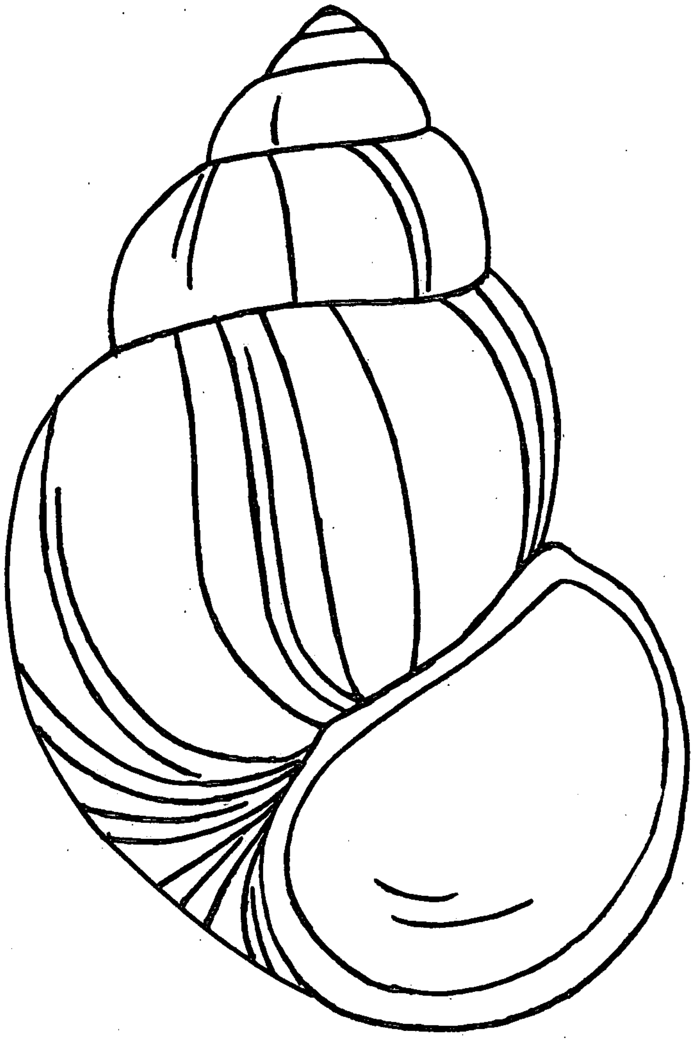
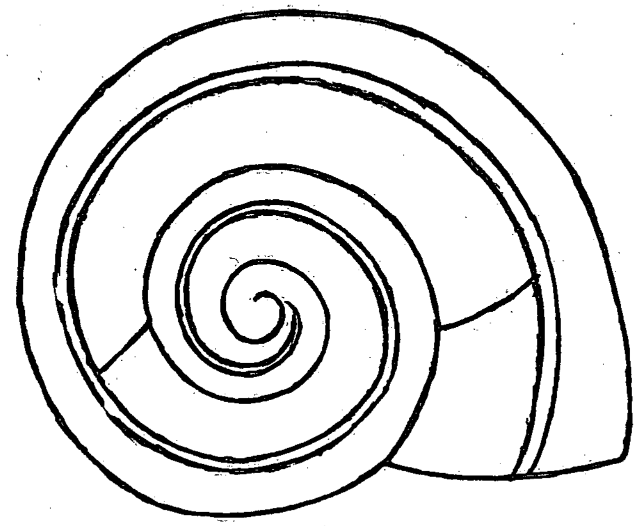


Figure 15. Valvata tricarinata (Say, 1817).

Apical (TOP) and front (BOTTOM) views of a strongly carinated shell from the Pelee Shoal Mid Holocene sediment: core 2, depth interval 434-443 cm, inferred age 8,500-8,250 years B.P. The chronostratigraphical distribution of this lacustrine species covers the entire Late Quaternary of the Pelee Shoal.



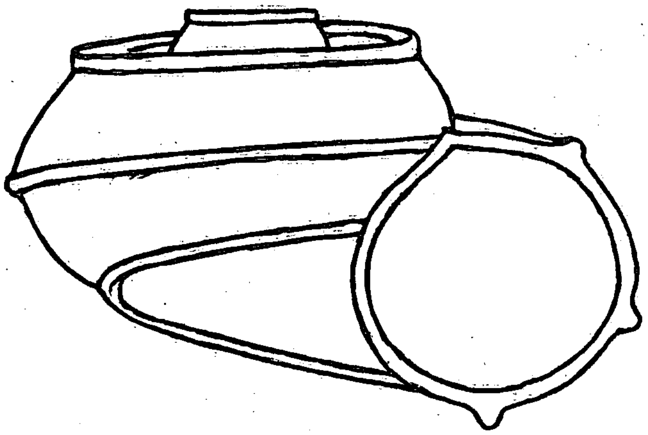
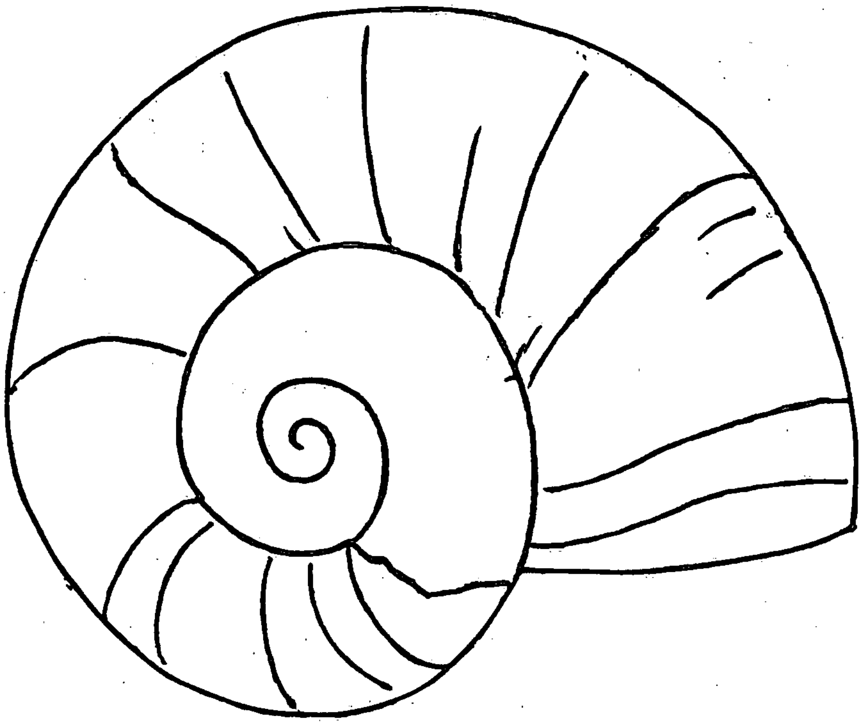


Figure 16. Valvata perdepressa (Walker, 1906).

Apical (TOP) and front (BOTTOM) view of a low spired shell from the Pelee Shoal Mid Holocene sediment: core 2, depth interval 317-326 cm, inferred age 6,250-5,750 years B.P. This species appeared first at Pelee Shoal some 7,250 years ago and then rapidly increased its abundance some 6,250 years ago. In this context the species provides an important intra-Holocene biochronological datum.



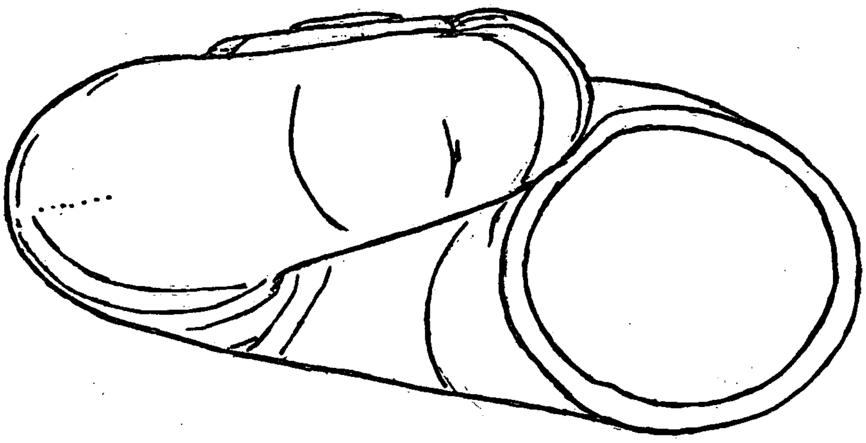
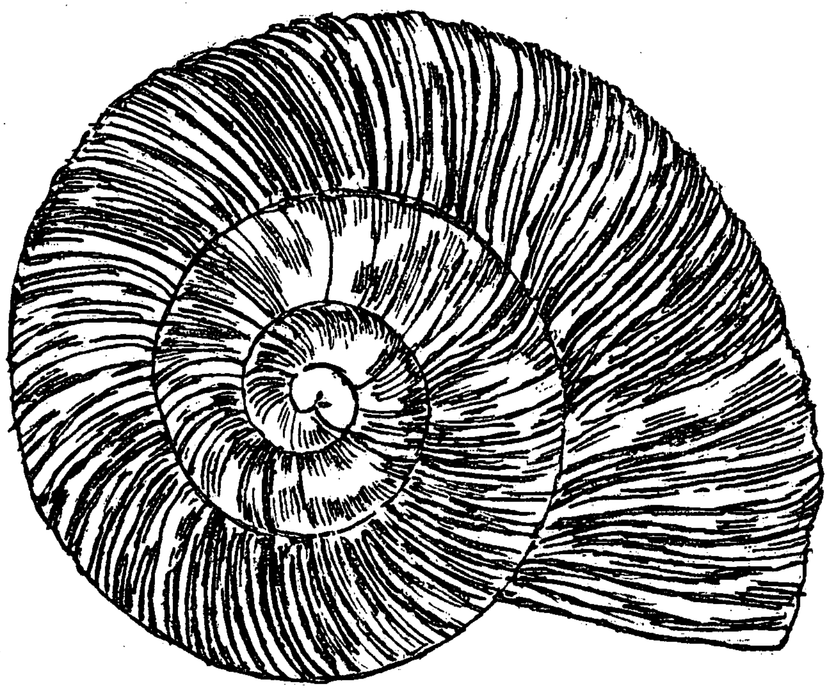


Figure 17. Valvata sincera helicoidea (Dall, 1905).

