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ABSTRACT

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During the deglaciation assemblages of arctic to arctic/boreal molluscs and crustaceous inhabited submerged areas of southwestern Sweden. Shells representing 100 species of invertebrates have been found in the area as well as subfossil skeletal parts of at least 13 species. Most of the recorded species, 104 of 113, have been found in the Uddevalla area, about two-fifths (44 of 113) in the Vänern basin.

Radiocarbon datings indicate that arctic to arctic/boreal faunas existed along the Swedish west coast from 13 000 to 10 200 years B.P. in the region of Uddevalla; in the southern part of the Vänern basin from 11 800 to 10 000 years B.P., and in the western part of the Vänern basin during 9 900–9 600 years B.P. The migration intensity reached its maximum 11 000–10 400 years B.P., i.e. during the Younger Dryas chronozone.

The occurrence of shells in the Vänern basin indicate two types of glacial clays here. One of them, known as Skagerrak clay, contain frequent shell-bearing layers as well as individual shells and shell fragments. The Skagerrak clay sequence was formed during deglaciation up to the time of the Billingen terminal moraines, which constitute the deposits of Late Younger Dryas times.

The other type of glacial clay is known as Värmland clay here. This clay is almost barren of fossils and also differs from the Skagerrak clay by a higher content of clay particles in the upper part of the sequence. The Värmland clay was formed during the first c. 500 years of Preboreal times, i.e. during the ice recession from the Billingen terminal moraines to the region situated above the highest shoreline. It overlies the Skagerrak clay with diminishing thickness to the southwest.

A brief outline of the main events of the marine development in the Vänern basin is given in chronological order with calculated ages based on biostratigraphy and radiocarbon age determinations of shells and of skeletal parts of vertebrates.

c. 12 250 years B.P. Ice recession from the Berghem terminal moraine
c. 11 800 years B.P. Ice recession from the Trollhättan terminal moraine
c. 11 300 years B.P. Ice recession from the Levene terminal moraine
c. 11 000 years B.P. Formation of the oldest Skövde terminal moraine
c. 10 250 years B.P. Ice recession from the Billingen terminal moraine
c. 10 000 years B.P. Otteid and Närke straits opened; saline water enters the Baltic basin. Arctic/boreal fauna extinct in the southern part of the Vänern basin and at the Swedish west coast
c. 9 900 years B.P. Ice recession from the Karlstad terminal moraine
c. 9 800 years B.P. Arctic/boreal fauna inhabits the western part of the Vänern basin.
c. 9 500 years B.P. Arctic/boreal fauna extinct in the whole region

The Otteid and Uddevalla straits dried up about 9 300 years B.P. The threshold of the Närke strait dried up about 9 000 years B.P. The Vänern basin became isolated from the sea about 9 000 years B.P.

The Karlstad terminal moraine zone is introduced because of its pronounced glaciofluvial deposits in a 15 km wide east–west zone. It is situated north of Lake Vänern. Its continuation westwards to the contemporary Ski terminal moraine in Norway is not investigated. The formation of the deposits imply a retardation of the rapid ice recession during early Preboreal times.

Introduction

Marine vestiges in the Vänern basin have been known of since 1700's, when the subfossil finds of marine animals firstly absorbed the scientists. Since the first geological maps of the southwestern part of the basin appeared in 1870, the knowledge of the distribution of marine clays and the finds of marine mega fossils have increased. In due course growing knowledge and usage of new methods gave a circumstantial development of the marine stage of the Vänern basin.

The marine life had an arctic to arctic/boreal character and its ecology is linked with the deglacial conditions. It must be noted that in this survey the marine life is mirrored by subfossil occurrence only and not by glaciomarine relicts in the deep lakes.

The past and present knowledge of the Late Quaternary development of southwestern Sweden is primarily based upon radiometric determinations of organic matter, of varve chronology and of biostratigraphical investigations. Deglaciation history is often linked to main ice marginal zones which constitute stadials. A revised chronology of the deglaciation is at hand. Opinions differ due to methods used. Investigations and radiometric determinations of lake and peat sediments have been carried out by Berglund (1979) and Björck & Digerfeldt (1984). Studies of varved clays have been presented by Strömberg (1985) and Kristiansson (1986).

The present opinion of the deglacial chronology of southwestern Sweden is based upon different investigations of subfossil finds of marine vertebrates (Fredén 1975), cirripeds and molluscs (Fredén 1986a). Subfossil finds of marine animals are of great importance in this region as most of the area is situated below the highest shoreline, i.e. the glacial sediments have been deposited in a marine environment.

The first radiocarbon age datings of marine shells were carried out twenty years ago by Eriksson & Olsson (1967) on shells sampled at Lindalsskogen shell-bank, northeast of Kungshamn, a locality situated north of this investigated area. Shells and shell deposits are common in Bohuslän and relatively common in the southern part of the lake Vänern area. In order to establish a chronology of the deglaciation of Western Sweden based on radiocarbon age determinations of marine animals, the investigated area was restricted to the lake Vänern basin and to the southern part of Bohuslän as these parts of western Sweden form a marine environmental unit during the deglaciation. The investigation was supported by regular geological mapping of Quaternary deposits south and southwest of lake Vänern (Fredén 1974, 1984, 1986b, 1987; Adrielsson & Fredén 1987; Magnusson 1978). The investigation also gives a picture of the development of the marine fauna at different times. Invertebrates are more sensitive to hydrographical changes than vertebrates which have a larger living space and also a high tolerance of e.g. salinity changes.

Described localities are referred to topographical map sheets. Codes (1a, 5e) after names of the map refer to the 25-square grid marked in the margin of the map concerned.

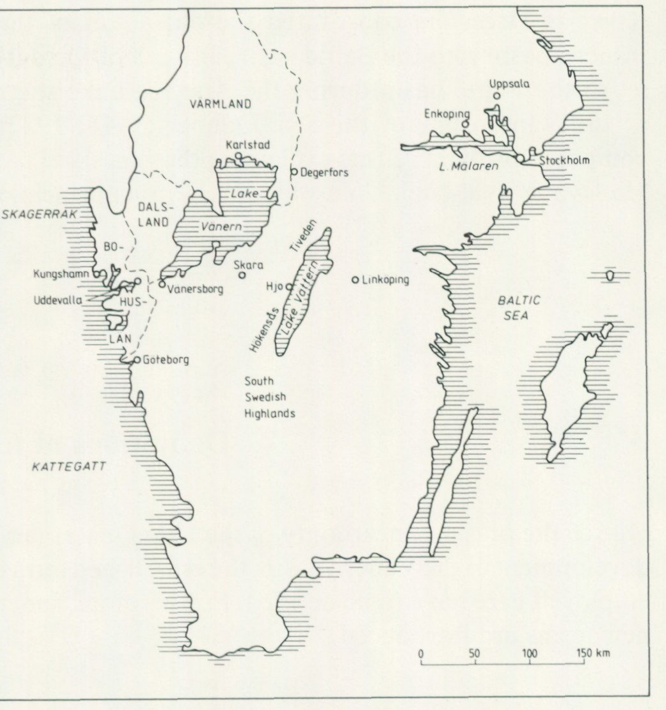

Fig. 1. Key map showing provinces and localities mentioned in the text and not shown in detailed maps.

Historical review

In the old days inland shell deposits were interpreted as conclusive evidence of "the Flood". Numerous localities in Bohuslän showing a withdrawal of sea water were known (see Kalm, 1746). Celsius (1743, 17 §) reported shells of molluscs at levels of 30 ells (about 20 m) in the river Göta älv valley, of 70 ells (about 50 m) in Dalsland and on high slopes at Uddevalla. The shell deposits at Uddevalla are briefly discussed by Swedenborg (1719) in his work on ebb and flow in the Old World as well as the find of skeletal parts of a whale at Norra Vånga, 15 km southwest of Skara town (see Fredén 1975 pp. 25–26). Linné (1747) produced an excellent description of the so-called shell hills at the "Sammered domains" (Kapellbacken and Kuröd, at Uddevalla). In an effort to explain their origin, Linné made comparisons with mollusc finds around the coasts of Norway, Great Britain and France. Linné thought that the molluscs had drifted to Uddevalla with the westerly winds. Of the many foreign researchers that visited the shell-banks, the famous scientists Lyell (1835), Forbes (1846) and Jeffreys (1863) may be mentioned.

The first man to draw conclusions from comparisons of subfossil and recent faunas was Sven Lovén (1846). Together with Otto Torell (1859), he realized the importance of the shell deposits and formed the basis of our knowledge about this part of the Quaternary development. Erdmann (1868) divided the deposits into glacial and postglacial deposits depending on their faunal composition and the height above sea level. Olbers (1870) distinguished between two different and noncontemporary faunas in the Uddevalla area. In 1900, Brögger established the fact that the shell-banks in the vicinity of Uddevalla were formed during the land uplift in Late Glacial times. However, De Geer (1910) and, especially, Antevs (1917, 1921) introduced another hypothesis. On the basis of statistical, layer-by-layer, faunal investigations they concluded that the shell-banks were formed during the Fini Glacial lowering of the land. This interpretation of the ecostratigraphy had both chronological and palaeogeographical consequences which contradicted established opinions. In an encyclopedia (Svensk uppslagsbok 1925) De Geer contended that the erosional landscape of Svea

River at Degerfors constituted the old outlet of the Vänern basin into the Baltic basin, instead of the outlet of the Baltic basin during the Ancylus Lake stage to the Vänern bay of the Sea. Odhner (1918, 1927) composed brilliant retorts explaining the genesis of the Uddevalla shell-banks in a way which, in its principle features, is still acceptable. The discussion part of this paper starts with a review of Odhner's opinion, see p. 54.

A detailed review of previous works concerning shell deposits is given by Hessland (1943) in his thesis on shell deposits in northern Bohuslän.

Definitions of terms used in the text

Due to the present uncertainty of the Late Quaternary development of the Vänern basin, the established terms employed here have to be defined. Furthermore, some new terms are introduced.

Geochronological classification

In 1974 (Mangerud et al.) geologists from the Nordic countries presented a proposal for terminology and classification of the Quaternary stratigraphy of Norden. One of these geologists has proposed a revised deglaciation scheme for southern Sweden (Berglund 1976, 1979). The greatest deviation of opinion in the chronology concerns the development before the Younger Dryas Chronozone (see Fig. 5). As this paper contributes to the debate, the use of geochronological terms in the text has been restricted

Late Weichselian (Late Glacial) denotes the time from the beginning of the deglaciation up to the *Pleistocene/Holocene boundary* at roughly 10 200 years B.P.

Younger Dryas Chronozone, about 11 000–10 200 years B.P. ends the Late Weichselian sub-age.

Preboreal, 10 200–9 000 years B.P. initiates the Holocene age.

Chronostratigraphy

At least in this paper, it is convenient to distinguish between clay deposited before and after the ice retreat from the Billingen terminal moraines (Fig. 3) which constitutes the Pleistocene/Holocene boundary.

During the Late Weichselian the Vänern basin formed a bay of the Western ocean and the rate of deglaciation was rather slow. During the Preboreal, the deglaciation pattern changed to a fast retreat of the ice front, and, due to the deglaciated areas and land uplift, the Vänern basin became an inland sea between the Ocean and the Baltic basin.

By tradition, the marine glacial clays in western Sweden have been divided into glacial and late glacial clays – a division which cannot be accepted with reference to the definition of the geochronological terms. In the descriptions of the geological map sheets of Värmland, the terms finiglacial brackish clay, postglacial marine clay, and postglacial brackish clay occur (Magnusson & Sandegren 1933, p. 71).

The glacial clays are designated unoccupied names of concept in a deglaciation succession and are not linked to any reference sequence. They are used more as a means of defining two types of glacial clays with regional extension. The characteristics are based mainly upon the occurrence of subfossil and fossil finds of marine vertebrates and invertebrates. To a certain degree these reflect the then prevailing hydrographical conditions.

Dennegård (1984, pp. 147–148) has investigated glacial clays at four sites in the southern part of the Vänern basin *inter alia* with a view to the content of foraminifers. The presence and absence of foraminifers and molluscs in the clays correspond, in character at least, in that part of the area.

Glacial sediments are related to deglaciation processes. Usually distinct *varved clay* is formed in fresh water and nonvarved or diffuse varved clay in waters with a salinity of more than 3 per mille (Stevens 1985).

Skagerrak clay is a marine glacial clay deposited up to the end of the Younger Dryas Chronozone. Usually the clay contains shells.

Värmland clay is a marine clay deposited in Preboreal times. It corresponds to the Yoldia clay in the Baltic basin. The Värmland clay is almost devoid of shells and shell fragments.

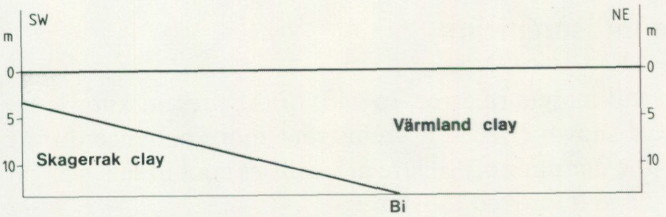

Fig. 2. Distribution of Skagerrak and Värmland clay in the Vänern basin. Bi=Billingen terminal moraine, cf Fig. 9.

Post glacial sediments are restricted to processes unrelated to deglaciation, e.g. the Vänern sediments, which consist of silt and silty clay.

Bio- and lithostratigraphical terms

Some of the terms are given schematically in Fig. 10. The terminology used by Hessland is described on p. 18.

Subfossil means that the weight of the object when found does not exceed its original weight.

Shells refer to shells of sea animals, chiefly of molluscs and barnacles.

A *shell layer* is a unit of shells or shell fragments mixed with mineralogical particles. In the layer the shells and shell fragments may have an imbricate structure, but more commonly they are irregularily deposited.

Shell-bearing sediments are thin shell layers embedded in sand, silt, or clay.

A *shell-bed* is a formation of stratified shell layers and sand, silt, or clay strata of about the same thickness. the total thickness of the shell-bed unit exceeds 0.5 m.

A *shell-bank* is a morphological unit covering an area of 500 square metres or more. The shell-bank consists of a shell-bed which is usually discordantly overlain by stratified sand and silt, partly shell-bearing.

Shell deposit is a universal term used for all kinds of units in which shells or shell fragments are prominent constituents.

Zoogeographical terms

Species are conventionally grouped into three marine regions with respect to their present distribution pattern.

Arctic is equal to the area north of Spitsbergen and north of the southern part of Greenland's east coast.

Boreal is the region between the British Isles and Spitsbergen.

Lusitanian distribution includes those species which occur in waters south of the British Isles.

Oceanographical terms

According to oceanographical nomenclature the following definitions are used:

Atlantic water, Ocean water and Sea water have a salinity of about 35 per mille or slightly more.

Brackish water has a salinity between 5 and 35 per mille.

Fresh water may have a salinity up to 5 per mille.

Palaeohydrographical term

In addition to the oceanographical terms, a palaeohydrographical term is introduced. The purpose of the term is shown in Fig. 3.

The *saline front* is the border zone between saline and fresh water during deglaciation.

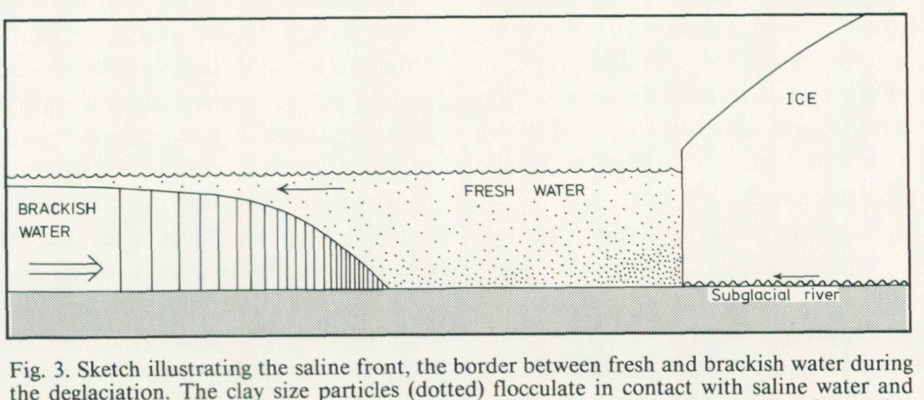

Fig. 3. Sketch illustrating the saline front, the border between fresh and brackish water during the deglaciation. The clay size particles (dotted) flocculate in contact with saline water and settle rapidly (vertical lines). The clearness of the water is one essential requisite for marine animal life.

Radiocarbon age measurements

All radiocarbon age determinations of subfossil finds of marine arctic–arctic/boreal animals in western Sweden are listed in Table 2.

Almost all determinations were carried out by the Laboratory for Isotope Geology in Stockholm; the ^{13}C-values given for the main part of the samples refer to the PDB standard and are based on measurements made by Dr R. Ryhage at the Karolinska Institute in Stockholm. Pre-treatment of samples included mechanical cleaning and ultrasonic washing in distilled water. The carbon dioxide was released by treatment with hydrochloric acid. After 10–20 per cent of weight reduction the innermost parts of the shells were used for dating purposes as far as the samples allowed. Age calculations are based on a contemporary value equal to 0.95 times the acitivity of the NBS oxalic acid standard and on a half-life for ^{14}C of 5568±30 years. Age expressed in B.P. means radiocarbon years (= years before 1950).

There is always discussion concerning the reliability of the ages shown. As radiocarbon determination is the only available method for absolute dating of the Late Weichselian evolution in western Sweden, some problems will be considered from a geological point of view. Radiocarbon dates of marine shells have been discussed in detail by Donner & Jungner (1975); Jardine (1978); Mangerud (1972); Mangerud & Gulliksen (1974) and Olsson (1974).

Contamination

Datings from multiple fractions of marine shells are necessary to ensure maximum reliability. Fractionization corrections, ^{13}C normalization and apparent age have been discussed by Olsson & Osadebe (1974).

Shells taken from shell-banks have been exposed to carbonate contamination and leaching over a long period of time. As appears in Table 2, fraction 2 of some samples show an age difference in comparison with fraction 1 (outer), 3, and 4 (innermost). It follows that the innermost fractions are considered to be the purest, but at times fraction 1 or 2 may also be reliable. A small deviation may indicate no contamination.

It is very important that attention is paid to the shell environment when sampling. Because of the internal problems of an isotope laboratory in achieving reliable results, high demands must be made on the external procedure (sampling) in order to decrease the sources and margin of error. In light of the present knowledge of shown effects, it seems that more patience during the sampling procedure in localities poor in shells might have improved the datings.

Samples of duplicate shells may have been contaminated during storage. The storing conditions since the field collection of the three museum samples are unknown. According to Olsson (1974, pp. 313–314) stored shells may show an activity corresponding to 1.5 per cent of the activity of the international ^{14}C standard.

Reservoir age of sea water

Exhaustive discussions have been published about the apparent age of sea water in general (Olsson 1974) and of recent marine shells in particular (Mangerud 1972). The complicated problems in determining and interpreting ^{14}C datings of marine shells are only very briefly touched upon in the following discussion of some special aspects.

Atmospheric ^{14}C is transferred at the ocean – atmosphere interface. The ^{14}C activity of oceanic bicarbonate is compared to ^{14}C activity of contemporary terrestrial material. Thus, there is a negative and a positive correction. According to the circulation pattern of water within the oceans, water masses show different ages.

Datings of recent "pre-bomb" marine shells of the Swedish west coast suggest an age of 400±25 years (Håkansson 1975, p. 80). The corresponding correction value has been used in Table 2, though it is doubtful if recent values are applicable to shells of animals which have existed in quite different hydrographical conditions. When corrections are made, the value of ^{13}C and the estimated apparent age of sea water are found to be almost equal for marine shells of Late Weichselian times. Tauber (Krog & Tauber 1974) has presented an opinion that corrections for the apparent age should not be applied on marine shells along the Danish west coast. The average activity of 11 "pre-bomb" shells of *Mytilus edulis* were found to be 99.9 per cent of the modern terrestrial value.

An outline of apparent ages of sea water samples from the east Atlantic Ocean is given by Mangerud (1972). The ages of surface samples vary from between 320±56 to 970±40 years (south Atlantic). Sub-surface samples show an increasing age with depth up to slightly more than 1000 years below 4000 metres. However, the sea surface layer down to several hundred metres seems to differ little in age. It must be noted that the apparent age of surface sea water increases northwards along the Norwegian west coast. Along the northwest part of the coast shells of *Mytilus edulis* show an age of 520±75 years.

Calculations of reservoir age depend primarily on the occurrence of "old water" along the west coast during deglaciation. The influence of meltwater decreases during the transgressive ocean phase in Late Quaternary times. The possible source of old carbon from meltwater during deglaciation has been briefly discussed by Mangerud (1972, p. 151). Calculations based on measurements of present carbon content in some glaciers compared with sea water give a figure of approximately 0.5% carbon deriving from the ice. Again, the discussion is theoretical, since absolute information is still lacking about past conditions.

During the Holocene, the circulation pattern in the Atlantic and in the North Sea shifted into that of the present day, which implies that there may be some difference in the reservoir age when samples from particular intervals are compared.

As is evident from the above discussion, calculation of the reservoir age of sea water is a difficult question. Geologically speaking, the calculation procedure of radiometric measurements is of the highest importance. In areas with no distinct varved clay, a minimal margin of error is desirable in order to ensure absolute datings as accurate as possible for the deglaciation and Late Quaternary development.

Summary

The radiocarbon determinations should be interpreted with care and, due to the necessary corrections, no farreaching inferences can be drawn. Even if the corrections are wrong the results are comparable to each other. The resulting date is a maximum value for the age of final deposition and a minimum age of the underlying sediment.

General morphology and geology of the Vänern basin

A brief and approximate summary of the main features of the Late Quaternary for the parts of western Sweden considered here is shown in Fig. 4.

The geology and hydrography of Lake Vänern is described by Håkansson et al. (1978). For these purposes Lake Vänern is usually divided into two parts. The greatest depth, 106 m, is recorded in the eastern section. Both parts of the lake are shallow in the very southern areas, while most of the bottom morphology elsewhere is hilly with a preferred north–south orientation of the valleys, see Fig. 4.

The modern Vänern region is properly defined as the drainage area of Lake Vänern and the river Göta älv (Fig. 4). Since the text deals with palaeohydrographical conditions this region is enlarged to enclude some former straits outside the present drainage area.

Comparisons are made with shell-bearing sediments west of Vänern as that area was influenced by melt water from the Vänern basin during the deglaciation.

The Vänern basin is the central part of the Lake Vänern drainage area, see Fig. 4. The relatively flat areas of the basin are part of the Precambrian peneplain, which is bordered to the west and to the south by a bare bedrock landscape of fault and fissure valleys. On the eastern coastal plain, Cambro-Silurian table hills are visible from far away. The eastern border of the region consists of the South Swedish Highlands and their continuation northwards along Lake Vättern. The highest parts of the Tiveden and Hökensås hills rise to more than 200 m above sea level.

The northern part of the drainage area is characterized by north–south running valleys in a landscape which gradually rises northwards to levels up to and above the timber line.

Terminal moraines

Knowledge of the location and age of main terminal moraines, as well as the highest shoreline level and the shoreline displacement, creates opportunities to describe the development of the marine fauna.

The characteristics and chronology of the main terminal moraine zones have been discussed at length (see Fig. 5). Berglund (1979) has summerized the discussion and on the basis of biostratigraphical studies and radiocarbon determinations of lake deposits carried out by researchers of Lund University, he has proposed a revised chronology.

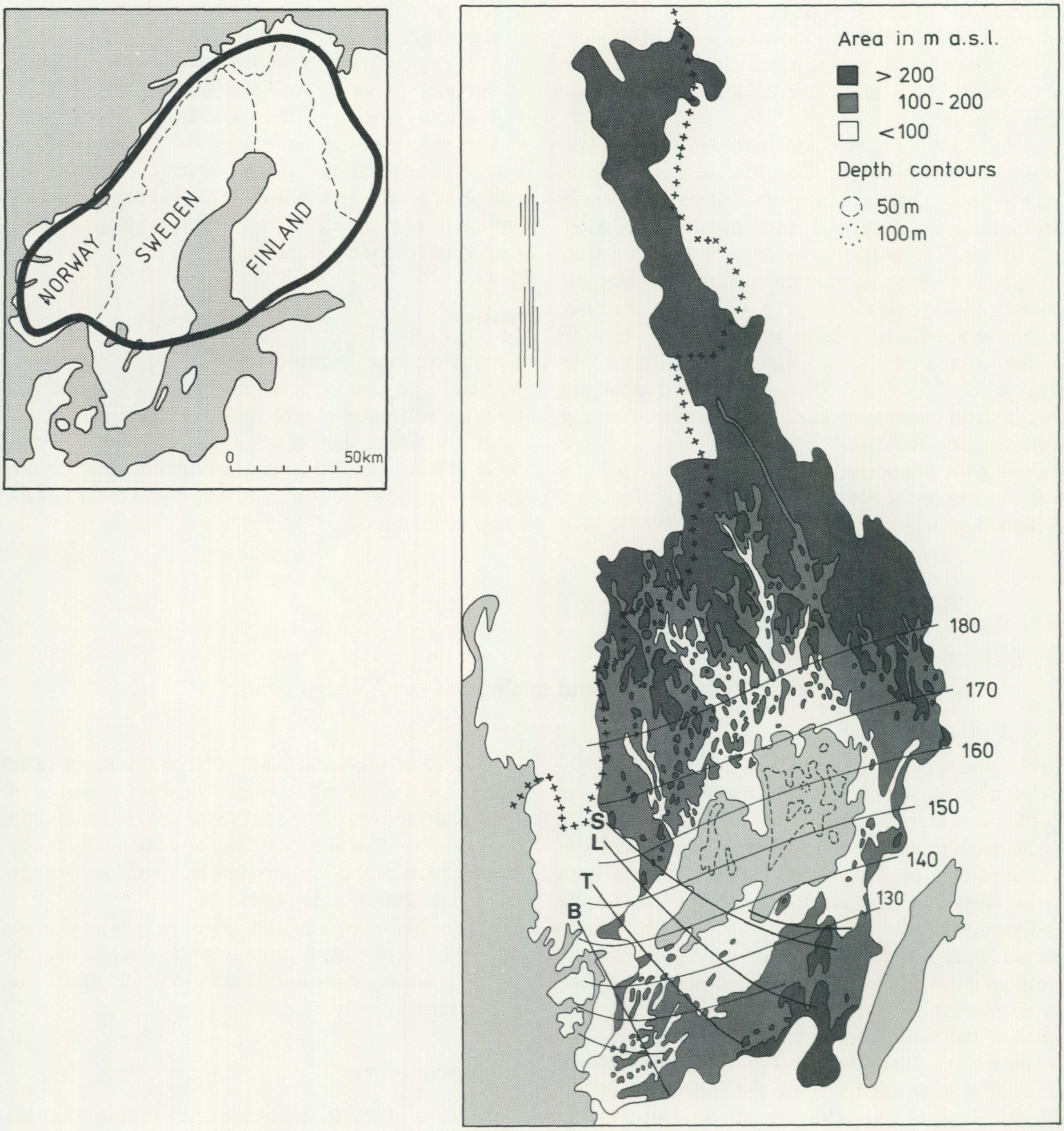

Fig. 4. Orographic map of the Vänern drainage area (Statens Naturvårdsverk 1972) with a rough outline of isobases in m above sea level for the highest shoreline. The main terminal moraine zones, i.e. from south to north, Berghem moraine (B), Trollhättan moraine (T), Levene moraine (L), Skövde moraine(s) and Billingen moraine are shown. The inset map shows the Fennoscandian terminal moraine zone, in which Levene, Skövde and Billingen moraines are included with the Salpausselkäs of Finland and the Ras in Norway.

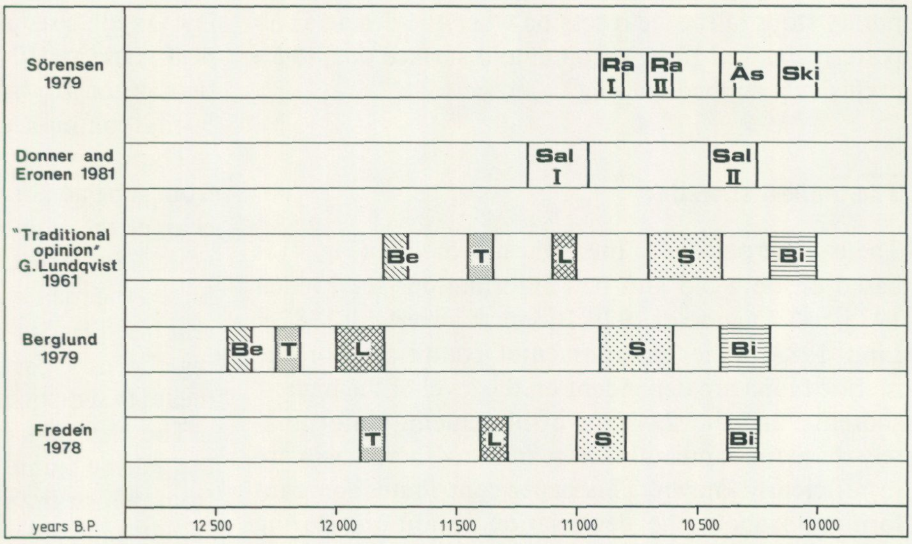

Fig. 5. The Late Pleistocene deglaciation chronology in southwestern Sweden, cf Fig. 4, according to various authors.

At the moment there are different opinions about the deglaciation pattern up to the Younger Dryas Chronozone (see Fig. 5, cf Fig. 59). Therefore the main terminal moraines are not related to specific chronozones in this work. The duration of regionally traced stagnation periods during the ice retreat is usually periods rounded off to a hundred years. However, stagnations may last for shorter periods – less than 100 years – which means that some terminal moraines may be formed at temporary stops during an interstadial, e.g. the Trollhättan and Levene terminal moraines. After varve studies, Strömberg (1985) concludes that large deltas in the Skövde terminal moraine zone east of Billingen hill were formed during a time span of at least 200 years.

The Late Quaternary development of the Vänern basin started when deglaciation continued after the temporary stop along the Berghem terminal moraine zone. For the evolution of the marine fauna in the Vänern basin only the parts of the moraine zones concerned (Fig. 4) are briefly described below.

The Berghem terminal moraine zone lies west of the former straits between the Vänern basin and the Western Sea. The deposits in the northern part of the province Bohuslän have been described by B. Johansson (1982). Though the deposits are non-continuous the zone is in general well defined: see map sheets of Quaternary deposits (Fredén 1974, 1984, 1986a, Magnusson 1978). The deposits of till and glaciofluvial sediments are distinct.

The Trollhättan terminal moraine zone is situated northeast of the main shell deposits in the southern part of the Vänern basin. The moraine deposits are fairly continuous and most pronounced north of river Göta älv (Fredén 1974, Johansson 1982). Southeast of Trollhättan isolated moraine ridges and glaciofluvial deposits occur (Fredén 1984) and the follow-up of the zone towards the South Swedish Highlands is not fully known. No investigations or modern geological maps of that area are at hand.

The Levene terminal moraine zone crosses the southern part of Lake Vänern. On both sides of the lake the moraine ridges are continuous up to the region of the highest shoreline (see Strömberg, 1969). Although the ridges are low and in places flattened by wave-washing, they are relatively distinct in the landscape, which is otherwise dominated by vast clay fields partly covered with sand.

Further northwards in the basin, the terminal moraine zones turn to a more east-westerly direction. East of Lake Vänern parallel moraine ridges are found in a zone 2–13 km wide. Their height above surrounding flatlands is 10–20 m, the thickness is 20 to 50 m. For detailed descriptions, see Strömberg 1969.

The southern system of ridges is called the *Skövde terminal moraines*, while the northern one belongs to the *Billingen terminal moraine*. Both are part of the Fennoscandian terminal moraines and thus linked with the Norwegian Ra system and the Finnish Salpausselkä system (Fig. 4).

No similar terminal moraine zones are known in the northern part of the Vänern basin. Fairly large glaciofluvial deposits are found in a 15 km wide and 70 km long zone northeast of Lake Vänern (Fig. 55).

Further northwards, possible terminal moraine deposits may be found in deltas, formed during temporary stops of the ice recession when the deglaciation pattern changed from a frontal and surface one, to an exclusively surface melting.

The highest shoreline

The isobase pattern of the highest shoreline (Fig. 4) is based on both old and new information (see Fredén 1975, p. 8, Digerfeldt 1979, Björck & Digerfeldt 1982b, Lind 1983). The environmental conditions for the marine fauna are dependent on the level of the highest shoreline and the shoreline displacement. Unfortunately these fundamental factors in the Vänern basin are insufficiently known. This paper contributes some information about the deglaciation conditions during Preboreal times.

Sedimentation of clay particles

During deglaciation large amounts of clay were deposited in the Vänern basin and in the river Göta älv valley. On the coastal plain of Lake Vänern the clay thickness is mostly 10–20 m, in fissure zones slightly more than 40 m. In the river Göta älv valley a thickness of 50 m is common; up to slightly more than 100 m occurs.

The main part of melt water from the ice derived from subglacial rivers. Due to various amounts of discharge, the volume of the marine fresh water body varied. Some distance from the ice, heavier saline water forced the melt water flow up to become a surface current (see Fig. 3). Along the saline front, the ions inducing the clay particles to flocculate and settle down meant that distinct varve structures were not formed.

The clearness of the water, which is important for the marine fauna, depends on the position of the saline front, which in turn depends primarily on fresh water supply and secondarily on long or short term meteorological conditions. Salinity and translucency increase with the distance from the ice front. Tentative models of described conditions are shown in Fig. 44.

Hydrography in general

The evolution and existence of marine animal life in the regions of Uddevalla and Vänern depend on *inter alia* hydrographical conditions in the North Sea basin. A true reconstruction of the palaeohydrography during the Late Weichselian is difficult to establish, especially as the present water exchange along the coasts of Sweden has been shown to be fairly complicated. However, a cautious picture of the past may be achieved if some basic information about the present conditions in general are applied to a presumed development of the North Sea basin, and its northwestern part in particular.

The following brief outline of some important factors is based upon three studies: A detailed survey of the present hydrographical open sea conditions in the Skagerrak and the Kattegatt has been published by Svansson (1975); a manual of oceanography with glances at the Baltic Sea conditions was published in 1974 by Fonselius; and the third work used is by Shephard (1973) and deals with submarine geology.

Bathymetrical conditions

The North Sea is shallow (see Fig. 6). Almost the entire basin is less than 200 m deep. In the southern part, towards the English Channel, its depth is less than 50 m. Around the southern part of Norway, a submarine valley extending from the Norwegian Sea into the Skagerrak is deepest (slightly more than 700 m) in Skagerrak. The sill depth of this Norwegian Trench (also called Norwegian Rinne, Skagerrak Trough) is about 270 m northwest of Stavanger. The physical conditions of the Norwegian Trench are similar in topography to a fjord.

In the Norwegian Sea basin depths of more than 3500 m are found with thresholds connecting to the North Atlantic lying at a depth of about 500 m.

The maximum water depth in the Väner basin in the ancient strait between Uddevalla and Vänersborg was about 85 m and about 95 m at the threshold of the Göta älv river. Coevally with the retreating ice front,

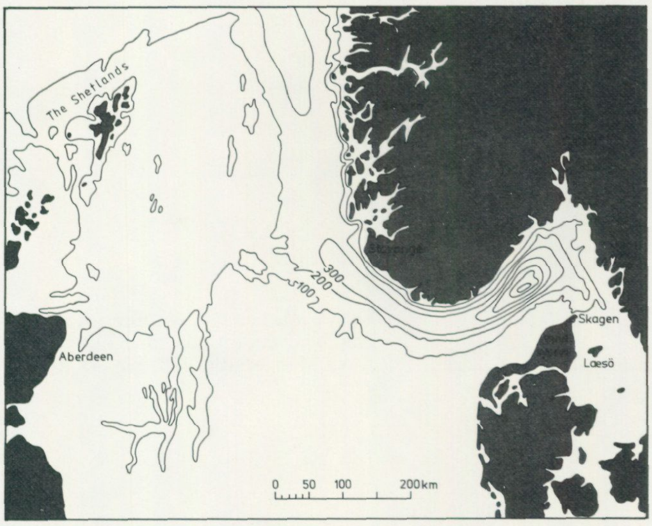

Fig. 6. Bathymetric map of the northern North Sea basin. Based on nautical charts.

the water depth decreased due to land uplift. Maximum water depth in the whole Vänern basin was slightly more than 260 m in the deepest parts (see Fig. 4). In the fault zone at Vänersborg the maximum depth was about 140 m. The maximum water depth on the Precambrian peneplain with its low amplitude was a little less than 100 m.

Meteorological conditions

Cyclone tracks followed the margins of the land-ice and caused a high frequency of strong winds close to the ice, whereas areas off the ice-sheet were characterized by less strong winds coming from opposite direction (Liljequist 1974). Probably cyclone tracks during the Weichsel deglaciation are shown on Fig. 7.

Waves and currents

Waves and currents are important during the formation of shell deposits.

Wave motion below the surface decreases rapidly with increasing depth. It becomes negligible at a depth equal to about one-half the wave length. The palaeogeographical conditions at Uddevalla suggest that waves have had an erosional effect at a water depth of less than 10 m.

If sub-surface wave action moves a shell downwards to its final deposition, the shell is not subjected to erosion comparable with that of a shell transported downwards by surface waves at the shore.

Another kind of waves are the internal waves found in stratified seas. In the boundary zone between fresh and brackish water internal waves may occur usually with the greatest horizontal velocity at the bottom. Observed velocities are capable of erosion and transportation of particles. The wave height may be up to 30 m and the wave length up to 200 km. At present the general opinion is that the internal waves are caused by wind and atmospheric pressure. The greatest apparent tidal effect in Kattegatt is an internal wave with a height of some metres.

There are different kinds of currents. Relevant to this text are wind-generated currents and permanent currents.

In marginal sea basins limited by narrow straits the level of the water surface is higher than in the ocean, due to the greater fresh water supply in the former. An outgoing surface current of fresh water is compensated by an incoming bottom current of saline water. The proportions of fresh to saline depend on the density conditions inside the threshold. Increasing vertical circulation decreases the density.

Surface currents generated by wind may go in the opposite direction to the sub-surface currents. Wind is caused by variations in the atmospheric pressure, which also has a decisive influence on the surface level of the water; this creates large salinity variations at the surface.

The velocity of permanent surface currents is about 1–2 knots along the west coast; off southern Norway more than 3 knots. Wind-generated currents are supposed to frequently reach one per cent of the wind velocity.

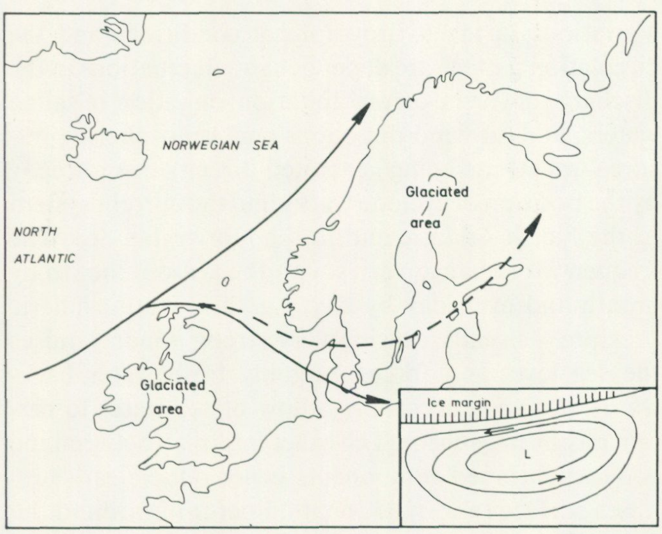

Fig. 7. Probable cyclone tracks during the deglaciation. Inset figure shows winds during the passage of a cyclone (L). After Liljequist 1974.

