SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 713 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 69 NR 5

LARS RUDMARK

THE DEGLACIATION AT KALMARSUND, SOUTH-EASTERN SWEDEN

WITH FOUR PLATES

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C DAVIDSONS BOKTRYCKERI AB, VÄXJÖ 1975

CONTENTS

ABSTRACT

The present investigation attempts to state the deglaciation at Kalmarsund, in the southern part of the county of Kalmar, south-eastern Sweden. Special attention has been given to the glacial striae, the highest shore line and the varved glacial clay.

The most common striae in the investigated area indicate an ice movement from the NNW—NW. The youngest striae show an ice movement more from the west. Besides, there are old striae which are engraved by an ice flow from the Baltic.

The highest shore line in the investigated area has mostly been determined as a limit between non-washed and wave-washed till at about 85 m above sea level. This altitude fluctuates somewhat.

The results derived from the connections of varved glacial clay show that the ice recession velocity was about 125—150 m per year in the investigated area with a much greater velocity in the Kalmarsund. A calving bay existed in Kalmarsund. The coastal region was deglaciated during the period 10 200—10 100 B.C., probably during the Oldest Dryas Stadial.

The ice was probably active during the deglaciation at Kalmarsund, primary indicated by moraine ridges in the vicinity of Kalmar.

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The diagrams and maps were drawn by Mrs Frymeta Flam. The English was corrected by Jean Maureen Gray, B.A. Miss Gunvor Nordenstam and Mrs Kerstin Brodén typed the manuscript. The photos were taken by Mr Tor Wiklund.

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Fig. 1. The location of the investigated area.

POSITION AND TOPOGRAPHY

The investigated area (Fig. 1) is located in the southern part of the county of Kalmar, between the Kåremo esker in the north and the Nybro esker to the south. To the west investigations extended to somewhat above the highest shore line, while to the east they reached Kalmarsund. Because of the large area some regions have been studied very briefly.

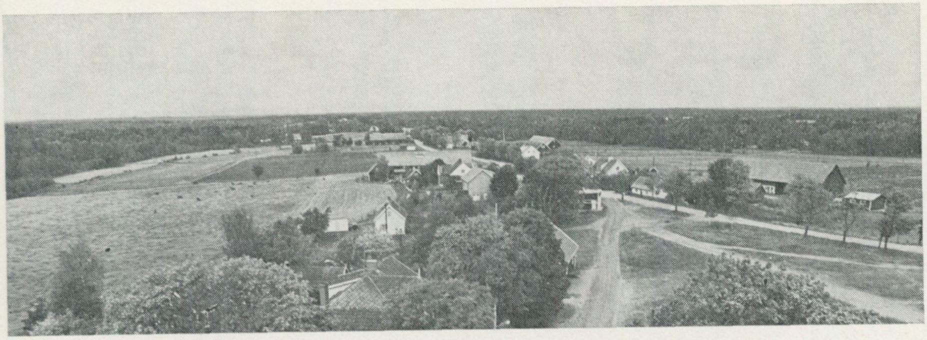

Fig. 2. The Sub-Cambrian peneplain. View from Bäckebo village looking WNW. Photo T. Wiklund 1974.

Modern maps of the investigated area are incomplete and it is covered only partially by the new topographical map (1:50 000). The ordnance map (1:100 000) and the economic map (1:10 000) were therefore used to a large extent. Position of localities is, for the sake of uniformity, locally assigned in relation to places, estates, roads, churches etc.

The geological maps of the southern part of the county of Kalmar are relatively old, from the later decades of the nineteenth century and the beginning of the twentieth. There are old geological maps (1:200 000) of some of the inland areas. Somewhat more recent and much better maps have been made (1:100 000) of the coastal regions. The latter are relatively detailed and show a good geological picture.

The investigated area can be divided into three parts according to the topography: the coastal region, in the vicinity of Kalmarsund to the east, the southern Swedish uplands in the west, and between them a transitional zone of a gently undulating terrain (Nordenskjöld 1944, pp. 113—114 and Pl. III; Knutsson 1960, p. 19).

The Pre-Quaternary sedimentary rocks in the coastal region dip about 5° towards the ESE (E. Åhman, pers. comm.). Their surface, where they are in contact with Quaternary deposits, is locally irregular and seems to be reflected to some extent in the surface of the Quaternary deposits.

The transitional zone forms a gently undulating landscape. The bedrock dips towards the SE at a low angle. In this region the topography is, to a certain extent, determined by the Quaternary deposits. Lakes are, as a rule, very shallow and occur only in the western areas (e.g. Allgunnen, Stensjön).

The southern Swedish uplands are marginal to this study but several examinations have been made there, primarily to determine orientation of glacial striation (see p. 11). The morphology of the bedrock tends to reflect the topography. The regional topographical inclination is towards the SE. On the Sub-

Cambrian peneplain (Fig. 2), which is especially well-developed in the southern part of the county (Magnusson 1963, p. 357), there are often small hills, which become lower towards Kalmarsund (Nordenskjöld 1944, pp. 34 et seq.).

BEDROCK

GENERAL

The bedrock has only been superficially studied in this investigation. The distribution of different rock units is indicated in Fig. 3, which is purely general in character, being based on geological maps (Geological Survey of Sweden, ser. A_1a, Ab and Ac) of differing age, character and mapping technique. The extent of different rock units is uncertain, particularly in the northwest. Little new information has come to light in this investigation, so that this chapter is based mostly on earlier works.

The bedrock consists of Precambrian rocks and basal Cambrian sandstone in the southern part of the county of Kalmar. Sandstone occurs in the coastal region near Kalmarsund; a band of it extends some 10 km inland. The greatest known width of the sandstone, about 15 km, occurs NW of Kalmar. The boundary of the Precambrian is fairly well-defined to the east by sandstone boulders occurring within the Quaternary deposits (e.g. Munthe 1902 a, pp. 21—22). Within the sandstone region some conspicuous quartzite hills are found, e.g. the peninsula of Skäggenäs and the islands of S. and N. Skallö.

The tectonics in south-east Sweden have been studied by Kaufmann (1931, pp. 292—306) and Stephansson (1971). The former shows that the Precambrian tectonics form part of a larger tectonic system. The joints generally run NE—SW, but an orientation NW—SE frequently occurs.

PRECAMBRIAN ROCKS

In the western part of the investigated area the bedrock is Precambrian. This is mostly covered by Quaternary deposits and patches of exposed bedrock are few. In general the areas of the outcrops are less than 200—300 m^2. Granites of Växjö-type are most abundant. Smaller amounts of porphyry, gabbro, diorite and quartzite are found, while syenite and uralite-porphyrite are of minor importance.

The oldest rocks in the county of Kalmar are the Småland-porphyries (Magnusson 1963, p. 110), which are situated in two E—W belts in the northern region. The boundary between them and the granites is difficult to draw. Transitions to quartz porphyries and hälleflinta are of frequent occurrence (Hedström 1904, p. 24). These transitions have been classed as porphyries in Fig. 3.

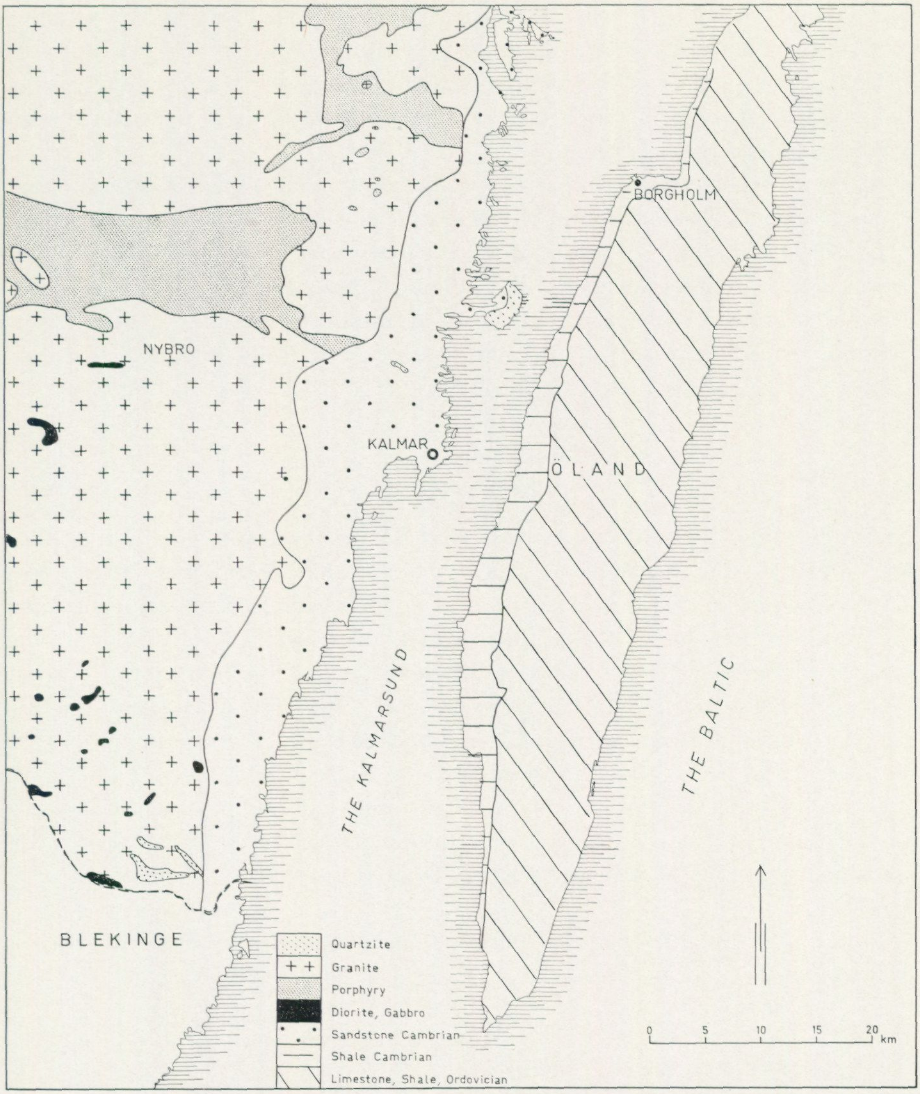

Fig. 3. Generalized map of solid rock of the investigated area and adjacent parts. Compilation from the geological maps SGU Ser. A_1a No. 5, Ab No. 15 and Ac No. 8. (Geological Survey of Sweden.)

The quartzites in the sandstone area are of the same age as the porphyry. At Skäggenäs the quartzite is generally white to red and sometimes brecciated.

The granites which cover the greater part of the investigated area (Hedström and Wiman 1906, map) are of a very different nature. The alkaline grey Växjö-granite is older than the acid red Växjö-granite (Magnusson 1963, p. 107).

The granites often show gneissic characteristics, particularly in the south. A porphyritic granite occurs in the north (Hedström 1904, p. 16), close to the margin of the map (Fig. 3). Generally, the granites are red, medium-grained and massive. Among the dark minerals biotite predominates over hornblende (Munthe 1902 a, p. 18).

In the Ljungby—Harby area, about 10 km W of Kalmar, a bottom conglomerate of quartz balls and weathered granite occurs (E. Åhman, pers. comm.).

The most common alkaline rocks are gabbro and diorite, which are found mostly in the south (Hedström and Wiman 1906, map). They are generally massive and usually appear in the form of relatively irregular limited lumps. Their occurrence in Fig. 3 is very much generalized.

SANDSTONE

The thickness of the sandstone ranges from 20 to 50 m (Åhman 1958, p. 481). The surface of the sandstone is probably not higher than about 20 m above the present sea level (Hedström and Wiman 1906, p. 83). The occurrence and even the stratigraphy of the sandstone is known almost exclusively through boulder studies as outcrops are rare. However, it has frequently been encountered in drillings in the Kalmar area. Åhman (1958, p. 483) states that the surface of the sandstone reflects the present landscape. The stratigraphy of the sandstone has been studied thoroughly by Holst (1893 a, pp. 4—7). He distinguished seven different layers. When studying till material and glaciofluvial deposits it has not been possible to make a clear-cut classification of the sandstone sequence. However, Holst has pointed out the following stratigraphy.

TABLE 1. Rock stratigraphic subdivision of basal Cambrian strata (Holst 1893 a)

calcareous sandstone (top)
white, fine-grained sandstone
sandstone with *Diplocraterion* sp. in two horizons
green-grey sandstone (crow stone)
sandstone with *Scolithus*
red-striped sandstone
sandstone with conglomerate (base)

The regional extent of these layers is known only in general. The conglomerate commonly occurs towards the west, close to the Precambrian area. Boulders of the upper layers have been observed along the coast. The *Scolithus* sandstone is the most widespread (Hedström and Wiman 1906, p. 85). Fossiliferous sandstone, considered to be younger than that mentioned above, have been observed on the peninsula of Skäggenäs (Åhman and Martinsson 1965, Bengtsson 1968).

GLACIAL STRIAE

GENERAL

The conditions for observing glacial striae are anything but favourable in the investigated area. The bedrock is mostly covered with Quaternary deposits. In the sandstone area the bedrock can only be seen at a few places, and there are no striae observed in this region, except on the quartzite outcrops. The exposed Precambrian bedrock is often weathered so severely that most of the striae have disappeared and only the coarse striae can be observed. The alkaline minerals are usually weathered in the granites. The harder porphyries are little weathered but are often split up. The glacial striae are best preserved on unweathered granites, which occur very seldom.

EARLIER INVESTIGATIONS

During the geological surveying of the area a systematical investigation of glacial striae was carried out. A great number of striae were observed, indicating different directions of ice movements.

In the area close to the border between the county of Kalmar and the province of Blekinge, only three localities with striae were found on the mainland. They all show an ice movement towards the SSE (Munthe 1902 b, p. 37). On the other hand striae corresponding to two different ice flows occur on the southern part of Öland, an older one towards S 8°—20° W and one more recent towards S 54° W (Munthe 1902 b, p. 38).

Further northwards, in the Kalmar area, about sixty localities with glacial striae were observed. Twenty-seven of these observations were made on the mainland (Munthe 1902 a, pp. 37—42). The latter tend to indicate an ice movement towards S 30°—35° E. The most divergent observations were at Åbro, about 23 km WNW of Kalmar, indicating an ice flow towards S 75° E, on the Skäggenäs peninsula, showing ice movements towards S 24° W and S 48° W and on the island of N. Skallö, indicating an ice flow towards S 26° W. According to Munthe, the striation at Åbro is dependent on the local topography and the ice movements towards the SW and SSW on Skäggenäs and N. Skallö are younger. Many different stria systems were observed on Öland. The oldest ice movement, as recorded by the striae, was from the north and was (during the same time) directed towards the SE on the mainland (Munthe 1902 a). The movement then gradually turned towards the SW on Öland. During the final stage, the ice flow was directed towards the W and NW. The ice flow is thought to have turned to the right (Munthe 1902 a, p. 42).

The glacial striae further north on the mainland were engraved by an ice flow directed towards the SE (Munthe 1904, pp. 72—73). This stria system was also observed on northern Öland, but here the ice flow ran south-south-

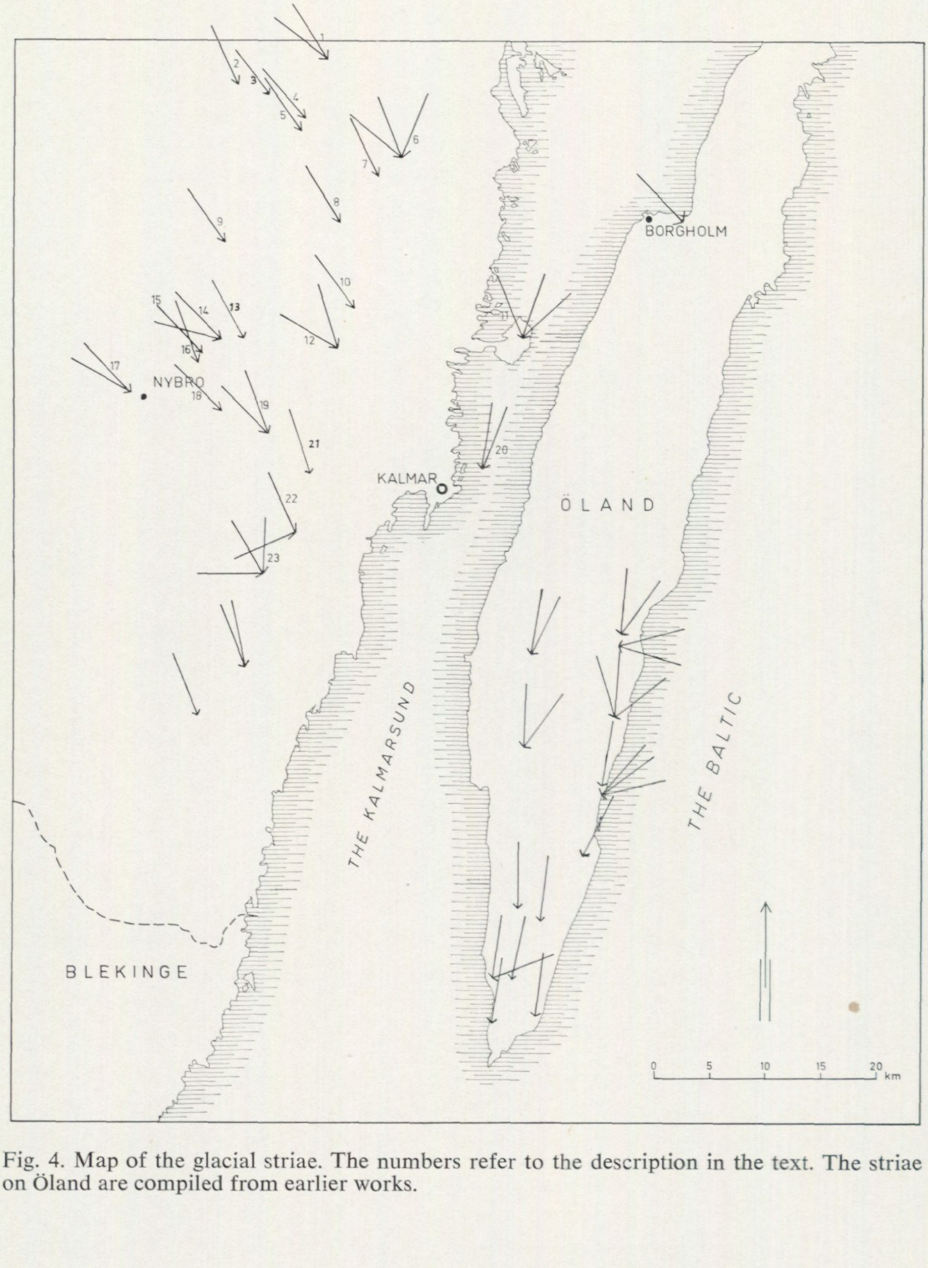

Fig. 4. Map of the glacial striae. The numbers refer to the description in the text. The striae on Öland are compiled from earlier works.

eastwards. There are a few glacial striae on Öland which correspond to an ice movement in a slightly different direction but this seems to be dependent on local conditions.

A great number of stria observations were made further to the north, in the vicinity of Oskarshamn (Svedmark 1904, pp. 53—54 and 72—73). Most of glacial striae show that the ice flowed south-eastwards, but some of them were engraved by an ice movement directed more from the west. At one locality, about 35 km NW of Oskarshamn, it was possible to determine the relative age. There, the ice movement towards the S 45° E was the youngest. At the northern point of Öland striae were found corresponding to a movement towards S 13° W several interpretations of which have been proposed (Svedmark 1904, p. 73).

In the inland regions the glacial striation indicates an almost homogeneous picture as far as different directions of ice streams are concerned (Holst 1879, 1885, 1893 b). The ice movement , recorded by the striae, was directed towards the SSE and SE. The former direction is found in the west, while in the east the ice flow ran south-eastwards.

Holmström (1904) studied traces of different ice movements in southern Sweden. His glacial striation picture is based on striae from the geological maps and his own observations. He described the following development in the Kalmarsund region (Holmström 1904, pp. 374—387 and Figs. 4 and 6): The oldest ice movement was from the north and crossed Öland and the Kalmarsund region. This is the so-called "high-Baltic" ice flow, and glacial striae from this period are preserved on Öland, N. Skallö and probably on Skäggenäs. Later on, the ice flow turned towards the SW and W. Striae from this period, the so-called "low-Baltic" period, occur only on the east coast of southern Öland. During the ice recession phase an ice flow from the NW engraved striae in the investigated area. The region to the south of this area was then entirely covered with water.

Wennberg (1949, pp. 161—164 and Pl. 11) observed striae on the southern part of Öland, not only on the east coast but also on the western side. He found old coarse striae, corresponding to an ice movement towards S 18° W, and small, more recent striae showing a flow towards the WNW.

Svensson and Frisén (1964) did not observe the striae which show an ice flow directed towards the WNW, described by Wennberg. They stated that an old ice stream from the NNW formed the bedrock. This stream was followed by an ice movement from N 8° E. The latter was probably of short duration and had little influence on the bedrock (Svensson and Frisén 1964, p. 28).

To the north of the investigated area Johnsson (1956, pp. 228—231) observed glacial striae in the vicinity of Oskarshamn and on the island of Blå Jungfrun. He described the following development in this area:

An ice flow from the N, which formed the bedrock, is oldest.
An ice flow from the NNE.
An ice flow from the N.
During the deglaciation phase an ice flow from the NW.

Johnsson (1956) did not find the striae, corresponding to the ice movement directed towards S 68° E, which had been observed by Holmström (1904) on N. Skallö. He observed no striae whatsoever on this island.

An investigation of the glacial striae on Blå Jungfrun (Holdar 1974) indicates two main ice movements, an older one directed towards the SSW, and one more recent towards the SE.

G. Lundqvist (1961, p. 10) discussed the directions and ages of different ice streams on the south of Öland. His interpretation thereof partly coincides with Munthe's. The oldest ice movement as recorded by the striae was from the NW, and this movement produced the most common striation found on the mainland at Kalmarsund. Later on, the ice movement turned towards the S and SW. Glacial striae showing directions of ice flow towards the WSW and W are even younger.

On the southern Swedish uplands G. Lundqvist (1961, p. 8) observed striae which could also indicate a right turn by the ice movement. However, the westernmost ice flow in this region ran from S 80° W, the northernmost from N 15° W.

In the area surrounding Nybro, Knutsson (1960, pp. 34—40, 1962, p. 24) established two entirely different directions of ice movement. The ice flow towards the SE resulted in the most common striation found in this area. Older striae and facets show that previously the ice flowed south-south-westwards.

Ringberg (1971, pp. 13—18) made comprehensive studies of the glacial striation in the eastern part of the province of Blekinge. He states that striae engraved by ice movement from N 30° W—N 60° W are the oldest glacial marks in that region. Later on, the ice movement turned towards S 20° W—S 40° W. The bedrock was eroded by this ice stream. The direction of the youngest ice flow was from N 5° W—N 10° W. Furthermore, there are striae in south-east Blekinge, corresponding to an ice movement, directed towards N 65° W—S 60° W. This movement was older than the ice flows from the NNE and N.

Several other authors have discussed directions and ages of different ice movements in the area of Kalmarsund (e.g. Bergdahl 1947, Dannstedt 1947) but offered no stria observations of their own.

The earlier stria investigations at Kalmarsund indicate the existence of various interpretations of the age relations and directions of different ice movements. On the mainland, except in the sandstone region, the ice movement towards the SE and SSE produced the most common striation (Holst 1879, 1885, 1893 b, Munthe 1902 a, 1902 b, 1904, Svedmark 1904, Holmström 1904, G. Lundqvist 1961). A few authors have also observed striae, indicating an ice movement towards the SSE, which is usually considered to be older (Knutsson 1960, 1962, Holdar 1974, Johnsson 1956).

The striae on the quartzite outcrops in the sandstone region at Kalmarsund are of great importance for interpreting the different ice flows in this region.

The relative age of these striae is difficult to determine, because of their positions in relation to other striae. Sometimes, they are thought to have been engraved by an old ice stream (e.g. Holmström 1904) and sometimes by a young ice stream during the deglaciation phase (Munthe 1902 a).

The striation picture on Öland is greatly varied. Many striae have been observed, which indicate differences in the direction of ice movements. The theories on the relative age of these movements also vary. Sometimes, an ice flow moving WNW and W is considered to be younger (e.g. Wennberg 1949), and sometimes older (e.g. Holmström 1904). Therefore, it is impossible to determine the age relation between different ice movements on Öland without a thorough study of the striation.

THE PRESENT INVESTIGATION

The preceding section shows that earlier studies in the investigated area made only a minor contribution to the interpretation of various ice movements in the Kalmarsund area. Most interpretations are based upon observations made on Öland, so that intensive efforts were made to find glacial striae on the mainland, which indicate different ice flows. The striae in the southern Swedish uplands were only studied in brief, most of the observations being made between the sandstone region and the highest shore line. No systematic inventory has been made, owing to the size of the investigated area, but some regions, e.g. around certain lakes, were examined in detail. The distribution of observations is not uniform, as Quaternary deposits and weathering made it impossible to observe striae in some regions. In "description of glacial striae localities" (p. 78) all localities with striae which show two or more directions of ice flows are presented. There is in addition a representative selection localities with only one direction of striae. All these are presented in Fig. 4.

