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CONTENTS PAGE

IMPROVED METHODS FOR CULTURING THE SUBSPECIES OF *ONCOMELANIA HUPENSIS*: THE SNAIL HOSTS OF *SCHISTOSOMA JAPONICUM*, THE ORIENTAL HUMAN BLOOD FLUKE

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CONTENTS

LIST OF FIGURES

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INTRODUCTION

The several subspecies of *Oncomelania hupensis*, an amphibious snail in Southeast Asia, are very important to parasitologists because they are the intermediate hosts of *Schistosoma japonicum*, the Oriental human blood fluke. In 1959, the WHO Chronicle reported that 33 million people in that region were infected with *S. japonicum*, and that 1,700 American soldiers became afflicted during the second World War. When this situation was recognized as a major health problem, researchers in the United States (*e. g.*, Ward *et al.*, 1947; Bauman *et al.*, 1948; DeWitt, 1952) attempted to culture several subspecies of *O. hupensis* in order to enable further studies on the parasite. The importance of such research to the United States was increased when NIH laboratory-reared *Pomatiopsis lapidaria*, a close relative of *O. h. hupensis* but found in the eastern half of the United States, was successfully exposed to *Schistosoma japonicum* and cercariae emerged from the intermediate host (Berry and Rue, 1948).

Davis (1969) reported five distinct subspecies of *O. hupensis*, which are now isolated in the following four geographical regions: *O. h. hupensis* (China), *O. h. nosophora* (Japan), *O. h. quadrasi* (Philippines), *O. h. formosana* (Formosa) and *O. h. chiui* (also in Formosa). He also reported that the susceptibility of each of these subspecies is remarkably specific to the geographical 'strains' of *S. japonicum*. In interpreting data obtained from these cultures, genetics, morphology, ecology and geographical distribution of the snails are important, and appear to be related to discrepancies observed in the culturing of the various subspecies.

For several decades, investigators have attempted to culture *Oncomelania* in various kinds of vivaria. However, they have failed to produce these snails in numbers sufficient to provide material for extensive research programs involving the *S. japonicum* cycle. Experimental studies of *S. japonicum* thus, have lagged far behind those of the other two widely distributed human schistosomes, *S. mansoni* and *S. haematobium* (Davis and Iwamoto, 1969). Among the many reasons for such a lag are:

1. The prepatent period of *S. japonicum* in the *Oncomelania* snail is three months; this same period is only about one month in the pulmonate snails *Biomphalaria* and *Bulinus* that carry *S. mansoni* and *S. haematobium*, respectively.
2. To raise *Oncomelania* from the egg to sexual maturity requires about three months; the pulmonate snails can be raised in about one month.
3. Egg-laying for *Oncomelania* snails is not continual; quite often the process appears seasonal (van der Schalie, 1970).
4. Susceptibility of *Oncomelania* to the various strains of *S. japonicum* is usually quite low, so that the average ranges between 20 and 40% (van der Schalie, 1972).

The foregoing differences indicate that large numbers of snails must be made available for any thoroughly basic research program involving the *S. japonicum* cycle.

The vivaria used for culturing *Oncomelania* have been quite diverse. In studying the biology of *O. h. nosophora*, Sugiura (1933) discovered the first laboratory-laid eggs in a large, tall, clay flowerpot half-filled with damp soil and placed in the ground under a sheltering roof. Ward *et al.* (1947), Vogel (1948), and DeWitt (1952) all used aquaria supplied with various substrate--soil, sand, gravel, sticks and vegetation arranged as similarly as possible to conditions found in the natural habitat of *Oncomelania*. These vivaria were called, by DeWitt, aquaterraria; Bauman, *et al.* (1948) tested with battery jars in a like manner.

In the late 1950's the snails were placed in various culture dishes containing mud, sand, and gravel, but they were smaller and shallower than those used earlier. Surprisingly, in the smaller dishes, more eggs were laid. Wagner and Wong (1956), and Wagner and Chi (1959) initiated a clay flowerpot culturing method, using lots 5 to 6 in. diam. and 1.25 in to 1.75 in. high. About the same time, Komiya *et al.* (1959) introduced a breeding technique using standard Petri dishes. Moose and Williams (1961-1962) raised these snails in molded plastic trays (9 in. X 24 in. X 3.5 in.) the type often used by florists.

Studies in the Mollusk Division of the University of Michigan by van der Schalie and Davis (1968), using the vivarium types of early investigators, were undertaken to determine: (1) mortality of snails initially received; (2) productivity of young per female per month; and (3) survivorship and growth rate of the young. They found that the 'medium clay pots' (5 X 1.5 in.) were best both for adult survivorship and egg-laying; also Petri dishes (9 cm X 2 cm) were best for rearing young to maturity. Aquaria and battery jars, mostly 10 in. or more tall, were very poor since the snails tended to climb out of the water and become dehydrated and die when they were stuck to the glass walls. Plastic trays (11 X 7.5 X 2.5 in.) were considered 'intermediate' in comparison with tall and shallow cultures. The studies by van der Schalie and Davis failed to mention the apparent importance of the height of vivaria in making the environmental conditions most favorable for *Oncomelania* for producing offspring and for their survival.

With the above factors in mind, van der Schalie and Davis developed a method presently recommended for culturing *Oncomelania*. It involves the following important steps for rearing these snails to maturity:

1. Periodic collecting of the newly-hatched young from the breeding cultures;
2. Isolating limited numbers of young in individual growth cultures until the snails reach maturity, usually in about 8 weeks;
3. Harvesting the mature snails from the growth cultures and putting them into holding cultures for use in the *S. japonicum* cycle programs, or for selecting animals for additional breeding.

By using the methods developed by van der Schalie and Davis, Davis and Iwamoto (1969) found that the fecundity of the *Oncomelania* snails reared in the 406 Army Medical Laboratory in Japan was much lower than that recorded for the snails reared in Michigan. They stated that the greatest variable and only difference in their culture method was the origin and type of soil they used. The soil used in the Mollusk Division laboratory (obtained from a *Pomatiopsis* site) was rich in organic matter and diatoms needed as food for *Oncomelania*. Davis (1971) tried to use food additives and he also added chemicals to the soil in his cultures. He did manage to improve the fecundity of his laboratory-reared *Oncomelania*, but failed to surpass the records obtained in the snails cultured in the Mollusk Division at Ann Arbor. Davis reasoned that the microchemistry of the soil is important in relation to growth, maturation, survival and fecundity of the *Oncomelania* snails.

Studies presented herein show marked improvements which now enable culturing all of the geographic races of *Oncomelania* at a high productive rate (approximately 500 of each subspecies per month). These improvements are based on the studies of van der Schalie and Davis (1968). Details of the newer culture methods will appear elsewhere. The data that follow represent information from four experiments which show the importance of both the arrangement and the area of the mud surface in relation to the fecundity and growth of *Oncomelania* snails. The context of the four experiments was as follows:

Experiment 1. Methods for producing large numbers of young

Experiment 2. Methods for rearing young to maturity

Experiment 3. Improving cultures with food additives

Experiment 4. Evaluating the effect of different areas of mud surface on fecundity of laboratory-reared *O. h. nosophora*.

EXPERIMENT 1: METHODS FOR PRODUCING LARGE NUMBERS OF YOUNG

The 'medium clay pots' recommended for producing young of *Oncomelania* (van der Schalie and Davis, 1968) presented considerable maintenance difficulties. To maintain the water level and to avoid excessive evaporation through the porous walls, the pots had to be set in trays half-filled with water. The water in the outer tray quickly became contaminated with algae and fungi, which had to be scraped off the saucer walls regularly. Davis and Iwamoto (1969) stressed that Petri dishes provided with mud mounds were more effective than the clay pots, maintenance-wise, since one could handle and wash the Petri dishes more easily. Also, each dish required less shelf area; more cultures could be established in the available space.

To test the prospects for further improving the culture methods, each of the five subspecies of *Oncomelania hupensis* was tested in four different groups of vivaria, as follows:

1. Petri dishes with centrally placed mud mounds (control)
2. Petri dishes with peripherally placed mud rings
3. Plastic containers with centrally placed mud mounds
4. Plastic containers with peripherally placed mud rings

In the case of *O. h. hupensis*, the largest of the subspecies, medium clay pots were substituted for Petri dishes, since experience in the Mollusk Division Laboratory showed that this subspecies reproduced very poorly, probably due to the crowding effect which occurred in the smaller dishes.

The Petri-dish-with-mud-mound technique was similar to that used by van der Schalie and Davis (1965), except that it did not use filter paper. Also, another innovation was the installation of an erosion-preventing device called the plastic strap ring. These rings were made by cutting a clear acrylic sheet into thin straps and fusing the ends together with a hot spatula heated over flame. Such strap rings were used in all of the vivarium groups tested. They were placed in the center of the culture dishes and they served to hold the mud, arranged either in or around them.

A mud mound was prepared by placing a small lump of mud in the center of a vivarium and stretching it to the diameter of the strap ring by stroking the mud with a spatula to form a smooth, solid surface. In contrast, to prepare a peripheral mud ring, a large lump of mud was placed in the vivarium outside the centrally placed strap ring and again, worked with a spatula to form a smooth, solid surface sloping downward from the top edge of the vivarium to the top edge of the strap ring (see Fig. 1). The ring offered a greater mud surface area than that of a mound in the center of such a vivarium. The plastic containers used were the sour cream or liver containers as commonly encountered in supermarkets. The description and dimensions of these vivaria are shown in Table 1.

The mud for all vivaria was obtained from Raisin River, some thirty miles west-southwest of Ann Arbor, the habitat of *Pomatiopsis cincinnatiensis*, an amphibious, hydrobiid snail related to *Oncomelania*. Its microchemistry was described by van der Schalie and Davis (1965). The mud for the present study was heated in an oven at 80° C for 6 to 8 hours per day for three consecutive days instead of only one day (as in van der Schalie and Davis, 1965) to eliminate unwanted organisms such as annelids, alga spores and other potential pests.

Each of the vivaria, in groups of five, was populated with three females and three males. All snails used initially in this experiment were three months old, except *O. h. quadrasi*, for which eight-week old adults were used. It was discovered that at ten weeks of age *O. h. quadrasi* began to lay eggs. All snails were selected on the basis of development and maturity as indicated by the formation of a thickened varix-lip and a relatively large shell.

Small pieces of algal mat (a mixture containing among others, *Fischerella* sp., *Nostoc* sp. and *Schizothrix* sp.) were added to the cultures as food (Liang, 1974). These culture dishes were filled to the top of the strap rings with well-aerated tap water and were kept on shelves under a twelve-hour cycled (40 watt, white, cool, 100-150 foot candles) fluorescent light. The light tubes were 15 cm above the cultures and room temperature was maintained at 24° ± 1° C.

The recovery of newly hatched snails and dead adults of each of the subspecies was accomplished routinely, at bi-weekly intervals, over a period of one year. Live adults were added to the cultures to replace the dead adults of the same sex. All young were carefully removed from the cultures, with a pair of fine forceps. Both the number of the young collected and the mortality of the adults were recorded. Wwter was changed and fresh food was added to the culturrs, as needed.

Average productivity of each vivarium group was measured in terms of young produced per female per two weeks (y/f/biwk) and calculated from the number of young recovered from the parental culture, not from the number of eggs laid. To obtain the average young production rate of each vivarium group (as shown in Table 2) the total number of young recovered was divided by a multiple of fifteen females and twenty-six biweeks (each five-dish vivarium group contained fifteen females; twenty-six biweekly periods equal one year).

According to an analysis of variance (Table 14) there are significant differences in the young production of *Oncomelania hupensis* subspecies as affected by the vivarium types. Evidently, in both the Petri dishes and plastic containers the mud rings were more suitable for young production than the mud mounds (Table 2). *O. h. quadrasi*, *O. h. formosana*, and *O. h. chiui* yielded the highest total young collection in one year; 4,796, 3,354, and 2,622, respectively, in the plastic-container with mud-ring group. The second highest collection (3,190; 1,695; and 1,285 young) was in the Petri-dish with mud-ring group. In the control group, however, production of young was less than 1,000 per year. There is an apparent relationship between the young production and the increased mud surface area, which is emphasized by the most productive group. Here, the total young collection per two weeks skyrocketed to maximum peaks of 503 - *O. h. quadrasi*, 492 - *O. h. formosana*, and 262 *O. h. chiui*, a few weeks after the first eggs were laid (Figs. 2-7). The rate remained above 10 y/f/biwk for at least five continuous months. In contrast, in the Petri-dish with mud-ring group, only *O. h. quadrasi* maintained a rate over 10 y/f/biwk for as much as two continuous months.

The young production of all *Oncomelania* subspecies, except *O. h. nosophora*, correlates positively with the mud surface area (Fig. 7 and Table 3).

The positive correlation in these cultures indicates a favorable arrangement, which provides conditions needed for reproduction. Perhaps two factors should be considered. First increasing the mud surface area, in this case, increases the quantity of mud used in the culture and thereby provides nutrients needed by algae and diatoms growing on the mud surface. *Oncomelania* have been maintained solely on mud without adding supplementary food, as this mud supported an abundance of diatoms and algae (van der Schalie and Davis, 1965; 1968). In contrast, diatoms had to be used as a food additive to increase the fecundity of *Oncomelania* reared in Japan on a significantly poorer mud substrate (Davis and Werner, 1970). It appears that the nutrients in the mud kept the algae and diatoms growing continuously in the foregoing efforts. Secondly, in their reproductive behavior the *Oncomelania* tend to lay eggs in the mud above the water level. The mud ring offers a larger area that is suitable for egg laying than does the mud mound. On the mud ring, the females were observed to lay the majority of their eggs all along the perimeter of the vivarium, at a considerable distance from the water. Such a favorable region in the mud mound is at the apex, and is obviously limited in both area and distance from the water surface (Table 1). Consequently, only a number of eggs could be laid in the mud. The occurrence of eggs laid in or at the water surface was more common in the vivaria with mud mounds. However, the total number of young collected (Table 2) gives evidence that this situation is not preferable.

Production of *O. h. hupensis* and *O. h. nosophora* was affected by high mortality among the first set of adults used in the plastic-containers with mud-ring cultures. There is also the possibility that stunted adults replaced the dead ones. Stunting, as induced by crowding, has produced minute shells and gonads that did not mature (van der Schalie and Davis, 1965). In my experiment the surviving *O. h. hupensis* adults which replaced the specimens that had died (in plastic containers with the mud rings), were much smaller than their predecessors; some did not have the varix lip which serves as evidence of maturity. No eggs were found in these cultures.

Also, the foregoing two subspecies are more seasonal in their breeding habits than the other subspecies (van der Schalie, 1970). Since this experiment was started in September, 1970, *O. h. hupensis* eggs did not hatch until February, 1971 (Fig. 5). In the clay pots with mud rings, the biweekly total young collection soared to a maximum of 382 in two months. It is interesting that more young continued to be produced after the one-year experimental period, so that the total young produced in a one-and-one-half year period in these containers was 4,042—almost double that at one year (Table 2). There were two peaks in the production of young among the *O. h. nosophora* which occurred during spring and fall, 1971 (Fig. 6).

The first trial with *O. h. nosophora* was incomplete and discontinued, because live adults were unavailable for replacing those that died; a second trial could not be started for several months, until enough adults were available. Only the results of the second trial with this subspecies are reported here. A new method for preparing mud for these cultures (discussed later in this section) improved the survival of the second trial of *O. h. nosophora* in the plastic containers with mud rings. Therefore, it is not possible directly to compare the mortality of *O. h. nosophora* with the other subspecies. An analysis of variance showed that there are significant differences between the adult mortalities and the vivarium groups in which they were isolated (exception: mortality of *O. h. nosophora* adults showed no significant difference) (Table 15). However, there is no significant difference between male and female mortalities for most of the subspecies (exception: *O. h. quadrasi* - more females died than did males) (Table 15).

At the start of the experimental year, in both the Petri dishes and plastic containers, the mud rings appeared to cause higher adult mortalities than did the containers with mud mounds. The mortality rate, however, decreased appreciably as the year continued (Table 4). Vivaria with mud mounds have a smaller volume of mud than water, but the opposite is true for the vivaria with mud rings. It appears that the freshly prepared ('cooked') mud produced an anaerobic condition, which consumed most of the oxygen in the water reservoir of the vivaria with mud rings. This condition was indicated in the way the snails closed their opercula and remained inactive. Regrettably, measurements of dissolved oxygen were not made.

A small, special experiment was undertaken to attempt to reduce adult mortalities by maintaining freshly prepared plastic containers with mud rings provided with algae and water for known periods before introducing the breeding snails to the culture. Five vivaria groups (inoculated with algae) were established, as follows: (1) one hour (control); (2) one day; (3) three days; (4) five days; and (5) seven days. Each of these age cultural groups contained ten vivaria with ten adult *O. h. formosana* per vivarium. As indicated (Fig. 8), total mortalities appeared in the control and in one-day-old vivaria with mud-rings, whereas there was more than 90 per cent adult survival in the vivaria which were one week old. As suspected, much dissolved oxygen appeared to be consumed in the water by the chemical properties of the baked mud used and the adult snails were again observed to have closed their opercula and they did not move around in the control and the day-old vivaria. Another experiment was then set up, similar to the first, except that the method of preparing the mud was modified. It was dried completely after three consecutive bakings, crumbled into pieces, and allowed to oxidize in air for two weeks. This new method greatly improved adult survival as compared to the usual method (Fig. 9). Upon using mud prepared by the latter method, the second trial of *O. h. nosophora* in the plastic containers with mud-rings showed the lowest first-month mortality for this vivarium group for all subspecies (Table 4). It is to be noted that this mud surface area was slightly less than those specified in Table 1.

EXPERIMENT 2: METHODS FOR REARING YOUNG ONCOMELANIA TO MATURITY

In terms of time required and number of snails that can be isolated in each vivarium, the raising of young snails to maturity with efficient methods is of utmost importance. The data in Experiment 1 show that increasing the mud surface area will markedly increase productivity of *Oncomelania*. Experiment 2 was established to explore the effect of an increase in the mud surface area on the growth of the snails.

The generally accepted time for the young snails to reach maturity in laboratory culture is eight weeks (van der Schalie and Davis, 1965). The growth rate during this time is variable, depending on culture conditions used, subspecies studied, and frequency of measurements; consequently, no direct comparison can be made with any of the growth rates reported: 0.2 to 0.4 mm/wk (Chi and Wagner, 1957); 0.3 mm/wk (Komiya and Kojima, 1961); 0.65 mm/wk (van der Schalie and Davis, 1965). Also, of considerable importance is the stunting of growth and development, caused by crowding snails in the rearing cultures (van der Schalie and Davis, 1965). Culturing these snails is clearly limited by conditions that regulate their growth.

Since young *Oncomelania* spend most of their early life in water (van der Schalie and Getz, 1963), only containers with mud mounds were used; also the volume of w ter available in the cultures with mud rings appears to be insufficient for these snails. Newly isolated young of all five subspecies were reared to maturity for 8 weeks in two vivarium types: Petri dishes with mud mounds and plastic containers with mud mounds. The clear plastic containers were approximately the same diameter as the Petri dishes, but their sides were twice as high; hence, the mud mounds in these containers were also considerably larger (Fig. 10).

For each subspecies, except *O. h. hupensis*, five groups of a total of 25 vivaria each were established, as follows:

a. Petri dish without mud--5 young per vivarium--control
b. Petri dish with mud mound--5 young per vivarium--additional control
c. Clear plastic container with mud mound--5 young per vivarium
d. Same as c, but 10 young per vivarium
e. Same as c, but 15 young per vivarium

Since it was very difficult to obtain sufficient numbers of *O. h. hupensis* young, it was run only in groups b, c, and d

The Petri dishes with mud mounds were the same as those used by van der Schalie and Davis (1965), except that filter papers were not used. The mounds in these dishes were 6 cm X 1.5 cm, but, larger mud mounds (8 cm X 3 cm covered the entire bottom in the clear plastic containers (Fig. 10). Each plastic container was covered with Saran wrap, stretched smooth and held in place by a rubber band. This cover was perforated with numerous small pinholes to reduce the heavy condensation of water on the undersurface. Three weeks prior to the introduction of young, diatoms were introduced to the culture dishes, except in the Petri dishes without mud to which only algae were added when the young were isolated. All of the dishes were filled with aerated tap water to 1 centimeter below the covers. As indicated, the newly isolated young (shell height: 1-2 mm) were introduced to these cultures three weeks after they had been inoculated with the diatoms. The cultures were kept on shelves under the twelve-hour cycled light; water levels were checked weekly, and more water added as necessary to maintain the starting level.

For all the subspecies tested, the young grew, matured and survived best when only five snails were reared in each plastic container (Tables 5-9). The amount of mud surface area per snail was greatest in this vivarium group than in any of the others. It is suspected that this ratio is a major factor in the rearing of *Oncomelania*. In contrast, the absence of mud in Petri-dish containers apparently caused the slowest growth and poorest survival among the young. An analysis of variance revealed significant differences between the shell heights of the snails and the vivarium groups used (Tables 16 and 17). Also, the shell heights correlate positively with the mud surfsce area per snail isolated in a given container (Table 10 and Fig. 10). This correlation is further evidenced if one considers the 'second-best' rearing arrangement. The smallest of the subspecies, *O. h. quadrasi*, (3.5 - 6.0 mm high), showed a greater degree of maturation when ten snails were cultured in the plastic container in contrast to the five snails per Petri dish (Table 5). *O. h. hupensis*, the largest subspecies (7.5 - 10.0 mm) tended toward the exact opposite relationship (Table 9). *O. h. formosana* (5.0 - 8.0 mm) displayed no real difference in either vivarium (Table 7).

In general, between the sexes for each subspecies, there is no significant difference in the shell length, except *O. h. formosana* and *O. h. quadrasi* where females are larger than males (Table 18). An accurate statement relating the size of the subspecies and growth rate cannot be made, since the specimens were measured only once, at the end of the eight-week period. The smaller snails appear to have a 'slower' growth rate during this time than the larger ones (Tables 5-9). It is likely that the smaller subspecies (*O. h. quadrasi* and *O. h. chiui*) grew to maturity more quickly, as evidenced by the highest percentage to reach maturity, and a 'flat' average growth rate for all vivarium groups (Tables 11-12).

The stunting effect of crowding (like that reported by van der Schalie and Davis, 1965) was clearly evident when the number of snails per culture was increased beyond the apparently critical level. Noticeable dwarfing was obtained in the cultures with ten and fifteen snails per plastic container and is especially evident in the *O. h. hupensis*, *O. h. nosophora*, and *O. h. chiui* cultures. In some vivaria, less than half of the snails in the 10-per-container vivaria reached maturity as compared with those with 5 snails per container (Tables 5-9). Since *O. h. quadrasi* and *O. h. chiui* are approximately the same size, it seems difficult to attribute a size reduction in terms of available food as a major factor in producing stunting. It is generally conceded that there must be several unknown factors responsible for slowing down the growth rate of *O. h. chiui*.

In all of these test groups there was a remarkably high survival rate, which was consistently better than 75%. In contrast, van der Schalie and Davis (1965) in two experiments designed to raise young, obtained 64% and 72% respectively, with the *O. h. formosana* when cultured in Petri dishes with 10 snails per dish.

EXPERIMENT 3: IMPROVING CULTURES WITH FOOD ADDITIVES

The nutrient-rich mud used as a substrate for culturing *Oncomelania* (Experiment 1) successfully encouraged high fecundity. It supports a continual growth of algae and diatoms, the natural foods of the snails (Komiya *et al.* 1960; Dazo and Moreno, 1962). Natural and artificial food additives have been studied by several investigators, often in an effort to improve the fecundity of these snails. Rice cereal added to Petri dishes with mud mounds was thought to produce favorable results (Moose *et al.*, 1962). However, in testing diatoms, rice powder, and wheat germ, the diatoms were considered best as food-supplements for improving fecundity in *O. h. nosophora* (Davis, 1971).

Experiment 3 was established to determine the effects of food additives on the production of young in culture arrangements that were shown most promising, namely the plastic containers with mud ring. Only *O. h. nosophora*, the subspecies most often used by researchers, was used in this experiment. It was impossible to test the other subspecies due to a lack of time and the enormous amount of labor involved.

Altogether 120 largest three-month-old *O. h. nosophora*, with well-developed varix lips, were selected from a large supply pool. Then, twenty plastic containers with mud rings were established and inoculated with algae for two weeks before the adults were introduced into those cultures. The containers were then divided into four equal groups with three females and three males per container, and fed as follows:

1. Algae
2. Wheat-germ
3. Rice cereal (in the form of baby food manufactured by Gerber Products Co., Fremont, Mich. U.S.A.).
4. Combined ration using all three food additives

Since adult shells void undigested diatoms in their feces (van der Schalie and Davis, 1965), diatoms were not tested as additives. Within a month diatoms grew rapidly and spread throughout all cultures. Nevertheless, diatoms are recognized as a basic food of *Oncomelania*. All algal mats were removed from the groups fed algae and rice cereal before adult snails were introduced into the culture; the processed food additives were put into the cultures including the combined-food group. All young snails were removed biweekly and records were maintained on the number of young and of dead adults removed; dead specimens were not replaced. Rice cereal and wheat germ were added to the cultures every two weeks but the algae were added only as needed or when the adults had consumed the algae supplied. The data collected covered a period of one year.

The highest average in production of young appeared in the algae-fed group; the next highest was in the combined-food-fed group (Table 11). Averages higher than 500 young were collected in one year in three containers of the algae-fed group (i.e., 615, 562, and 504); but only one such (675) appeared in the combined-food-fed group.

In the group fed on ground wheat germ a foul odor of decomposition developed in two days. When wheat germ particles became swollen by absorption of water they were removed from the culture. The odor was avoided by grinding the wheat germ more finely with a mortar and pestle; it was then spread thinly over the mud surface. The abundance of food on the mud rings encouraged the rapid bacterial breakdown in the culture, which probably was the cause of the high adult mortalities. Whereas the rice cereal did not emit an odor, it did form a stone-like crust on the mud surface.

After the first 3 months, the production of young dropped to zero in the wheat germ group. Thick algal mats covered the mud surfaces above the water levels. When they were removed from the culture, numerous dead young were found beneath them. The algae grew fast, presumably due to the decomposition of the processed food, and it overgrew and trapped the young. A similar condition that reduced the number of young occurred with the overgrowth of algae in some of the containers with rice cereal and those with the combined food. Removing these algal mats usually brought a recovery of productive conditions favoring the young. The one vivarium among the combined-food fed group which had the greatest production of young did not develop a thick algal mat; the adults may have kept it clean by browsing to account for its success.

According to the analysis of variance (Tables 19 and 20) there is no significant difference in either fecundity or adult mortality of *O. h. nosophora* as affected by food additives.

EXPERIMENT 4: EVALUATING THE EFFECT OF DIFFERENT AREAS OF MUD SURFACE ON FECUNDITY OF LABORATORY-REARED O. H. NOSOPHORA

It was of interest that the fecundity of the *O. h. nosophora* in Experiment 3 was greater than that of their parents in Experiment 1. Laboratory-reared individuals of *O. h. nosophora* often can be less fecund and vigorous than field-collected specimens (Davis, 1971). This difference may be due both to microchemistry and to the diatom flora of the soil as important factors in relation to growth, maturation, survival, and fecundity. This experiment was conducted to determine whether the methods used in Experiment 1 and 2, but with increased mud surfaces, would make the fecundity of laboratory-reared snails surpass that of field-collected ones.

Four rearing groups consisting of 8 vivaria each were established, as follows:

1. Regular Petri dishes with mud mounds --5 young/vivarium
2. Plastic containers with mud mounds (same as in Experiment 2)--5 young/vivarium
3. Same as *2, but 10 young/vivarium
4. Larger plastic containers (11 cm X 4.5 cm) with mud mounds (10 cm X 3 cm) -- 5 young/vivarium

Routine maintenance and measurement of snails after an eight-week isolation in the rearing cultures was undertaken in the same way as in Experiment 2. After measuring, nine females and nine males with the largest shell heights and greatest number of the whorls were selected from each rearing group. They were then transferred to three freshly prepared plastic containers with mud rings; three females and three males were cultured in each container for six months. All young were removed biweekly and the number of young produced and of adult mortality, recorded.

There are significant differences between the shell heights of the snails when they are removed from the rearing culture (Tables 21 & 22). Also, the shell heights correlate positively with the mud surface area per snail. The coefficient of linear correlation, γ, of the females is 0.25; γ of the males is 0.38. Both γ-values are significant. There is no significant difference in the survival rate (Table 23).

The young grew, matured, and survived best in the large plastic containers (Table 12) indicating, once again, the importance of a large mud-surface-area for rearing young to maturity. They were about three months old when transferred to the breeding cultures, as this subspecies has been known to begin laying the first eggs at the age of four months. Surprisingly, when this transfer was made, as many as eighty eggs were found attached to the walls of some of the rearing cultures. It is possible that with this 'early' breeding, the snails were at such an advanced stage that their capacity to produce eggs in the breeding cultures was reduced, thereby yielding the second lowest young production (Table 13).

The snails, reared in the five-per-small-container group, were the second best in growth and maturity, but they suffered the highest mortality (Table 12). No eggs were found in these rearing cultures. However, in the breeding culture, these snails yielded the highest total young collection (Table 13). The young production of the large-container group might have surpassed or equalled that of the five-per-small containers, had there been no eggs laid 'prematurely.' It was impossible to count all the eggs laid by these snails, as many were buried and well camouflaged in the mud. Therefore, it is impossible to test for a significant difference.

The slowest growth, maturation, and poorest young collection was obtained from the crowded, ten-snail-per-small-container group (Tables 12-13).

There is no significant difference in the adult mortality in the breeding cultures (Table 24).

The fecundity in all these groups was greater than the highest observed by Davis (1971) among field-collected *O. h. nosophora* (13.7 y/f/m). Davis also added calcium carbonate to the soil, which increased fecundity among laboratory-reared *O. h. nosophora*. Nevertheless, he failed to surpass the fecundity found in the field-collected snails. His failure to increase fecundity of this laboratory snail was probably limited by the food available in the substrate since he used only ordinary Petri dishes with mud mounds. In fortifying soil with chemical additives, it would be advisable to use increased areas of substrate to test fecundity among *Oncomelania* snails.

SUMMARY

Rearing large numbers of *Oncomelania hupensis*, intermediate hosts for *Schistosoma japonicum*, is very difficult. This limitation has posed problems in maintaining the life cycle of this parasitic human blood fluke. The methods developed in this study were designed to enable culturing the five subspecies of *Oncomelania hupensis* in numbers approximating 500 snails of each subspecies per month. It was found that such a high production was possible only when the surface area of mud used in a vivarium was increased.

Peripheral mud rings, instead of the conventional central mud mounds, were used to increase the surface area per vivarium. As a result, more oncomelanid snails were reared. It was demonstrated that the production of young *Oncomelania*, except for *O. h. nosophora*, correlated positively with the mud surface area.

Plastic containers with mud rings proved to be the most productive culture method for *O. h. quadrasi*, *O. h. formosana*, and *O. h. chiui*. However, the largest number of offspring of *O. h. hupensis*, the largest subspecies, were produced in clay pots with mud rings because the clay pots were larger than the plastic containers. The rate of productivity of *O. h. hupensis* and *O. h. nosophora* on mud rings in the plastic containers remained uncertain, because all of the first breeding adults died; and adults replacing the dead ones were found to be smaller and less fecund than their predecessors.

Initially, extremely high mortality occurred in the plastic containers equipped with mud rings, because the freshly prepared substrate produced anaerobic conditions which were harmful to the snails. However, a special experiment demonstrated that adult mortality could be reduced when the mud in these containers was inoculated with algae for at least one week prior to the introduction of adults to the culture. Therefore, taking this precaution, the plastic containers with mud rings are recommended for breeding large numbers of *Oncomelania*.

While rearing young snails to adults, it was found that the snail shell height correlated positively with the mud surface area per snail. Young *Oncomelania* snails grew faster and larger, a greater percentage reached maturity, and showed better survival in plastic containers than in Petri dishes. The increased height of these containers made possible larger mud mounds than those in the Petri dishes. Furthermore, depending on the subspecies being isolated, the number of snails maintained successfully in such containers for eight-week periods could be increased from five up to fifteen per container.

In plastic containers with mud rings, algae appeared to serve better as food than processed food additives (wheat germ and rice cereal). However, some species of algae were harmful if allowed to form mats which trapped the young snails.

The last experiment demonstrated that the fecundity of laboratory-raised *O. h. nosophora* could be improved only when the snails were reared in a culture with an increased mud surface area per snail and then transferred to the recommended breeding culture. In this situation, the fecundity was increased to approximately 20 young per female per two weeks from a previous level of 7.3 young per female per month (van der Schalie & Davis, 1968).

The surface area and the arrangement of mud in a vivarium have been shown to be significant factors that must be considered in all steps of rearing *Oncomelania* in the laboratory, including the breeding of adults, rearing of young, and the subsequent fecundity of those young. Consequently, if one increases the surface area and uses mud rings and larger mud mounds, the production of these snails can be enhanced considerably.

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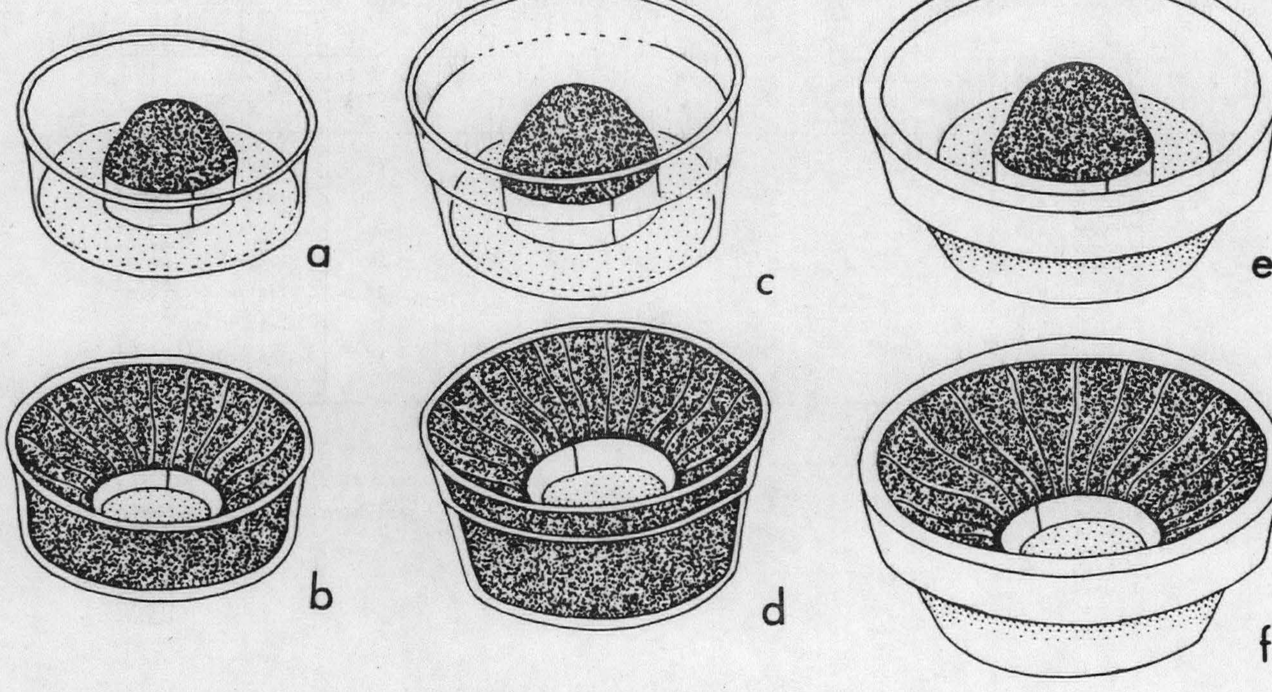

Fig. 1. Top view of vivaria used for producing *Oncomelania* young. -- A. Petri dish with mud mound; B. Petri dish with mud ring; C. Plastic container with mud mound; D. Plastic container with mud ring; E. Clay pot with mud mound; F. Clay pot with mud ring.

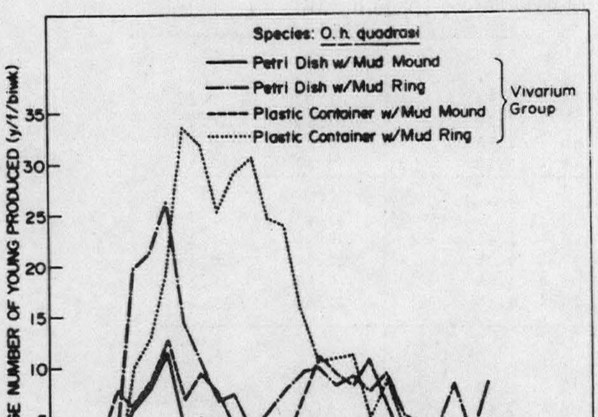

Fig. 2. Average number of Oncomelania hupensis quadrasi young produced biweekly per female (y/f/biwk) in four vivarium groups in one year.

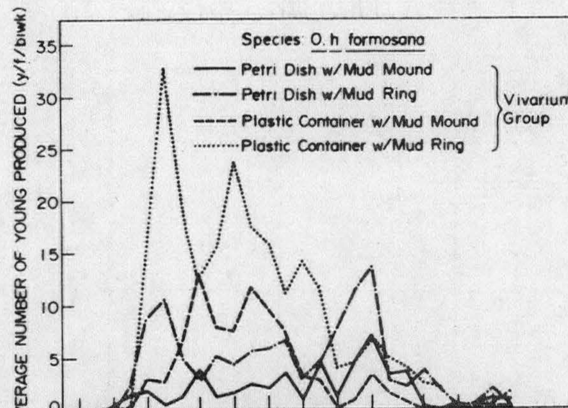

Fig. 3. Average number of Oncomelania hupensis formosana (Pu-yen) young produced biweekly per female (y/f/biwk) in four vivarium groups in one year.

Table 1. Descriptions of the Vivaria tested for producing large numbers of Oncomelania young.