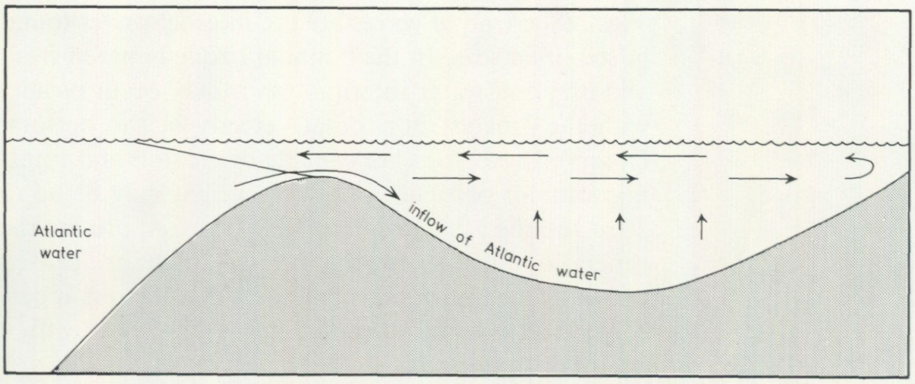

Fig. 8. Schematic profile of hydrographical conditions in a fjord basin. After Mangerud (1972, Fig. 4).

Unfortunately there are no localities today which are comparable with past conditions. However, a comparison with the circulation pattern of the Black Sea gives a relative idea of the forces once prevalent. The threshold area of the Bosporus and the Dardanelles reaches a depth of about 40 m while the width of the straits is about 2 km. The discharge of the rivers entering the Black Sea gives a surplus of fresh water. Due to mixing with the fresh water the density of the saline water is decreased, causing a compensating inflow current of saline water. The inflow along the bottom is about half that of outgoing fresh water. At times the velocities of the two currents are so obvious that deep-lying fishing nets are towed in the opposite direction to the outgoing surface current. Along the shores big eddies can be seen. The velocity of the bottom current should correspond to that of the surface current.

Hydrography

Variations in the hydrographical conditions and the circulation pattern are dependent on fluctuations in the discharge of rivers, on precipitation, on inflow of saline waters, and on wind directions and atmospheric pressure – all effects being generated directly or indirectly by the position of cyclone tracks and the current system in the North Atlantic and in the Norwegian Sea. The frequency of change varies with the season, month by month and even day by day; e.g., a low atmospheric pressure – usually causing very strong winds – raises the sea level and forces outgoing fresh water backwards. On such occasions inflow of sea water to certain basins may occur. The exact interplay between the above-mentioned components is not quite clear.

Sea surface salinity is about 35 per mille around the Shetlands, about 30 per mille at Skagen, about 20 per mille off Uddevalla, decreasing gradually southwards to the Baltic Sea, giving signification to the fresh water discharge of the Baltic Sea and its determining influence on the sea water along the Swedish coast. At a depth of 50 m in the North Sea, a salinity of 35 per mille or more is recorded as far eastwards as north of Skagen. According to the circulation pattern the main inflow of saline water to the Skagerrak comes from the Norwegian Sea and follows, broadly, the 150–200 m isobaths. The vertical exchange between the brackish water and the saline deep water is greatly intensified by the increasing salinity of the bottom water.

The circulation within a basin is determined by bathymetrical conditions around it. In the Norwegian Sea most of the basin is occupied by a homohaline deep water, located some hundred meters below sea surface (Mosby 1960, pp. 19–21).

The circulation in a fjord basin is shown in Fig. 8. Due to seasonal changes the surface salinity varies between 0 and 34 per mille (Mangerud 1972, p. 160).

Water circulation in the Arctic basin has been studied by many scientists. A review and an outline of present knowledge of the circulation pattern and the hydrodynamic conditions has been published by Treshnikov & Baranov (1973). The vertical structure of water masses is of special interest to this study. However, it must be observed that not only Atlantic but also Pacific water enters the basin, which somewhat limits comparisons. In the Arctic basin three main water masses are present; cold surface water 0–200 m, an intermediate layer of positive temperature 200–1000 m, underlain by cold deep water. The intermediate layer is limited by zero isotherms. At a depth of 25 m the salinity west of Berings strait is about 30 per mille and increases westwards to 34 per mille at the border of the Norwegian Sea. Close to ice, water in the layer 0–50 m is cooled and freshened. In the central parts of the basin the temperature at a depth of 75 m is -1.7 to

-1.8°C. The temperature increases away from the centre and the zero isotherm lies at a depth of about 200 m.

Palaeohydrography of the Arctic ocean has been discussed by Olausson (1981). The salinity stratification depends on inflow of fresh water and the thickness of ice cover in proportion to the amount of fresh water.

Shell-banks and shell-bearing sediments in general

Shells and shell fragments are found in shell-banks, in shell-bearing sediments and as individual components in clay.

Most of the molluscs found individually in clay are intact and show no traces of erosion. Usually such finds occur in the basal parts of the glacial clay, Skagerrak clay, implying occurrence at an early stage of the clay sedimentation. The majority of these individuals are considered to be found in situ. The species found isolated in clay are consistently the burrowing types which could tolerate a low salinity. The most common mollusc in the lower part of the Skagerrak clay is the bivalve *Portlandia arctica.* Observations in a few cuts of basal clays have shown that assemblages of *Mytilus edulis* may be found in limited horizontal zones at most one mètre long and ca 5 cm thick. The shells are often complete, they lie close to each other, and no coarse particles are present. They are considered to be autochthonous.

The shell-bearing sediments consist of one or more shell layers in sand or clay. Most of the shell layers are characterized by an abundance of shell fragments mixed with fine and coarse minerogenic particles. The thickness of each layer varies between one and ten cm. Sometimes signs of a vertical grading may be observed in which the grain size of particles gradually decreases upwards from the basal fraction, which is dominated by sand and gravel. Shell fragments are most commonly found in the upper part of the layer. Due to the restricted occurrence and the absence of suitable fragments, the number of shell species identified is usually low.

Shell-bearing sediments can be separated into shell-bearing clay and shell-bearing sand.

Shell layers embedded in clay are usually found in the middle valley floors with no apparent continuity to the valley sides. These shell layers are thus deposited in relatively deep water. The appearance resembles turbidity sediments of Norwegian fjord-type stratigraphy. The turbidity sediments are said to have had a downward movement induced by submarine slumps (H.Holtedahl 1975, pp. 67–79).

Due to the limited occurrence of shell layers the components are assumed to have been deposited synchronously and the shells are believed to come from one assemblage. In comparison with shell layers in sandy sediments, the number of identified shells and large shell-fragments is in this case relatively high. The erosional influence of littoral processes is thus in this case relatively small. When an embedded shell layer in clay is found to be continuous to the valley side, it often constitutes the most distal part of a shellbed.

Shell layers found in sandy sediments are most often lying close to the valley side. Within the layer, shell fragments are usually very small. The strong influence of littoral processes suggests much reworking before deposition in shallow water. In comparison with the faunal composition in the shell-bearing clay, the relatively longer time exposed to littoral processes involves a greater supply of primary and secondary shells for shell-bearing sand. The number of identified species is relatively low.

The whereabouts of shell-bearing layers are shown in Fig. 2 and 9.

Shell-banks

A rough outline of the location and stratigraphy of a shell-bank is given in Figs 10 and 11. All information given is based primarily on stratigraphy of the Uddevalla shell-banks.

Usually a shell-bank is positioned relative to a more or less steep hillside of bare bedrock, where often a small fissure valley occur. The stratigraphy of a shell-bank is divided into three units. The shell-bed, unit B, is covered by deposits belonging to unit A and is underlain by clay, sand, and gravel, or bedrock, unit C. These main units are divided into sub-units.

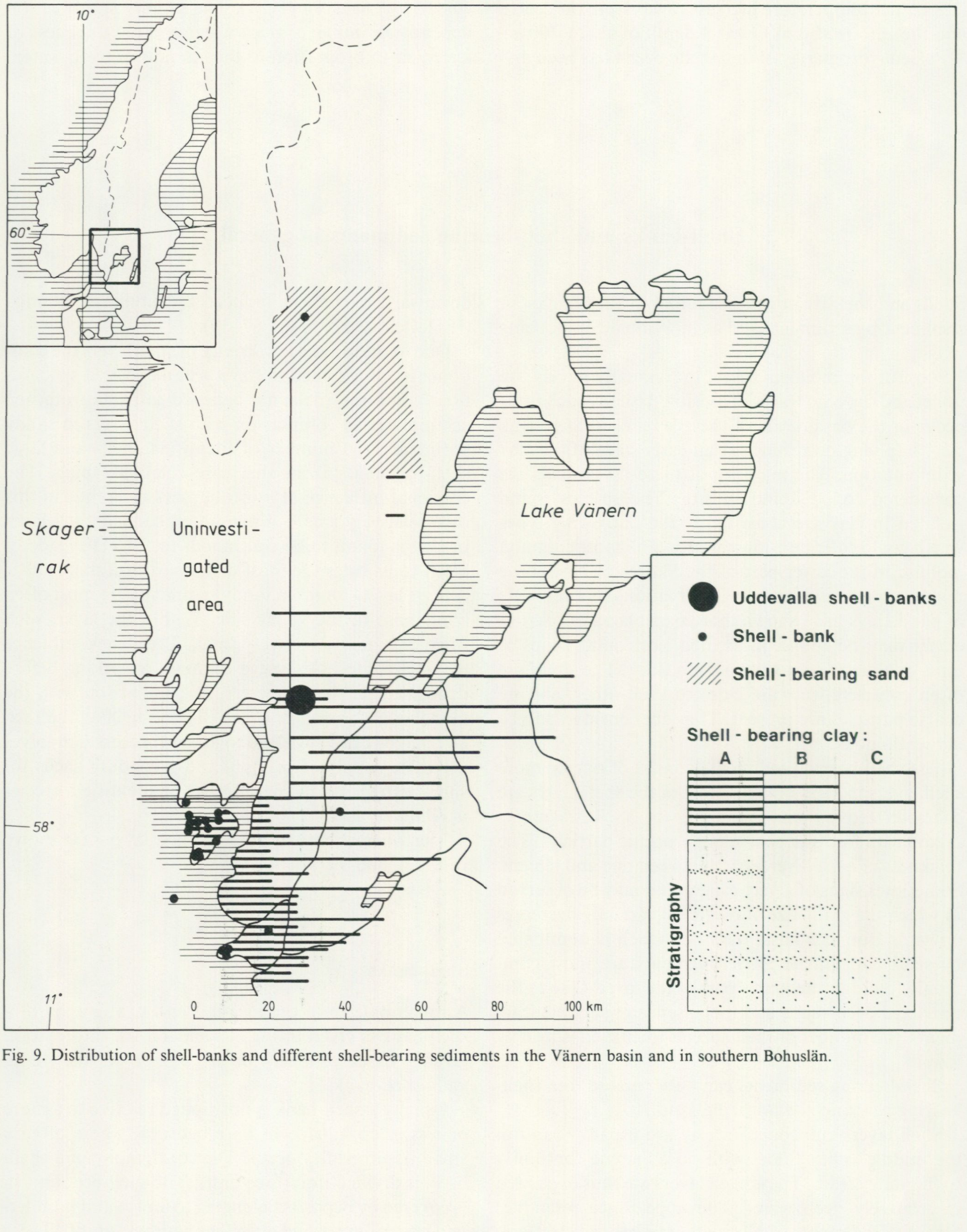

Fig. 9. Distribution of shell-banks and different shell-bearing sediments in the Vänern basin and in southern Bohuslän.

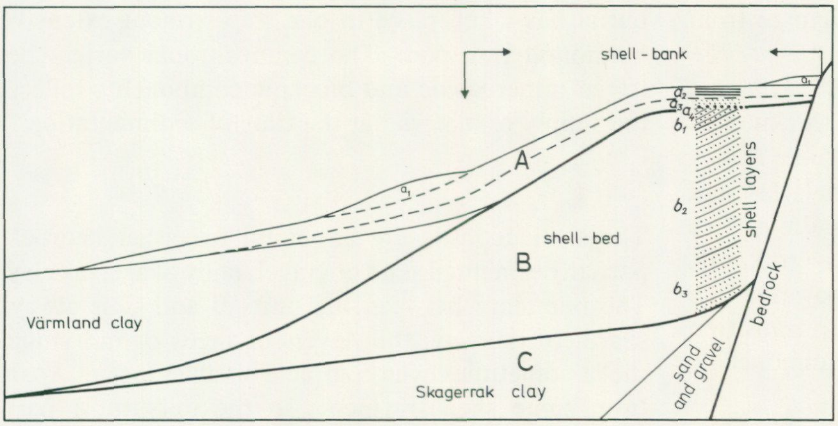

Fig. 10. An outline of a idealized stratigraphy of a shell-bank in the Uddevalla region. Characteristics of strata are given in Fig. 11. From Fredén (1986a, Fig. 3).

The stratigraphy of the deposits differ from place to place and usually all sub-units are not present. Shell layers often have irregularities caused by primary submarine and secondary terrestrial downslope processes.

Unit A

At the superficial morphologic foot of the shell-bank, or on top of it where it meets the hillside, a layer of shell-bearing gravelly sand may be found. This a_1 layer is rather insignificant as to distribution and thickness. The shell fragments are often crushed into very small pieces but within the layers less eroded shells of molluscs can also be found. Compared to unit B and identifiable shells of the other a-layers, the faunal composition is quite different, implying that the unit may have a Holocene origin as a beach deposit, though some shell fragments belong to species with a boreal – arctic character. In the Uddevalla area the a_1 sub-unit is restricted to areas below 55 m above sea level and thus may occur as surficial patches unconnected with shell-banks.

Usually the top unit of a shell-bank consists of a 0.5–1.5 m thick, horizontally laid and well-defined layer of silt, sand, and gravel. The grain size decreases with the distance from the bedrock. The a_2 sub-unit is always free of shells and shell fragments while the a_3 sub-unit is characterized by shell fragments broken into very small pieces. The whole of unit A lies discordant to the shell-bed underneath. The boundary layer, a_4, consists of coarser grain sizes, and has often well defined borders. This erosion layer is almost free of shell fragments. On the frontal slope the transition between a_3 and b_1 is gradational while no a_4 sub-unit is found there.

All substrata in unit A are deposited close to a beach. The sharply marked boundary surface, a_4, reflects erosion by waves.

Unit	Assumed max. thickness in m	Minerogenic components in shell layers					Occurence of		
		pebbles	gravel	sand	silt	clay	shells	shell - fragments large	shell - fragments small
a_1	0,5	-	+	+	+	-	+	+	(+)
a_2	1,0	-	(+)	+	+	-	-	-	-
a_3	1,0	-	(+)	+	+	(+)	-	(+)	+
a_4	0,2	(+)	+	+	+	-	-	(+)	-
Värmland clay		-	-	(+)	+	(+)	-	(+)	-
b_1	2,5	-	-	+	+	+	+	+	(+)
b_2	10,0	-	+	+	-	(+)	+*	+	-
b_3	10,0	+	+	+	-	-	+*	+	-
Skagerrak clay		(+)	(+)	+	-	(+)	+*	(+)	-
sand and gravel		-	-	-	-	-	-	-	-

Fig. 11. Characteristics of the composition of shell layers in Fig. 10. Occurrence is marked with a plus, rare occasion with a plus in brackets. Asterisk means that complete bivalves are to be found. From Fredén (1986a, Fig. 4).

Most of the components in unit A originate from unit B.

In the distal parts of a shell-bed the shell layers are covered by Värmland clay, the maximum thickness of which occurs in the centre of the valley. There it may be overlain by some metres of post-glacial clay and alluvial sediments. The Värmland clay is almost free from shells and shell fragments; cf. the Skagerrak clay, unit C, below. Close to the shell-bank, however, the clay is shell-bearing and sometimes a sharp transition between the sub-units a_3 or b_1 cannot be found.

Unit B

The shell-bed, unit B, consists of more or less well-stratified shell layers, which usually dip uniformly away from the hillside. The proximal upper part is cut off by wave action. The transitions between the three sub-units are gradational.

The b_1 sequence is found in the upper and distal parts of the shell-bed. This sub-unit is characterized by argillaceous shell layers or embedded clay layers up to 10 cm thick. Due to the clay content, the b_1 layers are fairly consolidated. The thickness and distribution of the clay layers vary. The thickness of the sub-unit seems to increase with the distance from the bedrock, unlike the sub-unit b_2, which decreases in the same direction. Usually the distal parts of the unit B are argillaceous. Shell fragments dominate and observed shells are usually eroded.

Apparantly, the b_1 stratum is deposited during moderately quiet conditions in shallow water. Shells and shell fragments have been extensively exposed to erosion before final deposition.

The sub-unit b_2 forms the main part of the shell-bed. Shell layers consist of less eroded shells and, for the most part, the shell fragments are large enough for reliable identification. Particles and layers of sand and gravel are mixed with the shells and the shell fragments, sometimes producing cemented strata. Complete bivalves (united shells) are also found. The grain size and the frequency of non-eroded shells decreases away from the hillside. The largest shell-beds are characterized by this porous type of deposit.

In the basal part of the shell-bed, b_3, the occurrence of minerogenic particles increases and the grain size becomes coarser; even pebbles and cobbles are recorded. Comparatively larger shells are also found.

Layers of the sub-units b_2 and b_3 are interpreted as having been deposited in relatively deep water. The shells show notably less evidence of exposure to erosion, which implies that vertical movement and burial has taken place in one step without extensive horizontal transport. The compositional variety between minerogenic and biogenic components reflects the supply of material at the time of sedimentation.

Unit C

The shell deposits are underlain by either bedrock, partially cemented sand or gravel, or by Skagerrak clay. The boundary between the units B and C is always sharp. In the clay, thin layers of shells or individual shells, sometimes even complete bivalves, occur. Apart from some shell fragments in the uppermost part, shells are totally missing in the stratified sand and gravel unit, as might be expected due to its glaciofluvial origin.

Genetic and morphological terminology

Concerning the genesis of shell deposits along the northern coast of Bohuslän, Hessland (1943) divided the shell-banks, which he called aggradational deposits, into progradational deposits and regradational deposits. The former were deposited in the main direction of movement of the transporting medium, while the latter were deposited in the opposite direction.

This division is not quite applicable to the Uddevalla area, where, in addition to normal wave and current dynamics along the coast, special hydrographical conditions have had an influence on both faunal habitat and deposition of shells, e.g. deposition within a strait perpendicular to the coast. In some cases due to morphological reasons shells could be deposited in one direction only. To avoid any misunderstanding, Hessland's terminology is not used in this paper.

In accordance with the morphology of shell-banks, Hessland (1943) differentiated between terraces, cones and deltas, all formed as progradational deposits. The terraces were found on slopes below fairly flat bedrock surfaces, while cones were mainly associated with accentuated fissures. Deltas occurred mostly on the lee side of local watersheds. Transitional forms were recorded between all three types of progradational deposits.

Regradational deposits were found only as terraces. A characteristic feature of this type was found to be a high content of minerogenic particles. The deposit was furthermore recorded below a thick top layer.

If the Uddevalla and Vänern deposits are related to the coastal ones of northern Bohuslän, representatives for each group and transitional forms are present.

Regional subdivisions

The area described is grouped into the Uddevalla region, southern, southwestern, northeastern and western parts of the Väner basin, Fig. 12. The lake Mälaren valley east of the Vänern basin, is included in the description of the northeastern part as the palaeoenvironmental conditions between them are linked together. Radiocarbon dated shells from localities in southern Bohuslän are described in order to compare the palaeoenvironmental development of this part of the Swedish west coast with that of the interior.

Palaeogeographical maps can be compared with maps of the deglaciation in order to get a picture of the development and intensity of the marin life in Late Weichselian and Early Holocene times.

Curves indicating shoreline displacment are missing for the greater part of the Vänern basin. Curves based on radiocarbon dated isolation sequences at Hunneberg and the northern part of Billingen have been published by Björck & Digerfeldt (1982a, 1984). A curve from the Karlstad area is based on radiocarbon dated beach deposits (Fig. 31). The few curves of shoreline displacement and the spread of localities with radiocarbon dated megafossils, makes it difficult to refer a dated sample to a corresponding sea level. In using the curves mentioned, one can get an idea of possible sea levels within a margin of 10 m.

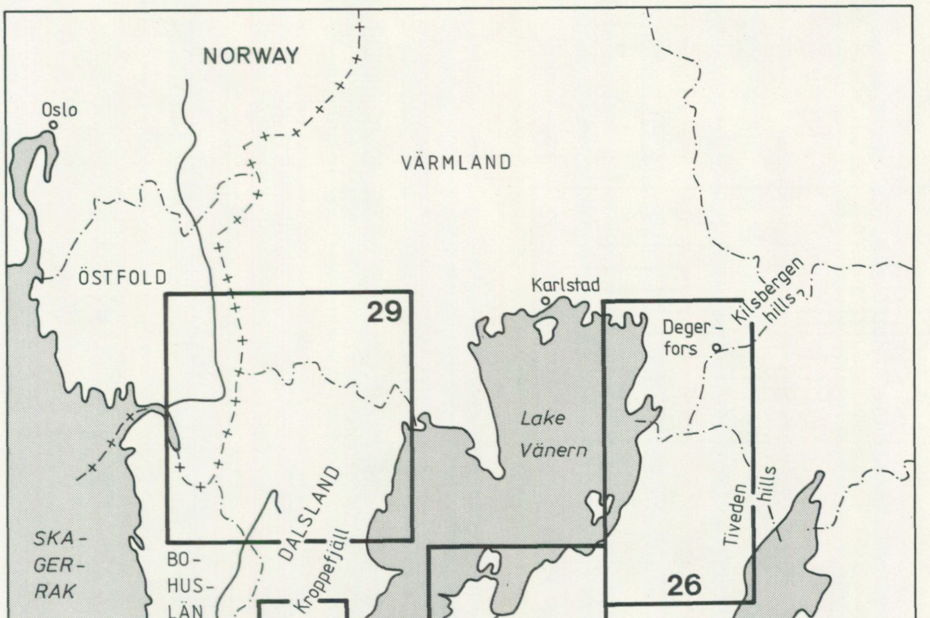

Fig. 12. Vänern drainage area with framed areas referring to detailed maps of described regions, see Figs 13, 20, 24, 26 and 29.

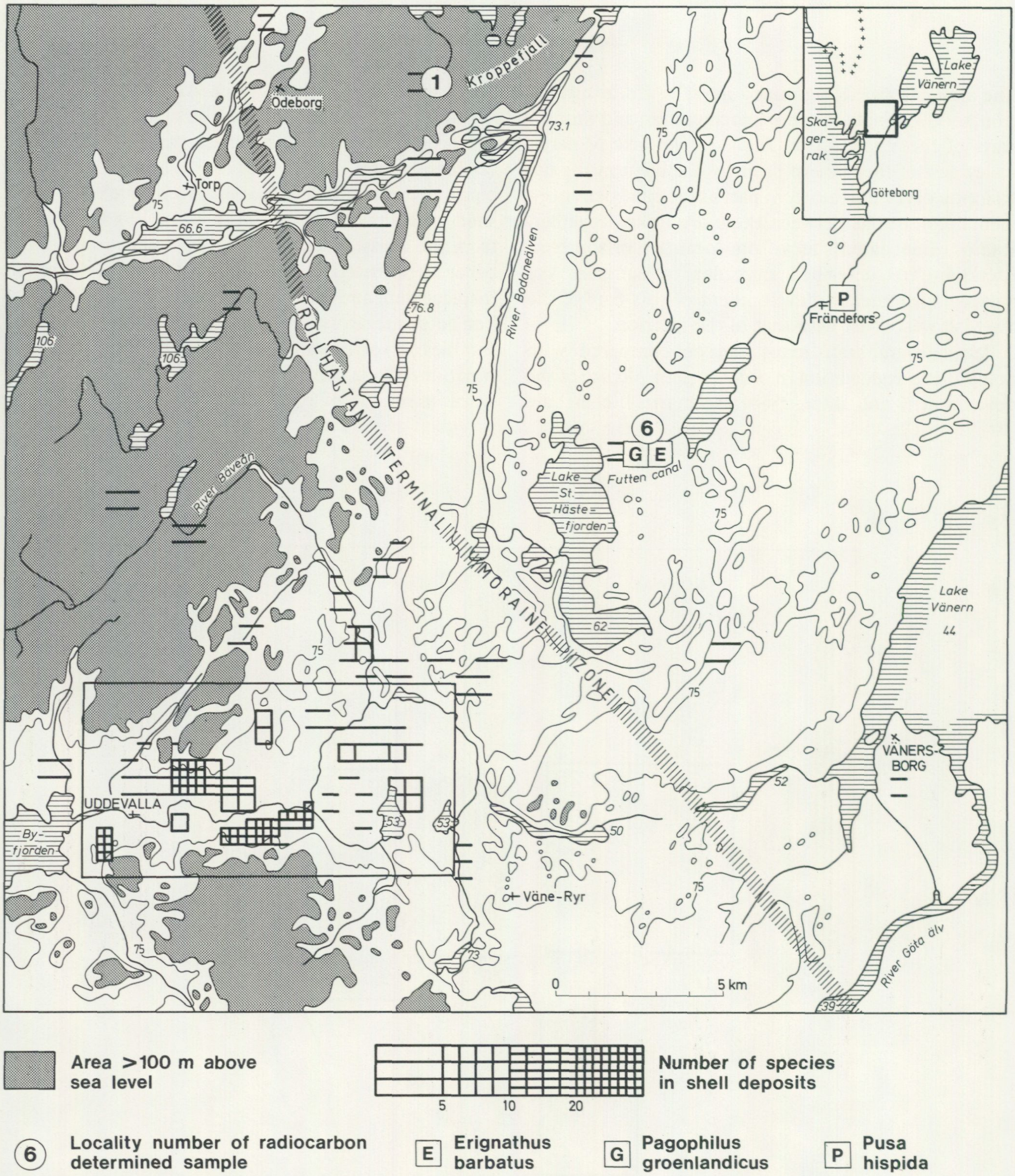

Fig. 13. Map of the Uddevalla region showing the subfossil frequency of species of marine molluscs and barnacles in the Uddevalla region. Radiocarbon dated samples of localities 2–5, 7–13 are shown in Fig. 14 (framed). Vertebrate finds in the Uddevalla area are given in Table 1.

Shell deposits in the Uddevalla region

The area between the southwestern part of the lake Vänern area and Skagerrak is known as the Uddevalla region (see Fig. 13).

Within this area shell deposits are concentrated to the vicinities of two main valleys running in the east–west direction. The valleys are separated by a flat bedrock plateau 100 to 125 m above sea level. Hilly areas above the highest shoreline, limit the Uddevalla region to the north (about 150 m above sea level) and the south (about 135 m above sea level).

Shell deposits in the region have recently been described by Fredén (1986a). No less than 23 shell-banks have been recorded in the valley east of Uddevalla (Figs 14-15) with an estimated volume of slightly more than one million cubic metres. Most of them are more or less totally exploited and the remains are covered by vegetation (Fig. 16).

The shell-banks have been exploited for centuries and have had a wide field of application. At the beginning their main use were for fertilizers, poultry-fodder, road and railway construction. When Nordmann (1906, p. 80) visited Uddevalla at the turn of the century, he was, upon arriving, immediately reminded of being in a town with shell-banks. All roads and paths in the residential district consisted of "macadamized" shells. Later haulage plants were used to extract shells and shell fragments below ground water level for limeworks. Due to low specific gravity, shells and shell fragments have also been used as insulation material in the unstable clay of the Byfjorden area.

The best known shell-banks in the region, and in Sweden as well, are located at the western end of the valley between Uddevalla and Vänersborg, i.e. where the land surface lowers to Byfjorden.

The classical "shell hills of the Samnered domains" are known since the beginning of the 1700's. Three of the deposits, Kapellbacken, Bräcke and Kuröd, have been examined several times before mining ended about 50 years ago. The Samneröd shell-bank was partly investigated before it was ruined in 1969.

The faunal composition of all the shell deposits in the region is given in Table 1.

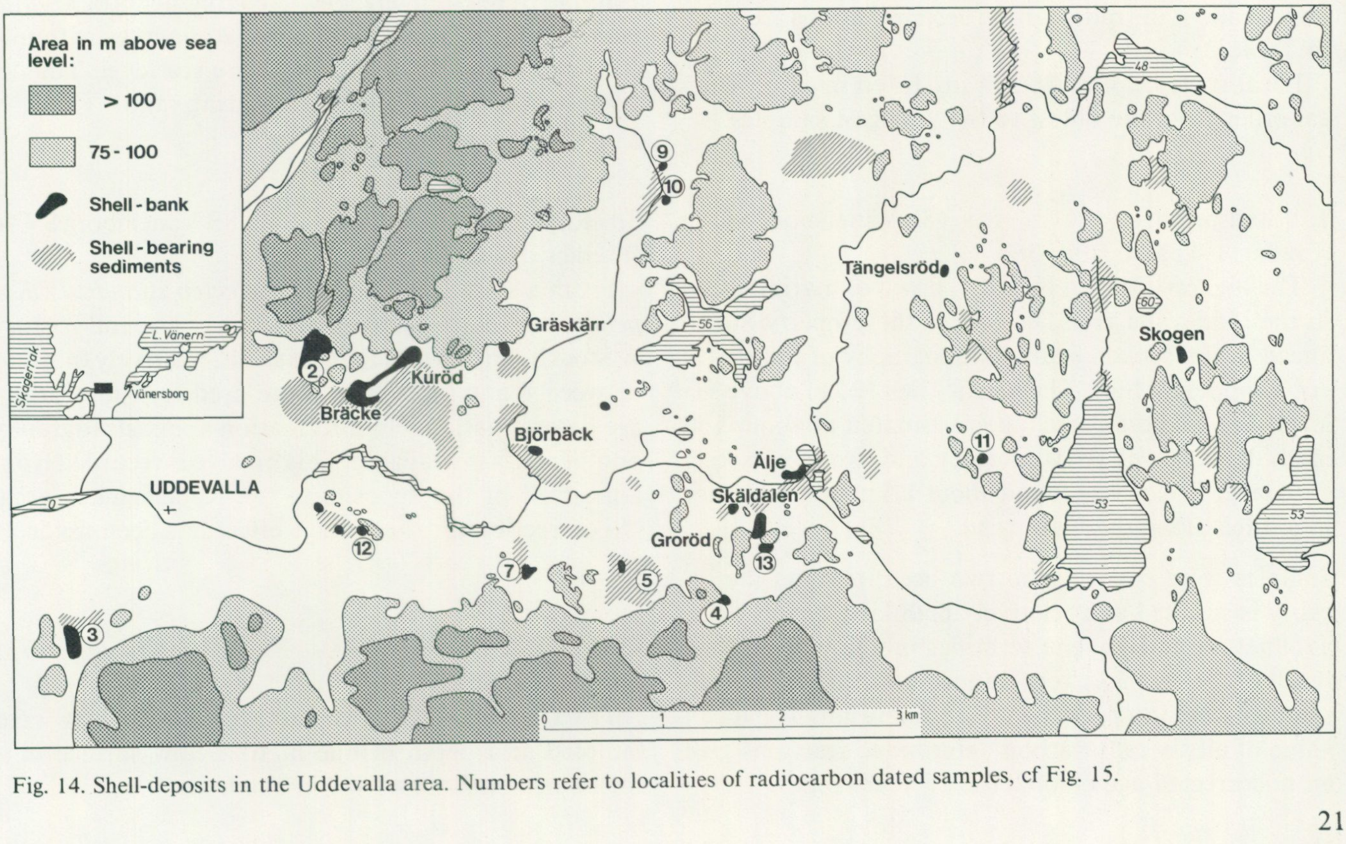

Fig. 14. Shell-deposits in the Uddevalla area. Numbers refer to localities of radiocarbon dated samples, cf Fig. 15.

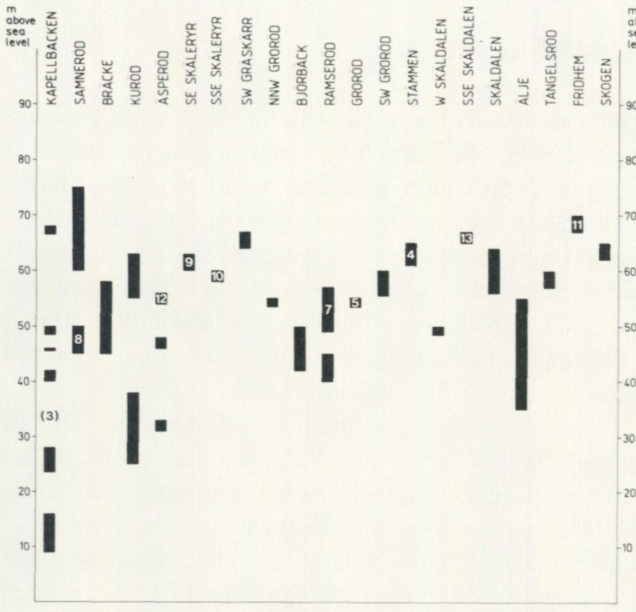

Fig. 15. Schematic profiles of the Uddevalla shell-banks and their level in m above sea level. The shell-banks are roughly listed from west to east. Locality names according to Fredén (1986a). Included in the Kuröd locality is a nearby deposit covered by 7 m of clay. Numbers refer to localities of radiocarbon dated sample.

Descriptions of localities with radiocarbon dated samples

19 subfossil samples of marine animals from 14 localities have been radiocarbon dated. All localities are shown in Figs 13–14 and data about them in Fig. 17. Details about the radiocarbon determinations are given in Table 2.

Locality descriptions below are listed in chronological order from the oldest to the youngest samples.

1. Stadsängen 8B Vänersborg NO 9g
(Fredén 1986a, locality 36).

The highest situated locality known of marine shells in the Uddevalla area lies east of the property Stadsängen in the broken bedrock topography of the southern Kroppefjäll hills. The locality lies 125 m above sea level. The highest shoreline is estimated at about 150 m above sea level. A 10 cm thick and two metres long shell layer in clay was found about 1.5 m below surface in a ditch along the main road.

Samples were collected on two occasions. As the locality is situated at a relatively high level between the Trollhättan and Levene terminal moraine zones, the result of the dating is very important. Apparantly both samples were too poor to give a good result. The mean value of all six radiocarbon determined fractions give an uncorrected age of 11 280±225 years B.P.

2. Råhagen 8B Vänersborg NO 5f
(Fredén 1986a, locality 28).

Samples of *Mya truncata uddevallensis* and *Hiatella arctica uddevallensis* plus shell fragments of *Mya truncata* were collected in 1968 (sample A) and 1972 (sample B) respectively. Few shell fragments of *Mytilus edulis* and side-plates of *Balanus hammeri* were found. The locality lies about 95 m above sea level. The deposit is characterized as shell-bearing sand.

3. Kapellbacken 8B Vänersborg SV 4e
(Fredén 1986a, locality 1).

From a storage box labelled "*Pecten islandicus, Kapellbacken*" at the Swedish Museum of Natural History in Stockholm, seven duplicate shells, relatively thin and between 8 and 9 cm high, were used for radiocarbon age determination. No information about stratigraphy or other data is available. This bivalve is recorded from almost all of the deposits in the Kapellbacken area. No correction for the storage effect has been made.

4. Stämmen 8B Vänersborg NO 5f
(Fredén 1986a, locality 16).

Thick shells of *Hiatella arctica uddevallensis* were sampled at a depth of one metre below surface in a shell-bank, situated 65–70 m above sea level.

Fig. 16. A westwards view of the remains of the Kuröd shell-bank at Uddevalla. The shell deposit is a nature reserve since 1983. Photo 1985.

5. Groröd 8B Vänersborg NO 5f
(Fredén 1986a, locality 29).

Sample was taken south of Groröd in a sandy shell-bed below 2.5 m of sand. All dug-out shells (few) and shell fragments of *Trophon truncatus, Hiatella arctica, Hiatella arctica uddevallensis* and side-plates of *Balanus hammeri* were used for dating.

6. Hästefjorden 8B Vänersborg NO 7h
(Fredén 1975, p. 43).

Three nearly complete skeletons of harp seal, *Pagophilus groenlandicus,* were found in glacial clay when the Futten canal between the lakes of St. Hästefjorden and Ö. Hästefjorden, 62.1 m above sea level, was under construction in 1867–68. Skeletal parts found 6.8 m (sample A) and 2.4 m (sample B) below surface were radiocarbon determined. The difference of depth, 4.4 m, between the harp seals corresponds to about 600 years. Besides the harp seals almost complete skeletons of a bearded seal, *Erignathus barbatus,* and of a cod, *Gadus morhua,* were found in the glacial clay. Shells of *Arctica islandica, Buccinum groenlandicum, Colus togatus, Neptunea despecta, Plicifusus latericus* and *Trophon clathratus* were also found.

7. Ramseröd 8B Vänersborg NO 5f
(Fredén 1986a, locality 13).

Shells and shell fragments of *Hiatella arctica* and *Hiatella arctica uddevallensis* were sampled in different layers in a shell-bank (Fig. 18). The surface of the shell-bank lies 57 m above sea level. The maximum thickness of the shell-bank is estimated to have been 8 m. Samples B and C are regarded as being of the same age, which is also supported by stratigraphy. The difference in age is at least 100 years between A and the B–C samples.

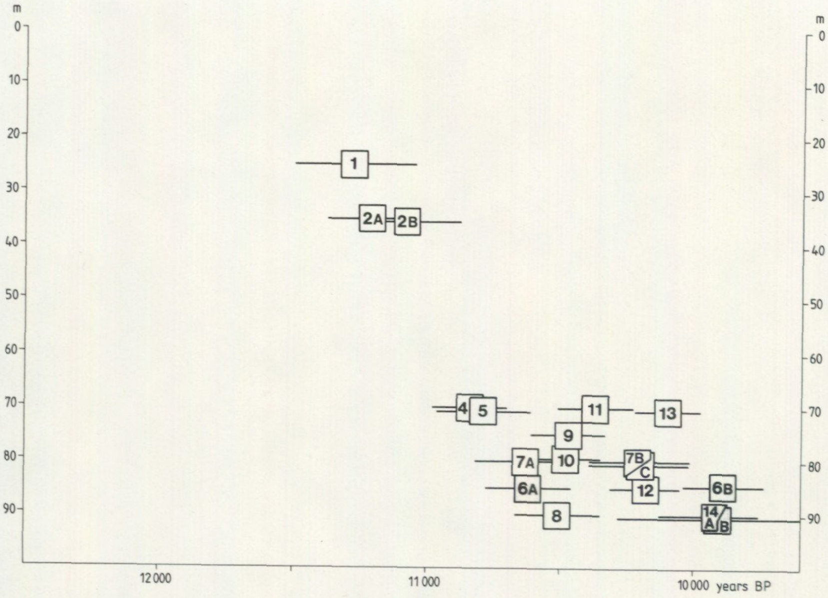

Fig. 17. Localities with radiocarbon dated marine invertebrates and vertebrates (grey) in the Uddevalla area. The localities are shown in m below the highest shoreline. Margin of error is indicated by the horizontal line. Numbers refer to Fig. 16 and Table 2.

