THE FRESHWATER MOLLUSCS IN THE LATE-GLACIAL AND EARLY POST-GLACIAL DEPOSITS IN THE BOG OF BARMOSEN, SOUTHERN SJÆLLAND, DENMARK

by

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Abstract

The present work gives a quantitative analysis of the freshwater molluscs in the deposits from the latest part of the Late-Glacial Age and the early part of the Post-Glacial Age in the bog of Barmosen, which was at that time a lake.

By means of this analysis, an attempt is made to reconstruct the development of the lake. The molluscs have been divided into different ecological groups to help estimating whether the water was quiet or subject to wave or current action; also the vegetational environment is estimated. An interpretation of the water level and its changes, made on the basis of the molluscs, seems to be confirmed by the geological conditions.

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INTRODUCTION

Shells of land- and freshwater molluscs are common in Late- and Post-Glacial deposits, and the state of preservation is often very good. Since all species from these deposits seem to be still existing a comparison with the Recent fauna will be natural. By studying the present environmental requirements of the molluscs and by assuming that these requirements have not changed, it will be possible to analyse the ecological conditions of the past.

As the molluscs in our fresh waters, as far as most of the species are concerned, spread very fast, the great majority of them have immigrated very shortly after the amelioration of the climate.

A necessary condition is, of course, that the molluscs were able to find those localities which satisfied their ecological requirements. The question of which kinds of ecological conditions existed in a given locality has to be answered by a study of the distribution of species as well as of individuals relative to the sediment in which they are found.

A factor which will always manifest itself is the climate, taken in the widest sense of the term; but the effect of the climate is of a very complex nature which has not yet been fully clarified. It seems, however, as if freshwater molluscs are less suitable as indicators of the climate; on the other hand they may yield much valuable information about local conditions.

Since there is always some current in the water of a lake, the dead molluscs may easily be exposed to mechanical action, so that the mollusc assemblages found by washing the samples are no longer representative, neither of species nor of number of individuals. A distortion may also result if many of the shells have been crushed to such an extent that they are difficult to determine. However, even though the material which is prepared out of a deposit only in a few exceptional cases is a biocoenose, it is still possible through a critical evaluation to obtain probable results.

PREVIOUS WORK

The freshwater moluscs of the Quaternary deposits have been studied by several authors. On the whole, the works fall within two periods. In the first decade of this century the utility of the freshwater molluscs for climatic interpretations was discussed very sedulously. The main subject of this discussion was the temperatures which JOHANSEN (1904) believed to be able to demonstrate for the Alleröd Time. JOHANSEN assumed a connection between the northern limit af the area of distribution of the molluscs and the july-isotherm and was thereby able to establish the minimum requirements to the summer temperature of the individual species.

JOHANSEN's results were much discussed, both in the Danish Geological Society, where WESENBERG-LUND (1906) strongly opposed them, and at the International Geological Congress in 1910 (see MENZEL 1910).

Besides demonstrating the Alleröd Time to be a major climate oscillation, JOHANSEN advanced an immigration history for the land- and freshwater molluscs in the Post-Glacial Age and divided on this basis this Age into three zones, each characterized by the immigration of a certain species.

Earlier, ELBERLING (1870 and 1875) had investigated deposits of calcareous tufa from a great number of localities all over the country, and in continuation of this, LEMCHE (1926) studied a calcareous tufa in the north-eastern Sjælland (Sealand). In both cases the molluscs were used for an interpretation of the local ecological conditions.

Through the last twenty years there have been published several important papers about the land- and freshwater molluscs of the Quaternary deposits. The considerable amounts of loess in Central Europe contain numerous land snails, which have been studied by many authors (see LOZEK 1964).

Also limnic deposits have been the subject of several authors, among whom SPARKS is to be mentioned first. In a series of papers SPARKS has explained his quantitative analyses of the non-marine molluscs and the hereby obtained valuable conclusions about the local-ecological conditions and the climatic changes.

TAYLOR (1960) has by means of a study of the molluscs in a series of Pliocene and Pleistocene deposits both described the climate during the sedimentation and determined their stratigraphic placing.

In KAUFMAN and MCCULLOCH'S (1965) paper the molluscs form an essential element in the interpretation of the development of a lake. The ecological requirements of the molluscs are compared with indications from other groups of animals and plants and with the limnological conditions in such a way that the history of the lake becomes clear.

THE DISTRIBUTION AND ECOLOGY OF THE FRESHWATER MOLLUSCS

The distribution of the freshwater molluscs depends on two circumstances: Their ability to spread and their ecology. By ecology is meant their demands to the environment in the widest sense of the term.

Geographically neither snails nor bivalves have the ability to move, and the spreading is passive. It is supposed that it takes place by means of other animals such as fishes and birds. The ability to spread is very different for the different species and is proportional to the adaptability of the species. According to HUBENDICK (1947), those species which make the smallest demands on the environment have the highest spreading ability. The same author has come to the conclusion that, provided suitable localities exist, the spreading is so effective that if a species is present in an area it will only exceptionally be missing from some of the localities within that area.

The demands on the surroundings may be divided into the following groups: The climatic, the chemical and the local demands (including depth, vegetation, quit water or water in motion, the possibility of drying up, etc.); since these several conditions interfere with each other, it will naturally be difficult and dubious to investigate only a single one of them.