Type of Vivarium	Dimensions in cm Diam.	He.	Dimensions of strap ring in cm Diam.	He.	Area of soil in cm^2	Maximum Depth of soil in cm	Water in Reservoir in cc	Vivarium Cover
PD-CM	9.0	2.0	4.5	0.5	16	1.5	25	Regular PD cover
PD-PR	9.0	2.0	4.5	0.5	50	1.8	8	Regular PD cover
PC-CM	11.0	4.0	5.8	0.5	27	2.0	50	Plastic lid cover
PC-PR	11.0	4.0	4.5	1.2	70	3.0	20	Plastic lid cover
PC-PR*	11.0	4.0	5.5	1.2	65	3.0	28	Plastic lid cover
CP-CM**	13.0	4.0	5.8	0.5	27	2.0	30	Glass plate
CP-PR**	13.0	4.0	5.8	0.5	100	3.0	15	Glass plate

* for the second trial of O. h. nosophora only

** for O. h. hupensis only

Vivarium Type: PD - Petri Dish

PC - Plastic Container

CP - Clay Pot

Soil type: CM - centrally placed mud mound

PR - peripherally placed mud ring

Table 2. Young of Oncomelania hupensis subspecies produced in Experiment 1.

Species & Vivarian Types	Total # of young collected in one year	Greatest # of young collected in one vivarium in one year	Average of young produced per female per biweek (y/f/biwk.)	Average of young collected per vivarium per biweek (y/viv/biwk.)	95% Condifence Limit Lower Level:	Upper Level:
O. h. hupensis						
CP-CM	359	215	0.92	2.76 ± 3.43	1.50	7.02
CP-PR	2544	859	6.52	19.57 ± 10.85	6.10	33.04
PC-CM	45	45	0.11	0.35 ± 0.77	0.00	1.31
PC-PR	No eggs or young were found in this type of vivarium.					
O. h. formosana						
PD-CM	724	252	1.86	5.57 ± 2.93	1.93	9.21
PD-PR	1695	522	4.35	13.04 ± 7.18	1.13	18.95
PC-CM	1248	419	3.20	9.60 ± 3.98	4.66	14.54
PC-PR	3354	1104	8.60	25.80 ± 13.13	9.50	42.10
O. h. quadrasi						
PD-CM	996	309	2.55	7.66 ± 2.42	4.66	10.66
PD-PR	3190	847	8.18	24.54 ± 9.35	12.94	36.14
PC-CM	1857	525	4.76	14.28 ± 3.88	9.46	19.10
PC-PR	4796	1635	12.30	36.89 ± 19.50	12.69	61.09
O. h. nosophora						
PD-CM	279	107	0.72	2.15 ± 1.48	0.31	3.99
PD-PR	517	178	1.33	3.98 ± 2.60	0.75	7.21
PC-CM	237	102	0.61	1.82 ± 1.28	0.23	3.41
PC-PR	301	262	0.77	2.32 ± 4.36	0.00	7.73
O. h. chiui						
PD-CM	785	236	2.01	6.04 ± 1.71	3.92	8.16
PD-PR	1285	433	3.29	9.88 ± 4.80	3.92	15.84
PC-CM	672	193	1.72	5.17 ± 1.42	3.41	6.93
PC-PR	2622	735	6.72	20.17 ± 7.68	10.64	29.70

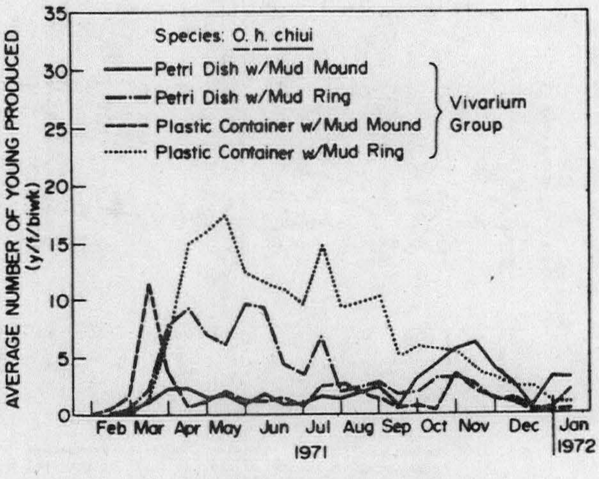

Fig. 4. Average number of Oncomelania hupensis chiui young produced biweekly per female (y/f/biwk) in four vivarium groups in one year.

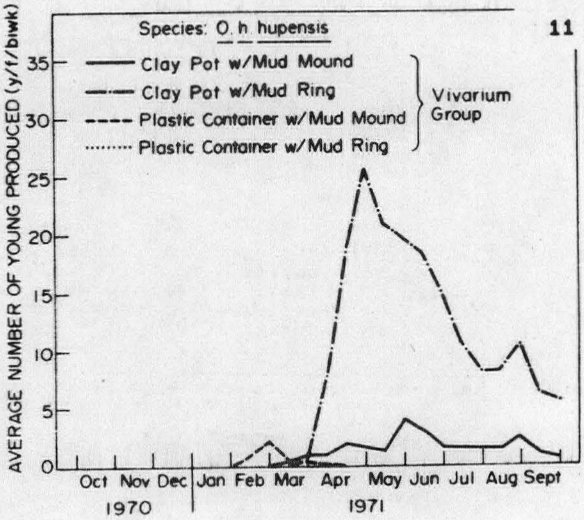

Fig. 5. Average number of Oncomelania hupensis hupensis young produced biweekly per female (y/f/biwk) in four vivarium groups in one year.

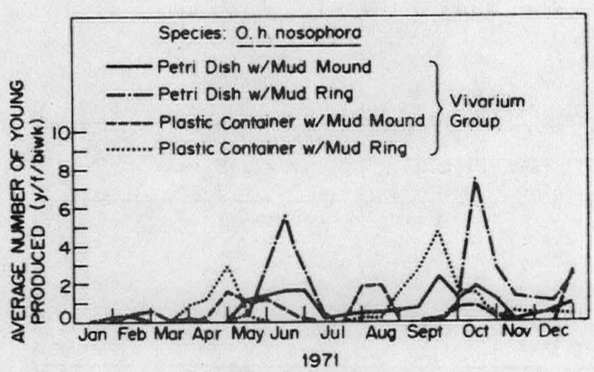

Fig. 6. Average number of Oncomelania hupensis nosophora young produced biweekly per female (y/f/biwk) in four vivarium groups in one year.

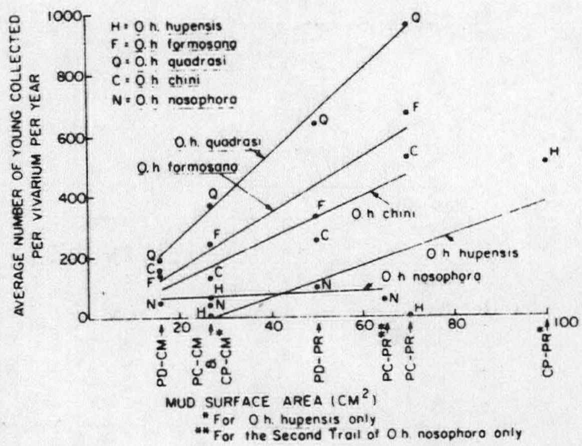

Fig. 7. Regression lines of Oncomelania hupensis subspecies fitted scatter diagram of average number of young collected per vivarium per year on mud surface area (cm^2)

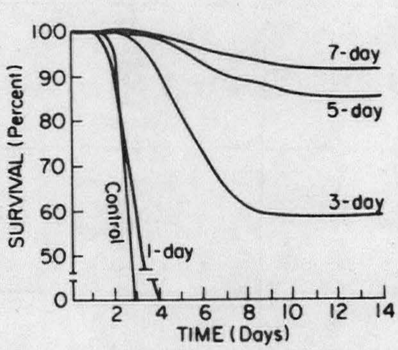

Fig. 8. Survival of adult O. h. nosophora in plastic containers with freshly prepared mud rings established for: 1 hour (control), 1, 3, 5, and 7 days before introducing the snails. The mud, prepared the standard way, was not completely dry before being used.

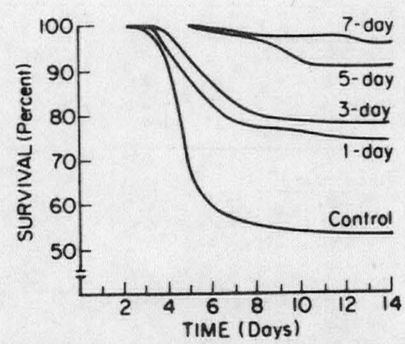

Fig. 9. Survival of adult O. h. nosophora in plastic containers with freshly constructed mud rings established for: 1 hour (control), 1, 3, 5 and 7 days before introducing the snails. Mud, baked 3 times, was thoroughly dried and was aerated for two weeks before being used.

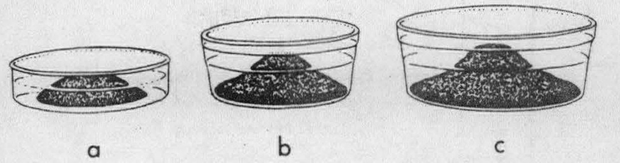

Fig. 10. Vivaria used for rearing *Oncomelania* young to maturity. A. Petri dish with mud mound. B. Plastic container with mud mound. C. Large plastic container with mud mound (used in Experiment 4).

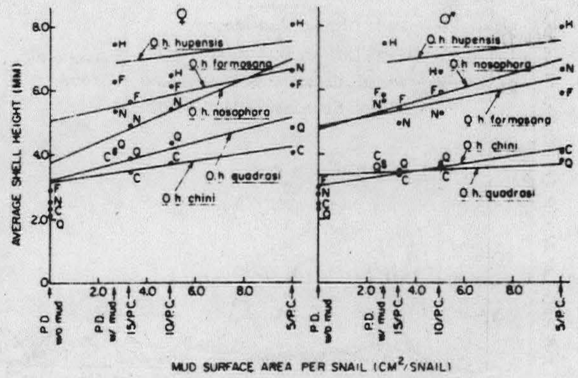

Fig. 11. Regression lines of Oncomelania hupensis subspecies fitted scatter diagram of average shell height (mm) on mud surface area per snail (cm²/snail).

TABLE 3. The coefficient of linear correlation (r) between the young production and the mud surface area

Species	Degrees of freedom	r	Conclusion
O. h. quadrasi	18	0.76	significant
O. h. formosana	18	0.70	"
O. h. chiui	18	0.76	"
O. h. hupensis	18	0.65	"
O. h. nosophora	18	0.13	not significant

The positive correlation in these cultures indicates a favorable arrange-

Table 4. Mortality Data

Species; Vivaria Types	Females 1st month	Females 11 last months	Females total in one year	Males 1st month	Males 11 last months	Males total in one year	Overall total
O. h. hupensis							
CP-CM	0	1	1	0	0	0	1
CP-PR	0	4	4	0	0	0	4
PC-CM	1	5	6	0	8	8	14
PC-PR	19	11	30	17	16	33	63
O. h. formosana							
PD-CM	4	27	31	1	27	28	59
PD-PR	11	26	37	13	23	36	73
PC-CM	1	25	26	1	18	19	45
PC-PR	21	25	46	23	19	42	88
O. h. quadrasi							
PD-CM	0	24	24	0	13	13	37
PD-PR	12	16	28	9	14	23	51
PC-CM	0	23	23	0	17	17	40
PC-PR	23	24	47	25	13	38	85
O. h. nosophora*							
PD-CM	1	24	25	0	29	29	54
PD-PR	2	32	34	2	26	28	62
PC-CM	1	32	33	0	25	25	58
PC-PR	5	20	25	5	17	22	47
O. h. chiui							
PC-CM	0	0	0	0	2	2	2
PD-PR	0	1	1	0	3	3	4
PC-CM	0	2	2	0	4	4	6
PC-PR	13	8	20	14	0	14	34

*This is the second trial of O. h. nosophora after the snails in the first trial were destroyed.

Table 5a. Vivaria tested for rearing O. h. quadrasi to maturity for 8 weeks in terms of survival rate, % of survived snails reaching maturity, average height, and average growth rate.

Vivaria types:	P.D. w/o mud	P.D. w/mud	5/P.C.	10/P.C.	15/P.C.
Survival rate (%):	46.4	80.8	88.0	77.2	90.4
% of survived snails reaching maturity:*					
Females	0.00	58.33	91.53	70.00	46.58
Males	0.00	86.79	92.15	92.47	77.20
Average height (mm):					
Females	2.13 ± 0.47	4.19 ± 0.77	4.83 ± 0.47	4.36 ± 0.60	3.88 ± 0.77
Males	2.32 ± 0.43	3.64 ± 0.49	3.79 ± 0.39	3.68 ± 0.28	3.48 ± 0.42
95% confidence limits (mm):					
Females	2.13 ± 0.20	4.19 ± 0.22	4.83 ± 0.12	4.36 ± 0.12	3.88 ± 0.13
Males	2.32 ± 0.17	3.64 ± 0.14	3.79 ± 0.11	3.68 ± 0.06	3.48 ± 0.06
Average growth rate in mm/wk:					
Females	0.02	0.27	0.35	0.30	0.24
Males	0.04	0.20	0.22	0.21	0.18

Abbreviations:

P.D. w/o mud - Petri dish without mud mound
P.D. w/mud - Petri dish with mud mound
5/ P.C. - 5 snails per plastic container
10/P.C. - 10 snails per plastic container
15/P.C. - 15 snails per plastic container

*Indicated by the presence of varix lip on the shell

Table 5b. Comparative (in terms of height (mm)) growth of O. h. quadrasi reared to maturity in the vivaria for 8 weeks. The number of snails is shown left of the parenthesis; percentage of the snails isolated in each vivarium group of each sex in the parenthesis.

Height (mm)	Petri dish without mud		Petri dish with mud		5 snails per container		10 snails per container		15 snails per container	
Sex:	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
6.0-6.4	---	---	---	---	1(1.7)	---	---	---	---	---
5.5-5.9	---	---	---	---	2(3.4)	---	---	---	---	---
5.0-5.4	---	---	5(10.4)	---	23(39.0)	---	17(17.0)	---	8(5.5)	---
4.5-4.9	---	---	18(37.5)	---	26(44.0)	1(2.0)	30(30.0)	---	29(19.9)	---
4.0-4.4	---	---	13(27.5)	16(30.2)	5(8.5)	17(33.3)	31(31.0)	16(17.2)	35(24.0)	27(14.0)
3.5-3.9	---	---	2(4.2)	24(45.2)	---	25(49.0)	11(11.0)	64(68.8)	29(19.9)	96(49.7)
3.0-3.4	---	2(5.9)	5(10.4)	7(13.2)	2(3.4)	7(13.7)	9(9.0)	11(11.8)	24(16.4)	52(26.9)
2.5-2.9	5(20.8)	15(44.1)	4(8.3)	3(5.7)	---	1(2.0)	1(1.0)	2(2.2)	16(10.9)	14(7.3)
2.0-2.4	9(37.5)	10(29.4)	1(2.1)	3(5.7)	---	---	1(1.0)	---	5(3.4)	3(1.6)
< 2.0	10(41.7)	7(20.6)	---	---	---	---	---	---	---	1(0.5)

Table 6a. Vivaria tested for rearing O. h. chiui to maturity for 8 weeks in terms of survival rate, % of survived snails reaching maturity, average height and average growth rate.

Vivaria types:	P.D. w/o mud	P.D. w/mud	5/P.C.	10/P.C.	15/P.C.
Survival rate (%):	40.0	88.0	85.6	88.0	84.8
% of survived snails reaching maturity:*					
Females	0.00	48.08	59.67	36.28	22.28
Males	0.00	44.83	64.44	45.79	32.89
Average height (mm):					
Females	2.32 ± 0.51	4.01 ± 0.77	4.09 ± 0.88	3.73 ± 0.85	3.49 ± 0.86
Males	2.43 ± 0.53	3.70 ± 0.62	4.06 ± 0.66	3.64 ± 0.80	3.41 ± 0.78
95% Confidence limit:					
Females	2.32 ± 0.19	4.01 ± 0.22	4.09 ± 0.22	3.73 ± 0.16	3.49 ± 0.13
Males	2.43 ± 0.25	3.70 ± 0.16	4.06 ± 0.20	3.64 ± 0.15	3.41 ± 0.13
Average growth rate in mm/wk:					
Females	0.04	0.25	0.26	0.22	0.19
Males	0.05	0.21	0.26	0.20	0.18

Abbreviations:

P.D. w/o mud - Petri dish without mud mound
P.D. w/mud - Petri dish with mud mound
5/P.C. - 5 snails per plastic container
10/P.C. - 10 snails per plastic container
15/P.C. - 15 snails per plastic container

*Indicated by the presence of varix lip on the shell

Table 6b. Comparative growth in terms of shell height (mm), of O. h. chiui reared to maturity in the vivaria for 8 weeks. The number of snails is shown left of the parenthesis; percentage of the snails isolated in each vivarium group of each sex in the parenthesis.

Height (mm)	Petri dish without mud		Petri dish with mud		5 snails per container		10 snails per container		15 snails per container	
Sex:	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
5.0-5.4	---	---	1(1.9)	---	4(6.5)	2(4.4)	7(6.2)	---	6(3.6)	1(0.7)
4.5-4.9	---	---	17(32.7)	9(15.6)	23(37.1)	7(15.6)	24(21.2)	20(18.7)	30(18.1)	11(7.2)
4.0-4.4	---	---	14(26.9)	16(27.6)	18(29.0)	25(55.6)	21(18.6)	27(25.2)	20(21.1)	42(27.6)
3.5-3.9	2(6.7)	1(5.0)	8(15.4)	12(20.7)	6(9.7)	4(8.9)	11(9.8)	16(15.0)	17(10.2)	15(9.9)
3.0-3.4	1(3.3)	2(10.0)	7(13.5)	10(17.2)	2(3.2)	3(6.7)	24(21.2)	18(16.8)	41(24.7)	34(22.3)
2.5-2.9	4(13.3)	5(25.0)	3(5.8)	11(19.0)	1(1.6)	2(4.4)	20(17.7)	18(16.8)	38(22.9)	33(21.7)
2.0-2.4	18(60.0)	9(45.0)	1(1.9)	---	7(11.3)	2(4.4)	6(5.3)	6(5.6)	12(7.2)	15(9.9)
< 2.0	5(16.7)	3(15.0)	1(1.9)	---	1(1.6)	---	---	2(1.9)	2(1.2)	1(0.7)

Table 7a. Vivaria tested for rearing O. h. formosana to maturity for 8 weeks in terms of survival rate, % of survived snails reaching maturity, average height, and average growth rate.

Vivaria types:	P.D. w/o mud	P.D. w/mud	5/P.C.	10/P.C.	15/P.C.
Survival rate (%):	37.6	84.8	88.8	85.2	92.3
% of survived snails reaching maturity:*					
Females	0.00	83.33	63.93	83.93	63.52
Males	0.00	67.30	80.00	89.11	66.31
Average height in mm:					
Females	2.94 ± 0.58	6.30 ± 1.21	6.19 ± 0.96	6.19 ± 1.04	5.62 ± 1.13
Males	3.02 ± 0.46	5.82 ± 0.92	5.92 ± 0.86	5.89 ± 0.66	5.44 ± 1.01
95% Confidence limits in mm:					
Females	2.94 ± 0.24	6.30 ± 0.33	6.19 ± 0.25	6.19 ± 0.19	5.62 ± 0.18
Males	3.02 ± 0.20	5.82 ± 0.26	5.92 ± 0.24	5.89 ± 0.13	5.44 ± 0.15
Average growth rate in mm/wk:					
Females	0.12	0.54	0.52	0.52	0.45
Males	0.13	0.48	0.49	0.49	0.43

ABBREVIATIONS: P.D. w/o mud - Petri dish without mud mound. P.D. w/ mud - Petri dish with mud mound. 5/P.C. - 5 snails per plastic container. 10/P.C. - 10 snails per plastic container. 15/P.C. - 15 snails per plastic container

* Indicated by the presence of varix lip on the shell.

Table 7b. Comparative growth in terms of height (mm) of O. h. formosana reared to maturity in the vivaria for 8 weeks. The number of snails is shown left of the parenthesis; percentage of the snails isolated in each vivarium group of each sex in the parenthesis.

Height (mm)	Petri dish without mud		Petri dish with mud		5 snails per container		10 snails per container		15 snails per container	
Sex:	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
7.5-7.9	---	---	3(5.6)	---	---	---	4(3.6)	---	1(0.6)	---
7.0-7.4	---	---	16(29.6)	4(7.7)	13(21.3)	1(2.0)	22(19.6)	1(1.0)	10(6.3)	1(0.5)
6.5-6.9	---	---	16(29.6)	10(19.2)	21(34.4)	11(22.0)	29(25.9)	17(16.8)	33(20.8)	22(11.8)
6.0-6.4	---	---	9(16.7)	15(28.8)	7(11.7)	21(42.0)	25(22.3)	43(42.5)	31(19.5)	57(30.5)
5.5-5.9	---	---	2(3.7)	9(17.3)	6(9.8)	7(14.0)	16(14.3)	28(27.7)	24(15.1)	29(15.5)
5.0-5.4	---	---	---	5(9.6)	5(8.2)	4(8.0)	3(2.7)	4(4.0)	15(9.4)	23(12.3)
4.5-4.9	---	---	1(1.8)	3(5.9)	4(6.5)	1(2.0)	4(3.5)	3(3.0)	15(9.4)	14(7.5)
4.0-4.4	3(12.0)	1(4.5)	1(1.3)	2(3.9)	4(6.5)	2(4.0)	2(1.8)	3(3.0)	17(10.7)	23(12.3)
3.5-3.9	1(4.0)	1(4.5)	3(5.6)	4(7.7)	1(1.6)	3(6.0)	3(2.7)	1(1.0)	7(4.4)	10(5.3)
3.0-3.4	6(24.0)	10(45.5)	3(5.6)	---	---	---	2(1.8)	1(1.0)	3(1.9)	8(4.3)
2.5-2.9	10(40.0)	8(36.4)	---	---	---	---	1(0.9)	---	2(1.3)	---
2.0-2.4	5(20.0)	2(9.1)	---	---	---	---	1(0.9)	---	1(0.6)	---
< 2.0	---	---	---	---	---	---	---	---	---	---

Table 8a. Vivaria tested for rearing O. h. nosophora to maturity for 8 weeks in terms of survival rate, % of survived snails reaching maturity, average height, and average growth rate.

Vivaria types:	P.D. w/o mud	P.D. w/mud	5/P.C.	10/P.C.	15/P.C.
Survival rate(%):	43.5	80.8	89.6	89.6	94.7
% of survived snails reaching maturity:*					
Females	0.00	22.64	62.07	28.32	17.65
Males	0.00	64.58	85.19	43.24	31.55
Average height in mm:					
Females	2.56 ± 0.67	5.39 ± 1.64	6.63 ± 1.05	5.39 ± 1.35	4.91 ± 1.13
Males	2.83 ± 0.70	5.65 ± 1.01	6.62 ± 0.91	5.26 ± 1.06	4.96 ± 1.07
95% Confidence limits in mm:					
Females	2.56 ± 0.22	5.39 ± 0.45	6.63 ± 0.28	5.39 ± 0.25	4.91 ± 0.16
Males	2.83 ± 0.36	5.65 ± 0.29	6.62 ± 0.25	5.26 ± 0.20	4.96 ± 0.16
Average growth rate in mm/wk:					
Females	0.07	0.42	0.58	0.42	0.36
Males	0.10	0.49	0.55	0.41	0.36

Abbreviations:

- P.D. w/o mud - Petri dish without mud mound
- P.D. w/mud - Petri dish with mud mound
- 5/P.C. - 5 snails per plastic container
- 10/P.C. - 10 snails per plastic container
- 15/P.C. - 15 snails per plastic container

*Indicated by the presence of varix lip on the shell

Table 8b. Comparative growth in terms of height (mm) of O. h. nosophora reared to maturity in the vivaria for 8 weeks. The number of snails is shown left of the parenthesis; percentage of the snails isolated in each vivarium group of each sex in the parenthesis.

Height mm)	Petri dish without mud		Petri dish with mud		5 snails per container		10 snails per container		15 snails per container	
Sex:	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
7.5-7.9	---	---	2 (3.8)	---	15(25.9)	2(3.7)	8(7.1)	---	4(2.1)	---
7.0-7.4	---	---	5(9.4)	2(4.2)	13(22.4)	6(11.1)	13(11.5)	3(2.7)	9(4.8)	1(0.6)
6.5-6.9	---	---	5(9.4)	16(33.3)	11(19.0)	30(55.5)	11(9.7)	7(6.3)	11(5.9)	19(11.3)
6.0-6.4	---	---	9(17.0)	12(25.0)	4(6.9)	8(14.8)	6(5.3)	25(22.6)	19(10.2)	19(11.3)
5.5-5.9	---	---	5(9.4)	6(12.5)	5(8.6)	1(1.9)	8(7.1)	18(16.2)	11(5.9)	19(11.3)
5.0-5.4	---	---	6(11.3)	1(2.1)	7(12.1)	---	15(13.3)	13(11.7)	16(8.5)	16(9.5)
4.5-4.9	1(2.7)	---	8(15.1)	4(8.3)	---	4(7.4)	22(19.4)	23(20.2)	35(18.7)	23(13.7)
4.0-4.4	---	1(5.9)	6(11.3)	5(10.4)	1(1.7)	2(3.7)	15(13.3)	8(7.2)	48(25.7)	35(20.8)
3.5-3.9	3(8.1)	3(17.6)	3(5.7)	2(4.2)	2(3.4)	---	12(10.6)	7(6.3)	25(13.4)	28(16.7)
3.0-3.4	4(10.8)	3(17.6)	2(3.8)	---	---	1(1.9)	1(0.9)	4(3.8)	9(4.8)	8(4.8)
2.5-219	13(35.1)	5(29.4)	2(3.8)	---	---	---	2(1.8)	3(2.7)	---	---
2.0-2.4	10(27.0)	4(23.6)	---	---	---	---	---	---	---	---
< 2.0	6(16.3)	1(5.9)	---	---	---	---	---	---	---	---

Table 9a. Vivaria tested for rearing O. h. hupensis to maturity for 8 weeks in terms of survival rate, % of survived snails reaching maturity, average height, and average growth rate.

Vivaria types:	P.D.w/o mud	P.D. w/mud	5/P.C.	10/P.C.	15/P.C.
Survival rate (%):	Not done	87.2	92.0	90.8	Not done
% of survived snails reaching maturity:*					
Females		38.71	59.32	21.01	
Males		53.19	71.43	32.41	
Average height in mm:					
Females		7.49 ± 1.42	8.06 ± 0.98	6.47 ± 1.39	
Males		7.41 ± 0.96	7.97 ± 0.71	6.57 ± 1.18	
95% Confidence Limits in mm:					
Females		7.49 ± 0.36	8.06 ± 0.26	6.47 ± 0.25	
Males		7.41 ± 0.28	7.97 ± 0.19	6.57 ± 0.22	
Average growth rate in mm/wk:					
Females		0.69	0.76	0.56	
Males		0.68	0.75	0.57	

Abbreciations:
- P.D. w/o mud - Petri dish without mud mound
- P.D. w/mud - Petri dish with mud mound
- 5/P.C. - 5 snails per plastic container
- 10/P.C. - 10 snails per plastic container
- 15/P.C. - 15 snails per plastic container

*Indicated by the presence of varix lip on the shell.

Table 9b. Comparative growth in terms of height (mm) of O. h. hupensis reared to maturity in the vivaria for 8 weeks. The number of snails is shown left of the parenthesis; percentage of the snails isolated in each vivarium group of each sex in the parenthesis.

Height (mm)	Petri dish without mud		Petri dish with mud		5 snails per plastic container		10 snails per plastic container		15 snails per plastic container	
Sex:	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
9.5-9.9	Not done.		3(4.8)	---	---	---	---	---	Not done.	
9.0-9.4			5(8.1)	2(4.3)	10(17.0)	3(5.4)	4(3.4)	---		
8.5-8.9			9(14.5)	3(6.4)	14(23.7)	9(16.1)	7(5.9)	2(1.8)		
8.0-8.4			6(9.7)	8(17.0)	13(22.0)	18(32.1)	12(10.1)	17(15.8)		
7.5-7.9			13(21.0)	15(31.9)	6(10.2)	18(32.1)	11(9.2)	13(12.0)		
7.0-7.4			7(11.3)	5(10.6)	9(15.2)	4(7.1)	10(8.4)	11(10.2)		
6.5-6.9			8(12.9)	6(12.8)	3(5.1)	1(1.8)	10(8.4)	16(14.8)		
6.0-6.4			4(6.5)	4(8.5)	1(1.7)	3(5.4)	22(18.5)	12(11.1)		
5.5-5.9			3(3.2)	3(6.4)	1(1.7)	---	12(10.1)	17(15.8)		
5.0-5.4			1(1.6)	---	2(3.4)	---	15(12.6)	11(10.2)		
4.5-4.9			---	1(2.1)	---	---	7(5.9)	7(6.5)		
4.0-4.4			2(3.2)	---	---	---	7(5.9)	1(0.9)		
3.5-3.9			1(1.6)	---	---	---	1(0.8)	1(0.9)		
3.0-3.4			1(1.6)	---	---	---	1(0.8)	---		

Table 10. The coefficient of linear correlation (γ) between the shell height at the end of the 8-week isolation in the culture and the mud surface area per snail

Species and Sex	Degrees of freedom	γ	Conclusion
O. h. quadrasi			
females	375	0.56	Significant
males	422	0.12	Almost significant
O. h. chiui			
females	421	0.32	Significant
males	380	0.33	Significant
O. h. formosana			
females	409	0.33	Significant
males	410	0.31	Significant
O. h. nosophora			
females	446	0.55	Significant
males	396	0.44	Significant
O. h. hupensis			
females	238	0.20	Significant
males	209	0.22	Significant

Table 11. Young production and adult survival of Oncomelania snails, as affected by the food additives.

Groups:*	A	WG	RC	C
A. Young production:				
Total # of young collected in one year	1,732	299	776	1,056
Average of young produced per female per biweek (y/viv/biwk)	6.20	1.07	2.32	3.45
Average of young produced per vivarium per biweek (y/viv/biwk)	13.32 ± 11.70	2.30 ± 1.91	5.97 ± 6.59	8.12 ± 10.44
95% Confidence Limit				
Lower level:	11.87	0.00	0.00	0.00
Upper level:	14.77	4.67	14.15	21.08
Greatest # of young collected in one vivarium in one year	615	120	430	675
B. Adult survival:				
Out of 15 females:				
Number at the end of one year	9	5	5	9
Percent survival	60.00	33.33	33.33	60.00
Out of 15 males:				
Number at the end of one year	9	9	11	11
Percent survival	60.00	60.00	73.33	73.33

* A = Algae
WG = Wheat germ
RC = Rice cereal
C = Combined food

Table 12a. O. h. nosophora in Experiment 4 reared to maturity in four vivarium groups for 8 weeks in terms of survival rate, % of survived snails reaching maturity, average height, and average growth rate.

Vivarian type:	P.D. w/o mud	5/S.P.C.	10/S.P.C.	L.P.C.
Survival rate (%):	82.5	67.5	95.0	100.0
% of survived snails reaching maturity:*				
Females	94.1	84.6	80.0	100.0
Males	93.8	100.0	93.5	100.0
Average height in mm:				
Females	7.44 ± 0.36	7.62 ± 0.74	7.15 ± 1.04	7.73 ± 0.35
Males	6.70 ± 0.47	7.04 ± 0.33	6.66 ± 0.44	7.11 ± 0.28
95% confidence limits in mm:				
Females	7.44 ± 0.19	7.62 ± 0.45	7.15 ± 0.39	7.73 ± 0.16
Males	6.70 ± 0.25	7.04 ± 0.19	6.66 ± 0.13	7.11 ± 0.13
Average growth rate in mm/wk:				
Females	0.67	0.70	0.64	0.72
Males	0.59	0.63	0.58	0.64

Abbreviations:
P.D. w/mud = Petri dish with mud mound
5/S.P.C. = 5 snails per small palstic container
10/S.P.C. = 10 snails per small palstic container
L.P.C. = Large plastic container

*Indicated by the presence of varix lip on the shell

Table 12b. Comparative growth in terms of height (mm) of O. h. nosophora reared to maturity in vivaria for 8 weeks. The number of snails is shown left of the parenthesis; the percentage of the snails isolated in each vivarium group of each sex in the parenthesis.

Height (mm)	Petri dish with mud		5 snails per container		10 snails per container		Large plastic container	
Sex:	♀	o	♀	o	♀	o	♀	o
8.5-8.9	---	---	---	---	---	---	1(4.8)	---
8.0-8.4	---	---	4(30.8)	---	4(13.3)	---	3(14.3)	---
7.5-7.9	10(58.8)	---	6(46.1)	2(14.2)	10(33.4)	2(4.3)	13(61.8)	3(15.8)
7.0-7.4	5(29.4)	5(31.2)	2(15.4)	6(42.9)	10(33.4)	8(17.4)	3(14.3)	11(57.9)
6.5-6.9	2(11.8)	8(50.0)	---	6(42.9)	2(6.7)	22(47.8)	1(4.8)	5(26.3)
6.0-6.4	---	2(12.6)	---	---	1(3.3)	13(28.3)	---	---
5.5-5.9	---	---	---	---	1(3.3)	---	---	---
5.0-5.4	---	1(6.2)	1(7.7)	---	---	1(2.2)	---	---
4.5-4.9	---	---	---	---	---	---	---	---
4.0-4.4	---	---	---	---	1(3.3)	---	---	---
3.5-3.9	---	---	---	---	1(3.3)	---	---	---

Table 13. Fecundity and adult survival of O. h. nosophora, reared to maturity for 8 weeks in various vivaria; then transferred to plastic containers with mud rings for producing young.

Vivarium types:	Petri dish with mud	5 snails per container	10 snails per container	Large plastic container
A. Young Production				
Total # of young collected in six months	1,216	1,376	853	967
Average of young produced per female per biweek (y/f/biwk)	11.36	11.76	7.29	8.63
Average of young produced per vivarium per biweek (y/viv/biwk):	31.18 ± 18.06	35.28 ± 20.50	21.87 ± 17.94	24.79 ± 9.54
95% confidence limit:				
Lower level	0.00	0.00	0.00	0.00
Upper level	76.07	86.23	66.46	48.50
Greatest number of young collected in one vivarium in six months	588	744	553	421
B. Adult survival:				
Survival rate (%) of females	88.89	100.00	100.00	77.78
Survival rate (%) of males	100.00	88.89	88.89	100.00

Table 14. Analysis of variance of the young productivity of Oncomelania hupensis subspecies tested in various vivarium types (Experiment 1).

Source	Degrees of freedom	Sum of Square	Mean Square	Fcal	Significant difference
Vivarium Type	3	2,046,739.44	682,246.48	20.51	Very significant
Subspecies	4	2,980,784.54	745,196.14	22.41	Very significant
Interaction	12	1,754,377.06	146,198.09	4.40	Significant
Error	80	2,660,661.60	33,258.27		
TOTAL	99	9,442,562.64			

Table 15. Comprehensive analysis of variance of the mortality of adult males and females of each Oncomelania hupensis subspecies tested in various vivarium types (Experiment 1).

Subspecies	Sex Fcal	Sex SD	Vivarium Type Fcal	Vivarium Type SD	Interaction Fcal	Interaction SD
O. h. hupensis	0.00	NS	99.29	VS	1.19	NS
O. h. formosana	1.86	NS	10.06	VS	0.18	NS
O. h. quadrasi	9.03	VS	18.21	VS	0.28	NS
O. h. nosophora	1.39	NS	1.35	NS	0.91	NS
O. h. chiui	0.00	NS	80.72	VS	4.27	LS

SD = Significant difference
NS = Not significant
VS = Very significant
LS = Little significance

Table 16. Analysis of variance of the shell height of Oncomelania hupensis subspecies tested in various vivarium types (Experiment 2).

Source	Degrees of freedom	Sum of Square	Mean Square	Fcal	Significant difference
Vivarium Type	4	15,260.22	3,815.06	1.234.65	Very significant
Subspecies	4	1,065.52	266.38	86.21	Very significant
Interaction	16	2,697.26	168.58	54.56	Very significant
Error	3,703	11,425.54	3.09		
TOTAL	3,727	30,448.54			

Table 17. Analysis of variance of the survival race of young of Oncomelania hupensis subspecies reared to maturity for 8 weeks in various vivarium types (Experiment 2).

Source	Degrees of freedom	Sum of Square	Mean Square	Fcal	Significant difference
Vivarium Type	4	6,921.11	1,730.28	109.30	Very significant
Error	18	284.84	15.83		
TOTAL	22	7,205.95			

Table 18. Comprehensive analysis of variance of the shell height of females and males of each Oncomelania hupensis subspecies reared to maturity in various vivarium types for 8 weeks (Experiment 2).

Subspecies	Sex		Vivarium Types		Interaction	
	Fcal	SD	Fcal	SD	Fcal	SD
O. h. quadrasi	187.61	VS	126.84	VS	0.63	NS
O. h. chiui	2.05	NS	48.07	VS	1.03	NS
O. h. formosana	13.27	VS	98.94	VS	0.49	NS
O. h. nosophora	3.50	NS	124.73	VS	1.26	NS
O. h. hupensis	0.01	NS	66.36	VS	0.36	NS

SD = Significant difference
NS = Not significant
VS = Very significant

Table 19. Analysis of variance of the effect of the food additives on the fecundity of O. h. nosophora cultured in the plastic containers with mud rings (Experiment 3).

Source	Degrees of freedom	Sum of Square	Mean Square	Fcal	Significant difference
Vivarium Type	3	215,168.95	71,722.98	1.45	
Error	16	792,043.60	49,502.73		No significant difference
TOTAL	19	1,007,212.55			

Table 20. Analysis of variance of the effect of the food additives on the mortality of adult females and males (O. h. nosophora) cultured in the plastic containers with mud rings (Experiment 3).

Source	Degrees of freedom	Sum of Square	Mean Square	Fcal	Significant difference
Sex	1	4.90	4.90	3.21	No significant difference
Food	3	1.10	0.37	0.24	No significant difference
Interaction	3	2.70	0.90	0.59	No significant difference
Error	32	48.80	1.52		
TOTAL	39	57.50			

Table 21. Fecundity of O. h. nosophora reared to maturity for 8 weeks in four vivarium types showing: analysis of variance of the shell height (Experiment 4).

Source	Degrees of freedom	Sum of Square	Mean Square	Fcal	Significant difference
Vivarium Type	3	10.46	3.49	8.31	Very significant
Error	172	72.28	0.42		
TOTAL	175	82.74			

Table 22. Analysis of variance of the shell height of O. h. nosophora females and males in Experiment 4 reared to maturity for 8 weeks.