Apical (TOP) and front (BOTTOM) views of a shell from the Pelee Shoal Early Holocene sediment: core 2, depth interval 371-380 cm, inferred age 7,750-7,500 years B.P. This species of prevalently northern latitudes occurs in the Pelee Shoal sequence discontinuously, sparsely and in abundances never greater than three specimens per sample interval.



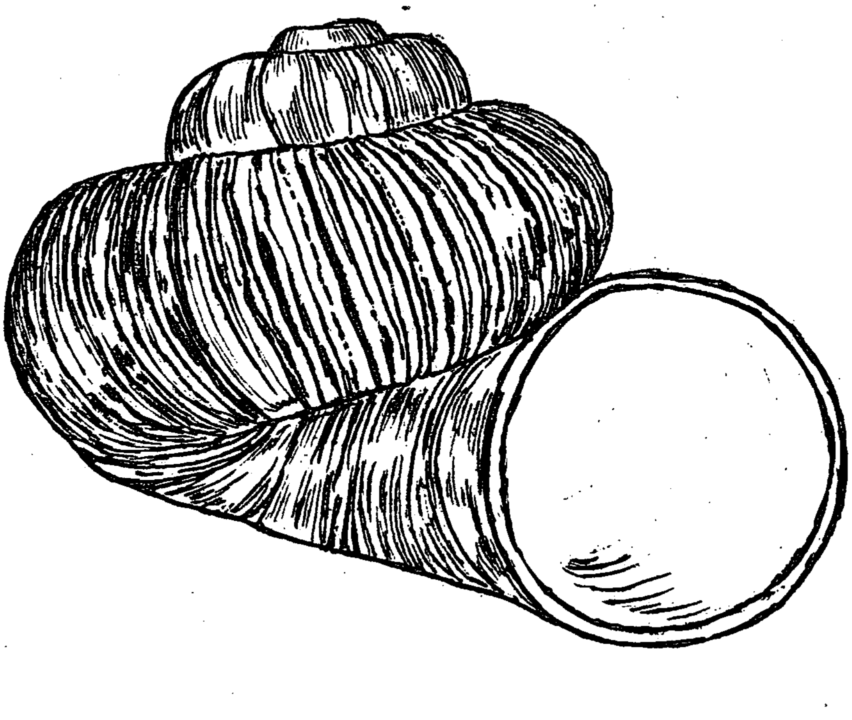
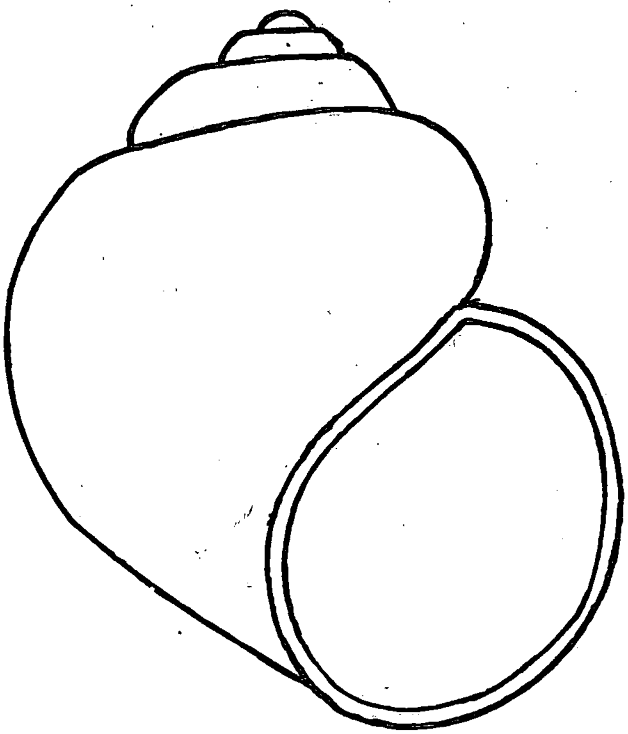


Figure 18. Cincinnatia cincinnatiensis (Anthony, 1840).

Two specimens in a front view: a female (TOP) and a male (BOTTOM) from the Pelee Shoal, Mid Holocene sediment: core 2, depth interval 317-326 cm, inferred age 6,250-5,750 years B.P. The chronostratigraphical distribution of this lacustrine species covers almost the entire Late Quaternary of the Pelee Shoal. It increases its abundances particularly at the beginning and end of the hypsithermal.



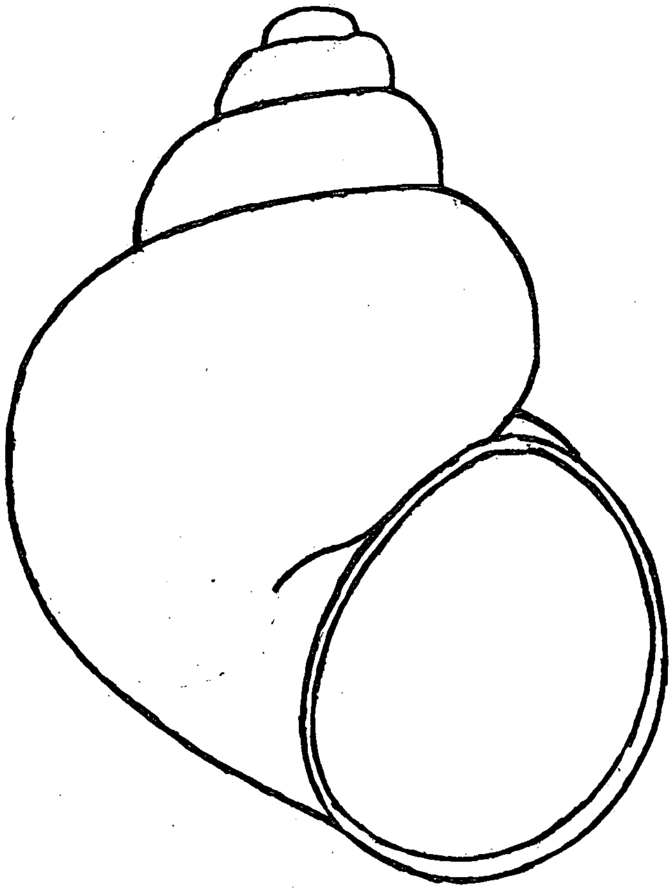


Figure 19. Marstonia decepta (Baker, 1928).

Front view of a specimen from the Pelee Shoal Early Holocene sediment: core 2, depth interval 434-445 cm, inferred age 8,500-8,250 years B.P. In addition to the figured specimen others were found at the following depth/inferred age intervals:

Depth interval (cm)	Inferred age (years B.P.)
27-36	500-250
209-227	4,750-4,500
272-281	5,250-5,000
308-326	6,250-5,750
344-353	7,250-7,000
380-398	8,000-7,500
416-425	8,250-8,000
616-625	11,000-10,750

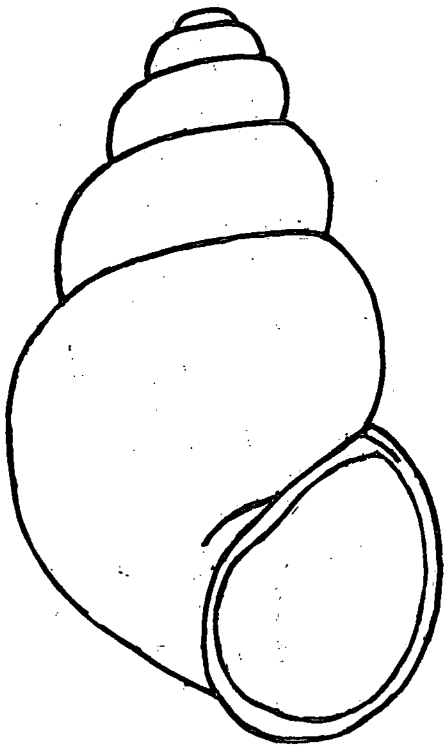
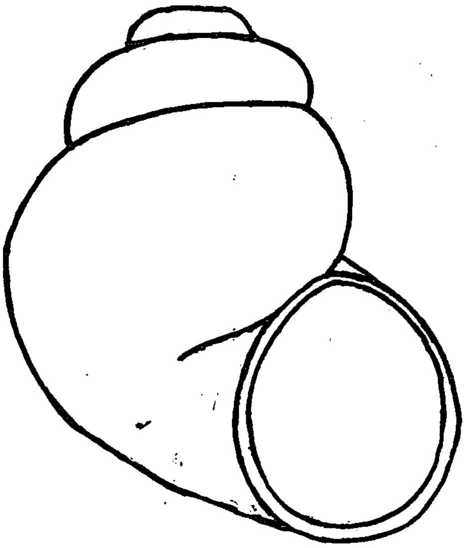


Figure 20. <u>Probithinella lacustris</u> (Baker, 1928).

Two specimens in a front view: a female (TOP) and a male (BOTTOM) from the Pelee Shoal Late Wisconsinan sediment: core 2, depth interval 923-932 cm, inferred age 12,000-12,250 B.P. This is most dominant species of the Pelee Shoal Late Quaternary and continuously covers the entire sediment sequence.