The part played by the climate in the distribution of the freshwater molluscs has not yet been finally determined. Already in 1906, WESENBERG-LUND showed that the temperature of the air is a poor indicator of the temperature in a lake; and HUBENDICK (1947) even doubts that the temperature, in the ordinary sense of the word, is a limiting factor at all.

On the other hand, SPARKS has, in his studies of the nonmarine molluscs from the last Interglacial Age, been able to show a connection between the frequency of the molluscs and the climate. It should be particularly noted that this connection was found for deposits from toward the end of an Interglacial Age. The increasingly bad climate must then have been the only or at least the main cause of the decrease of the number of individuals and of the gradual disappearance of some of the species. During an improvement of the climate the conditions will be much more complicated. Factors such as the ability to spread, the length of the immigration route and the limnological conditions will cause the dependence of the molluscs on the climate to become less clear. GEYER (1924) puts it this way: "Etwaigen tiefgreifenden klimatischen Schwankungen hinken sie nach."

Consequently the freshwater molluscs must be said to be poor indicators of the climate, especially in the case of short climate oscillations. For the same reasons, their utility for age-determination is less.

Among the chemical factors, the presence of lime, according to HUBENDICK's investigations (1947), is a favouring factor, whereas acidity is a restrictive one. HUBENDICK goes as far as to attach the greatest importance to the lime requirement. He says: "Mit grösster Wahrscheinlichkeit ist es eine Funktion, deren Erfüllung den dominierenden Einfluss auf die Gastropodenfauna ausübt, nämlich die Kalkversorgung"; "Klimatische Faktoren sind in diesen Zusammenhang von untergeordneter Bedeutung".

The local ecological factors are subordinated the other ones and can be investigated only when these can be left out of consideration.

In the present investigation the local conditions form the starting point, as the lime requirement of the molluscs is supposed to have been covered and as the changes in the climate which took place apparently have not had any influence on the mollucs in the lake investigated.

LOCATION AND GEOLOGICAL SITUATION; METHODS OF SAMPLING AND STUDY

The bog of Barmosen is situated about 5 km north of Vordingborg in South-Sjælland; it is, with an area of about 6 km², one of the largest bogs in this region. To the north-east of the Barmosen there is situated a still larger bog, whose separate parts are named Köng Mose, Lundby Mose and Sværdborg Mose (in fig. 1, the whole bog is however, named Köng Mose). This bog has been investigated by JESSEN (1935) in connection with extensive archæological exacavations.

The district is a young moraine landscape, which mainly consists of boulder clay. The geological structure of the bog is very simple. On top of a deposit of sand and clay, there is a bed of calcareous gyttja, which again is superimposed by peat. The upper part of the clay may contain some organic matter. The calcareous gyttja is found only on the lowest, bowlshaped parts of the surface of the deposit of clay and sand, and horizontally it extends only through the central part of the bog. In the border zone of the bog the peat thus rests directly on the sand and clay.

The locality at which the profile of this investigation is made was chosen at a place where the calcareous gyttja is close to its maximum thickness; this place was far out from the lake shores. Thus the profile may be considered to be representative of the lake and to be fairly free from local influence. The following profile was found (depths measured from the ground):

0 –0.25 m	peat with a gyttja content
0.25–0.85 m	calcareous gyttja
0.85–0.94 m	calcareous clay-gyttja
0.94–about 3.60 m	clay and sand
about 3.60 m–downward	boulder clay

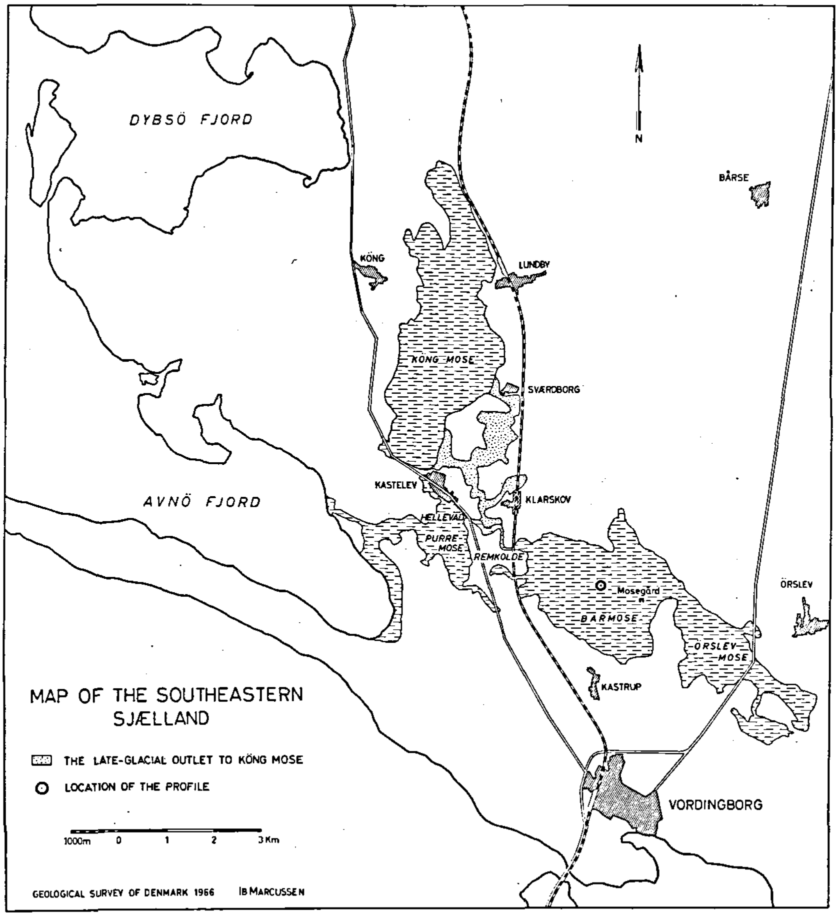

Fig. 1.

