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GLACIATION AND DEGLACIATION IN THE SOMMEN-ÅSUNDEN REGION, SOUTHEASTERN SWEDEN

Harald Agrell

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This investigation deals with the glacial geology and especially with the deposits from the deglaciation in the Sommen-Åsunden region on the north-eastern border of the southern Swedish uplands. The glacial erosion was determined by the pre-glacial bedrock forms. The till accumulated as distinct pre-crags and as hummocky moraine areas, which have a complex origin. The highest coastline, developed by the Baltic ice-lake, is indicated by wash limits in till slopes and by the levels of some glaciofluvial plains. The glaciofluvial deposits were concentrated in the valley bottoms, where plains and eskers reach the dammed water-table in the ice. The material has a variable grain-size composition. Traces of real, open ice-lakes seldom occur in this region. Periglacial deposits indicate a cold climate during the deglaciation. The chronology of the deglaciation has to be revised by work done outside the investigated area. The glacial deposits indicate that the receding ice sheet above the highest coastline was bordered by a wide zone of stagnant ice, in which the deglaciation features were created.

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CONTENTS

INTRODUCTION

General description of the area investigated

The north-eastern border zone of the southern Swedish uplands has its central part between the great lakes Sommen and Åsunden in the southern part of the province of Östergötland (Fig. 1). This region differs from its surroundings in having a distinct joint-valley morphology, rich in exposed bedrock. The general levels sink towards the NNE. with the highest summit in the SW. reaching 293 m a. s. l. Lake Sommen is situated c. 146 m a. s. l. and Lake Åsunden 86 m a. s. l. In the central and south-western parts of the region, the level differences often exceed 100 m.

The Quaternary glaciations have strongly influenced the present morphology. The joint valleys were eroded and often over-depressed. The till accumulated as drumlinoids, pre-crags and hummocky moraine areas. In general, the glaciofluvial deposits appear as valley fillings, often in the form of plains and eskers. The plains are especially frequent at the highest coastline, which was formed by the Baltic ice-lake. The level of the highest coastline intersects the eastern part of the area and below it, along Lake Åsunden, large areas were covered with glacial clay and silt. The survey map compiled by Sahlström (1947) gives a good impression of the soil distribution in this region.

Previous work in the region

Many papers dealing with the glacial geology in the southern Swedish uplands have appeared,

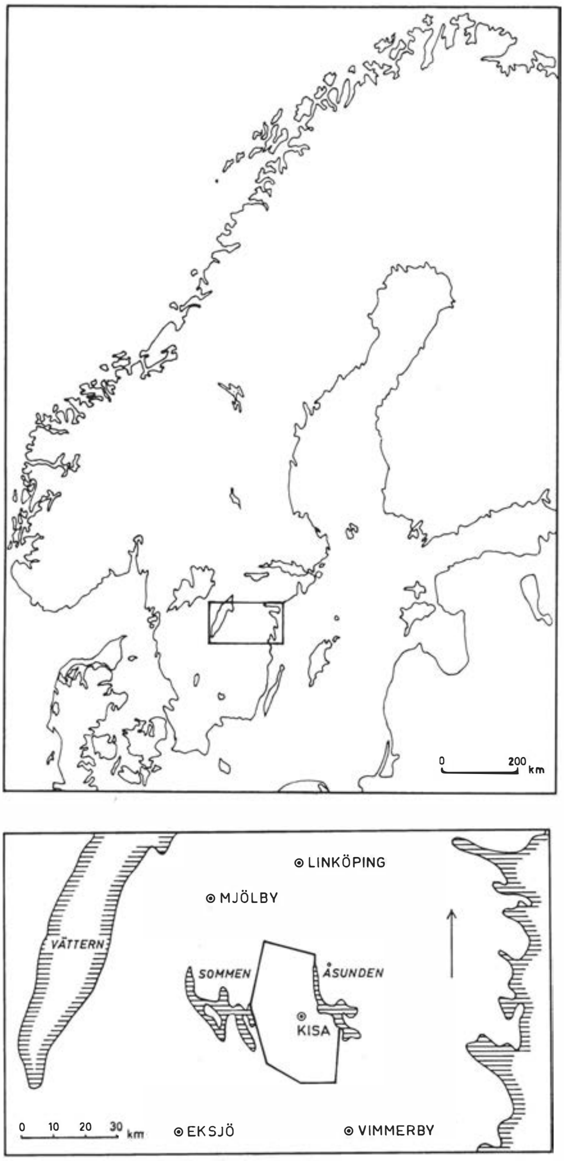


Fig. 1. The position of the investigated area.

especially during the last few years. A short review of some of them is given in a separate paper by the author (1973 *c*), in which some general aspects of the deglaciation in these uplands are discussed. The northeastern part of the uplands, however, is inadequately dealt with in the literature. The geological maps (Svedmark, 1904, 1906, 1913, Ekström, 1924, Sandegren, 1924) are old and schematic. They give scanty information for a reconstruction of the glacial geology. Sundelin (1917) deals with the Post-Glacial development in this region, but also the highest coastline and the varve chronology are briefly discussed. The investigations carried out by Björnsson mainly deal with the bedrock morphology, (1937), but some information about the glacial deposits is given in three small papers (1940, 1942, 1953). South of the area, investigations have been made by Friberg. Only some of his results have been published (1957). In the survey papers by Nilsson (1953, 1958, 1968), some sites indicating the deglaciation in this region are briefly mentioned. The northernmost part of the area has recently been covered by a modern soil map (Johansson, 1973) and the soil mapping on the map sheet Linköping SV continues immediately NW. of the area investigated. Together with the geological mapping, a study of the highest coastline was carried out (Cato & Lindén, 1973).

The main part of the material from the investigated area has been presented in an unpublished licentiate thesis (Agrell, 1972 *a*). It is not possible to treat all the local details in this published version. A preliminary report (Agrell, 1973 *b*) covers the investigated area and a popular study of its central part has been presented (Agrell, 1972 *b*). The periglacial deposits are treated in detail in a separate report (Agrell, 1973 *a*; cf. Agrell & Hultman, 1971 and Agrell, 1971).

The aim of the present investigation

The bedrock morphology and its influence upon the glaciation and deglaciation makes the Sommen-Åsunden region an interesting object for a detailed study. The aim of this investigation has been to give an interpretation of the deglaciation pattern in an Archaean joint-valley landscape around the highest coastline.

The main subjects studied in this investigation can be summarized as follows:

1. The ice movements and the till distribution
2. The features left by the Baltic icelake
3. The morphology, stratigraphy and distribution of the glaciofluvial deposits
4. The periglacial deposits

Other aspects of the geomorphology and the Quaternary geology of this region have not been studied in detail. The bedrock morphology was examined by Björnsson (1937). Varve chronology is being dealt with by Jan Kristiansson of the Dept. of Quaternary Geology at the University of Stockholm.

It may be possible to apply some of the interpretations suggested here to similar areas in other regions, especially in the southern Swedish uplands.

Acknowledgements

This investigation was suggested in 1968 by Dr. Bo Strömberg of the Department of Physical Geography at the University of Stockholm. The advice given by Dr. Strömberg has been of great value in the investigation. During soil mapping for the Geological Survey of Sweden in the summer of 1969, I had my first contact with the deglaciation problems in this region. Dr. Hans G. Johansson, State Geologist, has given valuable information about the northern part of the investigation area.

The investigation was started as an undergraduate project at the Department of Quaternary Geology at the University of Uppsala under the then head of the Department, Professor Sten Florin. Professor Lars-König Königsson, who has been the head of the Department since 1970, has supported my investigations with never-failing interest. The advice given by Dr. Gunnar Gillberg and Dr. Ragnar Dahl has been of special importance. The various problems which are treated in this investigation have been discussed with many of my colleagues, some of whom are mentioned in the text. Of especially great interest have been my discussions with Professor Nils Friberg, Dr. Nils A. Mörner, Professor John Norrman and Dr. Johannes Öster.

Financial support was received from the faculty of Natural Sciences at the University of Uppsala in 1970—71 and from the Swedish Society for Anthropology and Geography (Andréefonden) in 1972 and 1973. Parts of the field work were carried out as undergraduate projects by students (Rolf B. Bergström, Rolf Hultman, Björn Karlsson and Svante Rindetoft). The illustrations were re-drawn by Frymete Flam, Harry Holmström and Asta Kaljusaar. Some soil analyses were made by Fingal Karlsson. The English text was corrected by Neil Tomkinson, B.A. To them all I express my sincere thanks.

Uppsala January 14th, 1974

METHODS

General survey

The first part of the field work was done in order to determine the extent of the area to be investigated. The area to be selected must not be too large, as this would make the field work too extensive. It must not, however, be too small, as it must contain all the types of glacial deposits occurring in the region. The borders must, if possible, be located in areas where no objects of any interest occur. During the general survey, which was mainly carried out in the summer of 1970, it was also possible to get a knowledge of the glacial deposits in general in this part of Sweden, which is necessary for a correct interpretation of the objects in the investigate area.

The survey was made on the basis of the new topographic maps on a scale of 1:50 000, which were issued about 1965. These maps, with photogrammetric level curves, provide a much better basis for an investigation than the old maps in the 1:100 000 scale, in which the surface forms were only approximately shown. The aerial photographs on a scale of 1:30 000, taken in 1968, were studied. However, in this wooded region they yield little more information than the maps. The old geological maps on a scale of 1:50 000 were also studied in detail; they were supplemented with the field diaries preserved at the Geological Survey of Sweden.

The general survey included short inspections at all the localities which were supposed to be of any interest for the investigation. These localities were found in the literature, on the maps and in the field. Almost all the roads in the investigated area have been inspected.

Compilation of the general maps

The map of the exposed bedrock (Fig. 11) was compiled from the old maps, because the bedrock is not shown on the new maps. It is obvious that the bedrock was over-estimated on the old maps. The geological maps differ so much in the mapping principles used, compared with the topographic maps, that they cannot be used for this purpose.

The map of the glacial geology (Fig. 4) was made on the basis of the official topographic maps on a scale of 1:50 000. The drumlinoid ridges were drawn from the maps but were checked in the field. Only the ridges which indicate the ice movement are shown. The hummocky moraine regions were mapped in the field, as they were very difficult to distinguish from bedrock forms in aerial photographs. Glacial striae were mainly observed where fresh rock surfaces were found, for example, in road cuttings and near buildings. All the striae localities on the geological maps have been re-measured and doubtful localities have been inspected and re-investigated on several occasions.

The glaciofluvial deposits were mapped in the field. The distribution of the glaciofluvial material is underestimated on the map. Above the highest coastline, it is often covered by peat and below this level it may be covered by glacial fine sediments. On the borders of the hummocky moraine regions, the glaciofluvial material is often difficult to distinguish from ablation till.

Also the map of the Late-Glacial hydrography (Fig. 18) was drawn on the 1:50 000 maps with re-drawing on a scale of 1:100 000. Most of the levels were measured by instrument and the levellings were made between two fixed points or back to the starting-point. Even when the levelled distances exceeded 10 km, the error was found to be not more than ± 0,25 m and thus the levels are given in half metres. Also for scientific reasons a higher degree of certainty is useless (cf. Gillberg, 1956 *b*, p. 379). Some local ice-lake outlets, where a very variable water-level was supposed, were not levelled. The levels of the glaciofluvial plains and the ice-lake outlets refer to their highest points or to the interval between the highest and lowest points. The levels presented in the text as exact figures were measured by instrument; other levels are presented as "c".

The extent of the dammed bodies of water was drawn from the levels of the pass points, but in most cases the extent is rather hypothetical. The extent of the Baltic ice-lake (the highest coastline) has been estimated from glaciofluvial plains and from levelled wash limits in till slopes. Soil samples were taken for mechanical analysis. The methods used in this investigation are further dealt with in 2 special chapters.

Some detailed investigations

In some areas with glaciofluvial deposits, special maps were made. The basic material was the economic maps on a scale of 1:10 000 or enlargements of the maps on a scale of 1:50 000. All the official maps used will be found in a separate list following the list of references. Across most of the glaciofluvial plains, profiles were levelled by instrument. In large excavations, which are few in this region, sketches were made with the support of photographs. At some localities, motor drillings were made. Several measurements of elongated pebbles were made, but only a few are presented in the text. Typical soil samples, taken in fresh excavations, have been analysed by sieving and by hydrometer analysis. Some of the analyses are presented as cumulative diagrams in the text. Detailed investigations made at some localities will be mentioned together with the descriptions.

MORPHOLOGY

The bedrock

The investigated area is dominated by a coarse-grained, reddish granite (Filipstadsgranit). A fine-grained, reddish granite is brecciated by this type and thus is somewhat older (cf. Magnusson, 1924, pp. 18—21). The bedrock in the south-western part of the area consists of reddish leptite, which is older than both the granite types. The Archaean bedrock in this region was formed during the Gothian cycle (cf. Lundegårdh, 1970, p. 111). Dikes of coarse-grained dolerite, probably of Jotnian age, occur in some of the valleys (Björnsson, 1937, pp. 44—45). A sandstone dike, probably of Lower Cambrian age, has been found SE. of Ulrika (Magnusson, 1924, p. 23).