Locality 3, Kapellbacken, is excluded as relevant information is missing about the finds of origin.

8. Samneröd 8B Vänersborg NO 5f
(Fredén 1986a, locality 2).

Shells and shell fragments of *Hiatella arctica* and *Buccinum undatum* were sampled at a depth of slightly more than one metre in the distal part of the small remains of a shell-bank, which in the past had a volume of about 100 000 cubic metres and an extension from about 75 m above sea level in the proximal part at the bedrock slope to about 50 m above sea level in the distal part. The locality is situated 700 m west of Ängkasen.

9. Skäleryr 8B Vänersborg NO 5f
(Fredén 1986a, locality 8).

Shells of *Hiatella arctica uddevallensis* were sampled at a depth of about 1.5 m below the supposed original surface of a shell-bank at 63 m above sea level. The estimated volume of the shell-bank is less then 5000 cubic metres.

10. SSE Skäleryr 8B Vänersborg No 5f
(Fredén 1986a, locality 9)

Shells of *Hiatella arctica uddevallensis* were sampled superficially in one furrow of a cultivated field which touches a shell-bank. There are no cuts. The highest surface lies almost 60 m above sea level. The volume is estimated not to exceed 5000 cubic metres.

11. Fridhem 8B Vänersborg NO 5g
(Fredén 1986a, locality 22).

Shells of *Hiatella arctica uddevallensis* were sampled in the small remains of the easternmost shell-bank but one. The locality is situated about 70 m above sea level and has had a volume of about 5000 cubic metres. Sideplates of *Balanus hammeri* were 10–12 cm in height.

12. Äsperöd 8B Vänersborg NO 5f
(Fredén 1986a, locality 7).

Shells and large shell fragments of *Hiatella arctica,* mainly of the form *uddevallensis,* were sampled in the remains of a small shell-bank (volume less than 5000 cubic metres) at 56 m above sea level.

13. SSE Skäldalen 8B Vänersborg NO 5f
(Fredén 1986a, locality 18).

Shells of *Hiatella arctica* were sampled in a shell-bank at 67 m above sea level. The thickness of the proximal part is a few metres. The original volume is estimated to about 5000 cubic metres.

The locality contains the youngest shells with an arctic-boreal composition. Few shells of *Hiatella arctica uddevallensis* were found. Sideplates of *Balanus hammeri,* 5–7 cm in height and 3–4 cm in width, dominated the deposited together with *Hiatella arctica arctica,* 4–6 cm in height. Other identified shells were of *Buccinum undatum, Natica clausa, Trophon truncatus, Macoma calcarea, Mytilus edulis,* and side-plates of *Balanus crenatus.*

14. Uddevalla 8B Vänersborg NO 5f
(Fredén 1975, p. 28, 57–60).

One vertebra of a white whale, *Delphinapterus leucas,* and one of a grey seal, *Halichoerus grypus,* both

Fig. 18. The Ramseröd shell-bank, locality 7, showing the east–west wall. A–C show position of shell samples taken for radiocarbon determinations. The sandy top of the right-hand layer is destroyed; to the left the shell-bed is overlain by Värmland clay.
The dark-coloured areas to the left reflect clay layers, which consolidate the shell-bed. Clay layers are also found to the right, but due to a dry spell they are light in colour. Photo 1971.

found in the Bräcke or Kuröd shell-banks have been radiocarbon dated. There is no information available concerning the whereabouts of the finds. Both vertebrae showed distinct erosion marks from beach processes.

The find of the grey seal is one of the oldest finds in south-western Sweden of this boreal species. It marks the arrival of warmer water to the west coast and the end of conditions favourable for habitats of arctic–boreal faunas in the Uddevalla region.

Summary

Knowledge of the marine life in the Uddevalla region is based primarily upon investigations of shell-banks and shell deposits, especially of the great shell-banks at Kapellbacken, Samneröd, Bräcke and Kuröd. Subfossil finds in the region include more than 100 species of invertebrates and more than 15 species of vertebrates (see Table 1). Species with a boreal – lusitanian distribution are recorded at localities below 50 metres above sea level and belong to faunas which require temperate waters. They are not included in Table 1.

The oldest shells, slightly more than 11 000 years, are found in shell-bearing clay and sand of relatively high levels 90–125 m above sea level, i.e. 20–30 m below the highest shore-line. The faunas at these levels consists of *Hiatella arctica arctica, Hiatella arctica uddevallensis, Macoma calcarea, Mya truncata truncata, Mya truncata uddevallensis, Mytilus edulis* and cirriped *Balanus hammeri.* Morover individual finds of *Portlandia arctica* in the Skagerrak clay are known.

Shell-banks with a total volume of more than one million cubic metres have existed in the Uddevalla region. Most of them are found between 55 and 65 m above sea level.

The main part of the shell deposits are found in an

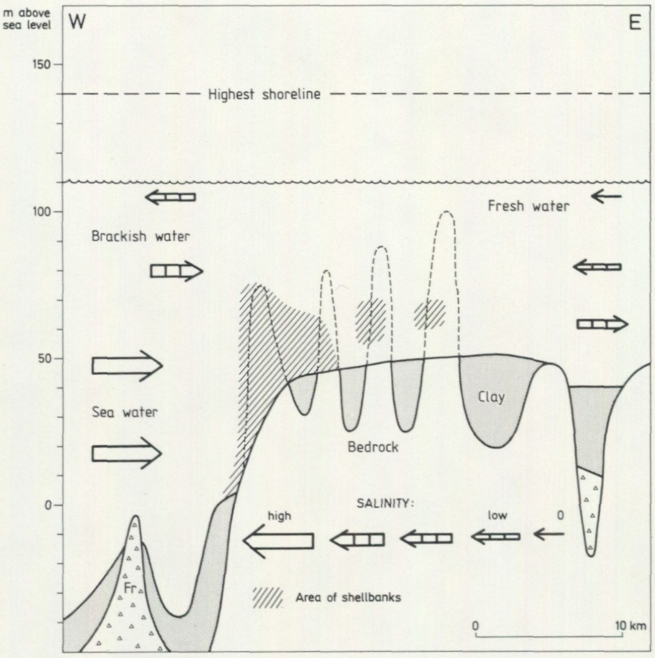

Fig. 19. A longitudinal section of the valley profile between Uddevalla and Vänersborg, Figs 13–14. The ridge (Fr) to the left is part of the Berghem terminal moraine and forms the threshold of Byfjorden. The shallow, southernmost part of lake Vänern is seen to the right. Hilly areas in the valley are shown by broken lines. Tentative estimation of hydrographical conditions correspond to about 11 000 years B.P., cf Fig. 22. All the shell-banks in the vicinity of Uddevalla are found on the western slopes, i.e., the habitats have been exposed to sea water leeward of the outgoing melt water currents.

area which has served as a water passage between fairly narrow straits to marine conditions in the west and eastwards to brackish waters (see Fig. 19). These conditions were favourable to an abundant and flourishing fauna for slightly more than 1000 years. Optimal conditions for the marine life prevailed for some hundreds of years about 10 500 years ago (see Fig. 17, cf, Figs 50–51, 53).

Shell deposits south of Lake Vänern

The landscape is characterized by large areas of exposed bedrock and vast clay fields in the east as well as in the main valleys, in which considerable sediment thicknesses, 30–100 m, are recorded. Two Cambro–Ordovician table hills, Halleberg and Hunneberg, are morphologically pronounced in the southernmost part of Lake Vänern. Both hills have been steep-sided islands during the marine stage of the Vänern basin.

The highest shoreline has been determined to lie almost 135 m above sea level on Hunneberg hill (Digerfeldt 1979) and about 110 m above sea level at the northwestern part of Lake Mjörn (Fredén 1986b).

The surveys of the Quaternary deposits of the map sheets Vänersborg SO (Fredén 1984), Göteborg NO (Fredén 1986b), and Göteborg SO (Magnusson 1978) showed that shell-bearing clay and sand were moderately common in the upper part of the Göta älv valley and south of Hunneberg. Most of the shell deposits have a fauna of more than five species of arctic to arctic-boreal species. Except for the occurrences along the east side of the pronounced valley between the lakes of Anten and Mjörn, the shell deposits are thus found in the area of fairly level landscape southwest of Hunneberg, where the ground surface has a low gradient towards the river Göta älv. The maximum water depth in the Göta älv valley was about 200 m during the deglaciation.

So far one shell-bank similar to those at Uddevalla has been found (locality 28, see below).

The first mollusc inhabitants in the area were *Portlandia arctica* and *Mytilus edulis*. Individual shells of both species are recorded from the southernmost area about 10 m below the highest shoreline (Fredén 1986a, locality 1). Both species are also known to be found in

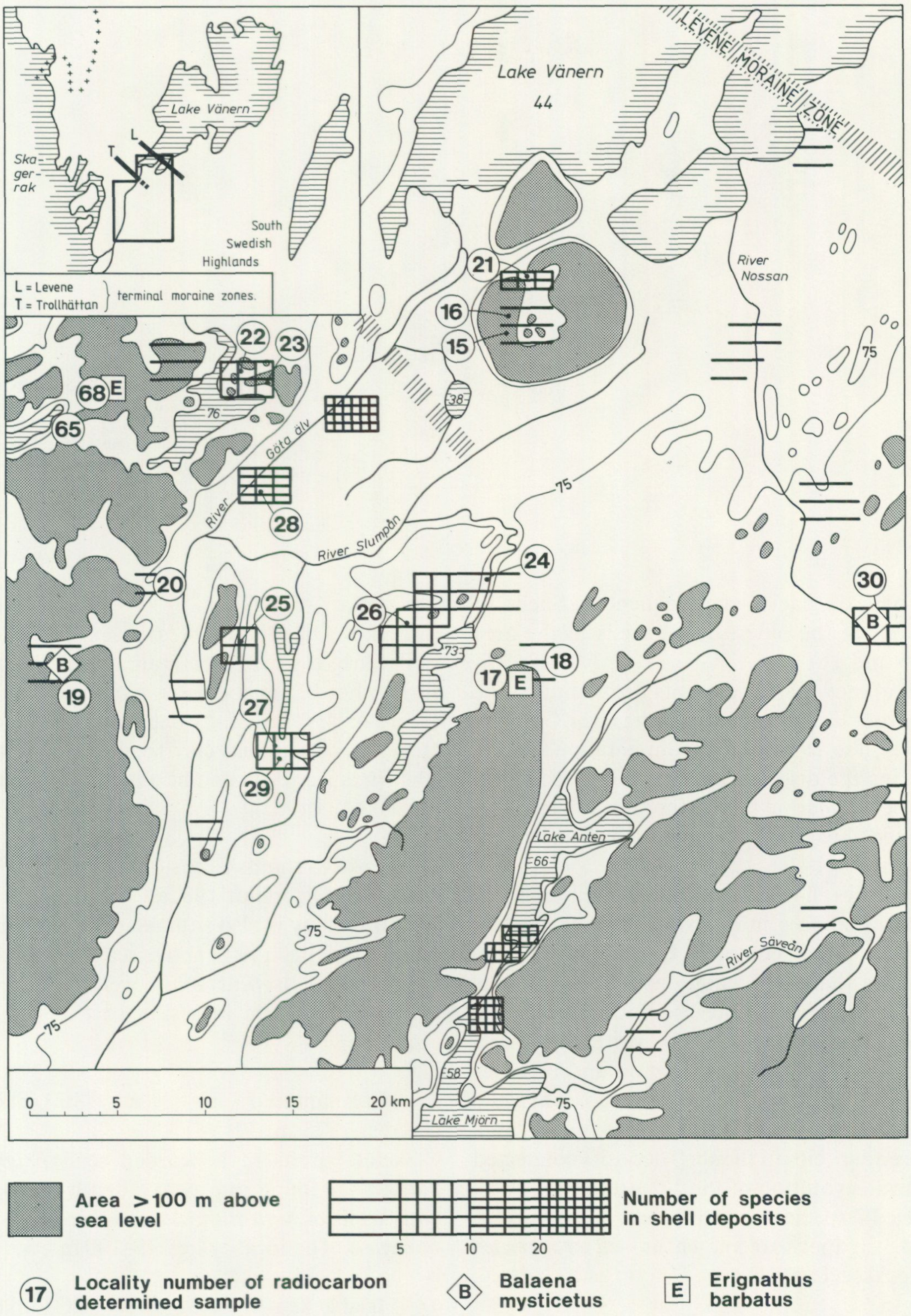

Fig. 20. Map of the area south of Lake Vänern showing frequency of marine species of molluscs and barnacles and finds of marine vertebrates. Number refer to described localities of radiocarbon dated samples.

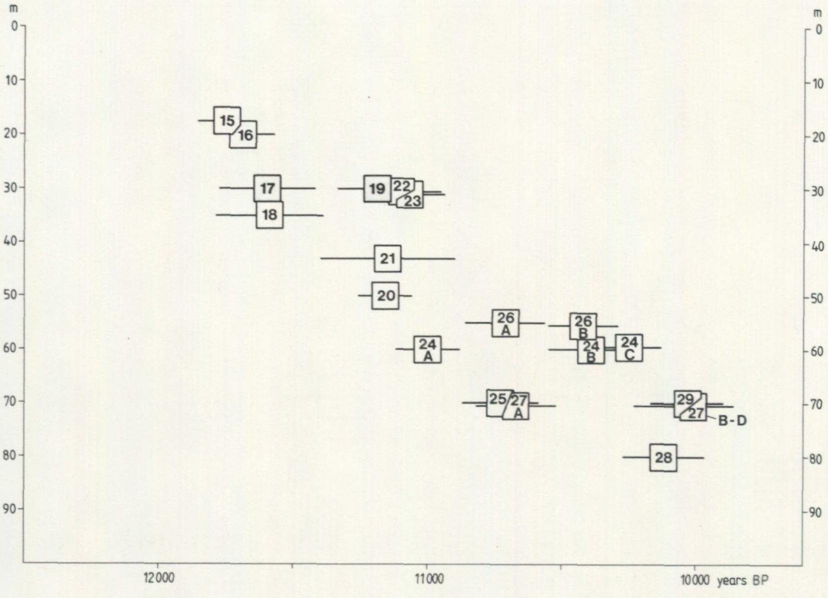

Fig. 21. Localities with radiocarbon dated marine invertebrates and vertebrates (grey) in the area south of Lake Vänern. The localities are shown in m below the highest shoreline.
Margin of error is indicated by the horizontal line. Numbers refer to Fig. 20 and Table 2.

the lowest part of glacial clay sequences. Shells of *Mytilus edulis* are the oldest dated shells in the area (localities 15 and 16).

Most of the known shell deposits are found to the east – away from the central part of the river Göta älv valley, mainly due to a heavy sedimentation of clay particles during the deglaciation there. The ecological conditions for the marine fauna were most favourable on the inclined "sea side" of the former Vänern bay area.

At two localities, 24 & 26, different shell layers in clay showed differences in age and in fauna composition. In some places complete bivalves have been found. It seems that sedimentation of clay particles have varied in space and time. Radiocarbon age determinations imply that marine vertebrates and invertebrates existed continously or on and off after deglaciation up to about 10 000 years ago, when the arctic – boreal fauna disappeared from the area. There are no Holocene species in the shell deposits connected with the marine evolution of the Vänern basin.

In the area 17 species of gastropods, 15 species of bivalves and 3 cirripeds are known, as well as 5 species of vertebrates (see Table 1).

Descriptions of localities with radiocarbon dated samples

All datings carried out are listed in Table 2. Information about the localities are shown in Figs 20–21, and shoreline displacement curve in Fig. 22.

15. Lake Kroppsjön 8C Lidköping SV 4a
(Björck & Digerfeldt 1982a)

The lake is situated on Hunneberg Hill and its water surface lies 122 m above sea level. Shells and shell fragments of *Mytilus edulis* deposited in a proximal silt-clay part of a glacial clay sequence have been dated. The finds were situated at a depth of about 6.8 m below lake bottom.

16. Lake Ekelunds Gransjö 8C Lidköping SV 4a
(Björck & Digerfeldt 1982a)

This locality is also situated on Hunneberg hill. The lake surface lies 119 m above sea level. Shells and shell fragments of *Mytilus edulis* were recorded at 4.2 m below lake bottom in a silty part of the glacial clay sequence.

17. Lagmansered 8C Lidköping SV 0a
(Fredén 1975, p. 39)

Skeletal parts of a bearded seal, *Erignathus barbatus,* were found in clay at a depth of 6.5 m together with shells of *Mya truncata* and side-plates of *Balanus hammeri*. The locality lies 95–100 m above sea level.

18. Iglabäcken 8C Lidköping SV 0a

At the deepening of the stream Iglabäcken, 50 m east of Sjöängen, a 20–30 cm thick layer of shells were found in clay, 3 m below surrounding surface lying 80 m above sea level. Shells of the following species were identified:

Buccinum undatum, 50–70 mm high
Chlamys islandica, up to 80 mm in diameter

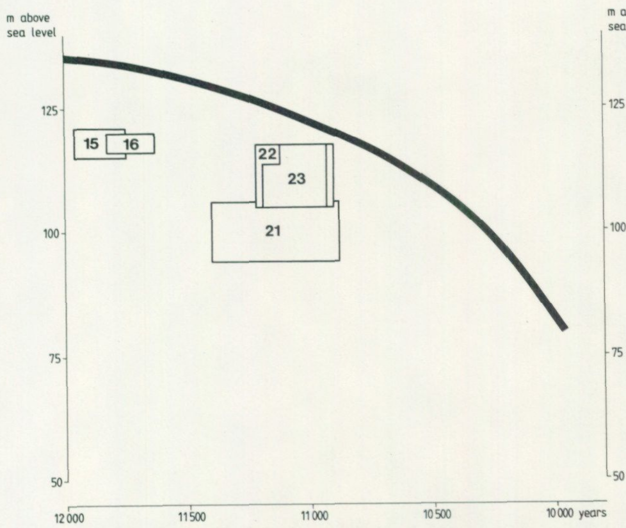

Fig. 22. Late Weichselian shore displacement at Hunneberg (Björck & Digerfeldt 1982b). The rectangles represent radiocarbon dated samples from the localities concerned. The base of the rectangle is equal to the age determination, including margin of error. The height represents maximum living conditions of the fauna according to bathymetrical conditions.

Hiatella arctica, most of them 15 x 40 mm
Hiatella arctica uddevallensis, 2–3 mm thick, 20 x 30 mm
Mya truncata, up to 48 x 64 mm
Mytilus edulis, complete bivalves, up to 70 mm high,
Balanus balanus, in colonies, 25–30 mm high side-plates
Balanus hammeri, side-plates 60–70 mm high

19. Lake Rishagerödvatten 8B Vänersborg SO 0f
(Fredén 1975, pp. 21–22)

A vertebra of a Greenland right whale, *Balaena mysticetus,* was found in clay at a depth of 2 m. The surface of the locality lies almost 100 m above sea level.

20. Hjärtum 8B Vänersborg SO 1g
(Hillefors 1969, p. 271; Håkansson 1975)

On the northern slope of a large ridge-shaped moraine, shells of *Mya truncata* were found in a 4 m clay sequence, which increases in thickness downslope. The surface of the ridge is about 85 m above sea level at the sampling patch.

21. Lake Eldmörjan 8C Lidköping SV 4a
(Fredén 1986a, locality e)

On Hunneberg hill, shells of *Saxicava rugosa* have been collected in clay at the outlet of Lake Eldmörjan, 96 m above sea level, and later stored at the Museum of the Geological Survey. Accessible duplicate shells were radiocarbon dated.

22. Smedstakan 8B Vänersborg SO 3h
(Fredén 1986a, locality c)

Shells and shell fragments of *Hiatella arctica, Mya truncata* and *Mytilus edulis* sampled in shell-bearing sand, have been dated. The locality lies 105 m above sea level (see Fig. 23).

23. Garnviken 8B Vänersborg SO 3b
(Fredén 1986a, locality c)

In small clay basins 1400–1500 m ESE of Smedstakan (locality 22) 5–10 cm thick shell layers are found at 0.5 m depth. The surfaces of the localities lie about 110 m above sea level. The fauna is identical with locality 22.

24. Ramsebacken 8C Lidköping SV 1a
(Fredén 1986a, locality h)

In 1972, when the river Vislaån was deepened, shells of molluscs and barnacles were found in clay about 0.7 m below the bottom of the river, which corresponds to some 5 m below the surrounding surface 75 m above sea level. The clayey shell layers are assumed to have been some tens of centimetres thick, cf locality 26. The thickness and frequency of shells diminished from a small bedrock hill northwards (downstream) along a distance of about 100 m. Three samples (A–C) were radiocarbon age determined. Shells of *Hiatella arctica* were found to be at least some hundred years older than shells of *Astarte borealis, Astarte elliptica* and of *Mya truncata.* The dated shells were not collected in situ but in the dredge waste.

25. Borydssjön 8B Vänersborg SO 0h
(Fredén 1986a, locality m)

Relatively thick shells of *Hiatella arctica* and *Mya truncata* were sampled at a depth of about 2 m in shell-bearing clay at the outlet of lake Borydssjön, 56.3 m above sea level.

26. Kullen 8B Vänersborg SO 0i
(Fredén 1986a, locality i)

In a cleaned-out ditch in a small valley, two 10–30 cm thick shell layers were found in clay at a depth of about one metre. The surface of the valley lies about 70 m above sea level. There was a horizontal spread of about 10 m, and there seemed to be a vertical difference of some tens of centimetres between the shell layers. Both shell layers dipped eastwards – away from firm ground. The fauna of the shell layers differed. The western – deeper – shell layer, which had a visible horizontal distribution of 7 m, was dominated by *Hiatella*

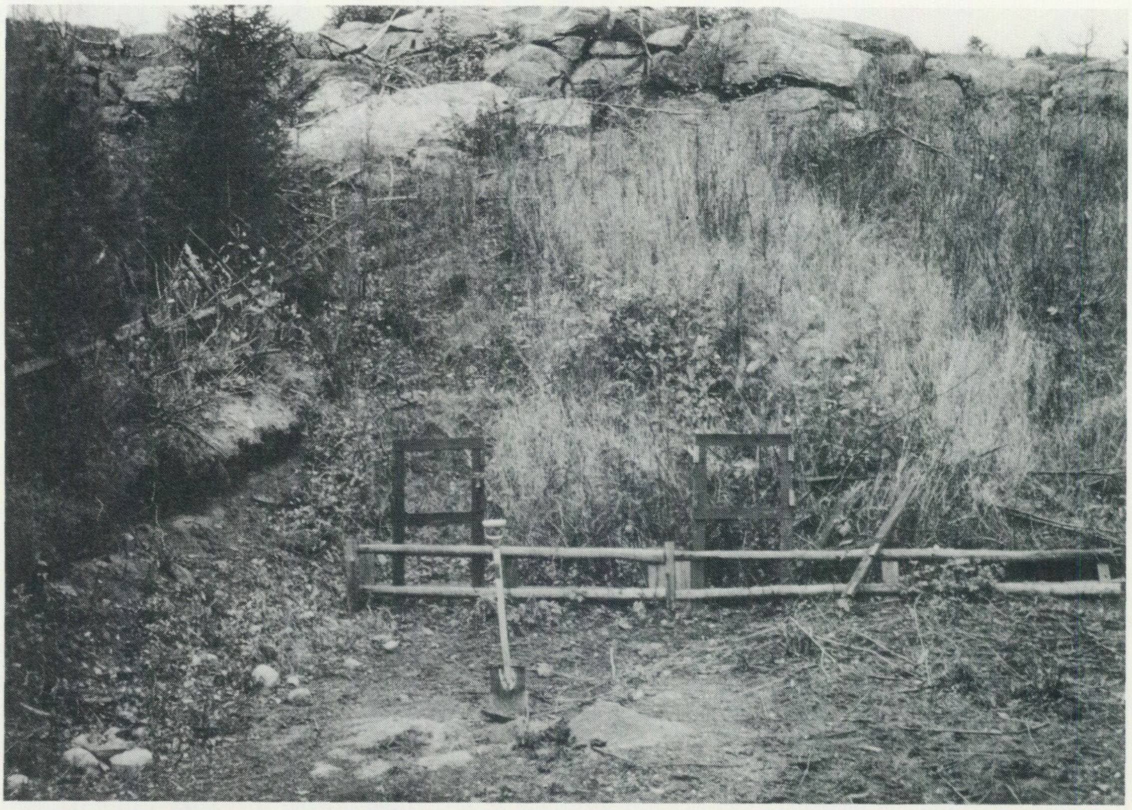

Fig. 23. Shell-bearing sand 200 m southeast of Smedstakan, locality 22. Light-coloured heaps of mostly shell fragments come from a 20–30 cm thick layer in the sand. The ground surface lies about 105 m above sea level which is about 30 m below the highest shoreline. Photo 1979.

arctica uddevallensis. Transitional forms to the less common, thinner and more elongated shells of *Hiatella arctica arctica* occurred.

The eastern shell layer (sample B), which had a length of about 10 m, was dominated by large, 30 to 36 mm, and thick shells of *Astarte borealis.* Shells of *Astarte elliptica* were moderately common.

According to the radiometric age there is a difference in age of some hundreds of years between the *Hiatella* shells of the western shell layer and the *Astarte* shells of the eastern, cf locality 24.

27. Hålan 8B Göteborg NO 9h
(Fredén 1986a, locality j)

The only shell-bank of this area is situated about 50 m above sea level in a narrow valley. The original volume has been estimated to about 2000 cubic metres.

Samples of four species were collected for radiocarbon age determination (samples A–D). All shells were taken in an area of about one square metre and with a sampling depth of less than 0.2 m. Shells of *Mya truncata* were about 500 years older than shells of *Hiatella arctica arctica, Hiatella arctica uddevallensis* and sideplates of *Balanus hammeri.* The expected difference in age between the two *Hiatella* species failed to appear, though efforts were made to sample only typical shells of each species. The radiocarbon age, about 10 000 years, of *Balanus hammeri* is remarkable. The sideplates were up to 85 mm high. The maximum water depth was about 70 m when the locality was deglaciated about 2 000 years earlier (Fig. 22). Thus the water depth of its habitat at about 10 000 years ago was at 10 m, much less than 40–50 m, which the species requires today.

28. Heden 8B Vänersborg SO 2h
(Fredén 1986a, locality g)

A sample of shell-bearing sand at a depth of about 2 m was collected in a sandy-silty cliff along a stream. The surface lies about 50 m above sea level. The sample consisted of shells and shell fragments of *Astarte elliptica, Hiatella arctica* (small ones) and *Mytilus edulis.*

29. Brännefjäll, east of Hålan 8B Göteborg NO 9h
(Fredén 1986a, locality j)

In small pockets of shell-bearing sand, shells and shell fragments of *Hiatella arctica* were sampled for radiocarbon dating. The age obtained was almost identical with the *Hiatella* shells of locality 27. The surface of the locality is about 50 m above sea level.

Shell deposits in the southeastern part of the Vänern basin

The drainage area of the rivers Nossan and Lidan are characterized as flat lands, known as the Västgöta plains, separated by Kedumbergen, Archaean bedrock hills (see Fig. 24). The major part of the plains lie less than 100 m above sea level. The highest shoreline lies about 120 m above sea level in the southern part and ca 130 m above sea level to the north. In the north the plains are bordered by pronounced moraine ridges of the Skövde and Billingen terminal moraine zones respectively. The deposits of the almost parallel Levene terminal moraine zone in the southwest are less pronounced and in places concealed by glacial clay. Along fault zones clay thicknesses of 20–30 m are recorded. Saline ground water is not uncommon in the area (Lindewald 1985). Gullies and scars of landslides occur along almost every watercourse.

In the area 11 species of bivalves, 2–3 of gastropods and one cirriped are known as well as three species of whales and three species of seals (see Table 1). All finds in clay are made in the lower part of the sequence. At some localities the finds were situated close to the underlying bedrock or till (Fig. 52) which means that some species, e.g. *Hiatella arctica, Portlandia arctica* and the harp seal *Pagophilus groenlandica* have lived close to the ice-front. Radiocarbon dated samples from four localities range in age from between 11 300 and 10 400 years B.P. (Fig. 25).

Descriptions of localities with radiocarbon dated samples

30. Essunga 8C Lidköping SV 0e–1e
(Fredén 1975, p.22)

Parts of cranium of a Greenland right whale, *Balaena mysticetus*, were found in 1876 southeast of Essunga church at a depth of 3.6 m. The find was made in clay which was overlain by shell-bearing layers containing *Astarte borealis, Hiatella arctica, Macoma* sp. and *Mya truncata*. The surface lies ca 85 m above sea level.

31. Sköttorp 8C Lidköping NO 5h
(Fredén 1975, pp. 44–45; 1986a, pp. 118–119)

At a landslide in 1951 skeletal parts of harp seal, *Pago- philus groenlandicus*, were found in a varved, marly clay at a depth of 20 m. The find was near the underlying bedrock. Shells of *Portlandia arctica* occurred at about the same depth.

32. Skara 8D Skara NV 5c
(Magnusson 1986, p. 36)

At drillings 500 m NNE of Skara cathedral shell fragments of *Hiatella arctica* were sampled in clay at a depth of 8.8 m. The total thickness of the clay was almost 10 m and it was underlain by till. Shells of *Macoma calcarea* and *Portlandia arctica* were recorded at about the same depth in nearby corings. The locality is situated about 115 m above sea level.

33. Vara 8C Lidköping SO 2g
(Fredén 1986a, p. 118)

Nearby the rivulet Dybäcken, 1500 m southwest of Vara railway station, shells of *Astarte borealis* and *Hiatella arctica* as well as 55 mm high side-plates of *Balanus hammeri* occurred in clay at a depth of 4 m. The locality lies ca 75 m above sea level.

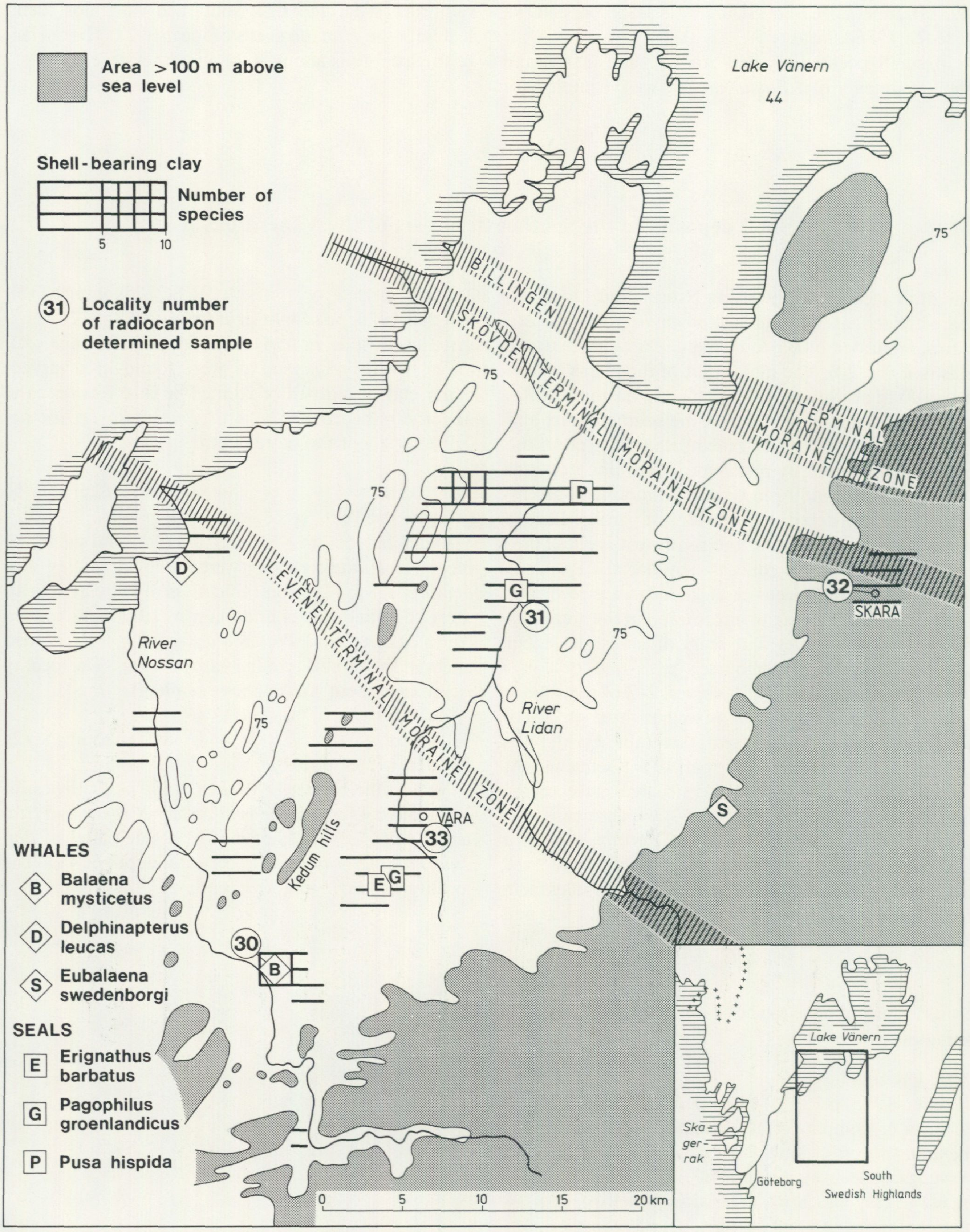

Fig. 24. Map of the area southeast of Lake Vänern showing frequency of marine species of molluscs and barnacles and finds of marine vertebrates. Numbers refer to described localities of radiocarbon dated samples.

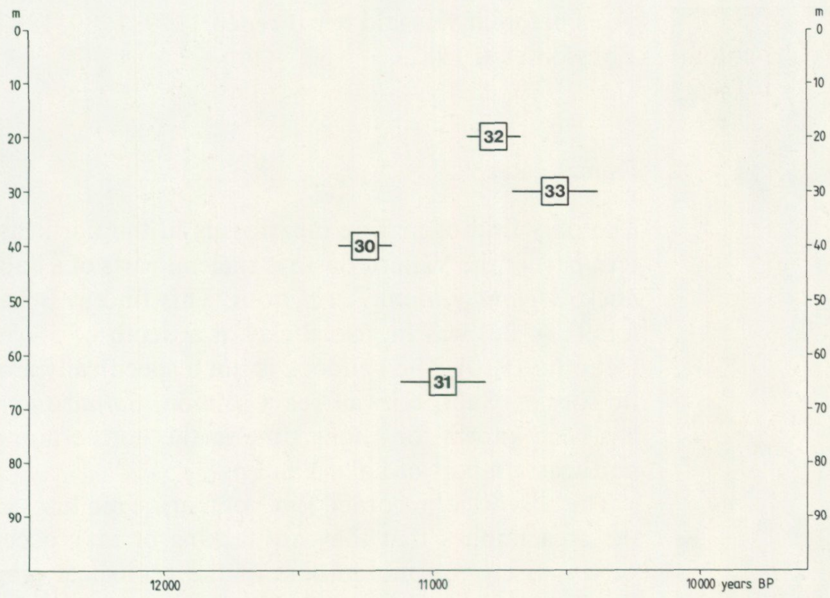

Fig. 25. Localities with radiocarbon dated marine invertebrates and vertebrates (grey) in the southeastern area of Lake Vänern. The localities are shown in m below the highest shoreline.
Margin of error is indicated by the horizontal line. Numbers refer to Fig. 24 and Table 2.

Subfossil marine animals in the northeastern part of the Vänern basin and in the Mälaren valley

The deglaciation history of the region is very important for the understanding of the development of not only the Vänern basin but particularly the Baltic basin.

Subfossil finds of marine animals are very rare or totally lacking in large areas.

When the ice-front finally left the northern end of Billingen Hill, the Vänern basin changed from a bay of Skagerrak to an inland sea between the Skagerrak and the Baltic basins. The latter was filled with melt water from the retreating ice.

Two broad valleys between the two basins have served as straits (Fig. 26). The south one runs between the relatively flat Tidan river valley and Lake Vättern. West of Karlsborg, a bedrock hill area divides this valley into two parts. The highest marine shore-line is found at an altitude of 126 m above sea level at Karlsborg (Norrman 1964, p. 31). Karlsborg is located at the shore of Lake Vättern, which, with its length of 130 km, its average width of 15 km and depths between 67 and 119 m (Norrman 1964, PL 1) has often been taken as a typical example of a rift valley or graben.

As to the palaeohydrographical conditions, the location of this deep basin east of the Atlantic/Baltic water divide is very important. When the Karlsborg area was deglaciated, a connection, here called the Vättern strait (Fig. 27) was established between the Skagerrak and the Baltic basins. Almost perpendicular to the strait, the deep Vättern valley served as a trap for inflowing saline water from the west. The glacial marine clays east of Lake Vättern are varved, which means that the salinity has not been high enough for a symmict sedimentation of clay particles, while in places the uppermost metre of the sequence has diffuse varves (H. G. Johansson 1975, 1976, 1979; Svantesson 1981; Kristiansson 1986).

The northern valley lies between the Tiveden and Kilsbergen hills (Fig. 26). The lowest spot of the Atlantic/Baltic watershed is situated 105 m above sea level at Degerfors (Fig. 27). The highest shoreline at Degerfors is about 160 m above sea level (Fredén 1967, p. 243).

When the area was deglaciated the lowland served as the main connection, the Närke strait, between the Baltic and Skagerrak basins. East of the water divide

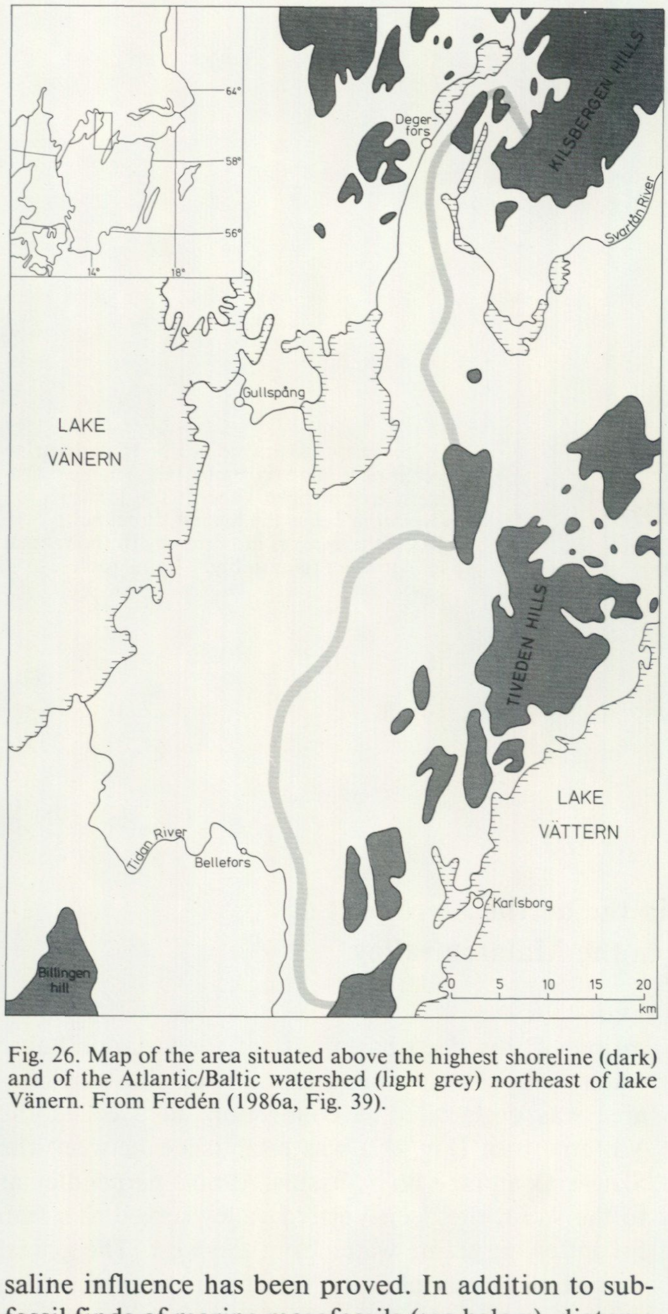

Fig. 26. Map of the area situated above the highest shoreline (dark) and of the Atlantic/Baltic watershed (light grey) northeast of lake Vänern. From Fredén (1986a, Fig. 39).

saline influence has been proved. In addition to subfossil finds of marine megafossils (see below), diatoms with relatively high demands on brackish water have been recorded in clay sequences from the Kilsbergen hills (M.-B. Florin 1977).