Source	Degrees of freedom	Sum of Square	Mean Square	Fcal	Significant difference
Vivarium Type	3	10.46	3.49	10.26	Very significant
Sex	1	16.92	16.92	49.76	Very significant
Interaction	3	-2.04	-0.68	-2.00	No significant difference
Error	168	57.40	0.34		
Total	175	82.74			

Table 23. Analysis of variance of survival rate of O. h. nosophora young in Experiment 4 reared to maturity for 8 weeks

Source	Degrees of freedom	Sum of Square	Mean Square	Fcal	Significant difference
Vivarium Type	3	600.00	200.0	0.21	No significant difference
Error	4	3,828.00	957.00		
TOTAL	7	4,428.00			

Table 24. Analysis of variance of the adult mortality of O. h. nosophora females and males reared to maturity for 8 weeks in various vivaria; then transferred to plastic containers with mud rings for producing young (Experiment 4)

Source	Degrees of freedom	Sum of Square	Mean Square	Fcal	Significant difference
Sex	1	0.82	0.82	2.14	No significant difference
Vivarium type	3	0.13	0.04	0.14	No significant difference
Interaction	3	0.54	0.18	0.62	No significant difference
Error	16	4.67	0.29		
Total	23	5.96			

PLEISTOCENE MOLLUSCA OF THREE SOUTHEASTERN MICHIGAN MARL DEPOSITS

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CONTENTS

ABSTRACT

A study of mollusks from continuous columns of sediment from Little Goose Lake, Lime Lake, and Marl Lake in southeastern Michigan provided data on the later stages of lake history. The three lakes probably formed as ice block depressions between 14,000 and 13,500 years B.P. during the waning of the Carey Subage. Marl Lake and Lime Lake lie in Saginaw lobe deposits. Little Goose Lake is situated in the Erie-Saginaw interlobate area.

Each section included an upper peat underlain by marl, often of considerable thickness. A basal sandy unit was exposed in the Lime Lake section, but due to the thickness of marl and the presence of the water table it was not studied in the other sections.

Each section was sampled at 2 inch increments of depth and the mollusks studied quantitatively. Percentages of each species were calculated for each increment. This permitted comparison of species from collection to collection which in turn allowed the use of changes in abundance for interpretation of environmental variations.

Forty-three species of mollusks and at least six species of ostracodes were found in this study. The mollusks included terrestrial pulmonates, ctenobranchs, sphaeriids, and Naiades. Fluctuations in species abundance in the sections are attributed to changes in bottom sediment, the lack or presence of bottom vegetation, changes in water level, and temperature variations. Each section records a gradual upward transition from aquatic to shoreline terrestrial conditions.

The study of the distribution of living mollusks at Little Goose Lake and the vertical distribution of mollusks in the Wisconsinan sections shows that several nearly concentric zones of mollusk communities exist in and around a marl lake.

ACKNOWLEDGEMENTS

I extend my sincere appreciation to my adviser, Dr. Aurèle La Rocque, for his help and advice during field work, laboratory preparation, and the writing of this paper. I also thank the Geological Survey Division, State of Michigan for permitting access to unpublished reports on the marl deposits of Michigan.

My field assistants Mike Burke, Carl Hopfinger, Frank Majchszak, Chuck Nicewonder, and Nick Valkenburg, all of the University of Toledo, deserve recognition for their help in collecting the samples. I also wish to extend my thanks to Merrell Miller of the Ohio State University for his help in identification of the ostracodes.

INTRODUCTION

Nature and Purpose

This study was undertaken to provide information on the paleoecology and molluscan fauna of three Late Wisconsinan lacustrine deposits in southern Michigan and to assist in the future determination of post-glacial redistribution patterns of mollusks. The paleoecology was derived from an analysis of the vertical distribution of significant species of mollusks in sediment sections taken from each lake basin and the relation of the mollusks to sediment type and other organisms.

Location of Deposits

Three lacustrine deposits of southeastern Michigan were sampled and studied (Figure 1). The southernmost locality was Little Goose Lake (SE¼, Sec. 5, T5S, R1E) situated 3/8 mile south of Cement City in Lenawee County. The section was obtained along the northern shoreline approximately 1000 feet west of Cement City Road.

The second locality is some 40 miles to the northeast at Lime Lake (SW¼, Sec. 25, T2N, R5E). This lake is ½ mile west of Brighton in Livingston County. The samples were collected on the north shore of a small inlet about 500 feet south of Brighton Road.

Marl Lake (NW¼, Sec. 4, T4N, R6E) is the northernmost deposit studied. It is located some 20 miles north of Lime Lake and 3 miles west of Fenton on the Genesee-Livingston County border. The section was taken along a 4-foot wavecut terrace of marl along the southeastern shoreline about 1000 feet north of Bennett Lake Road.

Method of Investigation

Several potential localities were selected from the perusal of topographic quadrangles, soil survey maps, and early reports of the Michigan Geological Survey for areas of subsurface lacustrine material and locations of abandoned marl pits. A general reconnaissance of each locality was made in order to determine if it was suitable for the study. Little Goose Lake, Lime Lake, and Marl Lake were chosen for the study on the basis of their fossiliferous marl, easy accessibility, low water table, and geographic location.

A detailed survey was made of each locality investigated. A soil auger was employed to map the overall extent of the marl deposit along the border of each lake. The measured section was located on shore near the margin of the marl deposit in order to obtain a record of the transition from marl to peat, and a more representative molluscan fauna since mollusks of present-day lakes are more common in the shallow littoral zone (less than 2 feet). Changes in the abundance of mollusks in vertical section are more pronounced in this part of the lake basin because even fluctuations of water level of a few inches could disrupt a shallow littoral community.

A pit with surface dimensions of 3 feet by 4 feet was dug, just large enough to allow working space and the removal of a 12 X 12 inch column of sediment. Samples were removed at each 2-inch depth, placed in labeled plastic bags, and sealed to prevent moisture loss.

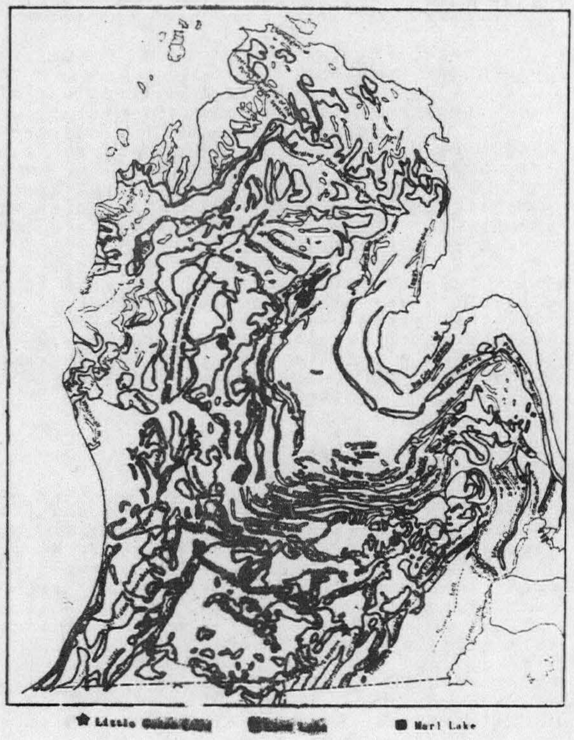


Figure 1. Generalized Glacial Map of Southern Michigan (Adapted from Leverett and Taylor, 1915)

Sampling continued downward until water seepage in the pit became too great. A soil auger was used to determine the nature of the sediment below the water table.

In the laboratory, the samples were allowed to soak 24 hours in water treated with water conditioner before being sieved. Each sample was then washed through 10, 20, and 40 mesh sieves to separate the fossils from the finer-grained sediment. Not all the fine material could be washed through the sieves for this required a strong spray of water which would easily break many of the shells. The 10 mesh sieve caught the larger shells and pebbles; the 20 mesh sieve held most of the adult shells; and the 40 mesh sieve retained immature and small adult shells. The pan fraction was examined, but was found to contain insignificant specimens, mostly ostracodes and shell fragments. After drying, the shells were stored, awaiting picking and identification.

The next step in the laboratory procedure involved the picking of 1000 shells from each collection. A collection consisted of the combined sieve fractions of each 12 X 12 X 2 inch sample. The collections usually contained several thousand shells and had to be split to reduce bias. This was accomplished by repeated halving with a sample splitter until the collection contained nearly 1000 shells. The resulting collection was then picked, using a moistened brush, until 1000 shells had been counted. These shells were then separated to species and the number of specimens of each species was counted.

The resulting data were used to calculate percentage abundance for each species found in a collection. For those collections where the total number of individuals was not equal to 1000 the percentages were calculated accordingly. The percentage abundance figures are shown in table form (Tables 3, 4, and 5) and in graph form for the important species. This allows for a comparison of species within one collection and of the vertical distribution in the entire section.

The relative abundance of mollusks in each collection was estimated. The volume of sediment that was picked to obtain the 1000 shells was estimated from the sample splitter. Thus the number of shells contained in the remaining volume could be estimated. These totals are shown in tables 3, 4, and 5.

Previous Work

Dr. Bryant Walker (1879, 1895, 1906) was a pioneer in the study of Pleistocene and living Mollusca of Michigan, having published a catalogue of Michigan Mollusca as early as 1879. As with many of the early workers, his studies were concerned almost exclusively with the identification and distribution of Mollusca. During the early 1900's a number of workers were studying the Mollusca of Michigan and the surrounding states. Mina L. Winslow (1917, 1921) studied mollusks from northern Michigan. F. C. Baker (1913, 1914, 1915, 1926) collected molluscan data from several Michigan localities. The continuing research of F. C. Baker resulted in his *Freshwater Mollusca of Wisconsin* in 1928, a work destined to become a standard reference in the field. Sterki (1920) was one of the first workers to suggest an interpretation of the depositional environment from collections of mollusks found in marl deposits at Castalia and along Tinker's Creek in Ohio.

More extensive ecologic studies began in the 1930's. F. C. Baker (1930, 1937) examined the effects of glaciation on the molluscan fauna and the use of Pleistocene mollusks as ecological and time indicators. Archer (1934, 1936, 1939), Berry (1943), Goodrich (1931, 1943), and van der Schalie (1939, 1940) were carrying on research on living mollusks.

Cain *et al.* (1950) conducted a study of Sodon Lake, Oakland County, Michigan, using pollen and molluscan data to reconstruct the depositional and ecological history of the lake and lacustrine community. Beginning in the 1950's, La Rocque and his students have provided much useful data on the distribution and ecology of Pleistocene mollusks through the study of numerous lacustrine deposits in Ohio and Canada (La Rocque, 1966, p. 10). La Rocque (1966-1970) has summarized and revised the classification, ecology, and distribution of Pleistocene and living Mollusca of Ohio, as well as Michigan, other northern states, and parts of Canada in his *Pleistocene Mollusca of Ohio*.

PLEISTOCENE GEOLOGY OF SOUTHERN MICHIGAN

Regional Geology

The earliest comprehensive study of the Pleistocene geology of Michigan was by Leverett and Taylor (1915). Wayne and Zumberge (1965) have written the latest account of the glacial features and history of Indiana and Michigan. The proglacial lakes ancestral to the Great Lakes have been discussed by the above workers and have received separate attention from Bretz (1951, 1964) and Hough (1958, 1963). Glacial drainage systems have been discussed by Russell and Leverett (1915), Bay (1938), and Bretz (1953). Surficial geology maps have been prepared by Leverett and Taylor (1915), Martin (1955), and Flint *et al.* (1959).

Southeastern Michigan is presumed to have been glaciated during the Kansan (?) and Illinoian due to the presence of such deposits in southern Ohio and Indiana (Dorr and Eschman, 1970, p. 161). Two major lobes of ice were present in southeastern Michigan and one in western Michigan. At its maximum, the Saginaw lobe extended from the Saginaw basin in a south-southwest direction across central Michigan and into northern Indiana (Bretz, 1951, p. 244). The maximum extent of the Erie lobe was from the Erie basin into eastern Michigan, northern Indiana, and northern Ohio (Wayne and Zumberge, 1965, p. 72).

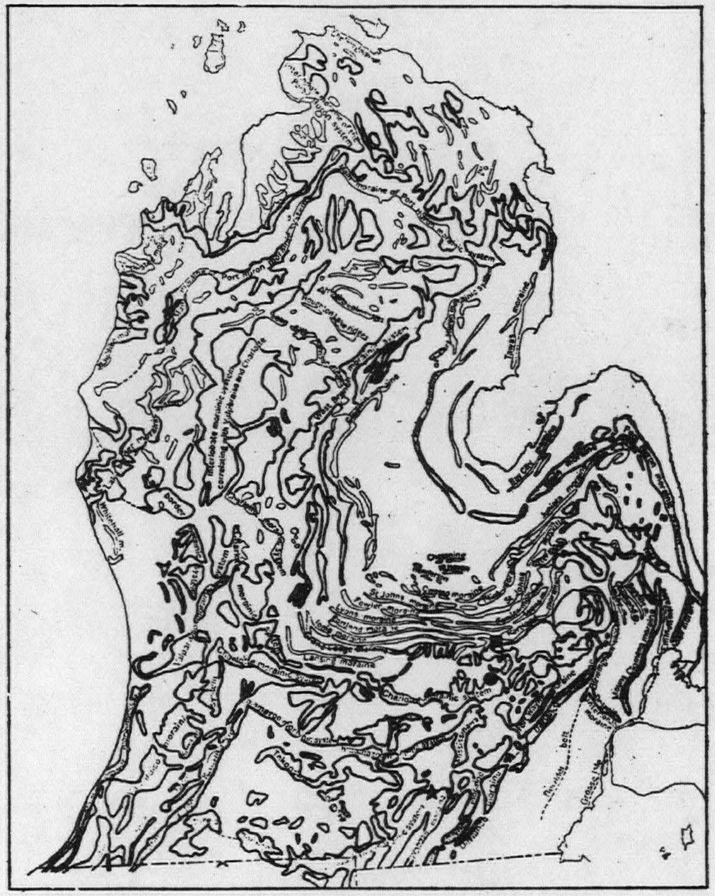
The Carey Subage was characterized by a general retreat of the Lake Michigan, Saginaw, and Erie lobes from the southern part of the state (Dorr and Eschman, 1970, p. 161). Temporary halts of the ice front produced a series of arcuate end moraines across the state (Figure 1). The moraines associated with the Saginaw lobe are well developed in southern central Michigan, encircling the Saginaw basin region (Martin, 1955). Erie lobe moraines developed in a southwestern direction in the eastern counties. The Erie lobe moraines have been disrupted by the formation of proglacial lakes along the ice front (Martin, 1955). Lake Michigan lobe moraines parallel Lake Michigan, but are outside the scope of this study.

Well defined moraines give way to a complex mass of kames, moraines, and outwash in the Saginaw-Erie interlobate area which stretches from the Thumb region, southwestward through Hillsdale County (Martin, 1955; Wayne and Zumberge, 1965, p. 72). Stratigraphic position in the Wisconsinan sediments of this region is nearly impossible to define. The Saginaw lobe receded more rapidly than the Erie lobe during the Carey Subage. A temporary readvance of the Erie lobe occurred in Washtenaw County and northeastern Indiana where Erie lobe till overlies Saginaw till (Zumberge, 1960, p. 1185).

Approximately 13,000 years B.P., the ice advanced from northern Michigan into Saginaw County, but was not destined to cover southern Michigan again (Wayne and Zumberge, 1965, p. 76). This marked the beginning of the Port Huron (Mankato) Subage. The ice retreated from the Port Huron moraine and by 12,000 years B.P. was far to the north (Wayne and Zumberge, 1965, p. 72, 76). Two more major ice advances occurred; one during the Two Creeks Subage (11,850 years B. P.) (Broecker and Farrand, 1963, p. 796) and the other in Valders time (Wayne and Zumberge 1965, p. 72). Broecker and Farrand (1963, p. 800) have stated that Michigan was completely free of ice by 10,000 years B.P.

Table 1. Classic Sequence of Ancestral Lakes in the Lake Erie and Lake Huron Basins (Adapted from Dorr and Eschmann, 1970)

DATE Years Before Present	GLACIAL EVENT	HURON BASIN	ERIE BASIN
3,000		ALGOMA 595'	LAKE ERIE 573'
4,000		NIPISSING 605' StCR + NB →	NR →
9,500		STANLEY 190' NB →	GR - Grand River I - Imlay MR - Mohawk River NB - North Bay NR - Niagara River StCR - St. Clair River TL - Trent Lowlands U - Ubly WR - Wabash River
		POST ALGONQUIN	
		ALGONQUIN 605'	
11,500	VALDERS MAX.	Ice StCR →	
11,850	TWO CREEKS	KIRKFIELD 565'(?) TL →	EARLY LAKE ERIE
		"EARLY ALGONQUIN" 605'	MR →
		LUNDY 620'	
		GRASSMERE 640'	
		← GR LOWEST WARREN 675'	
		← GR WAYNE 660'	
		← GR WARREN 690-680'	
13,000	PORT HURON (MANKATO)	← GR SAGINAW 695' Ice	← U WHITTLESEY 738'
		← GR LOWEST ARKONA II 695'	
13,300		CAREY - PORT HURON LOW WATER STAGE - Drained East	
	LAKE BORDER MORAINE	← GR ARKONA 710, 700, 695'	
		EARLY SAGINAW	← WR MAUMEE III 780'
		← GR	← I MAUMEE II 760'
	TINLEY-DEFIANCE MOR.	ICE	← WR MAUMEE I 800'
		ICE	ICE



★ Little Goose Lake ● Lime Lake ■ Marl Lake

Figure 1. Generalized Glacial Map of Southern Michigan (Adapted from Leverett and Taylor, 1915)

Reproduction at reduced scale of Figure 1 (page 23) and Table 1 (page 25) was so poor that the above reproduction at larger scale is given here.

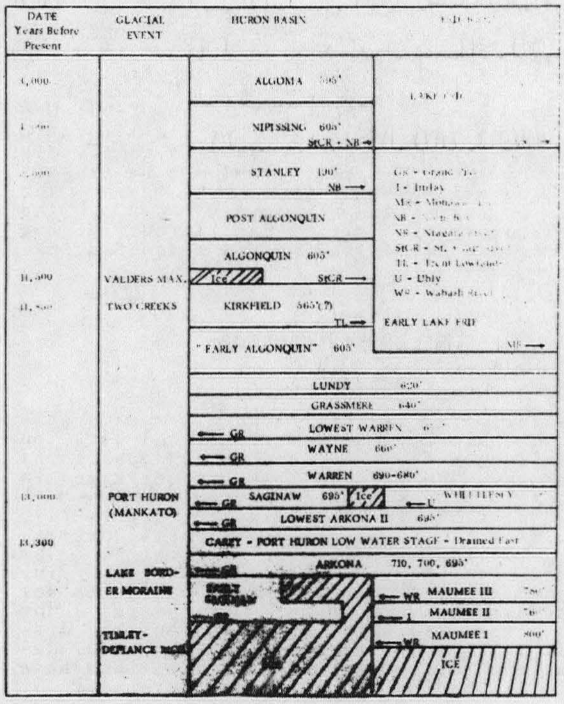


Table 1. Classic sequence of ancestral lakes in the Lake Erie and Huron Basins (Adapted from Dorr and Eschman, 1970)

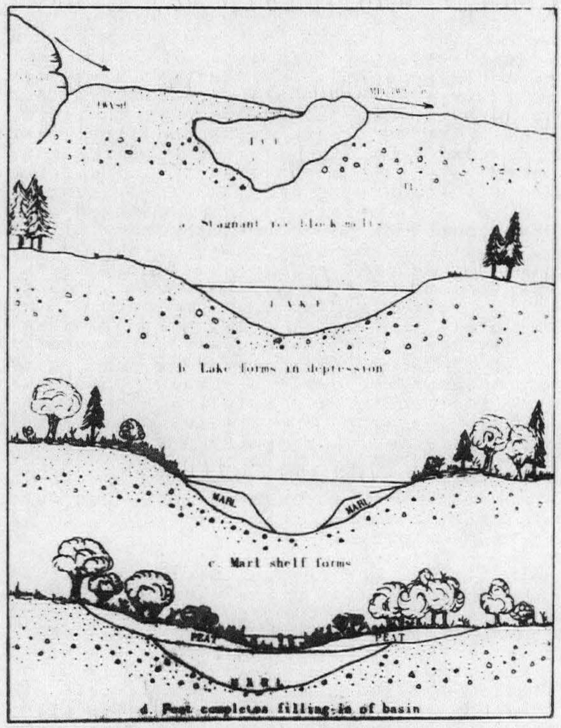


Figure 2. Stages of development of a typical marl lake.

Drainage History

The retreat of the ice sheet during the Carey Subage resulted in the establishment of new drainage patterns in southeastern Michigan. The first region to be freed of ice was the interlobate area between the Saginaw and Huron-Erie lobes (Bay, 1938, p. 25). This region was the channel for torrents of meltwater and accumulated thick deposits of sand and gravel. Blocks of ice broken from the main ice sheets were buried in outwash, later to melt and form the many lakes of the region. A westward-flowing drainage system developed in ice-free central southern Michigan which included the ancestral Huron and Raisin Rivers (Bay, 1938, p. 26, 27). Many streams emptied into Glacial Lake Dowagiac in western Michigan which had an outlet to the Mississippi River.

Movement of the lobes to the Portland-Defiance moraines left most of southeastern Michigan free of ice (Dorr and Eschman, 1970, p. 161). If the morainic sequence is followed, Little Goose Lake should have the earliest possible origin, followed by Lime Lake and Marl Lake respectively. However, the time of formation of each was controlled by several factors including the volume of ice mass that melted to form the basin and the insulating effect of the sediment cover. Further ice retreat marked the development of major proglacial lakes along the Saginaw and Erie lobes. The sequence of lakes is well known and is summarized in Table 1.

Lacustrine Deposits

Southeastern Michigan is dotted with many smaller lakes of glacial origin. Many of these resulted from the hummocky nature of end moraines. Depressions in the moraines commonly became the site of small lakes and ponds (Scott, 1921, p. 28). Lakes also formed in low areas of ground moraine, but generally were very shallow and short-lived (Scott, 1921, p. 28, 30). Many have already disappeared due to the process of hydroseric succession (Scott, 1921, p. 62-64).

Another common origin of lakes was the melting of buried ice masses, sometimes long after glacial retreat (Scott, 1921, p. 32). Large blocks of the decaying ice front broke off and were abandoned by the receding ice to be covered or partially covered with outwash. The sediment cover served to insulate the stagnant ice and permit slow melting. The overlying outwash gradually settled, creating a depression which often became the site of a lake. Other lakes formed from the damming of preglacial valleys by terminal moraines; others in depressions that sometimes formed between end moraines and associated outwash plains (Scott, 1921, p. 31).

Figure 2 depicts the history of a marl lake such as found in southeastern Michigan. The origin of the lake basin was probably from the melting of a stranded ice block. This origin was chosen from the several modes of origin discussed above because of the depth of the three lakes studied. Consultation with local fishermen and cottage owners yielded depths of 40 to 50 feet for parts of each of the three lakes. After the ice blocks melted those basins which intersected the water table became lakes with bottoms composed of glacial till and outwash.

Many of the lakes in southeastern Michigan accumulated extensive deposits of marl. Michigan marl deposits were extensively studied in the early 1900's by Hale *et al.* (1903) and Bergquist *et al.* (1932) because of their importance to the Portland cement industry. Marl may be defined as a fine-grained, loosely consolidated material composed mainly of calcium carbonate (Bergquist *et al.*, 1932, p. 3; Kupsch, 1956, p. 13). Its origin is still debated and several hypotheses have been proposed. It is evident that marl deposition involves the interaction of several parameters. Pleistocene ice sheets removed large volumes of carbonate rocks and redistributed them as part of the glacial drift. Most of Michigan's marl lakes lie within areas of calcareous till (Bergquist *et al.*, 1932, p. 9). Surface and ground water flowing through the drift are thought to take calcium bicarbonate into solution. These carbonate-rich waters flowed into postglacial lakes where carbon dioxide escaped as gas and marl (Bergquist *et al.*, 1932, p. 5). Hale *et al.* (1903, p. 59) reported that cold lime-rich water enters lakes through springs, but does not release calcium carbonate until it is warmed by overturning.

Kindle (1927) has stressed the importance of thermal stratification in marl formation. Marl accumulation appears to occur at a slow rate in deeper parts of a lake basin. Rapid marl accumulation is restricted to shallow areas where the temperature is warm (Hale, 1903, p. 60; Kindle, 1927, p. 7). These areas are often covered by dense growths of *Chara, Potamogeton,* and other lime tolerant plants. Photosynthetic processes of these plants cause precipitation of calcium carbonate coatings (Kindle, 1927, p. 28-30; Reid, 1961, p. 181). However, the presence of these plants is not necessary for marl formation. Marl occurs in areas devoid of *Chara* and *vice versa* (Hale *et al.*, 1903, p. 57; Kindle, 1927, p. 23). Filamentous blue-green algae have also been found to be active in marl precipitation (Kindle, 1927, p. 30; Kupsch, 1956, p. 17). Other probable factors entering into the precipitation of marl are hydrogen ion concentration, partial pressure at the water surface, and phosphate content (Reid, 1961, p. 181). Mollusk shells also add to the marl, but only in a secondary way (Hale *et al.*, 1903, p. 43; Kindle, 1927, p. 18-19).

With the development of a marl shelf around the perimeter of a lake, vegetation began to encroach into the shallows. This was the start of the process of hydroseric succession. Hydroseric succession involves the progressive development of concentric vegetation zones around a lake which move slowly inward restricting the open water area (Zumberge, 1952, p. 74-75). The ultimate result is total extinction of the lake.

The open water is dominated by algae and floating plants (*Lemna, Wolffia, Chara*) (Dachnowski, 1913, p. 229). Encircling this zone is a community of semi-aquatic plants (*Nymphaea, Nuphar, Polygonum*) (Dachnowski, 1912, p. 227). Immediately surrounding this is a fringing marsh zone which may include *Calla, Decodon, Eleocharis, Phragmites,* and *Typha* (Dachnowski, 1912, p. 231-235). Next is a shrub zone with *Rhus, Alnus,* and *Salix* (Dachnowski, 1912, p. 249). A swamp forest association encircles the shrub zone. Finally, in drier areas near the hydrosere a mesophytic forest is present (Dachnowski, 1912, p. 256). Hydroseric succession may be interrupted at any point, so the preceding represents an ideal case. A change in water level or destruction of vegetation could greatly disrupt this pattern.

Hydroseric succession results in another lacustrine deposit—peat, a dark-brown to black fibrous mass of partially decomposed plant matter (Taylor, 1907, p. 82-83; Dachnowski, 1912, p. 223-237; Scott, 1921, p. 62-64; Delorme, 1969, p. 1472). In the last aquatic stage of a marl lake the marl is completely covered by peat. A small bog pool is present in the deepest part of the former basin. The water is now distinctly acid because of the large amounts of decaying vegetation. The bog pool is gradually filled in and meadow succession begins.

MOLLUSCAN ECOLOGY

Autecology

The following section is an attempt to summarize ecologic and distributional data on the molluscan fauna of the three deposits of this study. The species have been arranged in taxonomic order, following La Rocque (1966-1970). La Rocque (1966-1970), Harman and Berg (1971), and Clarke (1973) provided the general distribution records used in this compilation. The general distribution of each species is included because it indicates some limits for the temperature ranges of the species. The latest available data are used, but the distributions are far from completely known. Taxonomic confusion and misidentifications have led to misleading distribution patterns.

The known ecologic data on each species are included; first the general habitats and then specific niches in these habitats. Harman and Berg (1971) and Clarke (1973) have provided much recent information in this field. The lack of data for some species may only be apparent because of taxonomic differences among workers. The author has not recognized subspecies in this study and has chosen to provide data only at the species level.

The distribution of each species in Michigan has been compiled from published information and it is hoped that it is as complete as possible. The occurrence of each species in Wisconsinan sediments in Michigan is also included for comparison with Recent occurrences. Due to the lack of collecting, especially of Wisconsinan mollusks, the present comparisons are very tentative.

CLASS GASTROPODA

Order Ctenobranchiata

Family Valvatidae

Valvata sincera Say, 1824

Valvata sincera ranges from New York north to Newfoundland, west to British Columbia (?), Minnesota, and Illinois. A few scattered populations have been recorded for Georgia, Louisiana, Wyoming, Colorado, Utah (?), and the Northwest Territories (La Rocque, 1968, p. 365-366; Clarke, 1973, p. 223).

This species occurs in large and small lakes, rivers, and streams. It is often associated with muddy substrate and submergent vegetation (Clarke, 1973, p. 224). Baker (1928, p. 23) listed this species as a deep water inhabitant of large lakes. Clarke (1973, p. 224) has confirmed its existence in large lakes and has also found it to occur in smaller lakes in the northern part of its range During the Wisconsinan it occurred throughout the state of Michigan in small lakes, indicating its preference for cooler water temperatures.

Valvata sincera has been reported from several localities in Michigan--Dickinson County (H. B. Baker, 1922, p. 7; Goodrich and van der Schalie, 1939, p. 10); Chippewa County (Goodrich and van der Schalie, 1939, p. 12); and from the Dead River and lakes in Marquette County; the Crow River in Mackinac County; Keweenaw County; and Schoolcraft County (Goodrich and van der Schalie, 1939, p. 25).

Wisconsinan occurrences have been recorded for Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541); Goose Lake, Lenawee County (Hale *et al.*, 1903, p. 101); and a marl pit near Colon, St. Joseph County (Wootton, 1974). *Valvata sincera* has been found in each of the three deposits of the present study.

Valvata tricarinata (Say, 1817)
This species is found from New Brunswick to Virginia, westwwrd to Alberta, South Dakota, and Iowa. Scattered populations also occur as far north as Great Slave Lake and the mouth of the Mackenzie River (La Rocque, 1968, p. 367-368; Clarke, 1973, p. 237) and as far south as Kansas, Oklahoma, Texas, and Alabama (La Rocque, 1968, p. 368).

Valvata tricarinata occurs in large and small lakes, rivers, and streams. It seems to be most characteristic of larger lakes and rarely occurs in temporary aquatic habitats (Harman and Berg, 1971, p. 52; Clarke, 1973, p. 237). Harman and Berg (1971, p. 52) found the populations inhabiting lotic habitats to be depauperate. In most of the lakes of central New York the largest populations were found in shallow areas protected from wave action (Harman and Berg, 1971, p. 52). In Seneca Lake in New York, *Valvata tricarinata* has been found at depths greater than 16 meters (Harman and Berg, 1971, p. 52). The species is not associated with a particular bottom sediment or vegetation (La Rocque, 1968, p. 367; Clarke, 1973, p. 237).

Valvata tricarinata is widespread in Michigan. It has been reported from the Union River, Ontonagon County (Ruthven, 1904, p. 190); Walnut Lake, Oakland County (Hankinson, 1908, p. 235); Magician Lake, Cass and Van Buren Counties (F. C. Baker, 1914); Crawford County (Winslow, 1921, p. 5); Isle Royale (Walker, 1909, p. 293); lakes and rocky rapids of streams in Dickinson County (H. B. Baker, 1922, p. 7, 22); White Lake, Oakland County (F. C. Baker, 1926, p. 50); Menominee, Dickinson, and Chippewa Counties (Goodrich and van der Schalie, 1939, p. 10, 12); the Ann Arbor region, Washtenaw County (Goodrich, 1943, p. 9); and Douglas Lake, Cheboygan County (Moffett, 1943, p. 10).

Wisconsinan specimens have been collected from marl near Howell, Livingston County; Pickerel Lake, Newaygo County; Cedar Lake, Montcalm County; Gratiot County; and Goose Lake, Lenawee County (Hale, 1903, p. 101); Steere's Swamp, Washtenaw County (Goodrich, 1943, p. 9); Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541); White Pigeon and Scotts, St. Joseph County (Semken *et al.*, 1964, p. 830); Lakeland, Livingston County and Marl Lake, St. Joseph County (Camp, 1972, p. 87, 94); and Fourmile Lake, Washtenaw County (Camp, 1973, p. 22). It occurs in each of the deposits of this study.

Family Amnicolidae

Amnicola limosa (Say, 1817)
Amnicola limosa occurs from Newfoundland to Florida and Alberta and from Texas to Florida and Manitoba. It has also been reported from Utah and Nevada (La Rocque, 1968, p. 385-386).

Large and small lakes, rivers, streams, and marshes provide habitats for this species (Berry, 1943, p. 26; Harman and Berg, 1971, p. 47); Clarke, 1973, p. 259). It is common in prolific growths of *Chara, Potamogeton, Vallisneria,* and *Elodea* (Berry, 1943, p. 26; Harman and Berg, 1971, p. 47). The species was found on all types of substrate, but larger populations were present where the habitat was protected from extreme wave and current action (Harman and Berg, 1971, p. 47). The species is often associated with *A. lustrica, Valvata tricarinata, Gyraulus parvus, Helisoma campanulatum,* and *Physa gyrina.*

Amnicola limosa is found in most streams and lakes of Michigan that have not been greatly polluted. It is the most abundant amnicolid in the state (Berry, 1943, p. 23, 30). The species has been collected from the following localities: East Saginaw, Saginaw County (Walker, 1894, p. 128); the Union River and Lake Gogebic, Ontonagon County (Ruthven, 1904, p. 190). Walnut Lake, Oakland County (Hankinson, 1908, p. 235); Isle Royale (Walker, 1909, p. 294); Magician Lake, Cass and Van Buren Counties (F. C. Baker, 1914); Bear Creek, Schoolcraft County; Alger County; and Isle Royale (Winslow, 1917, p. 10, 14); the Au Sable River, Crawford County, and the Pine River, Alcona County (Winslow, 1921, p. 5); from vegetation in lakes and rocky rapids in stream, Dickinson County (H. B. Baker, 1922, p. 7); White Lake, Oakland County (F. C. Baker, 1926, p. 50); Chippewa, Dickinson, Luce, Mackinac, Marquette, Menominee, and Schoolcraft Counties (Goodrich and van der Schalie, 1939, p. 10, 12, 25, 26); the Ann Arbor region, Washtenaw County (Goodrich, 1943, p. 9); Douglas Lake, Cheboygan County (Moffett, 1943, p. 10); and a number of other counties (Berry, 1943, p. 24).

Wisconsinan specimens have been recorded for marl deposits near Howell, Livingston County; Grand Rapids and Cedar Springs, Kent County; Pickerel Lake and Fremont Lake, Newaygo County; Spaulding Twp., Saginaw County; Gratiot County; and Goose Lake, Lenawee County (Hale *et al.*, 1903, p. 102). *Amnicola limosa* has been collected from the deposits in Huron County (Walker and Lane, 1900, p. 251); at Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541); Marl Lake, St. Joseph County (Semken *et al.*, 1964, p. 830; Camp, 1972, p. 994); Fourmile Lake, Washtenaw County (Camp, 1973, p. 22); and near Colon, St. Joseph County (Wootton, 1974). It occurs in each of the deposits of the present study.

Amnicola lustrica Pilsbry, 1890
This species ranges from Massachusetts to Virginia and west to Minnesota and Iowa. *Amnicola lustrica* has also been reported from Newfoundland and southern Ontario (La Rocque, 1968, p. 390-391).

Amnicola lustrica occurs in lakes, rivers, and streams, usually on coarser substrate than *A. limosa* (La Rocque, 1968, p. 390) Harman and Berg, 1971, p. 48). In marl lakes, the species seems to be associated with *Chara* and *Valvata tricarinata* (Harman and Berg, 1971, p. 48). It also occurs with *A. limosa, Gyraulus parvus, Helisoma campanulatum,* and *Physa gyrina.*

It has been recorded for a number of localities in Michigan and is the second most common amnicolid in the state (Berry, 1943, p. 30). *Amnicola lustrica* has been recorded for Carp Lake, Ontonagon County (Ruthven, 1904, p. 190); from beach drift at Walnut Lake, Oakland County (Hankinson, 1908, p. 235); Isle Royale (Walker, 1909, p. 294); Magician Lake, Cass and Van Buren Counties (F.C. Baker, 1914); in lakes and on the sandy bottoms of rivers in Dickinson County (H.B. Baker, 1922, p. 7, 22); for a creek in Dickinson County, a lake and river in Mackinac County, from lakes in Chippewa, Marquette, and Schoolcraft Counties (Goodrich and van der Schalie, 1939, p. 10, 12, 26); Douglas Lake, Cheboygan County (Moffett, 1943, p. 10; and a number of other counties (Berry, 1943, p. 30).

Amnicola lustrica has been collected from Wisconsinan deposits at Grand Rapids and Cedar Springs, Kent County; Pickerel and Fremont Lakes, Newaygo County; Cedar Lake, Montcalm County; Gratiot County; and Goose Lake, Lenawee County (Hale *et al.*, 1903, p. 101). It has also been reported from deposits at Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541), Marl Lake, St. Joseph County (Semken *et al.*, 1964, p. 830; Camp, 1972, p. 94); Lakeland, Livingston County (Camp, 1972, p. 87, 94), Fourmile Lake, Washtenaw County (Camp, 1973, p. 22), and near Colon, St. Joseph County (Wootton, 1974). In the present study it was found in all the deposits.

Order Pulmonata

Family Lymnaeidae

Lymnaea stagnalis (Linnaeus, 1758)
Lymnaea stagnalis has a circumboreal distribution generally between latitudes 40° and 70° (La Rocque, 1968, p. 436; Clarke, 1973, p. 298-299). In the United States it occurs from Vermont and Ohio west to Nevada and Washington (La Rocque, 1968, p. 436). Canadian occurrences are from Quebec west to Alberta and in the Mackenzie and Yukon River drainage area (La Rocque, 1968, p. 436; Clarke, 1973, p. 298-299).

This species has been collected from lakes of various sizes, creeks, rivers, and swamps (Clarke, 1973, p. 299). The type of bottom sediment and amount of vegetation do not seem to influence this species greatly. In the Finger Lakes of New York, *Lymnaea stagnalis* has been found living at a depth of 16 meters on a bottom devoid of rooted vegetation (Harman and Berg, 1971, p. 20). In other parts of New York it is abundant within 1 meter of the surface on debris and floating and decaying aquatic plants (Harman and Berg, 1971, p. 20). *Lymnaea stagnalis* feeds on decaying organic matter and is able to thrive under nearly stagnant conditions (La Rocque, 1968, p. 435; Harman and Berg, 1971, p. 20; Clarke, 1973, p. 300).