The leptite outcrops have an irregular, sharp-edged surface, mainly due to frost weathering. The glacial striae are thus badly preserved. The surface of the coarse-grained granite is strongly weathered by mechanical disintegration. Small quartz dikes show that the Post-Glacial disintegration on the outcrops cannot have exceeded c. 1 m, but this has been enough to destroy the glacial striae in most positions. Where recently uncovered surfaces not occur, the striae in general are only preserved on outcrops of fine-grained granite.

At three sites, the coarse-grained granite has been disintegrated several metres below the surface. Two of them, Knasekärret on Asby udde in Lake Sommen (Agrell, 1973 *b*, p. 62) and Grö-ninge, SW. of Hycklinge, are located outside the investigated area. The third locality, Lake Krampen, is situated in an irregular bedrock area around 200 m a. s. l. The material is visible in a cutting along the road from Kisa to Ulrika (Fig. 2). The disintegrated mass is covered by a thin layer

Fig. 2. Disintegrated granite bedrock with residual boulders, W. of Lake Krampen and NNW. of Kisa.

of basal till and it contains rounded residual boulders, 1—2 m in size. Probably the disintegration follows a zone of weakness in the bedrock, as the sharp contact with the fresh granite is visible in the excavation. The material has been micrographically examined by Professor B. Collini. The disintegrated mass has a quite normal mineral composition and thus the disintegration must have been due entirely to mechanical processes.

This site is briefly mentioned by Björnsson (1937, p. 80), who considers the disintegration to be of pre-glacial age. Hillefors (1969, pp. 16—25) describes several similar deposits from western Sweden, where a pre-glacial age is suggested. Collini (pers. comm.) suggests that these deposits are the remains of a widespread cover formed during the Tertiary epoch. In this region, well-rounded, large, granite boulders are rather common in the glacial deposits. Obviously they are residual boulders from similar localities which have been destroyed by glacial erosion and thus a Post-Glacial age of the disintegration can be excluded. However, it is impossible to say whether this disintegration material is of inter-glacial or pre-glacial age.

At the few localities where the dolerite is exposed, it is completely disintegrated. The dolerite occurs in deep valleys where the meltwater erosion was intense during the deglaciation. Disintegration gravel, older than the deglaciation cannot have been preserved under such conditions. As disintegration of dark rocks is common under the present conditions, it seems most probable that this disintegration is of recent age.

The pre-glacial bedrock surface

The main part of the investigated area may be characterized as one of the best-developed joint-valley landscapes in the country, the development of which has been examined in detail by Björnsson (1937). The valley from Kisa to Lake Sommen divides the area into two upland regions, the northern of which passes over into a flat bedrock surface. This surface, which can be traced further to the N. and W., is supposed to be the remains of the Precambrian peneplane (Björnsson, 1937, p. 75). To the S. and SW., the jointvalley landscape is replaced by surface forms with broader relief, typical of the central part of the southern Swedish uplands (Fig. 3).

Fig. 3. Large-scale landscape forms in the south-western part of the investigated area. Lake Glimmingen (145 m a. s. l.) towards the south.

The present bedrock surface is characterized by valleys oriented NNW.—SSE. and N.—S., but several other orientations occur. The fault zones running NNW.—SSE. are supposed to be slightly older than the zones running N.—S. (Björnsson, 1937, p. 49). As the latter are associated with the dolerites mentioned above, they are supposed to be of Jotnian age (Björnsson, 1937, p. 44). The valleys running N.—S. occurred as overthrusts eastwards along slightly dipping planes, a fact which has strongly influenced the present surface forms (Björnsson, 1937, p. 65). Movements in the bedrock, causing numerous joint fractures, also occurred in this region during the Caledonian orogenesis, when overthrusts to the S. took place (Björnsson, 1937, p. 68). The recent valleys often form resultants to zones of weakness with different directions (Björnsson, 1937, p. 35). Probably they received their present shape mainly as a result of fluvial erosion in pre-glacial time (Björnsson, 1937, pp. 74—75).

The ice-movements

The glacial striae in this region were supposed to show the influence of the surface forms on the ice movements. An ice-movement pattern strongly influenced by the valley directions may indicate that the ice was still moving when it had amalgamated, so that it had the form of lobes and tongues in the valleys. A total lack of such glacial striae may, however, indicate that the ice-front zone was stagnant during the deglaciation.

All the 77 sites with glacial striae in the area were noted on the map (Fig. 4). The striae occur at all levels and in all topographical positions. Orientations between *c.* N. 10°W. and N. 20°W. predominate in the whole area. Where two orientations are found on the same outcrop, facets indicate that the more westerly is the latest, for example, at Froghult and at Solberget (Fig. 5). On the slopes of the valleys running N.—S. direction the ice-movement may be only a few degrees from the W. and at one site (Lake Roten) even a few degrees from the E. Also deflections westwards occur, N. 30°W. at some sites near Lake Åsunden and in one case (Sörstugan at Lake Sommen) N. 40°W.

The only locality with greatly varying striae directions in this region was found in a road cutting E. of Ålhult (Fig. 6), below the highest coastline in the southernmost part of the investigated area. The easternmost direction is N. 3°E., the westernmost N. 62°W. The age succession is difficult to interpret, as the western part of the outcrop has been blasted away. The striae pattern shows that the ice mass plastically followed the bedrock forms, causing ice-movements differing from the main direction. This may have been due to the position of the site, in a lowland area distally of the uplands, which influenced the ice-movement during the final part of the deglaciation (cf. Larsson 1945, p. 9).

The distribution of the glaciofluvial deposits gives no indication of the ice-movements, as it was entirely caused by the surface forms. The direction of the glacial outcrops is the same as the main direction of the striae. In the leptite rock areas, transversal fractures are common, but their directions are variable and only at some sites in accordance with the striae direction. The well-developed pre-crag ridges (49 ridges noted on the map, Fig. 4) indicate an ice-movement from N. 25—30°W., which thus is a little further to the west than the striae directions. This fact may indicate that the ridges and the striae were developed at different times. It is, however, more probable that the ridges represent the main ice-movement in the upper parts of the ice mass, while the striae represent a slight deviation caused by the valley systems. The origin of the till ridges is further treated below.

The geological maps show a similar striae pattern. East of the area, the directions become more westerly, indicating a deflection of the ice margin towards the NE. (Sandegren, 1924, p. 35). West of the area, directions running nearly N.—S. predominate (Ekström, 1924, p. 25). The localities which, according to Ekström, indicate an ice-movement from the NE. have not been accepted as only striae from the NNW. were found on the outcrops. It can be stated that the ice-movement in the whole region was from NW. to NNW. during the last glaciation (cf. the map compiled by G. Lundqvist in 1961). It is not possible to reconstruct any ice-movement succession from the scattered observations of different ice-movement directions. The valleys crossing the area in the N.—S. direction caused a slight deflection of the main ice-movement, but in general the influence of the surface forms was rather small. The ice-movement pattern in this region may thus be characterized as rather uncomplicated.

The glacial erosion

As in most glaciated regions, the total amount of glacial erosion in the bedrock during the Quaternary glaciations is difficult to estimate. Independently of the exposure to the main ice-movement, all the valleys are of about the same size. This fact supports the suggestion by Björnsson (cf. above) that the pre-glacial relief is still well preserved in this region.

The glacial erosion was guided by the pre-glacial surface forms and thus was most intense along the zones of weakness parallel to the ice-movement (Björnsson, 1937, pp. 89, 91 and 93). Where the main valleys crossed each other, over-depressed areas were eroded. These depressions are now occupied by lakes which, considering their area, are among the deepest in the country, for example, Lake Verveln (40 m), Lake Rödingehultsjön (32 m) and Lake Svalsjön (30 m). The valleys running N.—S., which were caused by overthrusts and thus have steep western sides, have had their asymmetri-

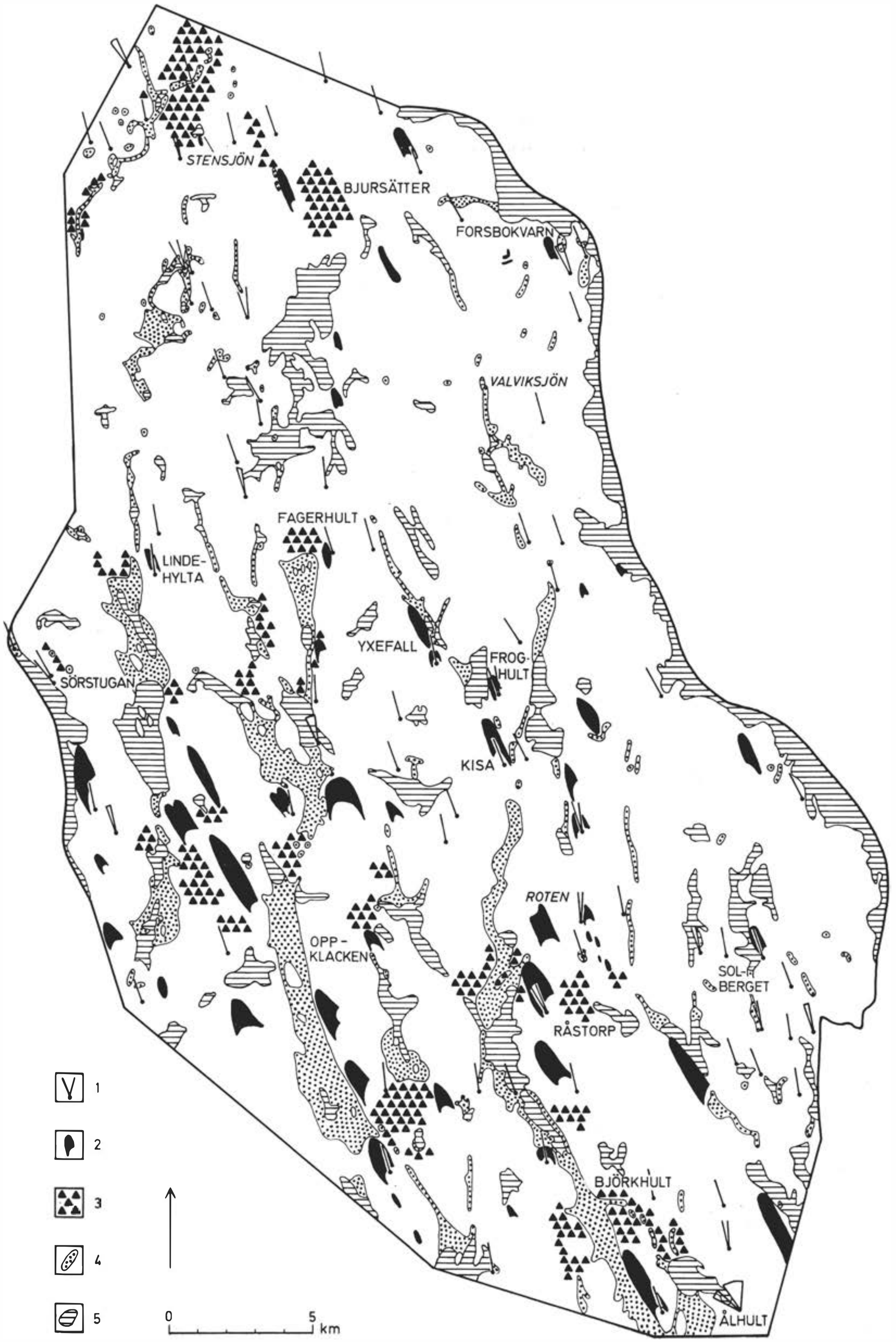

STENSJÖN
BJURSÄTTER
FORSBOKVARN
VALVIKSJÖN
FAGERHULT
LINDE-HYLTA
SÖRSTUGAN
YXEFALL
FROG-HULT
KISA
ROTEN
OPP-KLACKEN
SOL-BERGET
RÅSTORP
BJÖRKHULT
ÅLHULT
1
2
3
4
5
0
5 km

Fig. 5. Facet with glacial striae from *c.* N. 20°W (right) and N. 10°W. (left) in the Skjulå valley, W. of Horn.

cal forms made more pronounced by the glacial erosion (Björnsson, 1937, p. 88). Especially distinct are the valleys from Kättestorp to Mjölsefall and from Lake Verveln to Slätmon (Fig. 7).

The best-developed glacial outcrops occur in the valleys parallel to the ice-movement, where the glacial erosion was most intense (cf. Gillberg, 1955, p. 488). On the plateaus between the large valleys, the glacial erosion was slighter, as is shown, for example, by the remains of disintegrated bedrock. The large rock forms were always shaped by the glacial erosion, forming a sort of rock drumlins with well-developed stoss and lee sides. The cleavage planes in the granite have caused the accumulation of large boulder masses in lee positions. Sometimes the granite blocks have been moved only slightly, so that real caves were formed. Several such caves occur in the area N. of Lake Drögen (cf. Ekström, 1924, p. 26).