On account of an intensive cutting of peat in the bog, the present, thin layer is only a remnant of an earlier much thicker bed. The peat is homogenous, brownish black and without stratification. Only the lowermost 2–3 cm contains molluscs. Downward the peat has a sharp boundary toward the underlying calcareous gyttja.

Originally the calcareous gyttja has presumably been a very uniform sediment, which has consisted of calcareous matter exclusively, and the plant material which is to be found in it today are roots of a later vegetation. The calcareous gyttje is very rich in shells of molluscs and contains also many remains of ostracods and many oogonia of Chara. There have, however, been found no remains of vertebrates.

With an indistinct lower boundary the calcareous gyttja passes into a clay-gyttja with a large content of calcareous matter. However, that which has contributed most to the filling up of the basin is a deposit of well-sorted sand and clay. In the upper part this consists of a sticky, bluish grey clay which contains irregular schlieren of fine sand. This clay has an indistinct boundary toward the overlying calcareous clay-gyttja.

A pollen analysis shows that the bluish grey clay is of a Late-Glacial Age and that the boundary between the clay and the overlying clay-gyttja coincidences approximately with the transition from the Late-Glacial to the Post-Glacial Age. The uppermost part of the calcareous gyttja is to be placed at the transition between the pollen zones V and VI.

The samples were taken in an open profile and represent a column with a horizontal cross-sectional area of about 15 cm $\times$ 15 cm. The size of the samples can be seen in the diagram of the molluscs. The material was washed on a sieve with a mesh size of 1 mm. Then the molluscs were separated and determined according to MANDAHL-BARTH and BONDESEN (1949). Variants of a species are in what follows classed under the species.

In the counting of individuals only apical parts have been included.

In the case of *Bithynia tentaculata*, both shells and opercula have been counted. Since some of the opercula belonging to shells retained on the 1 mm sieve have been small enough to pass through, a correction to the number of *Bithynia tentaculata* opercula will have to be made. This correction is made in the following way: By means of a collection of Recent speciments, shells with thereto belonging opercula, the size of a sieve which will just retain the shells corresponding to the opercula just retained on a 1 mm sieve is determined. This size was found to be 1.410 mm, approximately. All the fossil shells of *Bithynia tentaculata*, which were retained on the 1 mm sieve, have then been sifted on the 1.410 mm sieve, and the number of shells which went through it, which should presumably be equal to the additional number of opercula (which passed through the 1 mm sieve and were thus not counted), were added to the number of opercula (retained on the 1 mm sieve and) counted. In the calculations only the number of opercula has been used, except in sample No. 6401.

The pisidia have been counted as single valves, but in the following calculations the number has been halved. The very large number of shells of pisidia has made it practically impossible to determine them all, and therefore a representative, smaller sample has been taken out for determination of species. In the samples No. 6401, 6406 and 6407, however, all pisidia valves have been determined. *Pisidium nitidum* dominates to such a degree that in an ecological evaluation the other species of pisidium may be left out of account.

The shells of *Sphaerium corneum* are often crushed, and the only with certainty recognizable part is the arched part with the hinge. This arched part is often broken in two at the cardinal teeth. All complete and "half" archs were counted, each "half" arch being counted as ½ specimen.

In the table of the number of counted molluscs (table II), an (x) marks that the species has been found in the material that passed through the 1 mm sieve. In the case of *Planorbis planorbis* in sample No. 6407 the specimen was retained on the 1 mm sieve, but is to be excluded for ecologica reasons.

Table I. The number of valves of pisidia in the Barmosen deposits; No. 6401, 6406 and 6407 total sample; No. 6402–6405 smaller, representative sample.

Sample No.	6401	6402	6403	6404	6405	6406	6407
Pisidium pulchellum JENYNS	0	2	0	0	0	0	0
Pisidium nitidum JENYNS	171	1830	669	798	555	13	17
Pisidium subtruncatum MALM	0	2	0	8	0	0	0

Table II. The number of molluscs in the Barmosen deposits.

Sample No.	6401	6402	6403	6404	6405	6406	6407
Valvata cristata O. F. MÜLLER	27	2.704	1.729	2.788	1.284	4	2
Valvata piscinalis O. F. MÜLLER	26	2.293	1.983	1.704	248	3	0
Bithynia tentaculata LINNÉ shells	25	1.439	830	665	125	1	1
Bithynia tentaculata LINNÉ opercula	0	771	484	378	190	12	1
Bithynia tent. opercula, corrected number	0	1.304	787	546	230	13	1
Physa fontinalis LINNÉ	0	50	160	63	21	0	0
Lymnaea pereger O. F. MÜLLER	10	2.776	2.655	2.389	2.140	1	1
Lymnaea stagnalis LINNÉ	0	1	0	0	0	0	0
Planorbis planorbis LINNÉ	11	406	280	472	26	x	x
Planorbis carinatus O. F. MÜLLER	0	1	2	3	0	0	0
Anisus leucostoma MILLET	0	1	0	0	0	0	0
Anisus contortus LINNÉ	0	1	0	0	0	0	0
Gyraulus laevis ALDER	0	0	0	0	4	0	0
Gyraulus crista LINNÉ	0	0	0	11	181	x	0
Hippeutis complanatus LINNÉ	0	0	7	14	4	0	0
Pisidium, valves	171	16.398	13.697	8.960	2.014	13	17
Pisidium, individuals	86	8.199	6.849	4.480	1.007	7	9
Sphaerium corneum LINNÉ, valves	8	93	36	18	50	x	x
Sphaerium corneum, individuals	4	47	18	9	25	0	0
Number of individuals	189	17.783	14.470	12.479	5.170	28	13
Number of individuals per 100 cm^3 sample	17	527	429	370	153	1	1
Number of species	7	14	10	12	11	8	6