The local topography often causes variations in the glacial striation picture as the ice mass plastically follows the bedrock forms. This phenomenon has been observed very distinctly on the southern Swedish uplands at Eskilsryd, about 15 km SW of Nybro (Knutsson 1960, pp. 38—39). In the investigated area the topography is smooth and few heights and valleys occur (cf. p. 7). The local topography has therefore only had a minor influence on the glacial striation.

A Silva mirror compass in 360° with clinometer was used during the field work. The direction of the ice movement is only given in round figures 0, 5, 10° etc.

Rocks with well-developed stoss- and lee-sides can sometimes be seen. The longitudinal axes generally run NW—SE. The appearance of the glacial striation varies widely. In addition to ordinary striae, there are grooves on Skäggenäs and fine scratches at Ljungbyholm, 13 km WSW of Kalmar. The directions of the different ice movements also vary, the easternmost being directed towards S 50° W and the westernmost towards N 70° E.

The ice movement towards S 20° E—S 40° E produced the most common striation found in the investigated area. Striae, engraved by this movement, were observed at almost every locality. In "description of glacial striae localities" (p. 78) only a few examples, representing this direction, were chosen. The movement from the NNW, as recorded by the striae, was observed throughout the area, except in the sandstone region. This direction was also observed at one locality on the west coast of southern Öland. This ice movement direction is often the only direction observed.

Localities with other ice flow directions seldom occur and are all mentioned in "description of glacial striae localities" (p. 78). A number of them are situated somewhat outside the investigated area but they have been included in order to present a more homogeneous striation picture.

In this chapter some interesting localities deserve a more detailed comment. The number before the localities is that cited in Fig. 4.

6. Häggemåla, 6 km SW of Ålem church (north of the investigated area). On the western side of the Ålem—Abbetorp road glacial striae corresponding to different directions of ice flow were observed on a newly exposed rock surface. The movement towards the SSE (S 20° E) produced the most common striation, but striae, showing ice flows directed towards S 50° E and S 25° W are also engraved at this locality. The striae, representing the ice movement towards the SSW, are very coarse, and the other stria systems are engraved into this system. Furthermore, the striae, engraved by the ice stream directed towards S 50° E, were observed in those representing the ice flow from the NNW.

11. Skäggenäs, 15 km NNE of Kalmar. The striation of Skäggenäs peninsula has been examined in detail in earlier works (cf. Munthe 1902 a, pp. 38—39, Holmström 1904, pp. 375—376, Rudmark and Sturesson 1970, pp. 6—8). Four different stria systems have been observed on the quartzite outcrops, all representing different ice movements: towards S 60° E, S 10° E—S 25° E, S 25° W and finally S 50° W. The ice movement towards S 60° E is recorded by striae on a small outcrop on the western part of Skäggenäs where there are no other striae. On the highest part of Skäggenäs (Alkullaberget, 32.7 m above sea level) there are striae, which resemble scratches, and indicate an ice movement towards S 10° E—S 25° E. The traces from the ice flows towards S 25° W and S 50° W are also found on Alkullaberget, on the eastern steep side (about 15 m high). The striae, which show the ice stream running SSW are very coarse, like grooves. The local topography must here be taken into account as the quartzite hill rises very abruptly in the smooth sandstone area.

14. Åbro, 23 km WNW of Kalmar (cf. Munthe 1902 a, p. 38). On the highest part of a well-developed *roche moutonnée* distinct striation is present, engraved by an ice movement towards S 75° E. On the lee-side, there are striae indicating an ice flow towards the SE. A quartz dike in N 45° E—S 45° W has shielded from erosion the one part of the outcrop where the striae were formed, representing the ice flow towards S 75° E. Coarse, weathered striae, which indicate an ice movement towards S 45° E, are frequently engraved on exposed outcrops in the area surrounding Åbro. The terrain seems to be very smooth there, and, according to the new topographical map, there are no pronounced differences in level.

20. N. Skallö, 3 km NE of Kalmar. Several different stria systems were previously observed on this small island (cf. Holmström 1904, pp. 375—376, Munthe 1902 a, pp. 38—39, Knutsson 1960, p. 40). Indistinct striae show that the ice flow was directed towards S 15° W and S 25° W during the glaciation. No other striae were observed in this investigation.

22. Ölvingstorp, 13 km WSW of Kalmar. Weathered striae are found on the highest part of a small outcrop, engraved by an ice movement towards S 30° E. On the lee-side, about 75 cm further down on a very small (2 m^2) newly exposed outcrop, a large number of fine scratches are observed. The ice flow, which produced these scratches, had a somewhat varied direction. Because of the small and smooth outcrop, it is difficult to determine whether the direction of the ice movement was towards S 70° W or N 70° E. It was probably towards N 70° E, as the surface dips about 10° towards the WSW, and the scratches do not occur on the smooth, highest part of the newly exposed outcrop. No other striae with this appearance were observed in the investigated area. The ice movement towards N 70° E probably produced striation in other parts of this region, but this has not been noted. However, the same ice flow direction was observed 15 km SW of Nybro (Knutsson 1960, p. 39, G. Lundqvist 1961, p. 8).

23. Mortorp, 16 km SW of Kalmar (south of the investigated area). This locality is found 350 m N of Mortorp church. Knutsson (1960, p. 37) studied this locality very closely (Flathallagården) and measured several hundred striae. The established two entirely different stria systems. The oldest ice movement at this locality, as recorded by the striae, was from the north. Later on, the ice movement turned towards the SSE, which produced the most common striation here (Knutsson 1960, p. 37). The site is a *roche moutonnée*. Besides striae, crescentic fractures occur, produced by an ice stream towards S 20° E. The ice flow directed towards the SSE has engraved most of the striae, and this system is incorporated in another stria system, which represents an ice flow running southwards. The striae of the latter system are often long and coarse. Furthermore there are a few very indistinct striae, indicating an ice movement towards the east, and these are also relatively long. At one place

they occur on both sides of a facet, formed by the ice movements from the north and NNW.

The interpretation of the relative age of different ice movements on the mainland at Kalmarsund was based on only a few stria localities. Of about 110 new stria observations, only ten indicate different ice flows. Few of these could be used to determine the intervals between the ice movements.

It is possible to interpret the relative age of different ice flows at some localities with just two stria systems. At Gräsmo (No. 19), and probably at Skrivnahallar (No. 18), it is clear that the striae which indicate an ice movement towards S 20° E—S 25° E, are older than those, which represent a flow more from the west. At Åbro (No. 14) the ice flow from the NW was older than that from N 75° W, as recorded by the striae. The striae of the latter ice stream were engraved because of favourable conditions (e.g. the quartz dike). The scratches, probably indicating an ice movement towards N 70° E, at Ölvingstorp are difficult to interpret with certainty. They were probably engraved by a plastic ice, the direction of which is dependent on the topography. Furthermore, they would seem to be the youngest because of their appearance on the WSW dipping newly exposed surface. The striae, which show ice movements towards the SSW and SW on Skäggenäs (No. 11) and N. Skallö (No. 20) are difficult to interpret accurately. It is possible that these striae developed solely because of the topography. On the other hand, two ice movements were in progress at both localities, as recorded by the striae. Probably, the ice flows towards S 25° W and S 50° W on Skäggenäs correspond to these flows towards S 15° W and S 25° W on N. Skallö. In addition, some of the striae on Skäggenäs (S 25° W) are very coarse. All the striae on Skäggenäs and N. Skallö, except those which represent ice flow towards S 60° E on Skäggenäs, were probably engraved because of the local topography and ice movements from the Baltic.

The oldest ice movement at Mortorp (No. 23), as recorded by the striae, was from the north. It is quite clear that the ice flow from the NNW is younger. The youngest ice movement at this locality is represented by indistinct striae engraved in E—W. The bedrock was eroded by an ice movement from the NW.

The longitudinal axes of the *roche moutonnée* in the area are in general orientated NW—SE. An ice stream from the NW formed the bedrock at Kalmarsund. This stream crossed the investigated area over a relatively long period. An ice movement from the Baltic prevailed over the ice stream from the NW during one period. This ice stream engraved striae on Skäggenäs, on N. Skallö, at Häggemåla, and probably at Mortorp. The ice stream was directed towards the south at Mortorp. Later on, the ice movement turned SSE. This movement produced the most common striation found in the area. The striae, corresponding to an ice flow towards S 20° E—S 40° E, were formed. Owing to the topography, the direction of the ice flow was more from the north on Skäggenäs.

The relatively deep Kalmarsund influenced the ice movement to some extent. The youngest striae on the mainland at Kalmarsund show that the ice flow was directed more towards the east during the deglaciation phase. These striae are engraved at e.g. Åbro, Mortorp and Häggemåla. The direction of the ice flow during the deglaciation phase varies widely from place to place, and the striae, representing it, are small and, in most cases, indistinct.

The suggested interpretation of the relative age of different ice movements in the investigated area diverges somewhat from previous conclusions. Munthe (1902 a, pp. 38—39) considers that the ice flows from the NNE and NE, represented by striae on Skäggenäs and N. Skallö, are younger than the ice flow towards S 20° E—S 40° E. Holmström (1904, pp. 386—387) is of the opinion that ice movements towards the SSW and SW are the oldest. These ice movements took place during the "high-Baltic" period. G. Lundqvist (1961, pp. 8, 10) considers that the ice stream turned westwards on Öland, and probably also in the southern Swedish uplands. Knutsson's view (1960, p. 40) is more or less the same as mine. He postulated an old ice movement from the NNE, and a more recent from the NW. The former ice movement, according to Knutsson, formed the oldest striae at Mortorp and some of the striae on Skäggenäs and N. Skallö.

TILL

GENERAL

The till in the investigated area has not been examined in detail. No systematic inventory has been made and the till has only been examined in connection with other Quaternary problems, such as lithological composition of glaciofluvial deposits and position of the highest shore line. Samples of till have in most cases been taken in the northern part of the coastal region and at localities indicating the highest shore line. Four aspects of the till have been studied: the morphology, the grain size distribution, the lithological composition and the interior structure. There are, however, very few observations of the interior structure owing to the almost total lack of instructive till pits.

The thickness of the till ranges from a few to about ten metres, with the greatest thickness in the coastal region (Munthe 1902 a, pp. 44—45). The till covers about 75 % of the investigated area. The most interesting till deposits are very distinct moraine ridges in the area surrounding Kalmar. They have been of great importance for the interpretation of the ice recession in SE Sweden during the twentieth century.

EARLIER INVESTIGATIONS

The till in the southern Swedish uplands was very briefly examined during the geological surveying. However, different moraine formations were observed, e.g. moraine ridges, orientated NW—SE. In addition, two entirely different till layers were found in some of the till pits (Holst 1879, pp. 24—26).

More detailed investigations of the till were carried out in the coastal region and the transitional zone for the geological maps (Munthe 1902 a, 1902 b, 1904, Svedmark 1904). In the coastal region the grain size distribution of the till is mostly sandy and gravelly, sometimes silty to fine sandy. Boulder clay is very rare. In the transitional zone, Munthe (1904, p. 78) observed a smooth moraine landscape, sometimes with a high frequency of boulders, and moraine ridges orientated NW—SE.

The moraine ridges in the area surrounding Kalmar were examined by Munthe (1902 a, p. 46). In his opinion, they are end moraines, developed at the ice border during the deglaciation phase. The height is usually less than two metres but may reach 5—10 m. The surface often has a high frequency of boulders.

These end moraines were examined in detail at the beginning of this century and played an important role in the discussion of the ice recession. They were thought to form part of a great terminal line through southern Sweden. The interior structure was not described, however. Only the morphology was examined.

Stolpe (1911, p. 39) stated that the end moraine zone, and thus the terminal line, follows the east coast all the way up to the province of Östergötland, while De Geer (1910) thought that this line crosses Kalmarsund at Kalmar and continues on Öland, first running west—east and then north—south. There was, in his opinion, an ice lobe in the Baltic during the ice recession phase.

The theory of the existence of an ice lobe during the deglaciation phase in the Baltic was also proposed by Mörner (1969, 1970, 1973). He is of the opinion that the lobe covered almost the whole Baltic and reached as far as Germany.

Munthe (1910) observed two zones of terminal end moraine ridges in the southern part of the county of Kalmar, one near Kalmar, the Kalmar line, and the other in the vicinity of Karlslunda, about 20 km S of Nybro, the Karlslunda line, running SW—NE from Vissefjärda to Kalmar. According to Munthe both zones cross Kalmarsund at Kalmar. Later, he described only one terminal zone here (Munthe 1940).

Dannstedt (1947) investigated the bottom topography in the southern part of Kalmarsund, where he distinguished an additional terminal end moraine zone. He found distinct annual ridges, running SW—NE across Kalmarsund, about 200 m apart.

The bottom topography of Kalmarsund between Kalmar and Öland, to the north of Dannstedt's investigation area, was studied by Bergdahl (1947). He confirmed the theory of the terminal end moraine zone at Kalmar, the Kalmar line. Bergdahl also investigated the moraine zone Vissefjärda—Kalmar, the Karlslunda line. He found many parallel terminal moraine ridges here in a zone at least 4 km broad (Bergdahl 1947, pp. 51—52).

Königsson (1967 a) examined material in some drill cores from Kalmarsund. The boreholes were situated in two sections across Kalmarsund, a few kilometres NE of Kalmar. In his view, the core material probably indicates an alternation between morainic and fluvial layers, which seems to support the interpretation of a terminal line at Kalmar. However, Königsson (1967 a, p. 273) pointed out that the core material is not a final proof of the validity of the terminal line theory.

Some moraine ridges on Öland, which supported the terminal line theory in the Kalmarsund region at the beginning of this century, were later investigated in some places (Königsson 1967 b, p. 55). According to him, the ridges are mostly built up of beach sediments and consequently are not moraine ridges, at least not in their present state.

The terminal moraine zones in the southern part of the county, the Kalmar line and the Karlslunda line, are thought by several authors to form part of great terminal lines. Mörner (1969, p. 127) correlates the moraine ridges in this area with the ice marginal lines in southern Scandinavia. Still no final proof of this theory has been presented. No pit in these ridges has been described, and almost the only proof of the terminal line theory is the location of the ridges, which corresponds with the terminal lines from other regions in southern Sweden.

Knutsson (1960, pp. 40—73) made a detailed study of the till surrounding the Nybro esker. He proved the difficulties of examining till and his study was the first modern till investigation in the Kalmar area. He determined the relation between the lithological composition and the bedrock. Furthermore, he observed many types of moraine ridges together with transitional deposits between till and glaciofluvial sediments. The boulder content of the till varies somewhat. Knutsson found two connections regarding the boulder content: one concerning the topography and the other the bedrock (Knutsson 1960, pp. 44—45). In the coastal region the till is often very poor in boulders and has a high frequency of sandstone.

The relation between sandstone and Precambrian in the grain size fraction 2—6 mm of the till in the coastal region was investigated by Carlstedt (1970). He found that the sandstone was comparatively frequent in this fraction. There is a sharp demarcation between samples containing sandstone and samples with only Precambrian gravel grains. The sandstone content however is highly irregular. His investigation probably indicates the occurrence of two different tills, according to the sandstone frequency. Samples taken in moraine ridges usually contain more sandstone than those derived from ordinary till deposits.

THE PRESENT INVESTIGATION

In the investigated area all types of till occur, from boulder clay in the coastal region to gravelly till having a high frequency of boulders in the western part. The till usually has a medium boulder frequency, but in some places boulders are numerous. There are topographical features in the investigated area which suggest ice activity in a late phase of the deglaciation. Furthermore, ablation till occurs at and above the highest shore line. It has been formed in connection with the washing away of a stagnant ice.

Samples of till were taken in the B-horizon at a depth of about 40 cm beneath the ground surface. The weight of the samples varied from 2 to 2.5 kg. Before analysis, the samples were pretreated with hydrogen peroxide (Jackson 1965) to remove organic material, and with sodium dithionite and sodium citrate (Mehra and Jackson 1960) to remove free iron oxides. The grain size distribution of the samples was determined by sieving for 15 minutes and by pipette analysis (Krumbein and Pettijohn 1938). All particles greater than 20 mm were removed before sieving.

Lithological composition. Samples of till were taken along the Bäckebo and Persmåla eskers in the coastal region in order to compare the lithological composition of the glaciofluvial deposits and the till, and to establish the transport distance of the esker material and the till. After sieving the samples, three grain size fractions were analysed with a stereo microscope, using a magnification of between 6 and 40 times. The fractions were: coarse gravel (5.6—20.0 mm), fine gravel (2.0—5.6 mm) and coarse sand (1.0—2.0 mm). Attempts were made to examine smaller components but it was impossible to separate sandstone grains from Precambrian quartz grains in fractions smaller than 1.0 mm. The Precambrian rock units were not divided because of the difficulties, and the purpose of this examination. Besides, it is only the boundary between the Precambrian and the sandstone region which is fairly well-defined (see p. 0). The position of the sampling localities are shown in Fig. 5. At some of the esker localities, samples were taken in different layers at various depths. More than 400 grains were counted, except in the coarse gravel fraction, where all grains were analysed (cf. J. Lundqvist 1952, pp. 11—12).

Five samples of till (I—V) were taken and analysed for this purpose. Samples I, III and IV derive from a till landscape with small hills, sample II, from one of the terminal end moraine ridges, and sample V, from an estuary end moraine ridge along the Persmåla esker near the Precambrian border. The results are presented in Table 2.

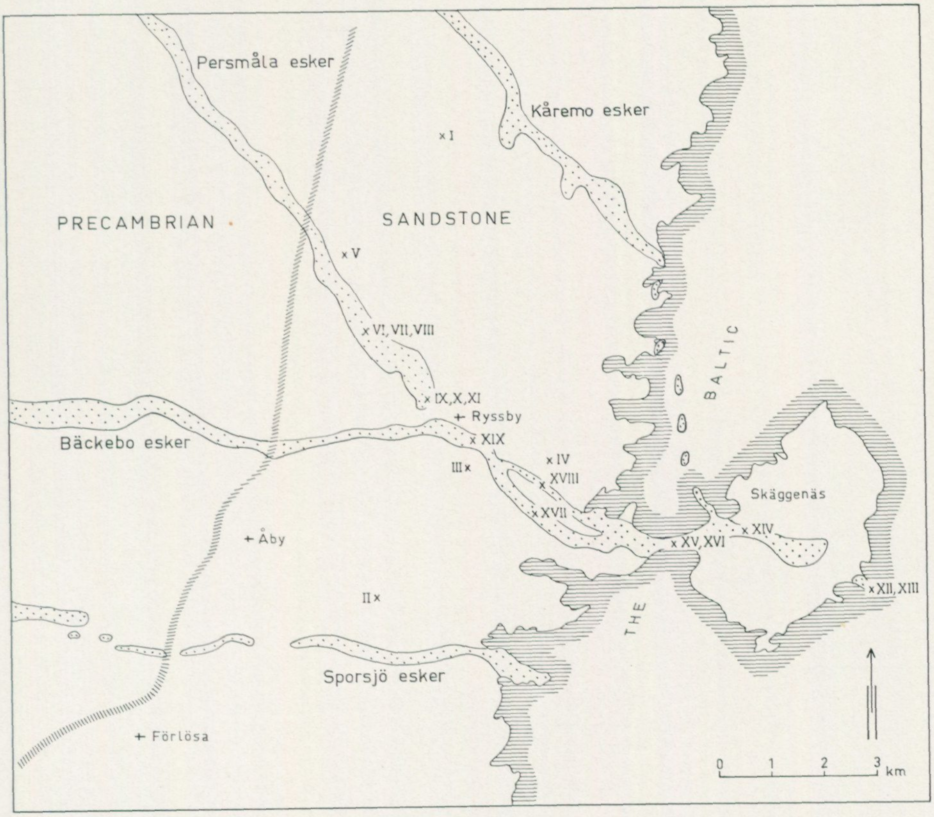

Fig. 5. Map of the northern part of the coastal region. The localities, where samples were taken for lithological determination, are marked (I—XIX).

TABLE 2. Lithological composition (in per cent) of the till in the coastal region at Kalmarsund

sample number	coarse gravel 5.6—20 mm			fine gravel 2.0—5.6 mm			coarse sand 1.0—2.0 mm		
	particles counted	Pre-cambrian	sand-stone	particles counted	Pre-cambrian	sand-stone	particles counted	Pre-cambrian	sand-stone
I	83	59	41	579	75	25	437	81	19
II	272	16	84	907	34	66	538	72	28
III	301	29	71	544	37	63	749	69	31
IV	230	16	84	507	17	83	448	56	44
V	478	9	91	452	31	69	498	93	7

The frequency of sandstone is highest in the coarse gravel fraction and lowest in the coarse sand fraction. The differences between the frequencies of sandstone are very large in the different fractions. The frequency of sandstone in e.g. sample II is 84 % in the coarse gravel fraction and only 28 % in the

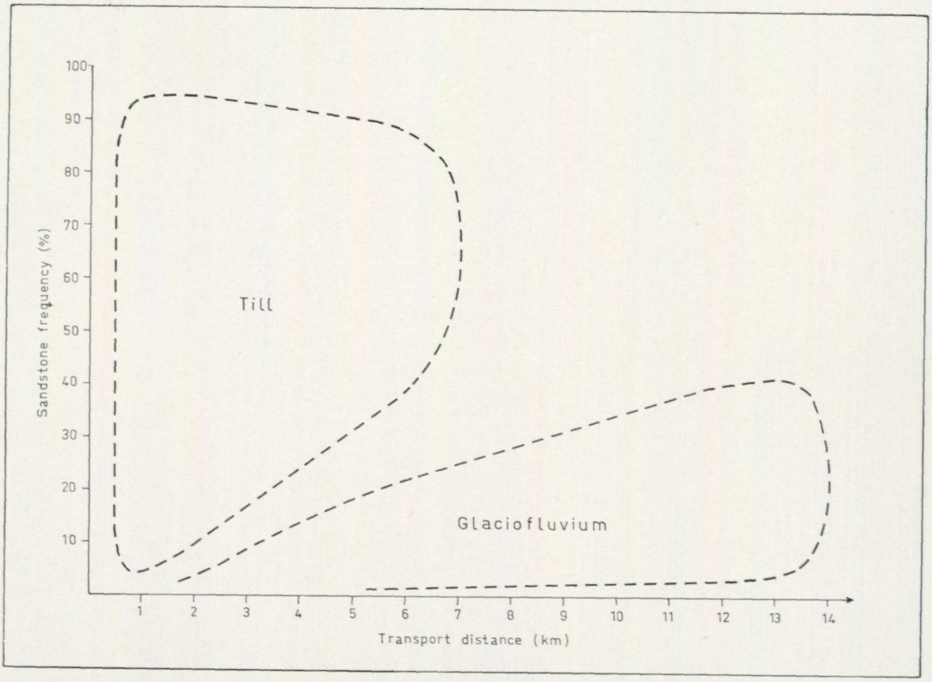

Fig. 6. Diagram showing the relation between the sandstone frequency (per cent) and the transport distance from the Precambrian border (km).

coarse sand fraction. Thus it is better to examine as many fractions as possible when analysing the lithological composition of till material. Usually, only the coarse gravel fraction has been examined in earlier works.

In order to calculate the transport distance of the sandstone material, an ice movement towards S 45° E was postulated. With this estimate, the transport distance from the Precambrian border to the sampling localities is roughly: No. I 2 km, No. II 3 km, No. III 4.5 km, No. IV 6 km and No. V 1 km.

The analysis results of samples I, III and IV indicate an expected and almost homogeneous picture. A long transport distance over the sandstone area gives high frequencies of sandstone. All these samples were taken in the same kind of till deposits, a till landscape with small hills. An indication of the sandstone frequencies in relation to the transport distance of the material can be seen in Fig. 6.

Samples No. II and V have high frequencies of sandstone material. The till at these localities was probably transported over a very short distance. The locality where sample No. V was taken is situated very near the Precambrian border in an estuary end moraine along the Persmåla esker. There are great differences in the sandstone frequency between the different grain size fractions. The frequencies are 91 % in the coarse gravel fraction and 7 % in the coarse

Fig. 7. A till pit in an estuary end moraine at the Persmåla esker near the Precambrian border. The till is gravelly, with a high frequency of angular sandstone stones. Photo T. Wiklund 1974.

sand fraction, regarding the sandstone. The sample was taken 2.5 m below the surface in a till pit (Fig. 7). The sandstone particles in this pit are very angular and occur almost exclusively as boulders, stones and gravel. The sandstone has not been broken down to sand and silt because of the short transport. They occur almost *in situ*.

Sample II was taken in one of the marginal moraine ridges and also has a high frequency of sandstone material. As in sample V, there are great differences in the sandstone frequencies between the coarse gravel fraction (84 %) and the coarse sand fraction (28 %).

This lithological investigation of the till indicates that the ice in the coastal region at Kalmarsund was probably active and had a great erosive capacity during the deglaciation phase. All till samples have high frequencies of sandstone material. There are also many different moraine ridges in this region, which also indicate an active ice with great erosive capacity during the deglaciation phase.