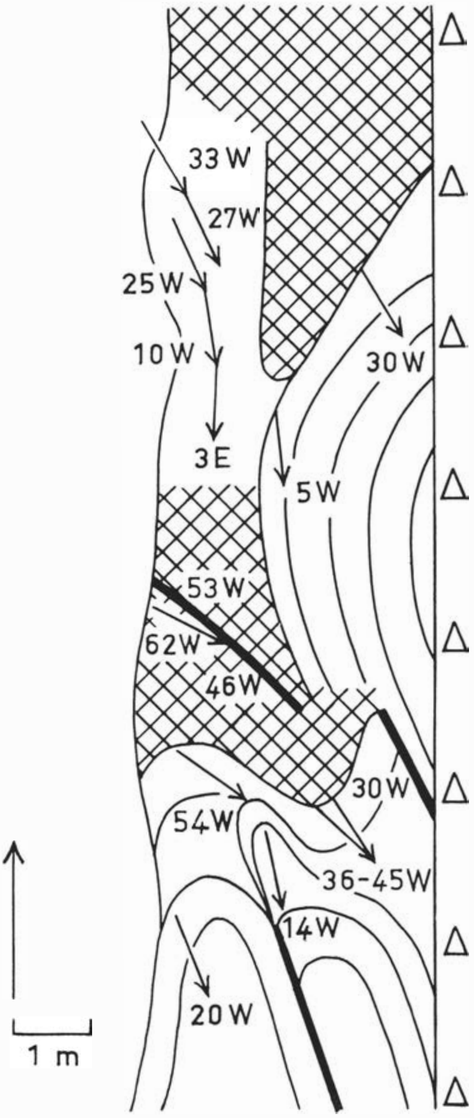


Fig. 6. Directions of glacial striae in a road cutting E. of Ålhult. Thick lines mark vertical slopes which have been striated; Hatched areas show destroyed bedrock surface.

Here may also be mentioned the bedrock forms caused by glaciofluvial erosion, particularly the rock gorges, which are further dealt with in a following chapter (cf. Figs. 36 and 44). Near the glaciofluvial deposits, the bedrock was eroded, forming various types of erosion marks (Figs. 8 and 9). The real potholes (Fig. 10), however occur in all topographical positions and some of them may be older than the last glaciation. Some potholes in the northern part of the area were described by Svenonius (1918, pp. 734—736).

This region is rich in exposed bedrock, except for the broad-lined area in the SW. and the flat

Fig. 4. The main features of glacial geology in the area. 1. Glacial striae. 2. Drumlins and pre-crags. 3. Hummocky moraine areas. 4. Glaciofluvial material. 5. Recent lakes. The northernmost area partly sketched from the map by SGU (Johansson, 1973, cf. Fig. 63).

Fig. 7. The Kölefors valley northwards from Kisa. Asymmetric cross profile.

northern area (Fig. 11). This fact may be due to the lack of till material in the ice (Rudberg, 1967, p. 350). The vast till accumulation in the northernmost part of the area and further to the N. may be one possible reason for the lack of till southwards (cf. Gillberg, 1955, p. 510). Also abrasion from glacial meltwater may have increased the areas of exposed bedrock (Björnsson, 197, p. 94). It may be noted that a thin cover of till often appears in the areas which are marked as exposed bedrock.

The till

The bedrock morphology in this region guided the till accumulation as well as the glacial erosion (Björnsson, 1937, pp. 87 and 89). The basal till was mainly accumulated as pre-crags, of which some form real ridges in the direction of ice-movement (cf. Section 3). The distribution of the pre-crags depends on the direction of the bedrock ridges parallel to the ice-movement (cf. Gillberg, 1955, p. 513) and on the main slope of the bedrock surface towards the ice-movement (Björnsson, 1953, pp. 116—119). It may be possible to characterize the northernmost, till-covered part of the area as an enormous pre-crag. In the southern part of the area, the pre-crags pass over into real drumlins of the elongated-ridge type (cf. the map, Fig. 4). Some of these ridges have been mapped and described by Björnsson (1953, pp. 108—113). In the ridges, a thickness of the till exceeding 20 m has been observed (Björnsson, 1953, p. 115). The accumulation of basal till might have continued until the ice had smoothed out the surface, so that the friction was maximally reduced (Gillberg, 1965, pp. 462—463).

The till in the pre-crags is often rich in small boulders, but, as these areas are often cultivated, the boulder content in the surface may be difficult to estimate. Some examples of the grain-size composition are shown in Fig. 12 and with few exceptions the till is relatively normal sandy-silty. A tendency towards finer material is obvious in the well-developed ridges. In the observed excavations, the basal till is very compressed and completely homogeneous, sometimes with pressure structures (cf. Johansson, 1973, p. 26). The distribution of the Cambrosilurian material, which occurs in the fractions less than 60 mm, has been examined by Gillberg (1965). This material is more frequent in the valleys parallel to the ice-movement (Gillberg, 1965, p. 457). This is also indicated by the fragments of alum shale, which frequently occur in some glaciofluvial deposits, for example, in the Yxefall valley.

In the lowermost parts of the broken terrain, hummocky moraine areas are common. In sheltered positions, such areas may occur even below the highest coastline. No particular ridge pattern can be traced and often the forms seem to be influenced by the bedrock. In general, the hummocky moraine regions are more rich in boulders than the pre-crags. The elongated pebbles have no distinct orientation (Fig. 13). The grain-size composition is variable, from a normal, sandy-silty basal till through a gravelly ”ablation till” to a material similar to unsorted gravel (Fig. 14). The latter material, for which the name ”ablation gravel” is suggested, is difficult to distinguish from the glaciofluvial deposits, which often replace the hummocky moraine in this topographical position (cf., for example, the Björkhult area S. of Lake Verveln). Also the compression of the till varies with the grain-size composition.

This distribution of the hummocky moraine regions is typical of most glaciated regions above the highest coastline, especially in the southern Swedish uplands, where it has been pointed out by many authors. The great variations in material composition indicate that the hummocky moraine

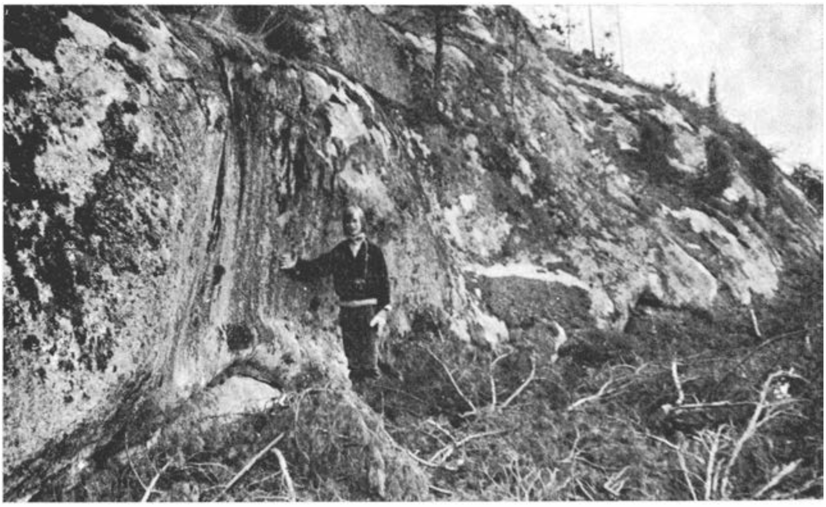


Fig. 8. Lateral glaciofluvial erosion N. of Mogård in the Svalsjö valley.

Fig. 9. Glaciofluvial erosion in a gravel pit at Björksätter, NNE. of Ulrika.

Fig. 10. A pothole, formed by the outlet from the Sommen icelake, at Örneström W. of Kisa. →

regions have a complex origin (cf. Johansson, 1972, p. 46).

Those areas which consist of firmly compressed basal till, for example, at Fagerhult, must have been formed below a thick and probably still-moving ice sheet. Other areas, for example, at Råstorp, must have originated entirely in a thin and stagnant ice mass, where the till deposition was influenced by glaciofluvial meltwater. Some areas, for example, at Oppklacken, contain a mixture of these two till types, which were probably formed during different phases of the deglaciation.

The vast hummocky moraine regions in the northernmost part of the area, at Stensjön and Bjursätter, are situated on the flat rock surface slightly dipping in the direction of ice-movement. The grain-size composition is variable and the till may form boulder ridges in the direction of ice-movement, for example, N. of Lake Stensjön. These areas must have occurred as a sort of crevasse fillings when the shrinking ice, loaded with till, had amalgamated so that it no longer could move over the surface (cf. Hoppe, 1952, p. 54).

The Forsbokvarn area W. of Rimforsa (Fig. 4) was mapped in detail. This map (Fig. 15) revealed an irregular pattern of moraine ridges rich in boulders, which are situated c. 100—105 m a. s. l. The material in the central ridge was examined

Fig. 11. Exposed bedrock in the investigated area. Compilation from the official maps on a scale of 1:100 000.

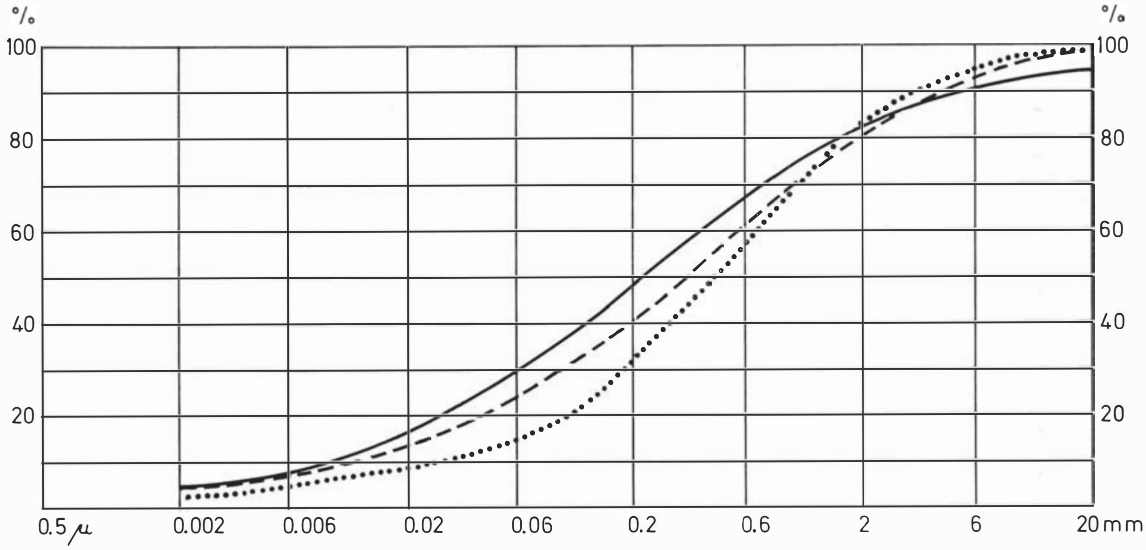


Fig. 12. Grain-size composition of basal till from the drumlinoids at Yxefall (continuous line) and Kisa (dashed line) and from the pre-crag at Lindehylta (dotted line).

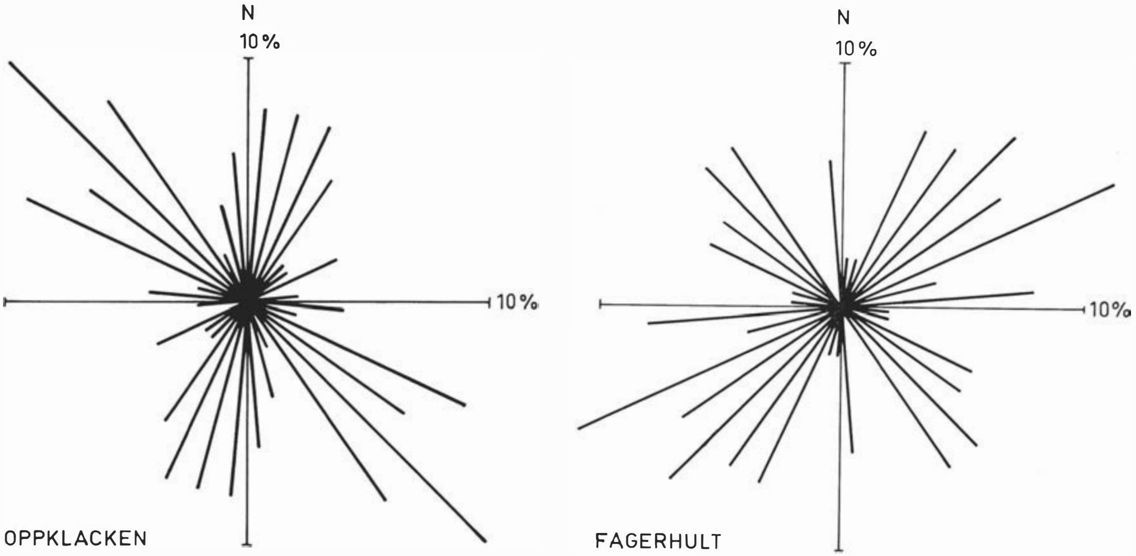


Fig. 13. Orientation of elongated pebbles in hummocky moraine. The surface forms have no distinct orientation; the ice-movement was from the NNW. At Fagerhult the orientation was measured *c.* 2 m below the surface and at Oppklacken *c.* 1 m below the surface.

in an excavation. The direction of the elongated pebbles was parallel to the ridge (Fig. 16) and the composition of the till was sandy-gravelly throughout (Fig. 17). Immediately S. of the ridge a steep rock hill reaches c. 150 m a. s. l., which is c. 10 m above the highest coastline in this area (cf. Chapt. 4, Section 4).