DIAGRAM OF THE MOLLUSCS

Ecological groups

The diagram of the molluscs (plate 1) illustrates by means of histograms the relative frequency of the molluscs found in the profile. However, the diagram does not include all the species but only those which were present in a representative quantity. Some species were present in such a small number that they may be left out of consideration in an evaluation of the ecological conditions of the lake.

The presence of *Planorbis planorbis* and *Sphaerium corneum* in the samples No. 6406 and 6407 is considered to be without importance. These molluscs are to be found almost exclusively in dense vegetation and at places with a bottom of mud. That such conditions have prevailed during the deposition of the samples (especially sample No. 6407) is considered impossible on account of the type of sediment.

The diagram is divided into four parts. In the first one (column 1–9) the relative variation in number of individuals of each species is shown. In the other three parts the mollusc species are grouped together into various ecological groups.

Most freshwater molluscs have a great adaptability but seem nevertheless to prefer some environments to others. By a division into ecological groups there must consequently be emphasized those conditions under which a species occurs with a particularly large relative frequency or in particularly great number.

On the basis of literature studies, SPARKS (1961) has according to this principle subdivided the freshwater molluscs into the following groups:

1. The slum group, comprising species that are able to stand stagnation and even drying up of the water. In the material investigated this group is represented only by *Anisus leucostoma.*
2. The catholic group, consisting of species which do not seem to make narrow demands on the biotope. They are found in all types of biotopes except in pronounced slum conditions. In this group fall the following species: *Lymnaea pereger, Anisus contortus, Gyraulus crista, Hippeutis complanatus, Pisidium nitidum, Pisidium subtruncatum,* and *Sphaerium corneum.*
3. The quiet-water group. This group comprises species which usually live in vegetation-rich ditches with slowly flowing water or in the dense vegetation in the quiet parts of bigger lakes. The group is represented by *Valvata cristata* and *Planorbis planorbis.* The variation of this group is illustrated in column 10 of the diagram.
4. The moving-water group. The species in this group are common in streams and larger lakes, where the water is not quiet because of current or wave action. The following species fall in this group: *Valvata piscinalis, Bithynia tentaculata,* and *Physa fontinalis.* The variation of this group is shown in column 11 of the diagram.

Of these four groups only the last two are of significance in the interpretation of the quietness of the water, and therefore part 2 of the diagram (column 10 and 11) has been based on the species of these two groups only.

It is also possible to divide the freshwater molluscs into groups according to the type of object on or in which they usually are to be found. This classification does not seem to meet with the same difficulties as the first one, since the specifications in the literature are more concordant. Thus there should be a reasonable basis for such a classification. The following groups may be established:

a. "On the plants". This group comprises molluscs which mainly or exclusively live on the living vegetation. The group includes *Valvata cristata, Valvata piscinalis, Physa fontinalis, Lymnaea pereger, Planorbis planorbis,* and *Hippeutis complanata.* The variation of this group is shown in column 12 of the diagram.
   It appears that the group can be further subdivided, as the valvates live mainly on the lower parts of the plants while the other species of this group live on the upper parts of the plants. The two subgroups are shown in columns 15 and 16 of the diagram.

b. "On or in the bottom". The species of this group most frequently live on or buried in the upper part of the bottom, where they feed on disintergrating plant material. The following species may be included: *Gyraulus crista, Pisidium nitidum* and *Sphaerium corneum.*
   In the diagram the variation of this group is shown in column 13.

c. "On firm objects". The molluscs of this group live mainly on firm objects such as stones and branches lying on the bottom. Of the species found in the material examined, only *Bithynia tentaculata* may be included in this group. The variation of this group is shown in column 14 of the diagram.

Interpretation

For convenience the profile has been divided into five ecological zones, *A–E.* These zones are purely local.

During the time of deposition of zone *A,* the water in the lake was quiet and the vegetation was scant and low.

The molluscan fauna was completely dominated by *Pisidium nitidum,* which has a very wide ecological and geographical distribution and which therefore must be characterized as a hardy species. The rather unfavourable conditions for the molluscs are evident also from the fact that both the number of species (6) and the number of individuals (1 pr. 100 cm^3) are very small. The preponderance of the quiet-water group suggests that the water in the lake has been quiet and without currents or wave action of importance; this may also be seen from the nature of the sediment, a sticky clay.

During the sedimentation of the calcareous clay-gyttja of zone *B,* the water seems to have been subject to wave and current action this is shown by the diagram of the molluscs and by the fact the shells are corroded and worn.

The shallow bowl-shape and the large horizontal extent, which the lake may be assumed to have had, make it likely that the motion of the water were caused rather by wind action than by true currents. The abrupt changes from zone *A* to zone *B* may therefore be most easily explained by a lowering of the level of the water.