Lymnaea stagnalis is generally distributed in the Upper Peninsula of Michigan. It has been recorded for the following locations: Isle Royale (Gleason, 1909, p. 60, 63; Walker, 1909, p. 289); lakes and ponds in Dickinson County (H. B. Baker, 1922, p. 6; Goodrich and van der Schalie, 1939, p. 10); Copper Harbor, Keweenaw County and Chippewa, Menominee and Schoolcraft Counties (Goodrich and van der Schalie, 1939, p. 10-12). It has also been reported for two Lower Peninsula localities—Port Austin, Huron County (Walker and Lane, 1900, p. 251) and Crawford County (Winslow, 1929, p. 4).

Wisconsinan specimens have been found in Gratiot County and at Goose Lake, Lenawee County (Hale *et al.*, 1903, p. 191) and at Oden, Emmet County (F. C. Baker, 1913). In the present study, specimens were collected at Lime and Marl Lakes, Livingston County.

Stagnicola catascopium (Say, 1817)
The general distribution of this snail is from Nova Scotia west to British Columbia and Washington; south in the Rocky Mountain area to nearly 40° N; Atlantic states (Maine to Virginia) west to North Dakota, Iowa, and Kansas (?), and Texas (La Rocque, 1968, p. 440; Clarke, 1973, p. 330-331). The northernmost record of this species is from near Richmond Gulf (56° N) westward along the southern margin of Hudson Bay to the vicinity of Great Slave Lake (above 60° N) (Clarke, 1973, p. 331).

Stagnicola catascopium inhabits lakes, streams, and rivers, but seems to occur more often in a lacustrine habitat (Harman and Berg, 1971, p. 23; Clarke, 1973, p. 331). The species is found on various substrates and in areas of sparse or thick vegetation (Clarke, 1973, p. 331). Harman and Berg (1971, p. 23) collected it most often from lake depths of 1 to 5 meters.

In Michigan, *Stagnicola catascopium* has been reported from Bayport and Port Austin in Huron County (Walker and Lane, 1900, p. 251); Isle Royale (Walker, 1909, p. 290), and from creeks in Delta, Mackinac, and Menominee Counties (Goodrich and van der Schalie, 1939, p. 10, 14). It also is common in Lakes Michigan, Huron, and Erie (Goodrich and van der Schalie, 1939, p. 14).

It has been found in the Wisconsinan deposits of Lime and Mwrl Lakes, both in Livingston County.

Stagnicola palustris (Müller, 1774)
This species is circumboreal, generally occurring north of 38° N except Texas, Arizona, and California where it extends to about 33° N (La Rocque, 1968, p. 445; Clarke, 1973, p. 353). In Canada, it extends as far north as the mouth of the Mackenzie and Yukon Rivers (Clarke, 1973, p. 353).

Stagnicola palustris is a very hardy species and can be found in all types of aquatic habitats. The species is usually more abundant in areas of dense vegetation, but is also found in significant numbers in areas of sparse plant growth (Clarke, 1973, p. 354). The bottom sediment and current activity are not major factors in controlling the distribution of this species (Clarke, 1973, p. 354). *Stagnicola palustris* is essentially omnivorous, eating just about anything it encounters while grazing on the surface film or crawling on the substrate or vegetation (La Rocque, 1968, p. 444; Harman and Berg 1971, p. 21; Clarke, 1973, p. 354). In Livingston County, Michigan, *Stagnicola palustris* inhabits large shallow pools having gravelly bottoms and supporting a *Polygonum-Iris* community and marsh and woodland pools filled with rotting leaves which occasionally dry up during the summer (Archer, 1939, p. 4-5).

S. palustris is recorded for the following Michigan localities: East Saginaw, Saginaw County (Walker 1895, p. 128); Port Austin, Huron County (Walker and Lane, 1900, p. 250); Ann Arbor area, Washtenaw County (Dawson, 1911, p. 38; Kenk, 1949, p. 53; Dewitt, 1955, p. 40); Alcona County (Winslow, 1921, p. 4); Duck Lake in Mackinac County, Chippewa and Menominee Counties (Goodrich and van der Schalie, 1939, p. 10, 11, 13); and Lakeland, Livingston County (Camp, 1972, p. 87).

Wisconsinan specimens have been identified from only the Marl Lake deposit of the present study.

Fossaria obrussa (Say, 1825)
Fossaria obrussa ranges from Newfoundland and Nova Scotia south to Virginia, across the United States to Washington, Oregon, and Utah and south from the Mackenzie District through Alberta and Saskatchewan(?) to northern Mexico, Texas, and Louisiana. The species also occurs in Alabama, southern Quebec, and southern Ontario (La Rocque, 1968, p. 475).

This species is a common inhabitant of mudflat habitats on the margins of ponds and lakes or on the floodplains of rivers and streams (Goodrich and van der Schalie, 1939, p. 15; La Rocque, 1968, p. 475-476). It is often found on debris along shore or sometimes on emergent vegetation near the water line.

F. obrussa has been listed for the following Michigan localities: Isle Royale (Walker, 1909, p. 290); beach drift at Magician Lake, Cass and Van Buren Counties; Alcona County (Winslow, 1921, p. 4); lakes and brooks in Dickinson County (H. B. Baker, 1922, p. 7; Goodrich and van der Schalie, 1939, p. 10); Chippewa, Delta, Mackinac, and Menominee Counties (Goodrich and van der Schalie, 1939, p. 10, 11, 15); the Ann Arbor region, Washtenaw County (Goodrich, 1943, p. 16); and Douglas Lake, Cheboygan County (Moffett, 1943, p. 10).

Specimens of Wisconsin age were obtained from deposits at Goose Lake, Lenawee County, Gratiot County, Cedar Lake in Montcalm County, Pickerel Lake in Newaygo County, and Cedar Springs, Kent County (Hale *et al.*, 1903, p. 101); Ford Lake, Schoolcraft County (Goodrich and van der Schalie, 1939, p. 15); Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541); Marl Lake, St. Joseph County (Semken *et al.*, *1964*, p. 830); Camp, 1972, p. 94); Fourmile Lake, Washtenaw County (Camp, 1973, p. 22); and near Colon, St. Joseph County (Wootton, 1974). *F. obrussa* was found in abundance in each of the three deposits of the present study.

Fossaria parva (Lea, 1841)
F. parva occurs from Connecticut and Maryland west to Idaho and Montana; Ontario west to Alberta; Kansas, Oklahoma, and Texas west to Utah and Arizona; in Kentucky, Tennessee, and Maine; and as far north as the Mackenzie District and Yukon Territory (La Rocque, 1968, p. 478-479; Clarke, 1973, p. 281).

This species is an inhabitant of shallow water areas and muddy banks of lakes, permanent pools and ponds, and rivers (Clarke, 1973, p. 281). F. C. Baker (1928, p. 287) had referred to this snail as an inhabitant of marshy areas, which frequently occurred out of the water on debris and muddy flats. *F. parva* is amphibious, but larger numbers exist in areas of vegetation in shallow water zones than on mud banks (Clarke, 1973, p. 281-282).

F. parva is widely distributed throughout Michigan. It has been collected from a woodland swale at Magician Lake, Cass and Van Buren Counties (F. C. Baker, 1914); a small stream in southwestern Berrien County (F. C. Baker, 1915); an artificial pasture pool in Livingston County (Archer, 1939, p. 13); and in the Ann Arbor vicinity, Washtenaw County (Goodrich, 1943, p. 23).

Records of Wisconsinan specimens are available for a dry lake bed near White Lake, Oakland County (F. C. Baker, 1926, p. 51) and a marl deposit bear Colon, St. Joseph County (Wootton, 1974). It was found in the Little Goose Lake deposit of the present study.

Family Planorbidae

Gyraulus parvus (Say, 1817)
G. parvus occurs throughout the United States and Canada, but has not been recorded for Washington, Oregon, Idaho, Montana, Nevada, Nebraska, Kansas, Oklahoma, Mississippi, Georgia, Tennessee, and South Carolina. Its occurrence in British Columbia is questionable (La Rocque, 1968, p. 491-492). Its northern limit is almost the same as the northern limit of boreal forest (Clarke, 1973, p. 403). It occurs as far south as Cuba (Clarke, 1973, p. 402).

This planorbid occupies almost every type of aquatic habitat. It is most abundant in shallow areas rich in aquatic plants where it occupies a periphytic niche (La Rocque, 1968, p. 491; Harman and Berg, 1971, p. 32; Clarke, 1973, p. 403). *G. parvus* tolerates various substrates and usually thrives at depths of 4 feet or less (La Rocque, 1967, p. 491). In Douglas Lake, Cheboygan County, Michigan, it has been found at depths of 1.8 to 3.0 meters (Moffett, 1943, p. 10). *G. parvus* lives in open water, sedge-mat pools, and *Thuja* pools of Mud Lake, Cheboygan County (Jewell and Brown, 1929, p. 434, 438, 440). *G. parvus* is usually associated with *Amnicola limosa*, *Gyraulus deflectus*, *Lymnaea stagnalis*, *L. elodes*, *Physa* sp., and *Promenetus exacuous* (Clarke, 1973, p. 403). It is also commonly associated with *Pisidium*, *Sphaerium*, and *Helisoma trivolvis*.

G. parvus is one of the more abundant mollusks in Michigan. It has been found at East Saginaw, Saginaw County (Walker 1894, p. 128); Port Austin, Huron County (Walker and Lane, 1900, p. 251); Ontonagon County (Ruthven, 1904, p. 190); Walnut Lake, Oakland County (Hankinson, 1908, p. 235); Isle Royale (Walker, 1909, p. 293); Magician Lake, Cass and Van Buren Counties (F. C. Baker, 1914); Beaver Pond, Chippewa County and Isle Royale (Winslow, 1917, p. 9, 13); temporary swamps and brooks in Dickinson County (H. B. Baker, 1922, p. 7, 15, 18); White Lake, Oakland County (F. C. Baker, 1926, p. 50); East Lake, Cheboygan County (Jewell and Brown, 1929, p. 452); bog lakes and pools in Livingston County (Archer, 1939, p. 4); Alger, Chippewa, Dickinson, Luce, Menominee, and all other Upper Peninsula counties except Gogebic and Iron (Goodrich and van der Schalie, 1939, p. 10, 11, 18); Ann Arbor region Washtenaw County (Dawson, 1911, p. 23; Goodrich, 1943, p. 17; Kenk, 1949, p. 54; Dewitt, 1955, p. 40); and Douglas Lake, Cheboygan County (Moffett, 1943, p. 10).

This species is also often the most abundant aquatic mollusk in Wisconsinan deposits. It has been listed for the following localities: near Howell, Livingston County; Grand Rapids and Cedar Springs, Kent County; Pickerel and Fremont Lakes, Newaygo County; Spaulding Twp., Saginaw County; Cedar Lake, Montcalm County; Gratiot County; and Goose Lake, Lenawee County (Hale *et al.*, 1903, p. 101); Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541); Marl Lake, St. Joseph County (Semken *et al.*, 1964, p. 830; Camp, 1972, p. 94); Scotts, St. Joseph County (Semken *et al.*, 1964, p. 830); Lakeland, Livingston County (Camp, 1972, p. 87); Fourmile Lake, Washtenaw County (Camp, 1973, p. 22); and near Colon, St. Joseph County (Wootton, 1974). It was also found in the three deposits of the present study.

Gyraulus circumstriatus (Tryon, 1866)
This species is found from Quebec, Vermont, Connecticut, Maryland, and Virginia west to

British Columbia, Wyoming, and Illinois. It occurs as far north as the Yukon Territory and as far south as Oklahoma and New Mexico (La Rocque, 1968, p. 495).

G. circumstriatus has been reported from small lakes, temporary ponds and creeks, and swamps (La Rocque, 1968, p. 495; Clarke, 1973, p. 398-399). It occupies a much more restricted habitat than *G. parvus*.

In Michigan, it has been recorded for Alcona County (Winslow, 1921, p. 4) and the Ann Arbor region of Washtenaw County (Goodrich, 1943, p. 23). Wisconsinan specimens have been found near Colon, St. Joseph County (Wootton, 1974) and in each of the deposits of the present study.

Helisoma anceps (Menke, 1830)
H. anceps is found in all the states east of the Mississippi River except Florida and Mississippi (?) and occurs as far west as Texas, Colorado, Wyoming, Oregon, and Washington (?). An isolated occurrence is reported for California. It ranges from Nova Scotia west to British Columbia and northward to Great Slave Lake in Canada (La Rocque, 1968, p. 499-500); Clarke, 1973, p. 430-431). The distribution data were compiled from records for all the subspecies of *H. anceps*.

H. anceps occupies permanent aquatic habitats in large and small lakes, ponds, rivers, and streams (Clarke, 1973, p. 431). Type of bottom sediment and the amount of vegetation do not seem to be major controls in the distribution of the species (Clarke, 1973, p. 431). It occurs at depths of 1 to 4 feet in Magician Lake, Cass and Van Buren Counties (F. C. Baker, 1914).

H. anceps is often associated with *Amnicola limosa*, *Valvata tricarinata*, and *Physa gyrina* (Clarke, 1973, p. 432). Harman and Berg (1971, p. 28) reported that in central New York when *H. anceps* and *Physa* sp. occur together, *H. anceps* usually lives at a depth of 10 cm. to 1 m., while *Physa* sp. occupies the shallower water.

H. anceps is widely distributed in Michigan. It has been found at the following localities: East Saginaw, Saginaw County (Walker, 1894, p. 128); rivers and lakes in Ontonagon County (Ruthven, 1904, p. 190); Isle Royale (Gleason, 1909, p. 60; Walker, 1909, p. 292); Magician Lake, Cass and Van Buren Counties (F.C. Baker, 1914); Schoolcraft, Chippewa, and Keweenaw (Isle Royale) Counties (Winslow, 1917, p. 9, 13); Oscoda and Crawford Counties (Winslow, 1921, p. 4); Dickinson County (H. B. Baker, 1922, p. 6, 15, 18; Goodrich and van der Schalie, 1939, p. 10); White Lake, Oakland County (F. C. Baker, 1926, p. 50); a bog lake in Livingston County (Archer, 1939, p. 3, 4); Chippewa and Menominee Counties (Goodrich and van der Schalie, 1939, p. 10, 11, 15); in the Ann Arbor vicinity, Washtenaw County (Goodrich, 1943, p. 17); and Douglas Lake, Cheboygan County (Moffett, 1943, p. 10).

H. anceps was also abundant during the Wisconsinan. It has been recorded for the deposits at the following localities: Bad Axe, Huron County (Walker and Lane, 1900, p. 251); near Howell, Livingston County; Grand Rapids, and Cedar Springs, Kent County; Pickerel and Fremont Lakes, Newaygo County; Spaulding Twp., Saginaw County; Cedar Lake, Montcalm County; Gratiot County; Goose Lake, Lenawee County (Hale *et al.*, 1903, p. 101); Oden, Emmet County (F. C. Baker, 1913); Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541); Marl Lake, St. Joseph County (Semken *et al.*, 1964, p. 830; Camp, 1972, p. 94); Lakeland, Livingston County (Camp, 1972, p. 87); Fourmile Lake, Washtenaw County (Camp, 1973, p. 22); and near Colon, St. Joseph County (Wootton, 1974). It also occurs in each of the deposits of the present study.

Helisoma campanulatum (Say, 1821)
This planorbid is found from New Hampshire west to Manitoba, North Dakota, Minnesota, and Iowa; New Brunswick south to Pennsylvania, west to Illinois; and north from Saskatchewan to the Great Slave Lake region (La Rocque, 1968, p. 505-506; Clarke, 1973, p. 447-448).

H. campanulatum is an inhabitant of large and small lakes, permanent ponds, and quiet parts of rivers (La Rocque, 1968, p. 505; Clarke, 1973, p. 447-448). The species seems to prefer highly vegetated areas, but tolerates various substrates (Clarke, 1973, p. 448). Associates of this species are *Gyraulus parvus*, *Helisoma anceps*, *Physa gyrina*, and various lymnaeids. Oneida Lake in central New York contains *H. campanulatum* living at depths of 5 to 9 meters (Harman and Berg, 1971, p. 30). In most lakes it lives at much shallower depths (La Rocque, 1968, p. 505).

In Michigan, *H. campanulatum* has been recorded for East Saginaw, Saginaw County (Walker, 1894, p. 128); Carp Lake and Lake Gogebic, Ontonagon County (Ruthven, 1904, p. 190); Isle Royale (Walker, 1909, p. 293); in beach drift at Walnut Lake, Oakland County (Hankinson, 1908, p. 235); in beach drift at Magician Lake, Cass and Van Buren Counties (F. C. Baker, 1914); Brown Lake, Dickinson County (F. C. Baker, 1926, p. 50); Chippewa, Dickinson, and Menominee Counties (Goodrich and van der Schalie, 1939, p. 10, 11, 16); the Ann Arbor region, Washtenaw County (Goodrich, 1943, p. 17); and Douglas Lwke, Cheboygan County (Moffett, 1943, p. 10).

Wisconsinan specimens have been collected from the following localities: Bad Axe, Huron County (Walker and Lane, 1900, p. 251); near Howell, Livingston County; Cedar Springs, Kent County; Pickerel and Fremont Lakes, Newaygo County; Spaulding Twp., Saginaw County; Cedar Lake, Montcalm County; Gratiot County; Goose Lake, Lenawee County (Hale *et al.*, 1903, p. 101); Oden and Kegomic, Emmet County (F. C. Baker, 1913); and near Colon, St. Joseph County (Wootton, 1974). It occurs in each of the three deposits of the present study.

Promenetus exacuous (Say, 1821)
P. exacuous is found from the Atlantic States, Maine to Virginia, westward to Utah, Oregon, Washington, and British Columbia. From British Columbia and Alberta it extends northward to Alaska and the Great Slave Lake region. The southernmost limit is New Mexico and Oklahoma (La Rocque, 1968, p. 510-511; Clarke, 1973, p. 411).

This species occupies a number of aquatic habitats from large and small lakes and ponds to creeks and rivers to marshes (Clarke, 1973, p. 412). Generally it occupies an area of quiet water with a muddy bottom and abundant vegetation (La Rocque, 1968, p. 510; Clarke, 1973, p. 412). Harman and Berg (1971, p. 33) collected this species in great abundance from *Typha* marshes in the Finger Lakes region of New York; mostly from the underside of floating plant leaves and from stems. *P. exacuous* occurs on mud flats in the quiet parts of streams (La Rocque, 1968, p. 510); it is often associated with *Gyraulus parvus*.

P. exacuous has been reported at the following Michigan localities: East Saginaw, Saginaw County (Walker, 1894, p. 128); Lake Gogebic, Ontonagon County (Ruthven, 1904, p. 190); Isle Royale (Walker, 1909, p. 293); lakes and a temporary swamp in Dickinson County (H. B. Baker, 1922, p. 7, 15; Goodrich and van der Schalie, 1939, p. 10); Mud Lake, Cheboygan County (Jewell and Brown, 1929, p. 434); a bog lake and temporary woodland pool in Livingston County (Archer, 1939, p. 3-5); and the Ann Arbor area, Washtenaw County (Goodrich, 1943, p. 17; Kenk, 1949, p. 54).

Wisconsinan deposits have yielded this species from Steere's Swamp, Washtenaw County (Goodrich, 1943, p. 17); Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541); near Colon, St. Joseph County (Wootton, 1974), and at Marl and Little Goose Lakes of the present study.

Family Ancylidae

Ferrissia parallela (Haldeman, 1841)
This species is distributed from Nova Scotia and New England west through the Great Lake states, Quebec, and Ontario to Manitoba, the Dakotas, and Iowa. Scattered populations also occur in Alabama, Louisiana, Texas, Kansas, and Arizona (La Rocque, 1968, p. 522-523).

F. parallela occurs in large and small lakes streams, and rivers (Harman and Berg, 1971, p. 36; Clarke, 1973, p. 482-483). It occupies a periphytic niche, often attached to the undersides of leaves of *Nuphar* and the stems of *Scirpus* and *Typha* (La Rocque, 1968, p. 522; Harman and Berg, 1971, p. 36; Clarke, 1973, p. 482-483). It also occurs in quiet areas of streams on stones, logs, and vegetation (Harman and Berg, 1971, p. 36).

F. parallela occurs throughout Michigan. It has been reported from the Saginaw River, Saginaw County (Walker, 1894, p. 128); the Carp River and Lake Gogebic, Ontonagon County (Ruthven, 1904, p. 190); Dickinson County (H. B. Baker, 1922, p. 7, 22; Goodrich and van der Schalie, 1939, p. 10); Mud Lake, Cheboygan County (Jewell and Brown, 1929, p. 434); Blaney Park in Schoolcraft County, Baraga, Houghton, Keweenaw, Mackinac, and Marquette Counties (Goodrich and van der Schalie, 1939, p. 23); and the Ann Arbor area, Washtenaw County (Goodrich, 1943, p. 18).

Wisconsinan specimens have been found at Marl Lake, St. Joseph County (Semken *et al.*, 1964, p. 830) and Lime Lake, Livingston County of the present study.

Family Physidae

Physa gyrina Say, 1821
This species occurs from Newfoundland to Virginia westward to British Columbia, Minnesota, Illinois, and Kentucky. It also has been recorded for Tennessee, Alabama, Texas, and Arkansas and from the Northwest Territories, Alaska, California, Utah, Idaho, Oregon, (?), Montana, Wyoming, Colorado, and South Dakota (La Rocque, 1968, p. 541, 543; Clarke, 1973, p. 378).

P. gyrina is found in many permanent and permanent and temporary aquatic habitats including lakes, ponds, streams, creeks, rivers, marshes, and swamps (Dawson, 1911, p. 4-44; La Rocque, 1968, p. 541; Harman and Berg, 1971, p. 11; Clarke, 1973, p. 378). Bottom sediment seems to have little effect on the abundance and distribution of this species, but it is generally more common in areas of mud bottoms (La Rocque, 1968, p. 541; Harman and Berg, 1971, p. 12; Clarke, 1973, p. 378). *P. gyrina* is usually associated with submergent vegetation (*Ceratophyllum*, *Chara*, *Elodea*, and *Hypnum*) (Dawson, 1911, p. 26-29; Clarke, 1973, p. 378). Immature *Physa* occupy a periphytic niche (Harman and Berg, 1971, p. 12). In the adult state the snail is also found grazing on the underside of the surface film and on bottom debris (Harman and Berg, 1971, p. 12). Dawson (1911, p. 29) found that *Physa* occurs in greatest numbers in areas of moderate plant cover and organic debris and may be totally absent in areas of luxuriant vegetation. In the pond habitat, *P. gyrina* is usually present in water less than 1 foot deep (Dawson, 1911, p. 43). At Mud Lake, Cheboygan County, Michigan, *P. gyrina* occurred in the open water zone, pools of a sedge mat, and *Thuja* pools (Jewell and Brown, 1929, p. 434-438, 440).

P. gyrina is often associated with *Helisoma anceps* and *H. trivolvis* (Harman and Berg, 1971, p. 12). It also occurs with abundant *Gyraulus parvus*, lymnaeids and sphaeriids.

P. gyrina is the most common physid in Michigan. It has been reported for the following localities: East Saginaw, Saginaw County (Walker, 1894, p. 128); Port Austin, Huron County (Walker and Lane, 1900, p. 251); Isle Royale (Walker, 1909, p. 291); Union River, Ontonagon County (Ruthven, 1904, p. 190); the Ann Arbor area, Washtenaw County (Dawson, 1911; Goodrich, 1943, p. 16; Kenk, 1949, p. 54; DeWitt, 1955, p. 40); a small stream in southwestern Berrien County (F. C. Baker, 1915); Alger, Chippewa, Schoolcraft Counties and Isle Royale (Winslow, 1917, p. 7, 13); Alcona and Crawford Counties (Winslow, 1921, p. 4); stream flats, permanent ponds, temporary swamps, creeks, rivers, and lakes in Dickinson County (H. B. Baker, 1922, p. 6, 15, 18, 22, 26); lakes in Alcona, Crawford, Iosco, Oscoda, Otsego, and Roscommon Counties and the Au Sable River (Clench, 1925, p. 401); Arnott Lake, Cheboygan County (Jewell and Brown, 1929, p. 447); Lily Lake, Keweenaw County (Goodrich, 1931, p. 6); creeks in Menominee and Dickinson Counties, a river in Baraga County, a river and brook in Delta County, Chippewa, Marquette, and Schoolcraft Counties (Goodrich and van der Schalie, 1939, p. 10, 12, 22); and a Black River pond in Cheboygan County (DeWitt, 1955, p. 42).

Wisconsinan deposits containing *P. gyrina* are located near Verona, Huron County (Walker and Lane, 1900, p. 251); near Howell, Livingston County and Spaulding Twp., Saginaw County (Hale *et al.*, 1903, p. 101); in a Saline River terrace in Monroe County (Kapp and Kneller, 1962, p. 140); Marl Lake, St. Joseph County (Semken *et al.*, 1964, p. 830); and Fourmile Lake, Washtenaw County (Camp, 1973, p. 22). It was found in each of the deposits of this study.

Aplexa hypnorum (Linnaeus, 1758)
This species is found from the New England states west to Utah, Idaho, Washington, and British Columbia. It also occurs as far north as Alaska, the Northwest Territories, and Victoria Island, and as an isolated population in Louisiana (La Rocque, 1968, p. 552; Clarke, 1973, p. 385-386).

A. hypnorum is a common physid of ephemeral aquatic habitats—temporary ponds, intermittent streams, roadside ditches, swamps, and marshes (La Rocque, 1968, p. 551-552; Harman and Berg, 1971, p. 16; Clarke, 1973, p. 385). Mud bottoms are usually present and the amount of vegetation is variable (Clarke, 1973, p. 385). In Livingston County, Michigan, the species was found in a tamarack bog pool, *Polygonum* pool, marsh pool, and a pasture pool (Archer, 1939, p. 4, 13).

A. hypnorum occurs throughout Michigan. It has been recorded for East Saginaw, Saginaw County (Walker, 1894, p. 128); Lake Gogebic, Ontonagon County (Ruthven, 1904, p. 190); Isle Royale (Walker, 1909, p. 292); Schoolcraft County and Isle Royale (Winslow, 1917, p. 8, 13); marsh at Magician Lake, Cass and Van Buren Counties (F. C. Baker, 1914); swwmps in Dickinson County (H. B. Baker, 1922, p. 15); tamarack swamp near White Lake, Oakland County (F. C. Baker, 1926, p. 51); Mud Lake, Cheboygan County (Jewell and Brown, 1929, p. 438, 440); Chippewa and Dickinson Counties; Schram's Creek, Mackinac County; and Pelkey Lake, Schoolcraft County (Goodrich and van der Schalie, 1939, p. 10, 12, 13); and the Ann Arbor region, Washtenaw County (Goodrich, 1943, p. 17; Kenk, 1949, p. 55). It was found in the Little Goose Lake deposit of the present study.

Family Carychiidae

Carychium exiguum (Say, 1822)
This species is generally distributed throughout the eastern United States from the Atlantic Coast to New Mexico, Colorado, Iowa, and North Dakota. In Canada, it ranges from Nova Scotia and Newfoundland west to Manitoba. It has also been listed for two isolated localities —Vancouver Island and Alaska (La Rocque, 1970, p. 560).

C. exiguum is found on the margins of marshes, swamps, ponds, and streams; and in woodland areas. It typically occurs in shady, damp areas; in moist leaf debris; in rotten logs; and under bark, stones, and dead wood (La Rocque, 1970, p. 558).

The species occurs throughout the state of Michigan. It is common in the Ann Arbor region (Goodrich, 1943, p. 15) and inhabits grass marsh, willow-red osier-dogwood, and oak-hickory habitats in Livingston County (Archer, 1939, p. 6-8). *C. exiguum* was found in the bog woods of Cheboygan County (Archer, 1936, p. 5) and in an ash-cedar swamp, alder-ash-dogwood-hazel community, and on a floodplain in Dickinson County (H.B. Baker 1922, p. 44, 47, 48). The species was also found in Ontonagon County (Ruthven, 1904, p. 190), Alcona County (Winslow, 1921, p. 4), and a number of other counties (Walker, 1906, chart).

Cain *et al*. (1950, p. 541) found *C. exiguum* in the upper peat unit of the lacustrine deposit of Sodon Lake, Oakland County. It has also been recorded from Wisconsinan peats of Fourmile Lake, Washtenaw County (Camp, 1973, p. 22) and Marl Lake, St. Joseph County (Camp, 1972, p. 94). In this study the species was found at each of the three localities.

Family Polygyridae

Stenotrema leai (Binney, 1842)
S. leai occurs from New Brunswick into Quebec and Ontario and from New York, Pennsylvania, and Virginia across the northern states to Minnesota, South Dakota, Nebraska, and Kansas. It has also been listed for Oklahoma, Texas, and Louisiana (La Rocque, 1970, p. 568-569).

It is found in deciduous and coniferous woods near water bodies and on stream banks. Damp shady areas under stones, logs, bark, and leaf litter are the favored niches (La Rocque, 1970, p. 568).

The range of the species in Michigan is south of the Saginaw-Grand River valley and in the type locality, Alpena County (Walker, 1906, p. 471). It also occurs in Saginaw County (Walker, 1894, p. 126), Ontonagon County (Ruthven, 1904, p. 190), Magician Lake, Cass and Van Buren Counties (F.C. Baker, 1914), Oscoda County (Winslow, 1921, p. 2), Cheboygan County (Archer, 1936, p. 6), Livingston County (Archer, 1939, p. 9-10), in lowlands of Wwshtenaw County (Goodrich, 1943, p. 11), and a number of other counties (Walker, 1906, chart).

S. leai was collected from the Marl Lake deposit, St. Joseph County (Camp, 1972, p. 95). In this study the species was found in the Little Goose Lake and Lime Lake deposits.

Triodopsis albolabris (Say, 1816)
This snail ranges from New Brunswick and Nova Scotia to Florida, westward through the eastern states, Quebec, and Ontario to Manitoba, Minnesota, Iowa, Kansas, Oklahoma, and Texas (La Rocque, 1970, p. 596-597).

T. albolabris lives in mainly deciduous woodlands, but some may live in hemlock and pine woods. It is found in leaf litter and under logs and bark (La Rocque, 1970, p. 596).

This species is abundant throughout the state of Michigan. It has been found in beech-maple, aspen, and bog woods and open fields in Cheboygan County (Archer, 1936, p. 4-7); in a pine forest with lime-rich substrate and along a river in Delta County (van der Schalie, 1939, 1940); and in fern meadow, willow-red osier-dogwood, oak-hickory, oak savanna, aspen-shrub, grass and numerous man-made communities in Livingston County (Archer, 1939). The species has also been recorded for East Saginaw, Saginaw County (Walker, 1894, p. 126); Porcupine Mountains and Lake Gogebic, Ontonagon County (Ruthven, 1904, p. 190); Isle Royale (Walker, 1909, p. 283-284); southwestern Berrien County (F.C. Baker, 1915); Isle Royale and Alger, Chippewa, and Schoolcraft Counties (Winslow, 1917, p. 2, 13); Alcona, Crawford, and Oscoda Counties (Winslow, 1921, p. 2); Dickinson County (Goodrich, 1931, p. 3); Mackinac Island (Archer, 1934, p. 139); Washtenaw County (Goodrich, 1943, p. 10); and several other counties (Walker, 1906, chart).

T. albolabris was found only in the upper part of the Little Goose Lake deposit.

Family Zonitidae

Euconulus fulvus (Müller, 1774)
This species occurs throughout the United States except in the southeastern states and Colorado and Nebraska. It has been recorded from Nova Scotia to British Columbia, Newfoundland, and the Yukon Territory in Canada. The northernmost occurrence in North America is in central Alaska, but it has been found at a higher latitude in west central Greenland (La Rocque, 1970, p. 608-609).

E. fulvus inhabits wooded areas, usually occurring in shady, damp spots in leaf mold, under bark, logs, and stones (La Rocque, 1970, p. 608-609).

This species is of general distribution throughout Michigan. It has been found in beech-maple woods of Cheboygan County (Archer, 1936, p. 4), in pine woods of Delta County (van der Schalie, 1940, p. 368), and stream flats in Dickinson County (H. B. Baker 1922, p. 26). It also occurs in Saginaw County (Walker, 1894, p. 126), Ontonagon County (Ruthven, 1904, p. 190), Isle Royale (Walker, 1909, p. 286), Alcona County (Winslow, 1921, p. 3), and in several other counties (Walker, 1906, chart).

E. fulvus has been reported from peat deposits at Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541), Goose Lake, Lenawee County (Hale *et al.*, 1903, p. 101; Camp, 1972, p. 79), and Marl Lake, St. Joseph County (Camp, 1972, p. 94). In this study it was found at Little Goose, Lime, and Marl Lakes.

Retinella indentata (Say, 1823)
R. indentata occurs from the Atlantic states west to Minnesota, Iowa, Kansas, Oklahoma, and Texas and in Canada from Nova Scotia, Quebec, Ontario, and Manitoba. It has also been reported from Nevada, Utah, northern Mexico, and Baja California (La Rocque, 1970, p. 620).

It lives in damp habitats in deciduous and pine woods. The species often is found under stones and logs and in leaf litter (La Rocque, 1970, p. 619).

R. indentata occurs throughout Michigan. In Cheboygan County, the species lives in beech-maple, pine, and aspen woods (Archer, 1936, p. 4-6). It is associated with fern meadow, oak-hickory, oak savanna, aspen-shrub, and grass communities in Livingston County (Archer, 1939, p. 6, 8-11). It has also been reported from Saginaw County (Walker, 1894, p. 126); Ontonagon County (Ruthven, 1904, p. 190); Copper Harbor, Keweenaw County (Goodrich, 1931, p. 4); Mackinac Island (Archer, 1934); Delta County, (van der Schalie, 1940, p. 368); the Ann Arbor region, Washtenaw County (Goodrich, 1943, p. 15); and a number of other counties (Walker, 1906, chart).

R. indentata has been recovered from Wisconsinan deposits at Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541), Fourmile Lake, Washtenaw County (Camp, 1973, p. 20), and Marl Lake, St. Joseph County (Camp, 1972, p. 95). The species is present in each of the three deposits of the present study.

Nesovitrea binneyana (Morse, 1864)
N. binneyana occurs from Maine to Pennsylvania and west through West Virginia, Ohio, Michigan, Wisconsin, and on to Montana, Wyoming, and Colorado. In Canada it is found in Quebec, Ontario, Nova Scotia, and Manitoba. Questionable records are available for Washington and Alberta (La Rocque, 1970, p. 626-627).

The species lives in moist, mainly deciduous woodlands, wooded floodplains, and some bogs. It occurs under and around stumps and logs (La Rocque, 1970, p. 626).

Walker (1906, p. 471) listed the species as an inhabitant of regions north of Iosco County. It has been identified from Ontonagon County (Ruthven, 1904, p. 190); Isle Royale (Walker, 1909, p. 285); Schoolcraft County and Isle Royale (Winslow, 1917, p. 4, 13); Alcona County (Winslow, 1921, p. 2); Cheboygan County (Archer, 1936, p. 4); Delta County (van der Schalie, 1939, p. 3); and Chippewa, Emmet, Kent, Mackinac, and Marquette Counties (Walker, 1906, chart).

The only Wisconsinan occurrence in Michigan is in the Little Goose Lake deposit, Lenawee County.

Hawaiia minuscula (Binney, 1840)
This species occurs throughout the United States although it is less common in the Pacific Coast states. It is also reported from Newfoundland to Manitoba, Vancouver Island, the Northwest Territories, Mexico, and the West Indies (La Rocque, 1970 p. 640).

H. minuscula seems to prefer moist areas of floodplains, fields, and woodlands. It occurs under stones and wood in leaf litter (La Rocque, 1970, p. 639). In Livingston County, Michigan it lives in willow-red osier-dogwood, oak-hickory, aspen-shrub, and in several artificial communities (Archer, 1939, p. 7-13).

The species is generally distributed in the Lower Peninsula of Michigan. It has been identified from East Saginaw, Saginaw County (Walker 1894, p. 126); Alcona County (Winslow, 1921, p. 3); in the Ann Arbor region, Washtenaw County (Goodrich, 1943, p. 15); and several other counties (Walker, 1906, chart).

Wisconsinan deposits from a Saline River terrace, Monroe County (Kapp and Kneller 1962, p. 140); Marl Lake, St. Joseph County (Camp, 1973, p. 22); and Little Goose Lake of this study have yielded the species.

Zonitoides arboreus (Say, 1816)
The species occurs throughout the United States, Canada, and Mexico (La Rocque, 1970, p. 653-654). Its northernmost occurrence is in Alaska and the Northwest Territories. Woodland habitats, both deciduous and coniferous, seem to be preferred by this snail, but it also has been collected from fields. It is found under logs, stones, and leaf litter (La Rocque, 1970, p. 652-654). In Cheboygan County, Michigan it lives in beech-maple, pine, aspen, and grass communities (Archer, 1936, p. 4-7). In Livingston County, it occupies tamarack bog, grass marsh, sassafras, oak-hickory, aspen-shrub, and several artificial communities (Archer, 1939, p. 5-13).

Z. arboreus is common throughout Michigan. It has been collected from East Saginaw, Saginaw County (Walker, 1894, p. 126); Ontonagon County (Ruthven, 1904, p. 190); Isle Royale (Walker 1909, p. 286; Winslow, 1917, p. 13); Magician Lake, Cass and Van Buren Counties (F. C. Baker, 1914); Schoolcraft, Alger, and Chippewa Counties (Winslow, 1917, p. 4, 13); Alcona and Oscoda Counties (Winslow, 1921, p. 3); Dickinson County (H. B. Baker, 1922, p. 26); Keweenaw County (Goodrich, 1931, p. 5); Mackinac Island (Archer, 1934); Delta County (van der Schalie, 1939, p. 3; 1940, p. 368); the Ann Arbor region, Washtenaw County (Goodrich, 1943, p. 14); and most of the remaining counties (Walker, 1906, chart).

Faunal assemblages of Wisconsinan age containing *Z. arboreus* have been reported from Huron County (Walker and Lane, 1900, p. 250); Cedar Lake, Montcalm County (Hale *et al.*, 1903, p. 101); Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541); Saline River terrace, Monroe County (Kapp and Kneller, 1962, p. 140); Marl Lake, St. Joseph County (Camp, 1972, p. 95); and Fourmile Lake, Washtenaw County (Camp, 1973, p. 22); It was found at each of the three localities of the present study.