Sandegren (1924, p. 40) mentions the occurrence of "terminal moraines" at Forsbokvarn. Some of the ridges are noted on the geological map sheet "Åtvidaberg". Björnsson (1937, p. 96) states that "terminal moraines" occur below the highest coastline in the lowlands around Lake Åsunden. The ridges at Forsbokvarn may be interpreted as cre-

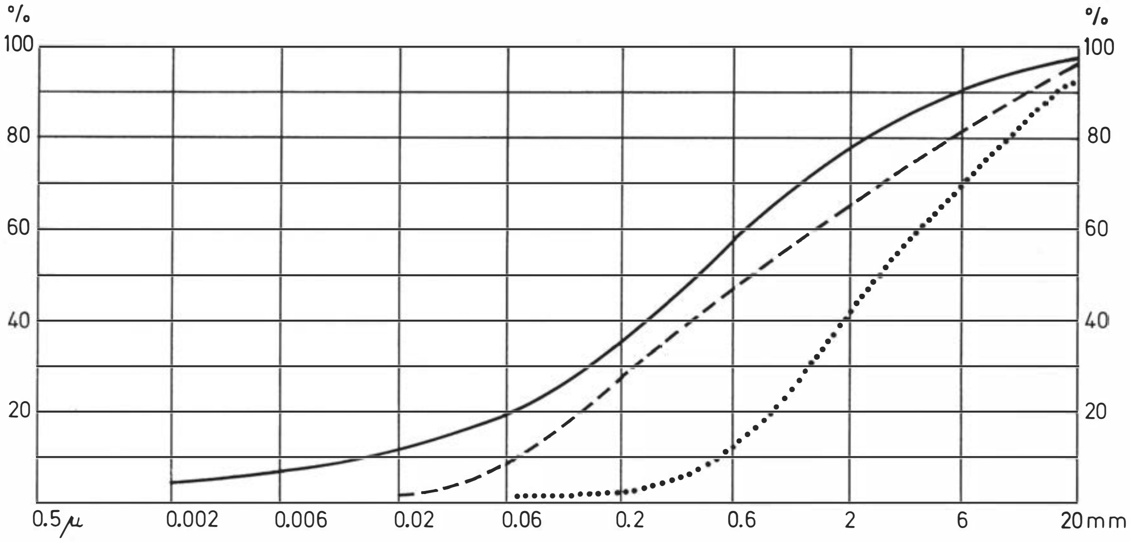


Fig. 14. Grain-size composition of different till types from hummocky moraine areas. Continuous line: basal till from Fagerhult; dashed line: ablation till from Oppklacken; dotted line: ablation gravel from Råstorp.

vasse fillings formed in the thin frontzone of the ice when it receded from the broken terrain around the highest coastline (cf. Johansson, 1972, pp. 38—39). It is most probable that the other "terminal moraines" in the Åsunden basin have a similar origin.

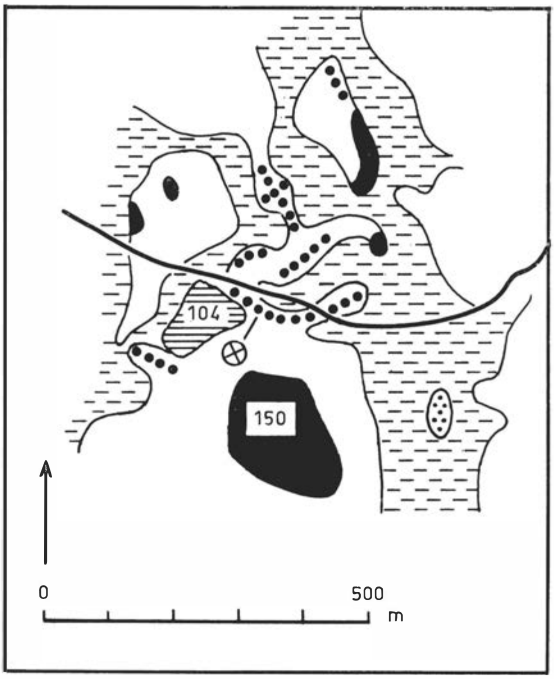


Fig. 15. Moraine ridges below the highest coastline in the Forsbokvarn area W. of Rimforsa. Ice-movement from the NNW. Broken stripes: area covered by clay and silt (the area 104 m a. s. l. is a pond); small dots: glaciofluvial gravel; large dots: till ridges; solid black: exposed bedrock (150 m a. s. l.). The rest of the area consists of basal till.

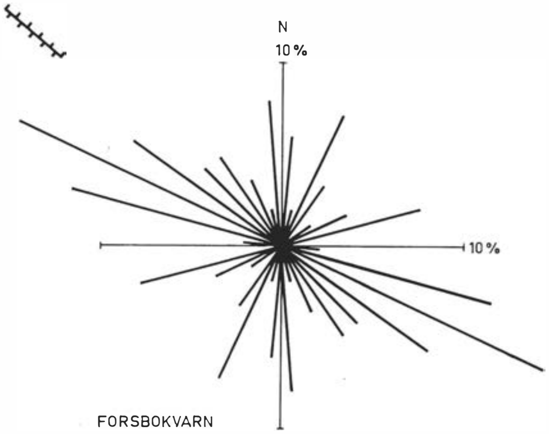


Fig. 16. Orientation of elongated pebbles *c.* 2 m below the surface in the main till ridge at Forsbokvarn. The position is marked on Fig. 15.

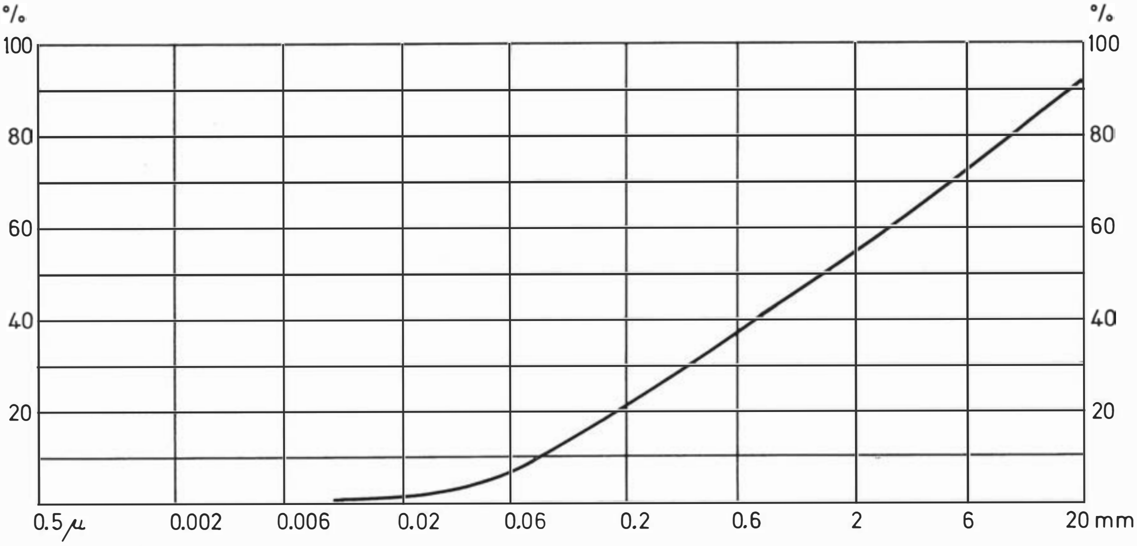


Fig. 17. Grain-size composition of gravelly till *c.* 2 m below the surface in the main till ridge at Forsbokvarn (the same site as that in Fig. 16).

THE HIGHEST COASTLINE

Historical review

In this part of Sweden the highest coastline (Sw. Högsta Kustlinjen, HK) was formed by the Baltic ice-lake during a late phase of its development. The different opinions held by the authors who have dealt with this problem have produced a rather confusing picture. It may be of interest to sum up some of those old opinions as a background to the present investigation.

The problem of the HK was first treated in the descriptions included in the geological maps. On the Vimmerby map sheet the level was estimated as 140—145 m a. s. l. from the levels of glaciofluvial plains in the Rumskulla valley (Svedmark, 1906, p. 26). This map covers the southernmost part of the investigated area. In the description in the Kisa map sheet no exact HK figure is given, but from the distribution of the clay sediments the level is estimated as *c.* 135 m a. s. l. (Svedmark, 1913, p. 24). The Sommenäs map sheet, W. of the above-mentioned map, covers the south-western part of the area. The HK is supposed to have been situated 160—165 m a. s. l. (Svedmark, 1904, pp. 24, 28), mainly because the shore marks in the Sommen basin were interpreted as having been formed by the Baltic ice-lake.

In the description in the Strålsnäs map sheet, covering the north-western part of the area, this problem was treated in a separate section by Munthe, who suggested that the HK was situated at *c.* 205 m a. s. l. (Munthe, 1924, pp. 46—49). The reason was that Munthe supposed that the Baltic ice-lake had been drained through Öresund at this time (cf. Nilsson, 1953, p. 196). Sandegren (1924, pp. 50—51) estimated the HK level on the Åtvidaberg map sheet, covering the north-eastern part of the area, at about 150 m a. s. l., mainly from observations of wave-washing on till slopes, for example, in the Törnevik area.

Sundelin (1917, p. 164) determined the HK as being at 167 m a. s. l. at the southwestern end of Lake Drögen, where some abraded boulder accumulations occur. He also tried to estimate the HK level by diatom analyses at Lake Verveln, where a figure of around 150 m a. s. l. was obtained (p. 216). The gravel plains around the lake (Fig. 18) were mentioned in support of this statement. According to Dr. Maj-Britt Florin (pers. comm.), the analyses presented by Sundelin cannot be interpreted as indications of the HK.

In the spring of 1927, Axel Gavelin gave a lecture to the Geological Society of Sweden entitled "Baltiska gränsen i sydöstra Sverige" ("The Baltic Limit in Southeastern Sweden"). The lecture was not reported, only the intense discussion which followed (Gavelin, 1927, pp. 302—305). Gavelin suggested that an ice-lake had occurred in the Sommen basin, which was thus never reached by the Baltic ice-lake. He was supported by Sandegren in his criticism of the opinion held by Munthe.

In the first edition of Sveriges Geologi (Geology of Sweden), which appeared in 1936, Dr. E. Granlund stated that the HK was situated 145 m a. s. l. in the Kisa area. This figure is still printed in the last edition of this standard work (G. Lundqvist, 1963, p. 523).

In his large work on the Late Quaternary development in Scandinavia (1940), Munthe still maintained his opinion from the 1920s about a very high level of the Baltic ice-lake. Several localities in the investigated area were briefly mentioned (Munthe, 1940, pp. 42—45).

Björnsson (1940) dealt with the level of the Baltic ice-lake in his discussion of the outlets from the Sommen ice-lake. He gave a figure for the HK of *c.* 130 m a. s. l. in the southern part of Lake Åsunden (p. 64) and *c.* 140 m a. s. l. in the valley from Kisa to Lake Sommen (p. 65). The main evidence for this opinion was the ice-lake outlet at Millingetorp (cf. a special description in the following chapter). In a popular study he stated that the HK reached 160 m. s. l. at Rimforsa (Björnsson, 1949, p. 348).

Nilsson (1953, p. 195) accepted the HK figure given for the Kisa area by Björnsson. In his paper on the ice-lakes in southern Sweden (1958), the HK level was estimated as being at 135 m a. s. l. at the railway station in Gullringen and at 140 m a. s. l. at Framnäs in Västra Eneby, E. of Kisa (p. 180). No details were mentioned from the localities.

On the map of the HK in Sweden compiled by G. Lundqvist (1961), a HK level of 137 m a. s. l. was noted at Hycklinge, S. of Lake Åsunden, 140 m a. s. l. E. of Kisa, 139 m a. s. l. E. of Rimforsa and 160 m a. s. l. S. of Mjölby. In the Vimmerby area, S. of the investigated area, it was suggested that the HK was at 142 m a. s. l. (G. Lundqvist, 1961, p. 90), and Lundqvist referred to a study made by Friberg. The planes investigated by Friberg are, however, all situated in the Rumskulla valley above the HK (Friberg, 1957, p. 104). Furthermore, the accumlulation marked on Lundqvist's map at 142 m a. s. l. N. of Vimmerby is situated at *c.* 125 m a. s. l., according to the new topographical map 6 G NV. From this map, it also appears that the large delta at Hultsfred, S. of Vimmerby, reaches only 105—110 m a. s. l., and not 125 m a. s. l., as is noted by Nilsson (1958, p. 180) and on Lundqvist's map. This level refers to a fixed point situated on a till slope.

A modern investigation has been carried out by Cato & Lindén (1973) at Törnevik on the north-eastern edge of the investigated area. The wash limit in several levelled profiles is situated at 139.5—140 m a. s. l. (p. 33).

Indications and errors

Only a few of the papers so far published which deal with the HK in Sweden discuss in detail the problems of estimating the level and the indications which can be used. One of the first to discuss these problems was Halden (1934), who examined exposed and unexposed areas of the HK at Kilsbergen, Närke, central Sweden. In the exposed area, the HK was represented by a wash limit, and in the unexposed area by small glaciofluvial plains. The level of these plains, somewhat lower than the wash limit, was supposed to give a satisfactory figure for the real HK level (Halden, 1934, pp. 321—322).

Gillberg (1952) investigated the HK in western Sweden, mainly on the north-western border of the southern Swedish uplands. He states that also the lowest level of the supra-aquatic features formed during the deglaciation gives an indication of the HK level (p. 73). Examples of such fatures in this region are lateral channels and ice-lake outlets (pp. 76—77).