With the aid of pollen analysis and radiocarbon determinations the lowest parts of the watershed area is found to have been dry about 9 000 years ago (Olsson & Fredén 1969). Through land uplift, the bottom currents of brackish water had been obstructed by the bedrock thresholds at least a couple of hundred years earlier. As there are no erosion marks in the area corresponding to the tremendous fresh-water discharge of the Baltic basin, it is clear that the water exchange through the Närke strait had stopped some hundred years before it was laid dry (Fredén 1979, 1980, 1982; Ericsson et al 1982).

Faunal notes

The only find of marine megafossils in the northeastern part of the Vänern Basin is skeletal parts of a haddock, *Melanogrammus aeglefinus*. This find at Bellefors (Fig. 26) was in glacial clay at a depth of 5–6 m (Munthe 1910). The haddock is not a specifically arctic species. Subspecies of relict salmon, *Salmo salar*, has been known for a long time in the northern and northeastern part of Lake Vänern.

The absence of recorded finds of marine molluscs in the area implies that they are lacking or may occur very sparsely. As the authors of the geological map sheets of the area were well aware of the importance of subfossil finds in clay, one can take for granted that inquiries were made during the surveying, especially as several finds of marine animals were known in the Mälaren valley (Fig. 28) east of the Närke strait.

In the Baltic basin only a few finds of marine vertebrates older than Litorina times (older than 8 000 years B.P.) have been recorded so far. All finds of seals and whales both in Finland and Sweden originate from the Litorina stage of the Baltic development.

In the northern environments of Stockholm, skeletal parts of an alpine char, *Salmo alpinus*, have been found (Möller & Stålhös 1964, p. 113). According to Möller there is no question about the glacial origin of the clay in which the alpine char was embedded. Skeletal finds of a whiting, *Merlangius merlangus*, at Södertälje (Munthe 1924) and of a herring, *Clupea harengus*, at Nora (Munthe 1932) also seem to have been deposited in glacial clay.

It must be noted that skeletal finds of a grey seal *Halichoerus grypus*, and a ringed seal, *Pusa hispida*, at Skattmansö, 25 km north of Enköping, are reported by Munthe (1895, 1900) as being found in glacial clay. Until a re-investigation of the finds has been carried out with stratigraphical reference the dating of the seals is regarded as uncertain.

The recorded finds of *Portlandia arctica* in the Mälaren valley (Fig. 28) were made in the lower part of varved clay sequences. Due to their occurrence in the varved clay, De Geer stated that the mollusc existed in the Stockholm area for at least 90 years. Almost all the known finds were recorded long ago, when there was plenty of time and the spade reigned supreme as a tool at all excavations. However, the latest find was made in 1966 (Nordberg 1967).

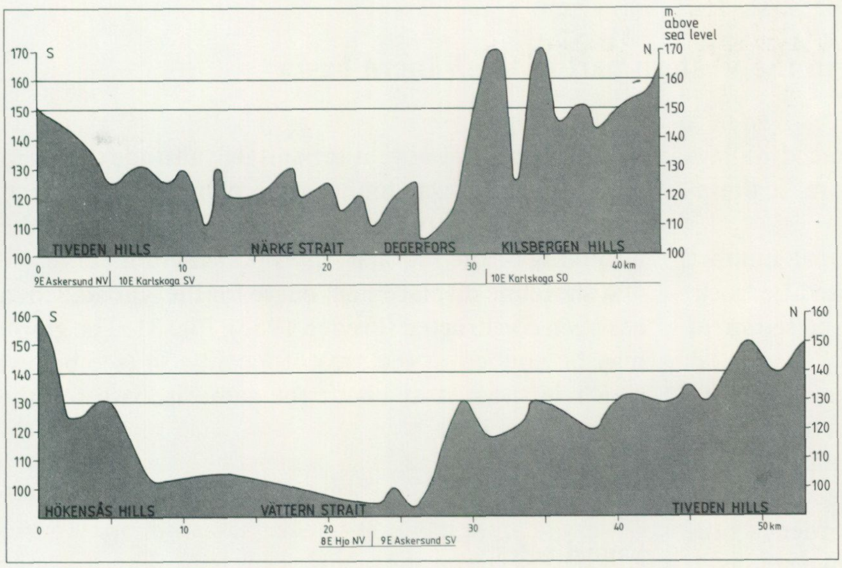

Fig. 27. Transverse sections of the strait areas along the Atlantic/ Baltic watershed, see Fig. 26. The two lines indicate the level of the highest shoreline in the southern (the lower line) and northern part of the section. From Fredén (1986a, Fig. 40).

In the Vättern basin and eastwards no subfossil finds of arctic animals are known (see Fredén 1975, p. 16).

The recorded animals in Mälaren valley have immigrated through the Närke strait and thus must have existed in the northeastern part of the Vänern basin.

According to Rolf Sörensen (personal communication) the last specimens of *Portlandia arctica* disappeared from the Oslo region before 10 000 B.P. The specimens in the Mälaren valley are thus the last known high arctic species in southern Scandinavia.

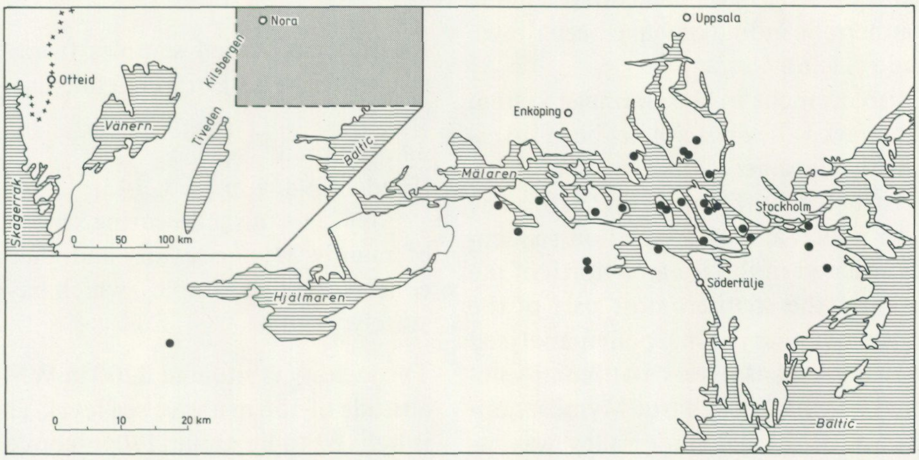

Fig. 28. Localities of *Portlandia arctica* (black dots) in the Hjälmaren–Mälaren valley. The map is based on Bergdahl (1961), Fries & Karlsson (1864), Fries et al (1863), Karlsson & Fries (1865), Nordberg (1967) and Törnebohm (1862, 1863).

Subfossil finds of marine fishes have been made at Nora, Stockholm and Södertälje. Finds west of Uppsala (Skattmansö) are not fully proved as being deposited in the Baltic basin's Yoldia clay, which corresponds to Värmland clay in the Vänern basin.

Shell deposits in the western part of the Vänern basin

Shell deposits are found in the pronounced valleys west of Lake Vänern, especially in the Stora Le drainage area (Fig. 29).

The landscape is characterized by a great number of fissure valleys and large areas of exposed bedrock. Except in the broad and deep valleys, till and sediment cover is thin.

The watershed boundary between Skagerrak and Lake Vänern runs along the Norwegian frontier to the Skövde terminal moraines where the deposits constitute the water divide southeastwards. The lowest part of the watershed along the Norwegian border is situated at Otteid (Norway), about 115 m above sea level, which is approximately 65 m below the supposed highest shoreline (Fig. 30). South of Otteid the lowest level varies between 140 and 160 m above sea level, which means that the local maximum water depths vary between 20 and 35 m.

The highest shoreline is fairly well-documented in the southern part of the area (Lind 1983) but insufficiently recorded in the northern part. As the purpose of the map is to show the palaeogeographical conditions governing the marine life, anticipated locality additions in the future will not influence the general picture. Small scale palaeogeographical maps of the deglaciation of southern Scandinavia have been drawn by Stabell & Thiede (1986).

The shoreline displacement in the drainage system of Stora Le and Aremark valley has not yet been investigated. A shoreline displacement curve for South Östfold has been constructed by Danielsen (1970). The graph was based on pollen-analysed isolation sequences from localities situated in the Ra area north of the Idefjorden deflection – the southernmost part of the Norwegian/ Swedish boundary. One pollen-analysed sequence outside that area has a very particular interest for this paper. The small lake basin Mymosetjern 112 m above sea level in the Aremark valley was assumed by Danielsen (1970, p. 39, cf. p. 128) to have been isolated about 9 500 years ago. In the pollen diagram this event is recorded well before the appearance of alder pollen grains. Before the isolation occurred, fresh or nearly fresh water with a depth of about 8 m prevailed (op.cit.). The conditions at Mymosetjern are supposed to be synchronous with those at Otteid.

On the Swedish side of the watershed, one peat bog at Blomma, 6 km east of Sandviken, locality 39, has been pollen-analysed (Lundqvist 1958, p. 136). Unfortunately, the peat bog, at the suitable altitude of 110 m above sea level was found to be paludicolous, which according to the pollen diagram took place after the beginning of the rational *Alnus* pollen-grain curve.

A shoreline displacement curve for the Karlstad area has been constructed (Fredén 1985), Fig. 31. The graph may be applied in the area of locality 34 (see below) which is situated at about the same isobase for the highest shoreline.

Faunal notes

Including subspecies the number of recorded invertebrates is 41 (see Table 1). When divided into geographical regions, 10 species are regarded as arctic, 22 as arctic–boreal and 9 as boreal. No less than 33 species of the total number derive from the localities 36 and 39.

The find of a bearded seal, *Erignathus barbatus*, is the only one of a marine vertebrate in the area.

Descriptions of localities with radiocarbon dated samples

Radiocarbon dated samples from eight localities are shown in Fig. 32. Further details are given in Table 2.

34. Bråtnäs 10B Årjäng SO 4g
(Fredén 1986a, p. 133, 142)

Four kilos of shell-bearing sand with shell fragments of mainly *Mytilus edulis* and *Balanus crenatus* were collected in two samples, which have been treated separately.

The locality is situated 2200 m WNW of Bråtnäs at an altitude of 156 m above sea level. The highest shoreline is belived to lie about 170 m above sea level.

35. Grums 10C Åmål NO 9i/11 Arvika SO 0j
(Fredén 1975, p. 37)

Skeletal parts of a bearded seal, *Erignathus barbatus* were found in 1892 "deep" in glacial clay when the lowering of the outlet of lake Lillsjön was carried out. Today the lake surface lies about 80 m above sea level. The highest shoreline in the area has an altitude of about 170 m above sea level. The radiocarbon dating was carried out on a elbow-bone.

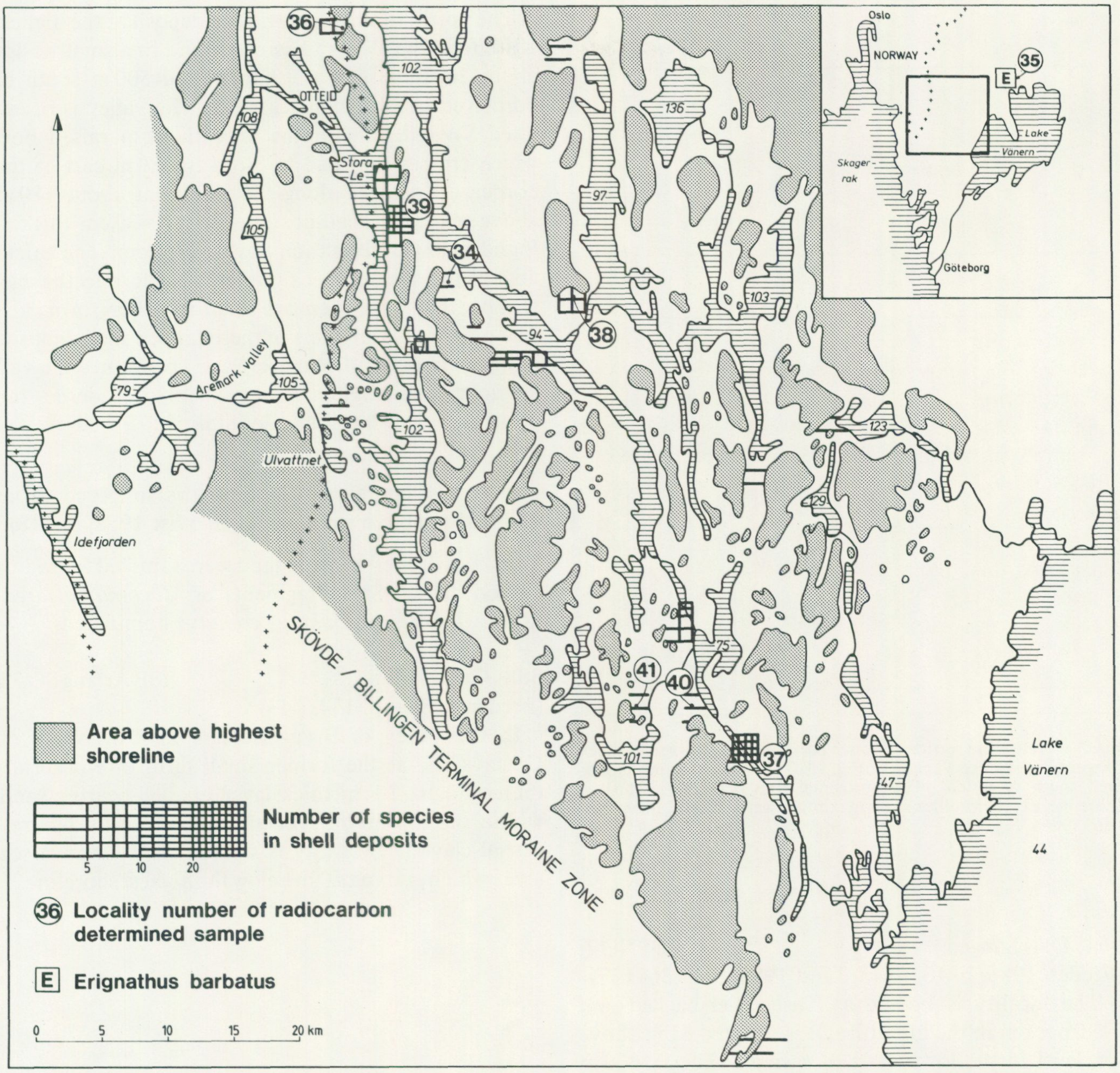

Fig. 29. Map of the area west of Lake Vänern showing frequency of marine species of molluscs and barnacles and the locality of a vertebrate. Areas (dark) above the highest shoreline are generalized. Numbers refer to described localities of radiocarbon dated samples. After Fredén (1986a, Fig. 41).

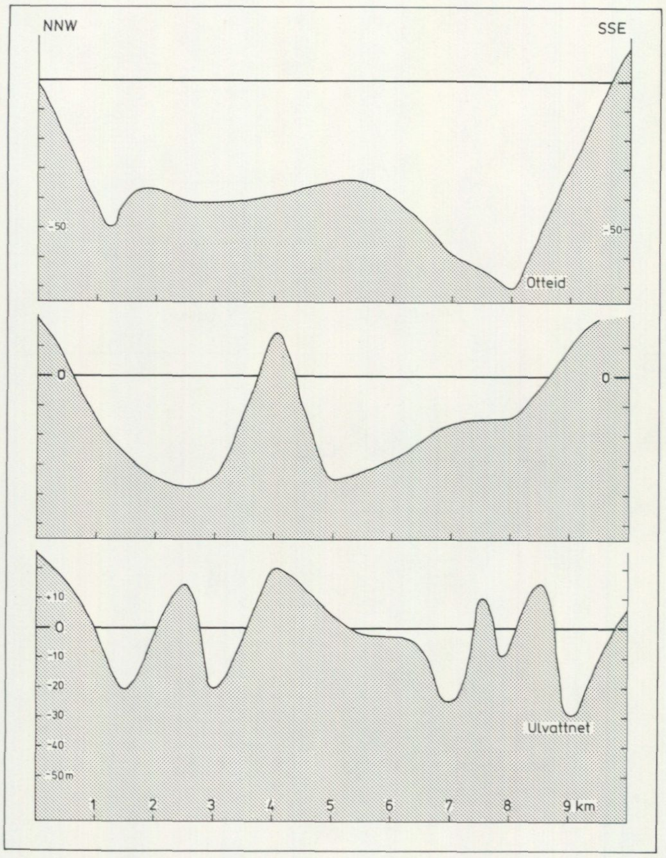

Fig. 30. Transverse sections of three parts of the watershed between Skagerrak and Lake Vänern, cf Fig. 29. The middle section is situated south of Otteid. The horizontal line denotes the highest shoreline, i.e. the profiles show maximum water depths. From Fredén (1986a, Fig. 42).

36. Dals Långed 9B Dals Ed NO 7j
(Fredén 1986, p. 137, 143; Lind 1983, pp. 136–137)

The locality is known as Tusendalersbacken and Fläskbacken in the literature. It is situated 81 m above sea level in the lower part of a small valley, 1400 m south of Dals Långed railway station. The highest shoreline is supposed to lie about 160 m above sea level in this area. In the Swedish National Museum of Natural History duplicate shells of *Hiatella arctica* were accessible for radiocarbon determination.

In the same valley at a level of about 90 m above sea level Lind (op.cit.) has found a 10–20 cm thick shell-bearing sand layer at a depth of 1.5 m. The shell layer consisted mainly of shell fragments. It was overlain by sand and underlain by clay. The shell fragments consisted of *Hiatella arctica, Mytilus edulis* and *Balanus* sp.

37. Hulabäcksröset 10B Årjäng NV 8e
(Fredén 1986a, p. 128, 142)

The northernmost known shell deposit at the highest altitude in the Vänern basin is found in a small valley about 200 m east of the border and 500 m south of border cairn 28, Hulabäcksröset. The valley is orientated SW–NE and drains a peatland, a raised bog, which crosses the road to Norway 750 m east of the border. In patches along the rivulet at about 170 m above sea level, shell-bearing sand 20–30 cm thick is found below a vegetation cover of 10 cm. The thickness of the sand exceeds one metre. Close to the eastern bedrock slope there are small and overgrown cuts. The maximum thickness of these tapped shell deposits has been about half a metre. Sand constitutes the valley floor upstream and most probably it underlies the peat bog, which has a level of almost 175 m above sea level.

The highest shoreline in the area is supposed to lie 180–185 m above sea level (Lundqvist 1958, p. 118).

Two kilos of shell-bearing sand were sampled for radiocarbon dating. Shell fragments of *Macoma calcarea, Mytilus edulis* and *Balanus crenatus* dominated.

38. Gustavsfors 10B Årjäng SO 3h
(Fredén 1986a, p. 134, 143)

In the valley of Bryngelsdalen, 2300 m NNW of Gustavsfors, at the former small farm of Kockerud, there is a 10–20 cm thick layer of shell-bearing sand within the top metre. The sand is underlain by grey glacial clay. The locality is situated 150 m above sea level, which is about 20 m below the highest shoreline.

Fig. 31. A tentative curve of the shore displacement east of Grums, locality 35. The curve is based on the present deglaciation chronology, the isolation of Lake Vänern and on two radiocarbon determinations of beach deposits from the lake stage. From Fredén (1985, Fig. 7).

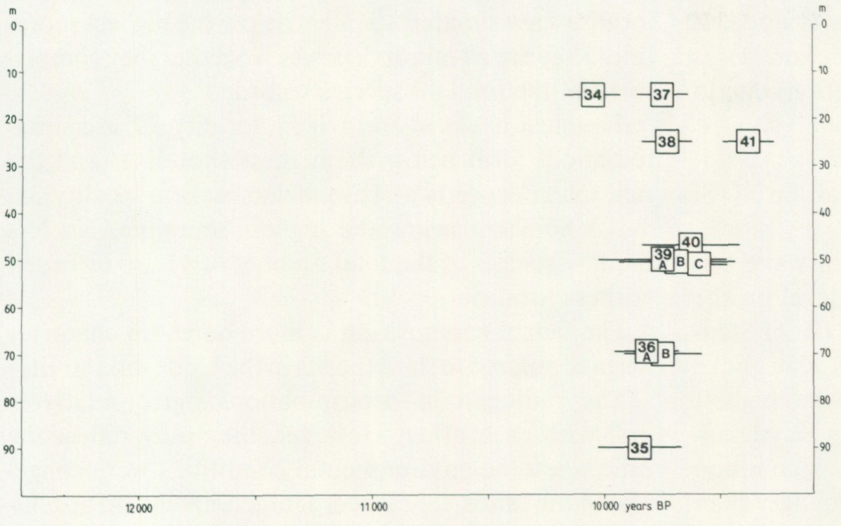

Fig. 32. Localities with radiocarbon dated marine invertebrates and vertebrates (grey) in the western part of Lake Vänern. The localities are shown in m below the highest shoreline.
Margin of error is indicated by the horizontal line. Numbers refer to Fig. 29 and Table 2.

Two two-kilo samples of shell-bearing sand were delivered for radiocarbon age determination. The samples were dominated by small shell fragments, some of them could be identified as *Mya* and *Mytilus*. The age determinations show a fairly large deviation between the dated fractions. Ergo, the shell fragments were affected by contamination.

39. Sandviken 10B Årjäng NO 5f
(Fredén 1986a, p. 130–131, 142)

In the vicinity of Sandviken several shell deposits are known (Fig. 33). In the upper part of the stream running from Lake V. Kvarntjärn, 129 m above sea level, two shell-banks are situated on the west side. The southern one is known as Gullingehålan. Most of the shell deposits are situated between 120 and 130 m above sea level. The highest shoreline is assumed to lie about 175 m above sea level. The lake of Stora Le has a maximum depth of 139 m.

From the Sandviken deposits shells of *Mya truncata* and fairly thin shells of *Pecten islandicus*, 2–5 cm in height, were obtained from the Swedish National Museum of Natural History for radiocarbon measurements.

Dug-out shell fragments of molluscs and side plates of *Balanus crenatus* showed about the same age as the stored shells. Among the large shell fragments, the following molluscs were identified: *Astarte borealis, Chlamys islandica, Hiatella arctica, Hiatella arctica uddevallensis, Mya truncata* and *Mytilus edulis*.

No less than 25 species of molluscs and 2 species of barnacles have been recorded at this locality.

40. Dingelvik Dals Ed NO 8i
(Lind 1983, p. 136)

1200 m northeast of Dingelvik manor on the slope of a large glaciofluvial deposit fragments of barnacles have been found in wave washed clayey sand. In the area the locality is known as Snickarkullen. The sample was taken at a level of 104 m above sea level. The highest parts of the glaciofluvial deposit have reached 130 m above sea level, which is about 30 m below the

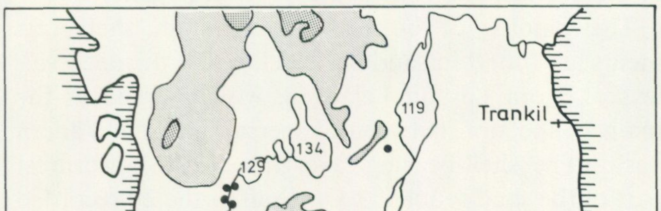

Fig. 33. Shell deposits (black dots) in the Sandviken area, locality 39. Dark grey areas lie more than 175 m above sea level, grey areas 150–175 m above sea level. From Fredén (1986a, Fig. 44).

highest shoreline. Only one fraction was measured. It is common that the outer fraction (fraction 1) is 200–300 year younger than the inner fraction, due to leaching.

41. Steneby Dals Ed NO 8i
(Lind 1983, p. 136)

Fragments of barnacles were sampled in wave washed sand at a level of 130 m above sea level on the slope of a glaciofluvial deposit 1800 m NNW of Steneby church. The top of the deposit reaches 140 m above sea level, which is about 20 m below the highest shoreline. The local name of the deposit is Havdekullen. Only one fraction was measured. It is common that the outer fraction is 200–300 years younger than the inner fraction due to leaching.

Summary

The most favourable bathymetric conditions along the Skagerrak – Vänern watershed were present in the Otteid area (see Fig. 30). Inflow of saline water could take place immediately or shortly after the strait was deglaciated. The meltwater discharge of the Aremark valley north of Otteid has been relatively small as the drainage area is limited. At that time the western part of the Vänern basin was an archipelago (see Fig. 29).

The sedimentation of glacial clay had ended when molluscs inhabited the water of the then existing archipelago. Except for individual shells in the coastland of Lake Vänern, no shells are covered by clay.

The majority of the recorded shells and shell fragments are found in sand on the slopes of the deep valleys of Stora Le and Lelången, which served as the main connection between Skagerrak and the Vänern basin. The shell-bearing layer lies in the lowermost part of the sand sequence. One-half of the 20 recorded localities are situated 10–30 m below the highest shoreline. They are all minor deposits. Together they comprise 10 of the total 40 species recorded.

The shell-banks at Sandviken, locality 39, are situated about 50 m below the highest shoreline, and the rich fauna deposits at Tusendalersbacken, locality 36, about 80–90 m below the highest shoreline. No less than 37 species of the total number of 41 are recorded at these localities.

The faunal composition is more boreal in character when compared to the deposits in the Uddevalla strait.

The radiocarbon determinations agree relatively well with each other. However, they only reflect the time when the environmental conditions were congenial to the fauna concerned. Unfortunately, no absolute datings of isolation sequences are available. According to a pollen analytical investigation by Danielsen (1970), a nearby basin at a corresponding level to Otteid is supposed to have been isolated at about 9 500 years B.P., an estimated figure which is more or less consistent with the radiocarbon determinations. The marine fauna seem to have disappeared from the region about 9 500 years ago.

The clay thickness at most of the sites where shells have been found is estimated to a couple of metres, which, with regard to the rate of sedimentation of clay particles, should correspond to a few hundred years. By comparison to the radiocarbon determinations, this means that the Otteid area was deglaciated more than 10 000 years ago. The changing hydrographical and bathymetrical circumstances, primarily caused by land uplift, caused relatively optimal edaphic conditions for a marine fauna to prevail only for 300–400 years in this region.

Only when reliable determinations of the highest shoreline are at hand can one discuss the rate of land uplift in areas where molluscs have existed at water depths less than 10–30 m.

Description of localities in southern Bohuslän where samples for radiocarbon dating have been collected

When discussing deglaciation conditions and the marine fauna development in the Uddevalla region and the Vänern basin one must consider the palaeoenvironment west of the area. The evolution of submerged areas deals with deglaciation chronology and hydrographical conditions in the whole region.

During the mapping of Quaternary deposits in western Sweden, samples of shells of an arctic/boreal character have been radiocarbon age determined as have samples within the programme for documentation (Fig. 34). The result of the radiocarbon datings together with those of marine vertebrates have been compiled in Fig. 35. Details are given in Table 2.

42. Huseby 8A Lysekil SO 1j

The locality is situated on the west side of a bedrock plateau about 80 m above sea level, 1 100 m east of St. Huseby. St. Huseby itself lies 55 m lower in a deep valley. The highest shoreline is supposed to lie about 120 m above sea level.

During the winter of 1979, a fen basin, 50 x 80 m, was dug out in order to supply a nearby refuse tip with cover material. The basin now ponded acts as a small scale irrigation plant for the farms in the valley.

The fen peat about 0.5 m thick, was underlain by 1–2 m sand, shell-bearing in the lower part, as was 0.2–0.4 m silty clay resting upon bluish fine clay (Fig. 36). The fine clay was 2-4 m thick and contained individual shells. The thickest shell-bearing layers lay at the outlet, which is situated in the northern part of the basin. The following bivalves were identified: *Chlamys islandicus* (common, height 80–95 mm), *Hiatella arctica* (common), *Hiatella arctica uddevallensis, Mya truncata* (common in the silty clay, 60–70 mm in width), *Mytilus edulis*. The following gastropods were observed: *Acmaea* sp., *Buccinum groenlandicum, Buccinum undatum* (common, 50–60 mm high), *Neptunea despecta, Trophon clathratus, Trophon truncatus.* Side plates of *Balanus hammeri*, 30–40 mm high occurred. *Balanus balanus* was relatively common, also attached to shells of *Chlamys islandica.* The faunal composition differed from place to place within the basin.

Six samples, A–E, have been radiocarbon dated. Three of them, A, B, and E, were collected in the upper part of the silty clay in November, 1978. The results showed too large a deviation between the fractions. New samples, C, D and F, were taken in the lowermost part of the silty clay in April, 1979.

43. Delsjön 7B Göteborg SO 0f
(Per O. Wedel, unpublished)

Shells of *Mytilus edulis* in clay was found at a road construction in 1972 at the southern end of Lake St. Delsjön (66 m above sea level).

44. Guldheden, Göteborg 7B Göteborg SV 0e
(Fredén 1975, p. 23)

Skeletal parts of a Greenland right whale, *Balaena mysticetus*, have been found in the lowermost part of a 9 m sequence of glacial clay, which was underlain by till. The surface lies at 53.6 m above sea level, (highest shoreline at about 90 m above sea level).

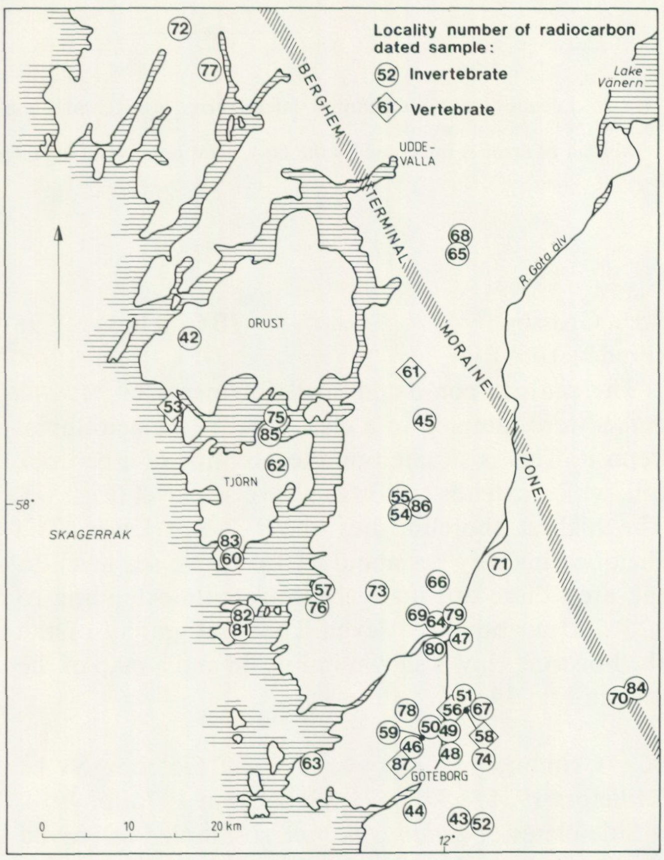

Fig. 34. Localities with radiocarbon dated arctic–arctic/boreal marine species of molluscs, barnacles and whales in southern Bohuslän.

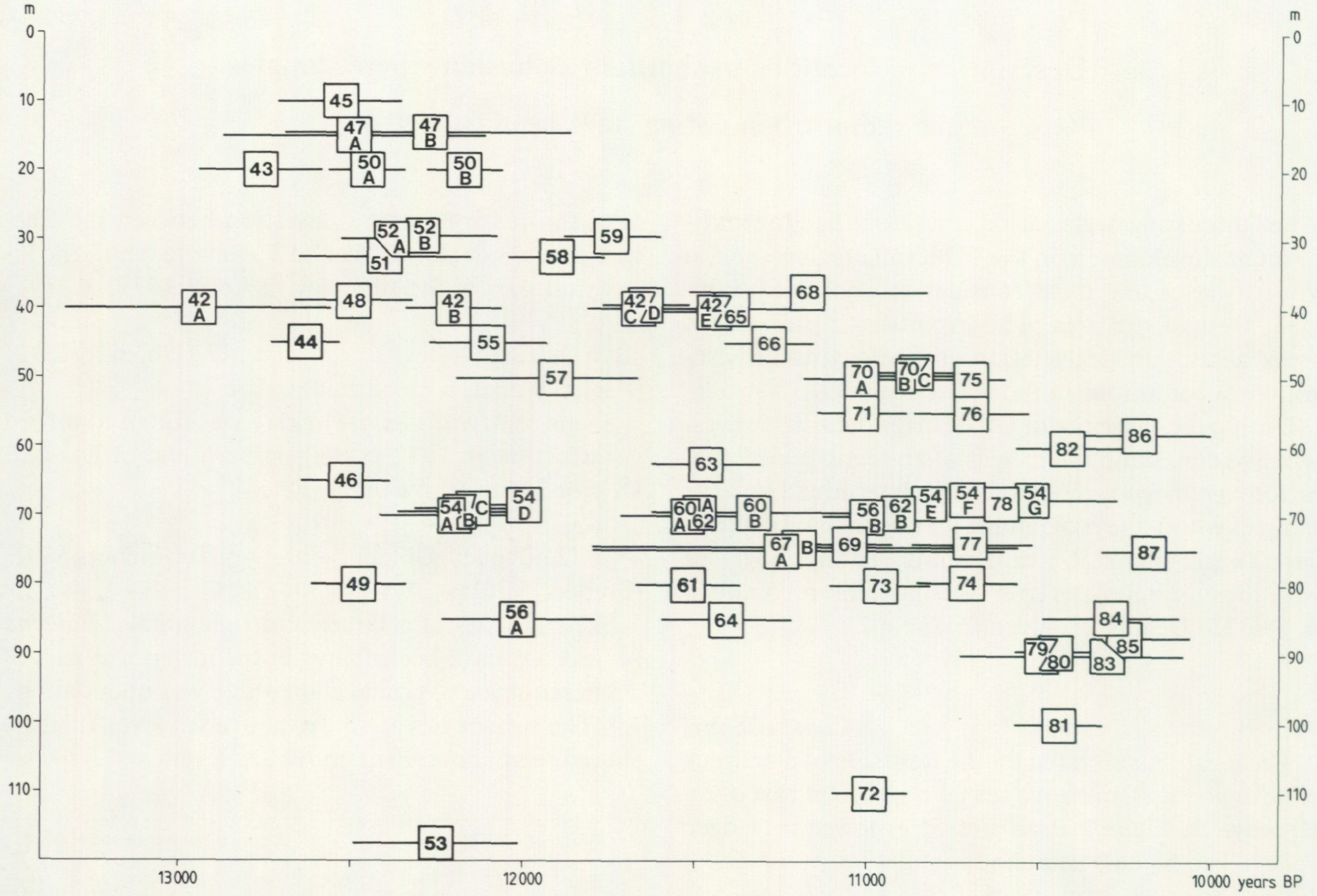

Fig. 35. Localities with radiocarbon dated marine invertebrates and vertebrates (grey) in southern Bohuslän. The localities are shown in m below the highest shoreline.
Margin of error is indicated by the horizontal line. Numbers refer to Fig. 34 and Table 2.

45. Grössby 7B Göteborg NV 9e
(Fredén 1987)

The radiocarbon-dated shell fragments of *Mytilus edulis* were sampled in a clay layer on a glaciofluvial deposit. This is situated on the east side of a bedrock hill, which extends to 130 m above sea level (Fig. 37). The highest shoreline lies about 7–8 m lower. The shell-bearing clay lies about 110 m above sea level. In the area there are many bedrock hills extending to 125–130 m above sea level. The stratigraphy of the shell-bearing clay is shown in Fig. 38 and a map of the area in Fig. 39.

46. Grimbo 7B Göteborg SV 1d
(Hillefors 1975, pp. 70–71; Håkansson 1975, p. 79)

Side-plates of *Balanus hammeri* sampled in varved clay upon glaciofluvial sediment were used for radiocarbon age determination. The side-plates were collected at 23 m above sea level.

47. Källtorp 7B Göteborg SO 4f
(Magnusson 1978, p. 98, 146)

On the east slope of the river Göta älv valley shell fragments of mainly *Mytilus edulis* in shell-bearing sand have been collected at a site about 90 m above sea level, about 15 m below the highest shoreline. The locality is known as Jennylund.

48. Nylöse 7B Göteborg SV 1e
(Adrielsson & Fredén 1987)

The locality is situated on the Göteborg terminal moraine at a level of 55 m above sea level. The stratigraphy is shown in Fig. 40.

49. Hjällbo 7B Göteborg SV 2e
(Hillefors 1975, p. 71; Håkansson 1975, p.79)

Fragments of *Balanus balanus* and *Balanus crenatus* from varved clay 18 m above sea level were sampled for radiocarbon age determination. The locality is de-

Fig. 36. Section in shell-bearing sand at Huseby, locality 42. The shell-bearing sand layers often have a weak undulating surface while the underlying shell-bearing silty clay is fairly level with a low gradient towards the center of the basin. The spade is one metre long. Photo 1978.

scribed as Bläsebo. It is situated 600 m south of Hjällbo church.

50. Bäckebol 7B Göteborg SV 2e
(Hillefors 1975, p. 71; Håkansson 1975, p. 79)

Separate samples of *Mytilus edulis* and *Hiatella arctica* were collected in wave washed gravel underlain by till at 70 m above sea level. Also a skeletal part of a ringed seal. *Pusa hispida*, was recorded. The stratigraphy was disturbed by an ice advance.

51. Granås 7B Göteborg SO 3f
(Magnusson 1978, p. 98, 146)

Shells of *Hiatella arctica* were sampled in clay 3 m below surface which lies about 65 m above sea level. The locality is described as Lövgärdet.

52. Helenedal 7B Göteborg SO 0f
(Magnusson 1978, p. 98, 146)

Shells of *Hiatella arctica* dominated in a 0.5 m thick shell-bearing clay layer 2.5–3.0 m below surface east of Helenedal. The locality lies about 65 m above sea level. It is situated about 2 km ESE of locality 43.