This lithological investigation does not suffice to describe the composition of the till in the coastal region at Kalmarsund but it does give an indication of the composition. The frequency of local rocks is high in all the samples. There

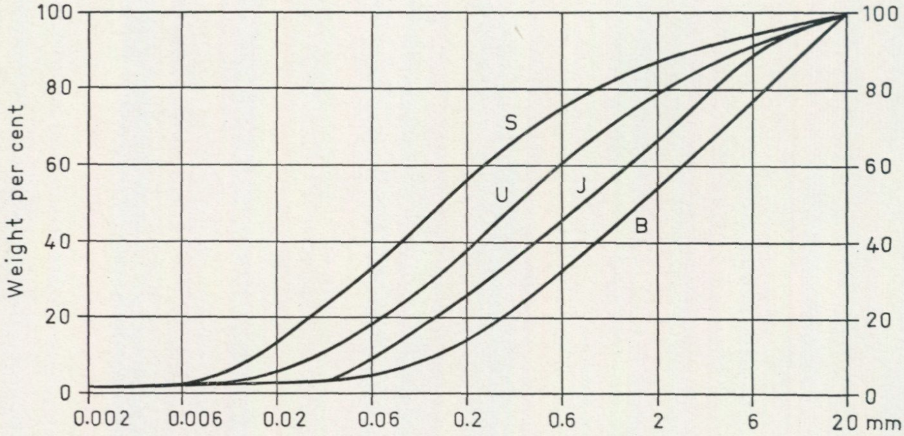

Fig. 8. Grain size distribution of till: Sjöbo, Uddevallshyltan, Jonsryd and Böle.

is a significant difference in the sandstone frequency between the till and the glaciofluvial deposits (see also p. 40).

Grain size distribution. In order to describe the grain size distribution of the till, samples were taken at the highest shore line, along the Bäckebo and Persmåla eskers, and in the northern part of the investigated area. Normally the till is sandy throughout the investigated area (see pp. 59—67 and Fig. 8).

In the coastal region, the till has a somewhat unusual grain size distribution. Often, there is a high frequency of sand particles (Carlstedt 1970, pp. 6—7) and the cumulative curve indicates a bimodal distribution. This is probably because the sandstone grains have been broken down to sand but not to smaller components. If a till consists mainly of one rock type, the grain size distribution is bimodal (Dreimanis 1969, p. 22). Near the Precambrian border there is a high frequency of gravel (sample V). There was probably a fast breakdown of the sandstone material.

The till surface often has a medium boulder frequency (Fig. 9), but large areas, especially in the southern Swedish uplands, have a high boulder frequency (Knutsson 1960, Mattsson 1955). Also in the investigated area there are till surfaces with high frequencies of boulders. Sometimes, periglacial phenomena have been developed, such as boulder depressions (Fig. 10) and indistinct patterned ground (Fig. 11). In all probability these features indicate that the deglaciation phase occurred during a period with a cold climate.

Interior structure. There are many glaciofluvial eskers in the investigated area, and therefore few till pits occur. One of the best localities for studying the interior structure is the pit in the estuary end moraine where sample No. V

Fig. 9. Hummocky moraine with a medium boulder frequency. View looking east at the Konungahultet hill. Photo T. Wiklund 1974.

Fig. 10. Boulder depression 2 km ENE of Bäckebo church, at the Bäckebo—Abbetorp road. View towards the west. Photo T. Wiklund 1974.

Fig. 11. Indistinct patterned ground 2 km ENE of Bäckebo church, at the Bäckebo—Abbetorp road. View towards the north-east. Photo T. Wiklund 1974.

was taken. As Fig. 7 indicates, the till is of local origin and is homogeneous except for a lens of fine sand. Other till pits often show the same interior structure. The till is normally homogeneous with high frequencies of local rock units and rich in lenses of fine sand and silt. The size of the lenses ranges from a few centimetres up to one metre.

Morphology. There are many different types of moraine ridge in the investigated area, probably produced by active ice. In the southern Swedish uplands there are large drumlin regions (Knutsson 1960, Persson 1972). In the transitional zone many types of moraine ridges occur. Sometimes they run NW—SE, sometimes NE—SW. In the coastal region, there are different types of marginal moraine ridges such as end moraines, which also occur at the bottom of Kalmarsund (Dannstedt 1947, Bergdahl 1947, Königsson 1967 a), and estuary end moraine ridges along some glaciofluvial eskers.

The drumlins are in most cases located to the west of the investigated area. They consist of compact basal till, usually with a core of bedrock. They are often cultivated and the farms stand on the tops of the drumlins. The drumlins have the same direction as the last ice movement. The Högebo drumlin, 5 km

NE of Nybro, is about 200 m wide and 600 m long, running NW—SE. It rises about 15 m above the surrounding terrain. It has a core of bedrock and consists of compact basal till.

The transitional zone is rich in small ridges, but no detailed investigation has been carried out. Probably, the morphology is to some extent determined by the bedrock surface. In some parts of this zone, radial moraine ridges occur, running NW—SE. Their height varies from 1 to 5 m and their length from 25 to 200 m. The surfaces often have a high boulder frequency.

Vast areas with hummocky moraine occur at and above the highest shore line. The composition varies, indicating a complex origin (cf. Johansson 1972, p. 46). No investigation of the hummocky moraine landscape has been made.

Estuary end moraine landscape occurs along some of the eskers. The most distinct estuary landscape in the coastal region is developed along the Persmåla esker, 1—2 km N of Rockneby church. On both sides of the esker, small moraine ridges have been formed. They form an oblique angle to the esker in a fish-bonepattern.

The development of the estuary end moraine landscape along the Persmåla esker probably occurred during the last phase of the deglaciation by active ice. Estuary end moraine ridges are also found around other eskers, probably indicating active ice during the last phase of the deglaciation in the whole coastal region.

The terminal end moraine ridges in the coastal region have been investigated by several authors (see pp. 20—21). Unfortunately, only position and morphology have been studied.

The end moraine ridges of the Kalmar line are more or less parallel to the coast south of Kalmar. It is possible to distinguish these ridges on different maps, the ordnance map, the new topographical map and the economic map, even at the bottom of Kalmarsund. Some of the ridges at the bottom of Kalmarsund seem to be very high, about 10 m. Ashore, they have been transformed by wave-washing to a large extent and the characteristic features of end moraines have disappeared in many places. G. Lundqvist (1961, p. 48) did not observe any features of end moraines in the vicinity of Kalmar. According to him the ridges are very flat, nor do they resemble any other types of end moraines. The flat morphology of the ridges is probably dependent on wave-washing. The ridges have been entirely transformed.

In the countryside round of Kalmar, the relative distance between the different ridges increases. It is not possible to locate exactly each end moraine ridge in the Kalmar area without detailed study. In some cases the ridges continue over a great distance, which makes is possible to locate them, and thus the position of the ice border during the deglaciation phase. The most distinct one of the end moraine ridges near Kalmar is that at Skälby (Fig. 12).

The orientation of the end moraine system changes at Kalmar. To the south

Fig. 12. The Skälby end moraine. View towards the north at Skälby. Photo T. Wiklund 1974.

the ridges are more or less parallel with the coast, while they are formed as large circles around Kalmar and continue towards ENE north of Kalmar (see also p. 74).

The size of the end moraines varies at Kalmar. Sometimes it is impossible to say whether a single small till deposit belongs to the end moraine system, owing to its small size. In some cases the end moraines are as high as 10—15 m with a breadth of 200—300 m (Fig. 12).

North of Kalmar, the end moraine ridges are not as distinct as they are southwards. The ridges run WSW—ENE and can be distinguished even at the bottom of Kalmarsund (cf. Bergdahl 1947, Königsson 1967 a). The end moraine system extends for about 10 km to the north of Kalmar.

In regions outside the investigated area, there are no end moraine landscapes similar to that at Kalmar. Ringberg (1971, p. 20) did not observe any ridges, which could be regarded as end moraines in the eastern part of the province of Blekinge.

To the north of the investigated area, only a few end moraines were found (Munthe 1904, p. 78, Svedmark 1904, p. 53). However, no detailed investigation of end moraines was carried out in the central region of the county of Kalmar.

GLACIOFLUVIAL DEPOSITS

GENERAL

The frequency of glaciofluvial deposits in the counry of Kalmar is relatively high. There are many glaciofluvial eskers, running roughly SE—NW. These deposits have recently been investigated in the southern and central parts of the county (Knutsson 1960, 1965, Johansson 1968). The glaciofluvial deposits were surveyed in connection with the geological map. Fig. 13 is based on the results of this investigation. There are a few small glaciofluvial deposits in the investigated area, which had not been observed earlier. They are of very small dimensions, and do not change the general picture.

According to Bergsten (1943, p. 185), the investigated area belongs to the regions called ”the eskers of the Kalmar plain” and ”the imcompletely terminal deposits in the Kalmar area”. Opinions differ on the morphology and the extent of the glaciofluvial deposits in the county of Kalmar. Nordenskjöld (1944, p. 14) considers that the eskers are very well-developed and beautiful. G. Lundqvist, on the other hand, maintains that the glaciofluvial deposits are of exceptionally small extent. The deposits are slightly stratified and seem to be of a local type (G. Lundqvist 1958, p. 59).

There are many eskers in the investigated area. They usually measure 5—15 m in height and 25—150 m in breadth (Fig. 14). The Högsby esker, to the north of the investigated area, and the Nybro esker are of much larger extent.

The eskers in the investigated area are, from north to south: the Kåremo esker, the Persmåla esker, the Bäckebo esker, the Sporsjö esker and the Ljungby esker. Most of them are of fairly small extent, but continuous and long in most cases. Furthermore, some very small ridges of glaciofluvial material occur in the vicinity of Kalmar.

There are many gravel pits in the eskers, which expose their internal stratification. Different kinds of stratification occur. Johansson (1960) made a great number of analyses in the Nybro esker, regarding the transport direction and deposition of gravel and pebbles. Investigations of the internal stratification of the eskers have been made, but the results are not presented here. Generally the pits are small, and most of them are old. Therefore, these investigations do not present a clear picture of the internal stratification.

The almost total lack of glaciofluvial deposits in the vicinity of Kalmar is somewhat confusing. In a triangular region of about 600 m^2 (Fig. 13) no glaciofluvial deposits occur, apart from some very small hills. The eskers outside this region have a somewhat remarkable orientation. In the coastal region the Sporsjö esker in the north runs E—W and the Ljungby esker in the south, a subsidiary esker of the Nybro esker, is running in SSE—NNW.

The glaciofluvial deposits are described from north to south in the following pages. The Nybro esker has recently been studied in detail by Johansson (1960)

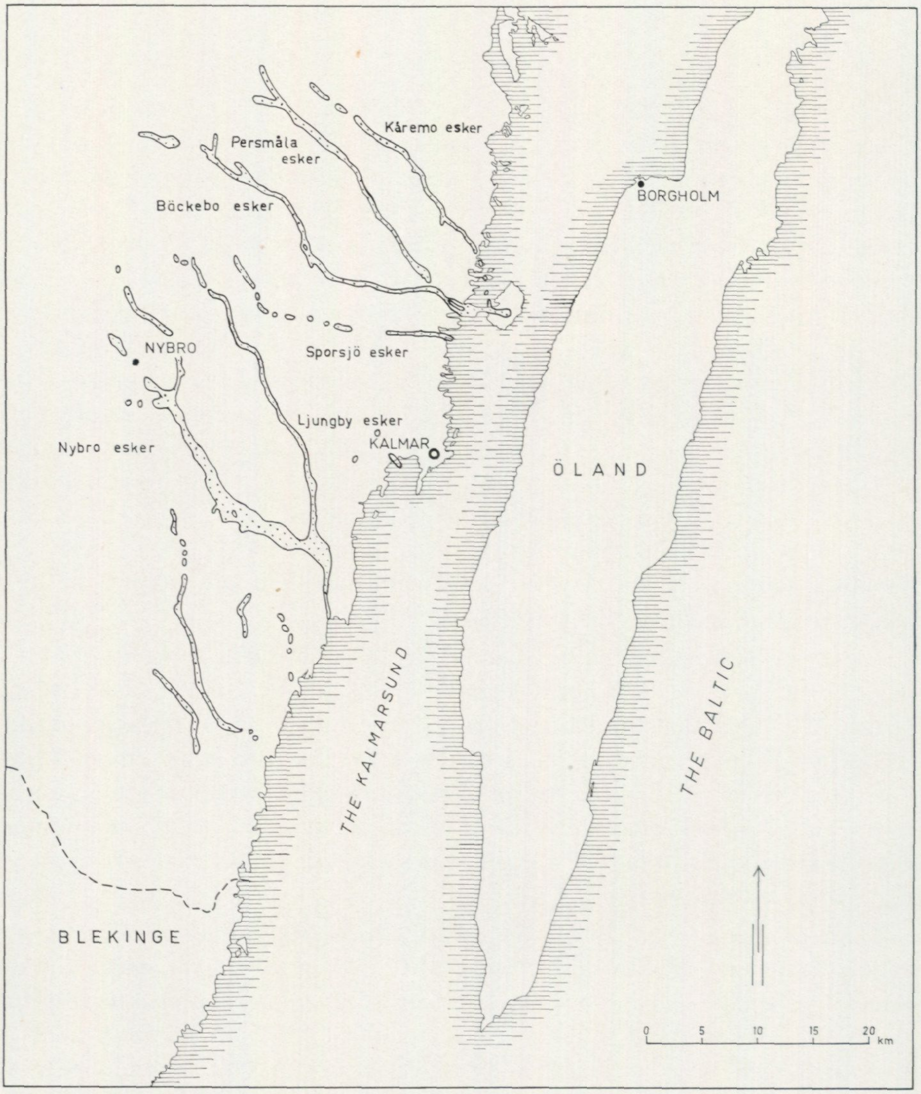

Fig. 13. Generalized map of the glaciofluvial deposits of the investigated area and its vicinity. Compilation from the geological maps SGU Ac 6 and 8.

Fig. 14. The Bäckebo esker at Luvehult. View towards the south-east. Photo T. Wiklund 1974.

and Knutsson (1960, 1965). Thus no investigation was made of this deposit. The description has been supplemented when the deposits are important for the interpretation of the ice recession in the investigated area.

THE KÅREMO ESKER

The Kåremo esker is a small subsidiary esker of the Bäckebo esker, running SE—NW for a distance of almost 30 km from the Skäggenäs peninsula. Investigations of the Kåremo esker were made by Munthe (1902 a, 1904) and Knutsson (1965).

The Kåremo esker begins in an association with the Bäckebo esker in the western part of Skäggenäs peninsula. The extent of the esker is here small, being less than 5 m high and 25—75 m broad. The orientation is almost straight to the north at the coast. Glaciofluvial deposits can also be observed on some small islands. Between these islands, it is possible to locate the Kåremo esker at the bottom of Kalmarsund on the new topographical map.

Ashore the orientation is towards the NW. It is a distinct alteration of the esker orientation from S—N at the coast to SE—NW further towards the north. The dimensions are rather small. In some cases it is difficult to distinguish the esker from till and beach deposits. The effect of abrasion is very conspicuous in the coastal region, so that the esker has therefore an asymmetrical profile.

At Kåremo, about 9 km from the Skäggenäs peninsula, the Kåremo esker becomes larger and forms a rather distinctive element in the landscape. The deposit consists in most cases of sand and gravel with some sandstone boulders. These boulders can be observed even to the west of the Precambrian border. There are many small pits in this area and in some cases till underlies the esker material.

Further towards the NW, in the vicinity of Åbro, the Kåremo esker is somewhat smaller in extent. The esker has a relatively high frequency of boulders, which are sometimes of sandstone. The morphology varies in this area. In some cases the esker is distinctly ridge-shaped and while in others it has been abraded to a great extent.

The Kåremo esker, at 50—55 m above sea level, is of very small dimensions with a distinct ridge-shape. Here, in the area NW of Helgesbo, it resembles a supra-aquatic esker. Obviously, the esker has not been abraded to such a high degree that the original shape has disappeared. The height is usually about 5 m and the breadth varies between 5 and 25 m.

It is difficult to locate the Kåremo esker further towards the NW. The topography is undulating and the esker has often the shape of small hills. Possibly there is a continuation, but it is impossible to locate its limits without investigations in detail. In this area, there are hills, which are built up of both glaciofluvial material and till.

The Kåremo esker is a relatively small esker. In some places it forms a distinct element in the landscape. The material is usually gravel and sand. In some places, till underlies the glaciofluvial material. The orientation is SE—NW, except at the coast, where the esker runs S—N. In the northernmost part, the Kåremo esker is developed as a supra-aquatic esker. All the way from the coast to about 50—55 m above sea level, the effect of wave-washing is very distinct, while most of the esker shape is still preserved at levels above 50—55 m.

THE PERSMÅLA ESKER

The Persmåla esker was investigated previously by Munthe (1902 a, 1904) and Knutsson (1965). Like the Kåremo esker, it is a subsidiary esker of the Bäckebo esker, running SE—NW from the village of Rockneby to the lake Stensjön, a distance of about 25 km. The dimensions vary, from only one or two metres in height and 10—20 m in breadth to 20—25 m high and 300—400 m broad.

The Persmåla esker begins near Rockneby church at a distance of about 100 m from the Bäckebo esker. The esker is here very large, about 400 m wide and 25 m high. Morphologically, it forms a very distinct element in the smooth landscape.

The glaciofluvial material is very coarse (Fig. 15). There are many sandstone boulders, which are angular (Fig. 16), indicating an occurrence almost *in situ*. The Precambrian border is situated west of the great gravel pit at Rockneby (Fig. 17). Samples of sediments have been taken from different layers in the pit (Nos. VI—VIII). Futhermore, samples have been taken near Rockneby church at different depths (Nos. IX—XI). The results of the lithological analyses are presented in Table 3.

Fig. 15. Very coarse glaciofluvial material in the Persmåla esker in the large gravel pit at Rockneby. View towards the north-west. Photo T. Wiklund 1974.

TABLE 3. Lithological composition (in per cent) of the glaciofluvial material of the Persmåla esker in the vicinity of Rockneby

sample number	coarse gravel 5.6—20 mm			fine gravel 2.0—5.6 mm			coarse sand 1.0—2.0 mm		
	particles counted	Pre-cambrian	sand-stone	particles counted	Pre-cambrian	sand-stone	particles counted	Pre-cambrian	sand-stone
VI	228	99	1	459	100	+	390	100	+
VII	312	100	+	466	100	—	429	100	+
VIII	403	100	+	516	100	+	360	100	—
IX	153	98	2	849	98	2	355	99	1
X	—	—	—	11	100	—	62	100	—
XI	25	100	—	809	99	1	477	99	1

The samples from the Persmåla esker near Rockneby show very low frequencies of sandstones. In comparsion with the till from the same area (cf. Fig. 5 and pp. 22—26), there is a significant difference in the sandstone frequency. The till has a much higher frequency of local rock units. The material in the glaciofluvial deposit seems to have been transported for a relatively long distance, while the till material probably have been transported a shorter distance.

The most distinct estuary end moraine landscape in the investigated area (cf. p. 29) occurs around the Persmåla esker at the large gravel pit of Rockneby.

Fig. 16. Angular sandstone boulders in the Persmåla esker near the Precambrian border at Rockneby. View towards the north-west. Photo T. Wiklund 1974.

The Persmåla esker is very wide and high at Rockneby and a large gravel pit has been opened here.

The Persmåla esker is of smaller dimensions further towards the NW, being about 200 m wide and 10 m high. The esker profile is somewhat asymmetrical, because of the influence of abrasion. The waves have affected the NE side of the esker. The material has been transported towards the SW and deposited on the SW side of the esker. There are many small gravel pits in this area. The material is rather coarse. All these pits are situated in the region with Precambrian rocks; nevertheless there are many sandstone boulders in the deposits, which is somewhat confusing. No sandstone material has been observed in the other Quaternary deposits. Nearly all glaciofluvial eskers in the

Fig. 17. The large gravel pit at Rockneby. View towards the north-west.
Photo T. Wiklund 1974.

southern part of the county of Kalmar contain sandstone boulders even in the Precambrian region in the southern Swedish uplands (Knutsson 1965). There are different possible explanations of this fact:

1. The sandstone boulders have been transported for a very long distance from one of the present sandstone regions in the south of Sweden.
2. An ice stream from the Baltic has transported the boulders into the transitional zone, and even into the southern Swedish uplands.
3. The sandstone region at Kalmarsund was formerly much larger and some remnants of this region may still exist. The most likely sandstone areas in the Precambrian region have been eroded in parts and the material can now be seen as boulders in the glaciofluvial deposits. This theory is the most feasible but does not explain the lack of sandstone material in till.

The dimensions of the Persmåla esker become smaller towards the NW. At Franketorp, the material is coarse with some boulders of sandstone. The esker is here almost cut off by till hills and bedrock outcrops. At about 65—70 m above sea level, the Persmåla esker is pronounced ridge-shaped. It is very small in extent, 4—8 m high and 20—75 m broad. The influence of abrasion has not been as conspicuous as further towards the SE.

At the village of Abbetorp, there are large areas with glaciofluvial deposits of various types, such as different kinds of ridges (Fig. 18) and a sand plateau (Fig. 19), similar to a delta. The level around Abbetorp is about 75—85 m above sea level. There is no typical esker net landscape at Abbetorp, but the Persmåla esker changes character completely at this level. The material is mostly coarse, as can be seen in many gravel pits. The Persmåla esker has

Fig. 18. A glaciofluvial ridge at Abbetorp. View towards the north-west.
Photo T. Wiklund 1974.

Fig. 19. A sand plateau at Abbetorp, just below the highest shore line. View towards the north.
Photo T. Wiklund 1974.

rather large dimensions about 1 km NW of the village of Abbetorp. Morphologically, it has a delta form, but no delta structures were observed. The level is here about 85 m above sea level.

The Persmåla esker divides further towards the NW. A subsidiary esker, the Mjösingsmåla esker, runs west-north-westwards, and the main esker continues towards the NNW. The Mjösingsmåla esker is about 3 km in length. It is of minor extent and has a high frequency of boulders on the surface. The esker becomes indistinct at the village of Mjösingsmåla. Further towards the west is is no longer possible to distinguish the till from the glaciofluvial material.

The main esker continues for a distance of 5 km from the division. It has a pronocunced ridge-shape all the way. The esker extends along the eastern side of the lake Stensjön and comes to and end north of Stensjön.

It is possible that some hills further towards the north contain glaciofluvial material, but it is impossible to distinguish the esker continuation in the hilly landscape to the north of the lake Stensjön.

The Persmåla esker is an esker of fairly large dimensions and forms, morphologically, a distinctive element in the landscape. The material is mostly coarse, with many sandstone boulders, also west of the Precambrian border. The orientation is SE—NW. The esker profile is usually asymmetrical, owing to redeposition by wave-washing. About 65—70 m above sea level the wave-washing effect is not as obvious as further towards the SE. Around the village of Abbetorp, about 75—85 m above sea level, the esker has a large dimension with different types of deposits. Above this line, the Persmåla esker is formed as a supra-aquatic esker with very small dimensions.

THE BÄCKEBO ESKER

The Bäckebo esker has rather large dimensions. It is the most important glaciofluvial deposits in the investigated area and it is often sinuous. In the coastal region, the orientation is almost E—W. The esker has been investigated by Holst (1893 b), Munthe (1902 a, 1904), Bergdahl (1947), Mattsson (1953) and Knutsson (1965).

It is possible to locate the Bäckebo esker on the bottom of Kalmarsund for a distance of at least 3.5 km. The orientation is here SSE—NNW, which is different from that found in the coastal region. The eskers north of the investigated area have an orientation similar to that of Kalmarsund only in the most eastern submarin part. Closer to the coast, they have the same NW—SE orientation as they have ashore. Bergdahl (1947) investigated the glaciofluvial deposits on the bottom of Kalmarsund and found that the Bäckebo esker has relatively large dimensions here.

Ashore the influence of abrasion is great. Almost every deposit has been redeposited on Skäggenäs peninsula, and beach deposits cover a large part of the peninsula. There are enormous beach ridges here, described by Munthe (1902 a), Thomasson (1926) and Rudmark and Sturesson (1970). A detailed investigation proved that the Bäckebo esker is almost continuous on the Skäggenäs peninsula but is usually covered with thick layers of beach deposits

(Rudmark and Sturesson 1970). The glaciofluvial deposit on the peninsula is covered in some places by beach deposits about 2 m thick.

The abrasion is also remarkable further west. There are two more or less parallel esker ridges from Skäggenäs peninsula to the village of Rockneby. Their dimensions are about 5 m high and about 100 m wide. It is possible, that one of the ridges belongs to the Bäckebo esker and the other to the Persmåla esker. This assumption cannot be proved without detailed investigation of the lithological composition. The material consists mostly of gravel and sand with an exceptionally low frequency of boulders.

Samples have been taken of the Bäckebo esker in the coastal region, and they have all been prepared before analysis (cf. p. 22). The positions of the sample localities are shown in Fig. 5.

TABLE 4. Lithological composition (in per cent) of the glaciofluvial material of the Bäckebo esker in the coastal region, from Skäggenäs peninsula to the village of Rockneby

sample number	coarse gravel 5.6—20 mm			fine gravel 1.0—2.0 mm			coarse sand 2.0—5.6 mm		
	particles counted	Pre-cambrian	sand-stone	particles counted	Pre-cambrian	sand-stone	particles counted	Pre-cambrian	sand-stone
XII	455	62	38	523	69	31	342	88	12
XIII	562	66	34	306	71	29	411	91	9
XIV	451	75	25	650	85	15	708	92	8
XV	126	78	22	761	87	13	556	95	5
XVI	58	81	19	571	90	10	439	95	5
XVII	343	83	17	492	88	12	477	95	5
XVIII	302	86	14	505	89	11	339	91	9
XIX	668	100	+	609	100	+	728	100	+

In Table 4, the samples are arranged in order of transport distance from the Precambrian border. The glaciofluvial material in sample No. XII was transported the greatest distance from this border, while that in sample No. XIX was deposited only some kilometres from the border.