Hörnsten (1964) examined the HK in the coastal area of Ångermanland. In this exposed area, the wash limits may reach an amplitude of *c.* 15 m (p. 184), while the glaciofluvial plains in the valleys indicate a more precise level (p. 189). J. Lundqvist, however, states that the glaciofluvial plains on the highest coastline in Värmland may reach levels within an amplitude of ± 10 m (1958, p. 35).

Bergström (1963) mapped the HK along the Norrland limit in northern Gästrikland and southern Hälsingland. He was the first to show levelled profiles across the wash limit, which here is extremely well developed in the exposed till slopes. The wash limit was estimated in the field and samples of the till were taken as a check on the result (p. 5). Bergström characterizes the wash limit as a maximum level for the activity of the sea, which for practical reasons may be equal to the HK.

A method similar to Bergström's was used by Ringberg (1971) in eastern Blekinge, south-eastern Sweden, where the wash limit is less distinctly developed. The glaciofluvial accumulations were used to get a rough figure for the HK (p. 32) and samples at a vertical distance of 1 m were taken along 25 levelled profiles (p. 34). Where morphological indications were lacking, the limit was placed between the highest washed and lowest unwashed sample (p. 110). A similar method was used by Cato & Lindén (1973), who estimated the wash limit entirely from the granulometrical composition with a sampling distance of only 0.5 m vertically (p. 29). The HK is characterized as a zone covering some metres of vertical distance (p. 33).

In this region, the wash limits show several errors when they are used as indications of the HK. With reference to the examples mentioned in Section 3, these errors may be briefly summarized as follows.

Where the *primary errors* occur, a true wash limit is developed. It may, however, represent an ice-dammed body of water above the HK. It can also show a level below the HK if stagnant ice remained longer in the area. Such features are common in most of the southern slopes on the HK. A wash zone at an ice-lake outlet may give the impression of a true wash limit (cf. Figs. 32 and 33).

The *secondary errors* include wash limits which have been destroyed by natural processes, mainly of peri-glacial origin (cf. Rapp, 1967, p. 233). Solifluction seems to have been common on the till slopes near the HK and in some cases the wash limit was hidden by wind-blown silt (Agrell, 1973 *a*, p. 13).

The *tertiary errors* are due entirely to cultural processes. In areas which have been cultivated, the boulder content and the grain-size composition on the surface have been changed, so that it is impossible to estimate the wash limit.

It may also be mentioned that on most till slopes on the HK no signs of abrasion at all are seen (for example, along Lake Åsunden between Västra Eneby and Slätmon). Thus, it was impossible to secure a net work of wash limits, not more distant than 5 km, which was the intention at the start of this investigation.

As the wash limits are insufficient for a determination of the HK, other indications were also used, for example, the glaciofluvial plains. However, the levels of the plains were also influenced by several errors. The surface could have been abraded or it might have been dammed by the ice or by local pass points. The changes around the mean waterlevel and the drainage of the water-saturated soils during the land uplift also cause large errors (cf. Nelson, 1910, p. 52). Some ice-lake outlets were levelled. The hummocky moraine regions were not used as indications as they also occur below the HK.

Only a few of the investigated objects form acceptable indications of the HK. However, when the different levels were compared over wider areas, a clear tendency was obvious. There is no doubt that the best picture of the HK in this region is obtained when all types of indications are used for the reconstruction (cf. Fromm, 1965, p. 140).

Localities

In this chapter, only the wash limits and similar objects are described. The other types of HK indications are treated in the following chapter. The sites are marked on the map (Fig. 18). The level was in all cases estimated from morphological in-

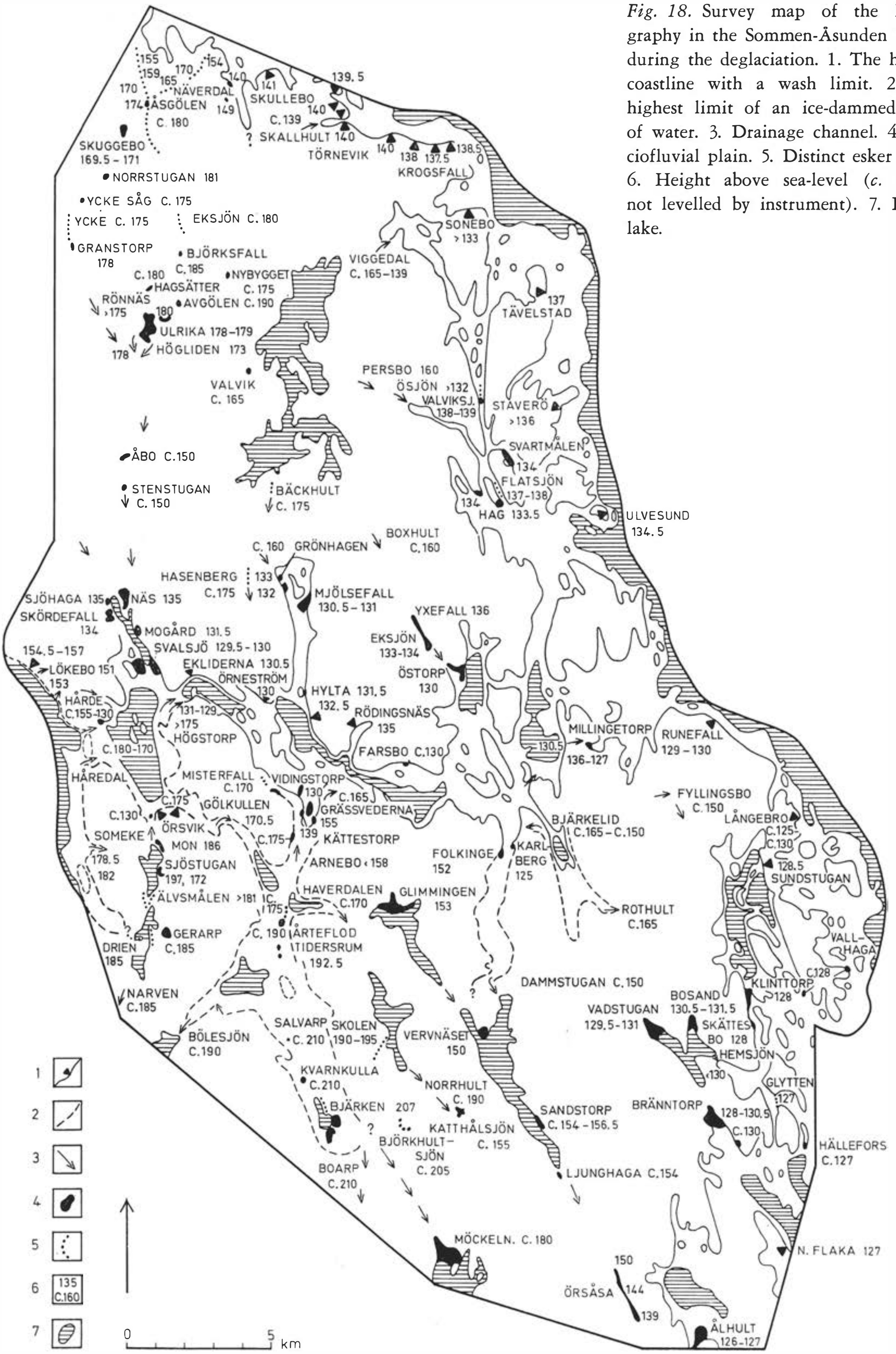


Fig. 18. Survey map of the hydrography in the Sommen-Åsunden region during the deglaciation. 1. The highest coastline with a wash limit. 2. The highest limit of an ice-dammed body of water. 3. Drainage channel. 4. Glaciofluvial plain. 5. Distinct esker ridge. 6. Height above sea-level (*c.* means not levelled by instrument). 7. Recent lake.

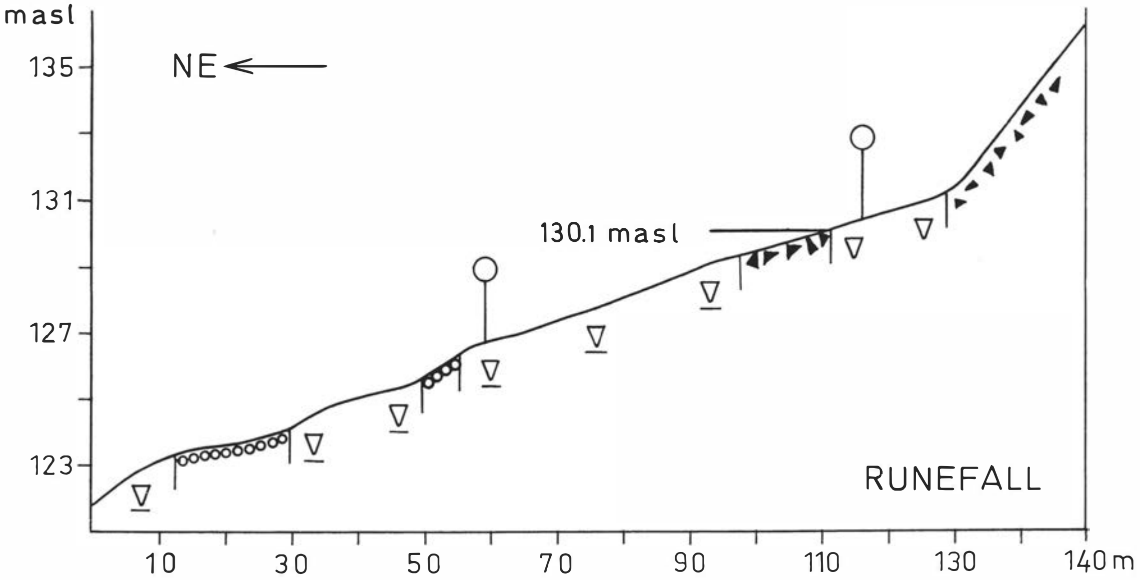


Fig. 19. Wash limit at the highest coastline NW. of Runefall on the western shore of Lake Åsunden. Legend from below: wave-washed till poor in boulders, cobble wall, boulder zone, non-washed till poor in boulders. The upper boulder zone is caused by supra-aquatic abrasion. The same symbols as those used in Figs. 20, 22, 24, 25 and 26. Profiles nos. 19, 22 and 25 were measured by Björn Karlsson.

dications, at most of the localities along levelled profiles. In some cases samples of till were analysed as a check on the result. These samples were collected on both sides of the wash limit near the surface.

On the eastern slope of the drumlinoid ridge at *Norra Flaka*, a distinct boulder wash zone is developed from *c.* 123—127 m a. s. l. and its upper edge may represent the HK. The soil here is glaciofluvial gravel, not till, and so the grain-size composition gives no further information.

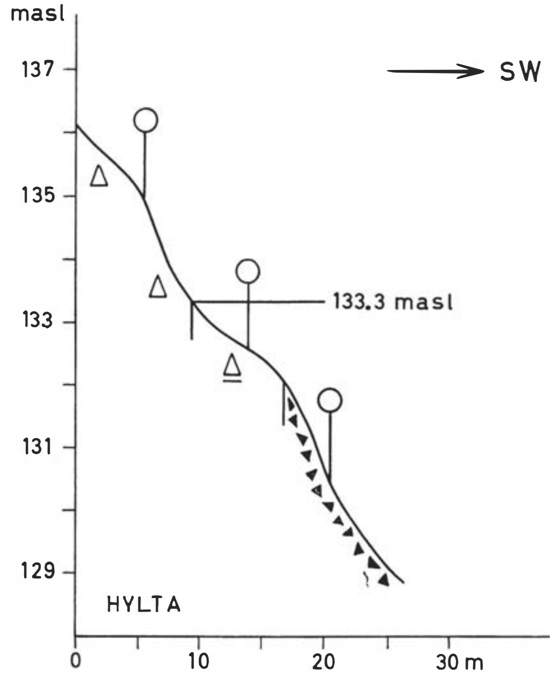
At the north-eastern end of Lake Täftern, W. of *Sundstugan*, a boulder zone is developed in the till from 126 to 128.5 m a. s. l. and above this level almost no boulders occur. The slope has been cultivated and thus the grain size shows no distinct difference. The locality must be designated as uncertain.

On a till slope exposed to the SE., NW. of *Långebro* near Lake Åsunden, a large accumulation of huge boulders occurs from *c.* 125 to 130 m a. s. l. The site has not been levelled.

About 300 m NW. of *Runefall* and SE. of Västra Eneby, a vast till slope is exposed to the NE. The lower part of the slope is covered by wave-washed gravel, partly covering glacial clay. In the upper parts, several cobble walls occur and the till has been intensely transformed by abrasion (cf. the profile, Fig. 19). The wash limit is situated at 130 m a. s. l. and slightly above this level a steep boulder zone occurs. As this boulder zone has a very restricted horizontal distribution, it may have a supra-aquatic origin.

In the deep valley at *Rödingsnäs*, N. of the Föllingen lakes, a terrace on the till slope NW. of the farm reaches 135 m a. s. l. Above it, vast and irregular boulder zones occur. Probably this is not an abrasion cut but a form caused by supra-aquatic melting of stagnant ice.