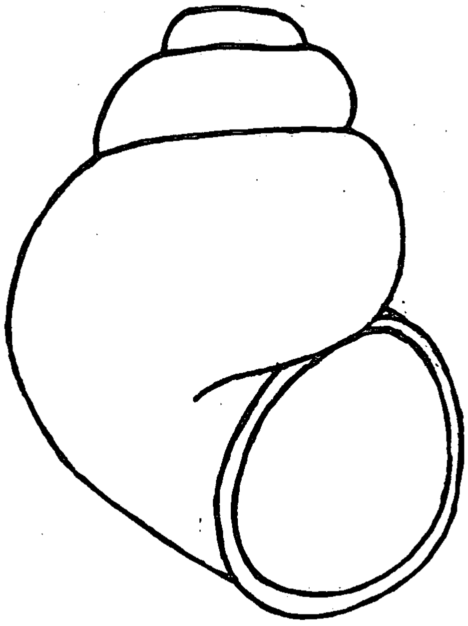
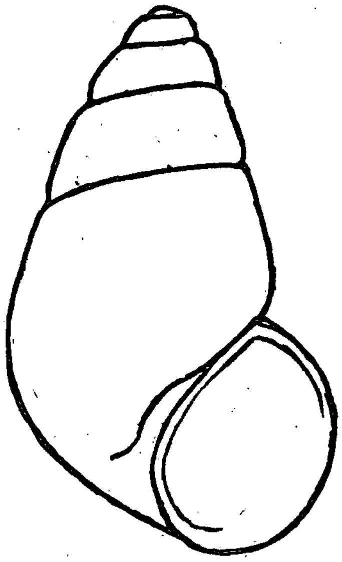


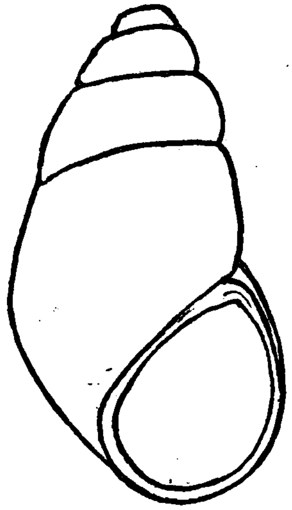
Figure 21. Pyrgulopsis letsoni (Walker, 1901).

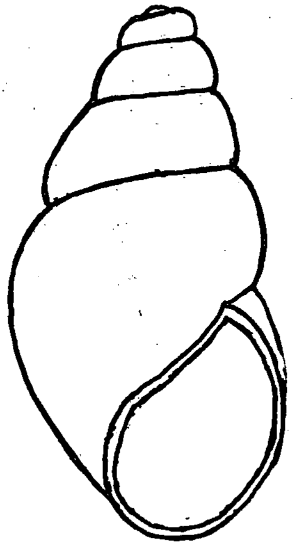
Four specimens in a front view from the various intervals of the Pelee Shoal Mid Holocene sediments: core 2.

Figure Arrangement:	Specimen No.	Depth interval (cm)	Inferred age (years B.P.)
TOP LEFT	1	317-326	6,250-5,750
TOP RIGHT	2	190-200	4,000-3,750
BOTTOM LEFT	3	317-326	6,250-5,750
BOTTOM RIGHT	4	317-326	6,250-5,750

The figured specimens illustrate the great variability in the species shell morphology. Pyrgulopsis letsoni is dominant species with continuous downcore distribution.







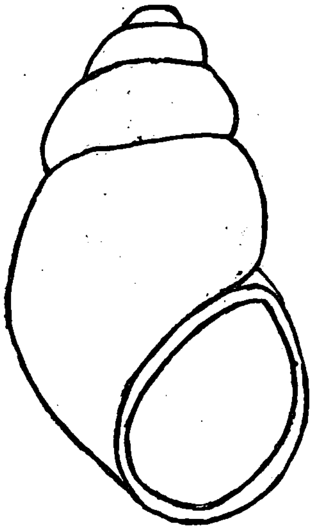
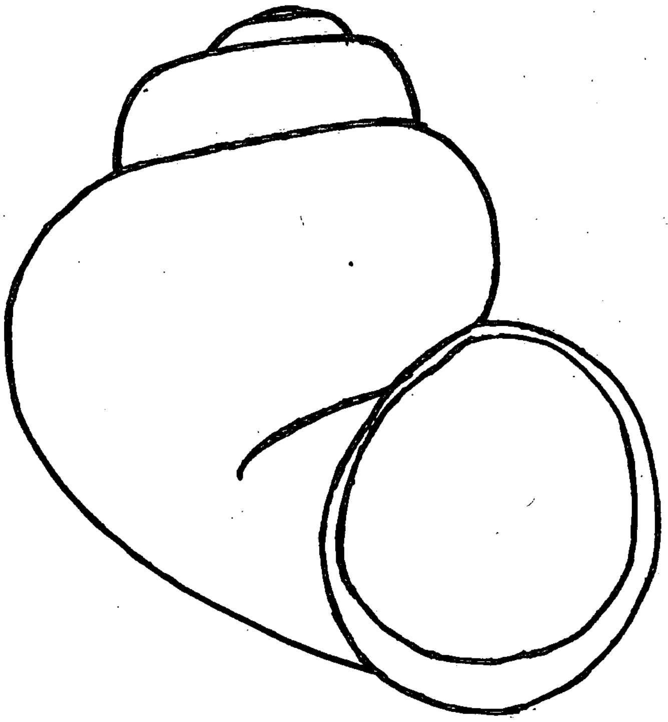


Figure 22. <u>Amnicola limosa</u> (Say, 1817).

Two specimens, a female (TOP) and a male (BOTTOM) from the Pelee Shoal Late Holocene sediment: core 2, depth interval 54-63 cm, inferred age 1,000-750 years B.P. In addition to the figures specimen others were found at the following depth/inferred age intervals.

Depth interval (cm	Inferred age (years (B.P.
0-63	1,000-Present
126-144	2,750-2,500
153-172	3,250-3,000
190-236	4,750-3,750
245-254	4,750-5,000
272-281	5,500-5,250
308-317	5,750-5,500
335-344	7,000-6,500
362-389	7,750-7,500
452-461	8,750-8,500
507-525	8,500-9,250
570-579	10,500-10,250
616-625	11,000-10,750
634-643	11,000-10,750
860-878	12,000-11,750



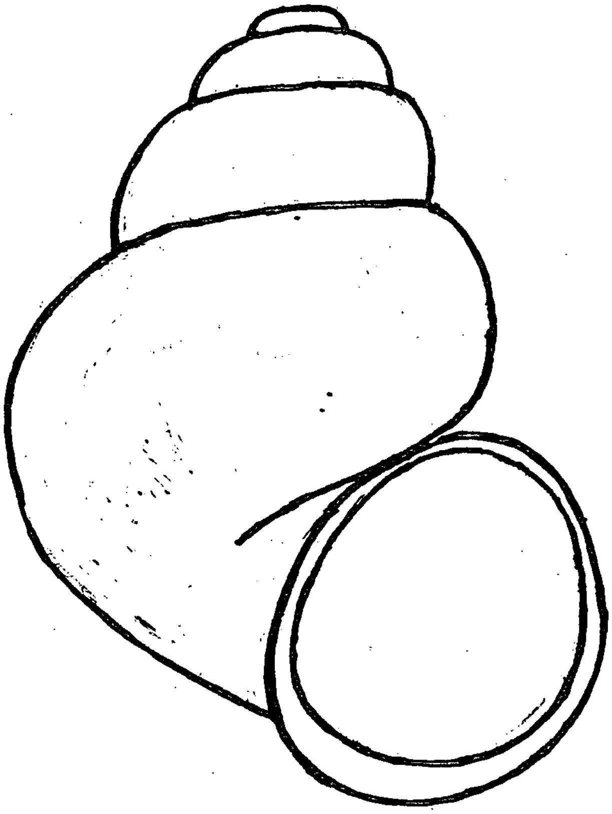


Figure 23. Amnicola walkeri (Pilsbry, 1878).

A front view of a specimen from the Pelee Shoal Late Holocene sediment: core 2, depth interval 27-36 cm, inferred age 500-250 years B.P. In addition to the figured specimen another two specimens were found at the depth/inferred age interval 0-18 cm (Present - 250 years B.P.) and 90-117 cm (2,250-2,000 years B.P.). Amnicola walkeri is rather rare sublitoral species of the Pelee Shoal Late Holocene.

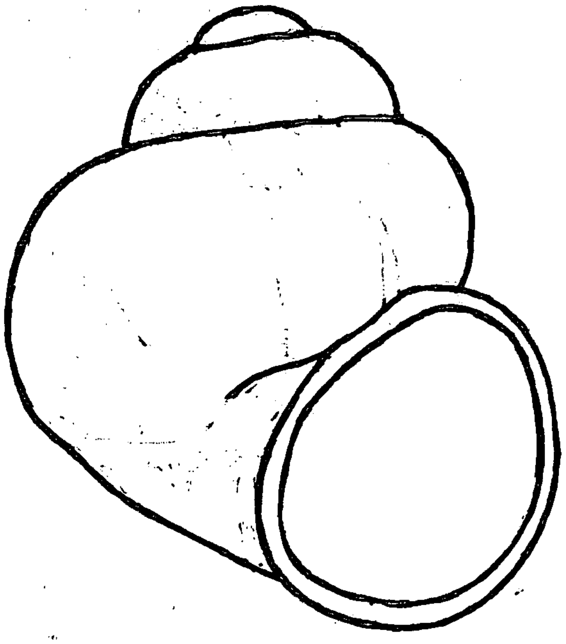


Figure 24. *Nleurocera acuta* (Rafinesque, 1831).

A front view of a specimen from the Pelee Shoal Mid Holocene sediment: core 2, depth interval 317-326 cm, inferred age 6,250-5,750 years B.P. This is a dominant species with continuous downcore distribution in the Pelee Shoal Late Quaternary sediments.

Figure 25. *Oxytrema livescens* (Menke, 1830).

A front view of a specimen from the Pelee Shoal Mid Holocene sediment: core 2, depth interval 218-227 cm, inferred age 4,750-4,500 years B.P. Oxytrema livescens is another characteristic Pleurocerid species with continuous downcore distribution.

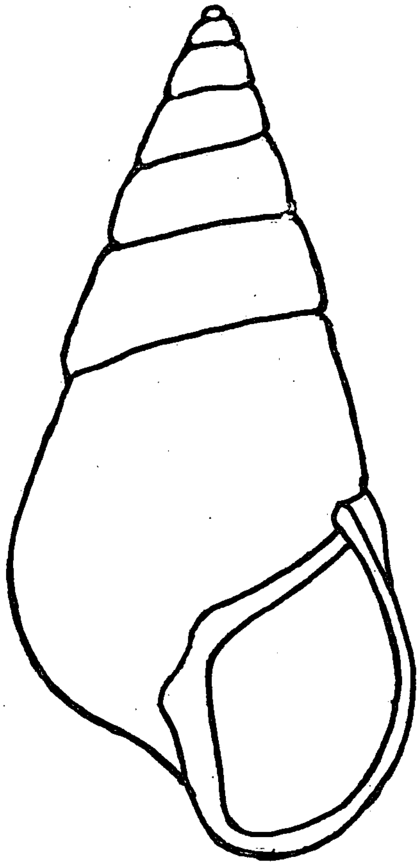


Figure 26. Oxytrema haldemani (Tyron, 1865).