53. Edshultshall 8A Lysekil SO 0i
(Fredén 1975, p. 20)

In 1968 a skeleton of a Greenland right whale, *Balaenoptera mysticetus* was found in clay at a depth of 1.4–1.7 m below surface, which lieas almost 3 m above sea level, (cf locality 42, situated about 8 km northnortheastwards).

Fig. 37. Stratigraphy of the glaciofluvial deposit at Grössby, locality 45. A=glaciofluvial sand and gravel, B=laminated clay and silt, shell-bearing silty clay, see Fig. 38, C=wave-washed sand and gravel. Position of Fig. 38 is marked by the arrow. Photo 1981.

54. Toröd 7B Göteborg NV 7d
(Fredén 1987)

During construction work on a small dam 700 m southwest of Toröd youth hostel, shells and shell fragments were exposed in a cut in clay on the southern slope of a valley orientated in east–west. The destroyed original surface lay close to 50 m above sea level. The bedrock slope extends to 80 m above sea level 100 m further south; to the east parts of the bedrock plateau lie above the level of the highest shoreline (Fig. 39). There were no distinct shell layers in the clay. Shells and shell fragments occurred throughout the sequence and where they occurred frequently enough samples for radiocarbon age determination were collected within a space limit of 15 cm cube. Stratigraphy and radiocarbon analyses are shown in Fig. 41.

The grain size distribution varied in the lower part of the sequence. The silt content was mainly of glaciofluvial origin while the sand particles were due to wave

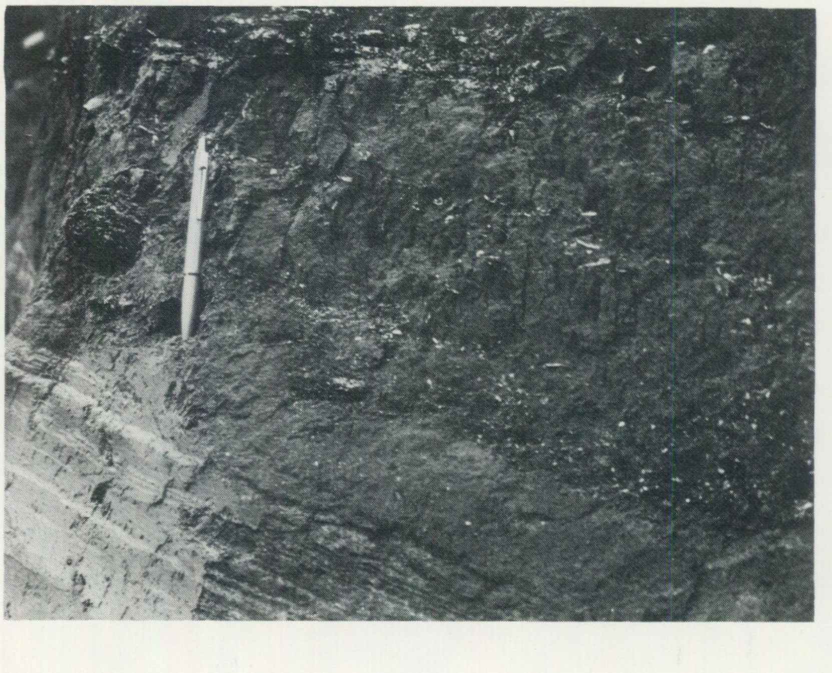

Fig. 38. Shell-bearing clay layer at Grössby, see Fig. 37. The pencil is 13 cm long. Photo 1981.

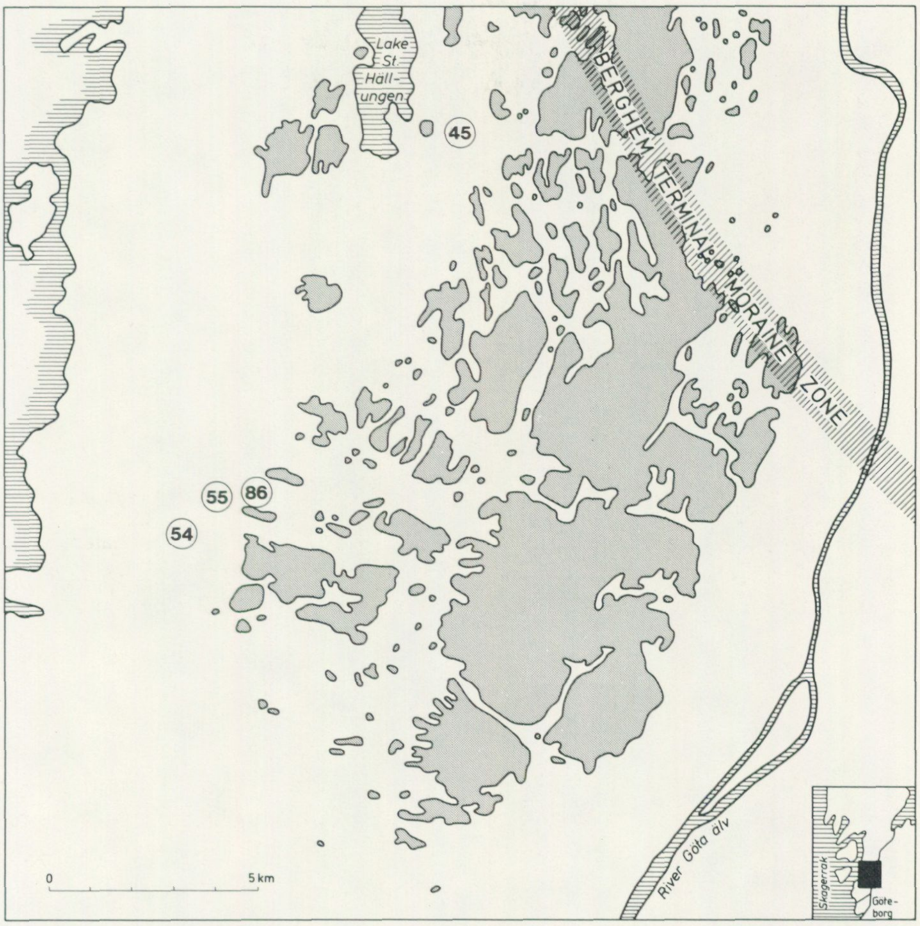

Fig. 39. The bedrock area between the west coast and Göta älv valley is characterized by fissure valleys. In the area shown, habitats of molluscs and barnacles have existed more or less continously from deglaciation (locality 45) to the end of arctic/boreal hydrographical conditions (locality 86) in southern Bohuslän. Grey areas are situated above the highest shoreline. From Fredén (1986b, 1987).

washing. According to the radiocarbon ages the clay in the lower and upper parts of the sequence has been deposited during a fairly short space of time. Between the two parts there is an interval of about 1 000 years, corresponding to a clay sedimentation 0.5 m thick.

55. Duvås 7B Göteborg NV 7d
(Fredén 1987)

Superficial shell-bearing sand on glacial clay about 60 m above sea level.

56. Agnesberg 7B Göteborg SV 2e
(Fredén 1975)

In 1925 skeletal parts of a white whale, *Delphinapterus leucas*, were found at a depth of 15 m in a clay pit at Steken brickyard. The clay was underlain by glaciofluvial sand and overlain by wave-washed sand. The thickness of the clay was about 10 m and its lowermost part consisted of 105 varves with shells of different species (Sandegren & Johansson 1931, pp. 126–128).

Shells have been sampled at a level of 60 m above sea level for radiocarbon dating (Brotzen 1961, pp. 145–146) giving an age about 1000 years younger than the white whale, see locality 56 B.

57. Ödsmåls mosse 7B Göteborg NV 5c
(Fredén 1987)

Shells of *Mya truncata* were collected in the remains of the shell-bank 350 m northwest of Ödsmåls mosse. The locality is situated about 65 m above sea level.

58. Granås 7B Göteborg SO 3f
(Fredén 1975, p. 23)

A jaw-bone of a Greenland right whale, *Balaenoptera mysticetus*, was found in 1970 in glacial clay at a depth

Fig. 40. Cut in the uppermost part of the Göteborg terminal moraine at Nylöse, locality 48. A=wave-washed gravel, B=gravelly till, C=clayey-gravelly till, D=grey clay which is shell-bearing at the bottom of the cut. Photo 1983.

of 4 m. According to corings, the clay thickness is about 20 m. The locality is situated almost 65 m above sea level in the Lövgärdet suburban area of Göteborg, cf locality 51.

59. Tuve 7B Göteborg SV 2d
(Adrielsson & Fredén 1987)

Shells have been collected by T.Påsse in shell-bearing sand on the Göteborg terminal moraine. The locality is situated 2200 m northeast of Tuve church at a level of about 70 m above sea level.

60. Rönnäng 7B Göteborg NV 6a
(Fredén 1987)

Shells of *Mya truncata* (sample A) and *Chlamys islandica* (sample B) found in the remains of a shell-bed in

Depth in m	Stratigraphy	Species	Radiocarbon age determinations St	Fraction 1	Fraction 2	Fraction 3	Corrected mean value
	Clay	G Mya truncata	7671 7672	10 445 ± 280	10 530 ± 230		10 520 ± 255
1	Clay	E Hiatella arctica Mya truncata Mytilus edulis	7673 7674	10 585 ± 270	11 000 ± 285		10 820 ± 280
	Clay	F Astarte borealis Hiatella arctica Mya truncata Balanus hammeri	7669 7670	10 455 ± 155	10 905 ± 300		10 710 ± 225
2	Silty and sandy clay	B Mytilus edulis Trophon clathratus	7679 7680	12 150 ± 195	12 170 ± 145		12 190 ± 170
3	Silty and sandy clay	D Fragments of Hiatella and Mytilus	7664 7665 7666	11 860 ± 260	12 010 ± 290	12 110 ± 140	12 005 ± 230
	Silty clay	C Shell fragments	7675 7676	12 105 ± 205	12 170 ± 145		12 145 ± 175
	Silty clay	A Shell fragments	7677 7678	12 020 ± 295	12 370 ± 145		12 205 ± 220

Fig. 41. Stratigraphy and radiocarbon age determinations of the Skagerrak clay sequence at Toröd, locality 54. The uppermost part is missing.

a narrow valley (Fig. 42) 1300 m northeast of Rönnäng church were collected for radiocarbon analysis. The diameter of the *Chlamys islandica* shells varied between 65 and 105 mm.

61. Svenshögen 8B Vänersborg SV 0e
(Fredén 1975, 21)

A rib fragment of a Greenland right whale was found at Bua in 1906 during the construction of the railway between Göteborg and Uddevalla. The locality is situated 50 m above sea level, 2 km SSE of Svenshögen.

62. Valla 7B Göteborg NV 8b
(Fredén 1987)

Large shells of *Chlamys islandica* (diameter between 80 and 100 mm) were sampled in shell-bearing gravel. The locality is situated about 45 m above sea level, 250 m east of Valla church.

63. Sillvik 7B Göteborg SV 1b
(Adrielsson & Fredén 1987)

In the remains of Sillvik shell-bank, 1800 m northwest of Torslanda church, shells of *Hiatella arctica* were collected for radiocarbon analysis. The locality lies about 30 m above sea level.

64. Skälebräcke 7B Göteborg SV 4e
(Adrielsson & Fredén 1987)

In the Skälebräcke district of Kungälv, 20 m above sea level, shells of *Mya truncata* were collected in a shell-bearing clay layer about 2 m below surface.

65. Funneshult 8B Vänersborg SO 3g
Fredén 1986a, p. 103

Shell fragments of *Hiatella arctica, Mya truncata, Mytilus edulis* and *Natica clausa* were dominant in shell-bearing layer at a depth of 50–60 cm in sand,

Fig. 42. Remains of the shell deposit in a narrow pass at Rönnäng, locality 60. The light colour on the bedrock slope marks the original extension of the shell-bed. Outcrop crosses the valley behind the car. View westwards. Photo 1981.

overlaying glacial clay. The locality is situated about 90 m above sea level.

66. Alekärr 7B Göteborg NV 5e
(Fredén 1987)

Shells of *Hiatella arctica, Mya truncata* and *Mytilus edulis* were found in shell-bearing layer in clay at a depth of 1 m. Particles of sand and gravel were common in the shell-bearing layer. The distance to a bedrock outcrop is about 10 m. The locality is situated 65 m above sea level, 1100 m south of Alekärr.

67. Äspered 7B Göteborg SO 2f
(Magnusson 1978, pp. 97–98, 146)

Shells of *Hiatella arctica* (sample A) and side plates of *Balanus balanus & Balanus crenatus* were collected in a shell-bearing clay layer, one metre thick, at a depth of 5 m in clay on the east slope of river Lärjeån. The locality is situated about 25 m above sea level.

68. Ödegårdshagen 8B Vänersborg SO 3f
Fredén 1984, pp. 68–69

Shells of *Mya truncata* were sampled in a 20 cm thick shell-bearing layer in clay at a depth of 2 m in a ditch. The locality is situated 90 m above sea level. Skeletal parts of a bearded seal, *Erignathus barbatus* have been found at the same locality.

69. Munkegärde 7B Göteborg SV 4e
(Adrielsson & Fredén 1987)

Shells of *Hiatella arctica* were sampled in glacial clay at a depth of 2 m. The surface lies 25 m above sea level.

70. Skallsjö ängar 7B Göteborg SO 2i
(Magnusson 1978, p. 103, 146)

Samples of *Hiatella arctica* were collected at three different levels in a one metre thick shell deposit, 48 m above sea level. It was overlain by 3.5 m sand and silt, underlain by clay. The locality is situated 350 m downstream the bridge at Brobacken, locality 84.

71. Alebräcke 7B Göteborg NO 5g
(Fredén 1986b)

Shells of *Mya truncata* dominated a 5 cm thick shell-bearing layer in clay about one metre below surface, which lies 60 m above sea level.

72. Skörbo 8A Lysekil NO 8j

Shells of *Mya truncata* were sampled by Per Adrielsson in clay 2.5 m below surface, which lies 35 m above sea level. The vertical wall was exposed due to the "Bärfendal landslide" which occurred on December 28th, 1977.

73. Kareby 7B Göteborg NV 5d
(Fredén 1987)

Digging a well exposed thin shells and shell fragments of molluscs which were sampled 2 m below surface in clay. *Astarte elliptica* dominated the fauna. The locality lies 20 m above sea level, 1900 m WNW of Kareby church.

74. Hjällbo 7B Göteborg SO 2f
(Magnusson 1978, pp. 74–75, 146)

A clay 3 m thick covering the easternmost glaciofluvial deposit in the valley of river Lärjeån, south of Hjällbo contained layers of shell fragments in the upper part. The locality lies about 30 m above sea level and is situated about 600 m east of locality 49.

75. Ramsdalen 7B Göteborg NV 9b
(Fredén 1987)

Shell fragments have been collected in the remains of a shell-bank. The locality lies 40 m above sea level, 200 m west of Ramsdalen, on the east side of the highest part of a valley orientated east–west.

76. Lökeberg 7B Göteborg NV 5c
(Fredén 1987)

Shell fragments of shell-bearing clay were sampled 200 m southwest of the eastern part of Lökebergs mosse. The locality lies about 40 m above sea level. Shells and shell fragments occur in the upper part of the clay within an area of 500 square metres.

77. Ormdal 8B Vänersborg NV 7a
(Fredén 1982b, p. 34)

Shells and shell fragments were sampled in the remains of a shell-bank about 75 m above sea level.

78. Skändla 7B Göteborg SV 2d
(Adrielsson & Fredén 1987)

Shells of *Mya truncata* were collected in the eastern part of the remains of the shell-bank at Skändla. The highest part of the shell-bank lies almost 40 m above sea level.

79. Mareberg 7B Göteborg SO 4f
(Magnusson 1978, p. 103, 146)

Shells of *Hiatella arctica* were sampled in a shell-bearing sand, about one metre thick, overlaying glacial clay. The locality lies 11–12 m above sea level in the valley of the river Göta älv, south of a bedrock hill extending 60 m above sea level.

80. Göddered 7B Göteborg SV 4e
(Adrielsson & Fredén 1987)

Shells of *Hiatella arctica* were sampled in shell-bearing sand about one metre below surface. The locality lies about 10 m above sea level. The distance to locality 79 is about 4 km.

81. Koholmen 7B Göteborg SV 4a
(Adrielsson & Fredén 1987)

Shells of arctic-boreal species are found at the surface of the sea water close to the steep bedrock slope north of the island Koholmen, cf. locality 82.

82. Björnängen 7B Göteborg NV 5a
(Fredén 1987)

Shells of molluscs were sampled in shell-bearing sand, about one metre thick, overlaying bedrock. The locality lies 30 m above sea level, 600 m ENE of Björnängen. The distance to the southwards situated locality 81 is 400 m.

83. Bleket 7A Marstrand NO 6j
(Fredén 1987)

Shells of *Mya truncata* were sampled 1.5 m below surface in a 5 cm thick shell-bearing layer in clay. The locality lies about 15 m above sea level in the east ditch of road 169, 1 km northeast of Bleket church.

84. Brobacken 7B Göteborg SO 2i
(Magnusson 1978, 103, 146)

Shells of *Hiatella arctica* were sampled from the riverbank of Säveån at Brobacken, downstream the small bridge. The locality lies about 45 m about sea level and is situated 350 m upstream locality 70.

85. Petersborg 7B Göteborg NV 8b
(Fredén 1987)

Shells of *Mya truncata* were sampled in the remains of a shell-bank (Fig. 43) about 50 m above sea level.

Fig. 43. Overgrown remains of the Petersborg shell-bank, locality 85. View westwards, i.e. the deposit lies as a terrace shaped cone on the east side of a bedrock ridge, cf. Fig. 45. Photo 1986.

86. Rörmyren 7B Göteborg NV 7d
(Fredén 1987)

Shells of *Mya truncata* were sampled 0.5 m below surface in a shell-bearing layer in clay. The locality is situated 60 m above sea level in a pronounced and narrow valley. The distance to locality 55, Duvås, in the same valley, is about one kilometre.

87. Slätta damm 7B Göteborg SV 1d
(Fredén 1975, p.30)

Skeletal parts of a white whale, *Delphinapterus leucas*, have been found 2.45 m below surface in a shell-bearing layer in clay. The surface is situated almost 30 m above sea level.

Genesis of the shell deposits

The occurrence of shells and shell deposits, and the implications for deglacial and hydrographical conditions they provide, will be discussed here.

The genesis of the shell-banks in northern Bohuslän, as well as succession and migration intensity of molluscs and barnacles, has been treated by Hessland in his classical work in 1943. The main features of the palaeogeographical conditions of the Bohuslän coastland, which is exposed to Skagerrak, are not directly comparable to those of the strait and inland sea areas of the Vänern basin.

The zoologist Nils Odhner (1885–1973) achieved much in his explanation of the shell-banks at Uddevalla such that the essential features are still valid after half a century. Naturally, the use of methods of absolute dating and more knowledge of the Late Quaternary evolution and of the faunal composition of the shell-banks have added some modifications.

Background

The isostatic effect of deglaciation had been proved by De Geer and was accepted in the beginning of the twentieth century (see Fredén 1979, p. 63). The principles of the eustatic changes were still unknown. De Geer and his pupil, Ernst Antevs, interpreted the stratigraphy of the shell-banks in northern Bohuslän and in Uddevalla in a way that almost completely changed the established opinion of the Late Quaternary evolution.

Based on his extensive experience of the living conditions of recent arctic molluscs, Odhner (1918) raised severe objections to the conclusions reached about level changes that Antevs (1917) had presented in his thesis. Antevs theories probably were intended to be revolutionary, and so they were, but in a different way. The theories of repeated subsidence and uplift were in the main based on the stratigraphy of the shell deposits. Antevs (1918, 1921, 1928) persisted in his opinion, which was also adopted by Cleve-Euler (1926) to a certain degree.

In 1927, Odhner made a critical review of the theories of the shell-banks at Bräcke, Kuröd and Kapellbacken. Three years later an article appeared in a popular science magazine. His convincing submission of evidence against his three opponents will be left to speak for itself. As an introduction to the discussion part of this paper, Odhner's well-founded theory about the genesis of the shell-banks is given in brief below.

The Odhner interpretation of shell deposits in the Uddevalla area

Odhner (1918) raised two crucial questions; which circumstances have caused the great thickness of the shell-banks and why are they attached to the Uddevalla area? As to thickness and areal extent no equivalent area was known in Scandinavia. Thus, exceptional conditions must have prevailed in the Uddevalla area.

On a basis of De Geer's (1910b) survey map of submerged areas in Late Weichselian times, Odhner showed that an archipelago had divided the Vänern basin from the Ocean. The main melt water masses from the retreating ice were discharged into the Ocean through straits in the archipelago. Due to land uplift, the straits became narrower and fewer. The widest strait was situated between Uddevalla and Vänersborg. A strong surface current of fresh or brackish water had passed through this strait. The surface current caused the bottom current of sea water to flow into the Vänern basin.

Animal life was favoured by the currents. It was characterized not only by an arctic shallow water fauna, but also by a boreal-arctic deep water fauna. The ecological and hydrographical conditions included a rocky bottom with a low rate of sedimentation, a fairly high salinity, and a comparatively low temperature. The main part of the shell-banks was composed of shells, which were eroded, often fragmentary, and lay disordered in layers with a certain dip. United bivalve shells implied an autochtonous sedimentation. The majority of the shells had been washed down from the surrounding hills by waves.

According to Odhner, the fauna was independent of the bathymetrical conditions. The hydrographical and ecological conditions were the determining factors which were at hand as soon as the deglaciation influence on the area had ceased, the sedimentation of glacial clay particles was finished and the outlined current pattern had arisen. The conditions lasted until the water circulation was obstructed by land uplift and the saline (recurrent) bottom current to the Vänern basin ceased. During this time the faunal composition in the area remained stable.

All the shell-banks with an arctic and arctic/boreal fauna had already been formed, irrespective of their levels relative to the sea, when the strait between Uddevalla and Vänersborg ceased to exist.

Odhner explained that the optimal conditions in the Uddevalla region for the marine fauna were related to the drainage of the Baltic Ice Lake at Billingen Hill. Odhner ends his bulky comprehensive survey and methodical submission of evidence of the genesis of the shell-banks by expressing a desire for absolute datings in the future.

Absolute datings presented in this paper have not tied the fauna to any specific event. Ecological conditions were favourable to habitats during a time span of 1500 years in the Uddevalla area. The main theme of Odhner's theories about the genesis of the shell-banks is still valid. However, details of the hydrographical environments must be adjusted as chronologically described below.

Palaeogeographical notes of the North Sea area

Hydrographical conditions along the Swedish west coast have been influenced by the development of the North Sea basin. Knowledge of the deglaciation pattern of the North Sea basin is incomplete. Tentative models can be corrected, thanks to much information gleaned from progressive explorations for petroleum and natural gas, as well as from other investigation, e.g. OSKAP (Oslofjord–Skagerrak project).

During the Weichselian glaciation the sea surface was lowered about 90 m, leaving large parts of the North Sea basin as land, occupied by or free from land-ice. Great Britain was part of the European continent until Holocene times, when the strait of Dover became submerged. Even deglaciated parts of Sweden belonged to the European continent up to Holocene times. The Late-Quaternary development of the Norwegian Trench (Fig. 6) is of great relevance to the palaeohydrography along the Swedish west coast. The threshold area of the Norwegian Trench may have been affected by land uplift to a small degree. The highest shoreline on the coastland of Jaeren is situated 7–8 m above sea level (Andersen 1965, p. 127). Thus the minimum water depth in the threshold area has been about 180 m (present depth 270 m minus the lowering of 90 m during the Pleistocene).

Due to combined effects of isostatic and eustatic changes water depth decreased along the Swedish west coast, because of dominating land uplift, and increased in the North Sea basin due to transgression.

The development of the submarine area south of Stavanger has been studied by the Oslofjord-Skagerrak project group – see special volume of Norsk Geologisk Tidsskrift 66, 1–149. Various analyses of microfossils in core 15530-4 indicate that Skagerrak retained a fjord-like shape until about 10 000 years ago. About 1500 years later the English channel was opened (Jelgersma 1979).

The biostratigraphic boundary between Younger Dryas and Preboreal recorded at a depth of slightly more than 6 m in the core, coincides in age with a change from cold to temperate water conditions, (10 200 years B.P. according to pollen analyses). Shell fragments of *Hiatella arctica* and *Macoma calcarea* at a depth of 8 m were some hundred years older in radiocarbon years (Stabell 1985).

Palaeoenvironments of marine faunas

Faunal composition of subfossil shell deposits cannot be directly compared to recent assemblages. Similar ecological conditions to those present during the deglaciation, vital for corresponding studies, are lacking in today's environment. The results and interpretations of the environments of southwestern Sweden during Late Quaternary times can be compared with past and present conditions along the Norwegian coast.

Environmental indicators of glaciomarine faunas have been investigated using sediments of the continental shelf off northern Norway by Thomsen & Vorren (1984) and by Vorren *et al* (1984). The bio- and lithostratigraphy as well as the ecological interpretations of the microfauna, can be applied to the Quaternary sediments in southwestern Sweden.

Studies of recent sediments and distribution of foraminifers along the Norwegian coast have shown that faunal assemblages in surface sediments are related to specific hydrographical conditions of bottom water rather than to water depth (Qvale 1981). The distribution pattern of foraminifer assemblages is related to variations in salinity, temperature, and oxygen content (van Weering & Qvale 1983, p. 95). Different assemblages are associated with specific water masses. Similar living conditions are valid for mollusc assemblages.

Stable long-term hydrographical conditions – temperature, salinity, clearness, currents – are essential factors for mollusc habitats. The living conditions also depend on the combination of specific environmental factors – depth and nature of bottom – and the adaptive powers of the faunal elements concerned. Stable conditions include annual fluctuations of temperature, salinity, and currents. Accidental and short-term variations may temporarily have influenced the habitats. The bathymetrical conditions determine the hydrography, which means that the hydrographical changes differ from one locality to another.

The currents during the deglaciation seems to have been the most decisive factor in the establishment of marine fauna habitats. The importance of current influence during ice retreat and standstills is related to the distance from the ice front and to sea conditions in Skagerrak (Fig. 44). According to biostratigraphy and radiocarbon age determinations, it seems that marine life was unfavoured by pronounced stagnation periods of the ice front and by rapid melting.

At a standstill, the unfavourable environmental factors for a benthic fauna were mainly cool and turbid water, low bottom-current energy, and shelf-ice formation in sheltered and shallow areas. Assemblages and species of micro- and macrofaunas migrated to areas with a more favourable environment. A decrease in the number of habitats is to be expected during such conditions.

A rapid ice retreat caused tremendous discharge of meltwater, strong currents, and a large amount of particle sedimentation. Away from this proximal part of the deglaciation process, ecological conditions were

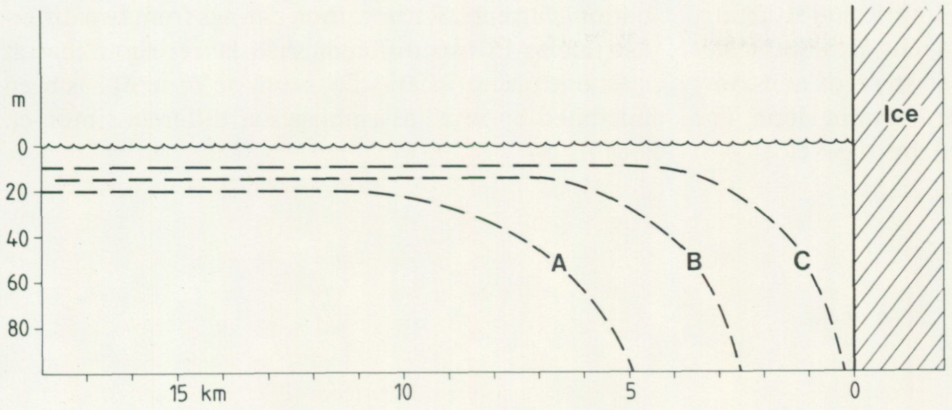

Fig. 44. Estimated positions of the saline front at rapid (A), moderate (B) and slow (C) ice retreat.

favoured by reaction currents containing high oxygen content and salinity.

Temporary breaks would influence environmental conditions so that incidental migrations of molluscs could take place.

The shell deposits show that the hydrographical conditions during deglaciation have favoured mollusc habitats. Faunal migration close to the ice front is documented from stratigraphic investigations of clay sequences in Sweden. Subfossil finds of shell valves in the lowermost part of glacial clay are not uncommon. Shells or shell fragments of bivalves are also known from localities close to the level of the highest shoreline. Early habitats in an almost lifeless bottom represent isolated outposts that fell victim, directly or indirectly, to changed hydrographical conditions caused by climatic fluctuations and land uplift.

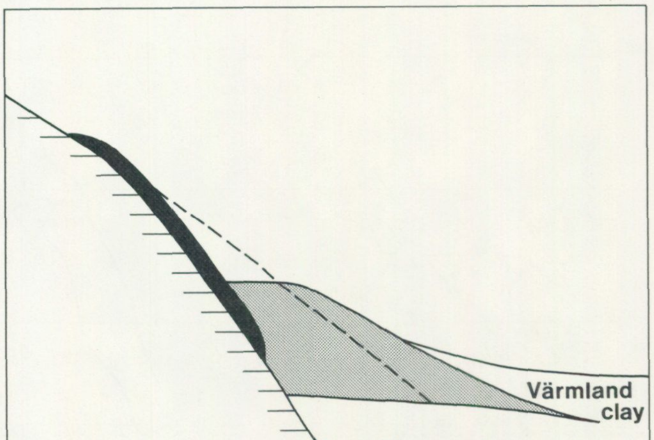

Fig. 45. Essential features of a shell-bank (grey) formation in the Uddevalla area. Littoral processes have transferred an originally cone formed deposit (broken line) to a terrace. The spreading out of shells at the base stands in relation to the downward transportation of shells, which is dependent on bathymetrical conditions. These factors give an idea of the living range of the habitats (black). In places different faunas can have existed contemporaneously at different depths.

The position of a shell-bank reflects the environment favoured by the marine fauna which have produced the calcarous components of the deposit. Most of the shells from mollusc assemblages are not found *in situ*. Most of the shell-banks have a very limited extension. The shells have not been transported far but are closely related to the bedrock slope on which the habitat existed. The horisontal spread is in proportion to the thickness of the originally cone-formed deposit (Fig. 45). This means that the species present cannot provide specific indications of e.g. water depth. Furthermore, the shells represent a mixed fauna in the deposit, though the species may not be contemporaneous. If they are contemporaneous they may have had different requirements of depth, salinity, and temperature. Radiocarbon age determinations and stratigraphical data have shown that ecological conditions have been favourable to different faunas at different times at the same place. Thus the shells in a shell-bank can comprise a mixture of different habitats. The statement above is based upon locality 7 in the Uddevalla area and locality 24 in the area south of Lake Vänern. Judging by radiocarbon determinations carried out on sampled shells from a limited region, one may assume that almost all the shell-banks consist of shells of different habitats and different ages. Shells have also been moved by wave action implying a mixture of different faunas.

Shell layers in clay reflect a habitat of a limited occurrence in space and time. Two types of shell layers in clay occur. One consists of vertically or almost vertically standing complete bivalves with a small amount of particles of sand and gravel. This habitat has been buried alive by clay particles and the shells are autochthonous. The other type consists of valves, shell fragments, and particles of sand and gravel. Sometimes the position of the valves indicate an imbricated structure, caused by bottom currents. The shells are allochthonous and have been transported downwards and away from a nearby bedrock hill or hard bottom slope. The transport distance is determined by the velocity of bottom currents. Radiocarbon datings from two different faunas in two different shell layers show that at least one place, (locality 26, south of Vänern) has been inhabited by small assemblages at different times, cf. locality 54.

Correlation of mollusc assemblages with deglaciation evolution

During the regular mapping of Quaternary deposits in western Sweden, samples of shells with an arctic-boreal character have been radiocarbon age determined. Details are given in Table 2. All the localities, including those from documented reports and from the literature, are shown in Fig. 46. The radiometric analyses are graphically reproduced in Fig. 59.

All known shell deposits have not been reinvestigated. For further details about finding localities, the reader is referred to the descriptions of the geological map sheets Marstrand SO/Göteborg SV (Adrielsson & Fredén 1987), Göteborg SO (Magnusson 1978), Marstrand NO/Göteborg NV (Fredén 1987), Göteborg NO (Fredén 1986b), Vänersborg SO (Fredén 1984), and Vänersborg NO (Fredén 1974).

The development of submerged areas deals with deglaciation chronology and hydrographical conditions. Dating of the deglaciation described is a problem due to lack of correlatable varved marine deposits. Radiocarbon dating of marine shells and skeletal parts of vertebrates verifies the time when marine conditions prevailed at the locality of the specific find. It is important to know the position of the ice-front at the time when the dated organism was alive.

In the following discussion of the deglaciation chronology, emphasis will be placed on radiocarbon age determinations and biostratigraphy based mainly on shells. A subjective opinion based on uncertain factors leaves the field open to alternative interpretations. Separate localities form a pattern when they are put together, and it is this pattern that forms the basis of the discussion.

Environmental conditions for mollusc habitats during deglaciation differ from time to time and from one place to another. Depending on several factors, hydrographical conditions can be favourable at one place and unfavourable at another. It has not yet been possible to draw any conclusions of general application to the formation of shell deposits.

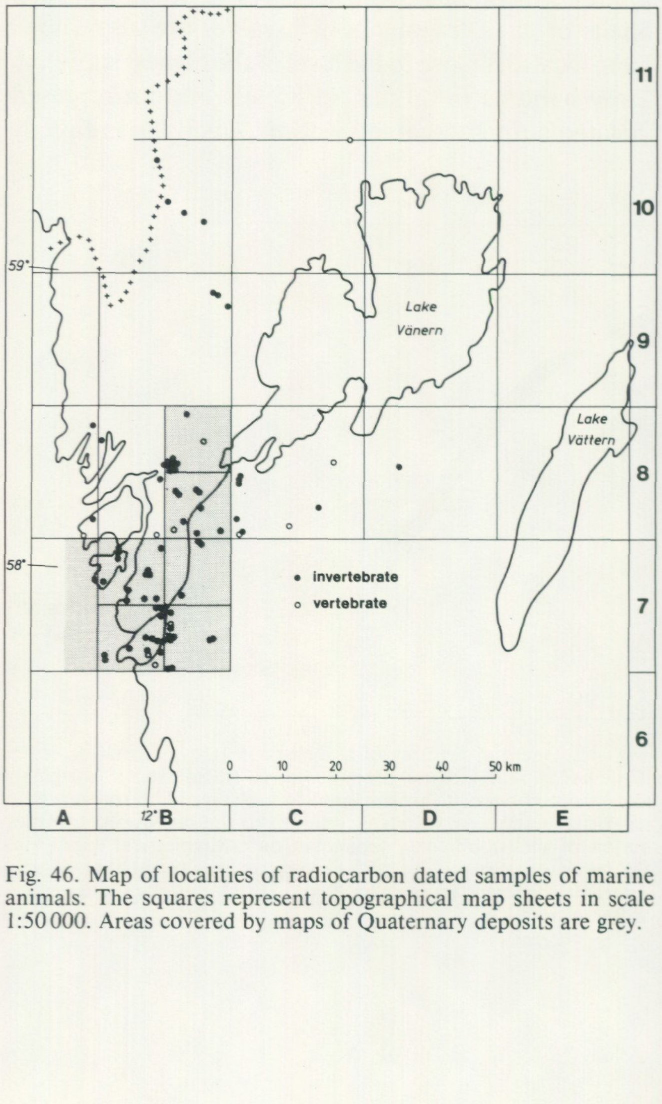

Fig. 46. Map of localities of radiocarbon dated samples of marine animals. The squares represent topographical map sheets in scale 1:50 000. Areas covered by maps of Quaternary deposits are grey.

Litho- and biostratigraphic record of the clays

Comprehensive investigations of clay sequences on the west coast have been carried out by a group of experts (Olausson 1982). Clay sequences of the Tuve landslide, 5 km north of Göteborg, have also been studied by Fredén *et al* (1981). The results are compared to other investigations made in the area and in the river Göta älv valley.

Clay sequences of the southern part of the Vänern basin have been studied by Dennegård (1984).

A general trend shown in the results is that the upper part of the sequence contain a high clay content and is devoid of mega fossils. Colour modulations due to organic matters occur in stripes in the greater part of the sequence. The lowest part has up to 50 varves or varvelike structures.

The same characteristics are true for the clays in the northern part of Vänern. However, the whole sequence is barren or almost barren of fossils. Clay samples for foraminifer analysis have been collected coincidentally at different depths of construction works. No foraminifers have so far been found.

Both clays are of glacial origin. Clay barren of fossils and containing a relatively large proportion of clay particles in the uppermost part dominate the northern part of the basin, while clay with fossils and shell-bearing layers dominate in the southern part (see Fig. 9).

In order to distinguish between these two glacial clays they have been named Skagerrak and Värmland clay respectively. The Skagerrak clay is found in the southern part of the Vänern basin and along the west coast. It was deposited during a relatively slow ice recession. The prevailing conditions created a favourable environment for mollusc habitats. Usually the shells and shell fragments are mixed with particles of sand and gravel. The bio- and chronostratigraphy of a Skagerrak clay is shown on Fig. 9, cf Fig. 41.

The Värmland clay was formed during a rapid ice recession caused by amelioration of the climate. The hydrographical conditions – fresh, cool, turbid waters, together with a heavy sedimentation of clay particles – created an unfavourable environment for a marine fauna in the Vänern basin. The principal cause of the fossil barrenness is thus the climatic change, which had an adverse influence on the marine fauna in the Vänern basin. Along the coasts of Bohuslän, the sedimentation rate was much slower and arctic–boreal mollusc habitats could still live in places. Thus, the Värmland clay along the western coast is not barren of fossils, though the frequency of arctic/boreal species is low. Because of inflowing temperate ocean water, a boreal fauna inhabits that area, while still arctic/boreal conditions prevailed in the Vänern basin.

The origin of clays devoid of fossils have been discussed by many scientists. One opinion is that sediments with a low carbonate content are due to an intensified vertical water circulation causing a high rate of dissolution (Olausson 1981). Another is that the environment has been unfavourable towards benthic organisms (e.g. Vorren *et al* 1984).

The high clay content in the upper part of the Värmland clay is explained by a heavy supply of fine clay particles. Strong meltwater currents have transported the fine particles over long distances before they flocculated and settled.

The thickness of the clays and of the terminal moraine deposits stand in glaring contrast to the extensive occurrence of bare bedrock in southwestern Sweden.

Ice recession as implied by radiocarbon datings of marine mega fossils

A picture of the deglaciation conditions up to the Late-Quaternary development of the Uddevalla region and the Vänern basin, which started with the ice retreat from the Berghem terminal moraine, is given in short. During the deglaciation of Denmark, sea conditions prevailed south of the Norwegian trench. Shells of *Hiatella (Saxicava) arctica* in the so-called *Saxicava* layers in Vendsyssel and on the island of Laesö (Fig. 6) give radiocarbon ages of more than 13 000 years (Krog & Tauber 1973, Petersen 1984). Molluscs inhabited waters of the Swedish west coast shortly after deglaciation (Fig. 47).

The age of the Göteborg terminal moraine has been discussed by Berglund (1979) and Hillefors (1975). Berglund's dating of the Göteborg terminal moraine, 12 800–12 600 B.P., is supported in this paper (Fig. 59).