At *Hylta*, where the Mjölsefall valley ends in Lake Övre Föllingen, the wash limit on a steep till slope reaches a little above 133 m a. s. l. (Fig. 20). In the southern part of the valley, hummocky moraine occurs *c.* 26 m below the HK. The large boulders covering gravel on the lower parts of the slope indicate that the valley was filled with stagnant ice and thus only a small, lateral, body of water occurred. Probably the front of the stagnant ice was situated on the northern edge of the Föllingen basin, just at the locality.



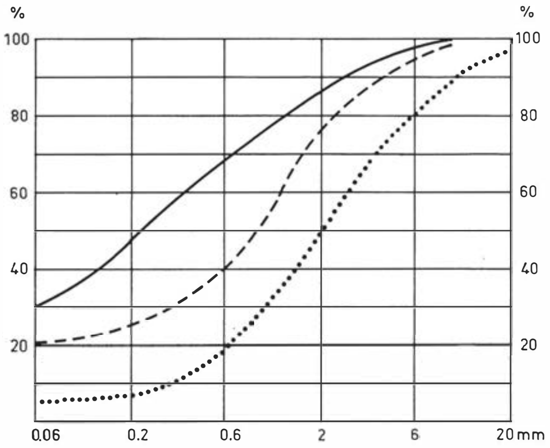


Fig. 20. A "wash limit", probably formed by lateral abrasion at the highest coastline, SE. of Hylta and N. of Lake Övre Föllingen. The three soil samples become coarser down the slope. Note the positions of the sampling sites.

At *Örneström*, N. of the outlet from Lake Örlången, exposed bedrock is followed by non-washed till *c.* 130 m a. s. l. (not levelled). Through the narrow strait at Örneström, the meltwater flow was intense during the deglaciation.

On the till slope southwards at *Ekliderna*, N. of Lake Örlången, the wash limit cannot be estimated, as the area has been cultivated. A supra-aquatic boulder wash zone reaches down to 130.5 m a. s. l., where a small glaciofluvial deposit occurs (Fig. 21).

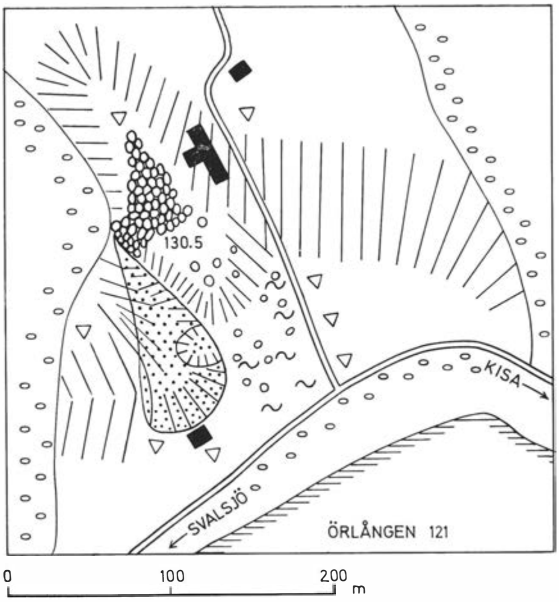


Fig. 21. The highest coastline at Ekliderna, N. of Lake Örlången, indicated by a supra-aquatic boulder wash zone and a small glaciofluvial deposit in a cultivated till area surrounded by deciduous forest.

West of *Ulvesund* in the northern part of Lake Åsunden, a steep hill reaches above the HK level. The lower parts of the till slope are covered with boulders and between the two tops the plane surface is covered with gravel. To the west, the gravel is bordered by a boulder terrace, the foot of which reaches 134.5 m a. s. l. Above this level, no traces of abrasion were observed. The development of the locality is uncertain.

On the vast till slope W. of Åsunden and N. of Vadstuguberget at *Staverö*, the till is exposed in a road cutting, which crosses the supposed HK level. The wash limit at 136 m a. s. l. is very distinct, as is obvious also from the analysed till samples (Fig. 22). A plain with sandy gravel occurs a little below the wash limit. This is the best-developed wash limit found in the investigated area.

West of *Tävelstad* and SW. of Rimforsa, vast and gently steeping till slopes are exposed to the east. Along the small road *c.* 600 m W. of Tävelstad, the limit between washed and unwashed till is situated only 132.5 m a. s. l., but doubtful boulder structures and the fine-grained, silty material indicate that solifluction has taken place here. About 100 m to the north, a well-developed abrasion cut is situated nearly 137 m a. s. l. (Fig. 23, 24) and this may be the correct HK-level at this site. Irregular boulder trains at *c.* 141 m a. s. l. must have been supra-aquatically formed.

The *Sonebo* valley, W. of Lake Järnlunden, is bordered to the south by a vast till slope and the border between washed till, rich in boulders, and almost boulder-free, fine-grained till is extremely well developed (Fig. 25). However, this limit is situated only at *c.* 133 m a. s. l., which is *c.* 5 m below the supposed HK level. By tube levelling, the "wash limit" was found to be sloping *c.* 2 m for 70 m eastwards, forming a sort of lobe, and, on digging it, the fine material was found to form only a thin cover above the stony material. This locality is the best example found of a wash limit transformed by solifluction (cf. Agrell, 1973 *a*, pp. 7—8).

In the till slopes W. and SE. of *Törnevik*, several profiles have been levelled by Cato & Lindén (1973). All these localities show a wash limit nearly 140 m a. s. l.

The wash limits around *Krogsfall* slightly to the east, which were investigated in the same paper, show levels between 137.5 and 140 m a. s. l. (cf. Fig. 26).

Two wash limits situated at the mouth of the narrow valley E. of *Skallhult c.* 140 m a. s. l. are very well developed, in spite of the lack of exposure (Cato & Lindén, 1973, p. 31). It seems probable that these wash limits were influenced by glacial meltwater flow from the west, as a large boulder field (139 m a. s. l.), representing the outlet from a large stream, is situated SW. of the farmhouse at Skallhult.

In the till slope S. of *Skullebo* and SW. of Lake Limmern in the northernmost part of the area, the wash limit is represented by an abrasion cut along a path *c.* 141 m a. s. l. with a gravel plain situated a few metres lower.

The south-western farmhouse in *Fågelkulla*, *c.* 1 km W. of this locality, is situated on a terrace of sandy material, which reaches 140 m a. s. l.

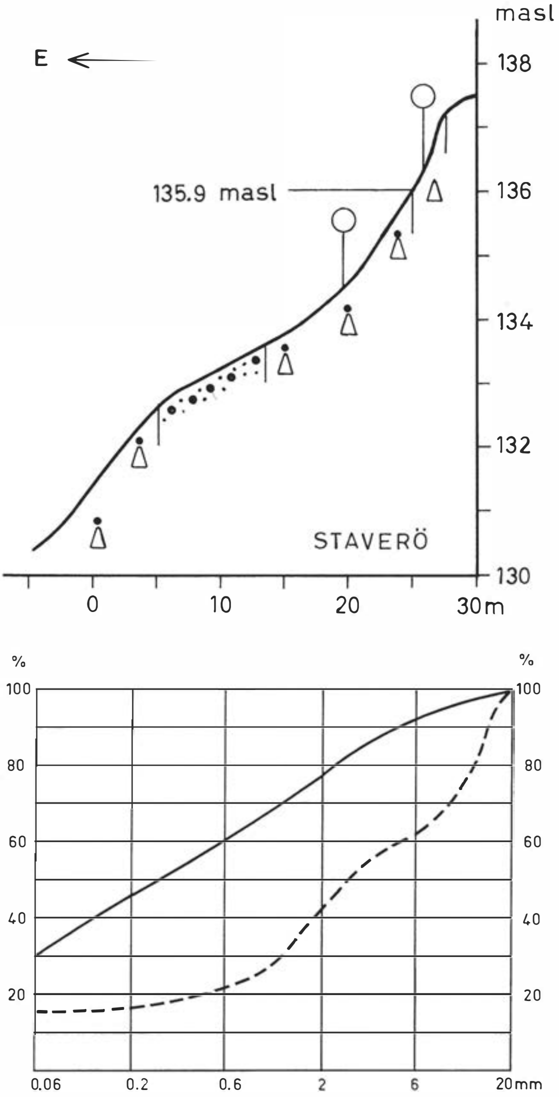


Fig. 22. Wash limit at the highest coastline at Staverö, W. of Lake Åsunden between Rimforsa and Slätmon. The dashed curve represents the wave-washed till rich in boulders, which passes over into a terrace of sandy-gravelly material.

The general progress of the highest coastline

All observations indicating the HK were plotted on the distance diagram (Fig. 27). The diagram is parallel to the main ice-movement, which can be supposed to form a right angle to the isobases of land uplift. Compared with the localities along

Fig. 23. The highest coastline, developed as a boulder scarp at *c.* 137 m a. s. l. W. of Tävelstad and SW. of Rimforsa (cf. Fig. 24).

Lake Åsunden, the localities in the valley from Kisa to Lake Sommen show a lower level. The reason may be that the stagnant ice melted away somewhat later in this system of narrow valleys. The glaciofluvial plains seem to be situated a little lower than the adjacent wash limits. The ice-lake outlets often reach below the HK, as they might have been active some time after the ice margin left the site. To get a uniform material, the HK line in the diagram has been sketched entirely from the true wash limits along the Åsunden basin.

In the northern part of the area, the gradient of the metachronous HK is relatively even (10 m/ 25 km or 0.4 m/km from Runefall to Törnevik). In the southern part of the area, however, the gradient is much less. Several reasons for this pronounced gradient change can be discussed. The new topographical maps, however, reveal that the body of water from the pass point *c.* 115 m a. s. l. at Solnehult, SSE. of Vimmerby, to the southern part of Lake Åsunden was dammed eastwards, thus forming a vast, ice-dammed lake slightly above the HK. This ice-lake, the Vimmerby ice-lake, formed a limit morphologically similar to the HK further to the north. The water-level in the ice-lake was lowered when it gradually found lower outlets eastwards, for example, along the road from Hycklinge to Odensvi. Only when the valley between Lake Björkern and Lake Tynn E. of Åsunden (pass point *c.* 105 m a. s. l.) became ice-free did the Baltic ice-lake reach the investigated area. This occasion may be represented by the "knee" in the diagram, which is found in the Långebro

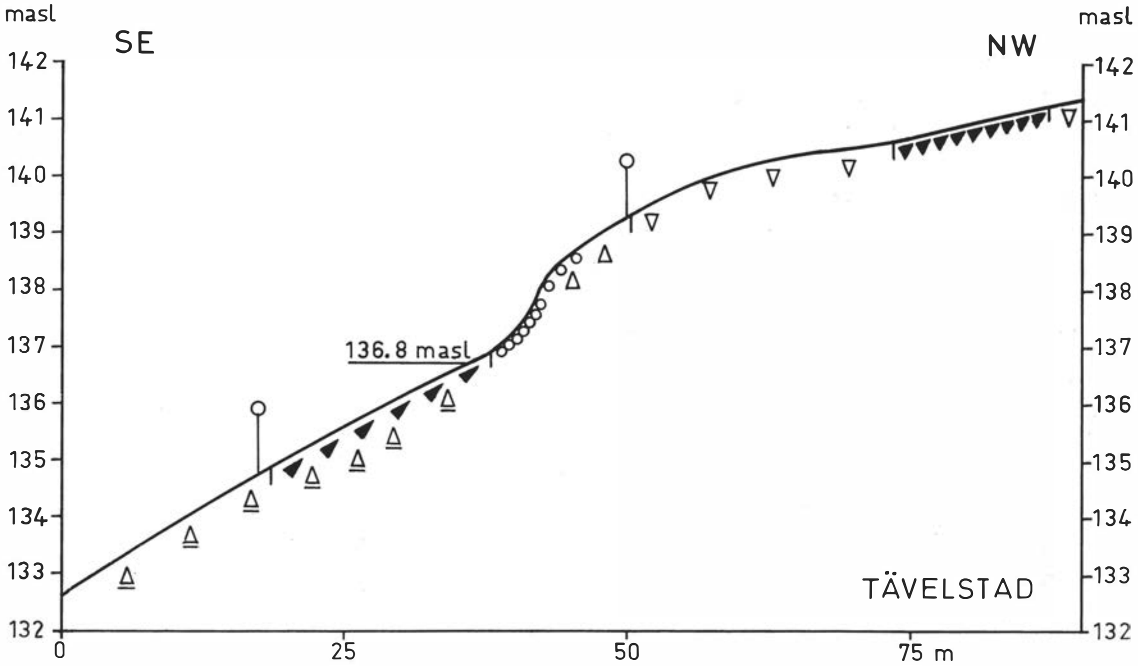
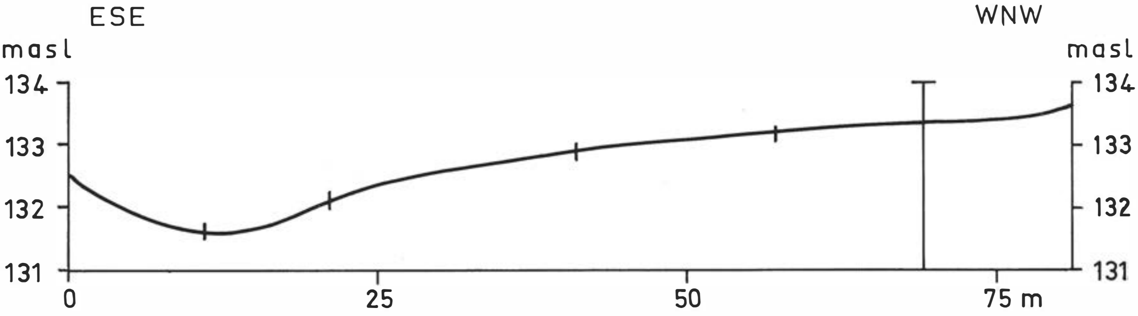


Fig. 24. Wash limit at the highest coastline, W. of Tävelstad and SW. of Rimforsa.