In zone *B* there is a decline of the bottom animals and a progress of the group "on the plants".

Among those molluscs which live on the plants the group living on the lower parts of the plants dominates. It will consequently be reasonable to suppose that the vegetation, though still comparatively scant, was less scant than in zone *A*, and that it still was a low vegetation.

At the transition to zone *C* and the beginning deposition of calcareous gyttja a considerable change of the lake took place. Those molluscs which prefer quiet water with tall vegetation make a considerable progress. Both the number of species and the number of individuals increases very quickly, and this indicates more favourable conditions.

Several species imigrate to the lake, and of these particulary *Physa fontinalis* is of interest, as this species, according to several authors, requires clear water.

During the deposition of the zones *C* and *D* there seems to have existed a state of balance in the lake. The boundary between the zones *C* and *D* does not mark any definite change in any of the properties or conditions, but has been established merely for convenience in describing and elucidating the nature of the slow and steady changes taking place during the time of deposition of these two zones. The small but systematic progress of forms which prefer water that is not quiet could maybe have a connection with the successive filling up of the lake, which will appear like a lowering of the level of the water. The group of molluscs which demand quiet water decreases correspondingly, and from zone *C* to zone *D* there is a decline of those species which shun places with wave action. This is to some extent the case for *Valvata cristata* and *Planorbis planorbis,* but especially for *Gyraulus crista* and *Hippeutis complanata.* As regards the vegetation of the zones *C* and *D* there does not seem to have occurred any change of significance for the molluscs.

The uniform conditions of sedimentation which have prevailed during the deposition of the calcareous gyttja reflect the uniform chemical conditions in the lake during this time. One of the most important (according to HUBENDICK (1947) the most important) ecological factors, namely the chemical one, and especially the quantity of lime available, has been approximately constant in the lake during this time. Consequently it has under these conditions been possible to investigate other, less essential ecological factors.

At the transition to zone *E* the sediment and the chemical conditions change decisively, and this means that the basis for the analysis of the molluscs has changed and that an interpretation of the local-ecological conditions of this zone is doubtful and difficult compared with the interpretation of the conditions of the previous zones.

The very distinct decrease of the number of species as well as the number of individuals testifies to a change to less favourable conditions for the molluscs. Those changes which may be read from the parts for the ecological groups in the diagram are contradicted by the indications of the variations of the individual species. A valid interpretation must therefore take its starting point in the frequency of the individual species. Concerning *Sphaerium corneum*, BERG (1938) writes that it is frequent "where there is a mud bottom with abundant, rather coarse plant detritus", and LUNDBECK (1926) has come to a similar result.

Several authors state that *Planorbis planorbis* prefers shallow water with a dense vegetation and a mud bottom. Besides these two species also *Bithynia tentaculata* increases in relative frequency in zone *E*, but this is probably not caused by improved ecological conditions for this species but is rather a consequence of its relative small requirements of lime (HUBENDICK 1949).

Of those molluscs which decrease in frequency in zone *E*, *Physa fontinalis* may be especially noted. This species requires, as mentioned above, clear water.

Summarizing, the lake has, during the time of deposition of zone *E*, been quiet and rich in vegetation and has had a bottom consisting of plantmaterial, which facts also are shown by the nature of the sediment.

LIMNOLOGICAL CONDITIONS

The preceding interpretation of the molluscan assemblage is made under the assumption that the shells found belong to a life-assemblage, that is, that the shells were deposited at just that place where the animals have lived, without having been transported by mechanical forces neither when they were alive nor after they had died.

In 1901 WESENBERG-LUND drew attention to an accumulation of shells found at a depth of 7–11 metre in the lake Furesøen. This shell-zone lies immediately outside the vegetation zone. WASMUND (1926) has confirmed this observation as far as North-German lakes are concerned, and WESENBERG-LUND (1937) is of the opinion that it is a characteristic feature of lakes in the Baltic area.

According to WESENBERG-LUND the majority of the shells in the shell-zone are *Unio* and *Anodonta* and some *Valvata piscinalis* var. *antiqua*. More locally there may be found large accumulations of opercula of *Bithynia tentaculata* together with a few pulmonates. There is some disagreement about the origin of the shell-zone but there is hardly any doubt that currents in the epilimnion of the lake somehow play a part.

The molluscan fauna found in the Barmosen has very little in common with the shell-zone assemblage of WESENBERG-LUND; this might, however, be a consequence of the dissimilarity of the fauna and may be of less importance. There is, however, a certain circumstance by *Bithynia tentaculata* which is of importance. This mollusc has got both a shell and an operculum, and hence if no mechanical sorting of the deposited, dead animals has taken place there will be the same number of shells as of opercula.