A front view of a specimen from the Pelee shoal Mid Holocene sediment: core 2, depth interval 317-326 cm, inferred age 6,250-5,750 years B.P. The chronostratigraphic distribution of this species in the Pelee Shoal sediments is rather inadequately known because of strong conchological convergence of this species to Pleurocera acuta and Oxytrema livescens shells.

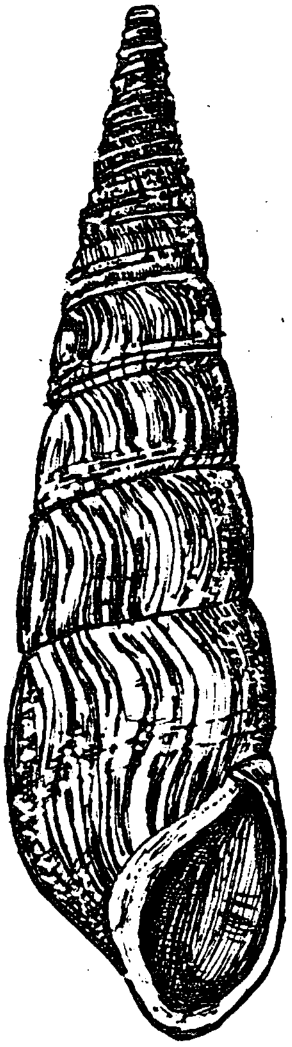


Figure 27. *Spirodon carinata* (Bruguière, 1786).

A front view of a specimen from the Pelee Shoal Mid Holocene sediment: core 2, depth interval 227-236 cm, inferred age 4,750-4,500 years B.P. This is a rather rare form among Pleurocerid gastropods with strong affinity towards high energy benthic environment.

FRESHWATER PULMONATE GASTROPODS

Figures 28-39

Figure 28. Fossaria decampi (Streng, 1896).

A front view of a specimen from the Pelee Shoal Late Wisconsinan sediment: core 2, depth interval 1,084-1,093 cm, inferred age 12,250-12,500 years B.P. In addition to the figured specimen another was found in Late Holocene sediment at depth/inferred age interval 45-54 cm (1,000-750 years B.P.)

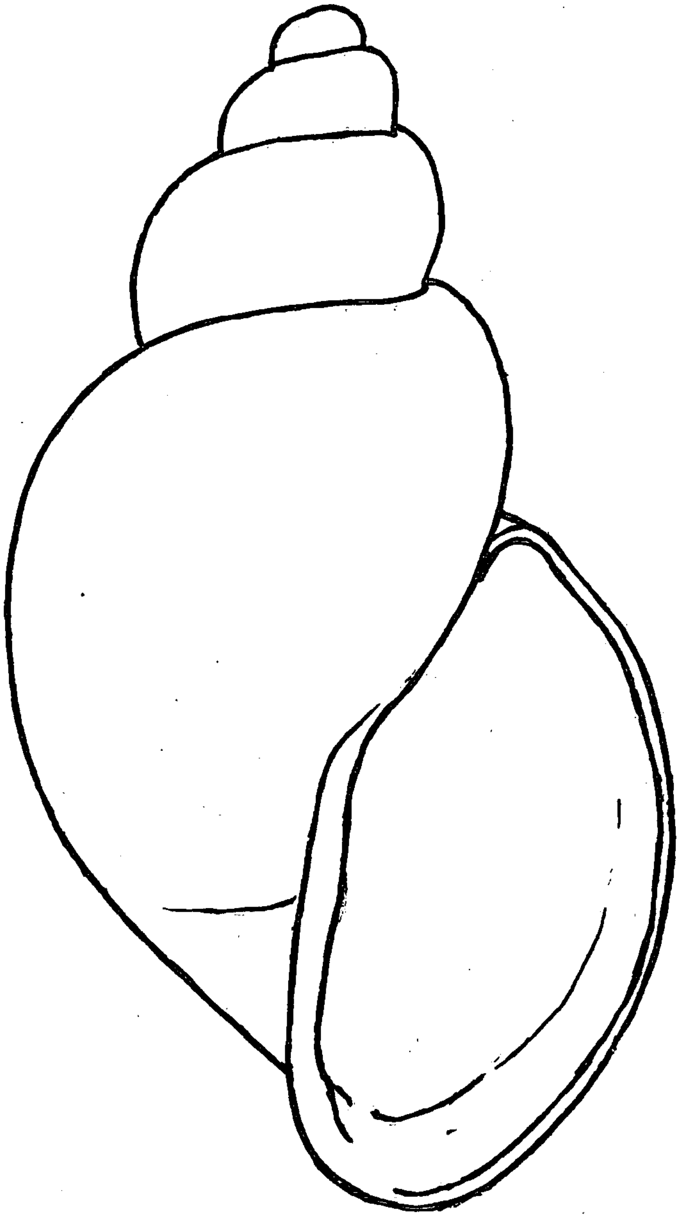


Figure 29. Lymnaea stagnalis appressa (Say, 1818).

A front view of a specimen from the Pelee Shoal Early Holocene sediment: core 2, depth interval 290-299 cm, inferred age 5,500-5,250 years B.C. In addition to a figured specimen the fragments of another was found at depth/inferred age interval 697-706 cm (11,500-11,250 years B.P.)

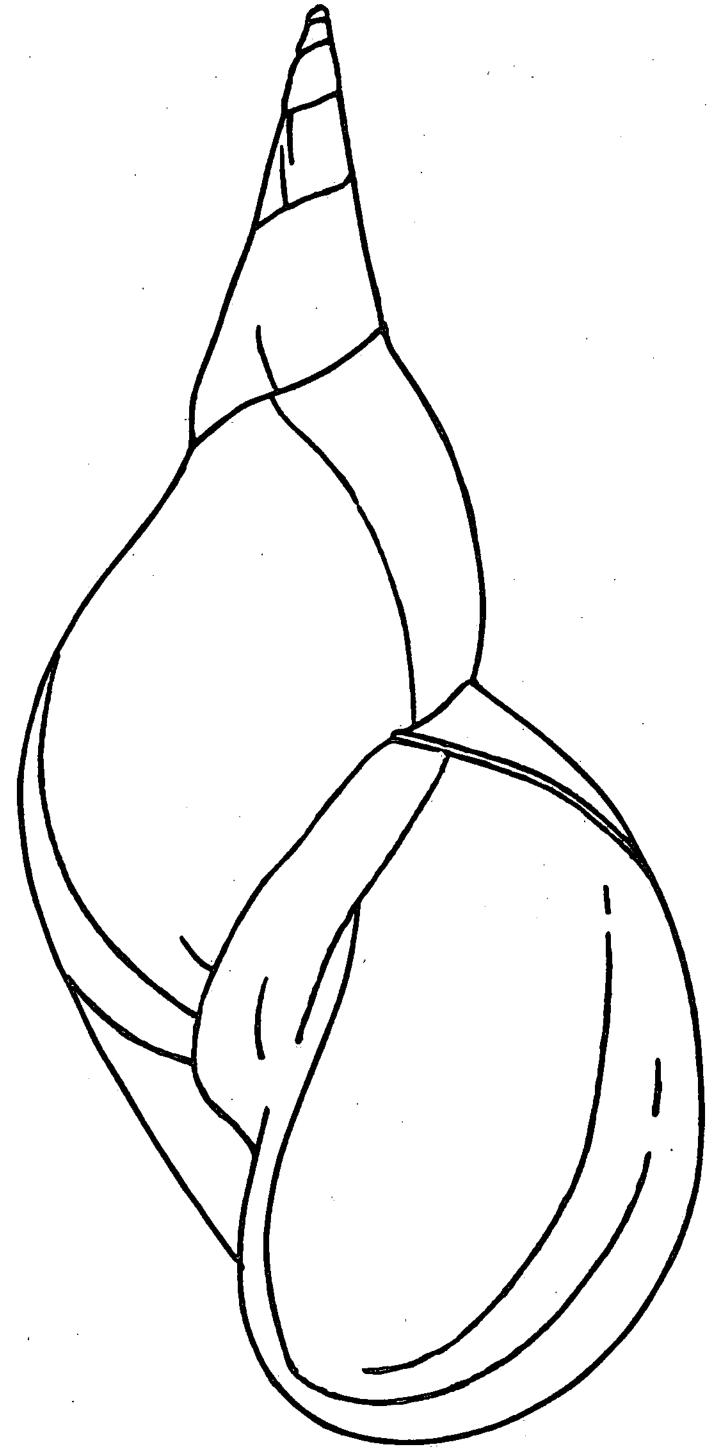


Figure 30. _Acella haldemani_ (Binney, 1867).

A front view of a specimen from the Pelee Shoal Mid Holocene sediment: core 2, depth interval 181-190 cm, inferred age 3,750-3,500 years B.P. In addition to the figured specimen another two fragmented specimens were found at depth/inferred age intervals 190-200 cm (4,000-3,750 years B.P.) and 299-308 cm (5,750-5,500 years B.P.). The species characterizes the initial and final stage of the hypsithermal marshland development at the Pelee Shoal.

Figure 31. Stagnicola elodes (Say, 1821).