Family Limacidae

Deroceras laeve (Müller, 1774)
D. laeve is distributed throughout the United States, Canada, and some parts of Central America. It occurs as far north as Baffin Land and Alaska (La Rocque, 1970, p. 668).

This slug inhabits a wide variety of habitats, but is most common on moist floodplains and terraces under wood, stones, and vegetation. In Livingston County, Michigan it has been found in willow-red osier-dogwood, aspen-shrub, and several artificial communities (Archer, 1939, p. 7, 9-12). Farther north in Cheboygan County this slug is present in beech-maple woodlands under logs and humus (Archer, 1936, p. 4). H. B. Baker (1922, p. 37) collected *D. laeve* from a number of habitats in Dickinson County including a swamp, pine and deciduous woods, floodplains, and a tag alder-dogwood-hazel-ash hollow community.

D. laeve is common and has a general distribution in Michigan. It has been collected in Ontonagon County (Ruthven, 1904, p. 190); Isle Royale (Walker, 1909, p. 287; Winslow, 1917, p. 13); Berrien County (F. C. Baker, 1915); Schoolcraft County (Winslow, 1917, p. 13); Alcona County (Winslow, 1921, p. 3); on Mackinac Island (Archer, 1934); in Delta County (van der Schalie, 1939, p. 3); the Ann Arbor vicinity, Washtenaw County (Goodrich, 1943, p. 12); and Wayne County (Walker, 1906, chart).

This species was found in the Little Goose Lake and Lime Lake deposits of the present study.

Family Endodontidae

Discus cronkhitei (Newcomb, 1865)
This species occurs in all states except Alabama, Mississippi, Louisiana, Georgia, South Carolina, North Carolina, and Tennessee and in all the provinces of Canada (La Rocque, 1970, p. 678).

D. cronkhitei usually lives in damp woodlands under dead wood or in leaf litter (La Rocque, 1970, p. 676).

It is generally distributed throughout Michigan. The species has been recorded from Isle Royale (Walker, 1909, p. 287; Winslow, 1917, p. 13); Magician Lake, Cass and Van Buren Counties (F.C. Baker, 1914); southwestern Berrien County (F. C. Baker, 1915); Chippewa County (Winslow, 1917, p. 5, 13); Alcona and Oscoda Counties (Winslow, 1921, p. 3); Dickinson County (H. B. Baker, 1922, p. 26); Copper Harbor, Keweenaw County (Goodrich, 1931, p. 4); Mackinac Island (Archer, 1934); Delta County (van der Schalie, 1939, p. 3; 1940, p. 368); Livingston County (Archer, 1939, p. 9-10); Washtenaw County (Goodrich, 1943, p. 13); and most of the other counties (Walker, 1906, chart).

D. cronkhitei occurs in the Wisconsinan deposits at Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541); a Saline River terrace in Monroe County (Kapp and Kneller, 1962, p. 140); and Fourmile Lake, Washtenaw County (Camp, 1973, p. 22). It occurs in each of the deposits of the present study.

Helicodiscus parallelus (Say, 1821)
H. parallelus is generally distributed along the Atlantic Coast westward to Manitoba, Minnesota, South Dakota, Iowa, Kansas, and New Mexico. It has also been reported from Idaho, California, and Colorado (?) (La Rocque, 1970, p. 684-685).

This species is found in deciduous and coniferous woodlands, bog hummocks, and along floodplains. A shady moist habitat usually in leaf litter or under logs, bark, and stones seems to be preferred. In Dickinson County, Michigan it occurred in the following habitats: rock outcrops, sandy outwash plains, hardwood forests, cedar-tamarack bog, arborvitae swamp, woodland clearing, and floodplains (H. B. Baker, 1922, p. 24-29). In Livingston County it was found in the oak-hickory community and several man-made habitats (Archer, 1939, p. 8, 10-13).

H. parallelus is of general distribution in Michigan. It has been recorded from Ontonagon County (Ruthven, 1904, p. 190); Isle Royale (Walker, 1909, p. 288; Winslow, 1917, p. 13); Alger and Schoolcraft Counties (Winslow, 1917, p. 6, 13); Alcona County, (Winslow, 1921, p. 3); Mackinac Island (Archer, 1934); Delta County (van der Schalie, 1939, p. 3); the Ann Arbor region, Washtenaw County (Goodrich, 1943, p. 12); and a number of other counties (Walker, 1906, chart).

Specimens of Wisconsinan age have been reported from Gratiot County (Hale *et al.*, 1903, p. 101); Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541); and a Swline River terrace in Monroe County (Kapp and Kneller 1962, p. 140). It occurs in the Little Goose Lake and Marl Lake deposits of the present study.

Family Succineidae

Oxyloma retusa (Lea, 1834)
The general distribution of *Oxyloma retusa* seems to indicate a northern species. It is found from Maine to New York; Ohio and Michigan west to Iowa and Montana; in Kentucky, Georgia, Wyoming and Colorado; from Newfoundland through Quebec to British Columbia; and north to Alaska and the Northwest Territories (La Rocque, 1970, p. 698-699).

Amphibious habits characterize this species. It is often found on shoreline vegetation of water bodies, in plant debris, and in marshes (La Rocque, 1970, p. 697-699).

O. retusa is widely distributed in Michigan. It has been collected from Port Austin, Huron County (Walker and Lane, 1900, p. 250); Ontonagon County (Ruthven, 1904, p. 250); Isle Royale (Walker, 1909, p. 288-289; Winslow, 1917, p. 13); Magician Lake, Cass and Van Buren Counties (F. C. Baker, 1914); southwestern Berrien County (F. C. Baker, 1915); Alger County (Winslow, 1917, p. 6, 13); Alcona County (Winslow, 1921, p. 3); Dickinson County (H. B. Baker, 1922, p. 6, 15, 18, 26) Goodrich and van der Schalie, 1939, p. 10); Menominee County (Goodrich and van der Schalie, 1939, p. 10); Delta County (van der Schalie, 1939, p. 3); the Ann Arbor area, Washtenaw County (Goodrich, 1943, p. 14); and several other counties (Walker, 1906, chart).

Wisconsinan specimens are limited to Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541) and the three deposits of the present study.

Quickella vermeta (Say, 1829)
Confusion in the taxonomy of this species and *Succinea avara* has resulted in sketchy information about the distribution and ecology of this species. It occurs from Delaware to Iowa, in North Dakota and Michigan, Alberta, Manitoba, Ontario, and Quebec. *Q. vermeta* inhabits shoreline areas of lakes and ponds (La Rocque, 1970, p. 699).

Walker (1906, p. 503) reported a general distribution of this species throughout Michigan. The only Wisconsinan occurrences are in the three deposits of the present study.

Family Strobilopsidae

Strobilops affinis Pilsbry, 1893

S. affinis occurs in Ontario and Alberta; the New England states; New Jersey westward to Kansas, northward to Michigan, Wisconsin, and Minnesota, southward to Oklahoma, Texas, Arkansas, and Alabama (La Rocque, 1970, p. 715).

Floodplain and marsh shoreline habitats seem to be favored by this species. *S. affinis* probably has a wide distribution in Michigan; however, confusion with *S. labyrinthica* has limited the number of known occurrences. Walker (1906, chart) records it for Eaton, Genesee, Kent, Lapeer, Lenawee, Macomb, Oakland, St. Joseph, and Washtenaw Counties. It has also been listed for the Ann Arbor region, Washtenaw County (Goodrich, 1943, p. 23) and for grass marsh and fern meadow communities in Livingston County (Archer, 1939, p. 6).

S. affinis of Wisconsinan age was found in each of the deposits of the present study.

Family Pupillidae

Gastrocopta contracta (Say, 1822)

This snail occurs from Maine to Virginia and westward to Illinois, Iowa, and North Dakota; New Brunswick to Manitoba; and in Alaska, Kansas, Oklahoma, Texas, Georgia, Florida, and Mexico (La Rocque, 1970, p. 720-721).

G. contracta is found in moist shady areas of fields and woodlands. It occurs in or around dead logs, bark, and leaf litter (La Rocque, 1970, p. 720). In Dickinson County, Michigan it has been recorded for hardwood forests and floodplains associated with tag alders, dogwoods, hazels, and ashes (H. B. Baker, 1922, p. 25-26). It was found in fern meadow, willow-red osier-dogwood, sassafras, oak-hickory, and artificial communities in Livingston County (Archer, 1939, p. 6-8, 10-11).

G. contracta is found throughout Michigan. It has been recorded for East Saginaw, Saginaw County (Walker, 1894, p. 127); Ontonagon County (Ruthven, 1904, p. 190); Alcona County (Winslow, 1921, p. 4); Cheboygan County (Archer, 1936, p. 6); Delta County (van der Schalie, 1939, p. 3); the Ann Arbor vicinity, Washtenaw County (Goodrich, 1943, p. 13); and a number of other counties (Walker, 1906, chart).

Wisconsinan occurrences of this snail have been reported from Sodon Lake, Oakland County (Cain *et al.*, 1950, p. 541); a Saline River terrace in Monroe County (Kapp and Kneller, 1962, p. 140); and Little Goose Lake and Marl Lake of the present study.

Gastrocopta pentodon (Say, 1821)

G. pentodon occurs throughout the United States except on the Pacific Coast. It is found in the southern provinces of Canada, Mexico, and Guatemala (La Rocque, 1970, p. 723-724).

G. pentodon inhabits wooded and open slopes and forests. It lives amongst plant debris, under bark and dead wood (La Rocque, 1970, p. 723). In Livingston County, Michigan the species was found associated with birch-maple, oak-hickory, and artificial communities (Archer, 1939, p. 5, 6, 8, 10-12).

It has been identified from the following Michigan localities: East Saginaw, Saginaw County (Walker, 1894, p. 127); Benzie, Gratiot, Kalamazoo, Kent, Macomb, Oakland, Ontonagon, St. Clair, and Washtenaw Counties (Walker, 1906, chart).

It has been identified from Wisconsinan deposits near Colon in St. Joseph County (Wootton, 1974) and from Little Goose Lake, Lenawee County of the present study.

Gastrocopta tappaniana (C. B. Adams, 1842)

The species is distributed from Maine to Florida west to Ontario, Minnesota, South Dakota, Iowa, Illinois, Kentucky, and Alabama. It has been reported from Kansas, Oklahoma, Texas, and Arizona (La Rocque, 1970, p. 725-726).

G. tappaniana occurs in low wetlands, marshes, floodplains; usually under wood or plant litter. It was found in an alder swamp in Dickinson County, Michigan (H. B. Baker, 1922, p. 29).

This species is generally distributed throughout Michigan. It has been found at the following localities: East Saginaw, Saginaw County (Walker, 1894, p. 126); Isle Royale (Walker, 1909 p. 285); Alcona County (Winslow, 1921, p. 4); the Ann Arbor vicinity, Washtenaw County (Goodrich, 1943, p. 21); and several other counties in Michigan (Walker, 1906, chart). It occurs in each of the three deposits of Wisconsinan age of the present study.

Vertigo morsei (Sterki 1894)

V. morsei ranges from New York and New Jersey westward to Illinois. It also has been found in southern Ontario and Kansas (La Rocque, 1970, p. 736-737).

Very little information is available on the ecology of this species. It seems to be an inhabitant of floodplains and wetlands.

Walker (1906, p. 516) has recorded this species from Eaton and Kent Counties in Michigan. Goodrich (1943, p. 22) lists it for the Ann Arbor area, Washtenaw County. It has been reported from Wisconsinan deposits in Bay and Washtenaw Counties and from three localities of the present study.

Family Valloniidae

Vallonia pulchella (Müller, 1774)

V. pulchella is found throughout the United States, but its distribution in the southeast and Pacific states is unclear because of the uncertainty of published records. It also occurs from Nova Scotia and Newfoundland westward to Manitoba and in Alaska (La Rocque, 1970, p. 757-758).

The species seems to have a wide range of habitat tolerances. It has been collected from open fields, pastureland, and occurs around old building foundations (Archer, 1939, p. 10-13).

V. pulchella occurs throughout the Lower Peninsula of Michigan. It has been listed for East Saginaw, Saginaw County (Walker, 1894, p. 126); Isle Royale (Walker, 1909, p. 288; 1906, chart); the Ann Arbor area, Washtenaw County (Goodrich, 1943, p. 13); and Ingham, Kent, Lapeer, Mackinac, Monroe, Oakland, and Wayne Counties (Walker, 1906, chart). Wisconsinan specimens have been found at Fourmile Lake, Washtenaw County (Camp, 1973, p. 22) and Little Goose Lake and Lime Lake of the present study.

Vallonia costata (Müller, 1774)
V. costata ranges from Alberta eastward to Quebec, Maine, and New York; southward to Virginia; and westward to Illinois (La Rocque, 1970, p. 760).

This species occurs in a number of diverse habitats from wet floodplains to woodlands to limestone talus slopes (La Rocque, 1970, p. 759).

Walker (1906, p. 521) listed this species as uncommon in Michigan; occurring only in Owosso, Shiawassee and Monroe Counties and on Isle Royale. It has also been found on Mackinac Island (Archer, 1934); in Livingston County (Archer, 1939, p. 10, 12); and Washtenaw County (Goodrich, 1943, p. 22).

V. costata was found in the Wisconsinan deposits at Little Goose and Lime Lakes of the present study.

Family Cionellidae

Cionella lubrica (Müller, 1774)
C. lubrica is found throughout the United States, Canada, and Mexico (La Rocque, 1970, p. 770). It occupies a number of habitats; floodplain, marshy shoreline, woodland, grassy open fields, talus slopes, and rock outcrops (La Rocque, 1970, p. 769-770). It usually occurs under leaf litter, logs, stones, or debris.

The snail is generally distributed throughout Michigan. It has been listed from Ontonagon County (Ruthven, 1904, p. 190); Isle Royale (Walker, 1909, p. 288; Winslow, 1917, p. 13); Schoolcraft County (Winslow, 1917, p. 6); Alcona County (Winslow, 1921, p. 4); Dickinson County (H. B. Baker, 1922, p. 26); Copper Harbor, Keweenaw County (Goodrich, 1931, p. 4); Mackinac Island (Archer, 1934); Delta County (van der Schalie, 1939, p. 3); the Ann Arbor area, Washtenaw County (Goodrich, 1943, p. 13); and a number of other counties (Walker, 1906, chart).

Wisconsinan specimens have been found at Fourmile Lake, Washtenaw County (Camp, 1973, p. 22) and at Little Goose and Marl Lakes of the present study.

CLASS BIVALVIA

Order Teleodesmacea

Family Sphaeriidae

Sphaerium rhomboideum (Say, 1822)
This sphaeriid occurs from Maine to Pennsylvania and west through Ohio, Michigan, Wisconsin, Minnesota, South Dakota, Montana, to Idaho. In Canada it ranges from New Brunswick west to Alberta and possibly British Columbia (La Rocque, 1967, p. 301-302; Clarke, 1973, p. 140-141).

S. rhomboideum is an inhabitant of muddy bottoms of large and small lakes, streams, and rivers (Herrington, 1962, p. 25; Clarke, 1973, p. 141).

In Michigan this species has been recorded from the Saginaw River, Saginaw County (Walker, 1894, p. 129); the Union River, Ontonagon County (Ruthven, 1904, p. 191; Goodrich and van der Schalie, 1939, p. 31); Chippewa County (Winslow, 1917, p. 12; Goodrich and van der Schalie, 1939, p. 31); Tamarack Lake, Dickinson County (H. B. Baker, 1922, p. 40); and Luce, Mackinac, Marquette, Menominee, and Schoolcraft Counties (Goodrich and van der Schalie, 1939, p. 30-31).

Wisconsinan specimens have been found at Marl Lake, St. Joseph County (Semken *et al.*, 1964, p. 830) and at Marl Lake, Livingston County of the present study.

Sphaerium sulcatum (Lamarck, 1818)
S. sulcatum is distributed from New Brunswick to Virginia and west to Illinois, Iowa, Montana, Wyoming, and Alberta (La Rocque, 1967, p. 303-304).

This species is an inhabitant of sandy bottoms of small lakes and pools in rivers and streams (Herrington, 1962, p. 29). It occurs throughout Michigan. *S. sulcatum* has been reported from Chippewa County (Winslow, 1917, p. 11; Goodrich and van der Schalie, 1939, p. 12); Alcona and Crawford Counties (Winslow, 1921, p. 5); in lakes and creeks of Dickinson County (H. B. Baker, 1922, p. 6, 18; Goodrich and van der Schalie, 1939, p. 11); Menominee County (Goodrich and van der Schalie, 1939, p. 11); and the Ann Arbor vicinity, Washtenaw County (Goodrich, 1943, p. 19). It was found in the Wisconsinan deposits of Lime and Marl Lakes of the present study.

Pisidium casertanum (Poli, 1791)
P. casertanum occurs throughout North America, as far north as the southern Arctic Islands. It also occurs in South America, Eurasia, Africa, and Australia (La Rocque, 1967, p. 343; Clarke, 1973, p. 173-174).

This species may inhabit a wide range of aquatic habitats, both permanent and temporary. It has been found in large and small lakes, permanent and temporary ponds, rivers, streams, swamps, and temporary pools (La Rocque, 1967, p. 342; Clarke, 1973, p. 174). *P. casertanum* usually is found on a mud substrate, but may also be found on sand (Clarke, 1973, p. 174). It is usually found in shallow water (0.5 to 3 meters) (La Rocque, 1967, p. 343), but has been collected at depths of 35 to 40 meters in some European lakes (La Rocque, 1967, p. 342-343). It is able to tolerate seasonal desiccation because of its burrowing habit (La Rocque, 1967, p. 343).

P. casertanum is one of the commonest sphaeriids in Michigan. It has been reported for Lake Gogebic, Ontonagon County (Ruthven, 1904, p. 191); Isle Royale (Walker, 1909, p. 296); a brook in Schoolcraft County (Winslow, 1917, p. 12); temporary swamps in Dickinson County (H. B. Baker, 1922, p. 15, 41); near White Lake, Oakland County (F. C. Baker, 1926, p. 51, 52); Independence and Arnold's Lakes, Washtenaw County (Goodrich, 1943, p. 26); and in Fleming and Mill Creeks in Washtenaw County and Ore Creek in Livingston County (Heard, 1965, p. 384, 385).

Wisconsinan specimens have been found in a Saline River terrace in Monroe County (Kapp and Kneller, 1962, p. 140) and a marl deposit near Colon, St. Joseph County (Wootton, 1974). *P. casertanum* was found in each of the three deposits of the present study.

Pisidium obtusale Pfeiffer, 1821
P. obtusale occurs from Maine through Virginia and west through the northern states to Missouri, Iowa, South Dakota, and Minnesota. In Canada it is found from the Northwest Territories and Alberta eastward to Quebec. It

also occurs in Montana and Arizona, Mexico, and Eurasia (La Rocque, 1967, p. 346-347).

This is a species of lakes and ponds. It occurs on various bottom sediments and at various depths (shallow and up to 12 meters) (La Rocque, 1967, p. 347).

In Michigan, *P. obtusale*, including *P. obtusale* form *rotundatum*, has been recorded from Isle Royale (Walker, 1909, p. 296); Dickinson County (H. B. Baker, 1922, p. 7, 42); White Lake, Oakland County (F. C. Baker, 1926, p. 50); and the Ann Arbor area, Washtenaw County (Goodrich, 1943, p. 25).

Wisconsinan specimens have been collected from marl deposits in the Bad Axe area of Huron County (Walker and Lane, 1900, p. 252) and near Colon, St. Joseph County (Wootton, 1974). It occurred in the Lime Lake deposit of the present study.

Paleoecology

GENERAL STATEMENT

Paleoecologic reconstructions of Pleistocene environments have an advantage over those for earlier geologic time for many of the species are still part of the present environment. In the case of lacustrine environments this is even more true. Representatives of all mollusk species collected during this study are still living although some are apparently extinct in southern Michigan. If one may assume that the species occupied the same type of environment in the Wisconsinan as they do today, one needs only to study the ecology of living species to obtain an understanding of their probable ecologic niches during the Wisconsinan. Regrettably, only limited data are available for present species and the lacustrine environment involves a complex interaction of physical, chemical, and biological parameters. In the paleoecologic interpretations that follow, care has been taken to consider as many of these factors as possible.

In this study several terms are used for describing the occurrence of mollusks in an environment. Indigenous species are those species that lived in the environment where the sediment in which they are preserved was deposited. They are found throughout a lithologic unit representing that environment, often in large numbers. The nature of the species must be considered for some species are known to be extremely abundant, *e.g. Valvata tricarinata, Fossaria* sp., and *Gyraulus parvus* (La Rocque, 1966, p. 18) whereas others *e.g.* freshwater limpets, are never very common even in favorable habitats. Intruders are species that are foreign to the area where they are preserved. They are often scattered throughout a section and are less abundant than the indigenous species. Lacustrine deposits are predominantly thanatocoenoses, that is, mixtures of both indigenous species and intruders that have been deposited together after death.

The abundance of a species at any time is partly determined by the availability of its specific ecologic requirements and the effective population of its competitors and predators. However, this relative abundance in the natural environment of a particular species may be difficult to estimate on the basis of its relative abundance in a fossil assemblage. As an example, currents and waves may lead to transport and hydrodynamic sorting of empty shells in the shore zone.

Among the indigenous species and intruders, certain species may be considered significant species. A significant species is one that makes up a considerable volume of the sample, *i. e.*, it is either extremely abundant or of large shell size (*e.g.*, *Helisoma*). Thus, not all indigenous species are necessarily significant, nor are all intruders necessarily insignificant.

The sediment is the key to the geologic history of a lake basin but in most cases only the latest stages of a lake history are obtained by pit sampling such as that used in this study. It must be remembered that the interpretation made from a section is only valid for the immediate area. It does not necessarily apply for the entire lake basin. In the typical marl lake the stratigraphic column contains three major sediment types. The original lake basin formed on till or outwash, so the lowermost sediment is gravel and sand. Above this is a unit of marl, often of considerable thickness. The section is capped by a peat unit, representing the final filling-in of the lake. Thus, the sediment indicates a gradual transformation of the lacustrine environment into a terrestrial one.

The fossils enclosed within the sediment units also reflect the change in habitat. Naiades, characteristic open water inhabitants, often dominate the lower sandy unit. Freshwater mollusks, ostracodes, diatoms, and charophytes are characteristic of the marl zone. The peat and muck, if fossiliferous, contain mainly land snails, insect remains, and plant fragments.

The molluscan fauna allows a further breakdown of the sediment units not readily observable in the sediment column. Dexter (1950), in his study of Dollar Lake, Portage County, Ohio, reported a water level rise of 8 to 10 inches during periods of increased runoff and precipitation and a corresponding decrease of 7 to 8 inches during droughts. These fluctuations respectively increased and decreased the range of freshwater mollusks living in nearshore areas (Dexter 1950). The range of terrestrial forms living in the fringing marsh would also be affected by the fluctuations, but in the opposite direction. These changes in distribution are reflected in the sediment column as variation in the abundance of species from collection to collection. Temperature conditions may also be determined from an analysis of the fauna. Certain mollusks and assemblages of mollusks, *e.g. Lymnaea stagnalis* and ctenobranchs in general are indicative of cooler wwter temperatures and presently only inhabit more northern regions (La Rocque, 1966; Frye and Leonard, 1967, p. 434).

LITTLE GOOSE LAKE, LENAWEE COUNTY

Glacial Geology. Little Goose Lake is located along an interlobate moraine of the Saginaw and Erie lobes (Martin, 1955; Zumberge, 1960, p. 179; Striker and Harmon, 1961, p. 54). To the west of the lake is an extensive pitted outwash plain and to the north lies a northeast-southwest trending esker. These features, considered with the overall topography of the area, indicate that the ice front must have extended in a northwest-southeast direction and have been very near the present Goose Lake for a considerable length of time. The lake formed from the melting of a stagnant ice block covered by outwash deposits after the ice retreated from this area during the Carey Subage (Striker and Harmon, 1961, p. 54). Little Goose Lake was part of a much larger lake which also included Lake Columbia and Goose Lake as indicated by buried marl deposits along parts of the shoreline and extensive muck soils in the surrounding lowlands (Striker and Harin the surrounding lowlands (Striker and Harmon, 1961, map 1). Goose Lake revealed several different surficial sediment types. The sediment directly underlying the marsh vegetation was a dark-brown peat. This material caps a low wave-cut bluff above the beach zone. Several auger borings were made in the marsh on the north side of the lake. The borings revealed continuous muck and peat to a depth of 3 feet. Striker and Harmon (1961, map 1) reported that the soil in this area is Edwards Muck. The Edwards Series overlies marl in marshes and lowlands (Striker and Harmon, 1961, p. 10). A profile description of the Edwards Muck is given below.

0-12 in.	very dark-brown to black; muck
12-24 in	brown to very dark brown; muck, may contain a few small shell fragments
below 24 in.	light gray to dark gray, marl, fossiliferous

(Adapted from Striker and Harmon, 1961, p. 10)

Along the eastern shore the peat zone is less than 1 foot thick. Below the muck and peat is a layer of gray marl, at least 6 feet in thickness as determined by an auger boring.

At times of low water the beach zone at Little Goose Lake is covered by a layer of mollusk shells and fragments. Below this thin layer of coarse shell material is a zone of sandy shell marl underlain by a gray marl. The sandy marl may be the result of the winnowing action of waves which has removed the finer sediments. Marl was deposited in the shallower areas of the lake forming terrace-like deposits. Nearshore areas were soon filled in by marl accumulation of terrigenous detritus, encroachment of plants, and lowering water level. Marsh vegetation claimed nearshore areas and peat was deposited on the marl. Wave action during times of high water eroded a section of the peat and formed a beach and wave-cut bench.

Stratigraphic Section

Unit	Collection	Description	Thickness (Inches)
1	1-2	Dark-brown peat, abundant plant matter, some mollusk shells. Upper 12 inches not sampled	16
2	3-4	Peat-marl transition	4
3	5-11	Light tan marl fossiliferous (mollusks, ostracodes, charophytes)	14
4	12-33	Brown marl, fossiliferous (mollusks, ostracodes, charophytes, abundant plant matter, peaty in upper part	44
5	34-43	Dark gray marl, fossiliferous (mollusks, ostracodes, charophytes). Coll. 41-43 not sieved. Coll. 42 and 43 are 4 in. thick	24
		Total	102

Faunal abundance

Hale *et al.* (1903) listed the following Mollusca from the Goose Lake marl without abundance data.

TABLE 2. Pleistocene Molluscan Fauna of Goose Lake Deposit. (Adapted from Hale *et al.* 1903)

Naiades	*Fossaria humilis*
	Fossaria obrussa
Pisidium adamsi	*Gyraulus parvus*
P. ferrugineum	*G. deflectus*
P. nitidum	*Helisoma anceps*
P. variabile	*H. campanulatum*
Sphaerium rhomboideum	*Lymnaea stagnalis* (?)
S. simile	*Physa elliptica*
S. striatinum	*P. heterostropha*
Amnicola limosa	*Carychium exiguum*
A. lustrica	*Euconulus fulvus*
A. walkeri	*Gastrocopta pentodon*
Valvata sincera	*Vertigo elatior*
V. tricarinata	

The mollusks collected in the present study are listed in Table 3 and the more important species are included in Plates I through IV. The Little Goose Lake section yielded 36 mollusk species, including 22 terrestrial pulmonates, 4 ctenobranchs, 9 aquatic pulmonates, and 1 sphaeriid.

Indigenous mollusks are *Fossaria obrussa, Gyraulus parvus, Helisoma anceps, Physa gyrina,* and *Pisidium casertanum* in the marl part of the section (Units 3, 4, and 5). Collections from the lower 4 feet of the section (Units 4 and 5) yield several other indigenous species ---*Amnicola limosa, A. lustrica, Valvata tricarinata, Gyraulus circumstriatus,* and *Helisoma campanulatum. Carychium exiguum, Gastrocopta contracta, G. tappaniana, Helicodiscus parallelus, Oxyloma retusa, Quickella vermeta, Strobilops affinis,* and *Vertigo morsei* appear to be indigenous during the deposition of the peat (Unit 1). The significant species are *Gastrocopta tappaniana, Oxyloma retusa, Quickella vermeta, Fossaria obrussa, Gyraulus parvus,* and *Pisidium casertanum.* The peat also contains a significant number of *Carychium exiguum, Helicodiscus parallelus,* and *Strobilops affinis.*

Fossaria obrussa and *Gyraulus parvus* show two peaks of maximum abundance (Plate III), one in the upper part of the marl (Unit 3) and the other 40 inches below the surface (Unit 4). *Pisidium casertanum* exhibits similar peak abundances, but the large number contained in Collection 26 (Plate IV) may be due to sampling error. The terrestrial pulmonates---*Gastrocopta tappaniana, Oxyloma retusa, Quickella vermeta,* and *Vertigo morsei* undergo a sudden increase in number between the peak abundance of the aquatic forms.

Ostracodes are present in most of the collections, but are most abundant in lower Unit 4, the brown marl. *Candona ohioensis* is extremely common from Collection 24 to 33. *Cypridopsis vidua* is abundant throughout Unit 4 and upper Unit 3. *Candona acuta, C. truncata, Candona* sp., and *Cyclocypris* sp. have also been identified.

The relative abundance of shells in each collection is fairly constant throughout the Little Goose Lake section (Table 3). Lower Unit 3 (Coll. 8-11) contained the lowest estimated total number of mollusks.

Nature of the environment

The mollusks of Little Goose Lake inhabited the waters and shoreline of a large kettle lake. Unit 5, a dark gray marl, probably re-

TABLE 3. VERTICAL DISTRIBUTION OF PLEISTOCENE FAUNAL ELEMENTS OF THE LITTLE GOOSE LAKE SECTION

Unit	COLLECTION	*Carychium exiguum*	*Cionella lubrica*	*Deroceras laeve*	*Discus cronkhitei*	*Euconulus fulvus*	*Gastrocopta contracta*	*Gastrocopta pentodon*	*Gastrocopta tappaniana*	*Hawaiia minuscula*	*Helicodiscus parallelus*	*Nesovitrea binneyana*	*Oxyloma retusa*	*Quickella vermeta*	*Retinella indentata*	*Stenotrema leai*	*Striatura ferrea*	*Strobilops affinis*	*Triodopsis albolabris*	*Vallonia costata*	*Vallonia pulchella*	*Vertigo morsei*	*Zonitoides arboreus*	*Amnicola limosa*	*Amnicola lustrica*	*Valvata sincera*	*Valvata tricarinata*	*Aplexa hypnorum*	*Fossaria obrussa*	*Fossaria parva*	*Gyraulus circumstriatus*	*Gyraulus parvus*	*Helisoma anceps*	*Helisoma campanulatum*	*Physa gyrina*	*Promenetus exacuus*	*Pisidium casertanum*	TOTAL SPECIMENS COUNTED	ESTIMATED TOTAL PER COLLECTION	RELATIVE ABUNDANCE OF OSTRACODES
	1	21.3	0.1	-	-	0.3	3.0	-	16.6	1.0	10.0	-	2.6	7.9	0.9	1.0	-	7.9	-	-	0.4	1.9	1.3	-	-	-	0.1	-	13.7	-	-	5.8	0.2	-	-	-	1.8	978	1500	R
PEAT	2	22.6	-	-	-	-	3.1	0.1	13.6	2.0	18.7	-	1.2	6.1	1.2	0.6	-	7.2	0.1	0.3	0.2	1.9	2.3	-	-	-	-	0.1	17.5	-	-	5.5	0.1	-	-	-	1.4	1000	2500	R
	3	6.8	-	-	-	-	1.9	-	4.0	0.1	6.1	-	3.6	7.3	1.6	0.4	0.6	3.7	-	-	-	2.1	0.3	-	-	-	-	0.1	40.9	-	-	10.2	-	-	0.1	-	5.3	977	3000	-
PEAT-MARL	4	2.8	-	-	-	-	0.3	-	1.6	-	0.6	0.1	0.5	5.0	0.2	-	-	-	-	-	-	1.2	0.4	-	-	-	-	-	71.9	-	-	9.9	0.3	-	0.5	-	5.2	982	6000	R
	5	0.5	-	-	-	-	-	-	0.6	-	0.2	-	2.0	1.7	0.1	-	-	0.1	0.1	-	-	0.4	-	-	-	-	-	0.1	38.9	-	-	22.6	-	-	2.1	-	9.8	995	6000	C
	6	0.1	-	-	-	-	-	-	0.3	-	-	-	1.6	2.1	0.1	-	-	-	-	-	-	0.5	-	-	-	-	-	-	31.3	-	-	39.9	0.1	-	0.7	-	3.5	1000	6000	R
	7	-	-	-	-	-	-	-	0.1	-	-	-	1.6	0.3	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	57.9	-	-	39.1	-	0.2	0.2	-	0.5	1000	2000	-
TAN MARL	8	-	-	-	-	-	-	-	0.2	-	0.1	-	1.6	0.3	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-	37.7	-	-	30.4	-	-	-	-	0.6	1000	1500	-
	9	0.3	-	0.1	-	-	-	-	3.9	-	0.1	-	0.5	7.2	-	-	-	0.3	-	-	-	0.2	0.1	-	-	-	-	-	66.6	-	-	17.8	-	0.4	-	-	0.2	976	1500	R
	10	0.3	-	-	-	-	-	-	18.8	-	-	-	1.4	12.0	-	-	-	0.7	-	-	-	0.1	0.1	-	-	-	-	-	66.9	-	-	7.4	0.2	-	-	-	0.1	1002	1500	-
	11	0.5	-	0.1	-	-	-	-	22.2	-	-	-	0.7	13.2	-	-	-	3.0	-	-	-	-	-	-	-	-	-	-	30.2	-	-	8.9	-	-	-	-	-	1000	1500	-
	12	-	-	-	-	-	-	-	37.2	-	-	-	1.9	20.6	-	-	-	0.6	-	-	-	-	-	-	-	-	-	-	35.3	-	-	0.9	-	-	-	-	-	1000	3000	-
	13	-	-	0.1	-	-	-	-	30.2	-	-	-	2.1	26.5	-	-	-	0.6	-	-	-	0.6	-	-	-	-	-	-	21.4	-	-	0.1	-	-	-	-	-	999	6000	-
	14	0.1	-	0.2	-	-	-	-	40.1	-	-	-	8.6	46.9	-	-	-	0.6	-	-	-	1.1	-	-	-	-	-	-	1.6	-	-	0.2	-	-	-	-	0.1	1000	6000	-
	15	0.2	-	0.1	-	-	-	-	37.9	-	-	-	2.3	31.0	-	-	-	0.5	-	-	-	1.6	-	-	-	-	-	-	6.2	-	-	0.6	-	-	0.1	-	0.3	1000	3500	-
	16	-	-	0.1	0.1	-	-	-	51.2	-	-	-	3.0	33.3	-	-	-	0.7	-	-	-	4.3	-	-	-	-	-	-	5.6	-	-	0.8	-	-	-	-	0.2	1000	3500	R
	17	-	-	0.1	-	-	-	-	47.2	-	-	-	3.2	39.2	-	0.6	-	8.1	-	-	-	3.9	0.1	-	-	-	-	-	4.2	-	-	0.6	-	-	-	-	0.1	1000	3500	-
	18	0.1	-	-	-	-	-	-	20.7	-	-	-	7.8	20.6	-	0.1	-	0.1	-	-	-	5.7	-	-	-	-	-	-	10.3	-	-	0.6	-	-	-	-	-	1000	4000	-
	19	-	-	-	-	-	-	-	28.7	-	-	-	11.6	26.2	-	0.2	-	0.2	-	-	-	10.1	-	0.1	-	-	-	-	20.4	-	-	0.4	-	0.1	-	-	-	1000	2000	-
	20	-	-	-	-	0.1	-	-	6.9	-	-	-	17.0	42.2	-	0.1	-	0.2	-	-	-	11.2	-	-	-	-	-	-	22.7	-	0.1	1.8	-	0.3	-	-	-	1000	3000	R
	21	-	-	-	-	0.1	-	-	12.0	-	-	-	10.8	30.2	-	-	-	0.2	-	-	-	5.1	-	-	-	-	-	-	28.8	-	0.1	3.4	-	0.3	-	-	-	1000	3000	R
	22	-	-	-	-	-	-	-	6.5	-	-	-	16.0	21.6	-	0.1	-	0.1	-	-	-	8.6	0.1	-	-	-	-	-	23.6	-	0.2	23.33	-	-	-	-	0.1	1010	2000	C
	23	-	-	0.2	-	0.1	-	-	2.8	-	-	-	12.2	7.9	-	0.1	-	-	-	-	-	3.3	-	-	-	-	-	-	33.0	-	0.3	38.1	-	-	-	-	-	1004	2000	R
BROWN MARL	24	-	-	0.5	-	0.3	-	-	0.8	-	-	-	13.7	4.0	-	-	-	-	-	-	-	3.2	-	-	-	-	-	-	47.0	-	1.0	25.4	0.2	-	-	-	1.7	1000	2000	R
	25	-	-	-	-	-	-	-	0.2	-	-	-	5.0	0.7	-	-	-	0.3	-	-	-	0.5	-	-	-	-	0.1	-	21.9	-	-	69.2	0.2	-	0.1	-	1.2	1000	4000	A
	26	-	-	-	-	-	-	-	0.9	-	-	-	8.0	1.2	-	-	-	-	-	-	-	3.2	0.1	-	-	-	-	-	13.8	-	-	32.2	-	-	-	-	40.4	1000	4000	C
	27	-	-	-	-	-	-	-	1.0	-	-	-	9.8	4.7	-	-	-	-	-	-	-	3.0	-	-	0.1	0.1	0.1	-	24.2	-	0.1	54.4	-	-	-	-	3.6	1001	3500	A
	28	-	-	-	-	0.1	-	-	0.8	-	-	-	17.8	1.3	-	-	-	-	-	-	-	2.0	-	-	0.1	-	-	-	31.7	-	0.2	45.8	-	-	-	-	0.2	1000	4000	C
	29	-	-	-	-	-	-	-	0.3	-	-	-	2.9	0.1	-	-	-	-	-	-	-	1.6	-	-	0.2	-	0.1	-	25.3	-	1.6	64.2	0.1	-	0.2	-	0.4	1000	4000	C
	30	-	-	-	-	0.1	-	-	-	-	-	-	2.6	0.3	-	-	-	-	-	-	-	1.0	-	-	-	-	0.5	-	26.6	-	3.4	63.3	0.6	-	0.6	-	0.9	1100	5000	A
	31	-	-	-	-	-	-	-	-	-	-	-	2.0	-	-	-	-	-	-	-	-	0.2	-	0.1	-	-	0.1	-	23.0	-	6.3	63.1	0.2	-	0.9	0.1	2.9	1001	5000	A
	32	-	-	-	-	-	-	-	-	-	-	-	4.1	0.2	-	-	-	-	-	-	-	0.6	-	-	0.2	-	0.1	-	26.8	0.1	8.2	31.3	0.2	-	1.6	-	6.5	999	6000	A
	33	-	-	-	-	-	-	-	-	-	-	-	1.0	0.1	-	-	-	-	-	-	-	0.2	-	0.2	1.6	-	2.7	-	32.3	0.1	6.1	49.7	0.5	0.5	3.4	-	1.6	1000	6000	C
	34	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	0.1	-	0.7	6.1	-	12.3	-	17.2	-	7.1	44.0	1.3	0.7	4.8	-	3.3	999	6000	C
	35	-	-	-	-	-	-	-	-	-	-	-	1.8	0.1	-	-	-	-	-	-	-	-	-	1.0	4.6	-	9.0	-	19.0	-	8.3	50.0	0.9	0.5	2.5	0.1	2.3	1010	6000	C
GRAY MARL	36	-	-	-	-	-	-	-	-	-	-	-	2.7	0.2	-	-	-	-	-	-	-	0.3	-	0.3	0.9	-	3.6	-	26.2	0.1	3.3	36.3	0.3	0.1	2.3	0.1	3.3	1000	6000	R
	37	-	-	-	-	-	-	-	-	-	-	-	1.6	0.1	-	-	-	-	-	-	-	0.2	-	0.5	4.4	-	9.5	-	17.2	-	6.0	40.0	0.7	0.3	6.0	0.6	13.0	1007	6000	C
	38	-	-	-	-	-	-	-	-	-	-	-	1.6	-	-	-	-	-	-	-	-	0.1	-	0.2	2.1	-	8.5	-	10.0	-	9.3	58.1	0.1	0.2	1.7	0.1	8.0	1000	3500	C
	39	-	-	-	-	-	-	-	0.1	-	-	-	0.4	0.2	-	-	-	-	-	-	-	0.1	-	0.2	4.4	-	22.9	-	8.6	0.1	7.7	50.6	0.4	0.4	0.7	-	3.3	1010	3500	R

A --- abundant
C --- common
R --- rare

presents the initial marl deposition in the lake. The aquatic molluscan fauna was most diverse during this stage. Twelve species were present. *Gyraulus parvus* was the dominant species during this early stage; followed by *Fossaria obrussa*. *Gyraulus parvus* favors water from 1 to 4 feet deep with abundant vegetation (La Rocque, 1968, p. 491; Harman and Berg, 1971, p. 32). *F. obrussa* is an amphibious form living on debris in shallow water and along the shoreline (La Rocque, 1968, p. 475). Many species of *Fossaria* are known to live on emergent vegetation and mud flats (La Rocque, 1968, p. 467-482; Harman and Berg, 1971, p. 20). Terrestrial gastropods are only represented by small numbers of *Oxyloma retusa* and *Quickella vermeta*. Thus, the mollusks of early Little Goose Lake tend to indicate a time of shallow water and adequate vegetation for the area of the section. The paucity of land snails may be explained by the absence of suitable habitats along the shore. Marsh vegetation and mud flats are inhabited by some succineids (Strandine, 1941; La Rocque, 1970, p. 708), which accounts for the presence of *Oxyloma* and *Quickella*. The absence of any distinctive woodland species such as *Nesovitrea electrina, Stenotrema leai*, and *Zonitoides arboreus* (Frye and Leonard, 1967, p. 433; La Rocque, 1970, p. 624, 652) indicates that the immediate area probably did not yet support deciduous forests. If the shoreline did have favorable habitats for terrestrial snails perhaps it was at some distance from the section and the shells were not washed into the area. The succineids could have reached the area on emergent vegetation and floating plants and debris.