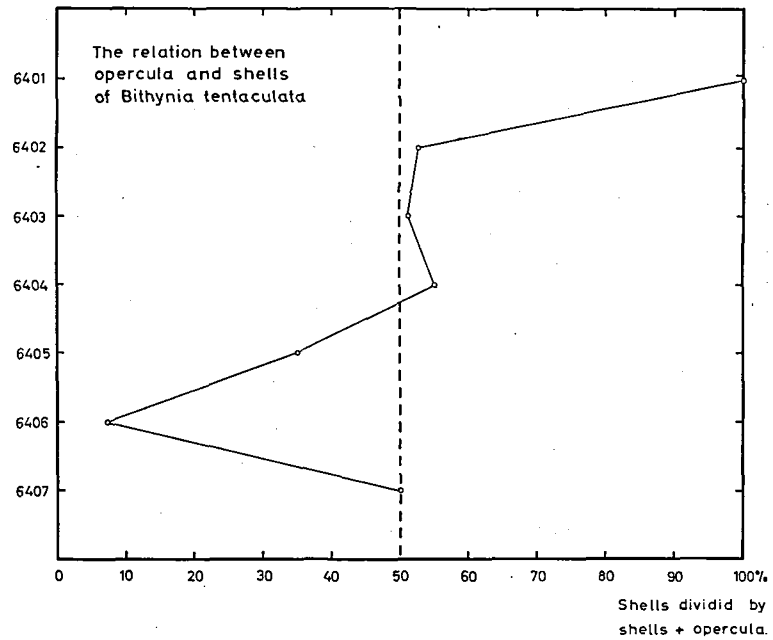

Fig. 2.

In fig. 2 the ratio between shells and shells + opercula is expressed in per cent. With the exception of the samples 6401 and 6406 the curve shows that there have been very quiet conditions in the lake. The deviations of maximally 15 % from the theoretical value of 50 % are too small to allow any definite conclusions to be drawn therefrom.

In sample 6406 there are many opercula (13) and only one shell. According to MENARD and BOUCOT's (1951) experiments with shells of brachiopods and KRUMBEIN's (1942) experiments with grains of gravel a smaller current is needed to set in motion a rounded body than a flat one. Shell and operculum of *Bithynia tentaculata* have just such a very large difference in sphaeridity and hence with a current of a certain strength the shells will be removed while the opercula will stay; this is probably what has happened in sample 6406.

More generally this may mean that the number of opercula gives a more correct picture of the number of *Bithynia tentaculata* than the number of shells does; also the opercula do not break as easily as the shells do.

As for sample 6401, in which there are many shells (25) but no opercula, it seems as if the shells have been transported to the locality by a current which was not strong enough to carry along the opercula. For samples with such a sorting of the material, interpretations have to be made with caution.

CHANGES IN THE WATER LEVEL

Indications by the molluscs

An attempt will here be made to give an elucidation of the height of the water-level and its changes, as they are reflected in the estimation of the molluscan faunas.

Only a few bits of information about the bathymetric distribution of the molluscs are available in the literature.

JOHANSEN (1899) gives many bits of information, and in STEENBERG'S (1917) paper a review of the extreme limits of the molluscs is given. In BERG'S (1938) paper the frequency of the molluscs at various depths are represented in some very clear diagrams. It is mainly this last work which has formed the basis of the following analysis.

In sample 6407 there are found four species to take into consideration. Of these *Pisidium nitidum* is the largest one in number of individuals. BERG has not found this species at greater depth than 5 metre, and STEENBERG describes it as a species belonging in small ponds (yet it is mentioned to be found occasionally out to a depth of 10 metre). The species *Valvata cristata* and *Lymnaea ovata* are by BERG listed from a depth of respectively 5 and 6 metre; outside these depths they have been found only sporadically. The fourth species, *Bithynia tentaculata,* is found at large depths, but is more frequently inside the depth curve of 5 metre than outside. As a consequence of all this, it is supposed that the depth of water at this part of the lake has been maximally 5 metre and, for reasons given below, not less than 2 metre, at the time when the uppermost part of the clay was being deposited.

In sample 6405 the fauna has been enlarged with several new species, and at the same time there has been a considerable increase in the number of individuals of those species already present in sample 6406. Of the new species, especially the following four are of interest in an estimation of the depth of the water: *Hippeutis complanatus, Gyraulus crista, Planorbis planorbis* and *Sphaerium corneum.* These all are stated to live in shallow water along the shore, and in the case of the three lastmentioned ones it is specified that they are found only at a water depth of less than 2 metre. This concerns particularly *Sphaerium corneum.* This means that the water depth during the deposition of the sediment of sample 6405 has been maximally 2 metre. This is indicated also by the increase in number of individuals, which the other species show, since they, according to BERG, have their largest frequency at a depth of water of 2 metre or less.

During the deposition of the calcareous gyttja the water-level has presumably been uniformly decreasing. The presence of *Anisus leucostoma* in the upper part of the calcareous gyttja may be regarded as indication that there have been marshy areas along the shores and that these presumably were not far from the place where the profile has been taken. Along with the change in the sediment from calcareous gyttja to peat consisting of plant material, one may suppose that the water-level has been further lowered and that the overgrowing has begun also out in the middle.

of the lake. There is nothing that indicates that there has been any drying up (for instance in the summer), and there must consequently have been a continuous cover of water also during the deposition of zone *E*.

Geological indications

In what follows the water-level will be evaluated from a geological point of view.