A front view of a specimen from Pelee Shoal Late Holocene sediment: core 2, depth interval 54-63 cm inferred age 1,000-975 years B.P. In addition to figured specimen several others were found at depth/inferred age intervals as follows:

Depth interval (cm	Inferred age (years B.P.)
117-126	2,250-2,000
190-200	4,000-3.750
227-236	4,750-4,500
317-326	6,250-5,750
389-398	8,000-7,750
407-416	8,250-8,000
425-434	8,500-8,250
598-607	10,750-10,500
994-1012	12,500-12,250

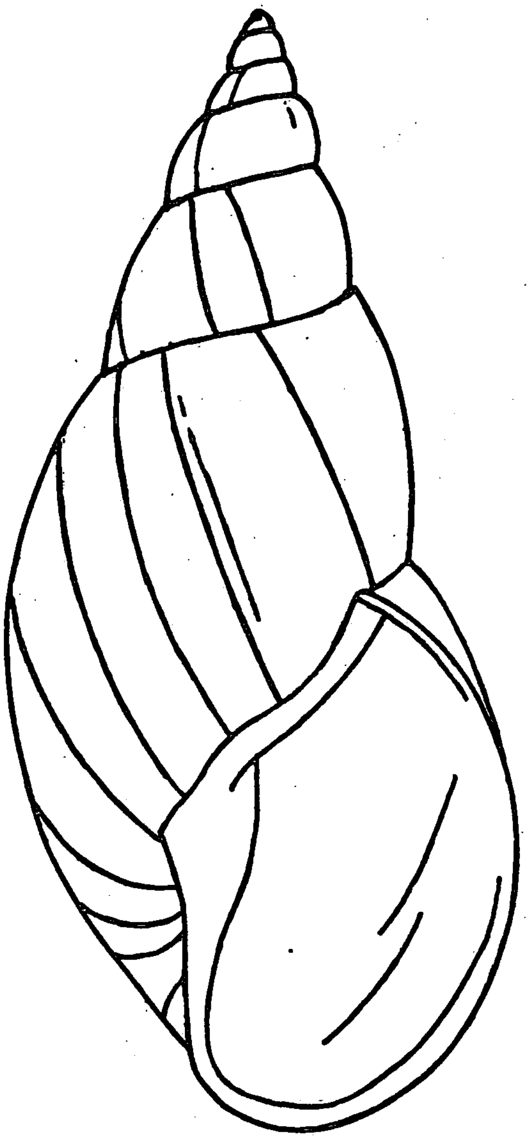


Figure 32. Physa gyrina (Say, 1821).

A front view of a juvenile specimen from the Pelee Shoal Late Holocene sediment: core 2, depth interval 27-36 cm, inferred age 500-250 years B.P. In addition to the figured specimen another few were found at depth/inferred age intervals as follows:

Depth interval (cm)	Inferred age (years B.P.)
0-36	500-Present
54-63	1,000-750
99-108	2,250-2,000
117-135	2,500-2,250
163-181	3,500-3,250
190-236	5,000-4,000
245-254	5,000-4,750
272-281	5,250-5,000
299-326	6,250-5,500
335-344	7,000-6,500

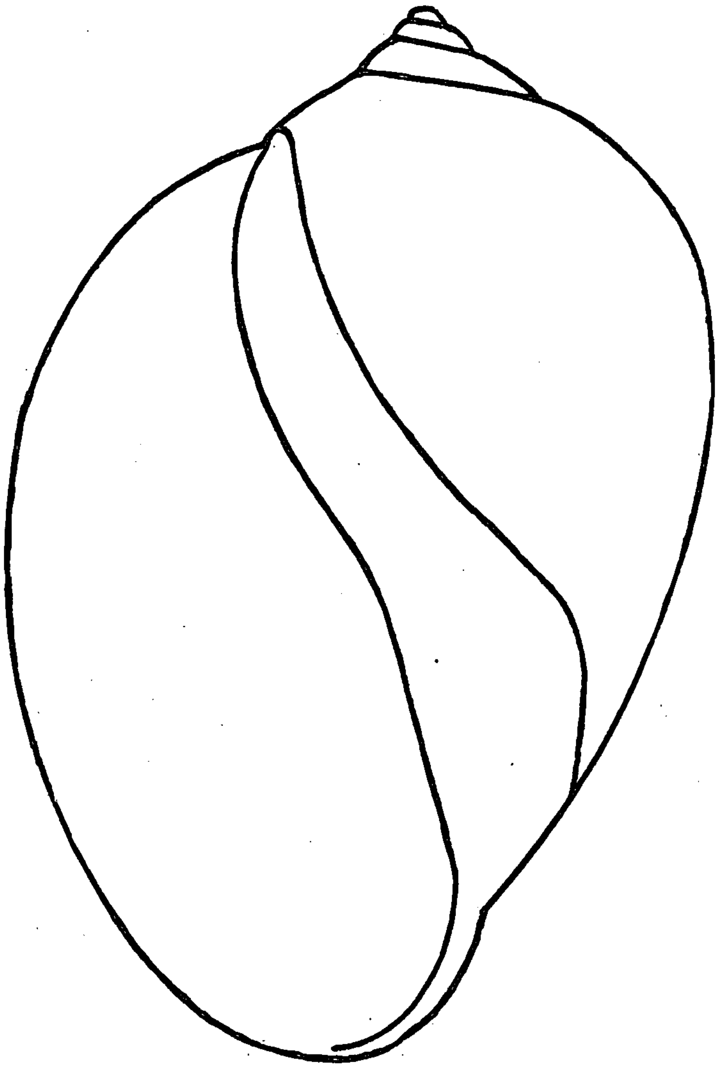


Figure 33. Physa skinneri (Taylor, 1953).

A front view of a specimen from the Pelee Shoal Late Holocene sediment: core 2, depth interval 153-163 cm, inferred age 3,250-3,000 years B.P. In addition to the figured species another was found at depth/inferred age interval 616-625 cm (11,000-10,750 years B.P.). The species is common in subarctic and boreal forest and prairie pond and lake environments.

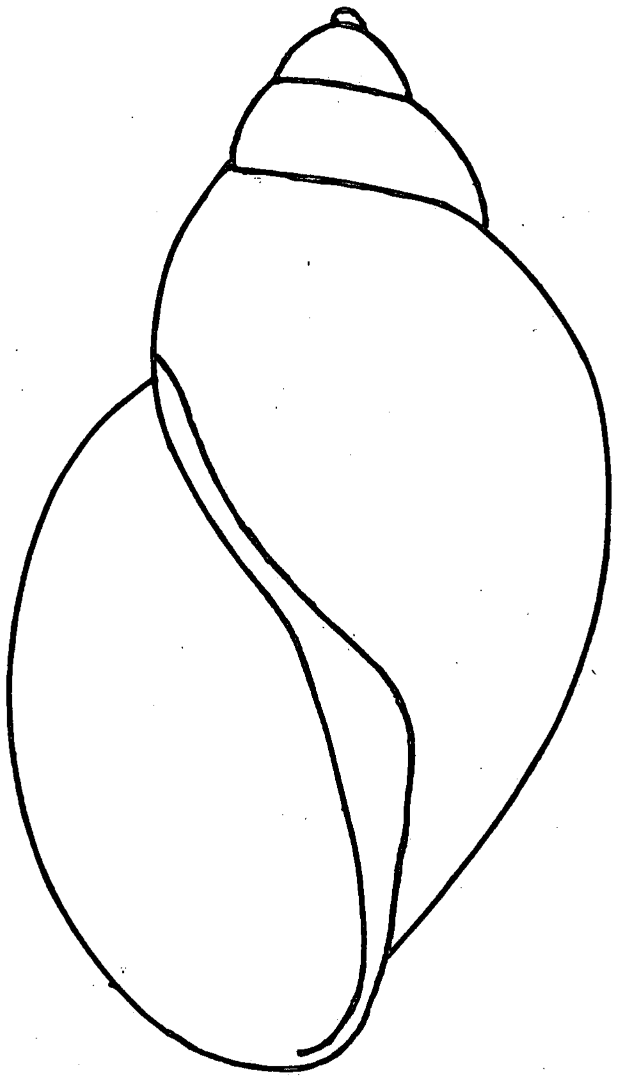
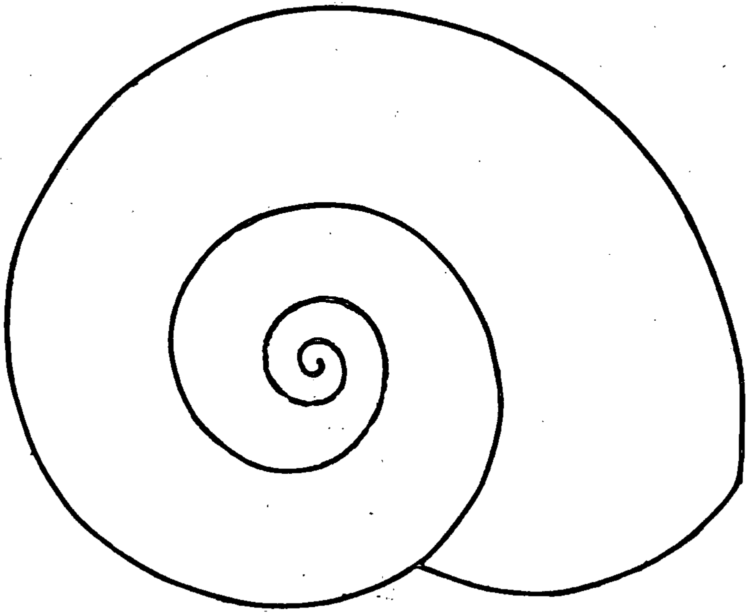
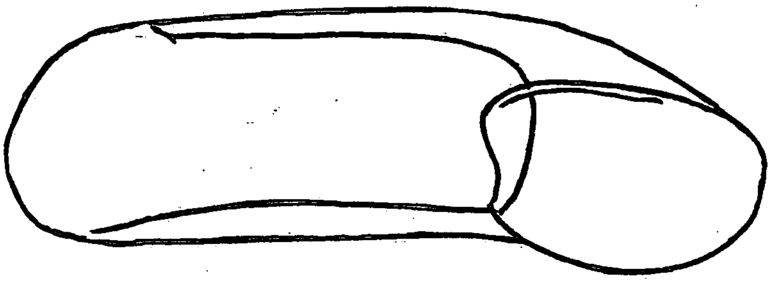


Figure 34. *Gyraulus parvus* (Say, 1817).

Apical, front and umbilical views of a specimen from the Pelee Shoal Holocene sediment: core 2, depth interval 181-190 cm, inferred age 3,750-3,500 years B.P. *Gyraulus parvus* is dominant species present in Early and Mid Holocene and lacking in Late Wisconsin and Late Holocene sediments.