Samples XV and XVI have been taken at various depth and in different layers in the same esker pit.

Table 4 shows an almost homogeneous and expected picture. There is a continuous increase of the sandstone frequency in the glaciofluvial material from the Precambrian border towards Kalmarsund. At localities where two samples have been taken at different depths (samples XII, XIII and XV, XVI) there are no differences in the sandstone frequency. On the other hand significant differences are found between the different grain size fractions. Coarse gravel always has higher frequencies of sandstone material in relation to the other investigated fractions while the sandstone frequency is lowest in the coarse sand fraction.

A comparison of the lithological composition of till and of glaciofluvial material in the Kalmarsund area indicates that there are large and significant differences. The till in the coastal region shows high frequencies of local rocks (sandstone) while the glaciofluvial material has often been transported for a long distance. The statistical basis is probably somewhat insufficient but there is no doubt that a significant difference exists. It is impossible to compare the lithological composition of the Bäckebo and Persmåla eskers owing to their relation to the Precambrian border. The material of the Persmåla esker is almost exclusively Precambrian. The two almost parallel eskers east of Rockneby village have almost the same sandstone frequency (samples XVI and XVII) and this suggests that they may belong to the same glaciofluvial deposits.

A great number of studies discuss the lithological composition of Quaternary deposits, e.g. Gumaelius 1876, Hellakoski 1930, Okko 1945, J. Lundqvist 1952, Repo 1957, Virkkala 1958, Gillberg 1955, 1965, 1967, 1968, Knutsson 1960, Carlstedt 1970 and Persson 1973. Lithological relations between till and glaciofluvial material have given varying results and divergent views. The explanation is that there are many aspects of the subject to be considered, such as:

1. The erosive capacity of the land ice.
2. The difference between local and far-travelled material owing to the topography.
3. The different units of eroded bedrock.
4. Different ages and layers of the material.
5. The dimensions of the glaciofluvial deposits and the extent and erosive capacity of the meltwater streams.
6. Varying directions of different ice streams.

The Bäckebo esker is continuous west of Rockneby village. Here it stands out against the smooth landscape. The height is about 5 m and the breadth about 50—100 m. The esker profile is asymmetrical, owing to the abrasion. The orientation is almost straight E—W, which is somewhat unusual. At St. Vångerslät village, near the Precambrian border, the frequency of sandstone conglomerate boulders is very high. The Bäckebo esker is here segmented with distinct mounds and valleys (Fig. 20). At a distance of about 1.5 km there are eight esker mounds about 150—200 m apart. The mounds are 1—7 m in height.

The theory of the segmented esker formation was first presented by De Geer (1897). The feature is rare and no other eskers in the investigated area have this distinctly segmented form. According to De Geer's theory, the ice recession velocity was about 150—200 m per year in this area.

To the west of St. Vångerslät village there are some moraine ridges at an oblique angle to the Bäckebo esker. They are probably estuary end moraines but no detailed investigations have been made to prove it.

Fig. 20. The segmented Bäckebo esker at St. Vångerslät village, indicating an ice recession velocity of about 150 m per year. View towards the west. Photo T. Wiklund 1974.

The Bäckebo esker completely changes character west of St. Vångerslät village. It becomes very wide, about 200—500 m with a height of about 5—10 m (Fig. 21). The material consists of gravel and sand with a low frequency of boulders. The esker has been considerably transformed by the waves and many beach ridges can be observed on its sides. The altitude is here about 25—45 m above sea level. The esker changes orientation in this area from E—W in the coastal region to SSE—NNW.

At Gelebo village there is a large kettle-hole. The size is about 400 ×600 m and it is the largest kettle-hole in the investigated area. Silt and till have been deposited in it and the surrounding esker ridges are about 10—15 m high.

At Luvehult village further towards the NNW, the Bäckebo esker is extensive. It is here developed as an esker net landscape (cf. pp. 56, 65) with a relative height of 20 m. The breadth is about 200 m. The effect of abrasion is distinct up to 85 m above sea level. Two esker ridges reach higher levels, and they surround a kettle-hole. No sediment has been deposited in this. Both the ridges and the kettle-hole seem to have preserved their original shape. The esker orientation changes from SSE—NNW to SE—NW at Luvehult village.

At Bäckebo village (cf. pp. 55, 63), the Bäckebo esker has very large dimensions. The breadth is 600 m and the relative height 15 m. An esker net landscape is developed here with many types of glaciofluvial deposits such as ridges, esker trenches, kettle-holes and, probably, deltas.

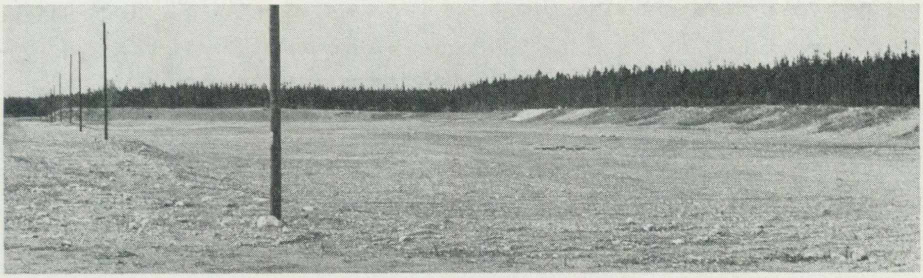

Fig. 21. The wide but low Bäckebo esker west of St. Vångerslät village. View towards the WNW. Photo T. Wiklund 1974.

Esker net landscapes are rather common in connection with large glaciofluvial deposits at the highest shore line. Nelson (1910, p. 29) is of the opinion that they generally occur somewhat below this line. J. Lundqvist (1958, p. 18), on the other hand, has rather frequently observed esker net landscapes and deltas above the highest shore line. The conditions for developing an esker net landscape seem to be a broken cracked ice or a dead ice with a channel system, in shallow water (Knutsson 1960, p. 111).

A subsidiary esker of small proportions occurs to the NW of Bäckebo church. It is almost parallel with the main esker. It is about 1.5 km long and it is rather distinctly segmented.

Further towards the NW the Bäckebo esker forms a very distinct element. The material is often rather coarse. There are some esker plateaux here with rather steep slopes. These plateaux are built up to about 85 m above sea level.

There is a subsidiary esker in this area, the Vackerslät esker (cf. p. 55). Its orientation is S—N. It is continuous for a distance of at least 2 km. The profile is completely symmetrical with a rather smooth top. The height is about 5 m and the breadth about 50 m. The Vackerslät esker is a plain esker, the top of which roughly indicates the highest shore line (cf. p. 55). The material is rather coarse and becomes towards the north a mixture of till and glaciofluvial stratified sediments.

The Bäckebo esker is not continuous further towards the NW. It is visible as isolated mounds of coarse glaciofluvial material. Between the mounds there are rock outcrops and sometimes till. Some of these esker mounds have rather large dimensions. The slopes are often steep, indicating ice-contact during the deglaciation. It is possible to locate glaciofluvial mounds, belonging to the Bäckebo esker, for a relatively long distance. The main orientation of the hills is E—W. They reach 90—100 m above sea level.

The Bäckebo esker is of considerable dimension. The orientation fluctuates somewhat. It is continuous all the way, except NW of Bäckebo village. For the most part it forms a very distinct element in the landscape. The material is usually coarse. At the St. Vångerslät village in the coastal region, the Bäckebo esker is very distinctly segmented, indicating an ice recession velocity of 150—200 m per year if the segments depend on an annual sedimentation cyclicity (cf. p. 41). At the Bäckebo village, there is an esker enlargement of an esker net landscape.

THE SPORSJÖ ESKER

The Sporsjö esker is of minor extent. It is continuous for only short distances and occurs mostly in elliptical mounds. The length is about 25 km. The Sporsjö esker runs E—W in the coastal region and in the eastern part of the transitional zone. In the western part of the transitional zone it runs SSE—NNW. Earlier studies of this esker have been made by Munthe (1902 a, 1904) and Knutsson (1965).

The Sporsjö esker begins on the coast of Kalmarsund and cannot be located on the sea bed at least not on the charts. The esker is very small at the coast and is sometimes difficult to locate. The effect of abrasion is severe and the Sporsjö esker has been transformed to a great extent. The material is often coarse with a high boulder frequency. The boulders are mostly of sandstone. The esker runs E—W near Kalmarsund, a somewhat unusual orientation.

Further towards the west the Sporsjö esker is also of minor extent. The orientation is the same, E—W. In some places till underlies the glaciofluvial material, which can be seen in some small gravel pits. The abrasion has transformed the esker to a great extent and in two places there are areas with only cobbles on the top of the esker. Even here, it is sometimes difficult to locate the esker. There are moraine ridges lying at an oblique angle on both sides of the esker in this area. They are most probably estuary end moraines.

The dimensions of the Sporsjö esker are rather large in the area around Sporsjö village, being about 200—300 m broad and about 5 m high. It is here continuous for some kilometres. The esker profile is somewhat asymmetrical, because of transformation by abrasion. The material consists mostly of gravel and sand, and the esker here runs E—W.

Further towards the west the Sporsjö esker consists of many small glaciofluvial mounds. Between the mounds, there occur rock outcrops and till. The material is rather coarse and sometimes there is a mixture of till material and glaciofluvial sediments. The esker orientation is E—W.

The Sporsjö esker changes character completely further towards the west. Here it runs SSE—NNW, a distinct alteration of the esker orientation in relation to that found in the east. The dimensions are still rather small but the esker here has a pronounced crest. The height is 2—5 m and the breadth 25—100 m. The esker profile is slightly asymmetrical. Obviously, the Sporsjö esker hase not been abraded to the extent that the original shape has disappeared. The altitude is here about 55—65 m above sea level.

It is possible to locate the Sporsjö esker further towards the NNW as small isolated mounds for a relatively long distance. The extent of wave-washing is very slight. In this area, some moraine ridges occur, lying at an oblique angle to the esker. They may be some kind of estuary end moraines, even if their position at a rather high level is somewhat unusual.

The material of the Sporsjö esker becomes morainic further towards the NNW and it is impossible to locate the esker with certainty without a detailed study of the undulating till landscape.

The most interesting features of the Sporsjö esker are the change in orientation from E—W to SSE—NNW, and the change from an abraded to a non-abraded esker over a short distance. The esker has rather small dimensions so that there are only a few gravel pits in it which show the material composition.

THE LJUNGBY ESKER

The Ljungby esker is a subsidiary esker of the large Nybro esker and has rather large dimensions. It is countinuous for a distance of about 30 km and generally runs SSE—NNW. It has been investigated by Munthe (1902 a, 1904), Dannstedt (1947), Bergdahl (1947), Johansson (1960) and Knutsson (1960, 1965).

The Ljungby esker begins from a junction with the Nybro esker at Vassmolösa. There is an enormous glaciofluvial deposit here, called the Hagby massif. The area is about 6 km^2 and the greatest thickness of the deposit is about 32 m. It has been investigated in detail concerning the interior structure and the lithological composition (Johansson 1960, Knutsson 1960, 1965).

The Ljungby esker runs towards the north from the Hagby massif. The morphology is somewhat complicated. Mostly there are two esker ridges of fairly large size and between them esker trenches and kettle-holes. The total breadth is 300—400 m and the height about 10 m. The abrasion was probably severe during the deglaciation phase so that the esker has been transformed to a large extent. The material is rather coarse in this area with a high frequency of sandstone boulders.

In the Ljungby—Trekanten area there are a great number of gravel pits and the esker has in most cases been completely excavated. It is sometimes possible to estimate the original shape. The abrasion had a large effect and resulted in wide areas of gravel and sand with a relatively high frequency of sandstone boulders. However, this frequency seems to be less here than southwards. The esker in this area runs SSE—NNW. The morphology is probably the same as further towards the SSE. There are parallel ridges with a total breadth of 300—400 m and a height of 5—15 m.

Towards the NW of Trekanten village, the Ljungby esker is 200—400 m broad and less than 4—7 m high. The abrasion has produced great changes in the esker. It is impossible to estimate the original shape. The material consists of gravel and sand.

Further towards the NW, the esker becomes more distinct. There are two or three parallel ridges with esker trenches and kettle-holes in between. The material is rather coarse and consists mostly of gravel and stones. The profile is somewhat asymmetrical, owing to the abrasion.

In the area around Kristvallabrunn village, the Ljungby esker has rather large dimensions being about 10 m high and about 300 m wide. There are many boulders on its crest and the profile is somewhat asymmetrical. The material is often coarse with a high boulder frequency.

Further towards the NW, the Ljungby esker reaches about 70 m above sea level. At Siggemåla village it is ridge-shaped with steep sides and fairly small dimensions. Abrasion has not resulted in the disappearance of the original shape.

An esker net landscape is found at Gunnabo village with three parallel ridges, beach ridges and esker trenches. This enlargement of the Ljungby esker has been described by Munthe (1902 a, pp. 64—65) among others. According to him abrasion can be observed up to about 82 m above sea level. The position of the highest shore line in this investigation (cf. p. 48) corresponds exactly with the former study of the Ljungby esker at Gunnabo village (Munthe 1902 a). Morphologically, there is an enlargement at the highest shore line and the crests of the ridges reach a higher level.

In the area west of Kristvalla church, the Ljungby esker is distinct and continuous non-abraded. It is fairly large with a height of 5—10 m and a breadth of 100—150 m. The composition is in some places a mixture of till and glaciofluvial sediments. The esker orientation fluctuates but is mainly SE—NW.

Further towards the NW, it is possible to distinguish the Ljungby esker as mounds for about 2 km. The material of the mounds is a mixture of till and glaciofluvial sediments.

The Ljungby esker has been transformed by abrasion, especially in the coastal region. There is a distinct change in type at about 85 m above sea level, from an abraded esker which partly has been transformed, to a non-abraded esker. At the same level, there is an enlargement in the form of an esker net landscape. In most cases, it stands out distinctly in the landscape. The material is usually gravel and sand. The boulder frequency is sometimes high, especially in the coastal region.

THE KALMAR AREA

In the Kalmar area, there are only a few very small glaciofluvial deposits (cf. p. 31). North of this area, there are seven large eskers, the distance between the farthest of them is 37 km along the coast; to the south, there are five eskers in 30 km. The reason for the almost total lack of glaciofluvial deposits here will be discussed later (p. 74).

In the Kalmar archipelago, there are some small glaciofluvial mounds. In all probability they constitute an incomplete esker with a SE—NW orientation. The mounds are visible over a distance of about 6 km. The abrasion has greatly transformed them.

A few very small and entirely isolated glaciofluvial deposits are found in the Kalmar area. No investigation in detail has been made in this area in order to locate glaciofluvial deposits but the possibilities of finding such in the Kalmar area are very slight.

GENERAL ESKER FEATURES

It is clear from the descriptions that all the glaciofluvial deposits in the investigated area show several general esker features. The orientation varies somewhat but, in rough outline, most of the eskers run SE—NW. In the coastal region and in some parts of the transitional zone all the eskers have been transformed by abrasion to a large extent. The abrasion effect was not as extensive at 50—80 m above sea level as at lower levels. At about 85 m above sea level there are usually an enlargement in form of an esker net landscape. Above these nets the eskers are developed as non-abraded ridge-shaped eskers of small dimensions. The material is here often morainic. Usually it is difficult to locate the eskers in the undulating till landscape owing to their small size.

THE HIGHEST SHORE LINE

GENERAL

The development of the Baltic has been greatly discussed during the twentieth century. Our present knowledge of the different stages has to some extent been established by investigations near Kalmarsund. The shore level displacement and the Baltic's development in this region have been investigated by e.g. Holst (1899), Munthe (1902 a, 1904, 1910, 1940), G. De Geer (1910), Thomasson (1927, 1935), G. Lundqvist (1928), E. Nilsson (1942, 1953, 1959, 1968), and Knutsson (1960); some of these are really pioneer works.

In the Kalmarsund region the highest shore line was developed during the deglaciation phase by the Baltic Ice Lake, the first stage of the Baltic after the last glaciation. The highest point of Öland reaches 57.4 m above sea level, which is far below the highest shore line.

The topography of the mainland at Kalmarsund is rather smooth, dipping slightly towards the SE which makes it a suitable object concerning the highest shore line. There was no vast archipelago during the deglaciation phase, so that the fetch length was considerable, and the abrasion on till slopes and eskers was severe. E. Nilsson (1958) has investigated local glacial lakes in the central parts of the southern Swedish uplands; such were also found close to the west of the investigated area (Knutsson 1960, p. 135). All former glacial lakes are probably not found, partly because of the lack of new topographical maps. Small local glacial lakes must therefore be considered with caution as they may be interpreted as related to the highest shore line.

EARLIER INVESTIGATIONS

The first information of the highest level reached by glacial clay and by thus a rough measure of the highest shore line was given by A. Erdmann (1865). His map provides a very good, although approximative picture of the extent of the glacial clay. In the province of Blekinge, Erdmann found glacial clay up to a level of 30—35 m, and in the southern and middle parts of the county of Kalmar up to 100—150 m above sea level.

Many localities, which, sometimes roughly, indicate the highest shore line, were found in connection with the geological surveying. Holst (1879, p. 33) observed glacial clay at Strömby, about 30 km SW of Kalmar, and suggested that the clay had the character of a glacial sea clay and occurred all the way up to a level of about 60 m. Further to the north, at Hultsfred, 20 km south of Vimmerby, Holst (1885, p. 52) considered that the glacial sea reached more than 100 m above sea level.

In his description of the geological map Kalmar, Munthe (1902 a, p. 72) presented an entirely new theory of the development of the Baltic. He was of the opinion that after the ice border retreated, a glacial lake, and not a glacial sea, was created. Munthe (1902 a, pp. 64—65 and 84) established the highest level of this glacial lake to about 82 m, 9 km NE of Nybro. Further to the north, at Flathult, 30 km NNE of Nybro, Munthe (1904, p. 98) considered the highest shore line to be about 89 m above sea level, and at Bockara, 20 km west of Oskarshamn, about 100 m. At the latter locality there is a glaciofluvial terrace. The plain of the terrace indicates the highest level of the Baltic Ice Lake.

In a general shore line displacement curve from the Kalmarsund region, Munthe (1902 a, 1904, 1910) stated that the highest shore line reaches 76 m above sea level in the Kalmar area. In 1910 he considered that gravel- and sandplains at Nybro (at 85 m) indicate the highest shore line.

Entirely different maximal values of the Baltic Ice Lake were presented much later by Munthe (1940). Concerning the Kalmarsund region, Munthe (1940, p. 42) was of the opinion that the region was for the most part covered by water. Terraces of till and gravel in exposed position about 5 km NW of Nybro indicated the highest shore line at 112 m above sea level. This was wholly contrary to his previous observations (1902 a). In the province of Blekinge his observations concerning the highest shore line ranged from 65—88 m above sea level (1940).

Before Munthe's glacial lake theory was published, De Geer (1890, pp. 61—110) presented all known observations of the highest, marine, late glacial shore line in Fennoscandia. He stated that the highest shore line on the border between Kalmar and Blekinge is found at about 65 m above sea level (De Geer 1890, p. 74). More over, De Geer (1910) later located the highest shore line at 82 m above sea level 5 km NE of Nybro, However, he regarded this observation somewhat uncertain.

Wholly different values of the highest shore line were presented by E. Nilsson (1953). He investigated the level of erosion notches and delta plains in southern Sweden, and depicted his results in a shore level displacement diagram (E. Nilsson 1953, Pl. IV). There were no observations from the area surrounding Kalmar. Only results from the northern part of the county of Kalmar and from the province of Östergötland were published in the so-called Småland—Östergötland diagram (E. Nilsson 1953, p. 242). The sites Berga and Gårdveda, to the north of the investigated area, have erosion notches at 105.0 and 150.0 m above sea level respectively. In Nilsson's opinion these notches were developed by the Baltic Ice Lake at a late stage. The highest shore line in the investigated area is placed at 150 m above sea level about 10 km NW of Nybro (Nilsson 1953, p. 177). This observation was later changed to 120 m (E. Nilsson 1959). On this occasion he also presented some other observations of the highest shore line from the Kalmarsund region, e.g. 135 m above sea level 40 km west of Oskarshamn. The difference of a highest shore line at 53 m in eastern

Blekinge, and 135 m west of Oskarshamn is notable. Over a distance of about 110 km in N—S the level of the highest shore line increases as much as 82 m.

Later E. Nilsson (1968) had no additional information from this area and according to him the highest shore line must be on a relatively high level in the Kalmarsund region.

In the area surrounding Nybro, Knutsson (1960, pp. 134—135) studied shore level displacement and he observed distinct marks of shore lines at different levels all the way up to 80 m. At this level he found littoral sand accumulations, probably indicating the highest shore line.

G. Lundqvist (1961) published observations of the highest shore line. The data from southern Sweden was based upon information from E. Nilsson. High levels were presented from the southern part of the county of Kalmar, which have since been the accepted levels of the highest shore line in the south-eastern part of Sweden.

Knutsson (1965) and Johansson (1968) studied the glaciofluvial deposits in the investigated area. They found many morphological features to indicate a changing character of the eskers from a sub-aquatic to a supra-aquatic type at levels between 80 m and 135 m. Johansson (1968, p. 24) placed the highest shore line at Ruda, 25 km SW of Oskarshamn, at a level higher than 85 m.

In a detailed investigation of the Nybro esker, Bramer (1960, p. 236) confirmed that the esker changes from a sub-aquatic to a supra-aquatic type at 80—85 m above sea level.

In the eastern part of the province of Blekinge, Bergdahl (1953, p. 43) placed the highest shore line somewhere between 63 and 65 m above sea level.

In the same region, Ringberg (1971, pp. 30—38) made a detailed study of the highest shore line and discussed the problems of its development. He investigated the limit of wave-washing on morainic slopes, a limit which here can be regarded as approximately synchronous. This limit fluctuates in level between 63.6 m and 67.5 m.

Opinions vary as to the morphological development of the highest shore line and the nature of shore marks which really indicate the highest shore line. Högbom (1896, p. 10) was the first to use the term limit of wave-washing. It is clear from his observations, that he used the expression to refer to the highest level at which the erosion of water can be observed.

De Geer (1898) and Munthe (1900—1940) used the terms beach ridges, erosion terraces, boulder notches and boulder zones without defining the relations between them and the former water level.

Granlund (1928, p. 12) pointed out the difficulties of determining the exact limit of wave-washing. He considered that the limit between wave-washed and non-washed till is a zone and not a sharp limit.

There are many variables which have a bearing upon, or sometimes protect, the development of a shore line. The exposure, the gradient of the slopes and the type of deposits are the main factors that must be taken into consideration (G. Lundqvist 1940, p. 57).

Terminology, methods, morphology and the relation between different shore marks and the water level was discussed by Bergsten (1943, pp. 187—195). He based his conclusions upon morphological observations. Gillberg (1952, p. 79) investigated the highest shore line in south-western Sweden and he discussed different methods of locating it. According to Gillberg (1952, p. 79) the highest shore line should be located at the lowest observed level of non-washed till in a slope.

A partly new method was introduced by Bergström (1963) in order to settle the highest shore line. His investigations show that the difference between wave-washed and non-washed till is especially visible in the proportion of silt and finer material. He pointed out that the limit of wave-washing does not exactly correspond to the highest water level. At localities with free exposure, erosion may occur several metres above the mean water level. However, for practical reasons, the highest limit of wave-washing has to be valid for the highest shore line.

The difficulties of determining the mean water level were demonstrated by Hörnsten (1964, pp. 182—188). He observed wide variations in level of the highest shore line on bedrock capped with moraine. He measured differences in height of more than 10 m within one locality. Hörnsten placed the highest shore line at the lowest established level of wave-washing.

THE PRESENT INVESTIGATION

The purpose of this investigation was to determine the highest shore line in the southern part of the county of Kalmar. No modern new topographical maps had been published when the field work was done. Thus it was difficult, and sometimes impossible, to find localities where the highest shore line was developed. The method used is a combination of these described above, i.e. morphological observations of shore marks and grain size analyses of till.

Till slopes between 70 m and 140 m above sea level were first examined in order to find the highest shore line. In order to eliminate shore marks which represented a small local glacial lake, it was necessary to find shore marks all the way from Kalmarsund up to the highest shore line (cf. Knutsson 1960, p. 134). Sometimes, a true limit of wave-washing is developed above the highest shore line but this limit there represents a level of a local glacial lake. The samples were pretreated before analysis (see p. 22). The profiles of the slopes and the sampling points were levelled by a tube, Wild NK 10. The levellings started and were terminated at a height station of the Geographical Survey Office of Sweden.