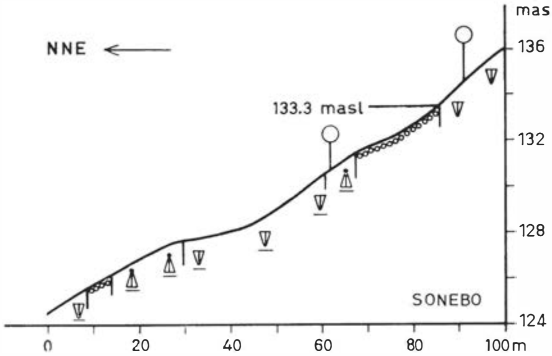
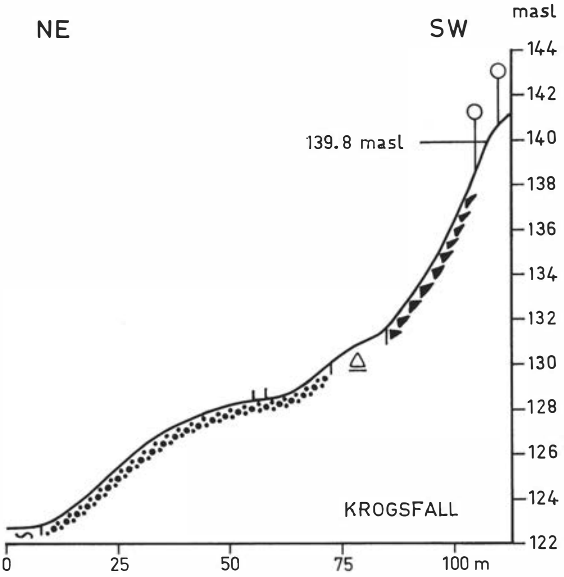


Fig. 25. Solifluction at the highest coastline, SW. of Sonebo and W. of Lake Järnlunden. The cross and length profiles show the boundary between cobbles and sandy-silty solifluction material.



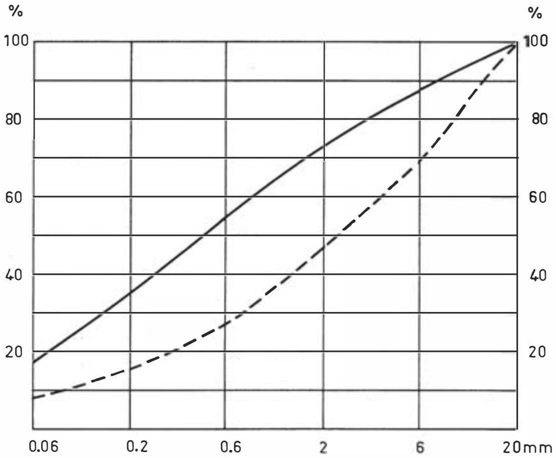


Fig. 26. Wash limit at the highest coastline at Scoutstugan, SW. of Krogsfall and the grain-size composition of the samples marked in the profile. Drawn from Cato & Lindén, 1973, p. 30.

area, where doubtful boulder fields were formed at the ice margin on this occasion.

To sum up, the HK was not developed in the southern part of the area, as it was covered by the Vimmerby ice-lake at 127—129 m a. s. l. In the central part of the area, the HK level is about 130 m a. s. l., gradually rising to 140 m a. s. l. in the northernmost part (cf. the map, Fig. 18). No indications of irregularities in the development of the HK have been found. It may be added that a denser network of observations might have shown a more irregular HK pattern (cf. G. Lundqvist, 1933, p. 522).

The observations are in good agreement with

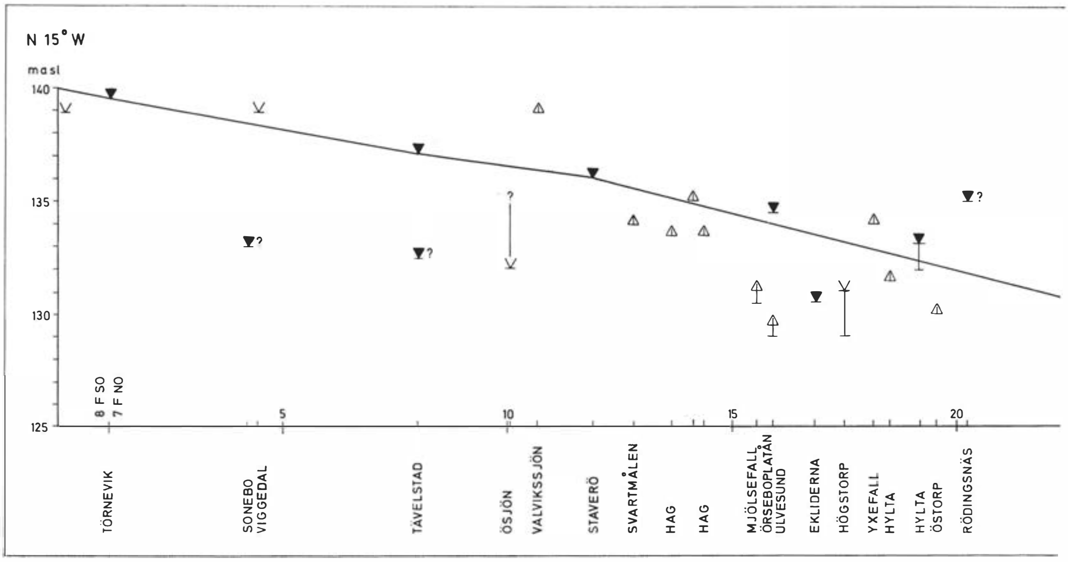


Fig. 27. Projection (distance diagram) of the objects indicating the highest coastline in the Sommen-Åsunden region, enlarged 500 ×. 1. Wash limits and similar abrasion scarps. 2. Outlets from ice-dammed areas. 3.

the levels of the Baltic ice-lake observed outside the investigated area. About 45 km to the south, the glaciofluvial deposits at the mouth of the Emå valley near Årena were developed in a water table at 100—105 m a. s. l. (Friberg, 1957, p. 104, Persson, 1971, pp. 87—88). East of the area, glaciofluvial plains around 135 m a. s. l. have been levelled by Mr. Rune Larsson of Gamleby (pers. comm.). The HK in the western part of Östergötland is being investigated by K. E. Perhans, of the Dept. of Physical Geography, at the University of Stockholm. North of the Östergötland plain, at Jakobsdalsberget in Kolmården, the wash limit reaches *c.* 154 m a. s. l. (Persson & Svantesson, 1972, p. 356).

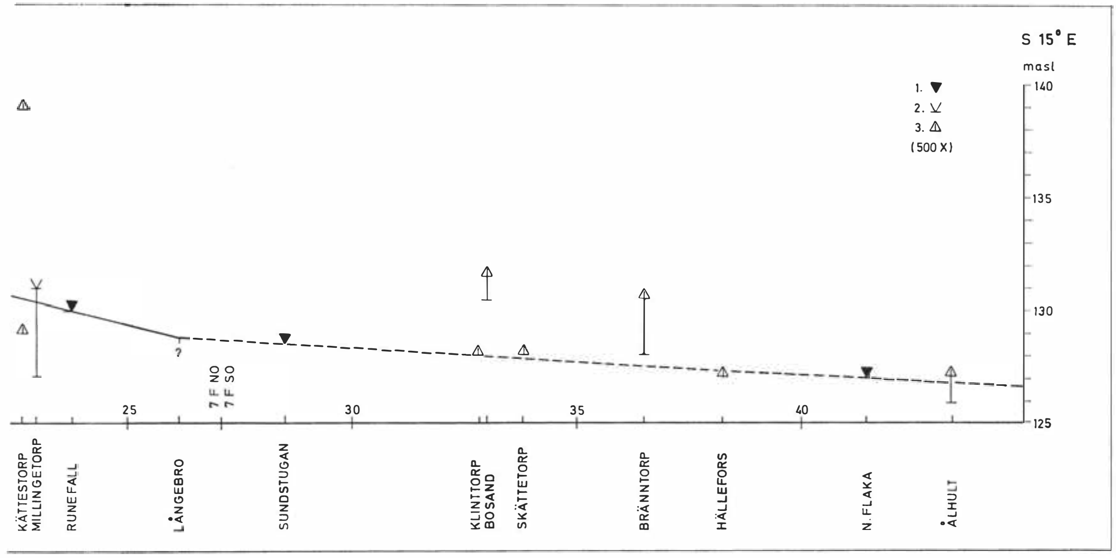
DEPOSITS FROM THE DEGLACIATION

The investigated area can be divided into separate parts, in which it is possible to trace an independent development of the deglaciation. In some of these areas, detailed studies were made, in other cases only survey observations. The sites examined in detail will be found on the map in Fig. 28, but most of the localities are marked on the maps in Figs. 4 and 18 or on the special maps. The reader who wants to get a detailed picture of some part of the area may study the topographical maps together with the text.

The Stångå valley

The south-easternmost part of the investigated area has an irregular surface form with vast areas of exposed bedrock. The glaciofluvial deposits appear as scattered areas, often forming small plains built up of fine material. Such plains occur, for example, in the Skjulå valley S. of Lake Täftern, where they reach 128 m a. s. l. at Klinttorp and Skättesbo. The level of 127—128 m a. s. l., which is reached by most of these deposits, probably represents the "HK", in this part of the area equal to the highest level of the Vimmerby ice-lake. The vast plain N. of Bränntorp only reaches this level in the distal part, but, as the slope of the surface has been levelled to *c.* 1/100, it probably was deposited as a supra-aquatic accumulation, where the lowest level represents the water table.

North of Lake Hemsjön, plains of sandy material reach a slightly higher level (*c.* 130 m a. s. l.). The plain at Bosand (Fig. 29), where a profile has been levelled (Fig. 30), is bordered to the north by a supposed dead-ice hollow and a proximal scarp (131.7 m a. s. l.). The slope is even down to 130.5 m a. s. l., which makes an angle



Glaciofluvial plains. Cf. the map, Fig. 18. The *HK*-line was sketched entirely from the wash limits along Lake Åsunden. The dashed line represents the highest level of the Vimmerby ice-lake.

of *c.* 1/200. This may indicate supra-aquatic deposition to a water level of 130.5 m a. s. l. The present water level of Lake Hemsjön reaches only 127.5 m a. s. l. and the plain may be misinterpreted as an indication of the HK. The water level in the lake has, however, been lowered several metres by blasting away the rock threshold in the SE. The distal scarp of the plain may thus represent the water table in the lake basin during the deglaciation.

The valley from Gullringen to Kisa

The plain W. of Ålhult slopes northwards from *c.* 127 to 126 m a. s. l. with an irregular continuation down to *c.* 120 m a. s. l. The glaciofluvial deposits reach a thickness of *c.* 20 m. A deep excavation shows that the homogeneous, sandy material dips a few degrees to the N. or NE., which, together with the slope of the surface, shows that the accumulation was built up from the S. or SW. The plain may be interpreted as an extramarginal deposit formed by the glacial meltwater, which for a long time was discharged through the valley from Gullringen to Lake Verveln. The highest part of the plain may be supposed to represent the HK.

The valley from Gullringen to Lake Verveln is filled with coarse glaciofluvial material. Along the western slope of the drumlinoid ridge at Örsåsa, a lateral terrace was formed. The surface slopes southwards from 150 to 139 m a. s. l. over a distance of 2 km. The slope of the accumulation is equal to the slope of the valley bottom.

At Björkhult, S. of Lake Verveln, vast areas of hummocky, coarse, glaciofluvial material were formed. The deposits are bordered by hummocky moraine, to which irregular transitions occur. Large areas of stagnant ice must have been isolated in this area.

Coarse glaciofluvial deposits also occur around Lake Verveln at 139 m a. s. l. The steep slopes towards the lake, which is 40 m deep in its northernmost part, indicate that the central part of the basin was filled with stagnant ice. Some plains were developed, for example, at Ljunghaga at the southern edge of the lake (154 m a. s. l.), at Sandstorp in the SE., (sloping southwards from 156.5 to 154 m a. h. l.) and at Vervnäset in the north (151 m a. s. l.). The variable levels indicate that no synchronous dammed water level can have occurred in the Verveln basin. The deposits are entirely of supra-aquatic origin.