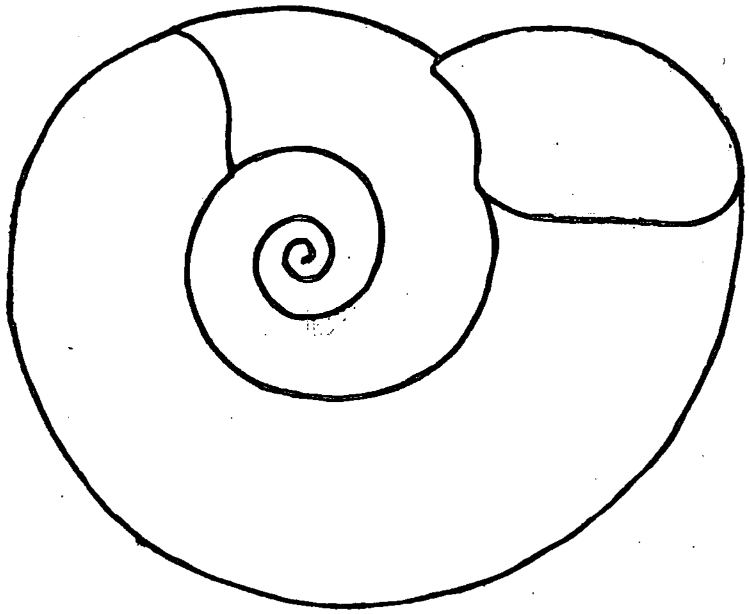
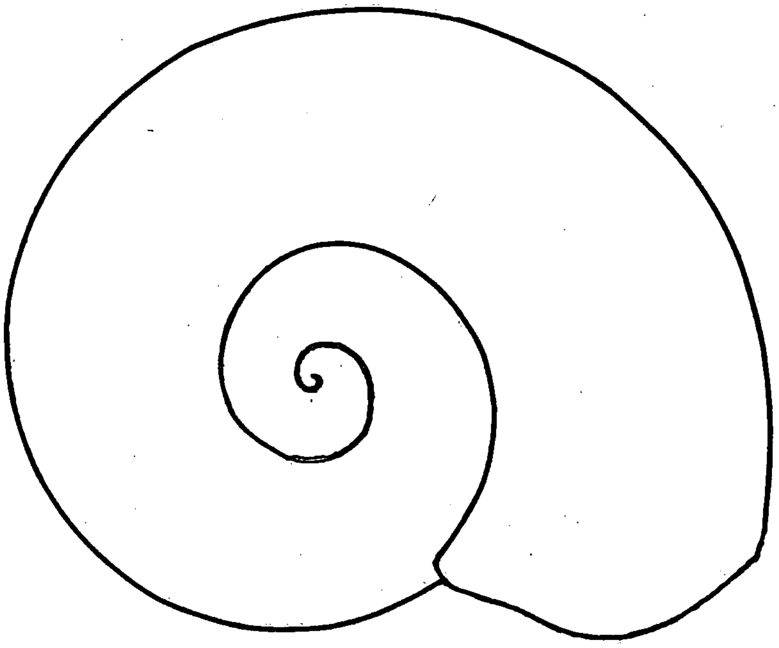
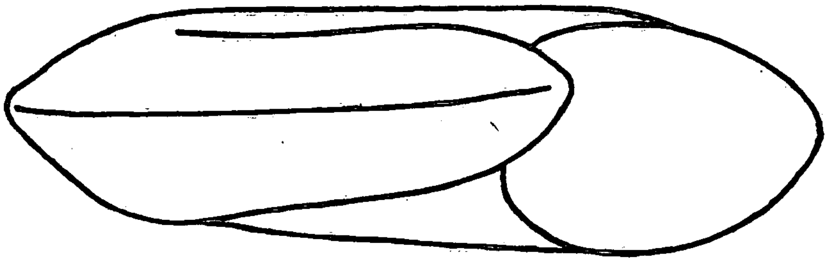


Figure 35. Promenetus exacuous (Say, 1821).

Apical, front and umbilical views of a specimen from Pelee Shoal Holocene sediment: core 2, depth interval 181-190 cm, inferred age 3,750-3,500 years B.P. The chronostratigraphic distribution of this species is rather narrow and covers only hypsithermal and pre-hypsithermal sediment complexes associated with development of the marshland conditions in the Pelee Shoal area.





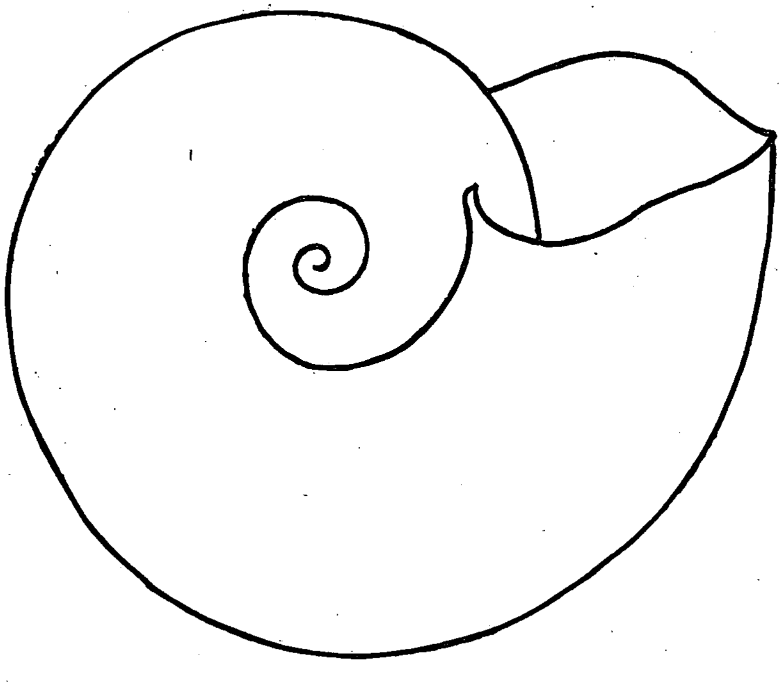
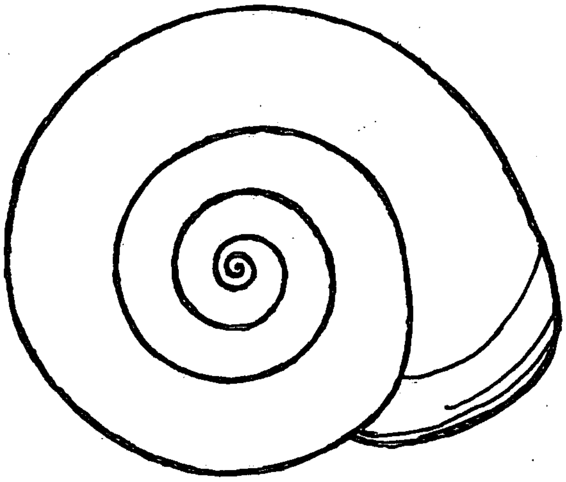
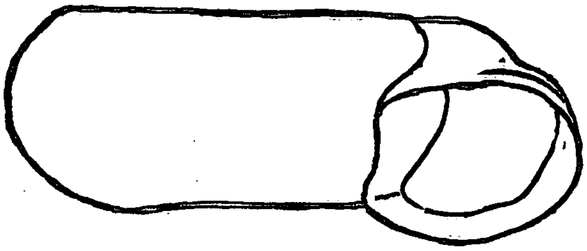


Figure 36. Planorbula armigera (Say, 1821).

Apical, front and umbilical views of a single specimen from Pelee Shoal Mid Holocene sediment: core 2, depth interval 218-227 cm, inferred age 4,750-4,500 years B.P.





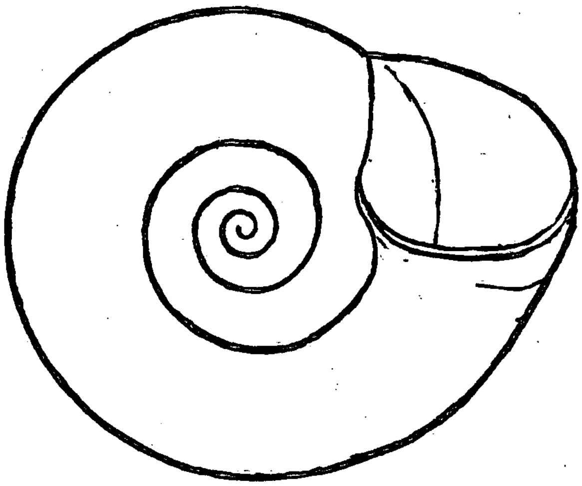
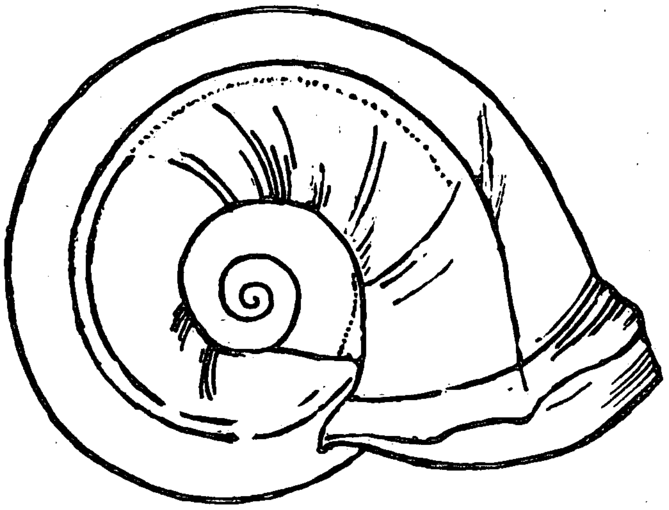
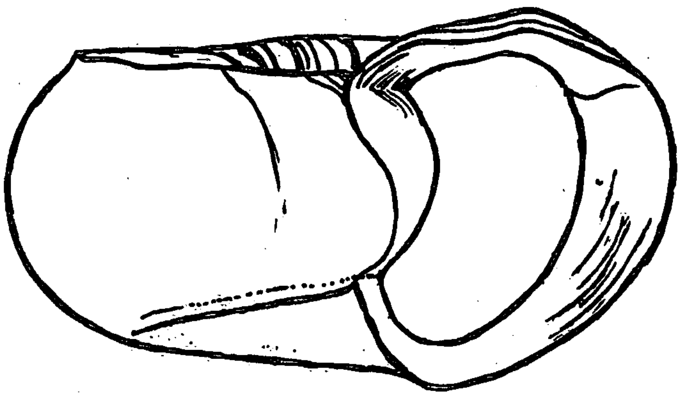


Figure 37. Helisoma anceps (Menke, 1830).