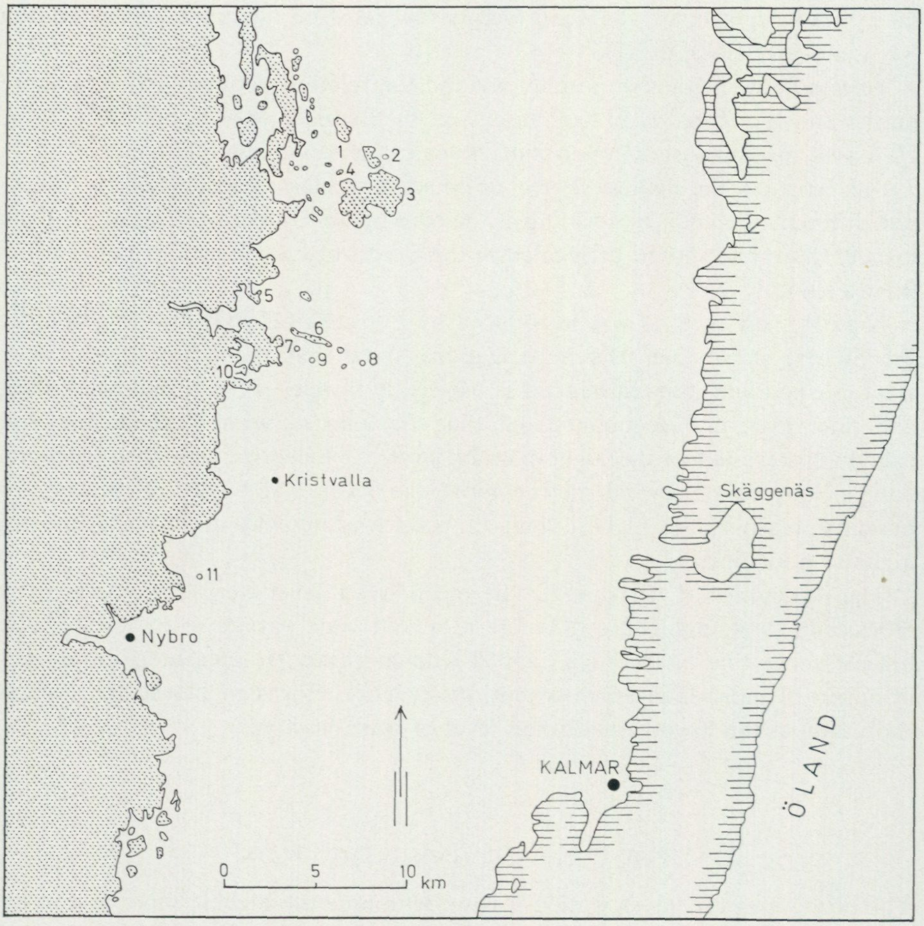

Fig. 22. The highest shore line in the investigated area.

Shore marks which could indicate the highest shore line, were examined and levelled in seven till slopes. The highest shore line zone is in the till slopes placed half-way between the highest washed and the lowest non-washed sample. The grain size distribution of the till varies widely from place to place and so it is impossible to compare two different localities.

The altitude of the highest shore line is given with a precision of 0.1 m. At the other localities, where morphological features indicate the highest shore line, the precision is given as a zone. For practical reasons, an average has been calculated.

In the investigated area eleven localities, all indicating the highest shore line, were investigated and levelled. The highest shore line is developed as an erosion limit at nearly all localities. Features, which sometimes complicate the examina-

Fig. 23. The upper limit of the boulder zone, indicating the highest shore line, on the eastern side of the hill of Konungahultet. View towards the west. Photo T. Wiklund 1974.

tion of the highest shore line in the investigated area, are periglacial processes and cultural activity. The highest shore line and all described localities indicating this line are marked in Fig. 22. The localities are described from north to south.

1. Arbåga, 300 m NE of the northern inlet of the lake Stensjön, entirely to the south of the Arbåga—Hornsö road. This area was protected during the deglaciation phase. Eastwards, there was an archipelago at this stage and the surrounding land generally reaches higher levels. Four samples were taken in a till slope (Figs. 26 and 27), two of which indicate wave-washing up to a level of 83.0 m (mean value of 82.5 and 83.5 m above sea level).

2. Konungahultet, 4 km north of Abbetorp, marked 96 on the ordnance map of Borgholm and on the economic map of Ruggstorp. The locality consists of a hill rising about 15—20 m above the surrounding terrain. Konungahultet hill and the Flathult area to the south are the most easterly areas in this region, which reach more than 90 m above sea level. No periglacial, cultural or other processes have been observed here. The hill is completely covered with till and beach deposits. There are organic deposits at the foot. All around the hill there is a vertical boulder zone of 5 m. This zone is most distinctly developed on the eastern and southern sides (Fig. 23). Non-washed till occurs above the boulder zone on the highest parts. Beneath the boulder zone there are

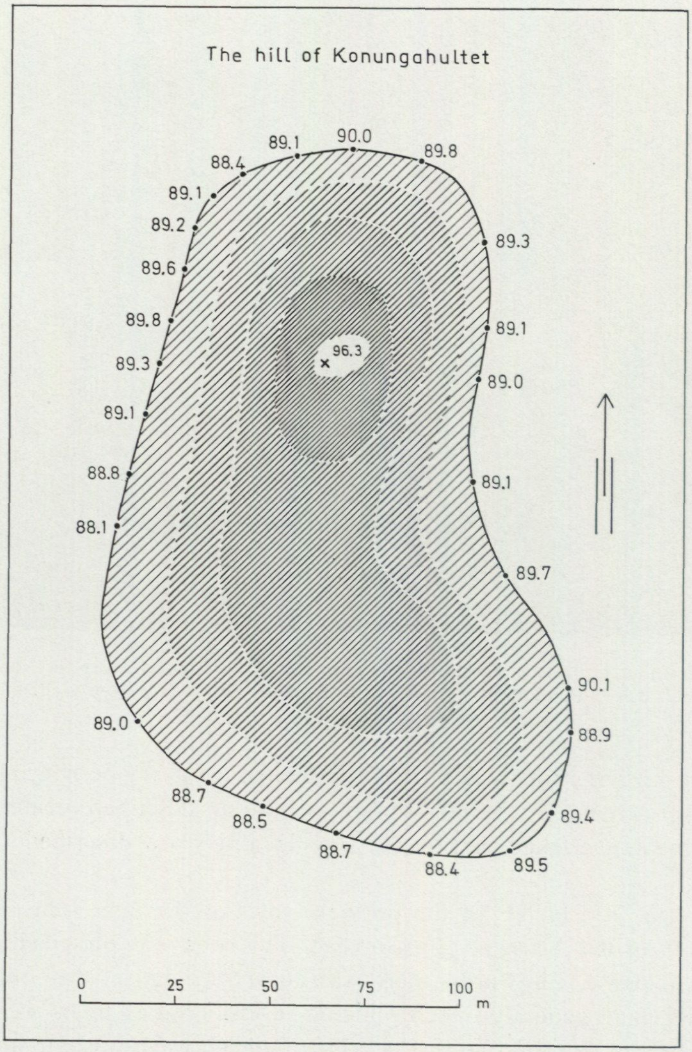

Fig. 24. Map showing the upper levelled limit of the boulder zone around the Konungahultet hill.

littoral gravel and sand. The profile of the hill (Fig. 28), and the upper limit of the boulder zone (Fig. 24) have been thoroughly levelled. Six samples were taken in the slope.

The grain size distribution of the non-washed till is that of sand (Fig. 29). There is a very sharp limit to the boulder zone and this limit fluctuates between 88.1 and 90.1 m above sea level. Consequently, the highest shore lines is placed at 88.1 m on Konungahultet hill. In the boulder zone the material consists of gravel, stones and boulders. Further down, sand and gravel dominate.

3. Flathult, 2.5 km north of Abbetorp. This locality lies on the minor road

between Flathult and Konungahultet hill. A relatively large area (0.3 km^2) east of the road is covered with boulders and some periglacial phenomena can be observed here. To the west of the boulder area, a till slope has been investigated. The locality was protected during the deglaciation phase. Only towards the east there was an open exposure.

Four samples of till have been taken. The vertical distance between the samples is about 1 m. The grain size distribution of these samples indicates that the till is wave-washed up to 83.5 m above sea level (Figs. 30 and 31). The non-washed till is sandy. Both wave-washing and periglacial processes probably affected the development of the boulder area.

4. Stensjöhyltan, 3 km NW of Abbetorp, on the minor road Stensjöhyltan—Norrgården. A till slope with a distinct erosion notch and littoral deposits has been investigated. During the deglaciation phase the exposure was limited but relatively open. Organic deposits occur at the foot. On the slope there are wave-washed till, fine sand and sand and, at the highest part, non-washed till (Fig. 32).

Four samples were taken in the slope which indicate that the highest shore line reaches 85.2 m above sea level (Fig. 33), i.e. just above the erosion notch. The grain size distribution of the non-washed till is somewhat uncommon. The sand fraction is fairly dominating, but it is no doubt that the till is non-washed. The till above the erosion notch has the same grain size distribution up to about 90 m.

5. Vackerslät, 3 km NW of Bäckebo church. The subsidiary esker, Vackerslät esker (see p. 43), forms a 2—3 km continuous ridge, running N—S. It is a plain esker type and reaches an almost constant level of about 84—87 m (Fig. 34). The summit of the Vackerslät esker provides a rough indication of the highest shore line.

6. Bäckebo (see also p. 42). The Bäckebo esker forms a large esker net landscape at Bäckebo village. The esker is very broad there. An investigation in detail indicates that the esker is about 500—600 m broad with a height of 10—15 m (Fig. 35). There are many parallel esker ridges and between them rather marked esker trenches and kettle-holes. Such a landscape usually occurs in connection with large glaciofluvial deposits at the highest shore line. The margin of the retreating ice stood more or less still owing to changing deglaciation conditions and much glaciofluvial material was deposited at the ice-margin.

All the eskers in the investigated area have formed an esker net landscape at the highest shore line, but only that at Bäckebo has been investigated in detail. At Bäckebo church, the esker forms a very smooth area in the nature of a delta. The level of this varies between 84 and 85 m. Further to the north, at Svenboryd, 3 km NW of Bäckebo church, there is a delta with ice-contact slopes at 84—85 m above sea level. These two plateaux were probably built up to the highest shore line.

Fig. 25. The erosion notch at Luvehult, indicating the highest shore line. There are some boulders in the notch. View towards the south-east. Photo T. Wiklund 1974.

7. Bäcken, 800 m SW of Bäckebo church. Three samples were taken in a till slope. The slope is very small and at its foot there is a boulder zone with periglacial structure in the form of indistinct ”sorted circles”. The boulder zone can be observed over a long distance at the same level. It was probably developed by a water stream just after the deglaciation phase.

A distinct erosion notch occurs at the foot of the slope. At the highest part the till is sandy and the limit of wave-washing lies at 83.3 m above sea level. The exposure was relatively open during the deglaciation phase but the locality was somewhat protected in the north by an archipelago (Figs. 36 and 37).

8. Luvehult, 4 km ESE of Bäckebo church (see also p. 42 and Fig. 25). The Bäckebo esker there reaches almost 90 m above sea level and is about 20 m higher than the surrounding terrain. No area in this region reaches higher levels than the Bäckebo esker at Luvehult. The esker forms an esker net landscape (Fig. 38) with a width of about 200 m.

On the southern side of the esker a very distinct erosition notch can be observed for a distance of about 100 m. The level of this notch varies between 83.0 and 83.8 m. Above this level the esker is more precipitous. There is no erosion notch at the northern side.

9. Balebo, 1.7 km SE of Bäckebo church, 300 m NW of the road Bäckebo—Nybro. A till slope has been examined and four samples were taken (Figs.

39 and 40). The highest points of the slope are at about 87 m and there is a boulder zone at the summit. The exposure was quite open during the deglaciation phase, but in the north and east the Bäckebo esker reaches a higher level.

The samples indicate that the till below the boulder zone is wave-washed. Only at the summit is the till non-washed. Littoral gravel and sand also occur below the boulder zone. The till is wave-washed up to 83.2 m.

10. Överstahult, 5.5 km NNW of Kristvalla church. This till slope had an absolutely open exposure during the deglaciation phase towards the east. Five samples were taken in the slope, indicating a limit of wave-washing at 83.3 m (Figs. 41 and 42). An erosion notch is developed just beneath this limit. The non-washed till is sandy and sandy to fine sandy.

11. Högebo, 5 km NE of Nybro (see also p. 28). Högebo village is situated on a moraine ridge, a drumlin, orientated in NW—SE. This ridge is built up of till and bedrock. Exposed bedrock can be observed on the highest parts of it. The Högebo drumlin reaches almost 90 m above sea level. No area in this region reaches higher levels than the Högebo drumlin.

At the SW and NE sides of the drumlin there are erosion notches. The notch on the NE side lies at 83.8—84.4 m above sea level (Fig. 43) and the highest shore line is placed at 84.1 m (a mean value).

The highest shore line is often developed as an erosion notch in the investigated area. At seven localities, the highest shore line has been determined as the limit between wave-washed and non-washed till, while at five there are morphological features, which indicate the highest shore line. The morphological features of shore marks cannot *per se* be regarded as suitable criteria of the highest shore line, but can be of great value in connection with investigations of the highest limits of wave-washing.

The erosion notches are often developed with a distinct foot. A boulder zone often occurs at and beneath this foot. The non-washed till is usually sandy and seldom silty to fine sandy, with a medium frequency of boulders at the surface. An enrichment of the boulders can de observed in the wave-washed till and the material is coarser there. The beach deposits below the highest shore line consist of gravel and sand, with a maximum thickness of 1 m. Silt is of very seldom occurrence.

The exposure strongly affects the formation of the highest shore line, especially in the investigated area, where the terrain is very smooth. During the deglaciation phase south-eastern Sweden was exposed to SE and E winds coming all the way from the Baltic States. The fetch was long, so that the waves could influence the investigated area at higher levels than the mean water level. Some of the localities (e.g. 1 and 3) were protected by their archipelagoes from wave action. At other localities (e.g. 2 and 8) the exposure was absolutely open.

The abrasion was in some cases not very strong at the highest shore line.

The abrasion in the investigated area was much greater below 55—60 m than above these levels and the highest shore line. This is probably dependent upon the existence of dead-ice and icebergs and/or on the shore displacement.

The limit of wave-washing fluctuates between 83.2 and 88.0 m in the investigated area. In the north, the highest shore line is in general developed at a higher level than in the south. Some localities diverge from the others (Nos. 1, 2 and 11). The exposure was probably the most important factor for developing the highest limit of wave-washing at these localities. They can give an indication of the highest shore line in connection with the till slope investigations. The erosion notch at Luvehult (No. 8) is probably the best indication of the highest shore line in the investigated area.

Owing to the size of the investigated area and the irregularities of the highest shore line, no attempt has been made to calculate the gradient of the highest shore line. The irregularities are probably largely dependent on the differences in exposure. It is also possible that the shore level displacement or dead-ice could have some effect. The results in this investigation diverge somewhat from previous observations. Munthe's early observations (1902 a) correspond almost exactly with mine, while his later results (1940) seem to be too high. The results of De Geer (1890, 1910) agree with the present results to a large extent. The erosion notches levelled by E. Nilsson (1953, 1959, 1968) probably derive from small local glacial lakes and his level of the highest shore line must be too high. The levels of the highest shore line settled during the 1960s (Knutsson 1960, 1965, Bramer 1960 and Johansson 1968) correspond with the results of this investigation.

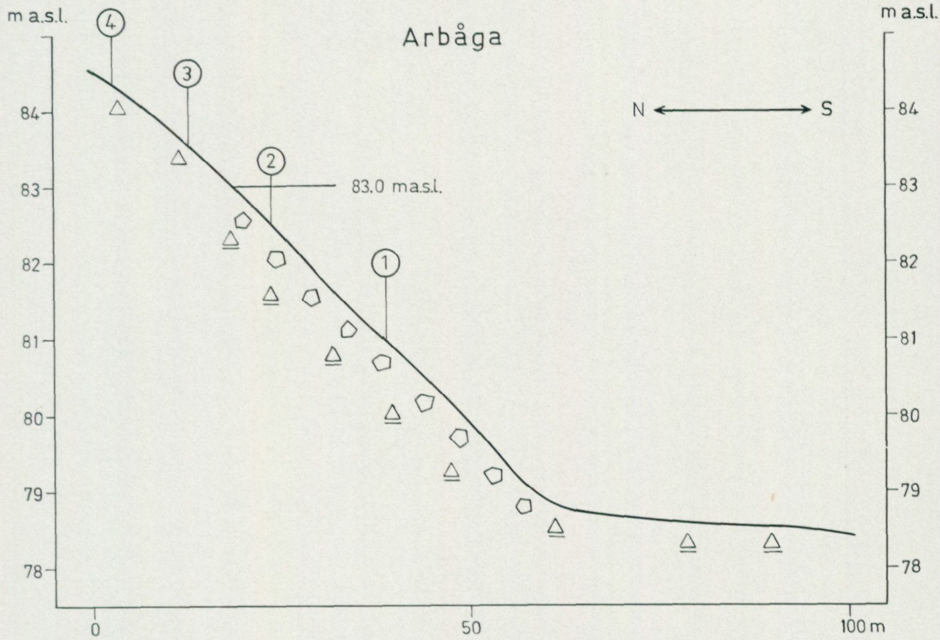

Fig. 26. The limit of wave-washing at Arbåga, indicating the highest shore line.

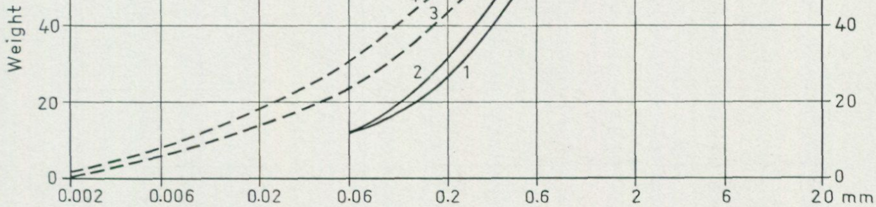

Fig. 27. The grain size distribution of the samples marked in Fig. 26.

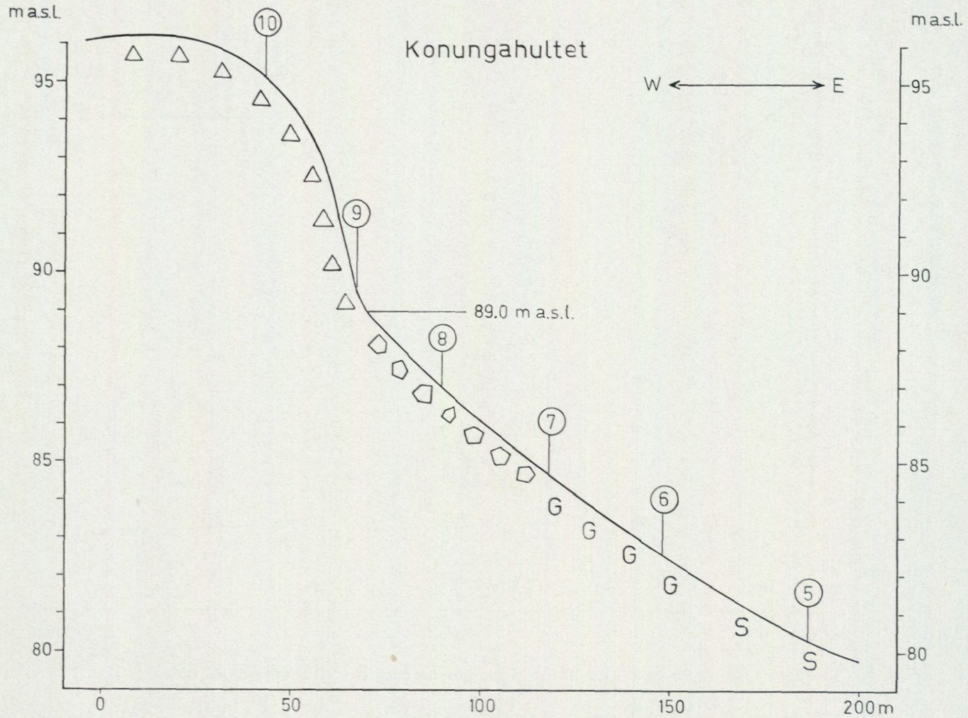

Fig. 28. The limit of wave-washing at the Konungahultet hill, indicating the highest shore line.

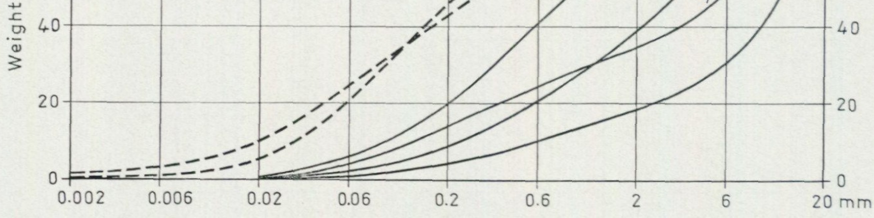

Fig. 29. The grain size distribution of the samples marked in Fig. 28.

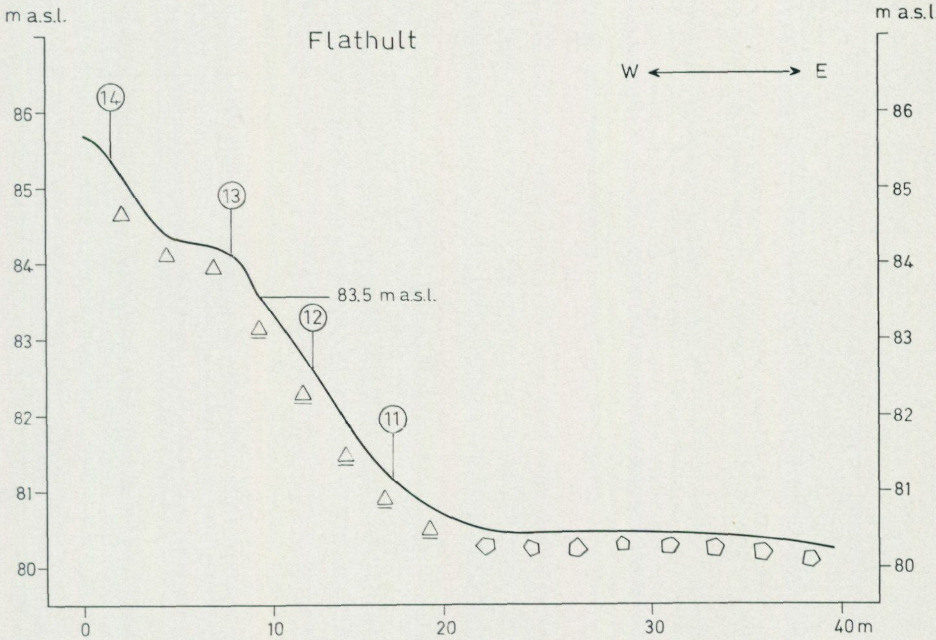

Fig. 30. The limit of wave-washing at Flathult, indicating the highest shore line.

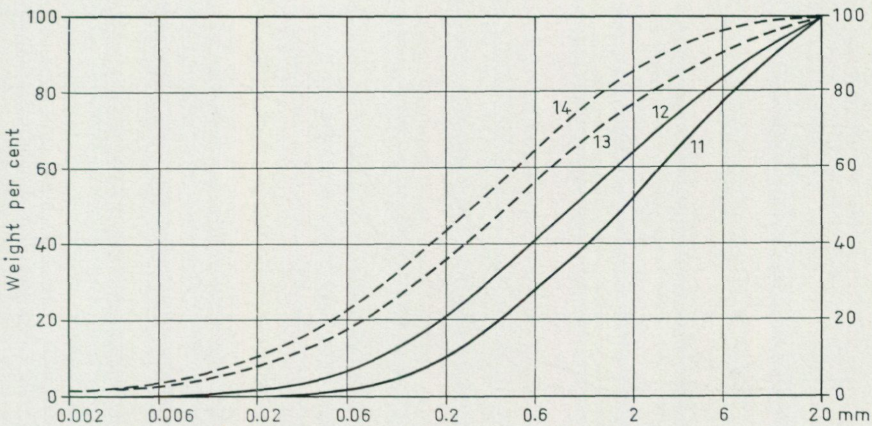

Fig. 31. The grain size distribution at the samples marked in Fig. 30.

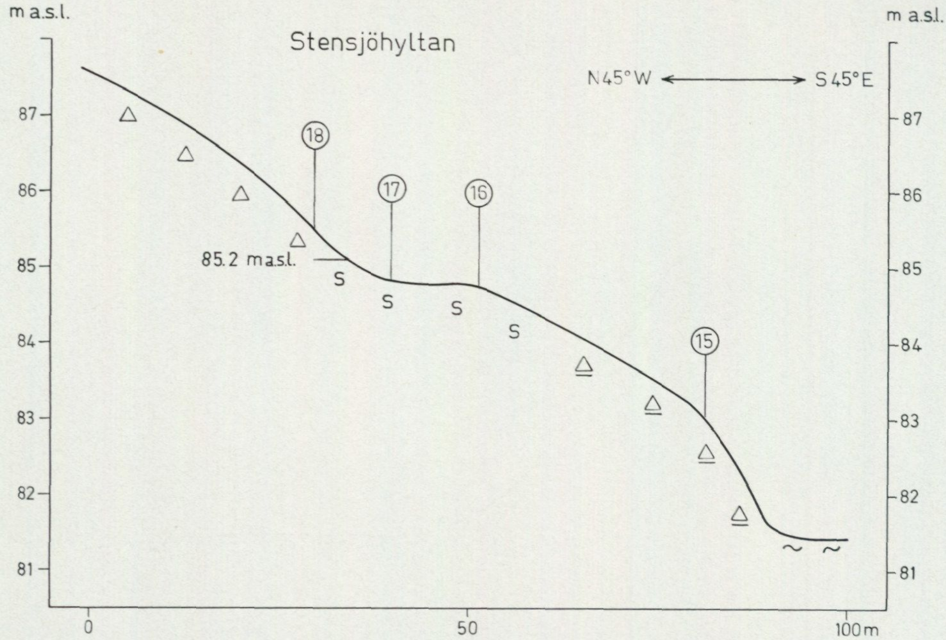

Fig. 32. The limit of wave-washing at Stensjöhyltan, indicating the highest shore line.