The stratigraphy of localities 46, 48–50, suggests an ice readvance, which has influenced the uppermost layer of the deposits. The traces of a readvance is thus moderate. An idea of a surging glacier in the relatively deep and broad valley of river Göta älv is not unlikely.

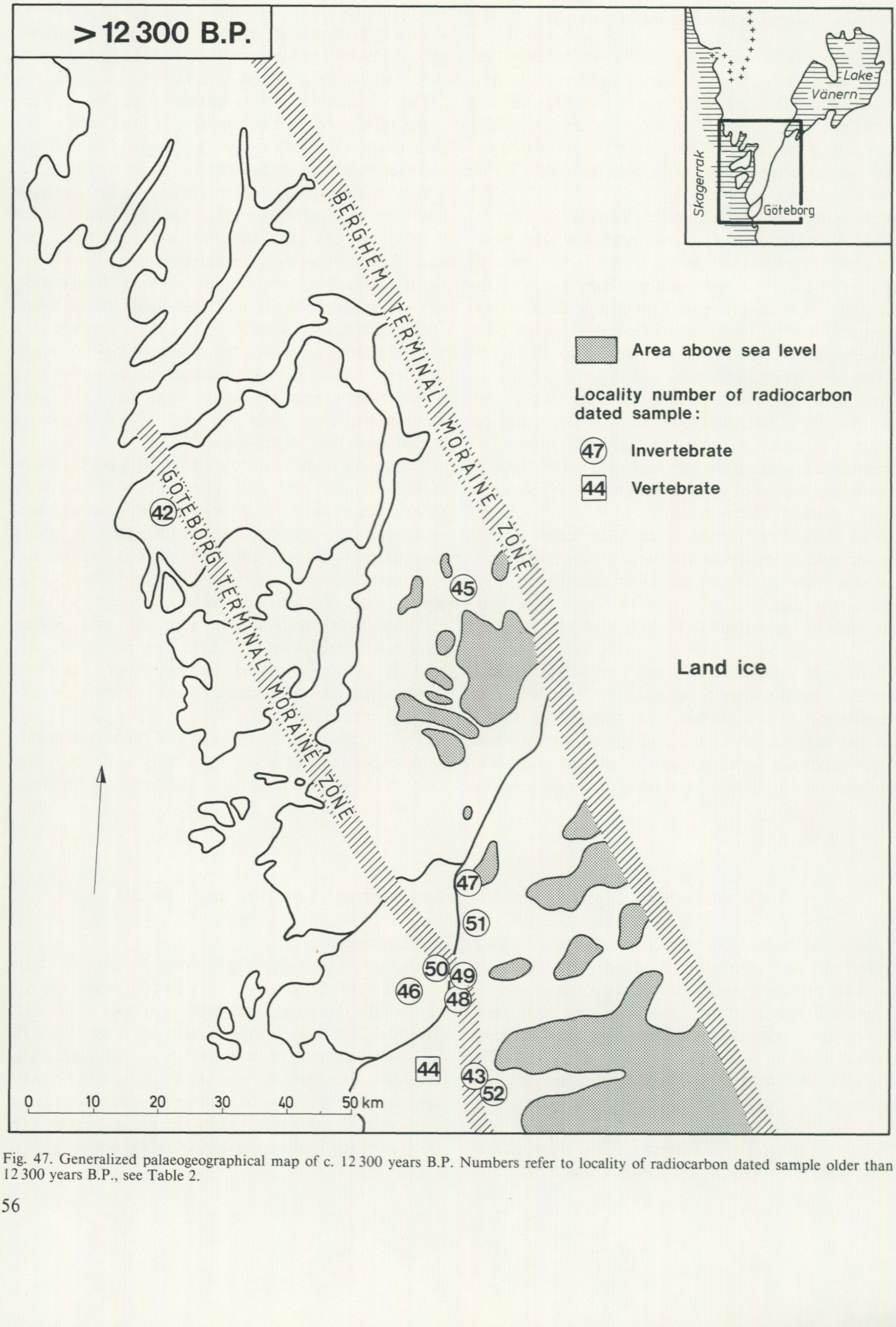

Fig. 47. Generalized palaeogeographical map of c. 12 300 years B.P. Numbers refer to locality of radiocarbon dated sample older than 12 300 years B.P., see Table 2.

Before 12 400 years B.P.

The deglaciated parts formed an archipelago. The geographical position of radiocarbon dated samples in relation to the Berghem terminal moraine zone is shown in Fig. 47. Berglund (1979) dates the ice retreat from the terminal moraine to 12 400 years B.P. Locality 45 contributes to the chronology discussion. The molluscs of the dated shells lived fairly close to the ice front as the shells are deposited in a varved silty clay and below a relatively homogeneous glacial clay. Considering the mean values of the dated samples it seems proper to revise Berglund's figure to 12 300 years B.P. On the other hand the fauna lived close to open sea, which had a strong influence on the ecological conditions at that time.

12 300–11 800 years B.P.

All known shell deposits southwest of Lake Vänern have not been radiocarbon age determined (Fig. 48). Samples for absolute dating have been chosen more or less randomly. Whether or not it is by pure chance that no radiocarbon data exist for the time interval between 12 000 and 11 800 years B.P. (Fig. 59) is not known. More localities with an arctic-boreal fauna composition should be investigated along the Swedish west coast. At the moment one may note that there is a decrease in the amount of data available at the time when a marginal moraine is supposed to have been forming.

The absence or scarcity of subfossil finds reflect unfavourable environments for a marine fauna. During this time interval, the archipelago extended. During a pronounced stagnation of the ice front, a shelf ice may have formed, influencing the fauna in an unfavourable way.

Berglund (1979) suggests that the Trollhättan terminal moraine was formed 12 250–12 150 years B.P. and the Levene terminal moraine 12 000–11 800 years B.P. As regards the occurrence of the marine fauna, the formation of the Trollhättan terminal moraine at 11 900–11 800 years B.P. seems more likely.

The distance between the Berghem and Trollhättan terminal moraine zones is about 20 km; between the Berghem and Levene terminal moraine zones about 45 km, in the southwestern part of the Vänern basin. The following calculations can be made according to Berglunds proposal (see Fig. 49). The rate of ice recession from the Berghem to Trollhättan terminal moraine zone – 20 km in 100 years – gives a mean value of 200 m/year; from the Trollhättan to Levene terminal moraine zone – 25 km during 150 years – gives an average rate of 167 m/year. Within a time span of 350 years there has been a rapid ice front retreat and a stagnation of about 100 years duration.

An alternative proposal considers an ice-front retreat of 20 km during 350 years, which is equal to a mean value of 57 m/year (Fig. 49). The hydrographical requirements for marine animals are well met by such a slow ice recession, e.g. clearness and salinity.

The highest shoreline on the steep-sided table hill of Hunneberg lies 133–134 m above sea level according to Digerfeldt (1979). The investigations on Hunneberg were later supplemented and expanded upon by Björck and Digerfeldt (1982a and b) so as to comprise 15 lakes at different levels. This lead to the construction of a shoreline displacement curve between 134 and 91 m above sea level (Fig. 22). The results and interpretations of these investigations are important for the discussion of the Late Pleistocene development of western Sweden. A brief summary of the investigation is essential for the discussion.

The highest situated marine sediments – brackish clay gyttja with thin silty layers – were recorded in Lake Domsjön at a depth of 12 m. The water-level of the lake is about 5 m below the highest shoreline. Three bulk samples of the clay gyttja yielded radiocarbon ages of about 12 400 years (Digerfeldt 1979). The age was surprisingly old when compared to the pollen-analytical data. Only a small area of Hunneberg lies above the highest shoreline.

The locality was later re-investigated by Björck and Digerfeldt (1982a). Samples of coarse organic matter yielded radiocarbon ages of 11 600–11 900 years. Shell fragments of *Mytilus* were sampled in clayey silts in two lake basins, Kroppsjön, locality 15, and Ekelunds Gransjö, locality 16, at altitudes of 122 and 119 m above sea level (Björck & Digerfeldt 1982b). The radiocarbon ages of *Mytilus*, obtained 11 800–11 600 B.P. (Håkansson 1982), were about the same as the coarse organic matter from Lake Domsjön. According to Björck & Digerfeldt (1982a, p. 402) the radiocarbon datings support Berglund's chronological proposal for the formation of the Trollhättan terminal moraine, about 12 200 years ago, and of the Levene terminal moraine, 12 000–11 800 years B.P. ago.

If, however, the present assumption namely that the Trollhättan terminal moraine was formed 11 900–11 800 B.P. is correct, there are possibilities for a mollusc habitat on Hunneberg some hundreds of years later in accordance with Björck and Digerfeldt's radiocarbon age determinations. The table hill may have been deglaciated somewhat earlier than the surrounding flatlands.

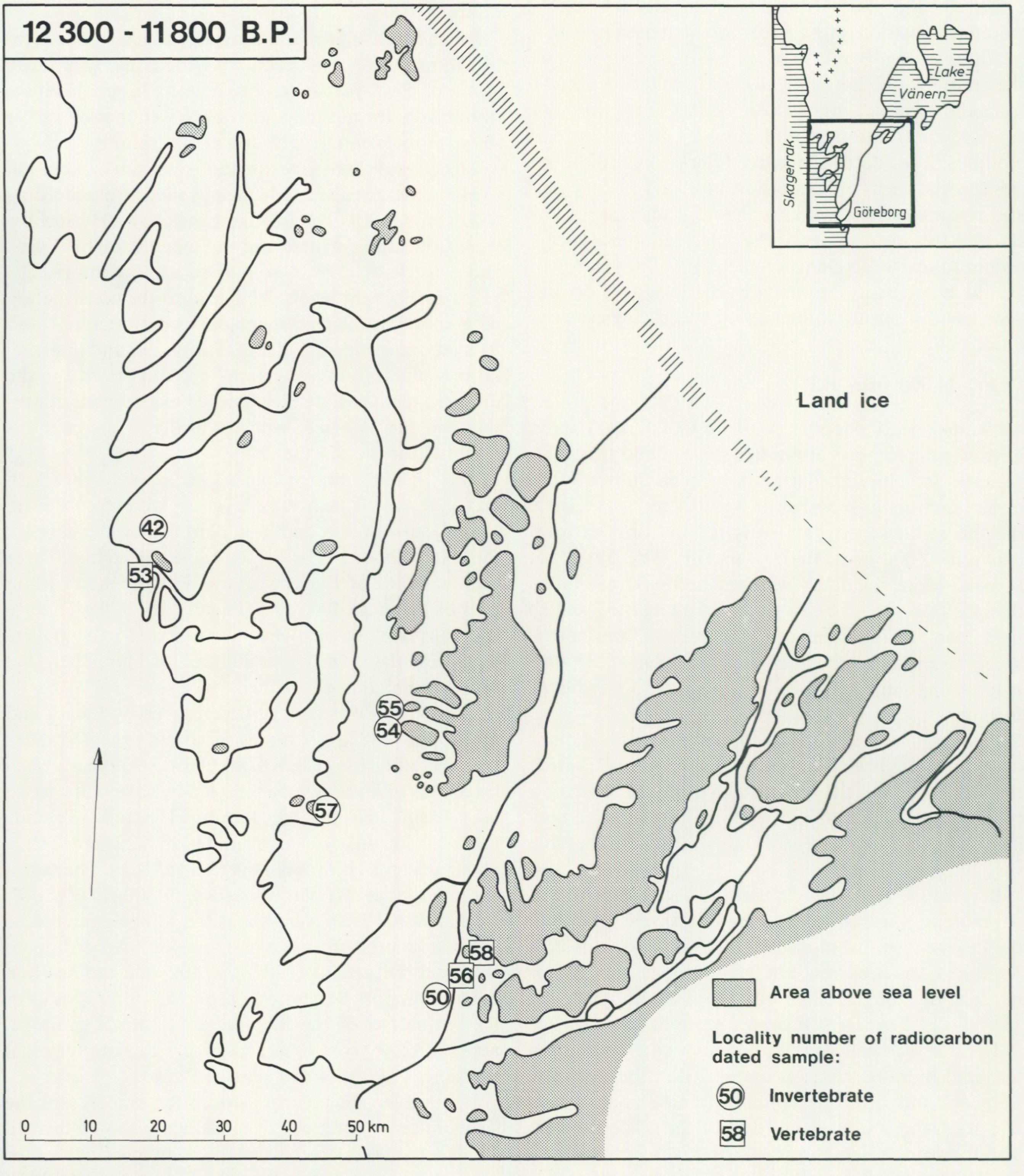

Fig. 48. Generalized palaeogeographical map of c. 11 800 years B.P. Numbers refer to locality of radiocarbon dated sample with mean value between 12 300 and 11 800 years B.P., see Table 2.

The bathymetrical conditions and the westerly exposition are suitable for an early colonization. The distance between the localities of finds on Hunneberg and the Trollhättan terminal moraine zone is about 5 km.

West of Hunneberg, the deposits of the Trollhättan terminal moraine are discontinuous. This feature suggests that the table hills of Halleberg and Hunneberg were obstacles for ice movement during the final phase of deglaciation; it also speaks for a relatively early deglaciation of the highest parts of these hills. This would have created a bay with suitable hydrographical conditions for mollusc assemblages, exposed to marine conditions with a relatively sheltered position from meltwater with a high content of clay particles. *Mytilus edulis* is known as one of the pioneer molluscs in the region (cf. Hjort & Funder 1974).

11 800–11 300 years B.P.

When the land-ice recession continued from the hills of Halleberg and Hunneberg, the broken morphology of an archipelago was replaced by a rather flat morphology providing a large water body with a width of 70 km and depths of 70–100 m. The western land areas of the archipelago increased gradually while the straits become fewer and narrower (Fig. 50). Thus the deglaciated part of the Vänern basin became an inland sea.

According to the present proposal, the average rate of ice retreat between Trollhättan and Levene terminal moraine zones was 62 m/year (Fig. 49).

The Levene terminal moraine is almost continuous across the whole Vänern basin. Assuming that the age determinations of the Trollhättan and the Skövde terminal moraines are correct (see below), the age of the Levene moraine lies between 11 800 and 11 000 years. The radiocarbon datings in Fig. 59 show a gap in the datings from localities south of Vänern at about 11 400 years. Up till then only four localities are known, 15–18, two on Hunneberg and two south of Hunneberg – molluscs from Iglabäcken and a bearded seal from Lagmansered (Fig. 20).

It appears that there was a change in the hydrographical conditions about 11 300 years B.P. after which mollusc habitats became relatively common in the then existing archipelago and in the area south of Vänern (Fig. 51).

Seemingly it follows that the Levene terminal moraine was formed 11 400–11 300 years ago.

11 300–11 000 years B.P.

The ice retreat from the Levene terminal moraine to the Skövde terminal moraine zone lead to the establishment of mollusc habitats at a distance of at least 20 km from the ice front (Fig. 51). The most interior finds are those at Stadsängen (locality 1), Eldmörjan on Hunneberg hill (locality 21) and Essunga (locality 30). The oldest known shell deposit at Uddevalla (locality 2) indicates that the strait area was now inhabited contemporaneously with a relatively rich fauna southwards. At the time water depths of the highest-situated localities of habitats were about 10 m or less, signifying saline water at or close to the surface.

Both the discharge of melt water and sedimentation of clay particles have been fairly moderate during the ice retreat from the Trollhättan to the Skövde terminal moraine (cf locality 54).

	Göteborg		Berghem		Trollhättan		Levene		Skövde		Billingen		Karlstad	TERMINAL MORAINES
		25		20		25		20		13		110		Distance in km
Berglund	200	150	100	100	100	150	200	900	300	200	200			Duration in years
Fredén			100	350	100	400	100	300	200	450	100	250	100	
Berglund		167		200		167		22		(18)				Ice recession in m/year
										oscillations				
Fredén				57		62		67		(17)		440		

Fig. 49. Calculations of deglaciation rates east of Lake Vänern, half the distance on the west side. Calculations are based on a line drawn SSE of Hunneberg perpendicular to the terminal moraine zones.

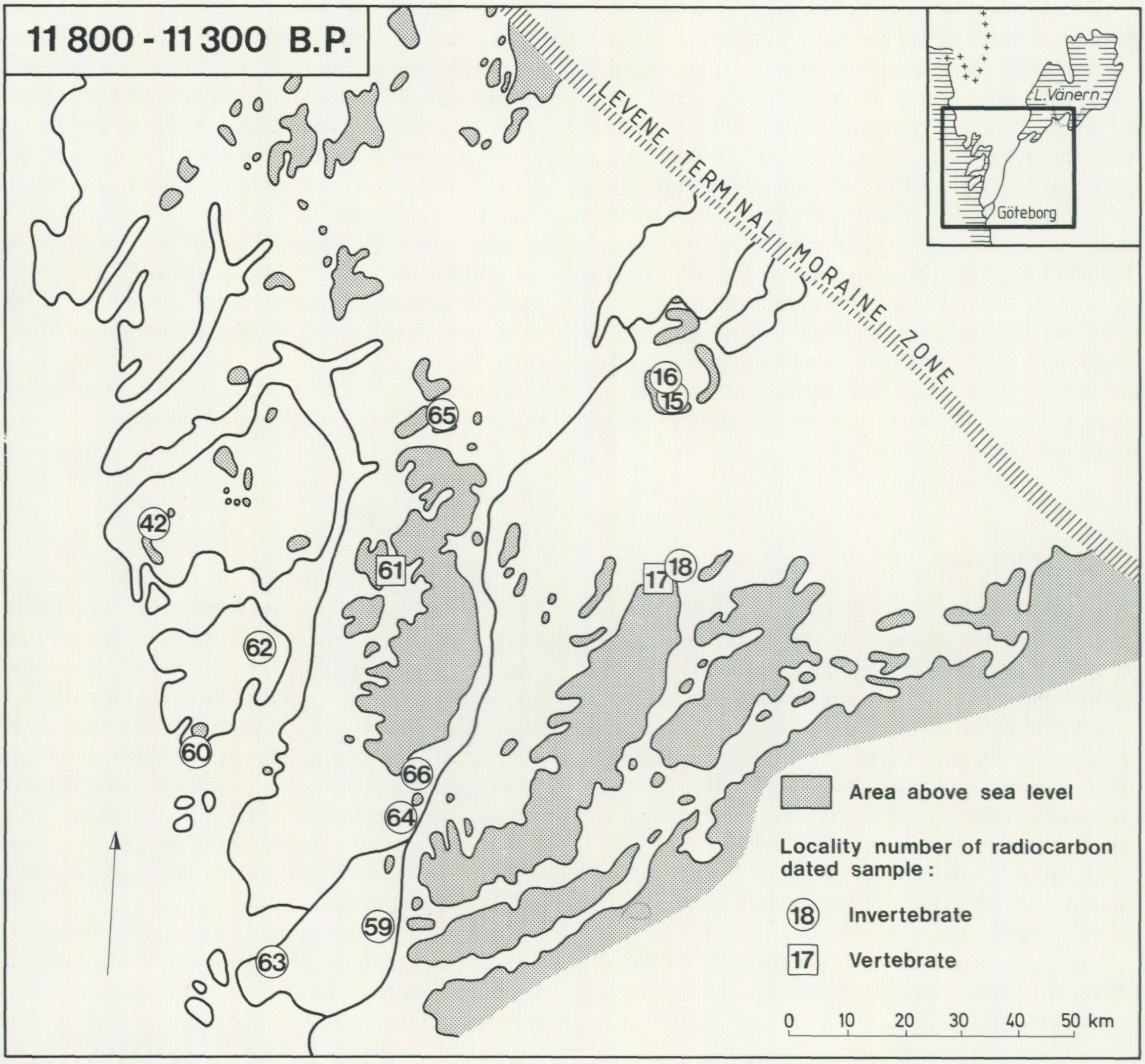

Fig. 50. Generalized palaeogeographical map of c. 11 300 years B.P. Numbers refer to locality of radiocarbon dated sample with mean value between 11 800 and 11 300 years B.P., see Table 2.

11 000–10 200 years B.P.

Solving the chronology of the Skövde terminal moraines is a difficult question, as is also the geographical limitation of the Billingen moraines. Deposits – mainly parallell ridges with a thickness of 20 to 50 m – are found in a zone 2 – 13 km wide east of Lake Vänern. The southernmost system of ridges is the most pronounced of them all and is thought to have been formed during a prolonged stagnation – the beginning of the Younger Dryas chronozone. About 600 varves have been measured by Strömberg (1985) between the southernmost and the northernmost systems of ridges.

The development and chronology of the Skövde and Billingen terminal moraines are subject to discussion (Björck & Digerfeldt 1984). So, too, is the final phase of the development of the Baltic Ice Lake (Björck & Digerfeldt 1984, 1986). The thick moraine ridges have been formed during oscillations. The amplitude of withdrawal and readvance of the ice-front is unknown.

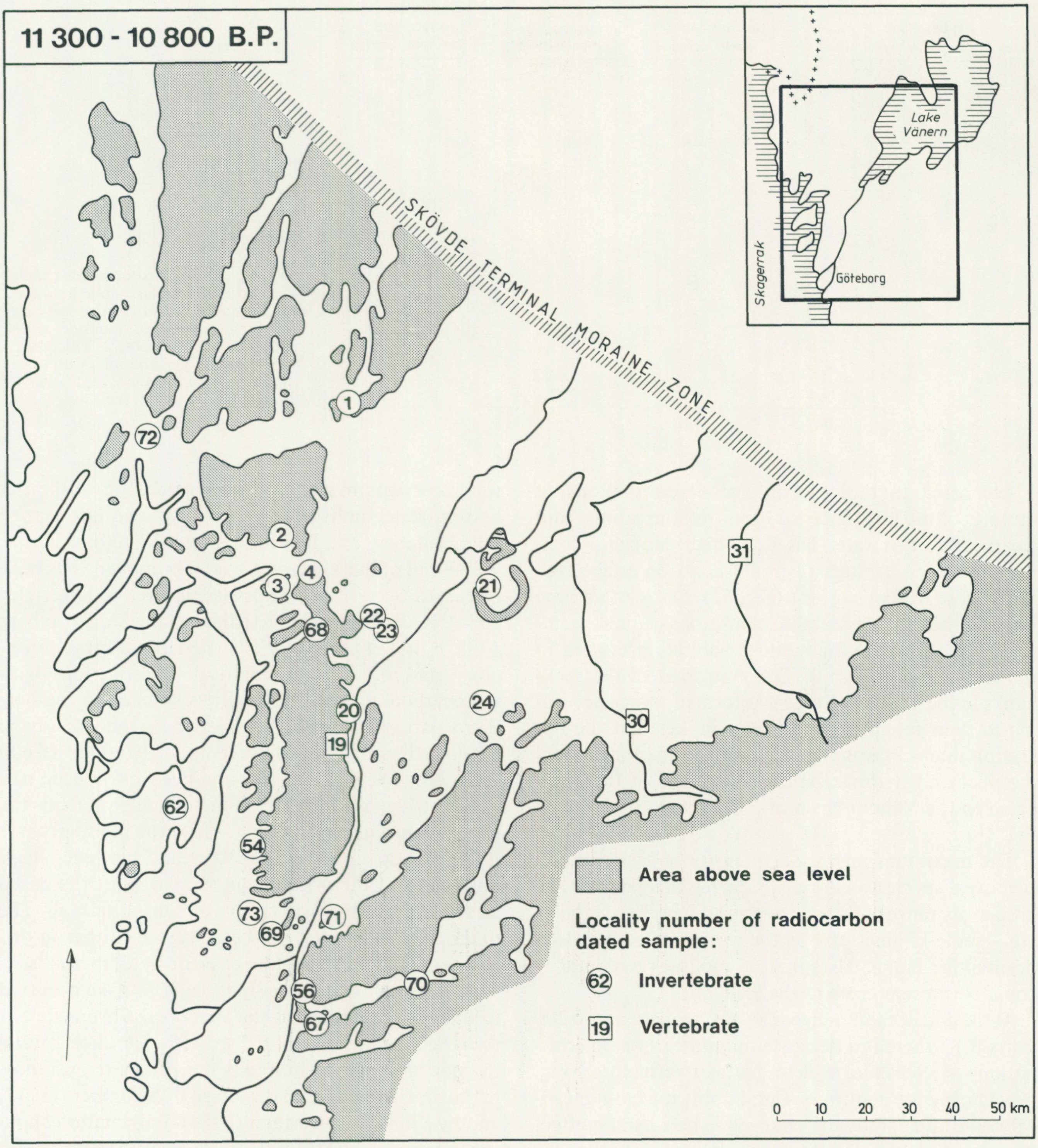

Fig. 51. Generalized palaeogeographical map of c. 10 800 years B.P. Numbers refer to locality of radiocarbon dated sample with mean value between 11 300 and 10 800 years B.P., see Table 2.

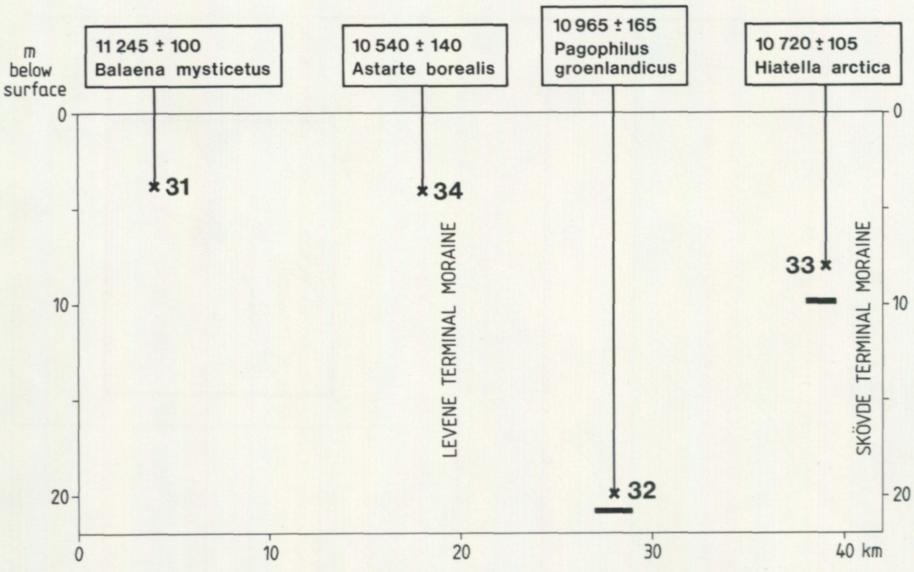

Fig. 52. Sketch illustrating four radiocarbon dated samples, depth in clay and the distance between the localities 31–34 and terminal moraine zones. Numbers refer to Table 2. Thick black line marks hard bottom. Vertebrates sink down in unconsolidated layers during deposition due to their weight.

According to radiocarbon age determinations of samples of the most interior localities, the salinity and clearness of the water has been high enough – temporarily – for habitats of molluscs to be established fairly close to the ice-front (Fig. 52). During this time interval the most favourable conditions (salinity, temperature, clearness) for mollusc habitats prevailed in the whole area (Fig. 53). The main part of the shell-banks in the Uddevalla area was formed, which according to their faunal composition, implies that the migration intensity was very high. A profile of the bathymetrical and hydrographical conditions of the strait between the Vänern basin and Uddevalla is shown in Fig. 19.

The maximum migration intensity of arctic to arctic/boreal species was reached during this period. The oscillatory range of the ice-front must have been moderate – some kilometres – as the environment has been optimal for fauna. Thus marine molluscs temporarily could be present close to the ice-front

At the end of the Younger Dryas Chronozone, 10 200 years B.P., there is a decrease in radiocarbon determinations of shells and skeletal parts of vertebrates (Fig. 59). During the continuous land uplift the bathymetrical conditions gradually changed. The isostatic effect cannot be neglected in the discussion, but its influence on hydrography was not so decisive as changes in the meltwater discharge.

The easternmost of the Uddevalla shell-banks, Fridhem (locality 11) originate from this time, indicating that bottom currents with a high salinity could intrude far eastwards (cf Fig. 19) and that the river Göta älv valley served as the main outlet. The narrow and hilly part of the valley at Uddevalla has obstructed the freshwater currents more and more in relation to the flat bottom topography east and west of the flat topped hills Halleberg and Hunneberg (see Fig. 20).

The end of the Younger Dryas Chronozone has been discussed by several authors (see Björck & Digerfeldt 1984). Recent opinions (Kristiansson 1986, Strömberg 1985, Björck & Digerfeldt 1984), based on varve chronology and on biostratigraphical investigations with radiocarbon analyses of localities situated in the northern part of the Billingen area, date the end of the Younger Dryas Chronozone to about 10 500 to 10 600 years ago. The same figures had been introduced earlier by Sörensen (1979) for the ice retreat from the Ra-moraines in Norway (Fig. 4). At the moment there is a discrepancy of 300–400 years between these opinions and the one presented here, which is based on radiocarbon determinations of marine animals. The differences in age will not be discussed further in this context. There are margins of error in all methods.

An event which is usually thought to have occurred in the very beginning of the Preboreal Chronozone is the drainage westwards of the Baltic Ice Lake around the northern end of Billingen hill. The circumstances of the drainage has been discussed by Strömberg (1977) and by Björck & Digerfeldt (1984). Information about the extent of lowering of the level of the Baltic Ice Lake comes primarily from other localities than Billingen hill. Whether it or part of it really took place at Billingen has been questioned by Fredén (1982, p. 22).

Meltwater discharge from the Baltic Ice Lake basin mixed with meltwater discharge from the whole ice front in the Vänern basin.

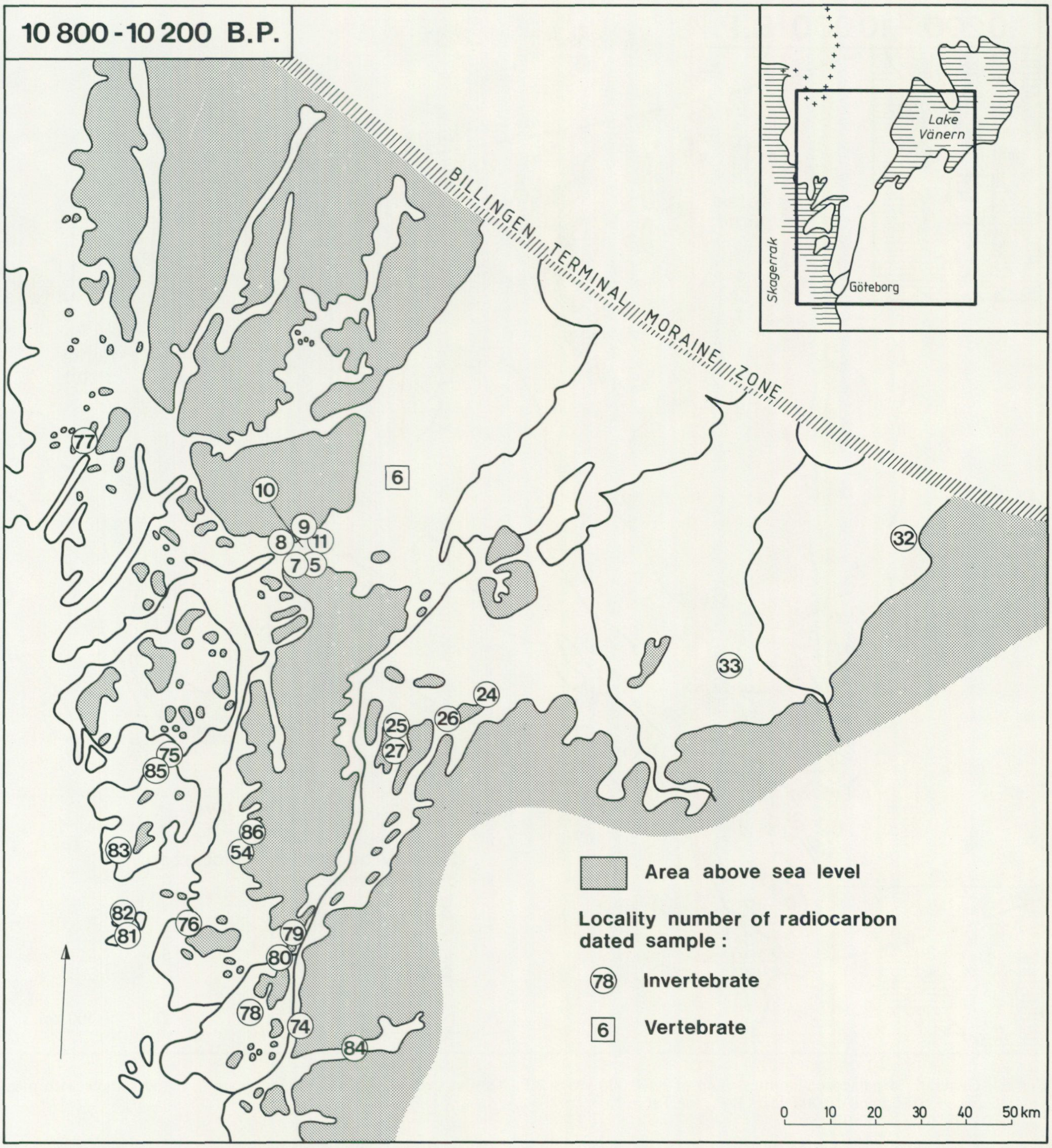

Fig. 53. Generalized palaeogeographical map of c. 10 200 years B.P. Numbers refer to locality of radiocarbon dated sample with mean value between 10 800 and 10 200 years B.P., see Table 2.

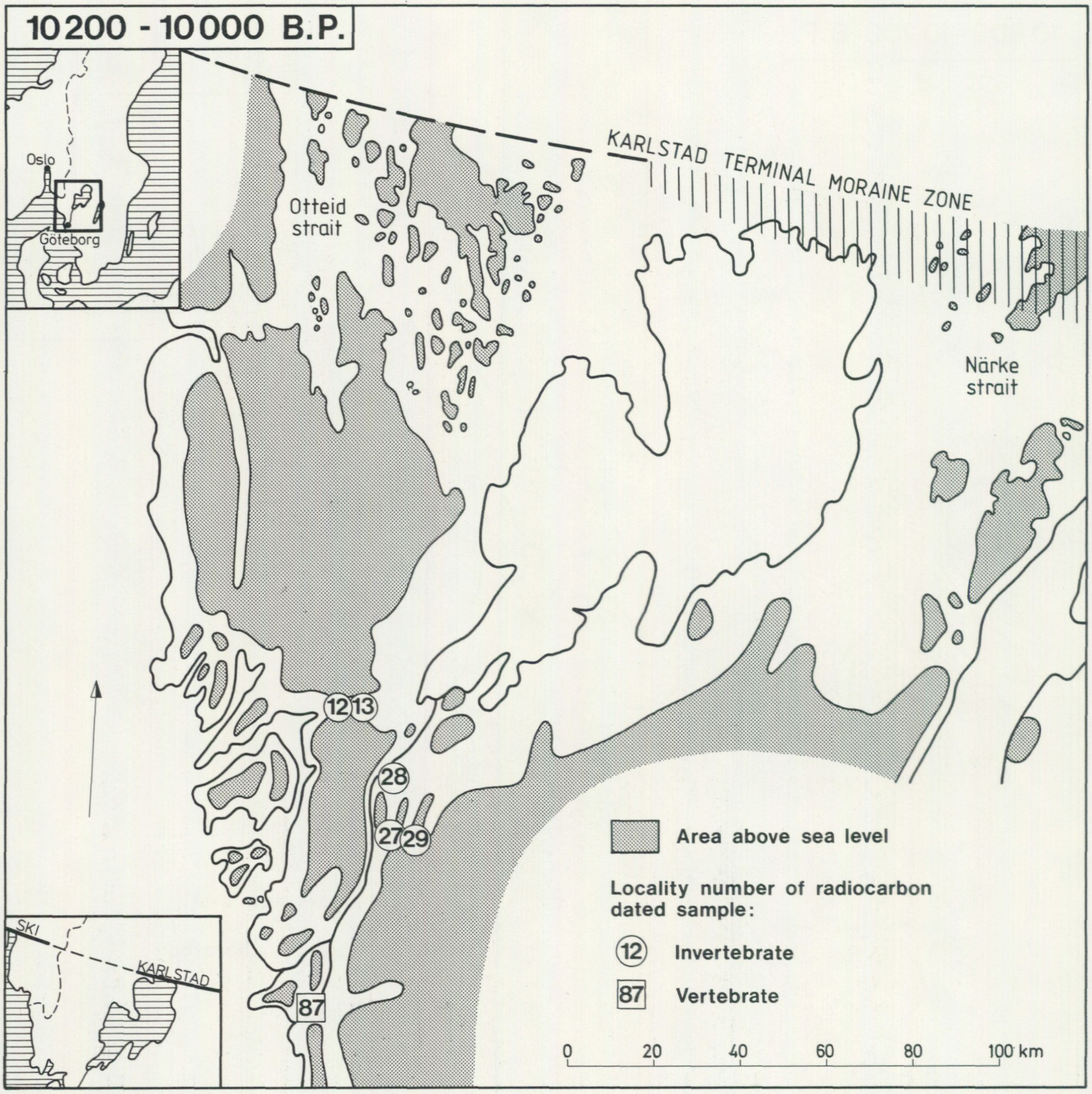

Fig. 54. Generalized palaeogeographical map of c. 10 000 years B.P. Numbers refer to locality of radiocarbon dated sample with mean value between 10 200 and 10 000 years B.P., see Table 2.

10 200–10 000 years B.P.

An amelioration of the climate led to less suitable living conditions for the arctic/boreal fauna. About 10 200 years B.P. this fauna had almost disappeared from the west coast waters (Fig. 54) due to an increase of the water temperature. Warm Atlantic water is recorded along the northern Norwegian coast some hundred years later, about 10 000 years B.P. (Thomsen & Vorren 1986).

After investigations of marine clay sequences on the Swedish west coast, a group of experts from various disciplines have noted a climatic improvement about 10 200–10 300 years B.P. (Olausson 1982). This amelioration is the beginning of the Holocene epoch. The radiocarbon dates of marine vertebrates and invertebrates agree fairly well with this opinion.

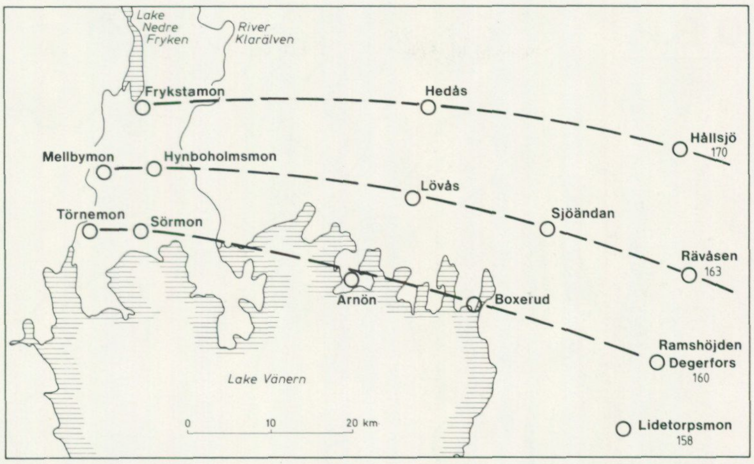

Fig. 55. Main ice marginal deposits in the proposed Karlstad terminal moraine zone. All the deposits are situated in glaciofluvial courses. Only the accumulations in the easternmost course have reached the water surface and thus formed ice marginal deltas. The highest level of the delta surfaces are expressed in m above sea level. The delta at Hållsjö is partly formed for topographic reasons, all other for climatic reasons. The map is based on Ericsson (1982), Ericsson & Lidén (1982), Lundqvist (1958) and Nelson (1910).