Apical, front and umbilical views of a normally right-coiled specimen from the Pelee Shoal Mid Holocene sediment: core 2, depth interval 190-200 cm, inferred age 3,750-4,000 years B.P. In addition to the figured specimens several others were found at various intervals of Early and Mid Holocene as follows:

Depth interval (cm)	Inferred age (years B.P.)
181-218	4,500-3,750
254-263	4,000-4,750
317-335	6,500-6,250
380-389	7,750-7,500
407-416	8,250-8,000
525-535	9,750-9,500





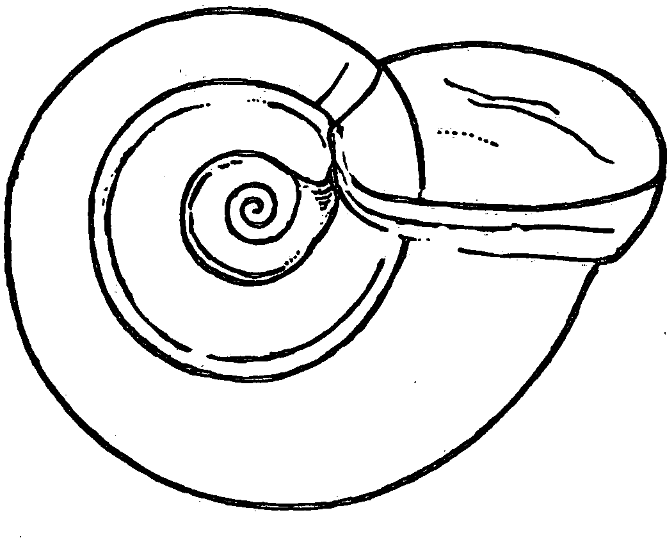
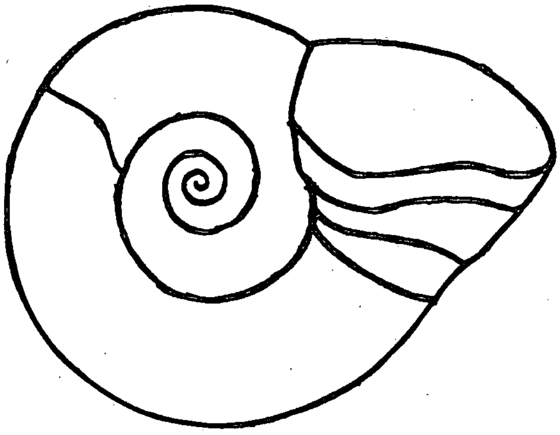
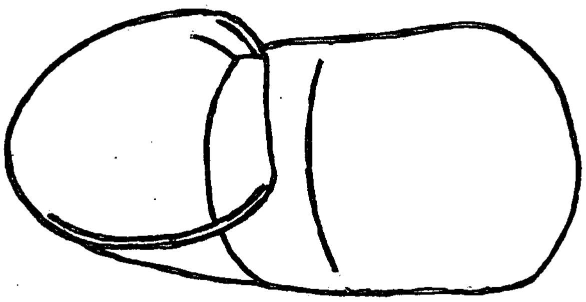


Figure 38. *Helisoma campanulatum* (Say, 1821).

Apical, front and umbilical views of a single normally left-coiled specimen from Pelee Shoal Mid Holocene sediment: core 2, depth interval 181-190 cm, inferred age 3,750-3,500 years B.P.





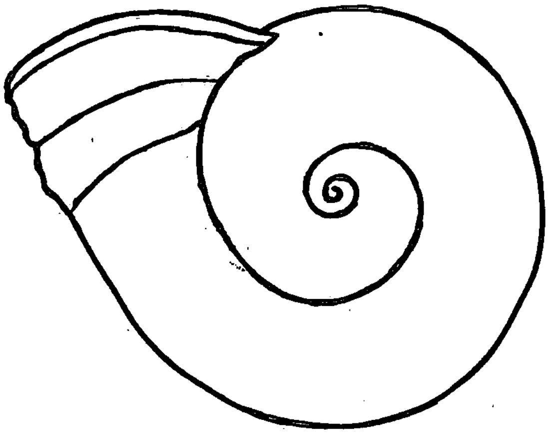
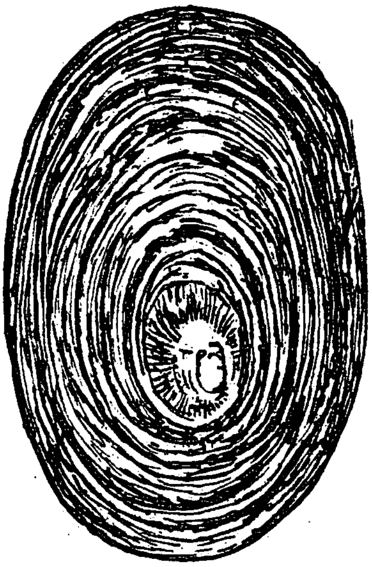


Figure 39. *Ferrissia rivularis* (Say, 1817).

Apical and side views of a single limpet-like specimen from the Pelee Shoal Mid Holocene sediments: core 2, depth interval 290-299 cm, inferred age 5,500-5,250 years B.P.



TERRESTRIAL PULMONATE GASTROPODS

Figures 40-43

Figure 40. Gastrocopta holzingeri (Sterki, 1889).

A front view of a specimen from the Pelee Shoal Mid Holocene sediment: core 2, depth interval 200-209 cm, inferred age 3,900 (4,250-4,000) years B.P. In addition to figured specimen two other specimens were found at depth/inferred age intervals 163-172 cm 4,460 (3,250-3,000) years B.P. and 190-200 cm 3,900 (4,000-3,750) years B.P.

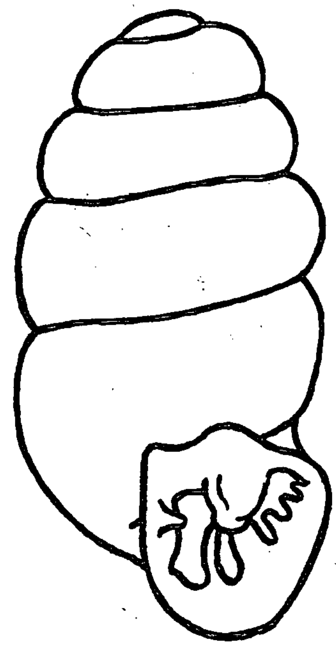


Figure 41. Gastrocopta pentodon (Say, 1822).

A front view of a specimen from the Pelee Shoal Recent sediments: core 2, depth interval 9-18 cm, inferred age 250 years B.P. In addition to the figured specimen, two other specimens were found at depth/inferred age interval 317-326 cm (6,250-5,750 years B.P.) and 344-352 cm 7,350 (7,250-7,000) years B.P.

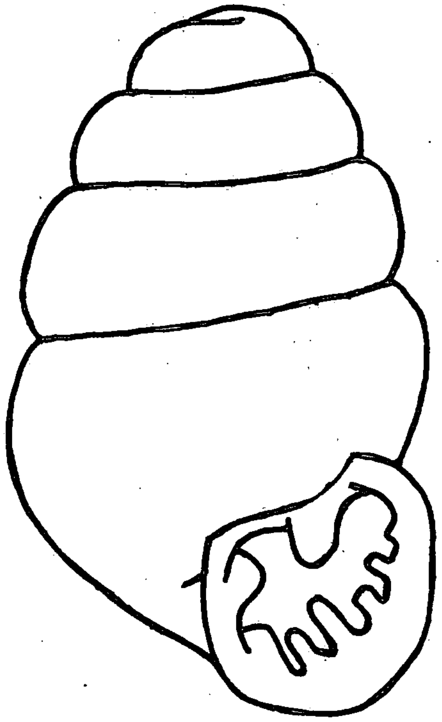


Figure 42. Strobilops labyrinthica (Say, 1817).

A front view of a specimen from the Pelee Shoal sediments: core 2, depth interval 200-209 cm, inferred age 4,250-5,000 years B.P. In addition to the figured speciman two other specimens were found at depth/inferred age interval 209-218 cm (4,450-4,250) years B.P. and 227-236 cm (4,750-4,500 years B.P.)

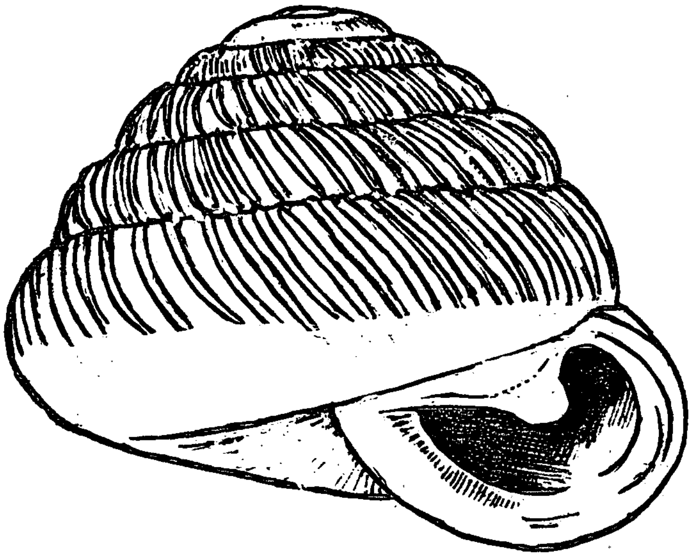
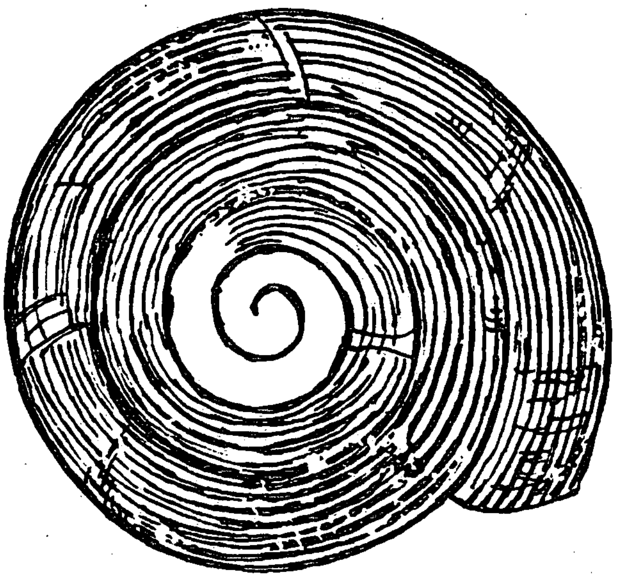
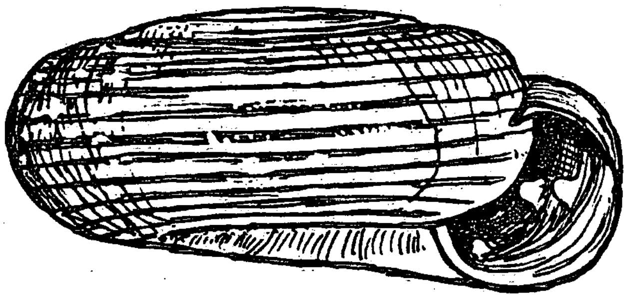