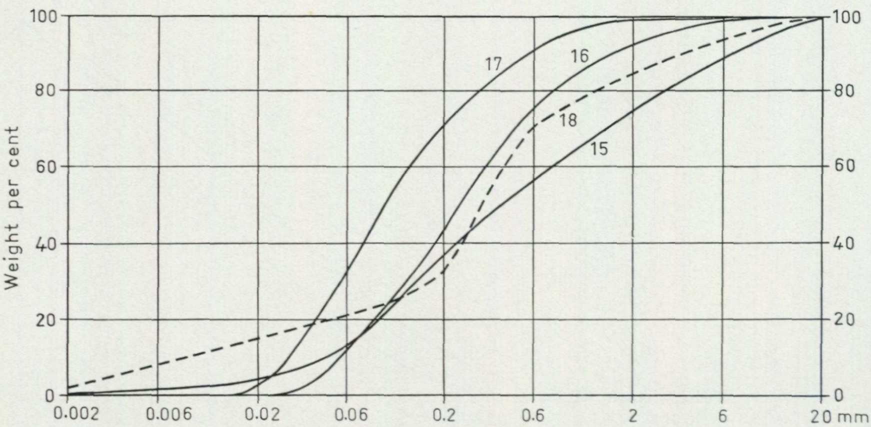

Fig. 33. The grain size distribution of the samples marked in Fig. 32.

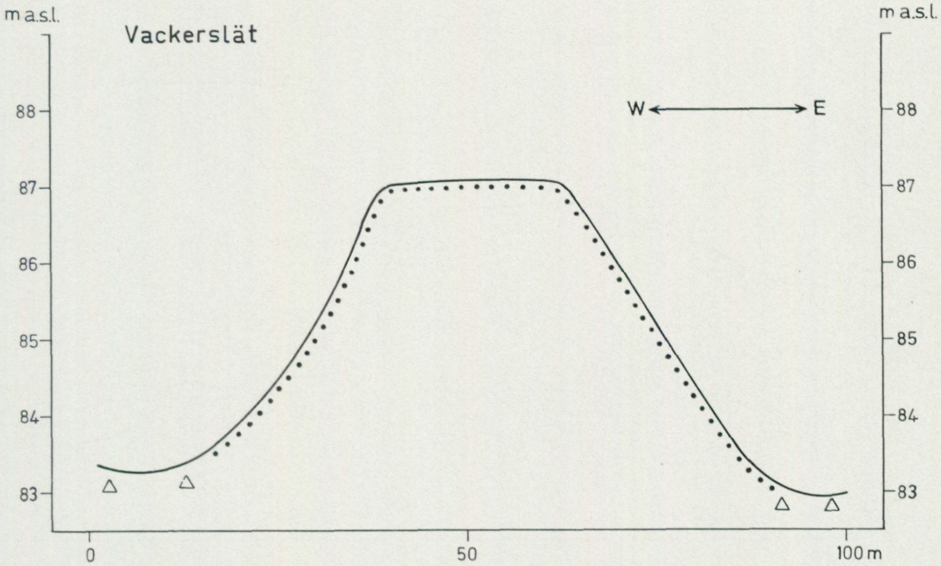

Fig. 34. Profile of the Vackerslät esker at the road Bäckebo—Alsterbro.

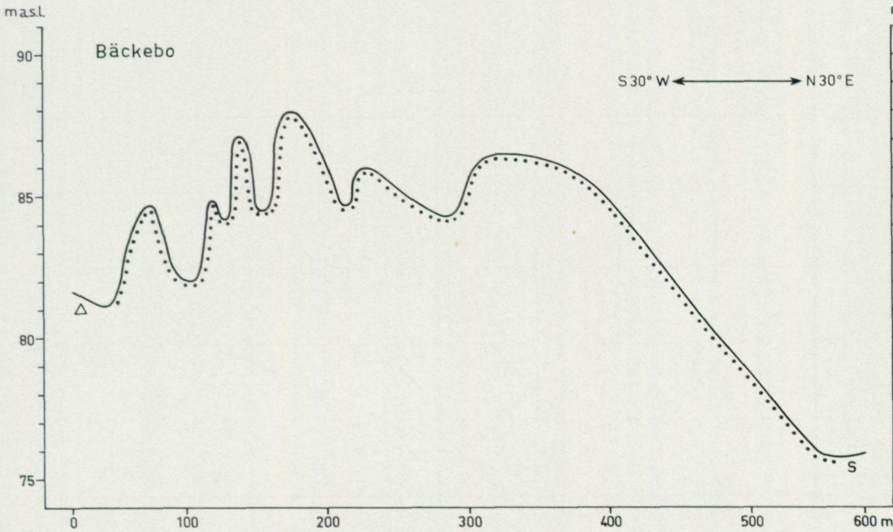

Fig. 35. Profile of the esker net landscape at Bäckebo village.

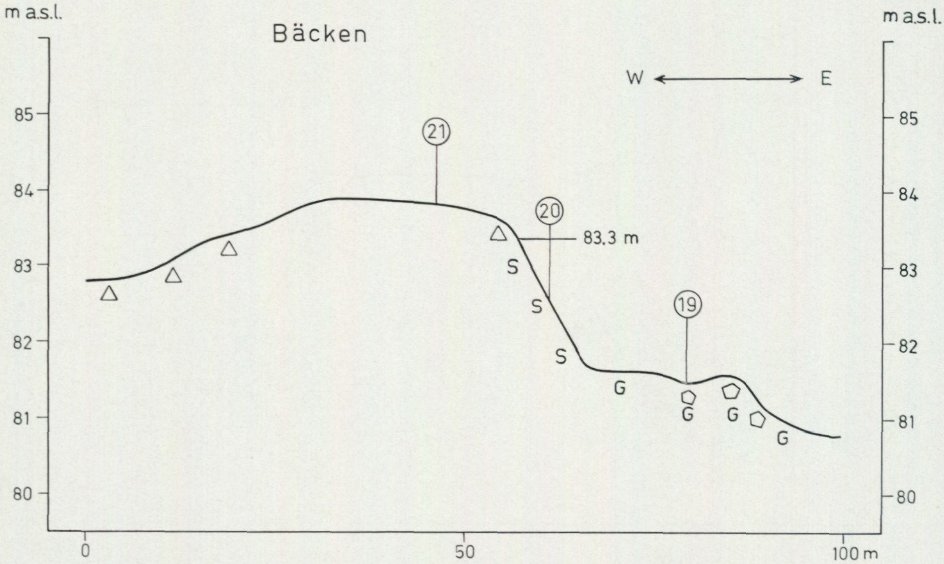

Fig. 36. The limit of wave-washing at Bäcken, indicating the highest shore line.

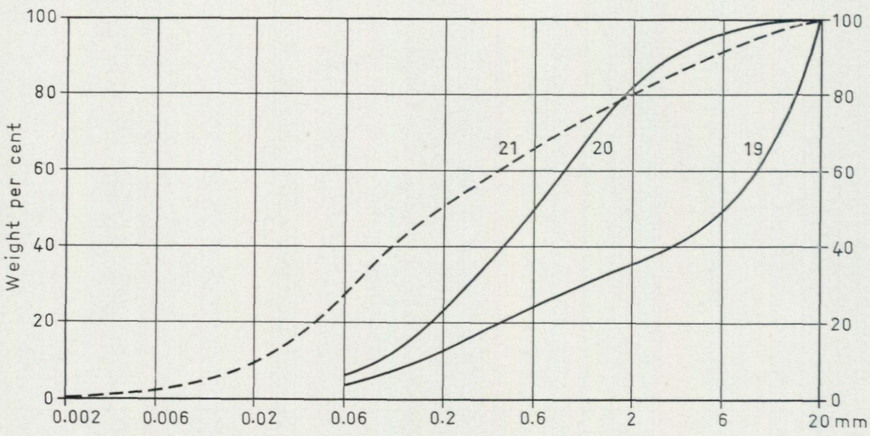

Fig. 37. The grain size distribution of the samples marked in Fig. 36.

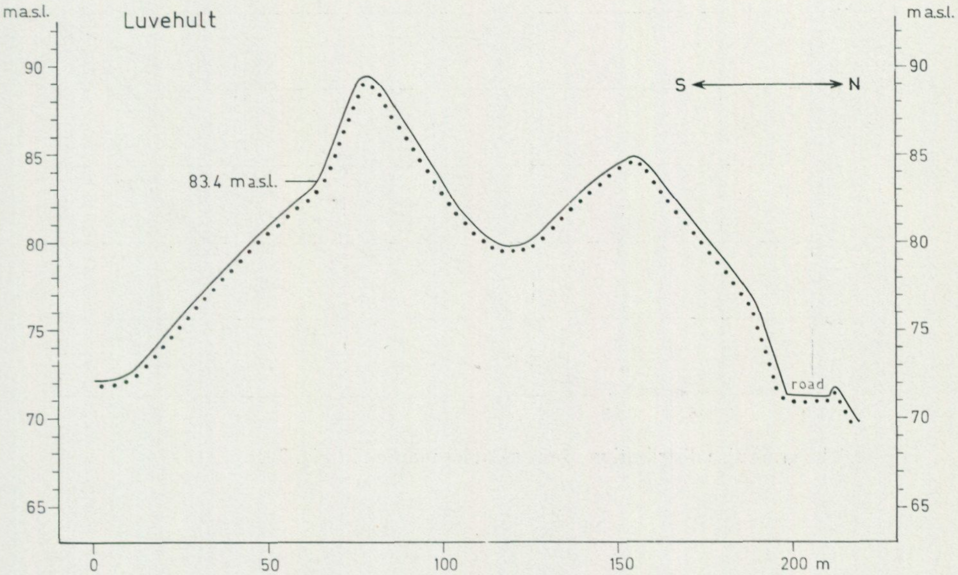

Fig. 38. Profile of the esker net landscape at Luvehult.

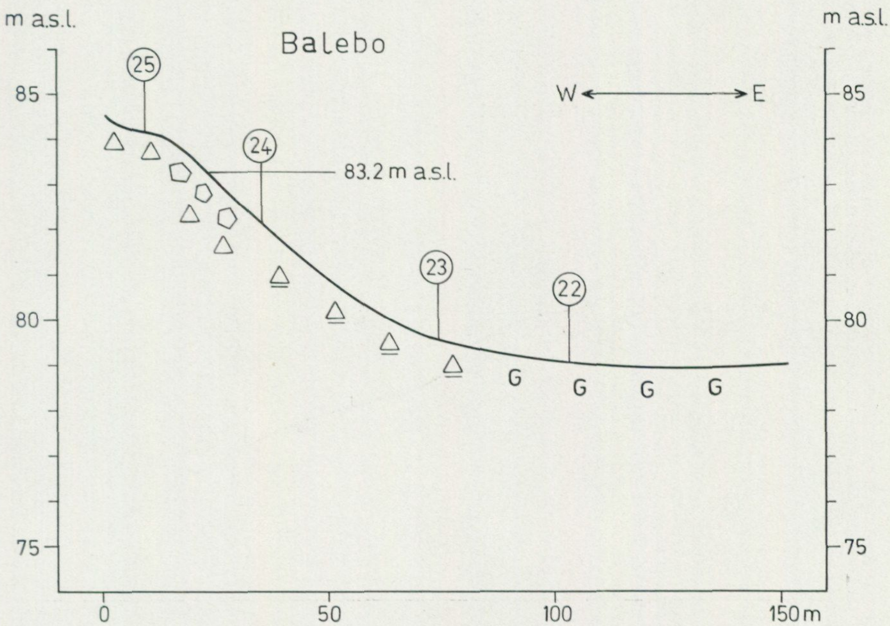

Fig. 39. The limit of wave-washing at Balebo, indicating the highest shore line.

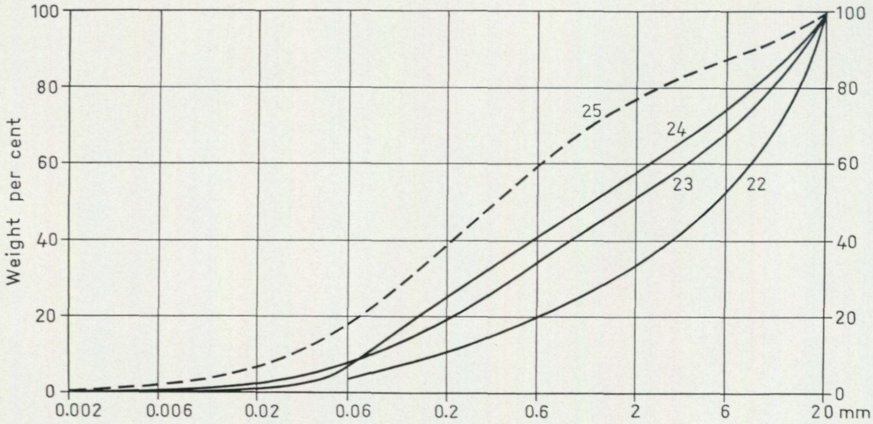

Fig. 40. The grain size distribution of the samples marked in Fig. 39.

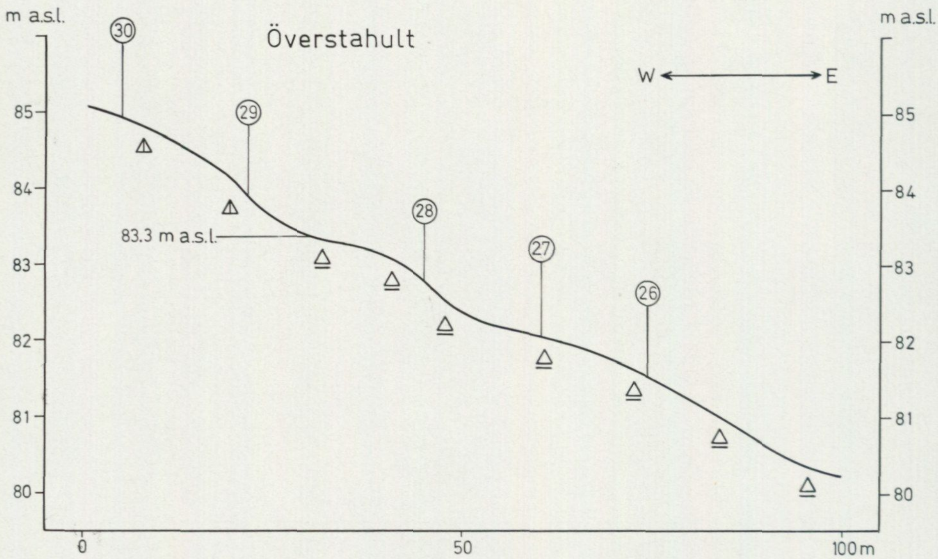

Fig. 41. The limit of wave-washing at Överstahult, indicating the highest shore line.

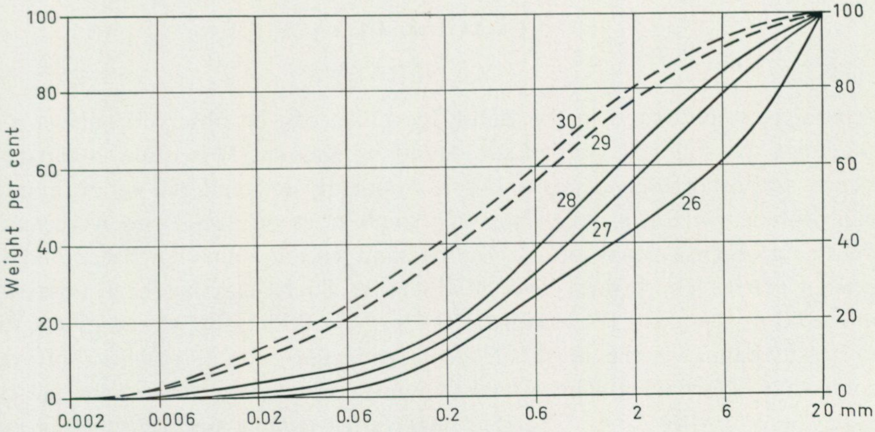

Fig. 42. The grain size distribution of the samples marked in Fig. 41.

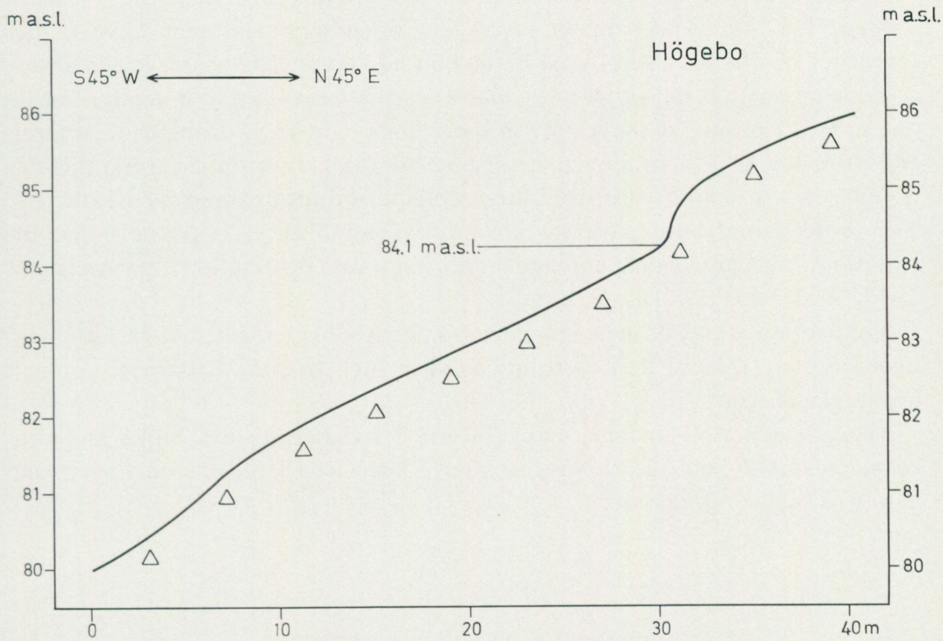

Fig. 43. Profile of the erosion notch in the Högebo drumlin.

GLACIAL CLAY

GENERAL

Glacial clay, deposited in the Baltic Ice Lake, can be observed only at a few places in the southern part of the county of Kalmar. It is often covered with beach and/or organic deposits but is frequently encountered in drillings (cf. e.g. Munthe 1902 a, p. 86). Thus only small areas of glacial clay were marked on the geological maps of the Kalmarsund region, but clay has certainly a greater extent. The highest level at which the glacial clay has been observed is about 60 m above sea level (Holst 1879, p. 33). At Högsby, about 25 km WSW of Oskarshamn, to the north of the investigated area, it reaches however a somewhat higher level. The glacial clay most frequently occurs near the coast at levels of up to 25 m. The thickness varies from a few centimetres up to several metres (cf. Munthe 1902 a, p. 86).

The minor thickness of the glacial clay may be due to the absence of appropriate sedimentation basins in the smooth coastal region. Another reason could be that almost no glaciofluvial deposits occur in the Kalmar area (cf. p. 47). In all probability the abrasion has also affected the distribution of the glacial clay.

The appearance and composition of the glacial clay vary. It is usually varved (Fig. 44). The summer layers are often light and they have a high frequency of silt, but also of sand in the bottom varves. The winter layers always consists of clay. At the surface, the glacial clay is weathered to a depth of about one metre. The surface varves are in most cases light grey, owing to weathering and probably also to culture processes. Below the grey surface varves, the clay is redbrown in colour. Probably these colours are also caused by weathering. The unweathered bottom varves are mostly grey-blue. It is possible that the variations also are dependent upon the grain size distribution (cf. Arrhenius 1947, Andersson 1971).

No determinations of the calcium carbonate has been made, but earlier investigations state (p. 69) that there are relative high calcium carbonate contents in the glacial clay.

The glacial clay is in some cases disturbed and redeposited. Slides and slips occur commonly and the varves are often folded to a large extent. Layers and lenses of fine sand also occur.

EARLIER INVESTIGATIONS

There are only a few investigations of the glacial clay in the southern part of the county of Kalmar. Most of these discuss the highest shore line on the basis of the highest level at which the glacial clay is found.

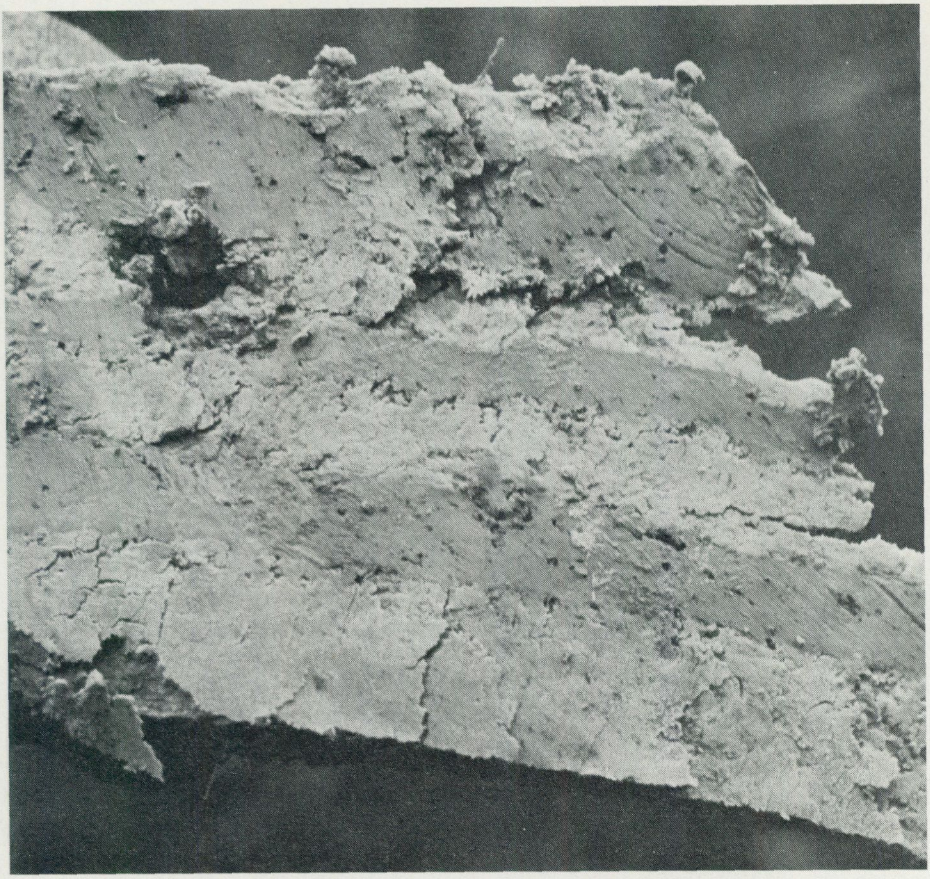

Fig. 44. Varved glacial clay at Skäggenäs. Photo T. Wiklund 1974.

The only investigations of the appearance and composition of the glacial clay were presented in connection with the geological surveying of the investigated area, and most of these results have already been presented above. They agree with the observations, made in this investigation.

A great number of analyses were made earlier of the glacial clay, concerning the calcium carbonate content, at the geological surveying (Munthe 1902 a, 1902 b, 1904, Svedmark 1904). They indicate that the clay tends to have a relatively high calcium carbonate content. At one locality, the calcium carbonate content decrease downwards (Munthe 1902a, pp. 86—87), probably owing to secondary leaching. Munthe is of the opinion that the calcium carbonate descended from Öland, from where is has been dispersed by currents to the coastal region (cf. G. Lundqvist 1963, p. 81). This region was thought to be deglaciated while the Baltic Ice stream was preserved on Öland (Munthe 1902 a, p. 86).

The only varve measurements in the Kalmarsund region were made by De Geer at the beginning of the 20th century. This material, however, was not published.

Ringberg (1971, pp. 68—95) investigated the glacial clay in the eastern part of the province of Blekinge. He measured a great number of varve series and linked his results with the revised Swedish varve chronology. Most of the work on this chronology in southern Sweden was made by E. Nilsson (1968). Ringberg investigated the glacial clay regarding appearance, thickness, extent and composition. This investigation indicates that the clay in eastern Blekinge has almost the same appearance, composition and thickness as the clay in the coastal region at Kalmarsund.

THE PRESENT INVESTIGATION

The glacial clay has only been investigated with respect to varve chronology. The method of basing chronology on clay varves was developed by De Geer (1932, p. 62, 1940, pp. 19—21). He also defined the connection between different varve series (De Geer 1940, p. 30).

Most of the positions of the localities were taken from De Geer's unpublished material. Unfortunately, no varve diagram could be found at the Geochronological Institute of the University of Stockholm, where most of De Geer's original material is collected.

All the measurements were made in excavations dug with spade. Several measurements were taken at each locality, especially where the varves were disturbed and folded. The underlying material was always determined. Attempts were made to get cores with the metal-foil corer (Kjellman *et al.* 1950). These were however unsuccessful, owing to the relative coarse material of the bottom varves. The location of the investigated localities are shown in Fig. 45 and the varve diagrams on Pls. 1—4. The stratigraphy of each varve locality is described in "description of clay varve localities".