Cooler water temperatures are suggested by the presence of large numbers of ctenobranchs in Unit 5. Frye and Leonard (1967, p.433) have indicated that a predominance of ctenobranchs points to cooler water temperature.

The fluctuations in ostracode abundance are at least partially due to temperature variations (Furtos, 1933, p. 420; Delorme, 1971, chart). *Candona acuta*, which is common in Unit 5, may be typical of cooler water habitats (Hoff, 1942, p. 100; Staplin, 1963, p. 763; Teeter, 1970, p. 587). *Cypridopsis vidua* tolerates most freshwater environments and is uncommon only in cold water with little bottom vegetation (Staplin, 1963, p. 1183; Teeter, 1970, p. 587). Thus the presence of *C. vidua* in Units 4 and 3 suggests an increase in water temperature. *Candona ohioensis* is most common in lakes bordered by mixed forests and ranges northward to the southern edges of the boreal forest (Delorme, 1970, p. 1112).

The sedimentary boundary between Unit 5 and Unit 4, a brownish marl, is irregular and not well marked by changes in mollusk abundance. *Gyraulus parvus* is extremely abundant (69.2%) in the lower half of this unit, but abruptly drops in numbers (3.4%) in Collection 21. *Fossaria obrussa* also exhibits a decrease in abundance in the upper part of Unit 4. The diversity of terrestrial gastropods is much greater than in Unit 5---now representatives of 12 species are present. In the upper part only 4 species of aquatic mollusks are present. The reduction in abundance of *F. obrussa* and *G. parvus* correlates well with the increase in abundance of *Deroceras laeve, Gastrocopta tappaniana*, and *Quickella vermeta*. This suggests that the lake waters temporarily receded from the area of the section probably due to a drought. During this time terrestrial forms may have been the indigenous species. Unit 4 sediments seem to have a peaty nature at this level. A thin buried peat zone was noted in an earlier study of the Little Goose Lake area (Camp, 1972, p. 76). The absence of ctenobranchs in upper Unit 4 supports a warming climatic trend.

Unit 3, a tan marl, marks the resumption of aquatic conditions in the area. The boundary between Units 4 and 3 is irregular and marked by an increase in the diversity of mollusks. Table 3 shows an apparent increase in percentage abundance of mollusks in lower Unit 3; however, this is only the result of picking a larger volume of sediment to obtain 1000 individuals.

The gradual transition from the marl of Unit 3 to the peat of Unit 1 is designated as Unit 2. This unit marks the second major encroachment of plants or the section area. Peat began to form in the shallow nearshore zone.

Peat deposition continued in Unit 1 allowing terrestrial snails to repopulate the area. The presence of *Helicodiscus parallelus, Retinella indentata, Stenotrema leai*, and *Zonitoides arboreus* points to the occurrence of deciduous woodlands near the lake (Frye and Leonard, 1967, p. 433; La Rocque, 1970, p. 619, 684).

Molluscan Ecology

General. A general study of the living mollusks in the shallow littoral zone of Little Goose Lake, Lenawee County allowed tentative comparison with the Wisconsinan fauna. Only aquatic species were examined for it is assumed that the terrestrial fauna is only partially represented in the Wisconsinan peat. The sampling was random and quantitative data equivalent to those obtained in the Wisconsinan section were not obtained. As a result the data are tentative. A more comprehensive molluscan survey of this lake and several other lakes in southern Michigan is in the planning stage.

Fauna. Of the 14 aquatic mollusks found in the Wisconsinan section only 5 representatives were found living in the lake (Table 6). The only ctenobranch found at Little Goose Lake was *Amnicola limosa*. It is found on *Chara* in depths up to 4 feet where sampling was terminated. *Fossaria obrussa* is very abundant along the shoreline in water up to 1 foot deep. It is often found in a periphytic niche, usually on floating vegetation such as water milfoil. Woody debris along the shoreline is often covered with this snail.

Table 6. Comparison of Wisconsinan and Living Aquatic Mollusks, Little Goose Lake.

Wisconsinan Species	Living Species
Amnicola limosa	*Amnicola limosa*
Amnicola lustrica	
Valvata sincera	
Valvata tricarinata	
Aplexa hypnorum	
Fossaria obrussa	*Fossaria obrussa*
Fossaria parva	
Gyraulus circumstriatus	
Gyraulus parvus	*Gyraulus parvus*
Helisoma anceps	
Helisoma campanulatum	*Helisoma campanulatum*
Physa gyrina	*Physa gyrina*
Promenetus exacuous	
Pisidium casertanum	*Pisidium casertanum*

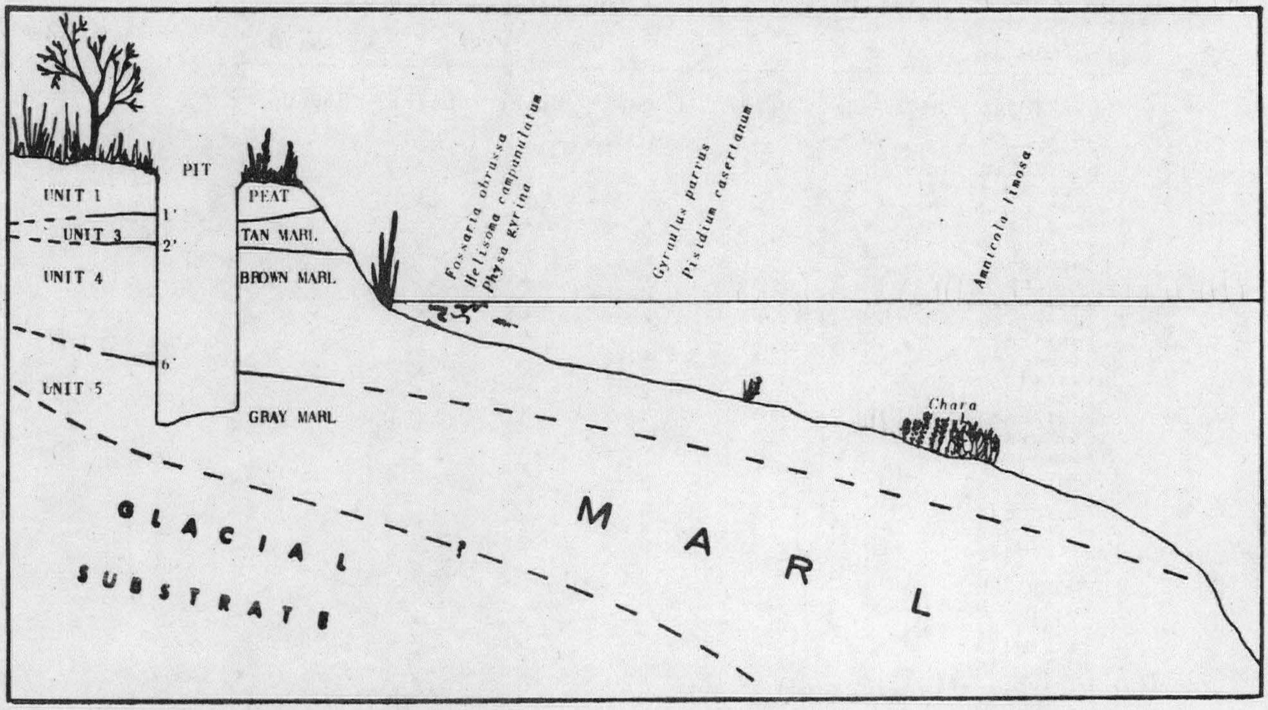


Figure 4 Cross Section of Shoreline and Littoral Zone, Little Goose Lake, Lenawee County, Michigan

Gyraulus parvus is found in abundance on and in the marly bottom sediments. The specimens were collected by removing samples of the bottom material. A few specimens were also collected from floating plants. *G. parvus* is found in bottom sediment out to depths of 4 feet where sampling was terminated.

Pisidium casertanum is also common in and on the marl substrate out to depths of 4 feet.

Helisoma campanulatum is an inhabitant of the periphytic niche, found on water milfoil, *Potamogeton*, reeds, and cattails. It is rarely found on *Chara*. *H. campanulatum* occurs wherever plant growth is well established. *Physa gyrina* either occupies a periphytic niche or grazes on the underside of the surface film. It seems to always be associated with an area of plant growth.

The apparent absence of abundant ctenobranchs from theshallow littoral zone of Little Goose Lake is probably the result of inadequate collection for they have been listed for many lakes in Michigan. *Amnicola lustrica* is usually found on coarser substrate than is found on the marly shelf of Little Goose Lake. It may be found in areas of the bottom where the coarser glacial material underlying the marl is exposed, probably in deeper water. *Valvata* may also occur in deeper wwter.

Aplexa hypnorum, *Fossaria parva*, *Gyraulus circumstriatus*, *Helisoma anceps*, and *Promenetus exacuous* are not significant species in the Wisconsinan section at Little Goose Lake and this seems to be the case today. If they are present it is improbable that they would be detected in a general survey.

Depth of water. The shallow littoral zone, defined as from shoreline to 4 feet in depth, contained abundant mollusks. *Amnicola limosa*, *Fossaria obrussa*, *Gyraulus parvus*, *Helisoma campanulatum*, *Physa gyrina*, and *Pisidium casertanum* occupy various niches in this zone. Shells of these species are deposited together after death with other shells washed in from other aquatic and terrestrial habitats to form thanatoccenoses.

Water depths greater than 4 feet were not examined in this study. From previous work it appears that *Valvata* and Naiades may inhabit this zone.

Bottom sediment. A fairly compacted marl forms the bottom of most of the shallow littoral zone. Directly along the shoreline shell fragments form the upper 2 inches of the substrate. These have been winnowed out of the marl offshore. The mollusks do not seem to be restricted by bottom type.

Water turbulence. Mollusks are not found in areas directly exposed to wave action. In some areas, shoreline plants provide protection.

Floral associations. *Fossaria obrussa* and *Helisoma campanulatum* are common on water milfoil, the dominant plant of depths less than 2 feet. These species also occur on the submerged parts of stems of reeds and cattails. *Amnicola limosa* is found on *Chara* which occurs in patches on the shallow marl shelf.

Faunal associations. Ostracoda of genus *Candona* are found among water milfoil with *Fossaria obrussa* and *Helisoma campanulatum*.

TABLE 7. Summary Diagram of Lithologic Distribution of Mollusca from Little Goose Lime, and Marl Lakes, Michigan

SPECIES	*PEAT*		*MARL*		*SAND*	
TERRESTRIAL PULMONATES	Upper	Lower	Upper	Lower	Top	Upper
Carychium exiguum	x	x	x			
Cionella lubrica		x		x		
Deroceras laeve			x			
Discus cronkhitei	x			x		
Euconulus fulvus		x	x	x		
Gastrocopta contracta	x	x		x		
G. pentodon		x				
G. tappaniana	x	x	x	x	x	
Hawaiia minuscula	x	x				
Helicodiscus parallelus	x	x	x	x		
Nesovitrea binneyana			x			
Oxyloma retusa	x	x	x	x	x	
Quickella vermeta	x	x	x	x		
Retinella indentata	x	x	x	x		
Stenotrema leai	x	x	x			
Striatura ferrea	x					
Strobilops affinis	x	x	x	x	x	
Triodopsis albolabris	x		x			
Vallonia costata	x	x				
V. pulchella	x	x				
Vertigo morsei	x	x	x	x	x	
Zonitoides arboreus	x	x	x	x		
CTENOBRANCHS						
Amnicola limosa	x		x	x	x	x
A. lustrica				x	x	x
Valvata sincera			x	x		
V. tricarinata		x		x	x	x
AQUATIC PULMONATES						
Aplexa hypnorum	x	x	x			
Ferrissia parallela					x	x
Fossaria obrussa	x	x	x	x	x	x
F. parva				x		
Gyraulus circumstriatus				x	x	
G. parvus	x	x	x	x	x	x
Helisoma anceps	x	x	x	x	x	x
H. campanulatum			x	x	x	x
Lymnaea stagnalis				x	x	
Physa gyrina	x		x	x	x	x
Promenetus exacuous				x		
Stagnicola catascopium				x	x	
S. palustris				x		
SPHAERIIDS						
Pisidium casertanum	x	x	x	x	x	x
P. obtusale				x	x	x
Sphaerium rhomboideum				x		
S. sulcatum				x	x	x
NAIADES				x	x	x

Leeches are also inhabitants of the floating vegetation and often are found attached to shells of *H. campanulatum*.

LIME LAKE, LIVINGSTON COUNTY

Glacial Geology

Lime Lake is one of several small lakes situated in the Charlotte moraine of the Saginaw lobe. To the northwest of the lake lies a rolling till plain and beyond it, the Lansing moraine (Bergquist and Price, no date). The Huron Valley Plain and interlobate moraines of the Saginaw and Erie lobes are southeast of Lime Lake (Martin, 1955). West and southwest of the town of Chilson is a prominent kame field (Leverett and Taylor, 1915, p. 214). An esker extends from southern Genesee County into Livingston County, passing through the towns of Oak Grove and Howell and terminating in a depression in the Charlotte moraine, 3 miles west of Lime Lake (Leverett and Taylor, 1915, p. 213). A series of subparallel eskers intersect the Charlotte moraine in Ingham County (Leverett and Taylor, 1915, p. 208; Martin, 1955). These suggest a prolonged stillstand of the ice in this region.

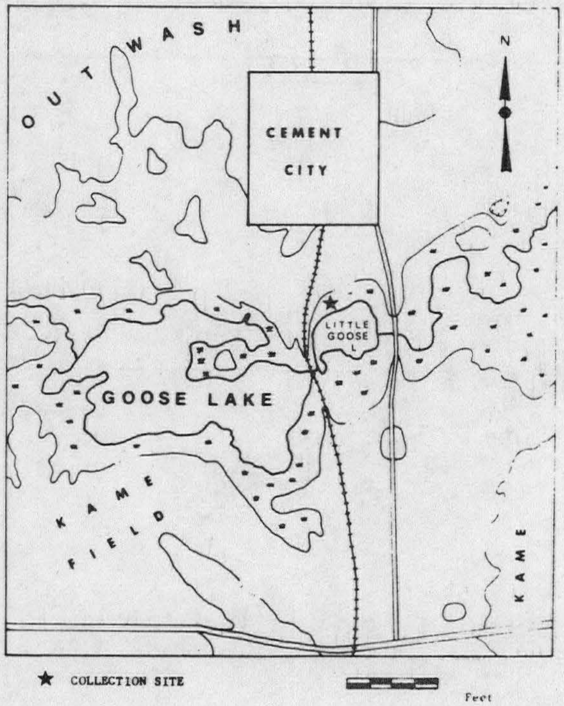


Figure 3. Little Goose Lake and vicinity, Lenawee County, Michigan.

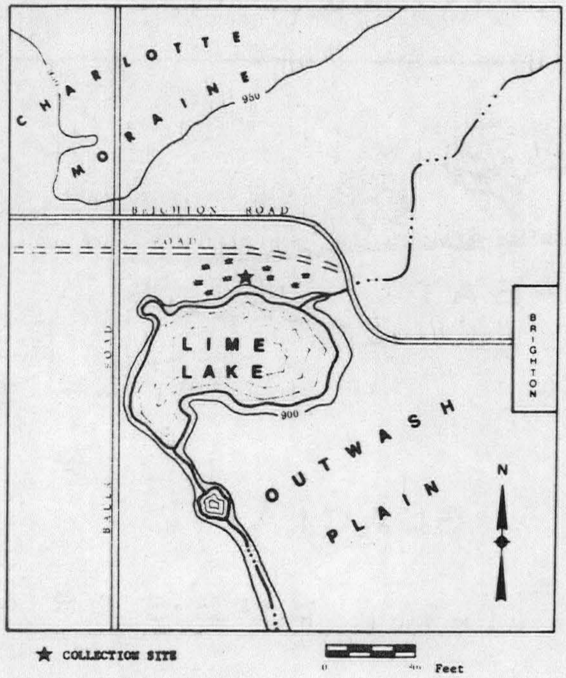


Figure 5. Lime Lake and vicinity, Livingston County, Michigan.

The Huron Valley Plain was the first area in the Erie-St. Clair drainage basin to become free of ice (Bay, 1938, p. 26). During the formation of the interlobate moraines, melt-water flowing into the valley built up great outwash deposits. Lime Lake probably formed in a depression left after a buried ice block melted.

While the ice was at the Charlotte moraine, drainage appears to have been to the west along the moraine as far as Charlotte, in Eaton County, and then down Battle Creek to the Kalamazoo River and into Glacial Lake Dowagiac (Leverett and Taylor, 1915, p. 207). Drainage continued to the west until development of Lake Maumee I caused drainage to turn southward (Bay, 1938, p. 32-33). As glacial lakes in the Erie basin became more extensive, the present eastward drainage developed. Lime Lake has a present outlet to the south by way of South Ore Creek.

Lime Lake, as the name implies, has extensive marl deposits. Bergquist and Price (no date) reported up to 12 feet of marl along the north shore. The lake has been dredged in recent years and the dredgings, consisting mainly of marl, have been dumped on the north shore. A narrow shelf of marl projects from the north shore and then the water abruptly deepens. Auger sampling revealed 2 feet of peat cover along the marshy northern shore. The remaining perimeter of Lime Lake has been partially developed for a cottage, farm, and camp.

Wheeting and Bergquist (1928) have mapped Carlisle Muck soils along the shore of the lake and sandy loams on the swells around the lake. Carlisle Muck consists of dark brown to black muck underlain at a depth of 3 feet or less by clay or marl. A layer of wood fragments is reported below a depth of 12 to 20 inches (Wheeting and Bergquist, 1928).

In the vicinity of Lime Lake are several other marl deposits. A deposit 10 to 14 feet thick occurs in Worden's Lake to the northeast (Bergquist and Price, no date). Long, Crooked, and Pardee Lakes contain pockets of marl in certain areas. Marl also underlies much of the marshland (Bergquist and Price, no date).

Although no radiometric dates are available for this deposit, several are available in Livingston County. Borings in a much deposit of a small lake in the Edwin S. George Reserve of the University of Michigan yielded the following radiocarbon ages.

	Depth (feet)	*Age (years B.P.)*
M-219	15	3,000 ± 500
M-220	20	4,550 ± 500
M-221	25	5,970 ± 900
M-222	30-31	8,570 ± 400
M-223	35-36	11,450 ± 600
M-224	40-41	11,450 ± 600

(Crane and Griffin, 1959, p. 173)

In an earlier study, Andersen (1954) conducted a pollen analysis of a pond in the George Reserve. The pollen at a depth of 54-55 feet indicates a warming trend which Andersen (1954, p. 151) correlated with the Two Creeks Interval. The Two Creeks Interval ended about 11,850 years ago (Broecker and Farrand, 1963). The earlier pollen analysis is thus supported by later radiocarbon dating in the same area.

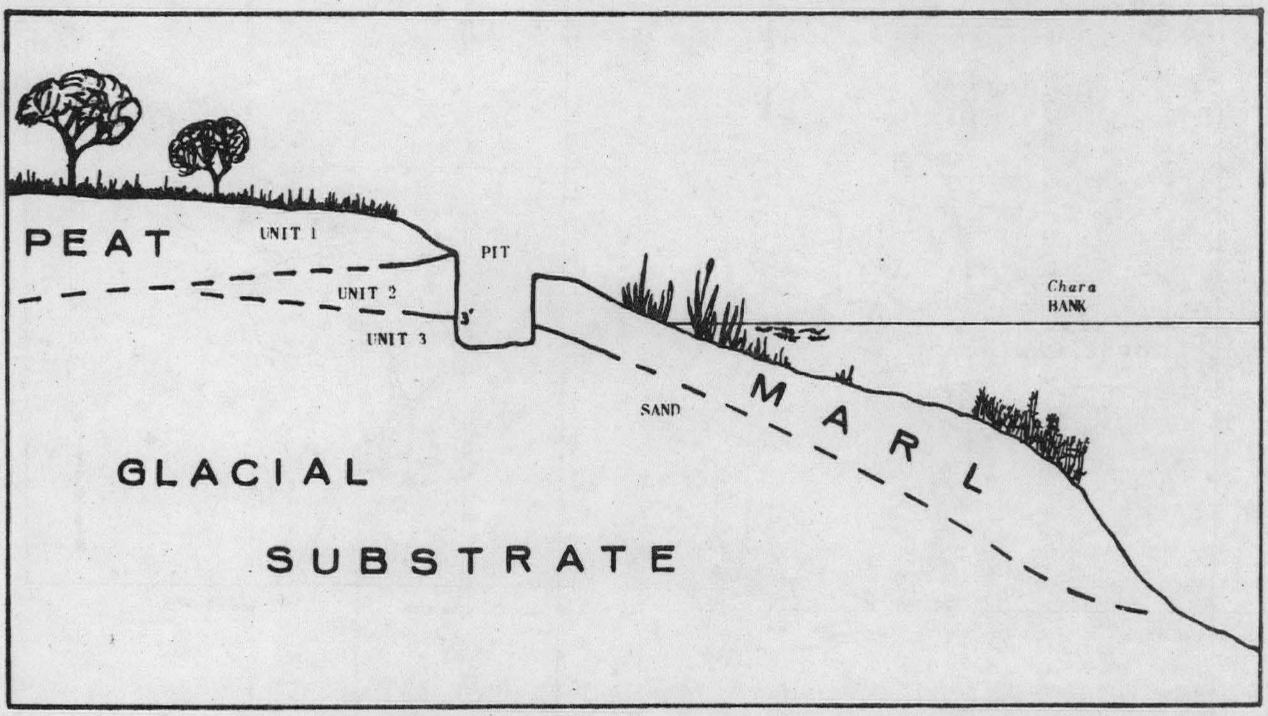


Figure 6. Cross Section of Shoreline and Littoral Zone, Lime Lake, Livingston County, Michigan

Another set of radiocarbon dates is available for a peat deposit at Dunlavy Lake in Hamburg Township (Crane and Griffin, 1966, p. 257). A core from this deposit yielded ages of 7,120± 220 years B.P. at 150-165 cm and 8,630± 300 years B.P. at 200-210 cm in depth. The glacial stratigraphy of this area does not allow correlation with Lime Lake.

Stratigraphic Section

Unit	Collection	Description	Thickness (Inches)
1	1	Dark-brown peat, abundant plant matter, some mollusk shells. Upper 12 inches not sampled	14
2	2-12	Gray marl, fossiliferous (mollusks, ostracodes) abundant *Chara* strands. Sandy in Coll. 12	22
3	13-17	Tan sand with pebbles, fossiliferous (mollusks)	10
		Total	46

Faunal Abundance

Thirty species of mollusks were identified from the Lime Lake section—- 14 terrestrial pulmonates, 9 aquatic pulmonates, 4 ctenobranchs, 3 sphaeriids, and unidentifiable Naiad fragments (Table 4). Indigenous species of Units 2 and 3 are *Amnicola limosa. A. lustrica, Valvata tricarinata, Fossaria obrussa, Gyraulus parvus, Helisoma anceps, Physa gyrina, Pisidium casertanum, P. obtusale,* and *Sphaerium sulcatum.* The indigenous species of Unit 1 are land snails, but the lower part of the unit, the only part sampled, contains a considerable number of aquatic mollusks, marking the transition from aquatic to terrestrial conditions. *Fossaria obrussa, Gastrocopta tappaniana, Carychium exiguum,* and *Oxyloma retusa* are the most common forms of lower Unit 1.

Terrestrial gastropod species exhibit two maxima of abundance; one in Collection 1 (Unit 1); and the other in Collection 5 (Unit 2). The aquatic mollusks present in these collections show a corresponding decrease in percentage abundance (Plates V, VI, and VII). *Fossaria obrussa* increases upward in the section to a maximum abundance (84.6%) in Collection 4. *Valvata tricarinata* is dominant in Unit 3 and shows a progressive decrease in abundance in Unit 2. In lower Unit 2 two species of *Pisidium* appear. *P. casertanum* began to replace *P. obtusale* as the dominant sphaeriid.

Nature of the Environment

The Lime Lake section reflects the inward migration of the shoreline into the central basin. The gravel and sand of Unit 3 consist of reworked till and outwash and represent the initial bottom sediment of Lime Lake. *Valvata tricarinata* tolerates sand and gravel bottoms and depths from 1 to more than 30 feet (La Rocque, 1968, p. 367). *Gyraulus parvus* also has a wide preference of bottom material, but prefers depths less than 4 feet (La Rocque, 1968, p. 491). Both species thrive in areas of abundant rooted vegetation (La Rocque, 1968, p. 367, 491; Harman and Berg, 1971,

TABLE 4. VERTICAL DISTRIBUTION OF PLEISTOCENE FAUNAL ELEMENTS OF THE LIME LAKE SECTION

	COLLECTION	*Carychium exiguum*	*Deroceras laeve*	*Discus cronkhitei*	*Euconulus fulvus*	*Gastrocopta tappaniana*	*Oxyloma retusa*	*Quickella vermeta*	*Retinella indentata*	*Stenotrema leai*	*Strobilops affinis*	*Vallonia costata*	*Vallonia pulchella*	*Vertigo morsei*	*Zonitoides arboreus*	*Amnicola limosa*	*Amnicola lustrica*	*Valvata sincera*	*Valvata tricarinata*	*Ferrissia parallela*	*Fossaria obrussa*	*Gyraulus circumstriatus*	*Gyraulus parvus*	*Helisoma anceps*	*Helisoma campanulatum*	*Lymnaea stagnalis*	*Physa gyrina*	*Stagnicola catascopium*	*Pisidium casertanum*	*Pisidium obtusale*	*Sphaerium sulcatum*	NAIAD MATERIAL	TOTAL SPECIMENS COUNTED	ESTIMATED TOTAL PER COLLECTION	RELATIVE ABUNDANCE OF OSTRACODES
PEAT	1	10.6	-	0.1	-	21.1	10.2	1.4	-	0.1	2.7	0.1	0.2	5.0	1.6	0.8	-	-	-	-	35.6	-	5.4	0.2	-	-	0.9	-	3.7	-	-	-	854	6000	-
	2	0.4	0.1	-	0.1	3.6	4.2	0.5	0.1	-	0.4	-	-	3.2	1.0	1.1	-	-	0.2	-	69.0	-	6.3	0.3	0.1	-	1.8	-	7.4	-	-	-	965	6000	R
	3	0.1	-	-	-	0.4	1.9	0.1	-	-	-	-	-	1.2	0.4	4.3	-	-	-	-	70.0	-	7.3	0.6	-	-	3.2	-	10.5	-	-	-	1000	6000	C
	4	-	-	-	-	0.2	0.7	-	-	-	-	-	-	0.1	0.1	0.1	-	-	0.1	-	84.6	-	5.3	0.2	0.1	-	4.0	-	4.5	-	-	-	1000	6000	C
	5	-	-	-	0.1	1.7	6.2	0.2	-	-	-	-	-	2.2	0.8	0.3	0.2	-	0.8	-	69.9	-	1.8	0.1	-	-	1.7	-	14.0	-	-	-	1000	6000	C
	6	-	-	-	-	0.6	3.2	0.5	-	-	0.2	-	-	0.6	-	3.9	1.8	-	11.7	-	32.9	-	19.1	3.6	-	-	6.4	-	15.5	-	-	-	1000	8000	R
MARL	7	-	-	-	-	0.1	1.4	-	-	-	0.1	-	-	0.8	-	1.8	2.3	-	10.2	-	43.3	-	17.1	4.6	0.1	-	5.3	-	12.9	-	-	-	1000	6000	C
	8	-	-	-	-	-	2.2	-	-	-	-	-	-	0.4	0.1	1.7	0.6	-	9.7	-	35.7	1.9	18.9	1.6	-	-	3.4	-	23.8	-	-	-	1000	6000	R
	9	-	-	-	-	-	1.1	-	-	-	-	-	-	-	-	3.2	2.7	-	6.0	-	33.7	0.8	16.4	3.7	0.2	-	3.4	-	28.7	0.1	-	-	1000	6000	R
	10	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	4.9	4.4	0.1	17.9	-	12.3	0.3	24.1	6.2	0.1	-	1.8	-	27.4	0.3	-	-	1000	6000	R
	11	-	-	-	-	0.1	0.4	-	-	-	-	-	-	-	0.1	3.5	4.0	0.4	19.9	-	12.8	-	28.9	4.7	0.3	-	2.6	-	21.6	0.7	-	-	1000	6000	R
	12	-	-	-	-	-	0.3	-	-	-	-	-	-	0.1	-	1.8	8.1	0.4	18.4	-	15.5	-	29.3	3.7	0.1	-	0.7	-	20.2	1.3	0.1	X	1000	6000	-
	13	-	-	-	-	0.1	0.3	-	-	-	0.3	-	-	0.2	-	1.1	14.2	-	22.3	-	14.9	0.1	25.0	2.4	0.1	0.4	0.3	-	16.6	1.7	-	X	1000	1500	-
	14	-	-	-	-	0.1	0.1	-	-	-	-	-	-	-	-	0.6	4.9	-	28.7	0.1	16.8	-	26.3	5.5	0.1	0.1	0.3	-	4.0	12.3	0.1	X	1000	4000	R
SAND	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	3.9	-	41.6	-	11.4	-	24.1	7.8	0.3	-	0.6	0.4	6.1	3.1	0.2	X	1000	1500	-
	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	2.2	-	39.4	-	7.8	-	22.2	5.5	0.1	-	0.1	-	0.5	21.9	0.1	X	1000	1500	-
	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4	-	35.8	0.2	11.9	-	16.8	8.1	-	-	-	-	3.5	21.8	0.5	X	1000	1500	-

X ABUNDANT FRAGMENTS

C --- common

R --- rare

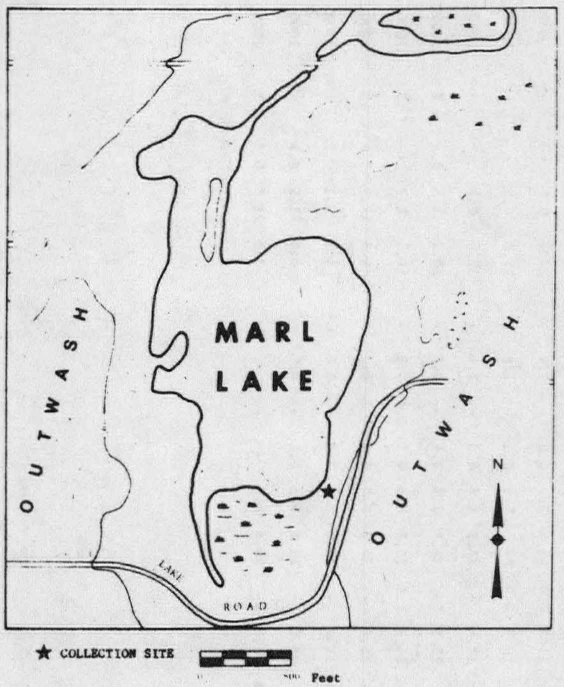


Figure 7. Marl Lake and vicinity, Livingston County, Michigan.

p. 32, 52). *V. tricarinata* was probably characteristic of the lake basin during this early stage, but was gradually replaced by its competitor, *Gyraulus parvus* in the area of the section. This may have represented a number of related environmental changes including a gradual warming in water temperature, changing vegetation, and shallowing water depth.

The sandy bottom supperted a population of Naiades, which disappeared when marl began to form. The Naiades probably found the marl unsuitable for their burrowing activities. Sphaeriids have been reported to favor sand and peat bottoms over clay substrate (Dawson, 1911, p. 37-38). The sudden disappearance of *Pisidium obtusale* in lower Unit 2 is unexplained. It appears that *Pisidium obtusale* and *P. casertanum* both occupied the same habitat during Unit 3 time. Upon the disappearance of *P. obtusale, P. casertanum* underwent a rapid expansion into areas formerly occupied by *P. obtusale*.

Unit 2 represents a period of active marl deposition. The marl shelf must have been covered in places by *Chara* and other algae for the marl is laced with algal strands and contains abundant *Chara* oogonia. The presence of large amounts of plant matter in the marl and the abundance of *Gyraulus parvus*, a species of heavily vegetated areas, seems to indicate that the marl also supported a rooted-plant community.

P. casertanum and *Gyraulus parvus* lived on and in the marl bottom. *Physa gyrina* and *Helisoma anceps* occupied a periphytic niche. *Fossaria obrussa* probably lived on the mud flats of the shore zone and were washed into the Unit 2 marl.

A sharp decrease in the abundance of many aquatic species (Plates V, VI, and VII) in Collection 5 may be interpreted as due to a low water stage. Terrestrial snails became more abundant at this point. *Fossaria obrussa* experienced a great increase in numbers during this time and probably flourished on muddy flats. Water level rose again in the upper part of Unit 2 and a less diversified fauna of aquatic mollusks became re-established. *Amnicola limosa, Gyraulus parvus, Helisoma anceps, Physa gyrina*, and *Pisidium casertanum* were the dominant forms (Plates V and VII).

A terrestrial community of various moisture-loving grasses probably existed onshore. Archer (1939, p. 6) listed the Mollusca from such a community in southwestern Livingston County---*Carychium exiguum, Euconulus chersinus, Nesovitrea electrina, Strobilops affinis, Succinea ovalis*, and *Zonitoides arboreus*. Except for *Nesovitrea*, these, or close relatives, are present at Lime Lake. *Gastrocopts tappaniana* and *Vertigo morsei* are also characteristic of this type of habitat (La Rocque, 1970, p. 725, 736).

Unit 1 is the result of filling-in of the lake in the area of the section by the build-up of peat deposits on the underlying marl. The habitat was a typical marsh with shallow water and emergent vegetation. Land snails were dominant, many of them indigenous and a few such as *Stenotrema leai* and *Zonitoides arboreus* probably washed in from nearby woodlands (La Rocque, 1970, p. 568, 652). *Fossaria obrussa*, the most abundant aquatic form, probably lived on mud flats within the marsh (La Rocque, 1968, p. 475).

MARL LAKE, LIVINGSTON COUNTY

Glacial Geology

Marl Lake is the southernmost water body in an elongate depression between the Ionia and Portland moraines which also includes Silver Lake and Lake Ponemah (Martin, 1955). Marl Lake lies in an area of outwash deposits although the more northern lakes in this depression are in ground moraine. The Ionia moraine lies to the south and east of the Marl Lake basin. Lacustrine sediments have formed between the Fowler and Portland moraines north of the lake. Meltwaters, ponded by the Portland moraine when the ice was at the Fowler moraine, flowed westward forming the Shiawassee River (Holcomb, 1972, p. 108).