Figure 43. Helicodiscus parallelus (Say, 1821)

Apical, front end and umbilical views of a single specimen from the Pelee Shoal Mid Holocene sediment: core 2, depth interval 181-200 cm, inferred age 4,000-3,750 years B.P.





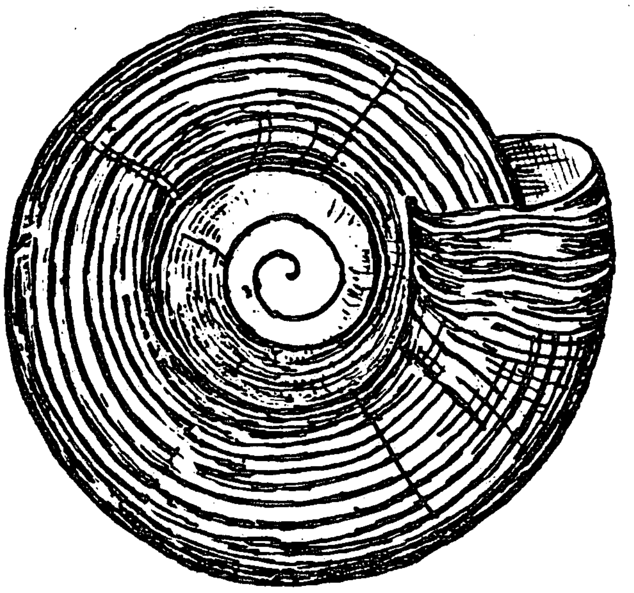


Figure 44. Five different indicators of climatic change from Canada (A,B,C,), Scandanavia (D) and the worldwide seas (E).

A) Faunal diversity of the mollusc taxocene from lacustrine sediments of the Pelee Shoal in Lake Erie during the last 12,500 years (this paper). The diagram is based on 123 combined samples, of which about half cover the Holocene and the other half the Late Pleistocene times. Diversity is expressed as total number of species in molluscan thanatocenosis per unit area 60 cm^2 per unit time interval 250 years.

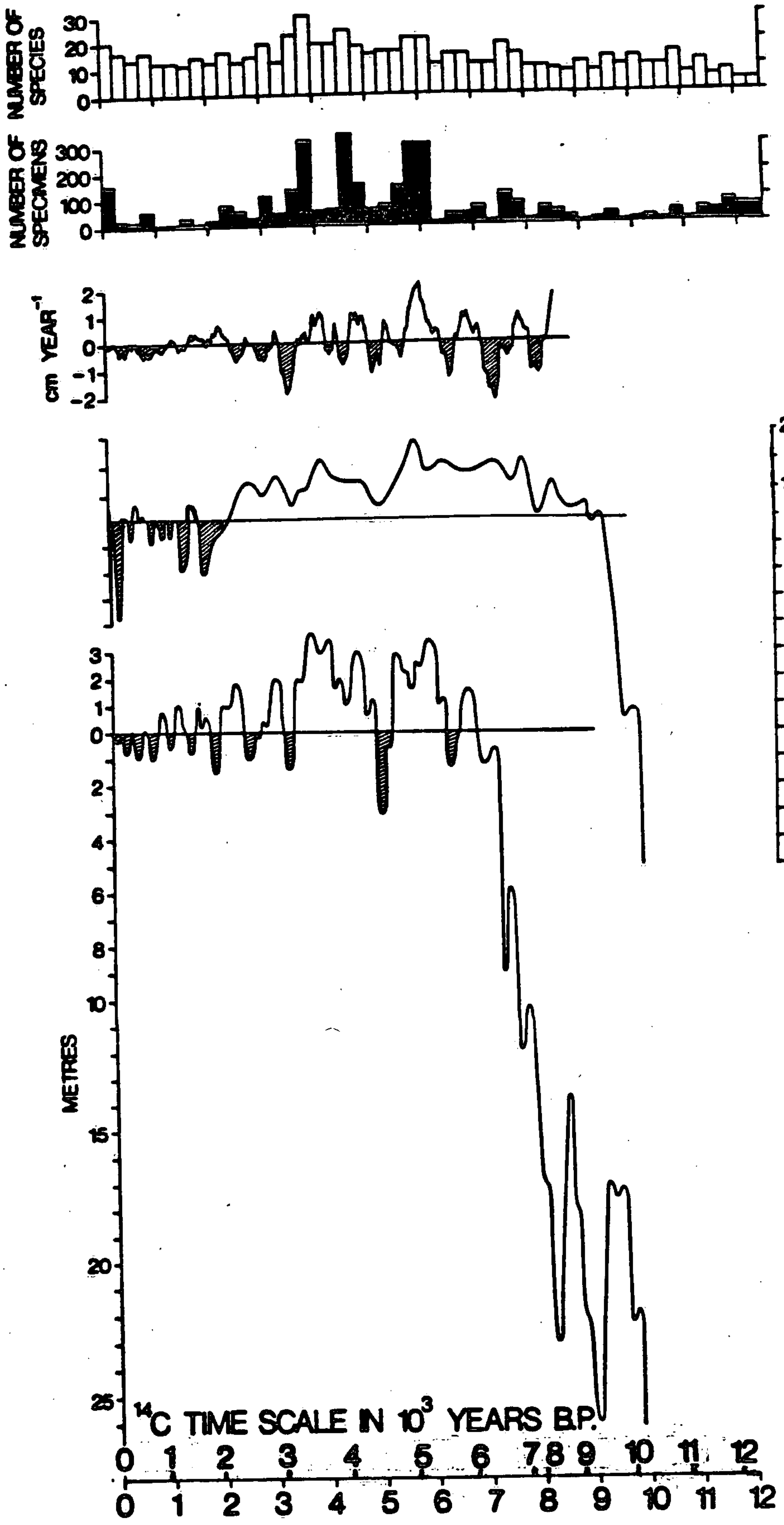
B) Specimen abundance of the mollusc population from limnic sediment of the Pelee Shoal in Lake Erie during the last 12,500 years. (This paper). Abundance is expressed as total number of specimens of mollusca per unit area 60 cm^2 per unit time interval 250 years.

C) The rate of sea level rise and fall as determined by M. Claude-Hillaire (1976) from the surveyed and dated set of 185 uniformly spaced, isostatically emerged and uplifted beach ridges on the eastern coast of Hudson Bay, Quebec, Canada. The highest (315 m a.s.l.) and oldest beach carries a date 8,300 sidereal years. This datum corresponds to the time interval when the Tyrrell Sea began to appear as a result of deglaciation of the Hudson Bay during the Flandrian (Holocene) Transgression.

The regular spacing of the beach ridges suggest a 45 year rhythmic cyclicity patterns of high tides, inreased wave action and long shore drift as the result of enhancing effect of the westerly storm tracks reaching the Hudson Bay, as far as Ungawa Bay. The isostatic variability relative to Hudson Bay, with approximative crustal rise, from at present 1.1 cm per yr^{-1} to as much as 5-10 cm per yr^{-1} around 7,000 to 8,000 years ago was removed from the record, to show eustatic (glacieustatic) oscillations.

D) N.A. Mörner's summer water temperature record based on a 5.5 m long sediment core obtained from Lake Tingstäge Träsk on the Island of Götland in the Baltic Sea, Sweden with gyttja and marl sequence. One of the most detailed and well dated summer water temperature curve that covers the last 10,700 years. The temperature departs from the present temperature of the lake (17°C) and fluctuates only within a few degrees, but the cold and warm peaks are at the corresponding chronological levels as Scandinavian eustatic regression and transgression maxima and known worldwide warm and cold climatic events. The temperature curve was obtained by conversion of ^{18}O curve through the relation between oxygen isotope composition and measured lake water temperature in °C. Conversion of the depth to absolute age was possible through numerous identified levels in the pollen zonation, in the paleomagnetic and ^{18}O records of the core.

E) The wellknown R. Fairbridge eustatic curve of global oceanic transgression and regression maxima correlated with climatic warmings and coolings obtained from a statistical summation of data on beach ridges, inter-tidal facies and corals in growth positions dated by 14 C. method. The curve in its original form was published in 1961 and later adjusted to sidereal year time scale (R. Fairbridge, 1976). It is in this adjusted form that it is used in this paper.


NUMBER OF SPECIES
30
20
10
0
NUMBER OF SPECIMENS
300
200
100
0
cm YEAR^{-1}
2
1
0
-1
-2
20
18
16
14
12
10
8
6
4
TEMPERATURE (°C)
3
2
1
0
2
4
6
8
10
15
20
25
METRES
^{14}C TIME SCALE IN 10^3 YEARS B.P.
0 1 2 3 4 5 6 7 8 9 10 11 12
0 1 2 3 4 5 6 7 8 9 10 11 12
TIME IN 10^3 SIDEREAL YEARS B.P.