The varve series are arranged regionally in the diagrams (Pls. 1—4). No distinct geographical areas occur in the coastal region. Pl. 1 comprises the northernmost varve series, and Pl. 4 the southernmost. On Pl. 4, two of Ringberg's series (1971) and one new series, taken on Öland, are linked up with the southernmost series from the investigated area. It has been possible to connect all investigated varve measurements. There are twenty-four measurements on the mainland which are connected with each other. The varve series are not long. They have usually been developed during a period of less than fifty years.

Pl. 1 comprises the seven northernmost localities. The connections are very good on the whole. The dissimilarities are confined to single varves. A single thick varve in one diagram, which is probably a result of local sedimentation, cannot be seen in the other diagrams. There are some distinct varves which can be observed in almost every diagram.

Pl. 2 comprises seven diagrams to the south of the localities on Pl. 1. The connections are very good, and there is no doubt, that they are correct. The connections on this plate are of the utmost importance for the interpretation of the ice recession in the Kalmar area.

Svaneberg is situated in the town of Kalmar and connections with the other localities have been made. Connections between Svaneberg and the localities south of Kalmar are also very good (Pls. 3 and 4). The connections between Källarbacken locality and the other localities are, however, unsatisfactory. This locality has been connected with Kärrtorp II (Pl. 1).

The four southernmost diagrams are found on Pl. 4 together with three other diagrams (see above). The connections between these diagrams show small differences but are in general good, and the connections to the localities on Pl. 3 are very good. The diagrams from Björklycke (Ringberg 1971) and Eckelsudde on Öland, are almost identical. There is only one single dissimilarity between these two diagrams. The results of this investigation are linked up with the revised Swedish varve chronology through varve series in the eastern Blekinge (Ringberg 1971). This varve chronology is probably somewhat unreliable. The connections between varves from different sedimentation basins in the southern Swedish uplands, in some cases covering very long distances, are not entirely satisfactory.

THE ICE RECESSION

The ice recession in southern Sweden and the Baltic were frequently discussed during the 20th century. There are many general surveys of the deglaciation phase in these regions (e.g. Munthe 1910, 1940, E. Nilsson 1968, Mörner 1969, 1971, Tauber 1970), but they are not based upon varve chronology from the Kalmarsund region. The views of the deglaciation vary.

There are many glacial marks and deposits in the investigated area, which indicate the ice recession. In this investigation, the deglaciation picture is mostly based upon the varve chronology. Glacial striae, moraine ridges, glaciofluvial deposits and some other features, however, complement the ice recession picture.

The varve chronology is summarized in Fig. 45. Equicesses for every ten years have been drawn. Equicesses known in detail occur in two regions, namely in Rockneby — Åby — Förlösa — Kläckeberga region north of the

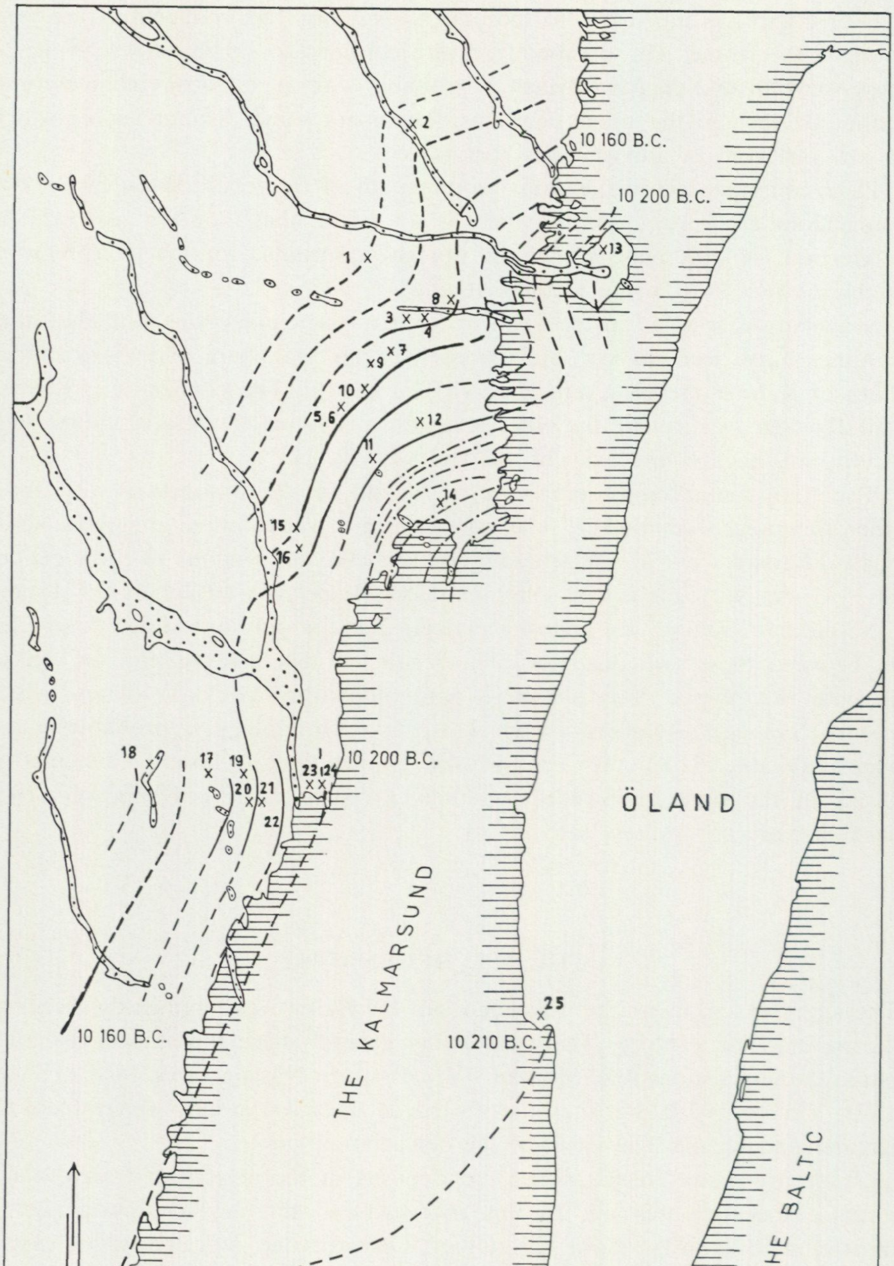

Fig. 45. Map showing the ice recession in the Kalmarsund region. Equicesses are marked for every ten years, except in the Kalmar area, where equicesses for every year are drawn. The localities of the measured clay varves (see p. 81) are marked with a cross.

Kalmar area, and in Arby — Voxtorp region south of the Kalmar area. In other parts, the equicesses are not known in detail.

Just before the deglaciation there was an ice movement towards the SSE in the investigated area. The ice mass was active, which is indicated by e.g. the glacial striae. The deglaciation phase began with an ice recession in the Baltic. Here, the shrinking ice mostly disappeared by a fast calving from the ice cliff.

Later, the ice border had a SW—NE orientation in the southern part of Kalmarsund. The ice recession velocity was estimated to about 200 m per year (Dannstedt 1947). The ice was probably active. Judging by the intense calving in the deep water, the ice recession velocity was high.

The ice recession in Kalmarsund, based upon varve chronology in this investigation, was very fast. It is impossible to state the exact position of the ice border in Kalmarsund, but a varve series from south-western Öland (Eckelsudde, Öland) shows that the ice recession velocity was extremely fast with a rate of more than 1 km per year. The calving was intense here dependent on the depth of Kalmarsund.

The deglaciation picture of Öland is almost completely unknown. Öland itself probably affected the deglaciation to a very slight extent. The highest parts of Öland, about 55 m above sea level, lay below the surface of the Baltic Ice Lake all the time. The deglaciation occurred through calving but the water was somewhat shallower there. The ice recession velocity was probably somewhat slower than in the Baltic. This deglaciation picture of Öland is however only hypothetical.

Later, the ice border was almost parallel to the coast, between the Nybro esker towards the north and the province border in the south. The ice recession velocity was about 125 m per year, as interpreted from the varve chronology. The coast was deglaciated about 12 200 B.P. (Fig. 45). There are a few glaciofluvial deposits in the southern part of this region. They mostly run E—W near the coast, i.e. at right angles to the ice front. Some glaciofluvial deposits are orientated parallel to the Kalmarsund i.e. they were developed parallel to the ice border.

The ice recession around the large Nybro esker is only superficially known. No varves have been measured near the esker. The northernmost varve series in the Arby — Voxtorp region, i.e. Resmo, Gräsgärde and Brobylund, indicate, however, that there was a calving bay along the esker (Fig. 45). This presumptive bay is also indicated by a series of estuary moraines at the Nybro esker (Knutsson 1960, pp. 66—67), and the youngest striae at Mortorp (see p. 17). The conditions during the ice recession, however, are only known in brief outline for this area.

Many factors indicate that the ice was active during the latest phase of the deglaciation. If a calving bay in the ice front did exist around the Nybro esker, the ice border ran at right angles to both the Nybro and the Ljungby eskers. This theory provides a plausible interpretation of the unusual orientation of the Ljungby esker in the coastal region. The ice velocity in this area is difficult to determine. Probably, it was 100—150 m per year.

Many varve localities have been measured in the Kalmar area, Rinkabyberg. Källarbacken, Svaneberg, Kläckeberga etc. It was difficult to estimate the course of the ice recession at the beginning of the measurements, owing to former interpretations of the deglaciation in the Kalmar area. The results of this investigation indicate a complex ice recession there.

The Kalmar area was deglaciated very rapidly. The ice recession velocity varied widely, but was always high. A mean value of the recession velocity in the Kalmar area is about 400 m per year. The great curved moraine ridges, such as the Skälby end moraine ridge, were unfortunately not investigated in detail (p. 29). In all probability the ridges are annual and show the position of the ice border during the recession phase. The moraine ridges in the Kalmar area do not indicate a stagnation of the deglaciation. Instead, they indicate a very fast ice recession. This phenomena has been found in other places in central Sweden (De Geer 1932, Möller 1962).

The fast ice recession velocity almost prevented the development of any large glaciofluvial deposits in the Kalmar area. There are a few small mounds of glaciofluvial material to the SW of Kalmar, constituting an incomplete esker, running SE—NW. Probably, it would have been a well-developed esker if the ice recession had been slower. The moraine ridges in the Kalmar area probably indicate that the ice was active here during the deglaciation. The water was relatively deep and this affected the calving intensity.

In the northern part of the investigated area, a great number of varve series have been measured (Pls. 1 and 2). In some parts of this area, it has been possible to determine the position of the ice border, e.g. south of the Bäckebo esker. The ice recession velocity was there about 150 m per year, i.e. somewhat faster than in the region south of the Nybro esker. Estuary end moraines around the Persmåla esker (p. 35) indicate that a calving bay probably existed around the esker during the deglaciation. The unusual orientation of the Bäckebo and Sporsjö eskers in the coastal region has consequently been given a plausible interpretation (Fig. 45). The ice border was orientated at right angles to the Bäckebo and Sporsjö eskers, if the calving bay around the Persmåla eskers did exist. The northern part of the investigated area was deglaciated during the same years as the region close to the border between the province of Blekinge and the county of Kalmar.

One varve series was measured on Skäggenäs (Fig. 45). This peninsula was deglaciated during the same years as some of the western parts of southern Öland (Fig. 45). The position of the ice front in Kalmarsund at the time can not be given. Varve measurements on Öland and probably in Kalmarsund, must be made to determine the equicesses east of the investigated area.

Summing up, the ice recession in the coastal region at Kalmarsund had a very rapid velocity. In most cases the velocity was 125—150 m per year, but rates of more than 1 km per year occurred there. The ice was probably active at the recessional stage in the whole coastal region, as indicated by the abundance of moraine ridges and glacial striae. The retreat of the ice margin mainly occurred by calving from the ice cliff. The calving was more intense in areas with deeper water, e.g. in Kalmarsund and in the Kalmar area, and less so in areas with more shallow water. The deglaciation occurred during 12 200—12 140 B.P.

The results of this investigation diverge almost completely from all earlier investigations. The former theories concerning the ice recession in the Kalmarsund region are that the large moraine ridges at Kalmar indicate a stagnation of the deglaciation (De Geer 1910, Munthe 1910, E. Nilsson 1968, Mörner 1969, 1970, 1971, Tauber 1970).

During this short stagnation, or maybe small re-advances, the ice margin was extended eastwards according to some investigations (e.g. Munthe 1910, Mörner 1969, 1970). These authors were of the opinion that an enormous ice-lobe covered a great part of the Baltic during the deglaciation. Besides, there were also in some cases (e.g. Mörner 1969) correlations westwards of the short stagnation in the ice recession.

Features indicating the deglaciation in the transitional region are few. The velocity of the ice recession is indicated by the segmented Bäckebo esker at St. Vångerslät village (p. 41). The esker mounds presumably show an ice recession of 150—200 m per year, i.e. somewhat faster than in the coastal region. This value is however only valid for the area around St. Vångerslät village, but in theory it could apply to the whole transitional region.

The orientation of the eskers in the transitional zone (p. 72) tends to be the same as in the coastal region. This fact probably indicates that the equicesses have the same orientation here as in the coastal region, if the eskers were developed at right angles to the ice border.

In the transitional zone (p. 29) there are a few moraine ridges, which probably means that the ice was active there during the deglaciation. This is also indicated by the youngest striae, engraved by an ice movement, directed ESE. The ice receded from the transitional zone by calving. The water was rather deep.

At altitudes between 50 and 80 m the glaciofluvial deposits change character and in some cases orientation (pp. 33—46). The abrasion has not been as extensive at these levels as at lower levels. Above 50 m all the eskers have an orientation in NW—SE. This may be due to changing deglaciation conditions. The water became shallow so that the calving was less intense. The icebergs may have remained on the bottom and were not transported by currents. Thus the abrasion could not affect the deposits to such an extent that the original shape of the eskers was transformed. If the ice receded in parallel with the eskers, the equicesses of the ice margin were orientated in SW—NE. No features indicating the ice recession velocity have been observed in these areas.

At the highest shore line (p. 48), there are often esker net landscapes. These objects are an indication of stagnant ice. The deglaciation here changed character from a sub-aquatic deglaciation with calving, to a supra-aquatic deglaciation with down-wasting. The ice recession velocity would have been different if the climate had not changed. Below the highest shore line, there was a fairly rapid deglaciation, while the recession was somewhat slower at, and above, the highest shore line. Owing to these circumstances, there was a stagnant phase at the highest shore line so that much material must have been deposited. The enlargement of glaciofluvial deposits is therefore natural at the highest shore line.

Above the highest shore line elements occur, which indicate a stagnant margin zone of the ice during the deglaciation. No investigations in detail have been made above the highest shore line.

SOME FINAL POINTS AND CONCLUSIONS

There are a great number of traces in the investigated area, which show the development of the deglaciation and, in some cases, old ice movements.

The main direction of the ice movements during the last glaciation was towards the SE. It is impossible to say, when an ice movement from the Baltic prevailed. There are no observed traces, which show a synchronism between the Baltic Ice stream and the ice stream towards the SE. The Baltic Ice stream had a rather large extension towards the west, according to the striae, and crossed the whole Kalmarsund region. In all probability it was of short duration, owing to the almost total lack of Cambrian and Ordovician material west of the basal Cambrian sandstone region. The theory of an interstadial in the investigated area before or after the Baltic Ice stream has not been confirmed (cf. Rydström 1965, 1971).

An ice movement from the NNW took place in the Kalmarsund region after the Baltic Ice stage. It is impossible, with the present material, to determine when this ice movement prevailed. The drumlins were probably formed during this stage and most of the glacial striae were engraved. Investigations in the southern Swedish uplands (Rydström 1965, 1971), and in the province of Blekinge (Ringberg 1971), show that the erosive capacity of the ice was very slight during this period. These investigations also suggest that the ice gradually passed into a stagnant state. Johnsson (1952, p. 5), on the other hand, considered that the ice was always active in the southern Swedish uplands, even during the deglaciation phase. The results of the latter investigation correspond closely with the present observations.

The ice recession, mostly based on varve chronology, in the investigated area, agrees with the results of Ringberg (1971) and Rydström (1965, 1971). Rydström determined the ice recession velocity as 275 m per year during 11 950—11 922 B.P. in the southern Swedish uplands. In the eastern part of Blekinge (Ringberg 1971), the ice recession velocity was about 90 m per year. The increase of the velocity would seem to depend upon a climate change from a cold stadial to a warm stadial (Ringberg 1971). The ice recession velocity in the Kalmarsund region, deglaciated at the same time as the coastal strip in Blekinge, was 125—150 m per year.

The theories concerning the climatic stadium during which the investigated area was deglaciated are very different. In earlier investigations, the Kalmarsund region was thought to be the easternmost part of a standstill of the deglaciation. These assumptions however are probably incorrect. This standstill has been determined in respect to time and climate.

According to E. Nilsson (1968, p. 29), the formation of the Kalmar moraines took place at the end of the Older Dryas Stadial about 12 050 B.P. The opinion of Mörner (1969, pp. 118, 125—126) was that the ice marginal line Fjärås — Bredåkra — Kalmar occurred between 12 300 B.P. and 12 350 B.P. during the latest phase of the Oldest Dryas Stadial. Moraine ridges were developed at the ice margin zone during the standstill. This stagnant phase is an indication of changing climatic conditions.

Several authors have placed the development of the Bredåkra delta in the province of Blekinge within the Oldest Dryas Stadial (e.g. Mörner 1969, p. 118, Tauber 1970, Berglund 1971). As the deglaciation of the Bredåkra delta took place at the same time as the coastal region at Kalmarsund, it is likely that the ice recession in the investigated area took place during the Oldest Dryas Stadial. No analyses of pollen or other organic remains, which could prove this theory have been made. An indication of an arctic climate during the deglaciation consists in traces of periglacial processes in the transitional zone (cf. Berglund 1966).

DESCRIPTION OF GLACIAL STRIAE LOCALITIES

The localities are described from north to south. Their location is given in relation to places, farms, roads, churches etc. The localities are marked by numbers on Fig. 4.

1. Lövhäll, 2,5 km WSW of the former Hornsö halt, 100 m S of the Lövhäll farm (north of the investigated area). A distinct *roche moutonnée* in NW—SE. Distinct striation occurs, engraved by ice movements from N 30° W and N 50° W. The latter dominates entirely. No crossing striae occur and it is not possible accurately to determine the age relation between the two systems. The ice movement from N 50° W is probably the youngest because of the abundance of striae with this orientation.

2. Stavviken, 50 m E of the easternmost inlet of the lake Allgunnen. A small flat outcrop is completely covered with striae, which indicate an ice movement from N 25° W.

3. Arbåga, 300 m SSE of the former Arbåga sawmill. Indistinct, weathered striae, showing an ice movement from N 40° W, occur on a *roche moutonnée* in NW—SE.

4. Flathult, 2.5 km N of Abbetorp. On the highest part of the Flathult hill (105.12 m a.s.l.) there are indistinct striae engraved by an ice movement from N 40° W.

5. Lindhyltan, 1.3 km NNW of Abbetorp, on the minor road Abbetorp to Flathult. On a relatively new exposed flat outcrop there are striae which indicate an ice movement from N 40° W.

6. Häggemåla, 6 km SW of Ålem church, 300 m WSW of Häggemåla village (cf. p. 16). On a new exposed rock surface there are three different striae orientations; developed by ice movements from N 25° E, N 20° W and N 50° W. Some striae of the system N 50° W are engraved into the other two systems and a few striae of the system N 20° W into the N 25° E system. The age relation between the striae systems is: the oldest striae are engraved by an ice movement from N 25° E while the youngest are developed by an ice movement from N 50° W. The system from N 20° W is most frequently found and the striae, engraved by the ice movement from N 25° E are sometimes coarse.

7. Helgesbo, 6,5 km ESE of Abbetorp, 100 m S of Helgesbo farm. Very distinct and long (2 m) striae occur on a small flat outcrop, which show an ice movement from N 25° W.

8. Traneven, 8 km E of Bäckebo church, 350 m W of the former Traneven farm. There are weathered, indistinct striae, engraved by an ice movement from N 30° W.

9. Överstahult, 4 km SW of Bäckebo church, at Överstahult farm. There are small but distinct striae, indicating an ice movement from N 35° W on a new exposed rock surface.

10. Plattekärr, 7 km W of Rockneby church. There are distinct striae orientated in N 35° W—S 35° E on a new exposed outcrop surface at the bottom of the large Plattekärr gravel pit. The ice movement was directed towards S 35° E.

11. Skäggenäs, 15 km NNE of Kalmar (cf. pp. 16 and 18). Four different stria systems occur on the Skäggenäs peninsula, which indicate ice movements from N 50° E, N 25°E, N 10°—25° W and N 60° W. On the highest part of Skäggenäs, Alkullaberget, all systems occur except that from N 60° W. No crossing striae were observed. The striae, which indicate an ice movement from NNW, are probably the youngest on the hill Alkullaberget because of their appearance and location. These striae are very small and indistinct and are engraved on the highest part of the hill. The systems from N 25° E and N 50° E are engraved on the steep eastern side of the Alkullaberget and it is impossible to determine the relation between their ages. The striae orientated N 25° E—S 25° W are very coarse, like grooves. The striae, which show an ice movement from N 60° W are formed on a small outcrop on the western part of Skäggenäs and no other striae were observed here. It is not possible to interpret the age relation between this system and the other systems present on Skäggenäs peninsula.

12. Sporsjö, 5 km WSW of Läckeby church, 100 m NW of the crossing between the road and the rill. There are distinct striae on the top of an outcrop, which indicate an ice movement from N 15° W. On the lee-side, very indistinct striae are found, engraved by an ice movement from N 60° W. No crossing striae occur and it is not possible to interpret the age relation between the two stria systems.

13. Maltebo damm, 800 m NE of the fork at Kristvallabrunn. Striae, formed by an ice movement from N 30° W, occur on the northern side of Maltebo damm.

14. Åbro, 800 m W of the fork at Kristvallabrunn (cf. p. 17). The outcrops to the north of the road, Kristvallabrunn—Nybro, are partly covered with distinct and coarse striae, which indicate an ice movement from N 45° W.

On a *roche moutonnée,* close to the rill, there are distinct striae engraved by an ice movement from N 75° W. The stria system, which shows the ice movement from the NW, is developed on the lee-side of this outcrop. There are several indications that the striae orientated in N 75° W—S 75° E are the youngest in this locality (cf. p. 17).

15. Högebo, 400 m NE of Högebo village. On a small flat outcrop in a cultivated area there are coarse, weathered but distinct striae, showing an ice movement from N 40° W.

16. Högebo, on the highest part of the Högebo drumlin. On the outcrop in the northern part of the drumlin there are indistinct striae, engraved by an ice movement from N 20° W.

17. Nybro, Jutabackarna, in the western part of Nybro. In an industrial area there are outcrops with distinct striae, indicating ice movements from N 40° W and N 60° W. No crossing striae occur and it is not possible to interpret the age relation between the two systems.

18. Skrivnahallar, 7 km ESE of Nybro, around the Skrivnahallar farm. There are many distinct striae engraved by an ice movement from N 40°—50° W. A distinct facet probably indicates an older ice movement from the NNE. There are also indistinct striae formed by an ice movement from N 25° W and two crossing striae show that the ice movement from N 25° W is older than that from N 40°—50° W.

19. Gräsmo, 1,5 km NW of Trekanten station, on the railway. Striae, corresponding to ice movements from N 20°—25° W and N 45° W occur on a small outcrop. The stria system N 45° W is distinct and is engraved on the highest part while the system N 20°—25° W occurs on the lee-side. The latter system is very indistinctly developed. The system orientated NW—SE is probably the youngest, because of its location and appearance.

20. N. Skallö, 3 km NE of Kalmar (cf. p. 17). There are indistinct striae on this island, engraved by ice movements from N 25° E and N 15° E. There are no crossing striae and one cannot deduce the age relation between the two systems.

21. Harby, 3 km SSE of Trekanten station, at Harby village. Weathered striae occur on a small flat outcrop, showing an ice movement from N 20° W.

22. Ölvingstorp, 3 km WSW of Trekanten station (cf. pp. 17), 250 m E

of the road crossing at Ölvingstorp. Striae, developed by an ice movement from N 20°—N 30° W, frequently occur in the area around Ölvingstorp, e.g. Anneberg, Nygård and Nybygget. On the northern side of the road a lot of scratches were observed on a very new exposed outcrop. These have an orientation which probably corresponds to an ice movement from S 70° W. They occur on the lee-side of the outcrop. Striae, engraved by an ice movement from N 30° W were observed on the highest part of the outcrop. The scratches are presumably the youngest striation at this locality because of their appearance and location.

23. Mortorp, 350 m N of Mortorp church (cf. p. 17, south of the investigated area). Striae, corresponding to three different ice movements are engraved at this locality. There are also lunate chatter marks, orientated N 20° W—S 20° E on this outcrop. Striae, engraved by an ice movement from the W occur on both sides of a facet, developed by ice movements from the N and NNW. Therefore, this stria system must be the youngest. A few striae, which indicate an ice movement from N 20°—40° W are engraved in striae, which show an ice movement from the north. Consequently, the ice movement from the north must be the oldest one at this locality. The striae, orientated in NNW—SSE dominate completely.