In the Uddevalla area and in sheltered positions in the upper part of the river Göta älv valley, the water temperature was still low enough for small isolated assemblages of molluscs to survive. In other parts of the Vänern basin, the marine mollusc population was totally extinct for other reasons – heavy sedimentation caused by a tremendous outflow of turbid meltwater during a very rapid ice retreat. No finds of molluscs are recorded in the area of Lake Vänern during this time span.

The absence of subfossil marine species – except the haddock at Bellefors – along the Atlantic/Baltic watershed was explained by Munthe (1910, pp. 40–41) as being caused by immense quantities of meltwater. The mean rate of ice recession during the Preboreal Chronozone, i.e. ice retreat from the Billingen terminal moraine to the total disappearance of the ice-sheet, was slightly more than 400 years (Fig. 49).

About 10 000 years B.P. the last molluscs of an arctic/boreal character also became extinct in the Uddevalla area and in the river Göta älv valley.

During the ice retreat northwards the important Otteid and Närke straits were opened approximately contemporaneously.

Karlstad terminal moraine

In a 15 km wide zone north of Lake Vänern there are many comparatively large glaciofluvial deposits (Fig. 55) which indicate retardation and temporary stops of the receding ice, cf Lundqvist 1958, p. 146. None of the deposits became built up to the sea surface. However, corresponding isolated glaciofluvial deposits north of the Närke strait – Lidetorpsmon to Hållsjö, Fig. 55 – are regarded as ice-marginal deltas. The deposits within the zone are referred to here as the Karlstad terminal moraine.

Primarily due to the retardation, relative clear saline water intruded eastwards through the Närke strait, conditions that were tolerable for *Portlandia arctica,* (Fig. 28). Judging by the vertical representation of this species in the varved clays, these ecological conditions existed for almost 100 years. The time of the event has been discussed and summarized by Fredén (1979, 1981, 1982) and by Berglund & Mörner (1984). The biostratigraphy of molluscs and the bearded seal at Grums (locality 35), as well as the radiocarbon age determinations and various investigations carried out in the Baltic basin (Florin 1977, Donner & Eronen 1981) indicate that the Närke and Otteid straits opened slightly before 10 000 years B.P.

Indirectly this dates the Karlstad moraine to about 10 000 years B.P., which corresponds to the age of the Ski terminal moraine in Norway (Sörensen 1979).

Tentative lines of ice recession through Värmland for every 50th year have been constructed by Lundqvist (1958, pp. 27–28). The Karlstad terminal moraine zone and its assumed connection with the Ski terminal moraine differ slightly from Lundqvist's recession lines.

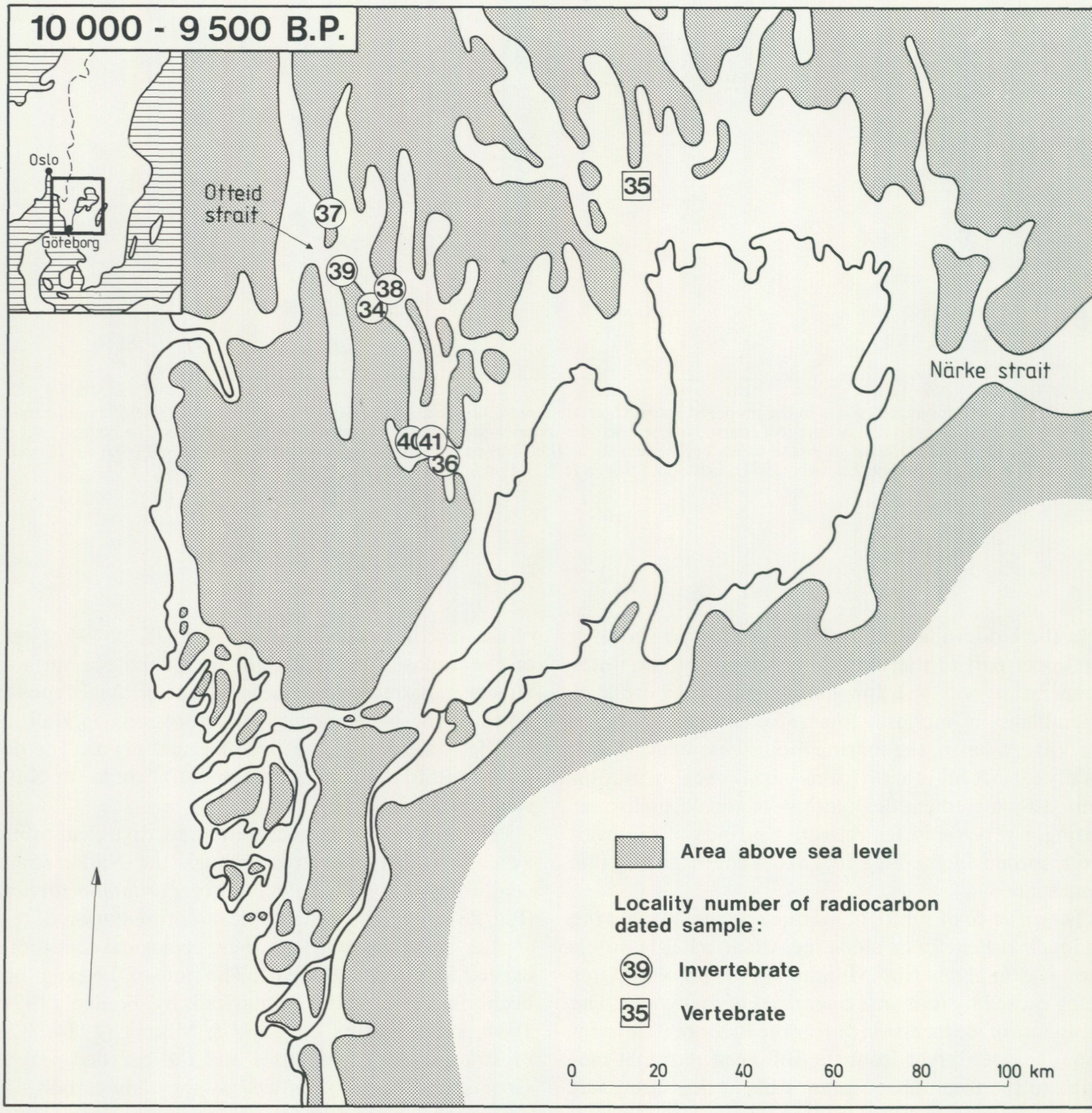

Fig. 56. Generalized palaeogeographical map of c. 9 500 years B.P. Numbers refer to locality of radiocarbon dated sample with mean value between 10 000 and 9 500 years B.P., see Table 2.

10 000–9 500 years B.P.

After the heavy sedimentation of clay particles had ceased, molluscs and barnacles invaded the archipelago west of Vänern. Melt water was discharged through the main valleys east and west of this area (Figs 56–57). The molluscs found their way to this part of the basin from the southwest.

The fauna stayed for some hundreds of years before the environmental conditions became unfavourable – increasing water temperature, and decreasing salinity due to bathymetry and land uplift.

In submarine sediments off the coast of northern Norway Hald & Vorren (1984, p. 151) have registered a temporary decrease in sea surface water temperature about 9 700 years ago. This relatively cool phase during

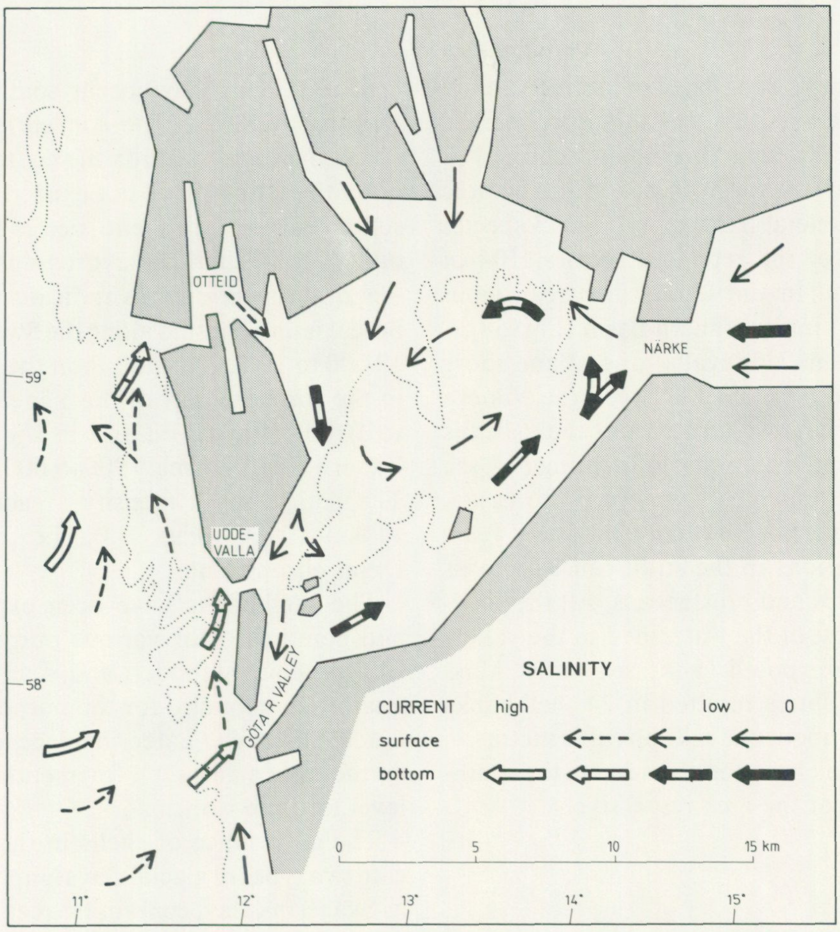

Fig. 57. Tentative water circulation pattern in the Vänern basin during the inland sea stage.

Preboreal times coincides with the existence of the arctic/boreal fauna in the western Vänern basin. The position of the ice-front about 9 700 years B.P. is not known. Temporary stops of ice recession during the Preboreal are known from Norway and Finland (Aa & Mangerud 1981, Andersen 1980, Ignatius et al. 1980, Sörensen 1979). Most of the area in the northern part of the Vänern basin is situated above the highest shoreline. Thus, stops of ice recession are also caused by morphological reasons implying a change from a sub-aquatic to a supra-aquatic deglaciation. The latter is a result of ablation rather than recession.

Land uplift

The radiocarbon age determinations of the shells sampled at Bråtnäs (locality 34) and at Hulabäcksröset (37) are interesting from the point of view of deglaciation and land uplift. The maximum water depth for the mollusc assemblages has been 10–15 m. During Preboreal times the rate of land uplift is assumed to have been rapid, in the southern part of the Vänern basin up to 10 m/100 years (Björck & Digerfeldt 1982b, 1986), and 6–7 m in the western part (Lind 1983, p. 162).

The radiocarbon age determinations when compared with the environment and with the supposed regional development indicate that the assumed rapid land uplift was retarded in deglaciated areas close to the ice front. The distance between the mentioned localities and the supposed terminal moraine zone Ski–Karlstad is about 40 and 20 km respectively. The total distance between the Skövde/Billingen and Ski/Karlstad terminal moraine zones west of lake Vänern is about 80 km. The time span for marine conditions at Hulabäcksröset and Bråtnäs is estimated to have lasted at least 200 years. As the rate of land uplift is governed by the weight of the land ice, a relatively slow rate is to be expected during the early deglaciation.

Summary

During the deglaciation assemblages of arctic to arctic/boreal molluscs and crustaceans inhabited submerged areas of southwestern Sweden. Shells representing 100 species of invertebrates have been found in the area as well as subfossil skeletal parts of at least 13 species (see Table 1). Most of the recorded species, 104 of 113, have been found in the Uddevalla area, about two-fifths (44 of 113) in the Vänern basin (Fig. 58).

The valley between Uddevalla and Vänersborg constitutes the shortest distance between the Vänern basin and Skagerrak. The western part of the valley is hilly, causing different watermasses to mingle – sea water from the west and meltwater from the east – when serving as a strait. For less than a thousand years hydrographical conditions in the strait caused a mass production of molluscs and crustaceans. All the shell-banks are situated west of the watershed in the valley, *inter alia* on the side exposed to the sea water. Mass production of i.a. molluscs resulted in 24 shell-banks with a total volume of about one million cubic metres.

One minor shell-bank has been recorded in the southern and western part of the area respectively.

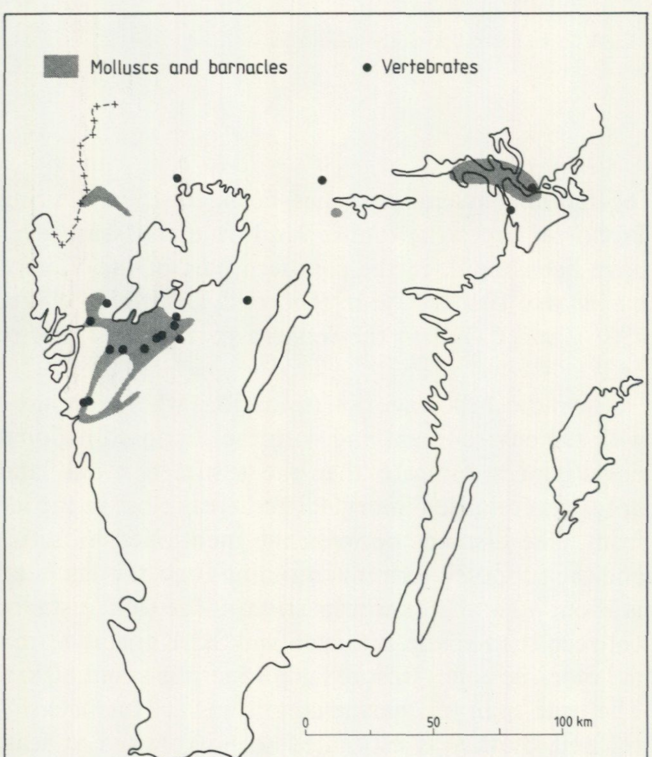

Fig. 58. Subfossil finds of marine arctic/boreal species in the area of the great lakes and the Göta älv valley. Some vertebrate localities contain more than one species.

Shell-bearing clays occur southwest of the Skövde terminal moraine. The concentration of species and layers increases towards the coast.

All the faunas have not existed contemporaneously. Assemblages of different species have succeeded each other due to changing hydrographical conditions.

Radiocarbon datings indicate that arctic to arctic/boreal faunas existed along the Swedish west coast from 13 000 to 10 200 years B.P. in the region of Uddevalla; in the southern part of the Vänern basin from 11 800 to 10 000 years B.P., and in the western part of the Vänern basin during 9 900–9 600 years B.P. (Fig. 59). The migration intensity reached its maximum 11 000–10 400 years B.P., i.e. during the Younger Dryas chronozone.

The shell-banks have been exploited for centuries and being used for various purposes such as for fertilizers, poultry-fodder, and road construction. Large quantities were also for the purpose of railways in the Uddevalla area. Later, haulage plants were used to extract shells and shell fragments below ground water level for lime-works.

The occurrence of shells in the Vänern basin indicate two types of glacial clays here. One of them, known as Skagerrak clay, contain frequent shell-bearing layers as well as individual shells and shell fragments. These circumstances imply that ecological conditions for mollusc assemblages have been favourable, at least periodically, during the sedimentation of clay particles. The Skagerrak clay sequence was formed during deglaciation up to the time of the Billingen terminal moraines, which constitute the deposits of Late Younger Dryas times.

The other type of glacial clay is known as Värmland clay here. This clay is almost barren of fossils and also differs from the Skagerrak clay by a higher content of clay particles in the upper part of the sequence. The Värmland clay was formed during the first c. 500 years of Preboreal times, i.e. during the ice recession from the Billingen terminal moraines to the region situated above the highest shoreline. It overlies the Skagerrak clay with diminishing thickness to the southwest. West of the Vänern basin shells and shell fragments may occur in the Värmland clay.

There is a discrepancy of some hundred years between chronologies based on radiocarbon age determinations of marine animals, on varved clay and on investigations of lake sediments (Fig. 59).

A brief outline of the main events of the marine development in the Vänern basin is given in chronological

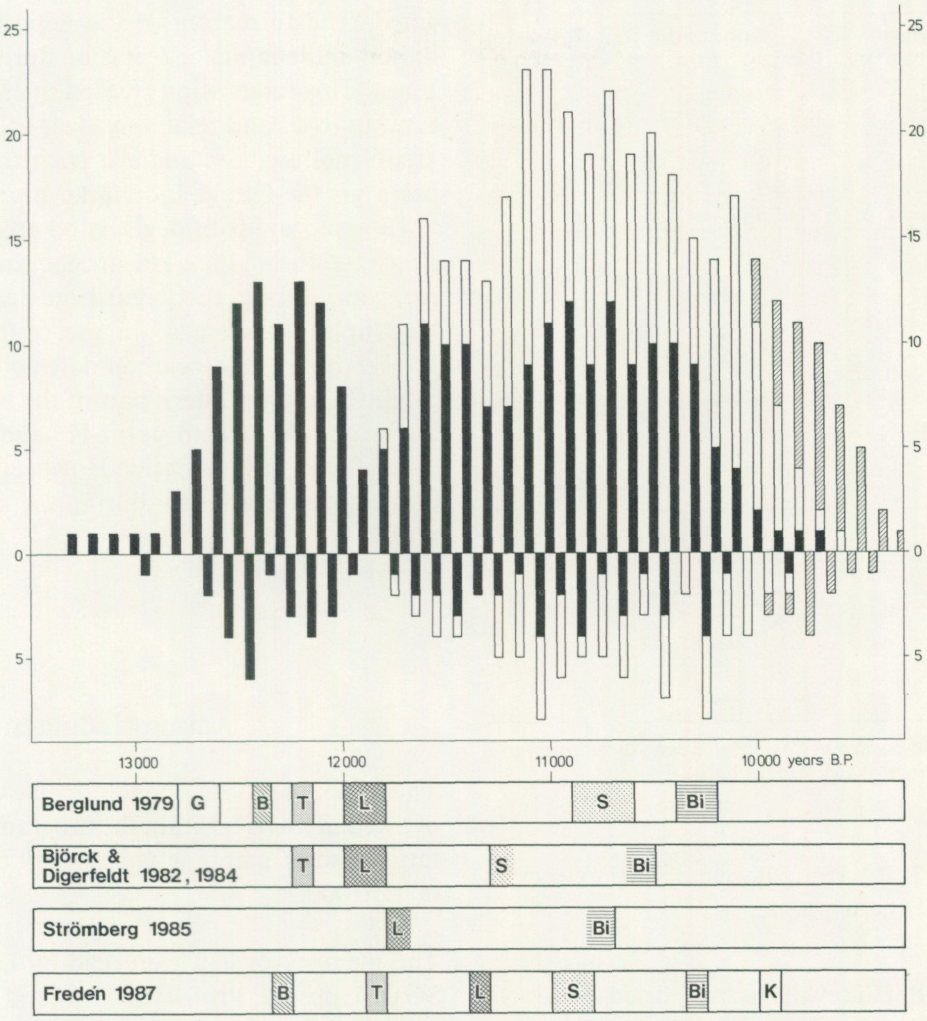

Fig. 59. Graph of radiocarbon dated marine shells and skeletal parts of vertebrates and, at bottom, opinions on deglaciation chronology in the region.

Samples from southern Bohuslän are in black, samples from the south part of the Vänern basin in white and samples from the western part of the Vänern basin in slanted line columns. The upper half represents the number of datings at every 100 year line; margins of error are included. The lower half refers to the number of datings of mean values, margin of error excluded.

Capitals are abbreviations for main terminal moraine zones, G=Göteborg, B=Berghem, T=Trollhättan, L=Levene, S=Skövde, Bi=Billingen, K=Karlstad. Björck and Digerfeldt (1984) regard the Skövde and Billingen terminal moraines as one oscillation zone. In the revised varve chronology Strömberg (1985) dates the onset of Younger Dryas Stadial with the Levene terminal moraine and the end with the Billingen terminal moraine.

order with calculated ages based on biostratigraphy and radiocarbon age determinations of shells and of skeletal parts of vertebrates (Figs 60–61).

c. 12 250 years B.P. Ice recession from the Berghem terminal moraine

c. 11 800 years B.P. Ice recession from the Trollhättan terminal moraine

c. 11 300 years B.P. Ice recession from the Levene terminal moraine

c. 11 000 years B.P. Formation of the oldest Skövde terminal moraine

c. 10 250 years B.P. Ice recession from the Billingen terminal moraine

c. 10 000 years B.P. Otteid and Närke straits opened; saline water enters the Baltic basin Arctic/boreal fauna extinct in the southern part of the Vänern basin and at the Swedish west coast

c. 9 900 years B.P. Ice recession from the Karlstad terminal moraine

c. 9 800 years B.P. Arctic/boreal fauna inhabits the western part of the Vänern basin.

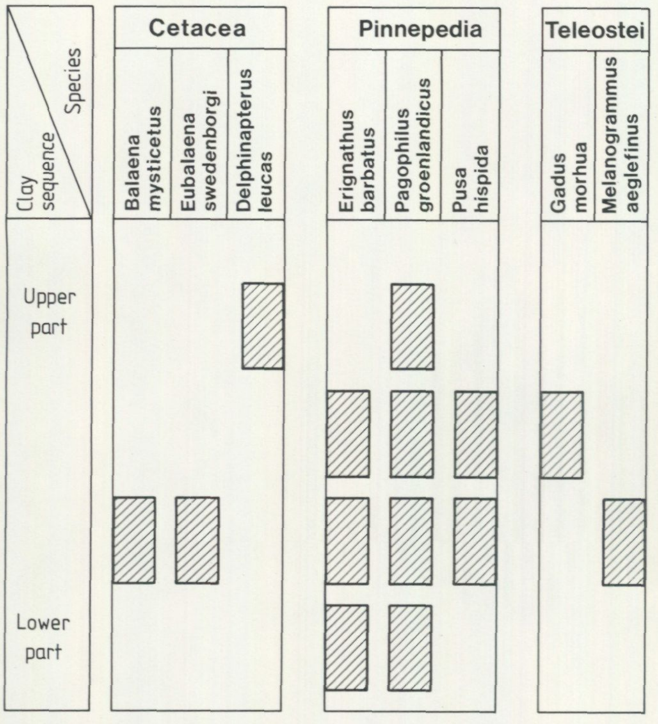

Fig. 60. Stratigraphical occurrence of skeletal parts of marine vertebrates in the glacial clays of the Vänern basin.

c. 9 500 years B.P. Arctic/boreal fauna extinct in the whole region

The Otteid and Uddevalla straits dried up about 9 300 years B.P. The threshold of the Närke strait dried up about 9 000 years B.P. The Vänern basin became isolated from the sea about 9 000 years B.P.

The Karlstad terminal moraine zone is introduced because of its pronounced glaciofluvial deposits in a 15 km wide east–west zone. It is situated north of Lake Vänern. Its continuation westwards to the contemporary Ski terminal moraine in Norway is not investigated. The formation of the deposits imply a retardation of the rapid ice recession during early Preboreal times. This retardation created hydrographical opportunities (cold and relatively clear saline water) for the arctic mollusc *Portlandia arctica* to enter the Baltic basin via the Otteid and Närke straits.

The land uplift of deglaciated areas proceeded at a slow rate during Late Pleistocene times. The rapid ice recession during Preboreal times caused the rate of land uplift to increase in the southern part of the Vänern basin. Radiocarbon dates of shells sampled at localities in the western part of the basin indicate that a similar rate of land uplift is valid for the northern part of the Vänern basin. However, close to the ice front, the rate was low during the first few hundred years.

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The manuscript has been read by Dr Lars Rudmark, SGU, Uppsala. Prof. Ivar Hessland read the original manuscript (including Fredén 1986 a) and made significant suggestions for improvements. Ms Lisbeth Hillén, SGU, Göteborg, has typed the manuscript and Ms Kerstin Berndtson, SGU, Göteborg, has made the drawings. Ms Helen Atkinson, Stockholm, has checked the language.

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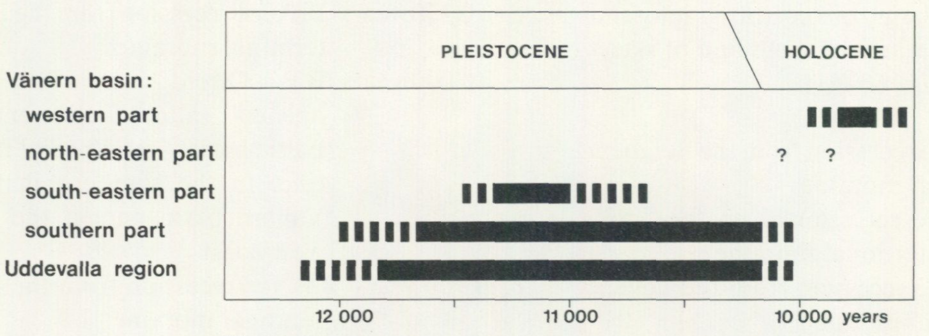

Fig. 61. The occurrence of marine fauna in the region of Uddevalla and Lake Vänern. The information is based on radiocarbon age determinations and biostratigraphical information.

REFERENCES

GFF = Geologiska Föreningens i Stockholm Förhandlingar
SGU = Sveriges Geologiska Undersökning

AA, A.R. & MANGERUD, J., 1981: Glasialgeologi og vegetasjonsinvandring i Indre Nordhordaland, Vestnorge. – Norges geologiske undersökelse 369, 33–75.

ADRIELSSON, P & FREDÉN, C., 1987: Beskrivning till jordartskartan Marstrand SO/Göteborg SV. – SGU Ae 72.

ANDERSEN, B.G., 1980: The deglaciation of Norway after 10,000 B.P. – Boreas 9, 211–216.

ANTEVS, E., 1917: Post-glacial marine shell-beds in Bohuslän. – GFF 39, 247–425.

ANTEVS, E., 1918: On the litoral mollusc-fauna of our west coast. – GFF 40, 469–479.

ANTEVS, E., 1921: Senkvartära nivåförändringar i Norden. – GFF 43, 642–652.

ANTEVS, E., 1928: Shell-beds on the Skagerack. – GFF 50, 481–748.

BERGDAHL, A., 1961: Det glaciala landskapet. – Kumlabygden I. Kumla.

BERGLUND, B.E., 1976: The deglaciation of southern Sweden. Presentation of a research project and a tentative radiocarbon chronology. – University of Lund. Department of Quaternary Geology. Report 10.

BERGLUND, B.E., 1979: The deglaciation of southern Sweden 13, 500–10,000 B.P. – Boreas 8, 89–118.

BERGLUND, B. & MÖRNER, N.-A., 1984: Late Weichselian deglaciation and chronostratigraphy of southern Scandinavia: Problems and present "state of the art". – In Mörner, N.-A., & Karlén, W. (eds): Climatic changes on a yearly to millennial basis, 17–24. D. Reidel Publishing company.

BJÖRCK, S. & DIGERFELDT, G., 1982 a: New ^{14}C dates from Hunneberg supporting the revised deglaciation chronology of the Middle Swedish end moraine zone. – GFF 103, 395–404.

BJÖRCK, S. & DIGERFELDT, G., 1982 b: Late Weichselian shore displacement at Hunneberg, southern Sweden, indicating complex uplift. – GFF 104, 132–155.

BJÖRCK, S. & DIGERFELDT, G., 1984: Climatic changes at Pleistocene/Holocene boundary in the middle Swedish endmoraine zone, mainly inferred from stratigraphic indications. – In Mörner, N.-A. & Karlén, W. (eds): Climatic changes on a yearly to millennial basis, 37–56. D. Reidel Publishing company.

BJÖRCK, S. & DIGERFELDT, G., 1986: Late Weichselian – Early Holocene shore displacement west of Mt. Billingen, within the middle Swedish end-moraine zone. – Boreas 15, 1–18.

BROTZEN, F., 1961: An interstadial (radiocarbon dated) and the substages of the last glaciation in Sweden. – GFF 83, 144–150.

BRÖGGER, W.C., 1900–1901: Om de senglaciale og postglaciala nivåforändringer i Kristianiafeltet (molluskfaunan). – Norges Geologiske Undersökelse 31.

CELSIUS, A., 1743: Anmärkningar om vatnets förminskande så i Östersjön som i Vesterhafvet. – Kungliga Vetenskapsacademiens Handlingar 4, 33–50.

CLEVE-EULER, A., 1926: Skalbankar och nivåförändringar i Skageracksområdet. GFF 48, 321–356.

DANIELSEN, A., 1970: Pollen-analytical Late Quaternary studies in the Ra district of Östfold, southeast Norway. – Årbog for universitetet i Bergen, mat.-naturv. serie 1969: 14.

DE GEER, G., 1910: Quaternary sea-bottoms in western Sweden. – GFF 32, 1139–1196.

DENNEGÅRD, B., 1984: Late Weichselian and early Holocene stratigraphy in southwestern Sweden with emphasis on the lake Vänern area. – Geologiska Institutionen, Göteborgs Universitet, A 48.

DIGERFELDT, G., 1979: The highest shore-line on Hunneberg, southern Sweden. GFF 101, 49–64.

DONNER, J. & JUNGNER, H., 1975: Radiocarbon dating of shells from marine Holocene deposits in the Disko Bugt area, west Greenland. – Boreas 4, 25–45.

DONNER, J. & ERONEN, M., 1981: Stages of the Baltic Sea and the Late Quaternary shoreline displacement in Finland. – Univ. Helsinki, Dept. Geol., Div. Geol. & Paleontol. Stencil 5.

ERICSSON, B., 1982: Beskrivning till jordartskartan Karlskoga NV. – SGU Ae 54.

ERICSSON, B. & LIDÉN, E., 1982: Beskrivning till jordartskartan Karlskoga SV. – SGU Ae 50.

ERICSSON, B., LIDÉN, E. & ROBERTSSON, A.-M., 1982: New pothole supports reinterpretation of Svea river. – GFF 104, 95–97.

ERIKSSON, K.G. & OLSSON, I.U., 1967: Några data från en planerad undersökning av en skalbank vid Linddalsskogen, Väjern, mellersta Bohuslän. – Teknik och Natur. Festskrift tillägnad professor Gunnar Beskow, 149–166. Göteborg.

FLORIN, M.-B., 1977: Late-Glacial and Pre-Boreal vegetation in southern central Sweden. II. Pollen and diatom diagrams. – Striae 5. Uppsala.

FONSELIUS, S.H., 1974: Oceanografi. – Stockholm.

FORBES, E., 1846: On the connexion between the distribution of the existing fauna and flora of the British Isles, and the geological changes which have affected their area, especially during the epoch of the northern drift. – Memoirs of the Geological Survey. I. London.

FREDÉN, C., 1974: Beskrivning till jordartskartan Vänersborg NO. – SGU Ae 17.

FREDÉN, C., 1975: Subfossil finds of arctic whales and seals in Sweden. – SGU C 710.

FREDÉN, C., 1978: Väneromrädets utveckling under de senaste 12 000 åren. – In Håkansson et al., 70–79.

FREDÉN, C., 1979: The Quaternary history of the Baltic. The western part. – In Gudelis & Königsson (eds): The Quaternary history of the Baltic. – Acta univ. Ups.symp.Univ.Ups.annum quingentesimum celebrantis 1, 59–74. Uppsala.

FREDÉN, C., 1981: Late Quaternary events at Degerfors, Sweden. – Striae 14, 159–162.

FREDÉN, C., 1982 a: An outline of the marine stage of the Väner basin. In Olausson (ed): The Pleistocene/Holocene boundary in south-western Sweden. – SGU C 794, 16–26.

FREDÉN, C., 1982 b: Geological notes on the Moltemyr, Brastad and Solberga areas. In Olausson (ed): The Pleistocene/Holocene boundary in south-western Sweden. – SGU C 794, 34–35.

FREDÉN, C., 1984: Beskrivning till jordartskartan Vänersborg SO. – SGU Ae 48.

FREDÉN, C., 1985: Aeolian and beach sand on the glaciofluvial deposit Törnemon, Värmland, Sweden. – GFF 107, 215–219.

FREDÉN, C., 1986 a: Quaternary marine shell deposits in the region of Uddevalla and Lake Vänern. – SGU Rapp. & medd. 46.

FREDÉN, C., 1986 b: Beskrivning till jordartskartan Göteborg NO. – SGU Ae 40.

FREDÉN, C., 1987: Beskrivning till jordartskartan Marstrand NO/ Göteborg NV. – SGU Ae 63.

FREDÉN, C., BRUSEWITZ, A.M., CATO, I., FÄLT, L.M., HÄGER, K.-O., MILLER, U., & SAMUELSSON, L., 1981: Tuveskredet 1977-11-30. Geologiska undersökningar. – SGU Rapp. & medd. 26.

FRIES, J.O. & KARLSSON, V., 1864: Några ord till upplysning om bladet "Ängsö". – SGU Aa 10.

FRIES, J.O., WAHLQVIST, A.H. & TÖRNEBOHM, A.E., 1863: Några ord till upplysning om bladet "Stockholm". – SGU Aa 6.

HALD, M. & VORREN, T., 1984: Modern and Holocene foraminifera and sediments on the continental shelf off Troms, north Norway. – Boreas 13, 133–154.

HESSLAND, I., 1943: Marine Schalenablagerungen Nord-Bohusläns. – Bull.Geol.Inst.Univ. Uppsala 31.

HILLEFORS, Å., 1969: Västsveriges glaciala historia och morfologi. – Medd. Lunds Univ.Geogr.Inst., Avh. 60.

HILLEFORS, Å., 1975: Contribution to the knowledge of the chronology of the deglaciation of western Sweden with special reference to the Gothenburg moraine. – Svensk Geografisk Årsbok 51, 70–81. Lund.

HJORT, C., & FUNDER, S., 1974: The subfossil occurrence of *Mytilus edulis* L. in central East Greenland. – Boreas 3, 23–24.

HOLTEDAHL, H., 1975: The geology of the Hardangerfjord, west Norway. – Norges Geologiske Undersökelse 323.

HÅKANSON, L., FREDÉN, C., LINDH, A., RONGE, B. & STIGH, J., 1978: Vänerns morfometri och morfologi – en sjömorfometrisk handbok. – Statens Naturvårdsverk, Solna.

HÅKANSSON, S., 1975: Radiocarbon dating of shell samples from western Sweden. – Svensk Geografisk Årsbok 51, 78–81. Lund.

HÅKANSSON, S., 1982: University of Lund radiocarbon dates XV. – Radiocarbon 24, 194–213.

IGNATIUS, H., KORPELA, K. & KUJANSUU, R., 1980: The deglaciation of Finland after 10,000 B.P. – Boreas 9, 217–228.

JARDINE, W.G., 1978: Radiocarbon ages of raised beach shells from Oronsay, Inner Hebrides, Scotland: a lesson in interpretation and deduction. – Boreas 7, 183–196

JEFFREYS, J.G., 1863: The upper Tertiary fossils at Uddevalla in Sweden. – Rep.Brit.Assoc.Adv.Sci.Liverpool.

JELGERSMA, S., 1979: Sea level changes in the North Sea basin. In Oele, E., Schüttenhelm & Wiggers, A.J. (eds): The Quaternary history of the North Sea. – Acta univ.Ups.symp.annum quingentesimum celebrantis 2, 233–248. Uppsala

JOHANSSON, B.T., 1982: Deglaciationen av norra Bohuslän och södra Dalsland. – Göteborgs Universitet, Geologiska Institutionen A 38.

JOHANSSON, H.G., 1975: Beskrivning till jordartskartan Hjo NO. – SGU Ae 22.

JOHANSSON, H.G., 1976: Beskrivning till jordartskartan Linköping NV. – SGU Ae 24.

JOHANSSON, H.G., 1979: Beskrivning till jordartskartan Linköping SV. – SGU Ae 36.

KALM, P., 1746: Wästgötha och Bohusländska resa förrättad år 1742. – Stockholm.

KARLSSON, V. & FRIES, J.O., 1865: Några ord till upplysning om bladet "Strengnäs". – SGU Aa 18.

KRISTIANSSON, J., 1986: The ice recession in the south-eastern part of Sweden. A varve-chronological time scale for the latest part of the Late Weichselian. – Univ. Stockholm, Dept.Quat.Res., Report 7.

KROG, H. & TAUBER, H., 1973: C-14 chronology of Late- and Postglacial marine deposits in north Jutland. – Danmarks Geologiske Undersögelse, årbog 1973, 93–105.

LILJEQUIST, G. H., 1974: Notes on meteorological conditions in connection with continental land-ices in the Pleistocene. – GFF 96, 293–298.

LIND, B., 1983: Deglaciationen och högsta kustlinjen i norra Dalsland. – Göteborgs Univ., Geol. Inst. A 43.

LINDEWALD, H., 1985: Salt grundvatten i Sverige. – SGU Rapp. & Medd. 39.

VON LINNÉ, C., 1747: Wästgöta-Resa 1746. – Stockholm 1961.

LOVÉN, S., 1846: Om Nordens hafs-mollusker. – Öfvers.K.Sv.Vet. Akad.Förhandl. Stockholm.

LUNDQVIST, J., 1958: Beskrivning till jordartskarta över Värmlands län. – SGU Ca 38.

LYELL, C., 1835: On the gradual rising of the land in certain parts of Sweden. – Philos.Trans.Roy.Soc.London.

MAGNUSSON, E., 1978: Beskrivning till jordartskartan Göteborg SO. – SGU Ae 26.

MAGNUSSON, E., 1986: Den geologiska utvecklingen. – Skara I. Skara.

MAGNUSSON, N.H. & SANDEGREN, R., 1933: Beskrivning till kartbladet Karlstad. – SGU Aa 174.

MANGERUD, J., 1972: Radiocarbon dating of marine shells, including a discussion of apparent age of recent shells from Norway. – Boreas 1, 143–172.

MANGERUD, J., 1977: Late Weichselian marine sediments containing shells, foraminifera, and pollen, at Ågotnes, western Norway. – Norsk Geologisk Tidsskrift 57, 23–54.

MANGERUD, J., ANDERSEN, S.T., BERGLUND, B.E. & DONNER, J.J., 1974: Quaternary stratigraphy of Norden, a proposal for terminology and classification. – Boreas 3, 109–128.

MANGERUD, J. & GULLIKSEN, S., 1975: Apparent radiocarbon ages of recent marine shells from Norway, Spitsbergen, and arctic Canada. – Quaternary Research 5, 263–273.

MOSBY, H., 1960: Surrounding seas. – In Sömme: A geography of Norden, 18–26. Oslo.

MUNTHE, H., 1895: Om fyndet af gråsäl i Ancylusleran vid Skattmansö i Uppland. – GFF 17, 583–589.

MUNTHE, H., 1900: Om ett fynd af piggvar i Litorinalera vid Skattmansö. – GFF 22, 3–15.

MUNTHE, H., 1901: Om faunan i Västgötaslättens Yoldialera mellan Skara–Herrljunga och Venern. – SGU C 187.

MUNTHE, H., 1910: Om ett fynd af kolja i glaciallera vid Bellefors i Västergötland. – SGU C 226.