The Barmosen is at the present time drained towards the west through

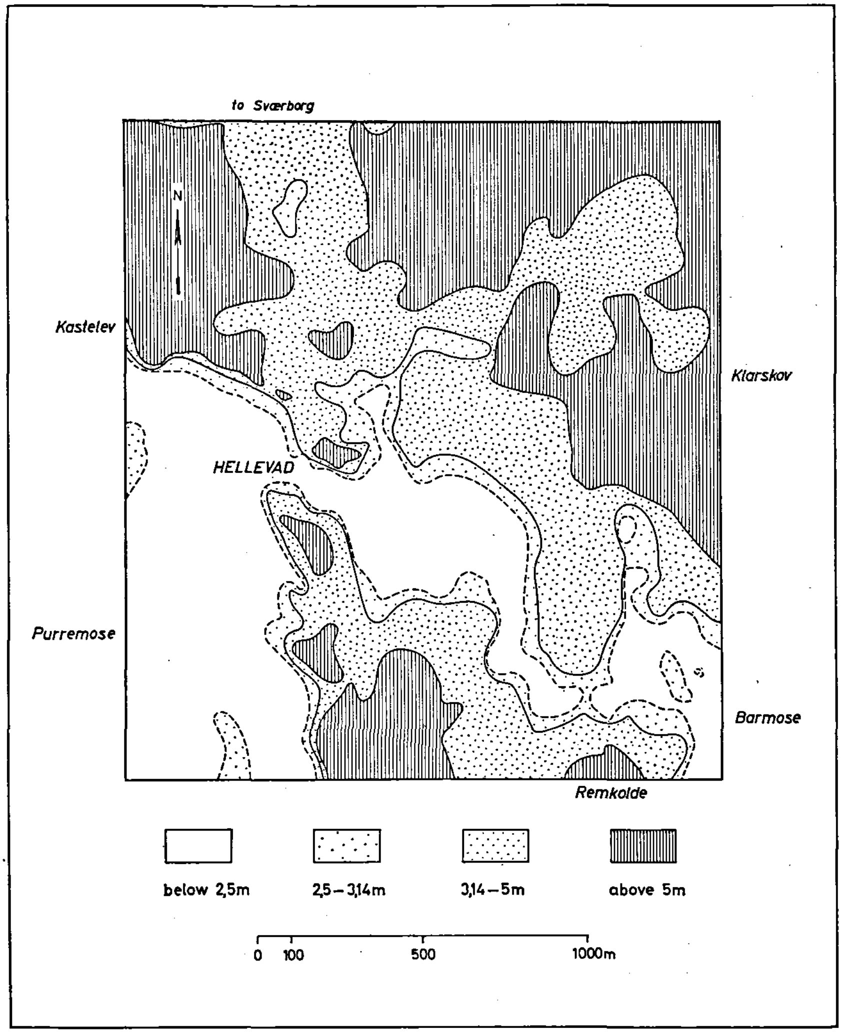

Fig. 3. Map showing the altitudes in the area around Hellevad.

Næs å (stream) to Avnø fjord (inlet), and the drainage has been like this throughout the whole Post-Glacial Age. This being the only possibility as the bog on all other sides is surrounded by high, glacigene land. The threshold for this drainage is located at Hellevad. To the west of this threshold the top of the Late-Glacial deposits is about 3 metre lower than east of it, which indicates that the two basins have been separated by this threshold during Late-Glacial Age. This area constitutes a crucial point for the understanding of the water levels and the drainage of the Barmosen.

Fig. 3 shows that between the high-lying land north and south of Hellevad there are only some smaller areas which reach heights above the 5-metre curve.

The saddles between these higher areas, except for the valley at Hellevad, do not bear the impression of ever having served as places through which the water of the lake has flowed. They are slightly undulating and show a glacigene character, and they correspond closely with the landscape which lies above the 5-metre curve.

To the west of Remkolde Late-Glacial clay has been found in two borings. The top of this clay was respectively 3.35 and 3.60 metre above sea-level. North-west of Klarskov the Late-Glacial clay has been found up to a height of 4 metre above sea-level.

In the north-south-extending hollow north of Hellevad there has been found Late-Glacial sand (clay in the lowest parts). Deposits of Post-Glacial peat have been found only in small, local areas in the lowest parts of the hollow and then only as thin layers.

The water-level in the Late-Glacial Barmosen lake is supposed to have been between 4 and 5 metre above the present sea-level, and the drainage has taken place toward the north to Køng mose (bog), from which there were unobstructed ways of drainage both to Avnø fjord (inlet) and Dybsø fjord.

The closing threshold is made of boulder clay in the part south of Hellevad and melt-water sand north of Hellevad. Since flowing water erodes easier in sand than in boulder clay, the threshold has broken down at the place where the water first met the sand. Then the erosion of the valley has begun.

To the east the Barmosen has connection with another bog, Ørslev mose, through a passage which is about 500 metre wide. The peninsula which separates the two bogs consists of boulder clay and melt-water sand. The sand is found mainly on the west side and generally below the 5-metre contour. In the Late-Glacial Age the water has eroded and redeposited the easily accessible material. In fig. 4 the line "A" indicates a steep slope (about one metre high) which presumably, at any rate as far as the part facing towards the north-west is concerned, may be regarded as an erosion slope. To the east of "A" there are found several remains of beach ridges, which are made of gravel. Because of intensive cultivation the beach ridges are disturbed and have in some places vanished. This process has affected especially those ridges which were at a higher level, and this might be the