DESCRIPTION OF GLACIAL CLAY LOCALITIES

The localities are described from north to south. Location is assigned in relation to places, farms, estates, churches etc. A rough estimate of the level has been presumed. The localities are marked in Fig. 45.

1. Örntorp, 500 m E of Örntorp farm, 100 m SW of the Åby—Bäckebo road. The level is 20—25 m a.s.l. There are 39 measured varves, the bottom one being dated at 10 140 B.C. Diagram on Pl. 1. The underlying material is till. Above the measured varves, there are some very thin varves, which were impossible to measure. The varves were somewhat folded.

2. Böle, 250 m NE of Böle village, at the little rill Norrebäcken. The level is 10—15 m a.s.l. Two varve series were measured by De Geer in the vicinity of Böle. There are 46 measured varves and the bottom varve is dated at 10 146 B.C. Diagram on Pl. 1. The underlying material is sand with a thickness of more than 1.5 m. The uppermost part of the glacial clay is not varved.

3. Melby, 1.3 km ENE of Melby farm, 300 m E of the railway. The level

is 10—15 m a.s.l. There are 36 measured varves, the bottom one being dated at 10 155 B.C. Diagram on Pl. 1. The underlying material is till. The varves are very distinct. Lenses of fine sand are of common occurrence.

4. Stävlö, 3 km W of Stävlö estate. The level is 10—15 m a.s.l. One varve series was measured by De Geer in the vicinity of Stävlö. There are 48 measured varves and the bottom varve is dated at 10 156 B.C. Diagram on Pl. 1. The underlying material is till. Sand is deposited above the glacial clay.

5. Kärrtorp I, 1.3 km NW of Kärrtorp estate. The level is 15—20 m a.s.l. There are 55 measured varves, the bottom one being dated at 10 168 B.C. Diagram on Pl. 1. The underlying material is till. The varves are very distinct and neither disturbed nor folded. The measurement was made at an excavated rill.

6. Kärrtorp II, 1.3 km NW of Kärrtorp estate, 100 m W of Kärrtorp I. The level is 15—20 m a.s.l. There are 50 measured varves, the bottom one being dated at 10 168 B.C. Diagram on Pl. 1. The underlying material is till. The varves were very distinct and not disturbed or folded. The measurements were made at an excavated rill.

7. Gösbäck, 1.3 km E of Gösbäck farm. The level is 10—15 m a.s.l. One varve series was measured by De Geer in the vicinity of Gösbäck. There are 67 measured varves, the bottom one being dated at 10 168 B.C. Diagram on Pl. 1. The underlying material is till. The glacial clay is disturbed and in some cases folded.

8. Kuleholm, 600 m NW of Kuleholm farm. The level is 5—10 m a.s.l. One varve series was measured by De Geer in the vicinity of Kuleholm. There are 55 measured varves and the bottom varve is dated at 10 158 B.C. Diagram on Pl. 2. The underlying material is till. The glacial clay is very much disturbed and the varves are folded to a large extent.

9. Borshorva, 400 m NW of Borshorva farm. The elevel is 10—15 m a.s.l. One varve series was measured by De Geer in the vicinity of Borshorva. There are 56 measured varves, the bottom one being dated at 10 163 B.C. Diagram on Pl. 2. The underlying material is till. Lenses of fine sand and silt frequently occur in the glacial clay. The varves are rather indistinct.

10. Ödingstorp, 100 m E of Ödingstorp village. The level is 10—15 m a.s.l. One varve series was measured by De Geer in the vicinity of Ödingstorp. There are 52 measured varves, the bottom one being dated at 10 168 B.C.

Diagram on Pl. 2. The underlying material is till, probably boulder clay. Above the measured varves, there are some very thin and indistinct varves, which were impossible to measure. The varves are folded in some cases.

11. Hårstorp, 600 m W of Hårstorp farm. The level is 5—10 m a.s.l. One varve series was measured by De Geer in the vicinity of Hårstorp. There are 47 measured varves, the bottom one being dated at 10 185 B.C. Diagram on Pl. 2. The underlying material is till. The measured varves are distinct. Above these varves, there were some very thin varves, which were impossible to measure.

12. Kläckeberga, 800 m NE of Kläckeberga church. The level is 10—15 m a.s.l. One varve series was measured by De Geer in the vicinity of Kläckeberga. There are 29 measured varves, the bottom one being dated at 10 188 B.C. Diagram on Pl. 2. The underlying material is till, probably boulder clay. The varves are disturbed and folded in some cases and lenses of silt occur frequently. A thin layer of sand is deposited above the glacial clay.

13. Skäggenäs, 100 m SW of Venenäs farm on the north-western part of Skäggenäs peninsula. The level is 5—10 m a.s.l. There are 39 measured varves, the bottom one being dated at 10 204 B.C. Diagram on Pl. 2. The underlying material is sand, with a thickness of more than 1.5 m. The varves are very distinct.

14. Svaneberg, 200 m W of Svaneberg farm, in the western part of Kalmar. The level is 5—10 m a.s.l. One varve series was measured by De Geer in the vicinity of Svaneberg. There are 80 measured varves, the bottom one being dated at 10 194 B.C. Diagram on Pl. 2. The underlying material is till, probably boulder clay. The measured varves are very distinct and neither disturbed nor folded. Layers of silt and sand occur in places in the glacial clay.

15. Källarbacken, 300 m NW of Källarbacken farm on a little rill. The level is 10—15 m a.s.l. One varve series was measured by De Geer in the vicinity of Källarbacken. There are 22 measured varves, the bottom one being dated at 10 170 B.C. Diagram on Pl. 3. The underlying material is till. Sand is deposited above the glacial clay. The varves are somewhat folded.

16. Rinkabyberg, 900 m NW of Rinkabyberg estate on a little rill. The level is 10—15 m a.s.l. One varve series was measured by De Geer in the vicinity of Rinkabyberg. There are 70 measured varves, the bottom one being dated at 10 176 B.C. Diagram on Pl. 3. The underlying material is till. Above the measured varves, there are some very thin varves, not measured. The glacial clay was in some cases disturbed and folded.

17. Gräsgärde, 600 m NW of Gräsgärde village on the little rill. The level is 15—20 m a.s.l. One varve series was measured by De Geer in the vicinity of Gräsgärde. There are 54 measured varves, the bottom one being dated at 10 166 B.C. Diagram on Pl. 3. The underlying material is till. The varves are disturbed and folded to a great extent. Sand is frequently found in the glacial clay.

18. Resby, 300 m NNE of Resby village. The level is 30—35 m a.s.l. One varve series was measured by De Geer in the vicinity of Resby. There are 65 measured varves, the bottom one being dated at 10 151 B.C. Diagram on Pl. 3. The underlying material is till. There is a thin layer of organic material above the glacial clay. Lenses of silt and sand occur frequently in the glacial clay.

19. Brobylund, 500 m W of Brobylund farm. The level is 15—20 m a.s.l. Many varve series were measured by De Geer in this area. There are 29 measured varves, the bottom one being dated at 10 175 B.C. Diagram on Pl. 3. The underlying material is till. Above the measured varves, there are some very thin varves, which were impossible to measure.

20. Karlshöjd, 1 km ENE of Karlshöjd farm. The level is 15—20 m a.s.l. Many varve series were measured by De Geer in this area. There are 35 measured varves, the bottom one being dated at 10 174 B.C. Diagram on Pl. 3. The underlying material is till. The varves are indistinct. It is possible that the measurement is not correct. Lenses of silt occur frequently and the varves are often folded.

21. Backagården west, 600 m WNW of Backagården farm. The level is 10—15 m a.s.l. There are 30 measured varves, the bottom one being dated at 10 181 B.C. Diagram on Pl. 4. The underlying material is till. The measured varves are often disturbed and folded. It is possible that the measurement is not correct. Lenses of sand occur in some cases.

22. Backagården, 100 m W of Backagården farm. The level is 10—15 m a.s.l. Two varve series were measured by De Geer in the vicinity of Backagården. There are 28 measured varves, the bottom one being dated at 10 184 B.C. Diagram on Pl. 4. The underlying material is till. The measured varves are very distinct and are neither disturbed nor folded. Sand is deposited above the glacial clay.

23. Lovers, 300 m ESE of Lovers farm to the E of the Kolboda—Loverslund road. The level is 0—5 m a.s.l. One varve series was measured by De Geer in the vicinity of Lovers. There are 64 measured varves, the bottom one being dated at 10 197 B.C. Diagram on Pl. 4. The underlying material is till. The

measured varves are distinct. Layers of sand and silt occur in some cases in the glacial clay.

24. Kolboda, 700 m NNE of Kolboda village. The level is 0—5 m a.s.l. Two varve series were measured by De Geer in the vicinity of Kolboda. There are 18 measured varves, the bottom one being dated at 10 200 B.C. Diagram on Pl. 4. The underlying material is till. The measured varves are distinct and exceptionally thick. Sand is deposited above the glacial clay.

25. Eckelsudde, Öland. The varved glacial clay was observed and collected by students under the leadership of Prof. Königsson. The location is about 1.5 km W of Ned. Väderstad village. Above the varved glacial clay, beach deposits occur. The underlying material is till. There are 33 measured varves and the bottom varve is dated at 10 207 B.C. The measured varves are very distinct. Diagram on Pl. 4.

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SGU = Sveriges geologiska undersökning

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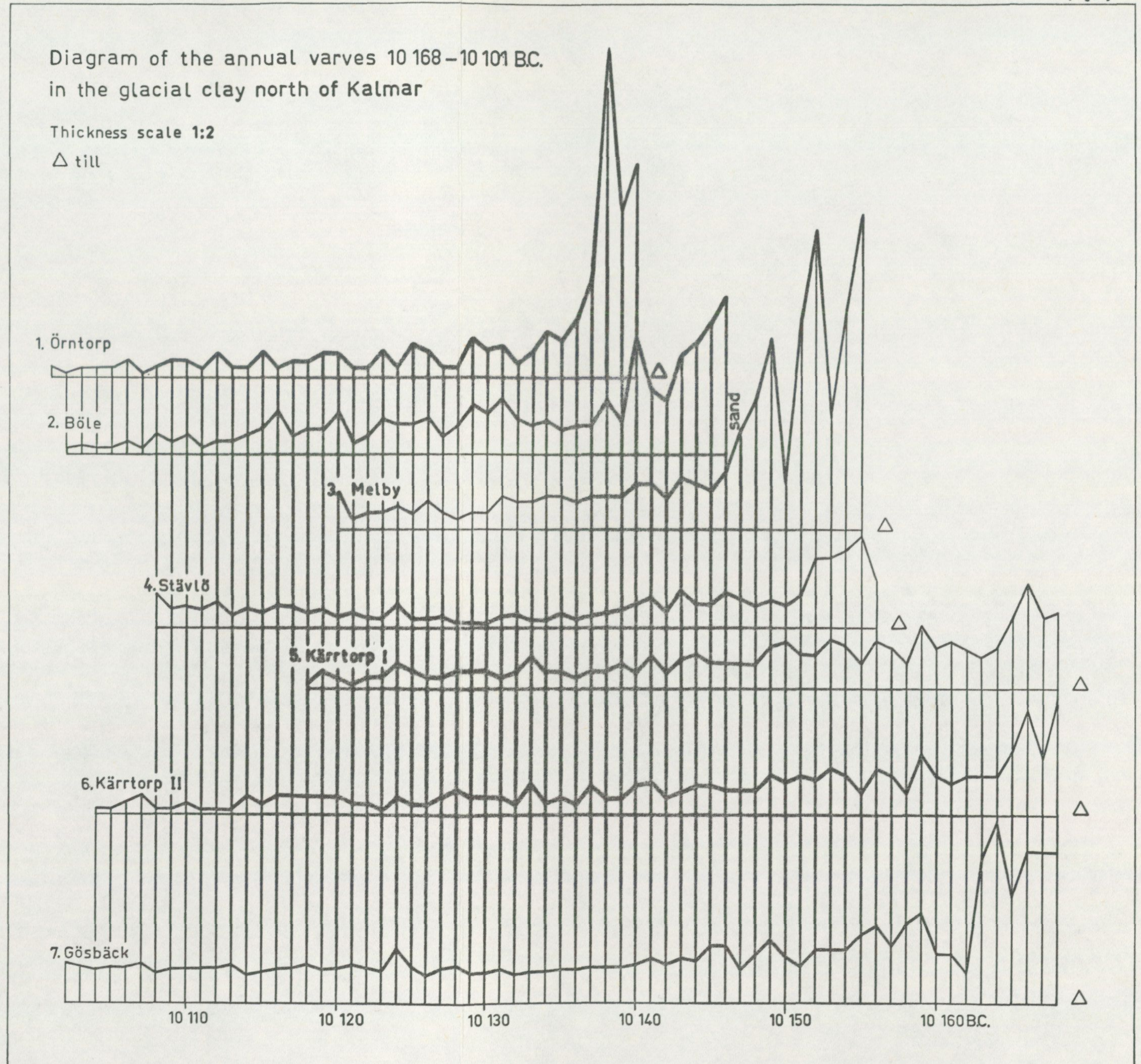
Diagram of the annual varves 10 168 – 10 101 B.C.
in the glacial clay north of Kalmar
Thickness scale 1:2
△ till
1. Örntorp
2. Böle
3. Melby
4. Stävlö
5. Kärrtorp I
6. Kärrtorp II
7. Gösbäck
sand
10 110
10 120
10 130
10 140
10 150
10 160 B.C.

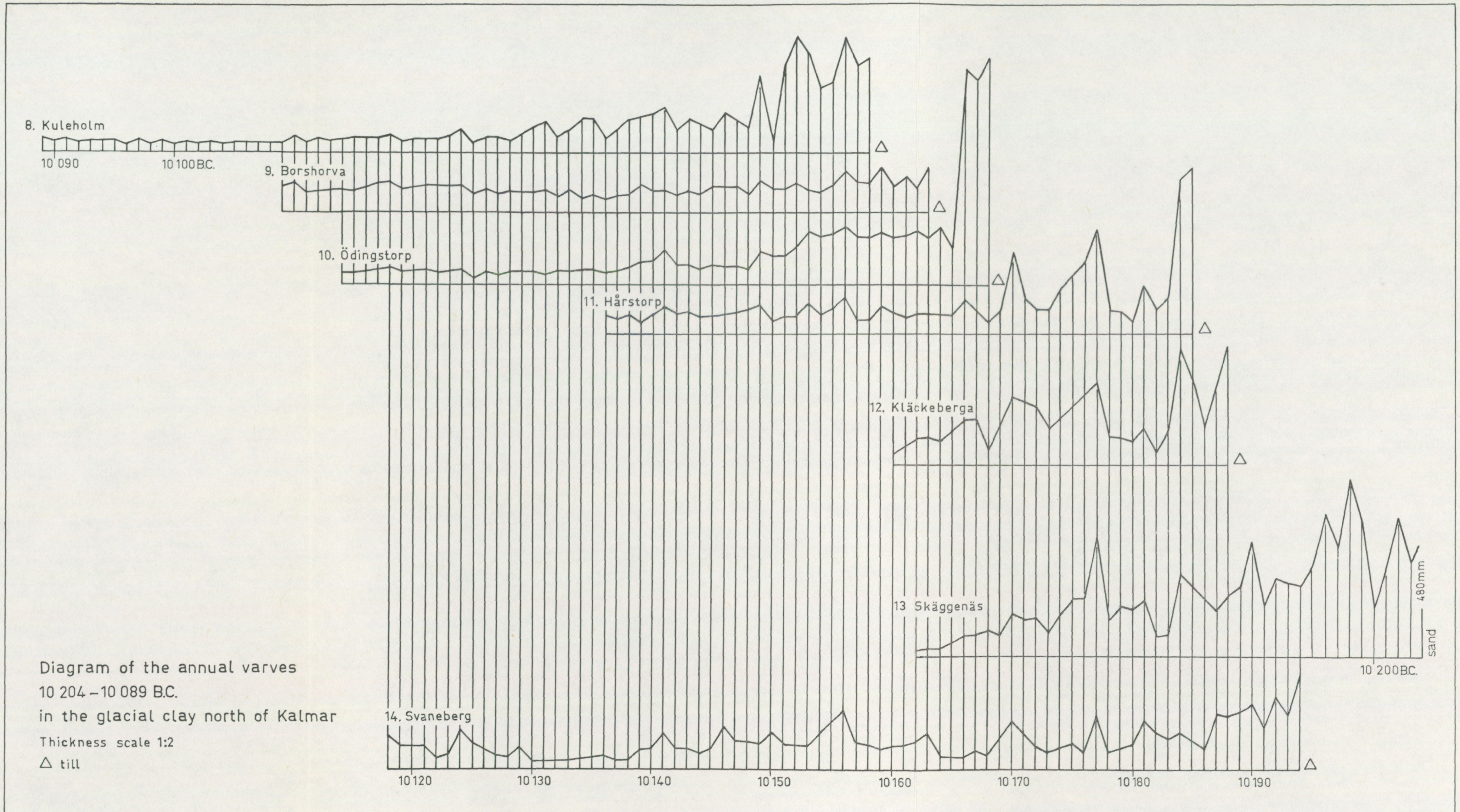

Diagram of the annual varves
10 204 – 10 089 B.C.
in the glacial clay north of Kalmar

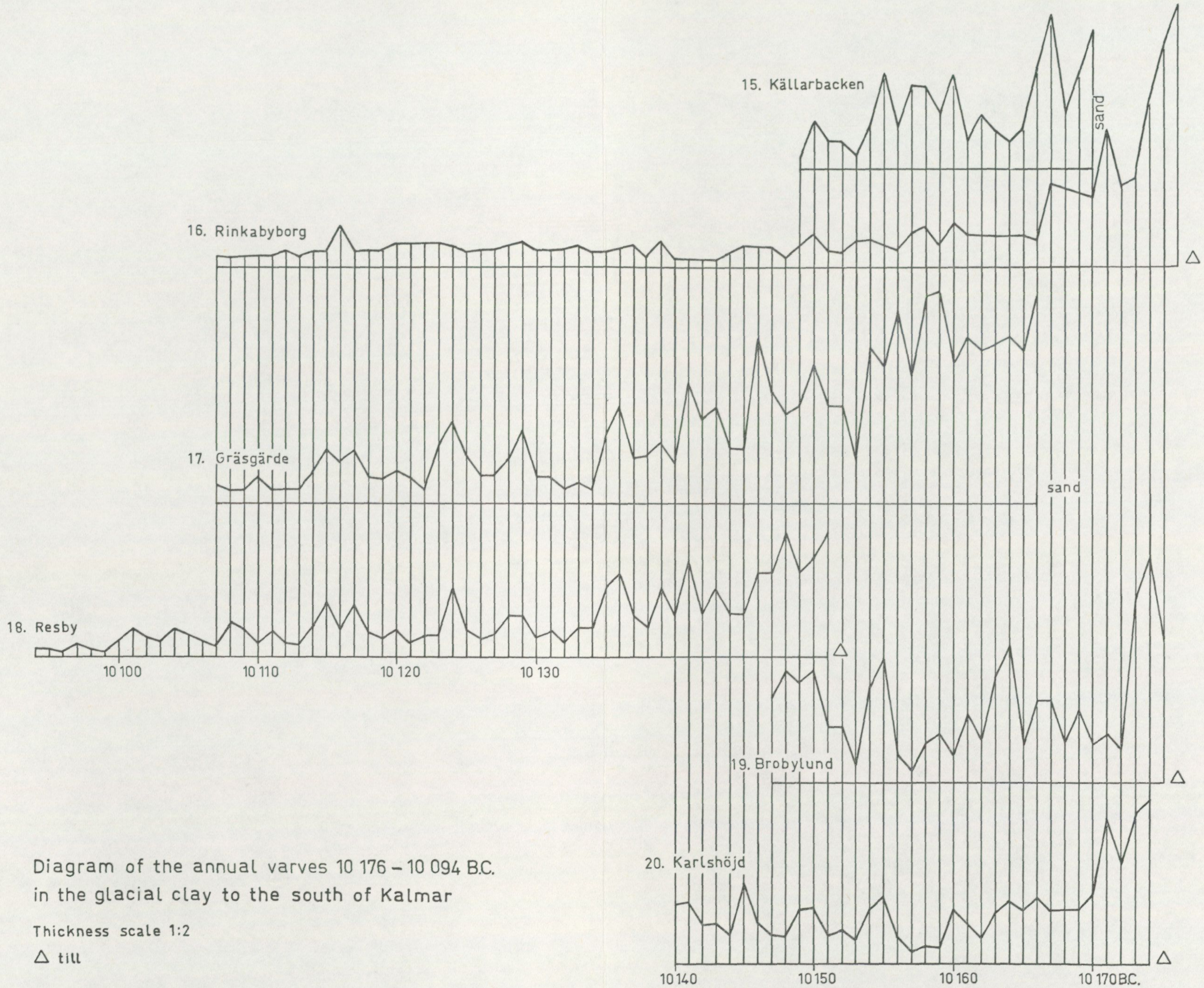

Diagram of the annual varves 10 176 – 10 094 B.C.
in the glacial clay to the south of Kalmar

Thickness scale 1:2

△ till

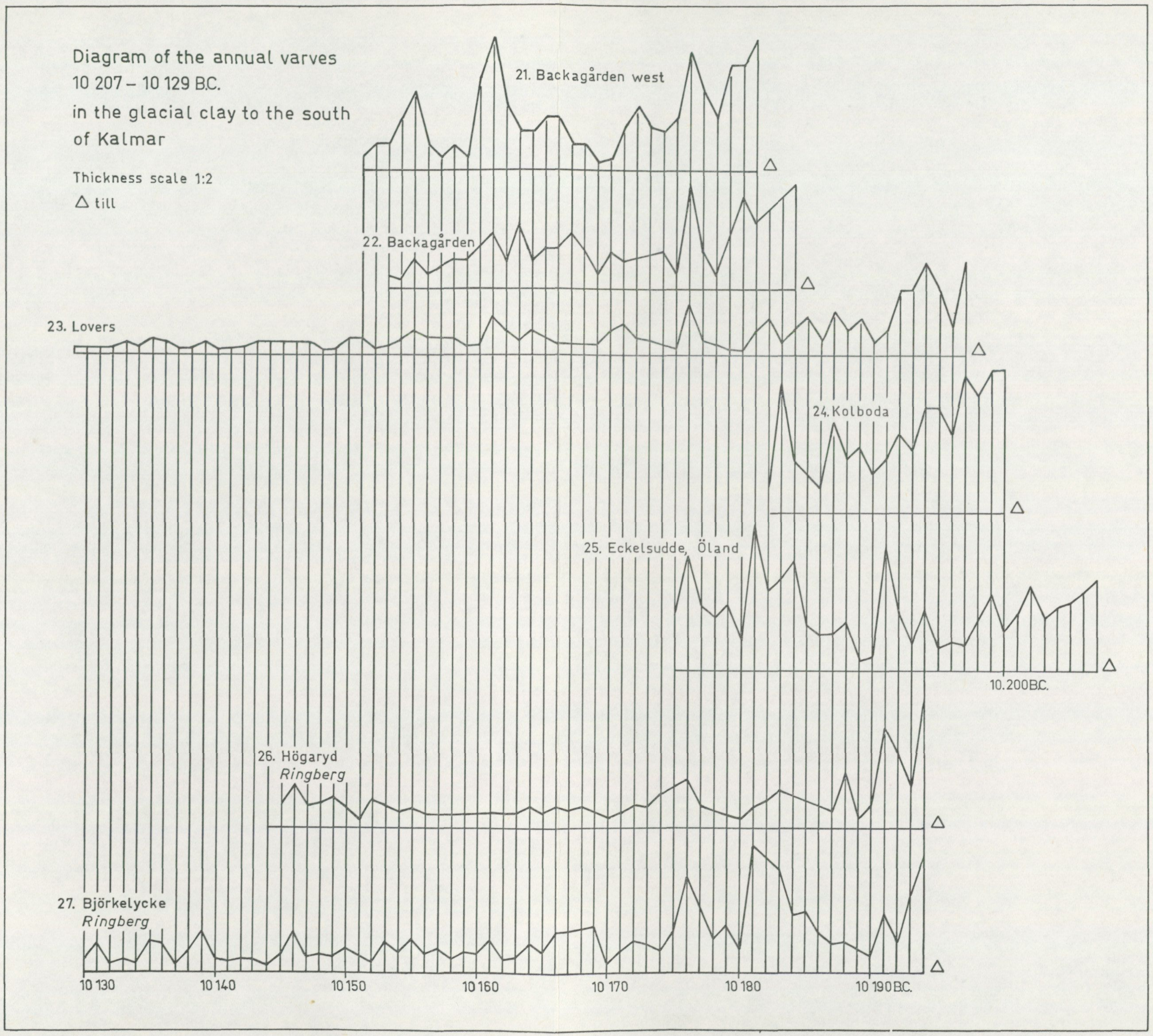
Diagram of the annual varves
10 207 – 10 129 B.C.
in the glacial clay to the south of Kalmar
Thickness scale 1:2
△ till
21. Backagården west
22. Backagården
23. Lovers
24. Kolboda
25. Eckelsudde, Öland
10.200 B.C.
26. Högaryd
Ringberg
27. Björkelycke
Ringberg
10 130
10 140
10 150
10 160
10 170
10 180
10 190 B.C.

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