MUNTHE, H., 1924: Ett fynd av vitling i Mälardalens Yoldiamärgel. – GFF 46, 356–357.

MUNTHE, H., 1932: Ett fynd av sill i Yoldialera vid Nora i Västmanland. – GFF 54, 60–64.

MÖLLER, H. & STÅLHÖS, G., 1964: Beskrivning till geologiska kartbladet Stockholm NO. – SGU Ae 1.

NELSON, H., 1910: Om randdeltan och randåsar i mellersta och södra Sverige. – SGU C220.

NORDBERG, L., 1967: En Portlandiaförande glaciallera från Bro i Uppland. – Kvartärgeol.Inst., Lunds Universitet.

NORDMANN, V., 1906: Bemaerkninger om senglaciale og alluviala skalbanker paa Sveriges vestkyst. – Dansk Geologisk Forening 12, 79–86.

NORRMAN, J.O., 1964: Lake Vättern. Investigations on shore and bottom morphology. – Geografiska Annaler 46, 1–238. Stockholm.

ODHNER, N.H., 1918: Skalbankarna och nivåförändringarna i Bohuslän. En kritik. - GFF 40, 204–251. Summary.

ODHNER, N.H., 1927: Några fakta till belysning av skalbanksproblemet. – GFF 49, 77–111. Summary.

OLAUSSON, E., 1981: On the glacial Norwegian-Greenland Seas and the Arctic Ocean. – Quaternary Studies in Poland 3, 79–89. Poznan.

OLAUSSON, E. (ed.), 1982: The Pleistocene/Holocene boundary in south-western Sweden. – SGU C 794.

OLBERS, E.W., 1870: Bidrag till Götheborgs och Bohus läns geologi. – Stockholm.

OLSSON, I.U., 1974: Some problems in connection with the evaluation of C^{14}dates. – GFF 96, 311–320.

OLSSON, I.U., 1980: Content of ^{14}C in marine mammals from northern Europe. – Radiocarbon 22, 662–675.

OLSSON, I.U. & FREDÉN, C., 1969: Radiocarbon measurements from the Degerfors area. – GFF 91, 201–207.

OLSSON, I.U. & OSADEBE, F.A.N., 1974: Carbon isotype variations and fractionation corrections in ^{14}C dating. – Boreas 3, 139–146.

PETERSEN, K.S., 1984: Late Weichselian sea levels and fauna communities in northern Vendsyssel, Jutland, Denmark. – In Mörner, N.-A. & Karlén, W. (eds): Climatic changes on a yearly to millennial basis, 63–68. D.Reidel publishing company.

QVALE, G., 1981: Distribution of foraminifers along the Norwegian continental margin – surface sediment assemblages. – Microfossils from Recent and Fossil Shelf Seas, 323–335. Chichester.

SANDEGREN, R. & JOHANSSON, H.E., 1931: Beskrivning till kartbladet Göteborg. – SGU Aa 173.

SHEPARD, F.P., 1973: Submarine geology. – New York.

STABELL, B., 1985: Shell material in core GIK 15530-4: Its radiocarbon age. – Norsk Geologisk Tidsskrift 65, 35.

STABELL, B. & THIEDE, J., 1986: Paleobathymetry and Paleogeography of southern Scandinavia in the Quaternary. – Meyniana 38, 43–59. Kiel.

STATENS NATURVÅRDSVERK, 1972: Fakta om Väneromrädet. – Publikation 1972:6.

STEVENS, R., 1985: Glaciomarine varves in late-Pleistocene clays near Göteborg, southwestern Sweden. – Boreas 14, 127–132.

STRÖMBERG, B., 1969: Den mellansvenska israndzonen. Översiktlig naturvårdsinventering med hänsyn till kvartärgeologisk-naturgeografiska värden. – Stockholms Univ., Naturgeogr. Inst. 6.

STRÖMBERG, B., 1974: Billingenområdet vid slutet av den senaste istiden. – Skaraborgs Natur 11, 2–16. Lidköping.

STRÖMBERG, B., 1977: Einige Bemerkungen zum Rückzug des Inlandeises am Billingen (Västergötland, Schweden) und dem Ausbruch des Baltischen Eisstausees. – Zeitschrift für Geomorphologie, N.F. 27, 89–111.

STRÖMBERG, B., 1985: Revision of the lateglacial Swedish varve chronology. – Boreas 14, 101–105.

SVANSSON, A., 1975: Physical and chemical oceanography of the Skagerrak and the Kattegatt. I. Open sea conditions. – Fishery Board of Sweden, Institute of Marine Research, 1. Lysekil.

SVANTESSON, S.-I., 1981: Beskrivning till jordartskartan Hjo SO. – SGU Ae 44.

SWEDENBORG, E., 1719: Om watnens högd och förra werldens starcka ebb och flod, bewjs utur Swerige. –Stockholm.

SÖRENSEN, R., 1979: Late Weichselian deglaciation of the Oslofjord area, south Norway. – Boreas 8, 241–246.

THOMSEN, E. & VORREN, T.O., 1984: Pyritization of tubes and burrows from Late Pleistocene continental shelf sediments off north Norway. – Sedimentology 31, 481–492.

THOMSEN, E. & VORREN, T.O., 1986: Late Quaternary macrofauna, palaeoecology and stratigraphy on the shelf off northern Norway. – Striae 24, 207–212.

TORELL, O., 1859: Bidrag till Spitsbergens molluskfauna I, jemte en allmän öfversikt af arktiska regioners naturförhållanden och forntida utbredning. – Stockholm.

TRESHNIKOV, A.F. & BARANOV, G.J., 1973: Water circulation in the Arctic basin. Translated from Russian. – Jerusalem.

TÖRNEBOHM, A.E., 1862: Några ord till upplysning om bladet "Södertelge". – SGU Aa 4.

TÖRNEBOHM, A.E., 1863: Några ord till upplysning om bladet "Fånö". – SGU Aa 8.

VAN WEERING, T.C.E. & QVALE, G., 1983: Recent sediments and foraminiferal distribution in the Skagerrak, northeastern North Sea. – Marine Geology 52, 75–99.

VORREN, T.O., HALD, M. & THOMSEN, E., 1984: Quaternary sediments and environments on the continental shelf off northern Norway. – Marine Geology 57, 229–257.

TABLE 1. Recorded subfossil finds of marine arctic to arctic/ boreal species in the Uddevalla region and Vänern basin. Old Latin names have been eliminated in favour of modern established names. Synonyms and cross-references are given by Fredén (1986a).

U = Uddevalla region

The Vänern basin is divided into four parts S=southern, SE=southeastern, NE=northeastern, and W=western.

M=finds in the valley of lake Mälaren, migration has taken place via the northeastern (NE) part of the Vänern basin.
– ( ) = occurrence not fully proved.

Number of species in the regions

	U	S	SE	NE	W	Total
Gastropods	55	9	2		13	59
Bivalves	31	15	12	(1)	21	36
Crustaceans	5	3	2		2	5
Vertebrates	13(16)	4	6	1(4)	1	13(16)

	U	Vänern basin S	SE	NE	W
Invertebrates	+				
GASTROPODA					
Acirsa eschrichti MÖLLER					
Acmaea rubella FABRICIUS	+				
Acmaea virginea MÜLLER	+				
Alvania mighelsi STIMPSON	+				
Amauropsis islandica GMELIN	+				
Aporrhais pespelecani LINNÉ	+				
Astyris rosacea GOULD	+				
Bela kobelti VERKRÜZEN	+				
Bela rugulata TROSCHEL	+				
Beringius turtoni BEAN	+				
Bittium reticulatum DA COSTA	+				
Buccinum canaliculatum HISINGER	+				+
Buccinum glaciale LINNÉ	+				
Buccinum groenlandicum CHEMNITZ	+				+
Buccinum hydrophanum HANOCK	+				
Buccinum hydrophanum elata		+			
Buccinum labradorense REEVE	+				
Buccinum meridionale HARMER	+				
Buccinum terraenovae BECK	+				
Buccinum undatum LINNÉ	+				+
Buccinum undatum coeruela SARS	+				
Buccinum undatum conoideum SARS	+				+
Capulacmaea radiata SARS *glacialis* ODHNER	+				
Colus islandicus CHEMNITZ	+				
Colus togatus MÖLLER	+	+			
Homalogyra atomus PHILIPPI	+				
Lacuna divaricata FABRICIUS	+				+
Lepeta caeca MÜLLER	+		+		+
Littorina littorea LINNÉ	+				
Littorina obtusata LINNÉ	+				
Littorina obtusata palliata SAY	+				
Littorina saxatilis rudis MATON	+	+			+
Lora pyramidalis STRÖM		+			
Lunatia pallida BRODERIP & SOWERBY	+	+			
Margarites argentata GOULD	+				
Margarites helicina FABRICIUS	+				
Margarites undulata SOWERBY	+				
Moelleria costulata MÖLLER	+				
Nassa reticulata LINNÉ	+				
Natica affinis GMELIN	+	+	+		+
Natica bathybi FRIELE	+				
Neptunea antiqua LINNÉ	+	+	–		
Neptunea despecta tornata GOULD	+				
Neptunea despecta carinata LAMARCK					+
Onoba aculea GOULD	+				
Peringia ulvae PENNANT	+				
Plicifusus kröyeri MÖLLER	+				
Plicifusus latericus MÖLLER	+				
Ptsianula limnoides	+				
Puncturella noachina LINNÉ	+	+			+
Rissoa inconspicua ALDER	+				
Rissoa membranacea ADAMS	+				
Rissoella opalina JEFFREYS	+				
Solariella obscura bella FRIELE	+				
Trophon clathratus LINNÉ	+	+	–		+
Trophon clathratus gunneri					+
Trophon truncatus STRÖM	+				
Turitella communis RISSO	+				
Velutina velutina MÜLLER	+	+			+
LAMELLIBRANCHIA					
Anomia patelliformis LINNÉ	+				
Arctica islandica LINNÉ	+		+		+
Astarte borealis CHEMNITZ	+	+	+		+
Astarte crenata GRAY	+				
Astarte elliptica BROWN	+	+	+		+
Astarte montagui DILLWYN		+	+		+
Astarte montagui striata LEACH		+			
Astarte sulcata DA COSTA	+	+			+
Bathyarca glacialis GRAY	+				+
Chlamys islandica MÜLLER	+	+			+
Heteroanomia squamula aculeata LINNÉ	+		+		+
Hiatella arctica LINNÉ	+	+	+		+
Hiatella arctica uddevallensis JEFFREYS	+	+	+		+
Lucina borealis LINNÉ	+				
Macoma balthica LINNÉ	+				+
Macoma calcarea GMELIN	+	+	+		+
Modiolus modiolus LINNÉ	+				+
Musculus discors LINNÉ	+				

	Vänern basin				
	U	S	SE	NE	W
Musculus laevigata substriata GRAY	+				
Mya truncata LINNÉ	+	+	+		+
Mya truncata LINNÉ *uddevallensis* HANOCK	+				+
Mytilus edulis LINNÉ	+	+	+		+
Nuculana minuta MÜLLER	+	+			
Nuculana pernula MÜLLER	+	+			+
Nuculana pernula costigera LECHE		+			
Nuculana tenuis expansa REEVE	+				
Portlandia arctica GRAY	+	+	+	M	+
Thracia myopsis MÖLLER					+
Thyasira flexuosa MONTAGU	+				+
Thyasira gouldi PHILIPPI	+				
Yoldia hyperborea TORELL	+				
Yoldiella fraterna VERRIL & BUSCH *nana* M.SARS	+				
Yoldiella frigida TORELL	+				
Yoldiella lenticula MÖLLER	+		+		
Zirphaea crispata LINNÉ	+				+
CRUSTACEA					
Balanus balanus LINNÉ	+	+	+		+
Balanus crenatus BRUGUIERE	+	+			+
Balanus hammeri LINNÉ	+	+	+		
Coronula diadema LINNÉ	+				
Verruca stroemia MÜLLER	+				

Vertebrates

	U	S	SE	NE	W
TELEOSTEI, bone fishes					
Clupea harengus, herring				M	
Gadus morhua, cod	+	+			
Melanogrammus aeglefinus, haddock	+			+	
Merlangius merlangus, whiting				M	
Molva molva, ling	+				
Salmo alpinus, alpine char				M	
PINNEPEDIA, seals					
Erignathus barbatus, bearded seal	+	+	+		+
Pagophilus groenlandicus, harp seal	+	+	+		
Pusa hispida, ringed seal	+	+	+		
CETACEA, whales					
Balaena mysticetus, Greenland right whale	–	+	+		
Delphinapterus leucas, white whale	+		+		
Eubalaena swedenborgii, Swedenborg whale	+		+		
Lagenorhyncus albirostris, white-beaked dolphin	+				
Phocaena phocaena, common porpoise	+				
CARNIVORA, beasts of prey					
Thalassarctos maritimus, polar bear	+				
AVES, birds					
Somateria mollissima, common eider	+				

Terrestrial vertebrate in marine deposit

	U	S	SE	NE	W
Rangifer tarandus, reindeer	+				

TABLE 2. Radiocarbon age determinations in chronological order of subfossil finds of marine megafossils in southwestern Sweden. References are given in descriptions of localities.

1–14 comprise the Uddevalla region, Fig. 13.
15–41 the Vänern basin
15–29 southern part, Fig. 20.
30–33 southeastern part, Fig. 24.
34–41 western part, Fig. 29.
42–87 the coast region of southern Bohuslän and the Göteborg area, Fig. 34.

Lu = Radiocarbon laboratory, University of Lund.
St = Laboratory for Isotope Geology, Stockholm.

Parentheses indicate that the mean value has been calculated without ^{13}C correction (0 years for invertebrates, -250 years for vertebrates).

Locality	Latitude N	Longitude E	Species	Lab. no.	Fraction	Radiocarbon age	Corrections $\delta^{13}C$ ‰PDB	Corrections reservoir effect −400 years	Years B.P.	References
42 A Huseby	58°10′	11°30′	*Chlamys islandica*	St 6871	1	12 180±190	+0.9	12 210±190		
				St 6872	2	13 675±590	+0.7	13 700±590	12 955±390	
43 Delsjön	57°41′	12°03′	*Mytilus edulis*	St 3967	1	12 720±165				Wedel unpubl.
				St 3968	2	12 805±170				
				St 3969	3	12 880±190	−1.5	12 855±190		
				St 3970	1	12 645±200	−3.9	12 610±200		
				St 3971	1	12 750±165				
				St 3972	2	12 860±160	+0.5	12 855±160	12 775±185	
44 Göteborg Guldheden	57°41′	11°59′	*Balaena mysticetus*	St 3596		12 890±110			(12 640±110)	Fredén 1975
45 Grössby	58°05′	11°58′	*Mytilus edulis*	St 8104	1	12 500±150	+0.3	12 515±150		
				St 8105	2	12 595±105	−0.6	12 595±105		
				St 8106	3	12 515±310	−0.7	12 515±310	12 540±190	
46 Göteborg Grimbo	57°45′	11°56′	*Balanus hammeri*	Lu 270	1		−0.1	12 480±128		Håkansson 1975
				Lu 271	2		−0.4	12 560±138	12 560±133	
47 A Källtorp (Jennylund)	57°52′	12°03′	*Mytilus edulis*	St 4213		12 495±385			(12 495±385)	Magnusson 1978
48 Nylöse	57°44′	12°01′	*Mytilus edulis*	St 9401	1	12 340±195	+0.8	12 365±195		
				St 9402	2	12 610±150	+0.7	12 630±150	12 500±175	
49 Hjällbo (Bläsebo)	57°46′	12°02′	*Balanus balanus* & *B. crenatus*	Lu 507			−1.5	12 490±133		Håkansson 1975
				Lu 281			−1.9	12 480±148	12 485±140	
50 A Bäckebol	57°46′	11°59′	*Mytilus edulis*	Lu 876:1			−0.8	12 370±128		Håkansson 1975
				Lu 876:2			−0.8	12 550±128	12 460±128	
51 Granås (Lövgärdet)	57°49′	12°03′	*Hiatella arctica*	St 4209		12 415±255			(12 415±255)	Magnusson 1978
52 A Helenedal (Hagen)	57°40′	12°04′	*Mytilus edulis*	St 4537	1	12 400±150				Magnusson 1978
				St 4538	2	12 375±150				
				St 4539	3	12 400±150			(12 390±150)	
52 B Helendal (Hagen)	57°40′	12°04′	*Hiatella arctica*	St 4529	1	12 190±270				Magnusson 1978
				St 4530	2	12 320±200				
				St 4531	3	12 400±210			(12 305±225)	
47 B Källtorp (Jennylund)	57°52′	12°03′	Molluscs	St 4212		12 270±425			(12 270±425)	Magnusson 1978
53 Edshultshall	58°07′	11°28′	*Balaena mysticetus*	St 3620		12 500±240			(12 250±240)	Fredén 1975
42 B Huseby	58°10′	11°30′	*Hiatella arctica*	St 6877	1	12 400±150	+0.3	12 420±150		
				St 6878	2	11 980±135	+0.4	11 995±135	12 210±145	
54 A Toröd	58°00′	11°53′	Molluscs	St 7677	1	12 020±295	−0.1	12 030±295		
				St 7678	2	12 370±145	−0.2	12 375±145	12 205±220	
54 B Toröd	58°00′	11°53′	*Mytilus edulis* &	St 7679	1	12 150±195	0.0	12 165±195	12 190±170	
			Trophon clathratus	St 7680	2	12 170±145	+1.8	12 210±145		
50 B Bäckebol	57°46′	11°59′	*Hiatella arctica*	Lu 877			+1.2	12 180±128	12 180±128	Håkansson 1975
54 C Toröd	58°00′	11°53′	Molluscs	St 7675	1	12 105±205	−0.2	12 115±205		
				St 7676	2	12 170±145	−0.5	12 170±145	12 145±175	
55 Duvås	58°01′	11°53′	*Hiatella arctica,*	St 7661	1	12 065±200	+0.7	12 090±200		
			H.a. uddevallensis	St 7662	2	12 100±140	+0.9	12 125±140	12 110±170	
56 A Agnesberg	57°47	12°01	*Delphinapterus leucas*	St 4083		12 270±220		(12 020±220)		Fredén 1975
54 D Toröd	58°00	11°53	*Hiatella*	St 7664	1	11 860±260	−0.2	11 870±260		
			Mytilus	St 7665	2	12 010±290	−0.1	12 020±290		
				St 7666	3	12 110±140	+0.1	12 120±140	12 005±230	
57 Ödsmåls mosse	57°55′	11°47′	*Mya truncata*	St 8322		11 950±290	+0.5	11 970±290	11 970±290	
58 Granås (Lövgärdet)	57°49′	12°03′	*Balaena mysticetus*	St 3595		12 165±140			(11 915±140)	Fredén 1975

Locality	Latitude N	Longitude E	Species	Lab. no.	Fraction	Radiocarbon age	Corrections $\delta^{13}C$ ‰ PDB	reservoir effect −400 years	Years B.P.	References
59 Tuve	57°46′	11°57′	*Hiatella, Mytilus,*	St 5827	1	11 260±130				
			Balanus balanus	St 5828	2	11 795±140	−3.0	11 755±140	(11 755±140)	
15 Kroppsjön	59°19′	12°26′	*Mytilus edulis*	Lu 1906			−0.9	11 770±110		Håkansson 1982
				Lu 1907			−0.5	11 720±110		
				Lu 1908			−0.3	11 740±110	11 745±110	
42 C Huseby	58°10′	11°30′	*Mya truncata*	St 7031	1	11 585±230	+1.5	11 620±230		
				St 7032	2	11 620±135	+1.4	11 655±135		
				St 7033	3	11 700±100	+1.5	11 735±100	11 670±155	
42 D Huseby	58°10′	11°30′	*Balanus balanus*	St 7029	1	11 710±130	+0.8	11 735±130		
				St 7030	2	11 545±130	−0.1	11 555±130	11 645±130	
16 Ekelunds	58°19′	12°26′	*Mytilus edulis*	Lu 1903			−0.3	11 700±110		Håkansson 1982
Gransjö				Lu 1904			−0.3	11 570± 90	11 635±100	
17 Lagmansered	58°08′	12°25′	*Erignathus barbatus*	St 4060		11 840±180			(11 590±180)	Fredén 1975
18 Iglabäcken	58°09′	12°26′	*Chlamys islandica*	St 8328	1	11 545±135	+1.3	11 580±135		
				St 8329	2	11 435±270	+1.6	11 475±270	11 530±200	
60 A Rönnäng	57°57′	11°35′	*Chlamys islandica*	St 8318	1	11 555±130	+0.8	11 580±130		
				St 8319	2	11 430±270	+1.3	11 465±270	11 525±200	
61 Svenshögen	57°58′	11°57′	*Balaena mysticetus*	St 4884		11 785±155	−15.2	11 525±155	11 525±155	Fredén 1975
62 A Valla	58°03′	11°43′	*Chlamys islandica*	St 8314	1	11 550±160	+0.8	11 575±160		
				St 8315	2	11 355±250	+1.7	11 395±250	11 485±205	
63 Sillvik	57°44′	11°45′	*Hiatella arctica*	St 9399	1	11 395±135	+2.9	11 455±135		
				St 9400	2	11 430±180	+2.9	11 495±180	11 475±160	
42 E Huseby	58°10′	11°30′	*Mya truncata*	St 6873	1	11 615±120	+0.5	11 635±120		
				St 6874	2	11 315±175	+0.5	11 335±175	11 445±150	
64 Skälebräcke	57°54′	12°00′	*Mya truncata*	St 6717	1	11 395±185	+0.6	11 415±185		
				St 6718	2	11 375±185	+1.0	11 405±185	11 410±185	
65 Funneshult	58°15′	12°00′	Molluscs	St 7237	1	11 270±135	−1.7	11 250±135		
				St 7238	2	11 320±185	−1.2	11 310±185		
				St 7239	3	11 445±135	−0.9	11 440±135		
				St 7240	4	11 515±140	−0.2	11 525±140		
				St 7241	5	11 750±330	−16.3	11 490±330	11 405±185	
60 B Rönnäng	57°57′	11°35′	*Mya truncata*	St 8324	1	11 340±340	0.0	11 350±340		
				St 8325	2	11 260±265	+1.1	11 290±265	11 320±305	
66 Alekärr	57°56′	12°00′	Molluscs	St 6653		11 260±135	+1.4	11 300±135	11 300±135	
1 Stadsängen	58°33′	12°05′	Molluscs	St 4445	1	11 450±210				
				St 4446	2	11 240±400				
				St 6654	1	11 565±320	+0.7	11 590±320		
				St 6655	2	11 090±175	+0.5	11 110±175		
				St 6656	3	11 400±115	+0.6	11 425±115		
				St 6657	4	10 830±130	+1.2	10 860±130	(11 280±225)	
67 A Äspered	57°47′	12°05′	*Hiatella arctica*	St 4210		11 245±545			(11 245±545)	Magnusson 1978
30 Essunga	58°11′	12°47′	*Balaena mysticetus*	St 3626		11 495±100			(11 245±100)	Fredén 1975
2 A Råhagen	58°22′	11°58′	*Mya truncata*	St 3963	1	11 395±175				
				St 3964	2	11 200±170				
				St 3965	3	11 170±175				
				St 3966	4	11 080±170	−5.1	10 995±170	(11 210±170)	
67 B Äspered	57°47′	12°05′	*Balanus balanus, Balanus crenatus*	St 4211		11 200±590			(11 200±590)	Magnusson 1978
19 Rishageröds-vatten	58°08′	12°00′	*Balaena mysticetus*	St 4887		11 440±155	−14.6		(11 190±155)	Fredén 1975
68 Ödegårdshagen	58°16′	12°02′	*Mya truncata*	St 8107	1	10 910±350	+0.6	10 930±350		
				St 8108	2	11 410±340			(11 180±345)	
20 Hjärtum	58°11′	12°07′	*Mya truncata*	Lu 199	1		+0.2	11 140±103		Håkansson 1975
				Lu 200	2		+0.8	11 190±113	11 165±108	
21 Eldmörjan Hunneberg	58°21′	12°26′	*Hiatella arctica*	St 5636		11 145±260	+0.2	11 155±260	11 155±260	
2 B Råhagen	58°22′	11°58′	*Mya,*	St 4751	1	10 995±200	−3.4	10 965±200		
			Hiatella	St 4752	2	11 290±200			11 085±200	
42 F Huseby	58°10′	11°30′	*Buccinum*	St 7027	1	11 065±170	+0.5	11 085±170		
			undatum	St 7028	2	11 055±230	−0.3	11 060±230	11 075±200	
22 Smedstaken	58°17′	12°09′	Molluscs,	St 7266	1	10 960±125	0.0	10 975±125		
			Barnacles	St 7267	2	11 095±180	+0.1	11 110±180		
				St 7268	3	11 210±130	+0.1	11 105±130	11 065±145	
23 Garnviken	58°16′	12°11′	Molluscs,	St 7316	1	10 715±125	−0.4	10 725±125		
			Barnacles	St 7317	2	11 405±130	−0.7	11 405±130	11 065±130	

Locality	Lati-tude N	Longi-tude E	Species	Lab. no.	Frac-tion	Radio-carbon age	Corrections $\delta^{13}C$ ‰ PDB	Corrections reservoir effect −400 years	Years B.P.	References
69 Munkegärde	57°53′	11°58′	*Hiatella arctica*	St 7034	1	10 985±125	−1.5	10 970±125		
				St 7035	2	11 115±130	+0.9	11 145±130	11 050±125	
70 A Skallsjö ängar	57°48′	12°20′	*Hiatella arctica*	St 4533		11 020±175			(11 020±175)	Magnusson 1978
71 Alebräcke	57°56′	12°07′	*Mya truncata*	St 5756	1	10 975±130				
				St 5757	2	11 050±135	−0.4	11 055±135	(11 020±135)	
24 A Ramsebacken	58°12′	12°26′	*Hiatella arctica*	St 7040	1	10 845±125	+1.1	10 880±125		
				St 7041	2	11 070±125	+2.0	11 115±125		
				St 7042	3	11 075±230	−3.2	11 030±230	11 005±125	
56 B Agnesberg	57°47′	12°01′	Molluscs	St 524	1	10 980±130				Engstrand &
					2	11 010±130			(10 995±130)	Östlund 1962
72 Skörbo	58°30′	11°30′	*Chlamys islandica*	St 7154	1	10 885±100	+1.4	10 930±100		
				St 7155	2	11 035±125	+0.6	11 060±125	10 990±115	
31 Sköttorp	58°24′	13°04′	*Pagophilus groenlandicus*	St 4997		11 280±165	−19.4	10 965±165	10 965±165	Fredén 1975
73 Kareby	57°55′	11°55′	Molluscs	St 6822	1	10 760±180	+0.5	10 780±180		
				St 6823	2	11 105±130	+1.7	11 145±130	10 960±155	
62 B Valla	58°03′	11°43′	*Mya truncata*	St 8316	1	10 490±250	+1.8	10 530±250		
				St 8317	2	11 260±245	+1.1	11 290±245	10 910±250	
3 Kapellbacken	58°20′	11°57′	*Chlamys islandica*	St 5013	2	10 855±235				
				St 5014	3	10 915±220	−0.4	10 915±220	10 890±230	
4 Stämmen	58°21′	12°02′	*Hiatella arctica*	St 5230	1	10 835±135				
				St 5231	2	10 730±215				
				St 5232	3	10 995±140	+1.9	11 000±140	(10 885±165)	
70 B Skallsjö ängar	57°48′	12°20′	*Hiatella arctica*	St 4534	1	10 810±175				Magnusson 1978
				St 4535	2	11 035±165				
				St 4536	3	10 765±315			(10 870±220)	
70 C Skallsjö ängar	57°48′	12°20′	*Hiatella arctica*	St 4532		10 870±175			(10 870±175)	Magnusson 1978
54 E Toröd	58°00′	11°53′	*Hiatella, Mya,*	St 7673	1	10 585±270	+0.8	10 610±270		
			Mytilus	St 7674	2	11 000±285	+0.8	11 025±285	10 820±280	
5 Groröd	58°21′	12°01′	Molluscs, Barnacles	St 4450		10 790±185			(10 790±185)	
25 Borrydssjön	58°08′	12°11′	*Hiatella arctica*	St 7127	1	10 675±125	+0.6	10 700±125		
			uddevallensis	St 7122	2	10 535±120	+0.7	10 560±120		
			Mya truncata	St 7123	3	10 835±105	+0.7	10 860±105		
				St 7124	4	10 785±210	+1.0	10 815±210	10 735±140	
32 Skara	58°23′	13°27′	*Hiatella arctica*	St 9524		10 675±105	+2.0	10 720±105	10 720±105	Magnusson 1986
74 Hjällbo	57°46′	12°02′	*Balanus* sp., *Hiatella*	St 5637		10 735±150	−1.9	10 715±150	10 715±150	Magnusson 1978
26 A Kullen	58°10′	12°21′	*Hiatella arctica*	St 5369	2	10 620±150				
				St 5370	3	10 810±140	−0.9	10 810±140	(10 715±145)	
54 F Toröd	58°00′	11°53′	Molluscs,	St 7669	1	10 455±155	+0.8	10 485±155		
			Balanus hammeri	St 7670	2	10 905±300	+0.8	10 930±300	10 710±225	
75 Ramsdalen	58°04′	11°40′	Molluscs,	St 8330	1	10 535±100	+1.3	10 570±100		
			Barnacles	St 8331	2	10 600±105	+1.0	10 630±105	10 700±100	
76 Lökeberg	57°54′	11°47′	Molluscs,	St 8320	1	10 795±210	+0.3	10 815±210		
			Barnacles	St 8321	2	10 555±160	+0.5	10 575±160	10 695±185	
77 Ormdal	58°26′	11°33′	Molluscs, Barnacles	St 5377		10 700±180	−1.3	10 690±180	10 690±180	
27 A Hålan	58°06′	12°13′	*Mya truncata*	St 4907	1	10 570±150				
				St 4908	2	10 815±145	−1.3	10 770±145	(10 675±145)	
6 A Hästefjorden	58°27′	12°10′	*Pagophilus groenlandicus*	St 4402		10 875±160			(10 625±160)	Fredén 1975
7 A Ramseröd	58°21′	12°01′	*Hiatella arctica*	St 4443	1	10 625±170				
				St 4444	2	10 625±210			(10 625±190)	
78 Skändla	57°47′	11°56′	*Mya truncata*	St 9397	1	10 605±130	+3.8	10 680±130		
				St 9398	2	10 460±170	+3.5	10 535±170	10 610±150	
33 Vara	58°15′	12°57′	*Astarte borealis*	St 7682	1	10 500±90	+0.8	10 525±90		
				St 7683	2	10 540±230	+0.1	10 555±230	10 540±160	
54 G Toröd	58°00′	11°53′	*Mya truncata*	St 7671	1	10 445±280	+1.2	10 475±280		
				St 7672	2	10 530±230	+1.1	10 560±230	10 520±255	
8 Samneröd	58°21′	11°58′	*Buccinum, Hiatella*	St 4753		10 575±160	−4.0	10 515±160	10 515±160	
79 Mareberg	57°53′	12°02′	*Hiatella arctica*	St 5638	1	10 590±175	0.0	10 600±175		
				St 5639	2	10 785±280	0.0	10 800±280		
				St 5640	3	10 050±260	0.0	10 065±260	10 490±240	

Locality	Latitude N	Longitude E	Species	Lab. no.	Fraction	Radiocarbon age	Corrections $\delta^{13}C$ ‰ PDB	Corrections reservoir effect −400 years	Years B.P.	References
9 Skäleryr	58°23′	12°00′	*Hiatella arctica*	St 5224	1	10 545±135				
			uddevallensis	St 5225	2	10 060±155				
				St 5226	3	10 680±130	+1.7	10 725±130	(10 470±140)	
10 SSE Skäleryr	58°23′	12°00′	*Hiatella arctica*	St 5227	1	10 355±140				
			uddevallensis	St 5228	2	10 515±150				
				St 5229	3	10 365±125	+2.6	10 420±125	(10 470±140)	
80 Göddered	57°52′	11°59′	*Hiatella arctica*	St 7038	1	10 235±120	+1.8	10 275±120		
				St 7039	2	10 575±130	+2.0	10 625±130	10 450±125	
26 B Kullen	58°10′	12°21′	*Astarte borealis,*	St 5371	1	10 605±160				
			A. elliptica	St 5372	2	10 345±115				
				St 5374	3	10 310±110	+0.3	10 325±110	(10 435±130)	
81 Koholmen	57°52′	11°37′	*Hiatella arctica*	St 7242	1	10 165±125	+0.6	10 185±125		
				St 7244	2	10 485±130	+0.1	10 495±130		
				St 7245	3	10 600±130	+1.1	10 630±130	10 435±130	
82 Björnängen	57°53′	11°37′	Molluscs	St 7248	1	10 375±180	+0.9	10 405±180		
				St 7249	2	10 480±295	+0.9	10 505±295	10 420±200	
24 B Ramsebacken	58°12′	12°26′	*Astarte borealis,*	St 7036	1	10 180±200	+0.7	10 205±200		
			A. elliptica	St 7037	2	10 540±120	+1.2	10 570±120	10 390±160	
11 Fridhem	58°21′	12°04′	*Hiatella arctica*	St 5233	1	10 425±145				
			uddevallensis	St 5234	2	10 150±155				
				St 5235	3	10 540±120	−0.7	10 540±120	(10 370±140)	
83 Bleket	57°57′	11°34′	*Mya truncata*	St 8332	1	10 225±220	+1.4	10 260±220		
				St 8333	2	10 280±245	+2.1	10 330±245	10 295±235	
84 Brobacken	57°40′	12°21′	*Hiatella arctica*	St 4525	1	10 405±170				
				St 4526	2	10 175±415			(10 290±295)	Magnusson 1978
85 Petersborg	58°04′	11°39′	*Mya truncata*	St 8326	1	10 250±250	+1.3	10 280±250		
				St 8327	2	10 180±130	+1.9	10 225±130	10 255±190	
24 C Ramsebacken	58°12′	12°26′	*Mya truncata*	St 6875	1	9 970±125	+0.7	9 995±125		
				St 6876	2	10 485±125	+1.5	10 520±125	10 255±125	
86 Rörmyren	58°00′	11°55′	*Mya truncata*	St 7667	1	10 165±135	+1.7	10 205±135		
				St 7668	2	10 195±280	+1.3	10 230±280	10 220±210	
7 B Ramseröd	58°21′	12°01′	*Hiatella arctica*	St 4447	1	10 235±165				
				St 4448	2	10 195±220			(10 215±190)	
7 C Ramseröd	58°21′	12°01′	*Hiatella*	St 4449		10 125±180			(10 215±180)	
87 Slätta damm	57°44′	11°56′	*Delphinapterus leucas*	St 4049		10 430±140			(10 180±140)	
12 Äsperöd	58°20′	11°58′	*Hiatella*	St 4749	1	10 195±130				
				St 4750	2	10 180±130	−4.0	10 120±130	(10 135±130)	
28 Heden	58°12′	12°10′	Molluscs	St 6820	1	10 100±170	+1.0	10 185±170		
(NNE Kalvhålan)				St 6821	2	9 955±120	+5.2	10 055±120	10 120±145	
13 SSE Skäldalen	58°21′	12°02′	*Hiatella arctica*	St 5221	1	9 860±125				
				St 5222	2	10 035±110				
				St 5223	3	10 685±125	+2.6	10 285±125	(10 100±125)	
29 Brännefjäll	58°05′	12°14′	*Hiatella arctica*	St 4909	1	10 100±155		10 095±155		
				St 4910	2	10 070±150	−1.3	10 060±150	(10 080±150)	
27 B Hålan	58°06′	12°13′	*Balanus hammeri*	St 4902	1	10 015±160		10 000±160		
				St 49 03	2	10 200±230	−2.7	10 150±230	(10 075±195)	
27 C			*Hiatella arctica*	St 4904	1	9 970±125		9 970±125		
				St 4905	2	9 940±150		9 910±150		
				St 4906	3	10 230±135	−0.7	10 210±135	(10 030±135)	
27 D			*H.a. uddevallensis*	St 4900	1	9 935±150		9 910±150		
				St 4901	2	10 125±150	−0.7	10 120±150	(10 015±150)	
34 Bråtnäs	59°13′	11°58′	Molluscs	St 6816	1	9 985±100	−0.9	9 980±100		
				St 6817	2	9 840±155	−0.4	9 845±155		
				St 6818	1	10 050±105	0.0	10 060±105		
				St 6819	2	9 895±115	+0.3	9 910±115	9 950±120	
14 A Uddevalla	58°21′	11°55′	*Halichoerus grypus*	St 4104		10 170±215			(9 920±215)	Fredén 1975 appendix
14 B Uddevalla	58°21′	11°55′	*Delphinapterus leucas*	St 4239		10 160±380			(9 910±380)	Fredén
6 B Hästefjorden	58°27′	12°10′	*Pagophilus groenlandicus*	St 4811		10 235±155	−19.5		(9 885±155)	Fredén 1975
35 Grums	59°30′	13°05′	*Erignathus barbatus*	St 4064		10 105±180			(9 855±180)	Fredén 1975

Locality	Latitude N	Longitude E	Species	Lab. no.	Fraction	Radiocarbon age	Corrections $\delta^{13}C$ ‰ PDB	reservoir effect −400 years	Years B.P.	References
36 A Dals Långed	58°55′	12°19′	Molluscs,	St 7246	1		−1.1	9 835±160		
			Barnacles	St 7247	2		−0.9	9 805±125	9 820±140	Lind 1983
37 Hulabäcksröset	59°25′	11°47′	*Macoma calcarea*	St 7113	1	9 935±110	−2.4	9 560±110		
			Mytilus edulis	St 7114	2	9 760±115	−1.5	9 745±115		
			Balanus crenatus	St 7115	3	10 000±120	−1.4	9 965±120		
				St 7116	4	9 765±115	−1.3	9 755±115	9 755±115	
36 B Dals Långed	58°55′	12°19′	*Hiatella arctica*	St 5020	2	9 770±165				
				St 5021	3	9 615±125				
				St 5022	4	9 925±250	−1.9	9 910±250	(9 750±175)	
39 A Sandviken	59°16′	11°51′	*Mya truncata*	St 5018	2	9 795±370				
				St 5019	3	9 755±200	−2.3	9 725±200	(9 750±285)	
38 Gustavsfors	59°12′	12°06′	Small shell	St 6812	1	9 525±115	−1.3	9 515±115		
			fragments	St 6813	2	10 335±95	−1.2	10 330±95		
				St 6814	1	9 200±105	−1.8	9 180±105		
				St 6815	2	9 900±115	−1.1	9 895±115	9 730±110	
39 B Sandviken	59°15′	11°51′	*Chlamys islandica*	St 5016	2	9 520±335				
				St 5017	3	9 835±170	−0.7	9 835±170	(9 690±250)	
39 C Sandviken	59°16′	11°51′	Molluscs	St 7117	1	9 470±110	−2.0	9 450±110		
				St 7118	2	9 740±115	−1.8	9 720±115	9 585±115	
40 Dingelvik	58°56′	12°15′	Barnacles	St 7663		9 635±215			(9 635±215)	Lind 1983
41 Steneby	58°56′	12°13′	Barnacles	St 7681		9 365±115	−0.4	9 370±115	9 370±115	Lind 1983

PRISKLASS C

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