Marl Lake, along with the other lakes in this region, seems to have had a water level nearly 3 feet higher than at present (Scott, 1921, p. 267). Marl underlies the southern shore and forms 3-foot wave-cut bluffs on the beach. The remaining perimeter of the lake does not exhibit such well developed bluffs, but this is probably due to the building of cottages along shore. Perusal of the Linden and Fenton 7.5' quadrangles will reveal that Marl Lake was once connected with Silver Lake and Lake Ponemah to form a larger glacial lake. Lowering of water level and deposition of marl in shallow areas led to the division of the lake into several smaller lakes.

Scott (1921, p. 262), in his study of Long Lake, just north of Marl Lake, observed that it was elongate transverse to the end moraines. He suggested that the initial basin for Long Lake may have existed before the ice front receded and then melted to form the present lake.

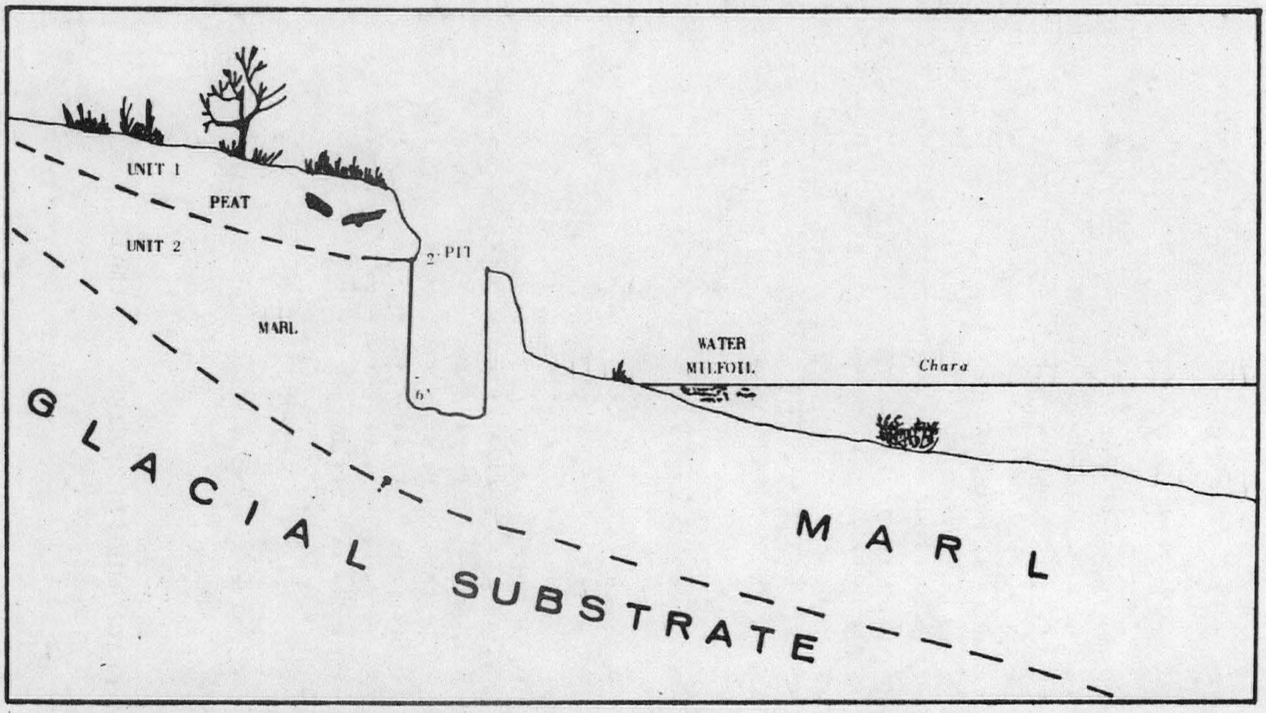


Figure 8. Cross Section of Shoreline and Littoral Zone, Marl Lake, Livingston County, Michigan

Marl Lake is also elongated perpendicularly to the end moraines and may have originated in a similar manner.

Drainage during the early history of Marl Lake was westward down the glacial Lookingglass River to the glacial Grand River and into glacial Lake Dowagiac (Bretz, 1953, map). The earliest possible formation of Marl Lake would have been when the ice was at the Portland moraine for before this time the area was covered by ice. Today, drainage is to the north into the Shiawassee River by way of Silver Lake (Martin, 1955).

Marl Lake contains an extensive marl deposit which covers the shallow water areas forming a shelf around the central basin. The depth is not known; however, Silver Lake, to the north, has a greatest depth of about 50 feet and most of the basin averages about 20 feet (Civil Works Admin.). Silver Lake was extensively dredged for marl in the early 1900's. The marl from the Marl Lake deposit is of very high quality and is well exposed along the western and southern shores. About 2 feet of peat overlies the marl in the marsh at the southern end of the lake.

The soil surrounding Marl Lake has been described as Edwards Muck by Holcomb (1972, p. 23). The Edwards Muck comprises organic-rich soils underlain by marl which form on till plains and moraines. A typical Edwards profile is given below.

Description	Thickness (inches)
Dark gray muck, well decomposed	0-8
Dark gray or reddish-gray muck, partly decomposed stems	8-14
Dark gray muck, with seams and a few chunks of dark reddish-brown and brownish-yellow marl	14-22
Gray marl with shells	22-48

(Adapted from Holcomb, 1972, p. 23)

The upland soils in the Marl Lake vicinity are loams and loamy sands with clay and loamy sand subsoils (Holcomb, 1972, p. 110). Oak, beech, sugar maple, hickory, and ash assemblages characterize the swells and oak, white pine, red pine, red maple, and birch assemblages are found in the lowlands (Holcomb, 1972, p. 109).

A radiocarbon date of 11,400 ± years B.P. is available for a mammoth tusk found at a depth of 12 feet in calcareous clay about 13 miles northwest of Marl Lake and just south of the Flint moraine (Crane and Griffin, 1966, p. 256).

Stratigraphic Section

Unit	Collection	Description	Thickness (inches)
1	not sampled	Dark brown peat, plant matter common, wood at 1 foot depth	24
2	1-26	Light tan marl, fossiliferous (mollusks, ostracodes, charophytes, abundant tufa	52
		Total	76

TABLE 5. VERTICAL DISTRIBUTION OF PLEISTOCENE FAUNAL ELEMENTS OF THE MARL LAKE SECTION

MARL

COLLECTION	*Carychium exiguum*	*Cionella lubrica*	*Discus cronkhitei*	*Euconulus fulvus*	*Gastrocopta contracta*	*Gastrocopta tappaniana*	*Helicodiscus parallelus*	*Oxyloma retusa*	*Quickella vermeta*	*Retinella indentata*	*Strobilops affinis*	*Vertigo morsei*	*Zonitoides arboreus*	*Amnicola limosa*	*Amnicola lustrica*	*Valvata sincera*	*Valvata tricarinata*
1	-	-	-	0.1	-	-	-	1.2	0.5	-	0.2	0.5	0.2	-	-	-	-
2	-	-	-	0.1	-	0.4	-	0.2	0.7	-	0.1	4.2	0.1	-	-	0.1	-
3	-	-	-	-	-	2.0	-	0.5	0.5	-	-	1.5	0.1	-	-	-	-
4	0.1	-	-	-	-	2.2	-	0.6	0.8	-	-	0.9	-	-	-	-	-
5	-	-	-	-	-	0.3	-	0.6	1.1	-	-	0.8	-	-	-	-	-
6	-	-	-	-	-	0.1	-	-	0.2	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	0.1	-	0.4	-	-	-	0.2	-	-	-	-	-
9	-	-	-	-	-	-	-	0.6	-	-	-	0.1	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	0.5	-	-	-	0.8	-	-	-	-	-
13	-	-	-	-	-	-	-	0.5	-	-	0.1	0.2	-	-	-	-	-
14	-	-	-	0.1	-	0.1	-	0.2	-	-	-	0.1	0.1	-	-	-	0.1
15	-	-	-	-	-	-	-	0.6	-	-	-	0.6	-	-	0.3	0.1	1.1
16	-	-	-	-	-	-	-	0.2	0.7	-	0.3	1.3	-	1.3	1.2	0.6	3.8
17	-	-	-	-	0.1	0.9	-	1.2	0.2	-	0.2	0.3	-	1.3	2.3	-	6.2
18	-	-	-	-	-	0.2	-	1.2	-	-	0.5	0.4	0.1	1.8	5.4	-	10.6
19	-	-	0.1	0.1	-	0.5	-	1.0	-	-	0.6	0.7	0.2	1.3	5.8	-	10.1
20	0.1	-	0.1	0.1	0.4	0.1	0.1	1.5	-	0.2	0.6	0.2	0.4	1.5	4.9	-	11.3
21	-	0.1	0.1	-	0.1	-	0.1	1.2	-	0.1	0.6	0.5	0.5	0.8	2.8	-	13.1
22	-	0.1	0.2	-	-	0.1	-	0.7	-	0.2	0.4	0.2	0.2	1.0	2.7	-	15.1
23	-	-	-	-	-	-	-	0.2	-	-	0.2	-	0.1	0.4	4.6	-	19.3
24	-	-	-	-	-	-	-	0.4	-	-	-	-	-	0.3	1.3	-	11.7
25	-	-	-	-	-	-	-	0.7	-	-	-	0.2	-	0.7	1.6	-	11.9
26	-	0.1	-	-	-	-	-	0.1	-	-	-	0.2	0.1	0.2	1.9	-	12.4

COLLECTION	*Fossaria obrussa*	*Gyraulus circumstriatus*	*Gyraulus parvus*	*Helisoma anceps*	*Helisoma campanulatum*	*Lymnaea stagnalis*	*Physa gyrina*	*Promenetus exacuous*	*Stagnicola catascopium*	*Stagnicola palustris*	*Pisidium casertanum*	*Sphaerium rhomboideum*	*Sphaerium sulcatum*	TOTAL SPECIMENS COUNTED	ESTIMATED TOTAL PER COLLECTION	RELATIVE ABUNDANCE OF OSTRACODES
1	17.9	-	51.8	-	-	-	-	-	-	-	27.6	-	-	1114	6000	-
2	18.5	-	46.0	-	-	-	-	-	-	-	29.5	-	-	895	6000	R
3	37.4	-	45.7	-	-	-	-	-	-	-	12.3	-	-	1177	3500	R
4	57.9	-	29.1	-	-	-	-	-	-	-	8.4	-	-	990	10000	R
5	43.8	-	48.9	-	-	-	-	-	-	-	4.4	-	-	994	20000	C
6	24.1	-	74.1	-	-	-	-	-	-	-	1.5	-	-	1000	10000	C
7	12.5	-	87.1	-	-	-	0.1	-	-	-	0.1	-	-	1000	25000	C
8	27.8	-	70.0	-	-	-	-	-	-	-	1.5	-	-	1000	25000	C
9	38.7	-	57.6	-	-	-	-	-	-	-	3.0	-	-	1000	10000	R
10	55.3	-	44.0	-	-	-	-	-	-	-	0.6	-	-	1000	8000	R
11	64.2	-	34.7	-	-	-	-	-	-	-	1.1	-	-	1000	3500	R
12	56.3	-	38.5	-	-	-	-	-	-	-	3.9	-	-	1000	3500	R
13	61.2	-	27.6	-	-	-	-	-	-	-	10.4	-	-	1000	3500	R
14	73.5	-	18.3	-	0.1	-	-	-	-	-	7.3	-	-	901	3000	R
15	77.1	-	13.5	-	0.2	-	0.2	-	-	-	6.2	-	-	969	2000	-
16	64.1	0.5	18.8	0.1	-	-	0.9	-	0.4	-	5.7	-	-	986	2500	-
17	41.2	0.5	40.0	0.2	-	-	2.6	-	0.9	-	1.5	-	-	994	3500	-
18	31.0	1.0	38.5	2.5	-	0.1	3.1	-	1.6	-	2.0	-	-	1000	20000	-
19	29.6	1.3	39.1	1.4	0.2	0.1	3.6	-	0.5	-	3.8	-	-	1000	20000	-
20	28.3	1.6	38.9	1.6	0.1	-	3.3	-	0.7	-	4.1	-	-	1003	20000	-
21	27.8	1.5	41.5	2.2	0.1	-	3.6	0.1	0.9	-	2.1	0.1	0.2	1013	20000	-
22	30.5	1.6	39.3	2.5	0.1	0.1	2.6	-	0.5	-	1.4	0.5	-	1005	10000	R
23	30.5	0.4	39.6	2.5	-	-	1.3	-	0.5	-	0.4	-	-	1000	3500	-
24	43.7	-	31.2	4.8	0.3	-	2.0	-	-	-	4.3	-	-	1000	8000	-
25	39.8	0.1	35.0	4.3	0.3	-	1.3	-	0.3	0.1	3.7	-	-	1000	6000	-
26	38.5	-	35.1	3.3	0.6	0.1	1.9	-	-	0.1	5.5	-	-	1000	6000	-

C - common

R - rare

Faunal Abundance

The Marl Lake section yielded 30 mollusk species including 13 terrestrial pulmonates, 10 aquatic pulmonates, 4 ctenobranchs, and 3 sphaeriids (Table 5). The fauna is dominated by *Fossaria obrussa*, *Gyraulus parvus*, and *Pisidium casertanum* which are present in significant numbers throughout the section (Plates IX and X).

Lower Unit 2 (Collections 14-26) contains a great diversity of aquatic and terrestrial forms. *Amnicola limosa*, *A. lustrica*, *Valvata tricarinata*, *Gyraulus parvus*, *Helisoma anceps*, *Physa gyrina*, *Stagnicola catascopium*, and *Pisidium casertanum* appear to be indigenous. Significant species are *Valvata tricarinata*, *Fossaria obrussa*, *Gyraulus parvus*, *G. circumstriatus*, *Helisoma anceps*, *H. campanulatum*, *Physa gyrina*, and *Pisidium casertanum*. Upper Unit 2 has only *Fossaria obrussa*, *Gyraulus parvus*, and *Pisidium casertanum* as indigenous forms. They are also the only significant species. Unit 1 is a peat, is almost unfossiliferous, and was not sampled.

Gyraulus parvus and *Fossaria obrussa* show inverse relationships in abundance throughout the section (Plates IX and X). *Amnicola lustrica* and *Valvata tricarinata* show direct relationships (Plate VIII).

Six to seven terrestrial species occur in the upper collections of the upper Unit 2, but only *Oxyloma retusa* and *Vertigo morsei* occur in significant numbers in the lower collections. The marl was extremely rich in mollusk shells from Collections 4 to 9 and 18 to 22 and poor in shells between Collections 11 and 17. Ostracodes are abundant in Collections 1 through 13, but scarce in the lower part of the section. *Candona ohioensis* is common between Collections 5 and 8. *Cypridopsis* sp. occurs throughout the upper part of the section. *Chara* oogonia are scattered throughout the section, but never occur in large numbers.

Nature of the Environment

Marl formed a broad shallow platform around the central basin of Marl Lake at an early stage in its history, providing a favorable molluscan habitat. During the deposition of lower Unit 2 the fauna showed the greatest diversity. Terrestrial snails, such as *Euconulus fulvus*, *Retinella indentata*, and *Zonitoides arboreus* signify the presence of nearby deciduous woodlands from which they were washed into the littoral zone (Frye and Leonard, 1967, p. 433; La Rocque, 1970, p. 608, 609, 619). The most abundant land snails in this unit, *Oxyloma retusa*, *Gastrocopta tappaniana*, and *Vertigo morsei* were inhabitants of the wetlands immediately surrounding the lake (La Rocque, 1970, p. 697, 725, 736). The habit of *Lymnaea stagnalis* of crawling out of the water onto emergent vegetation may account for its sporadic distribution in the section. Upon death, the shells may have floated for some time before finally settling to the bottom. The same may be said for the planorbids.

The presence of numerous ctenobranchs again suggests cooler water temperature during the deposition of lower Unit 2 (Frye and Leonard, 1967, p. 433). These species are not present in upper Unit 1. The occurrence of large numbers of *Stagnicola catascopium*, *Gyraulus parvus*, and *Amnicola limosa* is also indicative of cooler waters (Klassen *et al.*, 1967, p. 439).

The marl shelf probably contained scattered charophytes and abundant growths of blue-green algae. Rooted submergent and emergent vegetation was probably not common. Most present-day marl lakes have essentially barren littoral zones (Wohlschlag, 1950, p. 323). Rooted plants may have grown along the shoreline where organic-rich material accumulated (Wohlschlag, 1950, p. 323). *Physa gyrina*, *Stagnicola catascopium*, *Helisoma anceps*, and *H. campanulatum* occupied a periphyton niche. The sphaeriids and *Gyraulus parvus* inhabited the benthic niches.

Fossaria obrussa, *Gyraulus parvus*, and *Pisidium casertanum* are the only aquatic species present in upper Unit 2, although they are all present in significant numbers. *Fossaria obrussa* experienced a sharp increase in abundance in Collections 4, 11, and 15 while *Gyraulus parvus* decreased in number. *G. parvus* increased to a maximum abundance in Collection 7, while *Fossaria obrussa* was at a minimum. At the times when *F. obrussa* was abundant the water was probably at a low stage exposing shoals and mud flats. Abundant *Gyraulus parvus* seems to indicate more aquatic conditions with abundant vegetation.

The paucity of land snails in the lower part of upper Unit 2 suggests a shallow water habitat far from the shoreline where land snails did not accumulate. If it was a nearshore environment, the shoreline must have provided favorable terrestrial mollusk habitats. The absence of ctenobranchs points to a warming of the water temperature (Frye and Leonard, 1967, p. 433).

Pisidium casertanum and *Gyraulus parvus* lived in and on the marl. *Fossaria obrussa*, an amphibious species, probably lived on marl shoals or on emergent vegetation (La Rocque, 1968, p. 475-476). The land snails, *Oxyloma retusa* and *Quickella vermeta* probably flourished in the marsh surrounding Marl Lake and occasionally were washed into the deposits.

Unit 1 records the filling-in of the shallow shoreline zone of Marl Lake. Terrestrial mollusks were surely present during this stage, but have not been preserved in the peat. At a depth of 1 foot a layer of wood fragments was encountered which suggests a time of high water.

DISCUSSION

Little Goose Lake, Lime Lake, and Marl Lake appear to be of similar ice-block origin. The initial opening of the Saginaw-Erie interlobate area of southern Michigan must have occurred around 14,000 years B. P. for Ohio and Indiana were reportedly first free of Wisconsinan ice at this time (Forsyth, 1965, p. 226; Wetzel, 1970, p. 495). According to these data and the extent of the Carey deposits (16,000 to 13,500 years B.P.) (Dorr and Eschman, 1970, p. 161) it can be said that the earliest possible date of formation of the lakes was between 14,000 and 13,500 years B. P. Little Goose Lake may be the oldest lake since it is situated in the southern part of the interlobate area. As the interlobate region opened, the Saginaw lobe retreated at a faster rate than the Erie lobe (Zumberge, 1960, p. 1185).

When the Saginaw ice front reached the position of the Portland moraine around 14,000 years B. P. (Dorr and Eschman, 1970, p. 167) all three lakes could have been present. There could have been few separate lake basins, except for temporary ice-dammed meltwater lakes, until the ice retreated from the area and ice blocks left behind were allowed to melt. The blocks of larger volume must have taken some time to disappear completely. However, the distances between the lakes of this study are thought to be large enough and the lake basins of comparable size and volume to reduce the possibility of Lime Lake or Marl Lake being older than Little Goose Lake.

During the initial opening of the interlobate area, mollusks could have been brought into the region by various methods of dispersal. Freshwater and terrestrial snails are known to be distributed by insects, fishes, turtles, birds, storms, and floods (Rees, 1965). Mollusks could also have entered the region from Indiana through the southwestward flowing drainage system (Bay, 1938, p. 27). Continued retreat of the moraines brought a more extensive drainage system and more arteries for mollusk dispersion. Mollusks were able to enter the study area from Ohio at about the time of the formation of Lake Maumee I (Bay, 1938, p. 32). Thus, in the early history of at least Little Goose Lake, mollusks may have arrived by way of streams flowing into western Indiana and eastern Illinois. Later in the history of the lake, mollusks may have been introduced from western Ohio and the proglacial lakes.

If stratigraphic control could be obtained in lake sediments, the amount of time (taking into consideration a compaction factor) required to deposit a given thickness could be determined. Thus deposits could be compared from one basin to another. Pollen and plant pigment analyses seem to have limited use in marl deposits where pollen is sometimes absent or poorly preserved.

The effect of a change in mollusk dispersal routes on the fauna of a lake could possibly be observed if stratigraphic control could be obtained. Study of the graphs of species abundance reveals many fluctuations in percentage abundance; many of these may be attributed to variations in water level and temperature changes. Perhaps some of these are due to a change in the source area of mollusks entering the habitat. Drainage patterns are temporary geologic features and stream piracy and consequent reversal of flow are common events.

Terrestrial snails are just as readily transported by streams as are aquatic forms. Some species can survive lengthy periods of submersion.

A species did not necessarily become immediately established when it arrived in the new habitat, even if conditions were favorable. Species which had already become established may have prevented the new species from forming a successful population. The aggressiveness of a species, referring to its ability to maintain itself, was certainly an important factor. Periodic or continuous influx of species into the new habitat may have occurred over a considerable period of time before the species became established as important members of the community. Warming temperatures and changes in sedimentation and vegetation opened up the littoral zone for new species which had not found the previous conditions overly favorable. The original species either migrated to more favorable parts of the lake, often deeper water, or gradually disappeared from the basin.

The rise and fall of lake level as suggested by the fluctuations in the abundance of mollusk species has been explained by a blockage or downcutting of the outlet and alternating periods of above average precipitation and drought. The author feels that workers have neglected an important member of the Pleistocene community---the extinct giant beaver, *Castoroides*. The modern beaver is well known for its ability to pond stream waters behind its dams. *Castoroides* probably occupied similar habitats. Gnawed logs have been found in several peat deposits in Indiana (Ansel Gooding, 1974, personal communication). A linear concentration of gnawed logs in a peat deposit in Alaska has been interpreted as a preserved beaver dam (Gooding, 1974, personal communication). It seems probable that beaver activity during Wisconsinan time could have caused relatively rapid changes in water level in some aquatic habitats and thus directly affected the distribution of mollusks and other aquatic organisms. The construction of a dam would increase the area occupied by mollusks and create new niches. Destruction of a dam would result in a restriction of mollusk habitats.

The molluscan faunas of the three marl deposits contained a combined total of 43 species of which 22 are common to all. Of the 21 species which occur in only one or two of the sections, only one, *Pisidium obtusale*, is significant. *P. obtusale* occurs in only the lower part of the Lime Lake section---the only section to yield the initial sandy stage of lake sedimentation. Therefore, *P. obtusale* may be present in the Little Goose Lake and Marl Lake sections at a greater depth. Naiades exhibit a similar pattern of occurrence. Thus the faunas exhibit no major overall differences.

Figure 9 shows the similarity in lithologic sequence of the three sections and relates this to suggested water depths and the occurrence of certain molluscan species. Each section records a gradual transition from open water to shoreline marsh. *Amnicola lustrica*, *Valvata tricarinata*, and *Gyraulus circumstriatus* are generally limited to the older lake sediments recording somewhat cooler water temperatures (Frye and Leonard, 1967, p. 434; La Rocque, 1968, p. 500-501). Applying Walther's law to the Wisconsinan sections indicates that these species are probably offshore inhabitants. This may account for their absence in the collection taken during the molluscan survey of present-day Little Goose Lake for depths greater than 4 feet were not collected. *G. parvus*, *Fossaria obrussa*, and *Pisidium casertanum* are the most significant species and occur in fluctuating numbers throughout the time represented by each section (Figure 10). *G. parvus* and *F. obrussa* show an inverse relationship in abundance. *F. obrussa* was probably common at times of extremely low water (less than 2 feet). *G. parvus* became more common when the water deepened (2 to 4 feet) and vegetation became dense. The inverse relationship in abundance of these two species is also evident in the abundance records of other workers (*e.g.* Clark, 1961, p. 32; Mowery, 1961; Roy, 1964; Clowers, 1966, p. 51; Gibson, 1967, p. 7; Warner, 1968, p. 3-4; Nave, 1969, p. 43; Bickel, 1970, p. 36, 38, 45, 46).

In Table 7 the vertical distribution data for mollusks found in the three Wisconsinan sections have been combined to show their general occurrence in sediments of a lacustrine environment. This table shows that a particular species may occur in more than one sediment type. Quantitative data, however, show that a mollusk species is present in large numbers in the depositional medium closer to the habitat in which it lived. Terrestrial pulmonates, for example, occur in greater numbers in shoreline sediment, usually peat. They also occur offshore in marl and sand, but usually in smaller numbers.

The scattered occurrence of a land snail in sediment far from the shoreline may be due to

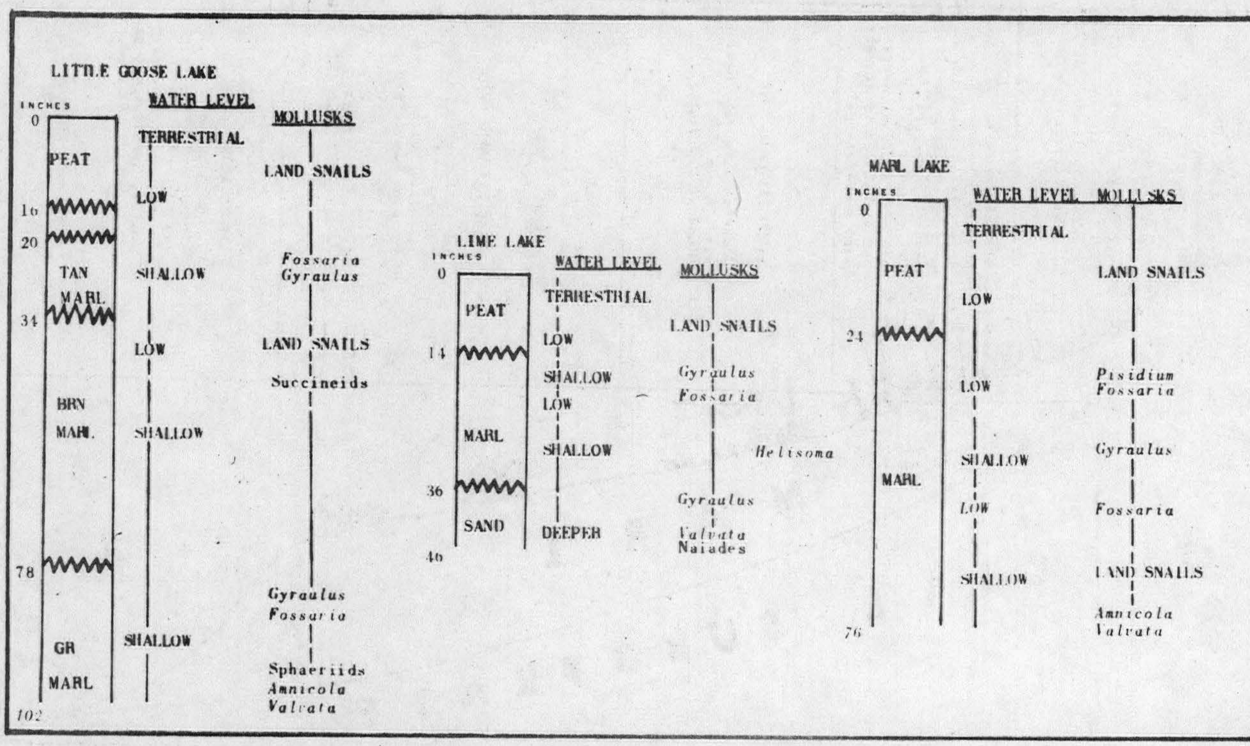


Figure 9. Comparisons of Little Goose Lake, Lime Lake, and Marl Lake Sections

a number of factors including rafting, wind or current action, and dispersal by birds, insects, or amphibious animals. The occurrence of an abundance of land species in a marl however, probably represents a temporary shallowing of water and an increase in terrigenous influx.

Table 7 shows that the common species of the peat are the terrestrial pulmonates, *Carychium exiguum, Gastrocopta contracta, G. tappaniana, Oxyloma retusa, Quickella vermeta, Retinella indentata, Stenotrema leai, Strobilops affinis, Vertigo morsei, Zonitoides arboreus*; the aquatic pulmonates, *Fossaria obrussa, Gyraulus parvus*; and the sphaeriid, *Pisidium casertanum*.

The marl is characterized by the ctenobranch *Amnicola limosa*; aquatic pulmonates *Fossaria obrussa, Gyraulus parvus, Physa gyrina*; and the sphaeriid, *Pisidium casertanum*. The upper part of the marl also contains significant numbers of the following terrestrial pulmonates: *Gastrocopta tappaniana, Oxyloma retusa, Quickella vermeta*, and *Vertigo morsei*. The lower marl often yields abundant ctenobranchs, e.g. *Amnicola lustrica* and *Valvata tricarinata*. *V. sincera* occurs throughout the marl, but is never abundant.

The ctenobranchs *Amnicola lustrica* and *V. tricarinata*; the aquatic pulmonates *F. obrussa* and *G. parvus*; the sphaeriids *Pisidium obtusale* and *Sphaerium* sp. and the Naiades are abundant in the sand part of the section.

Table 7 can also be interpreted in a lateral sense using Walther's law (Figure 9). The combining of data from the Wisconsinan sections and the survey of living Mollusca supports the presence of a series of molluscan habitat zones in and around marl lakes of southeastern Michigan. Upland areas around a lake basin contain a fauna of terrestrial snails adapted to moist meadow and woodland habitats (e.g. *Stenotrema leai, Triodopsis albolabris, Euconulus fulvus, Retinella indentata, Discus cronkhitei*, and *Helicodiscus parallelus*). This area is underlain by peat in lower areas and sandy soils in better drained areas.

Basinward from the upland zone is a peaty slope habitat with moisture-loving land snails (e.g. *Carychium exiguum, Deroceras laeve, Strobilops affinis, Gastrocopta tappaniana*, and *Vertigo morsei*). This zone is often flooded at times of high water and during storms. Wave accumulations of aquatic mollusk shells are often present.

The shoreline zone contains a mixed aquatic and terrestrial molluscan fauna. A marl-peat substrate supports marsh plant growth. The indigenous terrestrial snails are mainly succineids (*Quickella vermeta* and *Oxyloma retusa*). *Fossaria obrussa* is extremely abundant on mud flats and vegetation. *Gyraulus parvus, Physa gyrina*, and *Helisoma* may be present. Ostracodes are most abundant in this zone, which is often subject to drying out at times of drought or low water level.

The floating plant zone contains an abundant molluscan fauna, including *Gyraulus parvus, Physa gyrina, Helisoma campanulatum*, and *Pisidium* sp. The *Chara* zone supports abundant *Amnicola limosa, G. parvus, Valvata tricarinata*, and *Pisidium* sp. may be present.

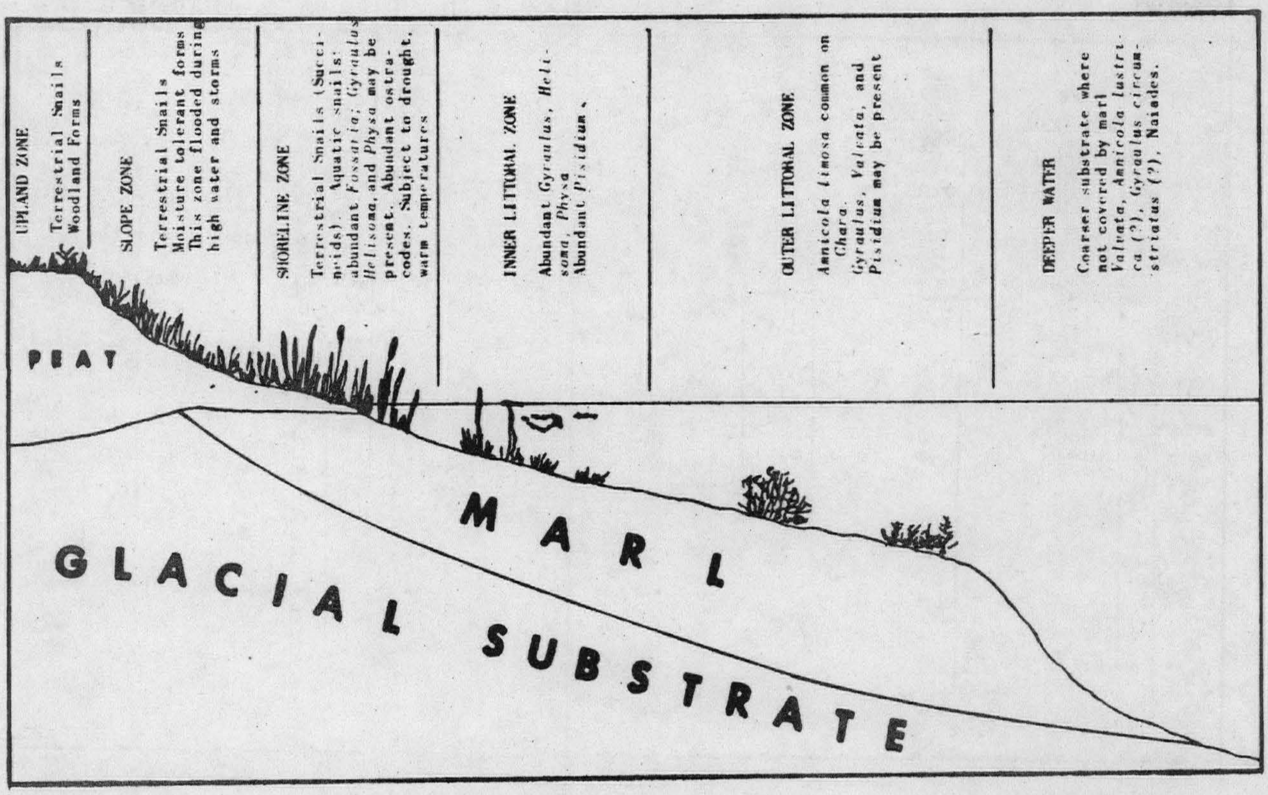


Figure 10. Molluscan Habitats of a Typical Marl Lake

Depths greater than 5 feet probably contain *Amnicola lustrica* (?), *Valvata tricarinata*, *Gyraulus circumstriatus* (?), and Naiades. The substrate at this depth may be coarse sand, gravel, or marl.

Van der Schalie and Berry (1973) conducted temperature tolerance studies of six aquatic pulmonates and one ctenobranch under laboratory conditions. The results of this study (Table 8) have shown that temperature is an important limiting factor in mollusk distribution. Small variations in water temperature (5 - 10° C), which probably occurred throughout the time represented by the sections, may have caused the fluctuations in the populations of mollusks. A small increase in temperature was found to inhibit the reproductive capabilities of the more sensitive species (van der Schalie and Berry, 1973, p. 7, 86). Thus a change in water level combined with a warming climatic trend could have led to the variations in molluscan abundance exhibited by all sections in this study.

Table 8. Optimal temperatures of freshwater Gastropoda (Adapted from van der Schalie and Berry, 1973, p. 7, 88)

	Growth-Survival	Reproduction
Planorbids	22-25° C	22-25° C
Helisoma anceps	26	26
H. campanulatum	24	26
Lymnaeids	19-22	19-22
Lymnaea stagnalis	20	22
Physids	12-30	12-30
Physa gyrina	26	20
Amnicolids	cooler temperatures	
Amnicola limosa	24	18

CONCLUSIONS

1. Sedimentary sections taken along the margins of Little Goose, Lime, and Marl Lakes typically include an upper peat underlain by marl, often of considerable thickness, and a lower sand zone.

2. Distributional data from the Wisconsinan sections and a survey of living Mollusca support the presence of a series of concentric molluscan habitat zones around the lakes of the study area.

3. *Stenotrema leai*, *Triodopsis albolabris*, *Euconulus fulvus*, *Retinella indentata*, *Discus cronkhitei*, and *Helicodiscus parallelus* are characteristic of the upland zone surrounding the lakes and the peat.

4. *Carychium exiguum*, *Deroceras laeve*, *Strobilops affinis*, *Gastrocopta tappaniana*, and *Vertigo morsei* live on the peaty slope and occur in the peat.

5. *G. tappaniana*, *Oxyloma retusa*, *Quickella vermeta*, *Fossaria obrussa*, and *Gyraulus parvus* characterize the shoreline zone and the lower peat.

6. The inner littoral zone includes *Gyraulus parvus*, *Helisoma campanulatum*, and *Pisidium* sp. These species are characteristic of the upper marl.

7. The outer littoral zone supports *Amnicola limosa*, *G. parvus*, *V. tricarinata*, and *Pisidium* sp. These species are also characteristic of the marl.

8. Depths greater than 5 feet probably support *Amnicola lustrica*, *V. tricarinata*, and Naiades. These forms occur in the sand unit of Lime Lake.

9. *Fossaria obrussa*, *G. parvus*, and *Pisidium casertanum* are the most common species of the lakes of the study area and occur in all sediment types.

10. Naiades and *Pisidium obtusale* are characteristic of the early stages of Lime Lake. They would probably have been found at the other localities if the marl thickness had not prevented the excavation from reaching the sandy zone.

11. *F. obrussa* and *G. parvus* show an inverse relationship in abundance. When *F. obrussa* experiences a sharp increase in numbers, *G. parvus* shows a corresponding decrease and *vice versa*. An abundance of *F. obrussa* probably represents extremely shallow water (less than 2 feet deep), whereas an abundance of *G. parvus* indicates shallow water (2 to 4 feet deep).