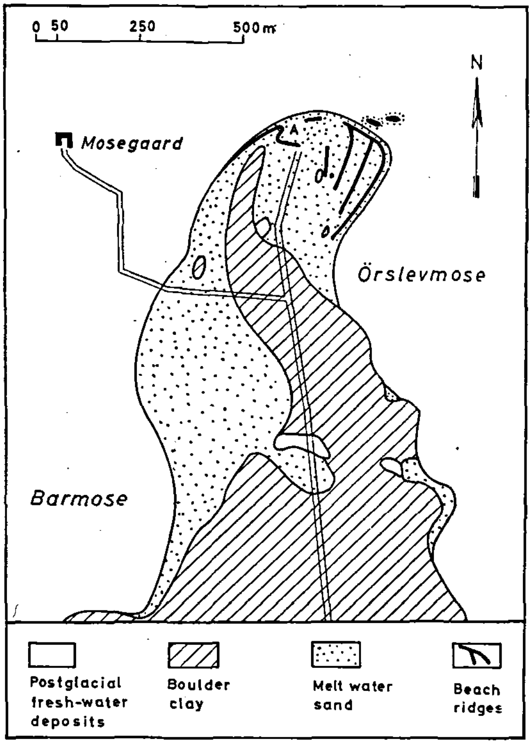

Fig. 4. The Quaternary deposits at the east side of the Barmosen. At "A" the erosion slope and east of that the beach ridges.

reason why there are now no signs of beach ridges higher up than those that have been found.

The flat, slightly arched surface of the beach ridges and their configuration may, in accordance with SCHOU (1945) indicate, that the prevailling wind has come from a direction somewhere between the south-west and the north-west.

Of those four ridges which in fig. 4 are shown going in a direction of N-S to NNE-SSW, the westernmost is at the highest elevation, namely 3.20 metre above sea-level. The other follow at elevations of respectively 3.00 m, 2.86 m, and 2.75 m, reckoned from the western toward the eastern one.

The NW-SE-striking part of the easternmost ridge is at an elevation of 2.50 metre, and the small remains of ridges just to the north of it reach 2.35 metre above sea-level.

The well-marked ridges and the decreasing elevation at which they are found show that the lowering of the water-level of the lake has extended over some time and has not taken place in the form of a sudden draining.

CONCLUDING REMARKS

The results of the investigation give the following picture of the development of the lake.

At the end of the Late-Glacial Age the shores of the lake reached an elevation of 4-5 metre above the present sea-level. In the deep part of the lake there was deposited a sticky clay while in the shallower part sand was deposited. The submersed vegetation was poor and low, and only a few molluscan species and individuals lived there. The lake had its drainage to Køng mose through a water-course west of Klarskov.

At the transition between the pollen zones III and IV a change of the drainage way began. The erosion of the narrow strip of land which separated the Barmosen from the Purremosen north and south of Hellevad had then progressed so far that it could not dam the water any longer. A valley was then cut through the threshold, whereby the water-level of the lake was lowered 2-3 metre. This lowering of the water-level, which extended over some time, has brought about that the hitherto quiet water of the deeper parts of the lake began to be wind-disturbed.

The lower water-level has, together with a better climate, resulted in a vigorous growth of the submersed vegetation and an enormous increase in the frequency of the molluscs. At the same time the water has again become more quiet. A considerable bed of calcareous gyttja was deposited in the central part of the lake, while along the shores there probably began a stagnation with deposition of peat.

Approximately at the transition from pollen zone V to VI the deposition of peat also began in the central part of the lake. The change in sedimentation from calcareous gyttja to peat witness to the overgrowing of the lake, and the modified environmental conditions have not been favourable for the molluscs.

DANSK SAMMENDRAG (SUMMARY IN DANISH)

Ferskvandsmolluskernes anvendelighed til tolkning af paleoøkologiske forhold er diskuteret, og det fremhæves, at det lokale miljø har en mere umiddelbar indflydelse på ferskvandsmolluskerne end klimaet. De er derfor bedre egnede til et studium af et søbassins udviklingshistorie end til klarlæggelse af klimasvingninger.

Det undersøgte profil i Barmosen har følgende opbygning:

0–25 cm gytjeholdig tørv (zone *E*)
25–85 cm kalkgytje (zonerne *C*+*D*)
85–94 cm kalkholdig lergytje (zone *B*)
94–ca. 360 cm ler og sand (zone *A*)
derunder moræneler.

Profilet er inddelt i 5 økologiske zoner *A–E*, som er rent lokale, og hvis begrænsning kan ses af diagrammet (tavle 1).

Grænsen mellem zonerne *A* og *B* er tilnærmelsesvis sammenfaldende med pollenzonegrænsen III–IV og grænsen *D–E* med pollenzonegrænsen V–VI.

Med udgangspunkt i en kvantitativ analyse af ferskvandsmolluskerne i aflejringerne i Barmosen er der forsøgt givet følgende oversigt over dette bassins udvikling i slutningen af senglacialtiden og begyndelsen af postglacialtiden.

I senglacialtiden antages det, at Barmose-søen er blevet afvandet mod nord gennem en dal vest for Klarskov til Køng mose (se fig. 1). Det nuværende afløb

økologiske zoner	maksimale vanddybde	vegetationen	vandets beskaffenhed
E	tilgroning	rig	roligt vand med en bund af plantemateriale
D	aftagende	rig	roligt og klart vand
C	2 meter	rig	roligt og klart vand
B	tapning	sparsom, lav	uroligt og uklart vand
A	5 meter	sparsom, lav	roligt og lerholdigt vand

ved Hellevad er blevet etableret i zone *B* ved nedbrydning af en spærrende dæmning. Samtidig er vandstanden i Barmosen sunket 2–3 m. Under tapningen er der vest for Mosegård dannet strandvolde (fig. 4) som tyder på en fremherskende vindretning fra SV–NV.

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