12. An abundance of *Oxyloma* and *Quickella* seems to indicate a stage of low water and exposed mud flats.

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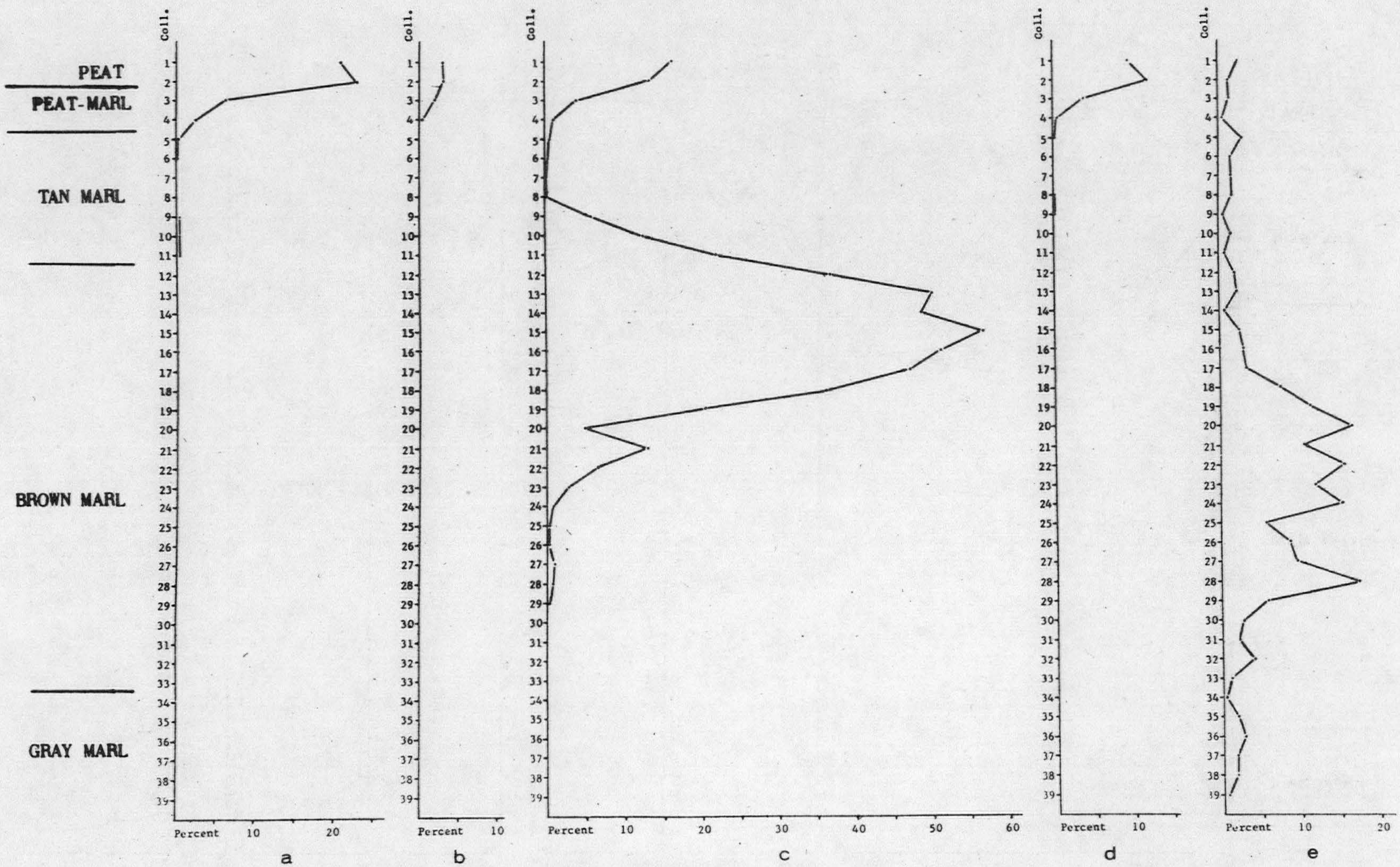
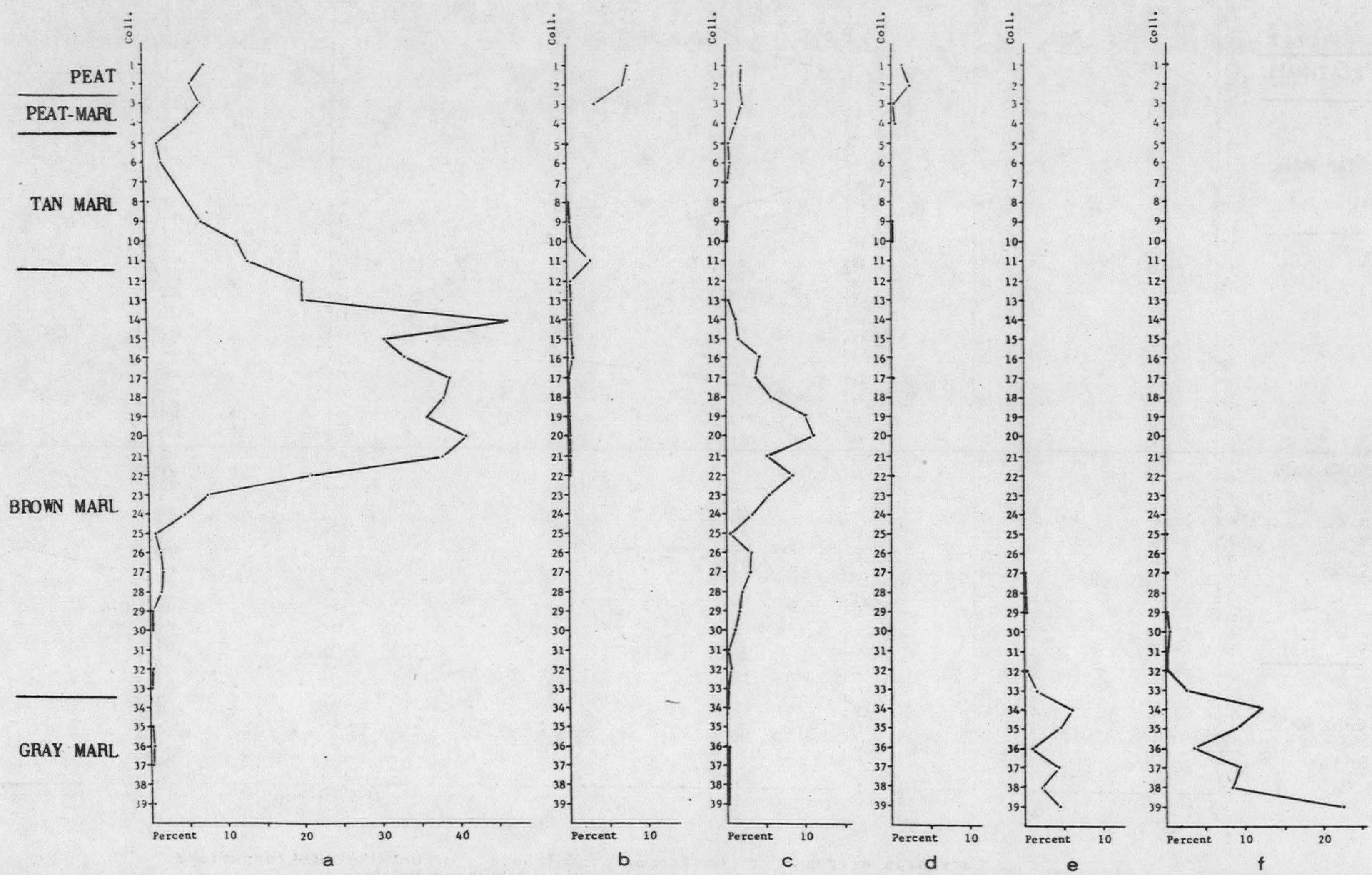


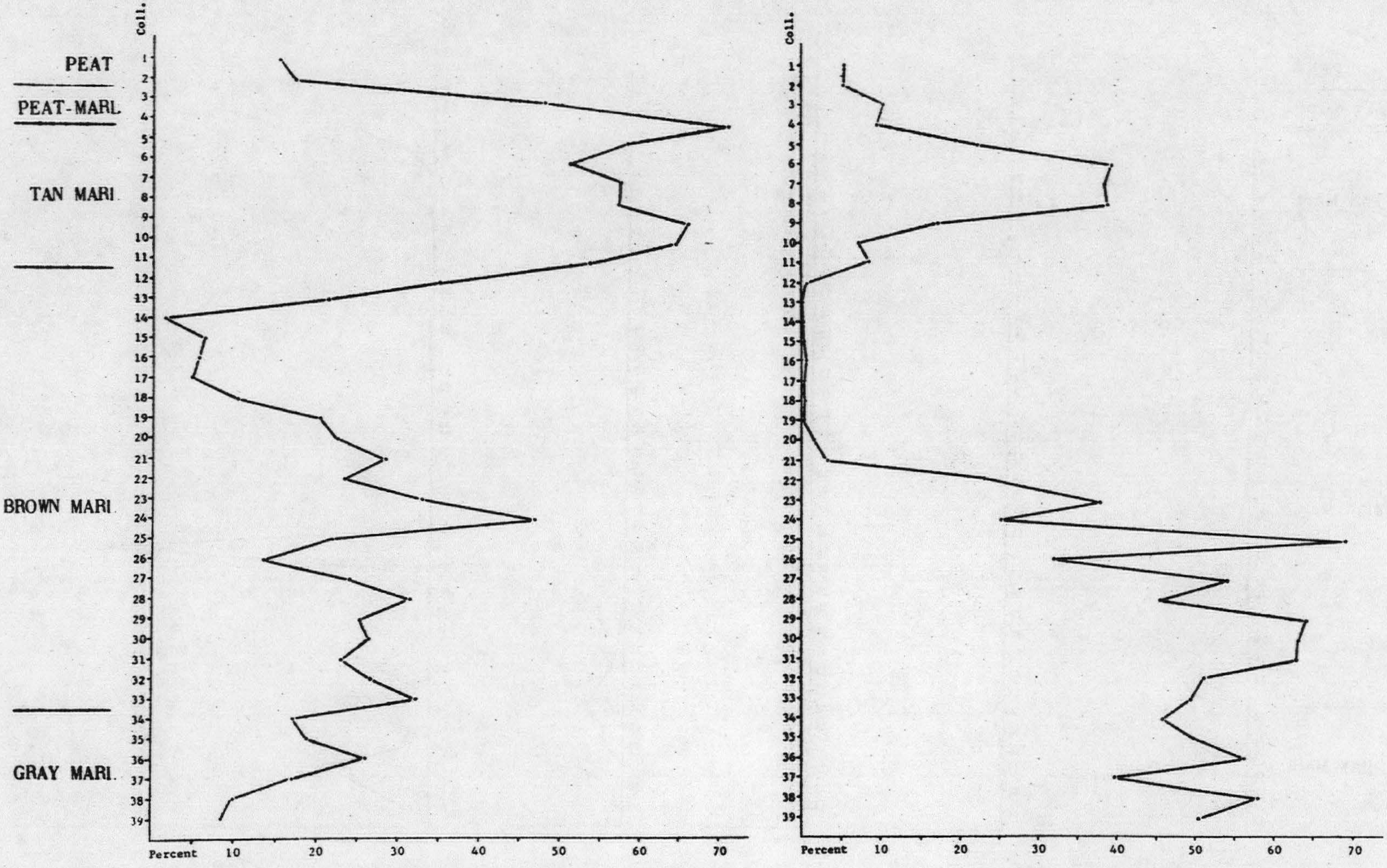
a. Carychium exiguum *b. Gastrocopta contracta* *c. Gastrocopta tappaniana*
d. Helicodiscus parallelus *e. Oxyloma retusa*

PLATE I. VERTICAL DISTRIBUTION OF MOLLUSCAN SPECIES IN THE LITTLE GOOSE LAKE SECTION



a. *Quickella vermeta* b. *Strobilops affinis* c. *Vertigo morsei* d. *Zonitoides arboreus*
e. *Amnicola lustrica* f. *Valvata tricarinata*

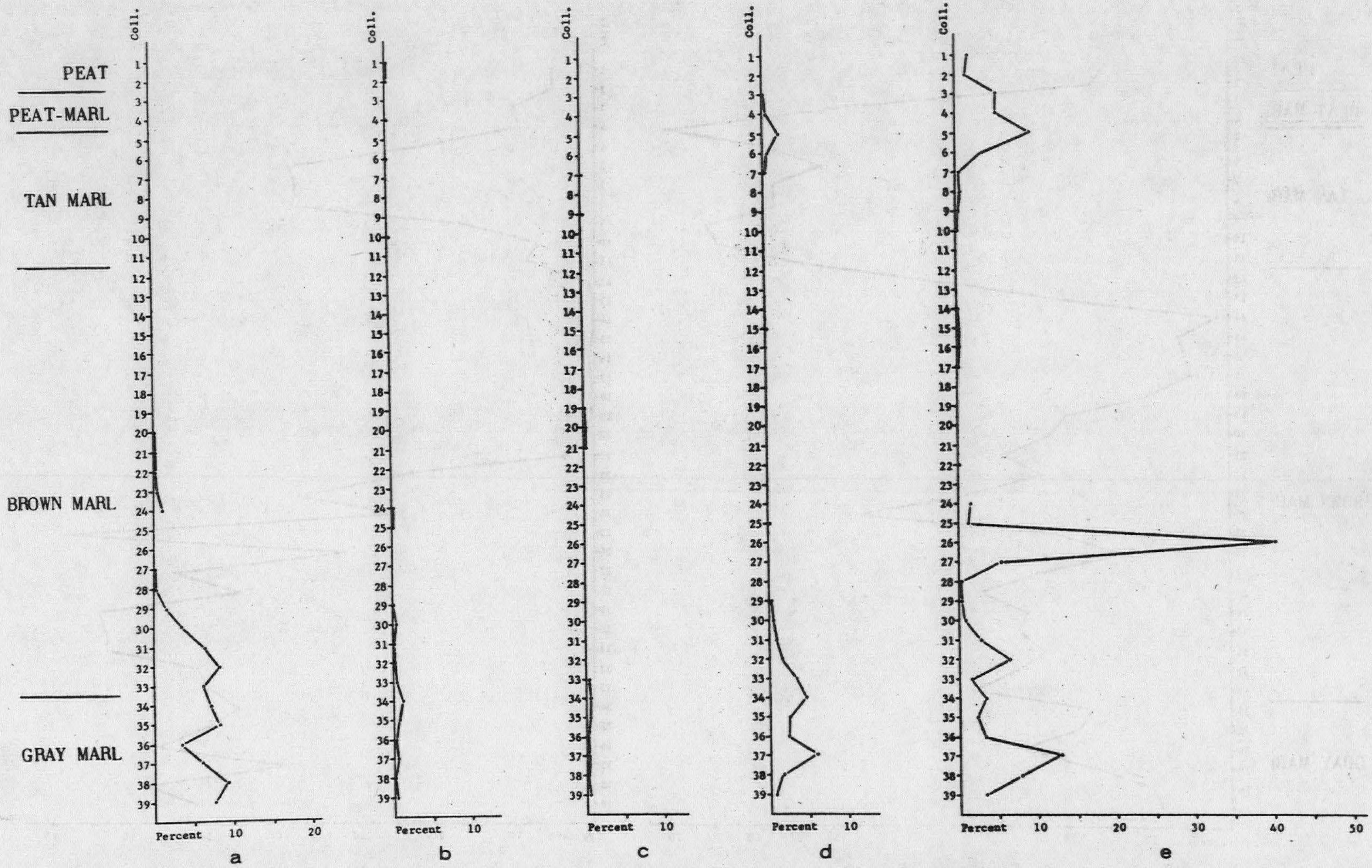
PLATE II. VERTICAL DISTRIBUTION OF MOLLUSCAN SPECIES IN THE LITTLE GOOSE LAKE SECTION



a. Fossaria obrussa

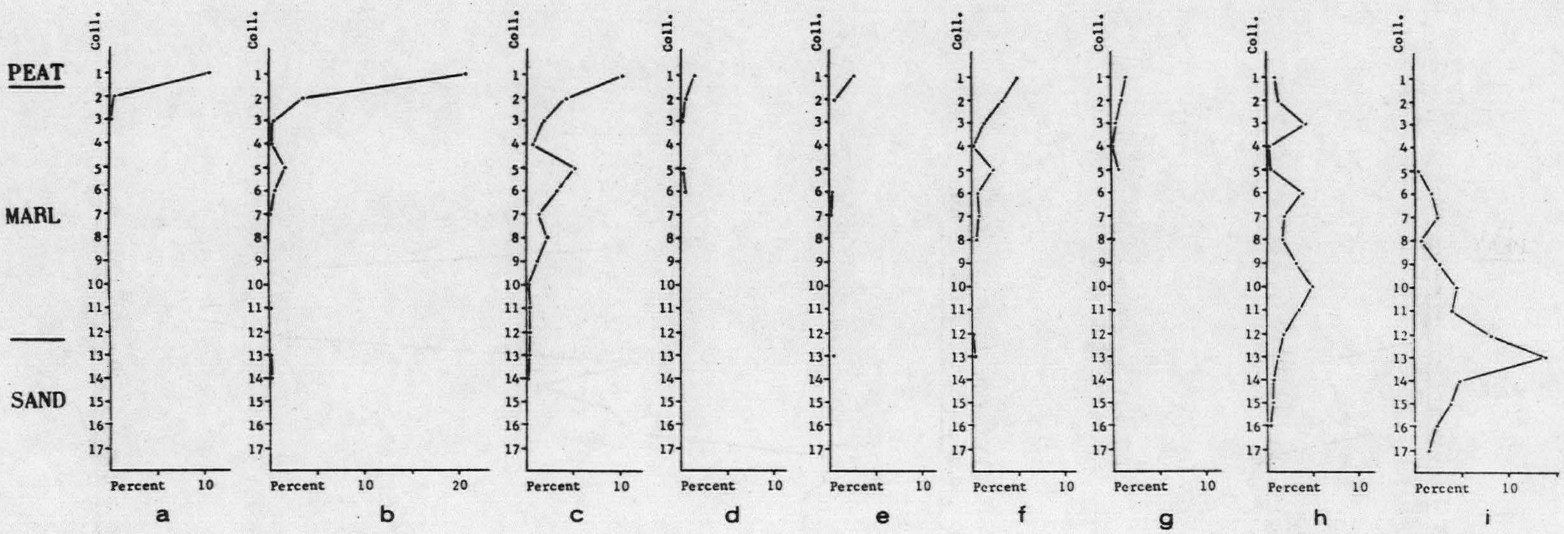
b. Gyraulus parvus

PLATE III. VERTICAL DISTRIBUTION OF MOLLUSCAN SPECIES IN THE LITTLE GOOSE LAKE SECTION



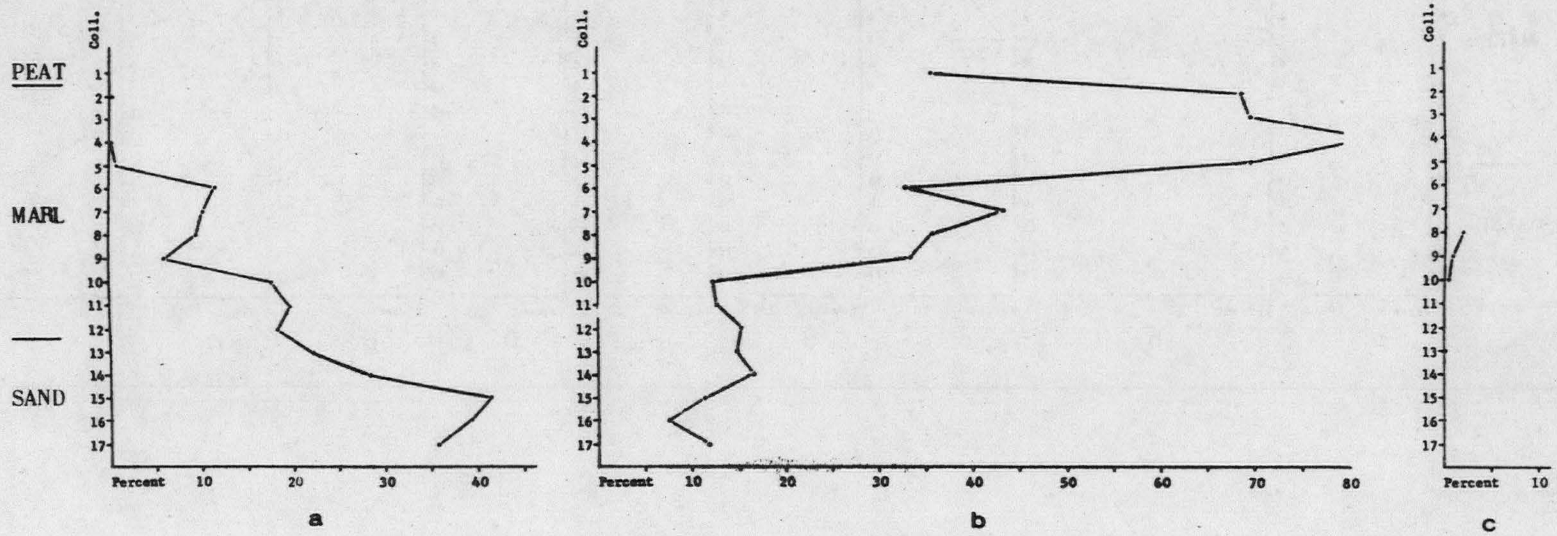
a. Gyraulus circumstriatus *b. Helisoma anceps* *c. H. campanulatum*
d. Physa gyrina *e. Pisidium casertanum*

PLATE IV. VERTICAL DISTRIBUTION OF MOLLUSCAN SPECIES IN THE LITTLE GOOSE LAKE SECTION



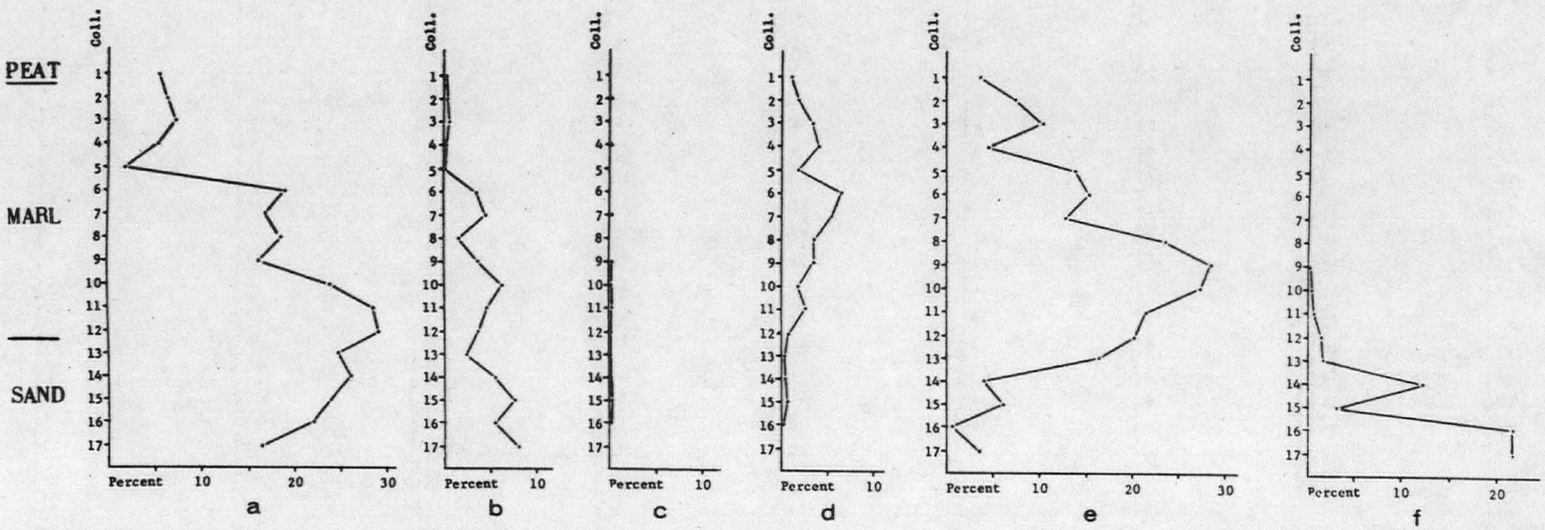
a. *Carychium exiguum*
b. *Gastrocopta tappaniana*
c. *Oxyloma retusa*
d. *Quickella vermeta*
e. *Strobilops affinis*
f. *Vertigo morsei*
g. *Zonitoides arboreus*
h. *Amnicola limosa*
i. *Amnicola lustrica*

PLATE V. VERTICAL DISTRIBUTION OF MOLLUSCAN SPECIES IN THE LIME LAKE SECTION



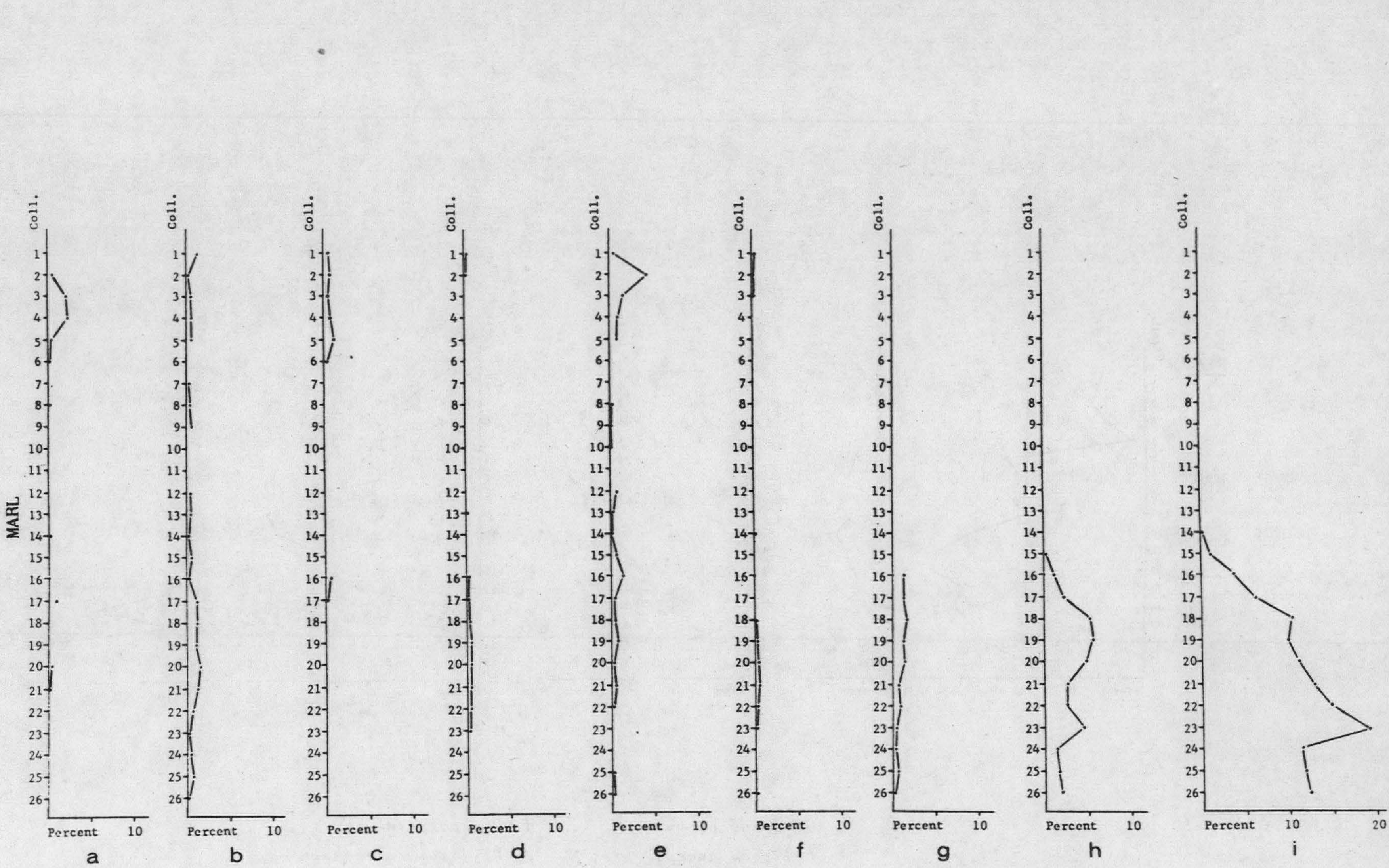
a. *Valvata tricarinata*
b. *Fossaria obrussa*
c. *Gyraulus circumstriatus*

PLATE VI. VERTICAL DISTRIBUTION OF MOLLUSCAN SPECIES IN THE LIME LAKE SECTION



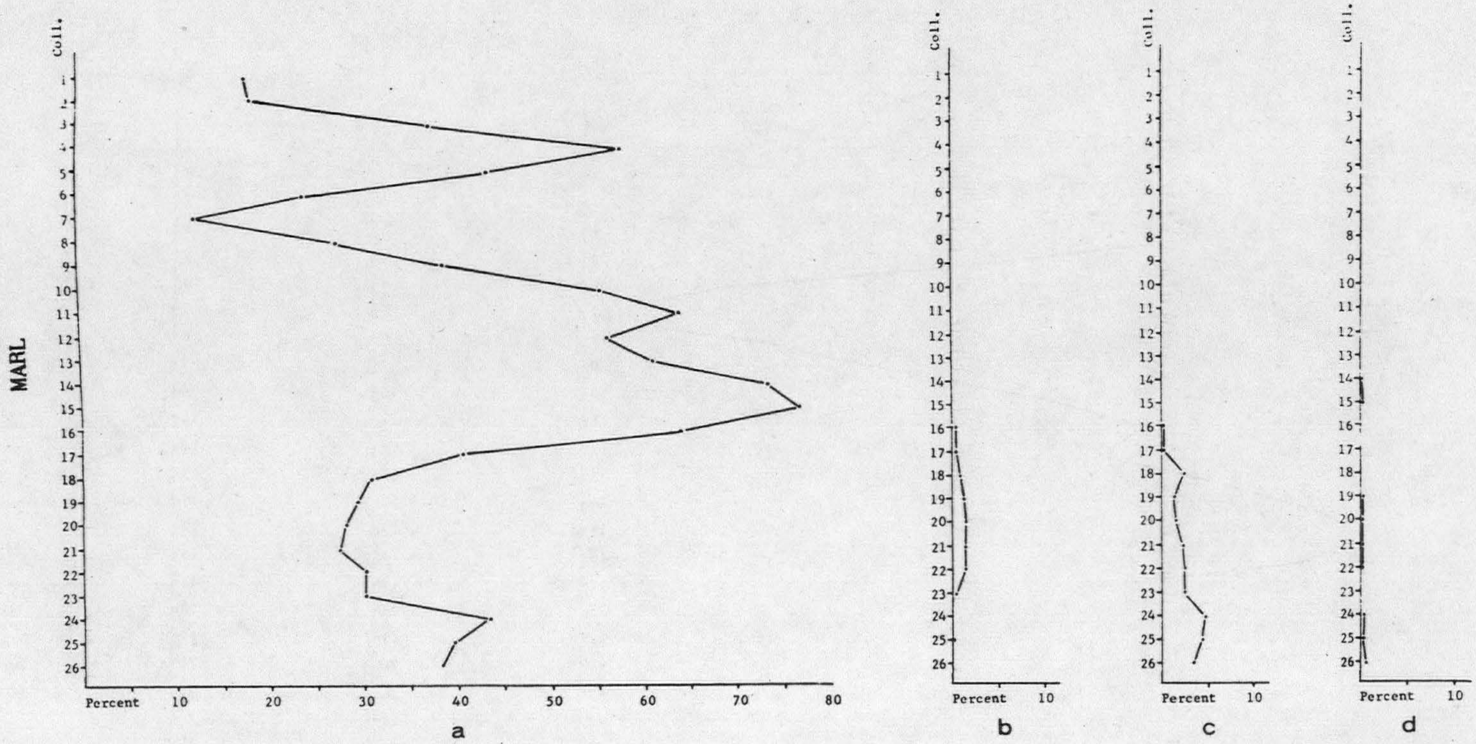
a. Gyraulus parvus
b. Helisoma anceps
c. Helisoma campanulatum
d. Physa gyrina
e. Pisidium casertanum
f. Pisidium obtusale

PLATE VII. VERTICAL DISTRIBUTION OF MOLLUSCAN SPECIES IN THE LIME LAKE SECTION



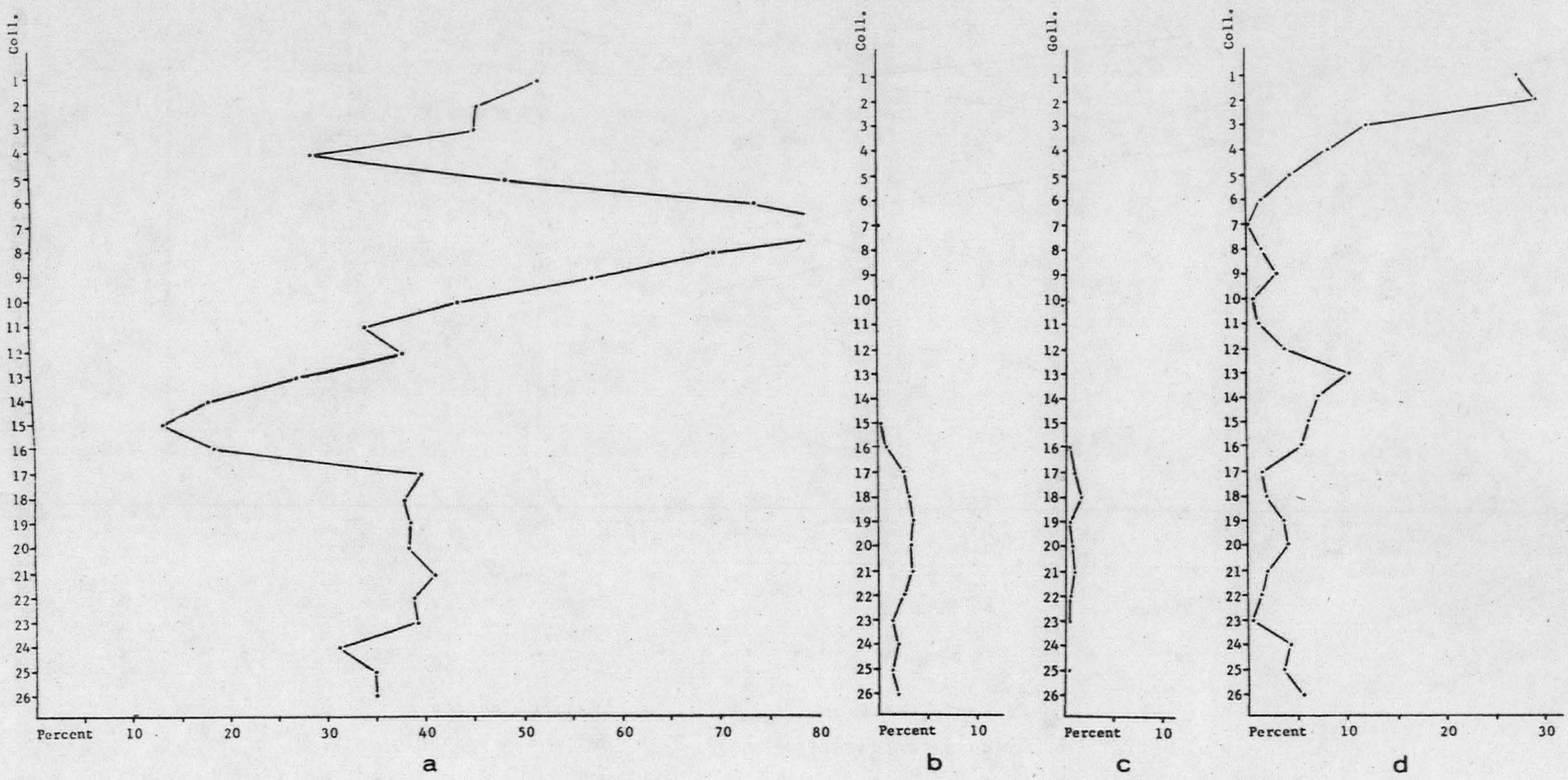
a. *Gastrocopta tappaniana*
b. *Oxyloma retusa*
c. *Quickella vermeta*
d. *Strobilops affinis*
e. *Vertigo morsei*
f. *Zonitoides arboreus*
g. *Amnicola limosa*
h. *A. lustrica*
i. *Valvata tricarinata*

PLATE VIII. VERTICAL DISTRIBUTION OF MOLLUSCAN SPECIES IN THE MARL LAKE SECTION



a. Fossaria obrussa
b. Gyraulus circumstriatus
c. Helisoma anceps
d. Helisoma campanulatum

PLATE IX. VERTICAL DISTRIBUTION OF MOLLUSCAN SPECIES IN THE MARL LAKE SECTION



a. Gyraulus parvus

b. Physa gyrina

c. Stagnicola catascopium

d. Pisidium casertanum

PLATE X. VERTICAL DISTRIBUTION OF MOLLUSCAN SPECIES IN THE MARL LAKE SECTION

INDEX TO STERKIANA NOS. 41-50 : AUTHOR INDEX

SINCLAIR, Ralph (1971) Annotated bibliography on the exotic bivalve *Corbicula* in North America, 1900-1971. -- 43: 11-18, 6 text figs.

SMRCHEK, Jerry (1971) Present status of *Elliptio complanatus* in Douglas Lake, Michigan. -- 43: 10

VAILLANCOURT, G. & AUBIN, A. (1972) Liste des Sphaeriidae du fleuve Saint-Laurent région de Gentilly. -- 46: 1-5, 1 fig.

---- & DINGEMANN, M. (1972) Liste des gastéropodes du fleuve Saint-Laurent, région de Gentilly. -- 48: 17-29, 2 text figs.

VALENTINE, B. D. & STANSBERY, D. H. (1971) An introduction to the Naiads of the Lake Texoma region, Oklahoma, with notes on the Red River fauna (Mollusca:Unionidae). -- 42:1-40, 1 fig. (map)

WALKER, Bryant 1918 (1969-1972) A synopsis of the classification of the fresh-water Mollusca of North America, north of Mexico, and a Catalogue of the more recently described species, with notes. ---Continued from Sterkiana 39. 43: 27-52; 44: 45-56; 45:45-50; 46: 19-63 (Pagination of original only; the reprint has no Sterkiana pagination).

WILSON, M. & La ROCQUE, A. (1973) Fossil gastropods from a Paleo-Indian archaeological site in Calgary, Alberta, Canada: local and regional significance. -- 49: 1-10, 3 text figs.

YATES, Roger L. & RAWLS Hugh C. (1972) The anatomical distribution of fluorescence caused by Pseudomonads in *Anguispira kochi* (Pfeiffer). -- 45: 14-21

JOINT AUTHORS

Note to the binder: This sheet (2 pages) should be bound at the end of Sterkiana No. 50.