The Korpklev valley, N. of Lake Verveln, with its bottom only *c.* 120 m a. s. l., is bordered on the lake by pass points at *c.* 150 m a. s. l., which are

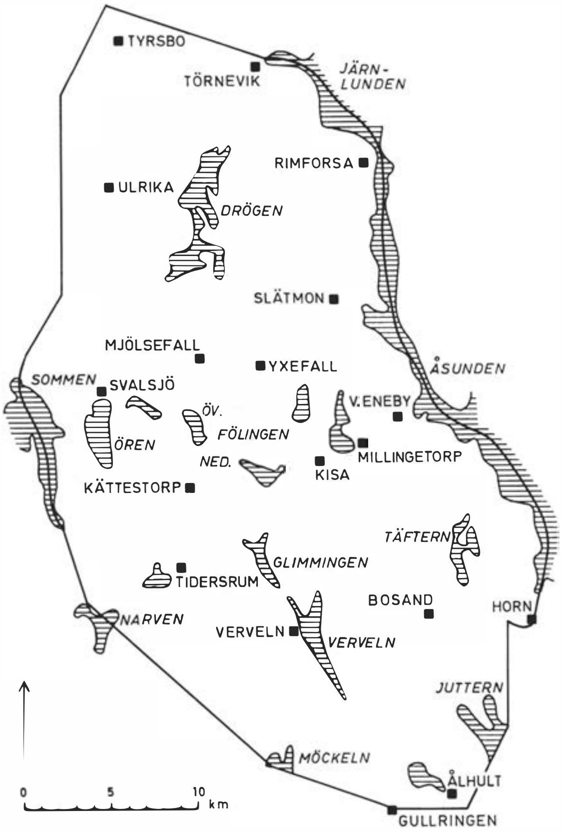


Fig. 28. The position of some important localities mentioned in the text.

situated in a vast hummocky moraine area. Thus, it is difficult to say whether a real, open ice-lake occurred in the valley, the bottom of which is filled with sandy glaciofluvial material, forming areas with hummocks and ridges. The northern mouth of the valley, at Folkinge, is almost entirely blocked by a large accumulation of sand and coarse silt, which reaches 152 m a. s. l. This level corresponds to the pass point in the south.

The vast sandy plane 153 m a. s. l. at the northern end of Lake Glimmingen (145 m a. s. l.) may have been influenced by the same pass level.

The deep valley from Kisa to the SSE. must have been filled with open water during the deglaciation, as grey silt occurs in a free position northwards (*c.* 140 m a. s. l.) S. of the small lake of Gummetorpasjön. The level was initially regulated by the pass point at 165 m a. s. l. at Rothult, but it must have been lowered westwards to the Korpklev valley at Bjärkelid. The dammed water table in the valleys south of Kisa thus reached a few metres above 150 m a. s. l.

This large dammed water system was lowered down to the Baltic ice-lake when the ice had left the pre-crag ridge at Millingetorp. A dry channel, maximally 14 m deep and with the pass point in the W. at 130.5 m a. s. l., was eroded in the basal till (Fig. 31). This site was discovered and briefly described by Björnsson (1940, pp. 64—65). The eastern outlet of the valley was mapped in detail by the author (Fig. 32). The stream was, for topographical reasons, deflected to the south at the outlet, causing erosion on the north-eastern side. A boulder row, sloping from 136 m a. s. l. to the sandy bottom at 128 m a. s. l., separates barewashed bedrock from nonwashed till (Fig. 33).

In the south-western part of the outlet, where deposition occurred, plains of gravelly material were formed at various levels. The flat bottom surface reaches down to a boulder scarp (127 m a. s. l.), which represents the lowest water level at the outlet of the valley. Probably the stream through the valley continued for some time, as the uplift of the land proceeded. Lower levels occur at Knoppetorp *c.* 2 km to the north. The level of the HK when the valley was formed is difficult to estimate, but it cannot have exceeded the pass level. The material removed from the valley occurs further to the east, where a large accumulation of sand and gravel has been deposited at Slycke. The amount of sediments may seem small compared with the size of the drained area. It may, however, be pointed out that the area is dominated by exposed bedrock (cf. J. Lundqvist, 1973, p. 78).

The Tidersrum-Kättestorp valley

The Tidersrum valley, which has a length of *c.* 10 km in the NNW.—SSE. direction and a width of 1—2 km, is entirely filled with glaciofluvial deposits (cf. Fig. 4). The pass point to the south is represented by a hummocky moraine area *c.* 200 m a. s. l. and thus no exact figure can be given for it. During the first stage of deglaciation in the valley, this area must have been entirely blocked by stagnant ice, as a deep channel was eroded in the basal till further to the west, between Bänarp and Boarp, with the pass point *c.* 210 m a. s. l.

At the northern end of Lake Möckeln (176 m a. s. l.), a vast accumulation of sandy material reaches a little above the present water level in the lake. This deposit may be interpreted as an extramarginal delta, formed at the mouth of the lowest outlet of the Tidersrum valley, which can be followed as a joint valley to the NNW. from the accumulation.

In the hummocky moraine area SE. of the Tidersrum valley, Lake Björkhultsjön is bordered by a curving esker ridge, reaching c. 205 m a. s. l. and built up of well-stratified sand (Fig. 34). Towards Lake Skolen, further to the north, the hummocky moraine is gradually replaced by coarse glaciofluvial material, forming a distinct ridge in the lake. The Skolen area was drained southwards through an erosion channel at Norrhult. The gravelly material contains dead-ice hollows, rich in boulders, which are water-filled for most of the year. During the dry season, they give the impression that the ice has just melted away (Fig. 35).

In the southernmost part of the Tidersrum valley, S. and SE. of Lake Bjärken (193 m a. s. l.), two plains with steep slopes and sandy material reach 207 m a. s. l. They indicate the level of the dammed water table in the stagnant ice. At the northeastern side of the lake, a well-developed esker ridge reaches slightly below this level. This ridge

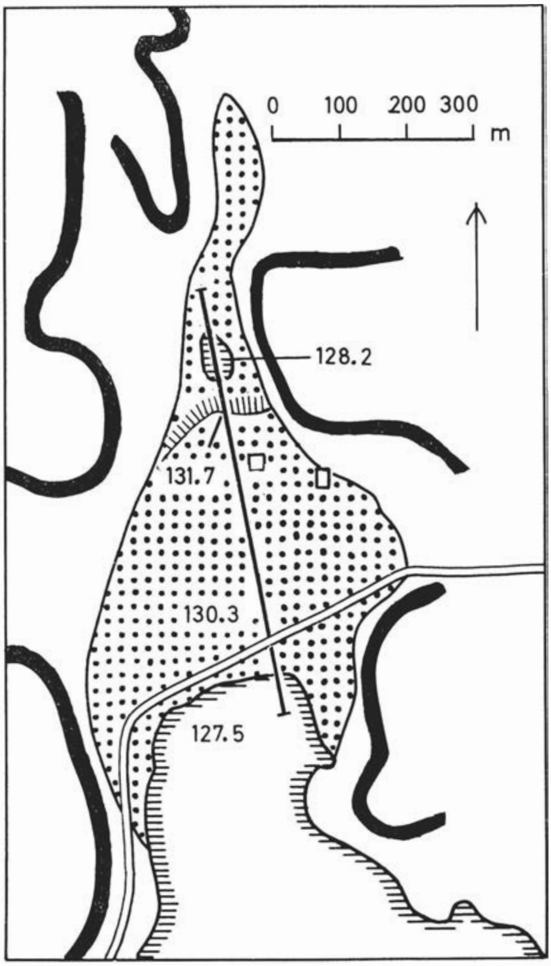


Fig. 29. The glaciofluvial delta at Bosand, N. of Lake Hemsjön. The sandy delta plane is surrounded by till and exposed bedrock (black borders). Note the position of the levelled profile, Fig. 30.

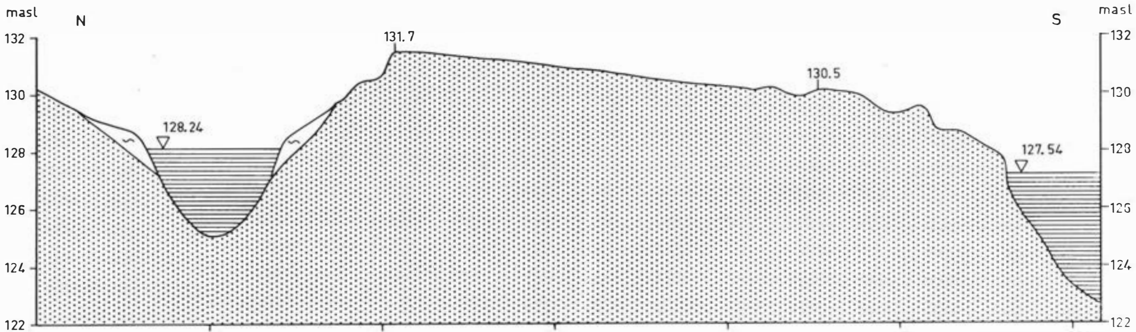


Fig. 30. Levelled profile along the glaciofluvial delta at Bosand.

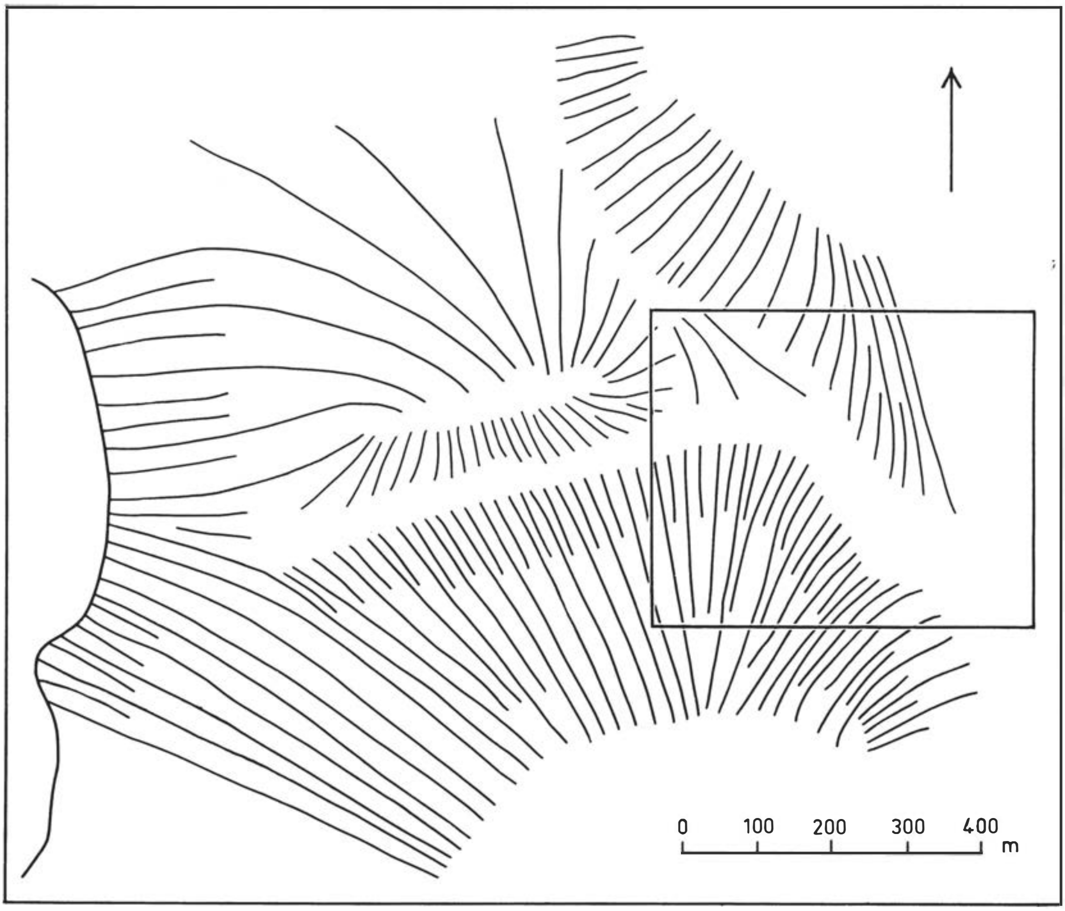


Fig. 31. Sketch map of the drainage valley at Millingetorp, E. of Kisa. Detailed map inside the marked area. Drawn from a photogrammetric map of the Kisa area made by AIB in 1966.

is a part of an esker network, indicating a large area of stagnant ice.

Further to the north, for example, at Kvarnkulla and Salvarp, the glaciofluvial deposits are coarse and till-like, but local accumulations with sorted material also occur. The highest parts reach *c.* 210 m a. s. l., which corresponds to the dammed water level in the ice. Fine sediments are almost totally lacking. Also here the deposits indicate vast areas of stagnant ice (cf. Björnsson, 1937, p. 104).

When the ice melted away from the vast lowland around the Tidersrum lake and the church at Tidersrum, a lower outlet was opened to the W., between Lakes Bölesjön and Narven. This outlet (*c.* 190 m a. s. l.), is indicated by a sloping boulder field (cf. Björnsson, 1940, p. 59). The high mounds of glaciofluvial sand and gravel E. and N. of the church at Tidersrum reach slightly above this level, which now replaced the southern pass point. The glaciofluvial deposits are concentrated along the eastern slope of the valley, indicating that the flat area from Tidersrum northwards to Lake Bröten was filled with stagnant ice during their formation (cf. Björnsson, 1937, p. 102). This area is now covered by sand. Fine sediments, indicating a deep, open body of water, are totally lacking.

At Årteflod, N. of Tidersrum, a gravel mound *c.* 190 m a. s. l. passes over to the N. into a distinct, curved, esker ridge which only reaches *c.* 175 m a. s. l. A lowering of the water table may now have taken place eastwards, over a pass point at *c.* 170 m a. s. l. at Haverdalen, E. of Lake Välen.

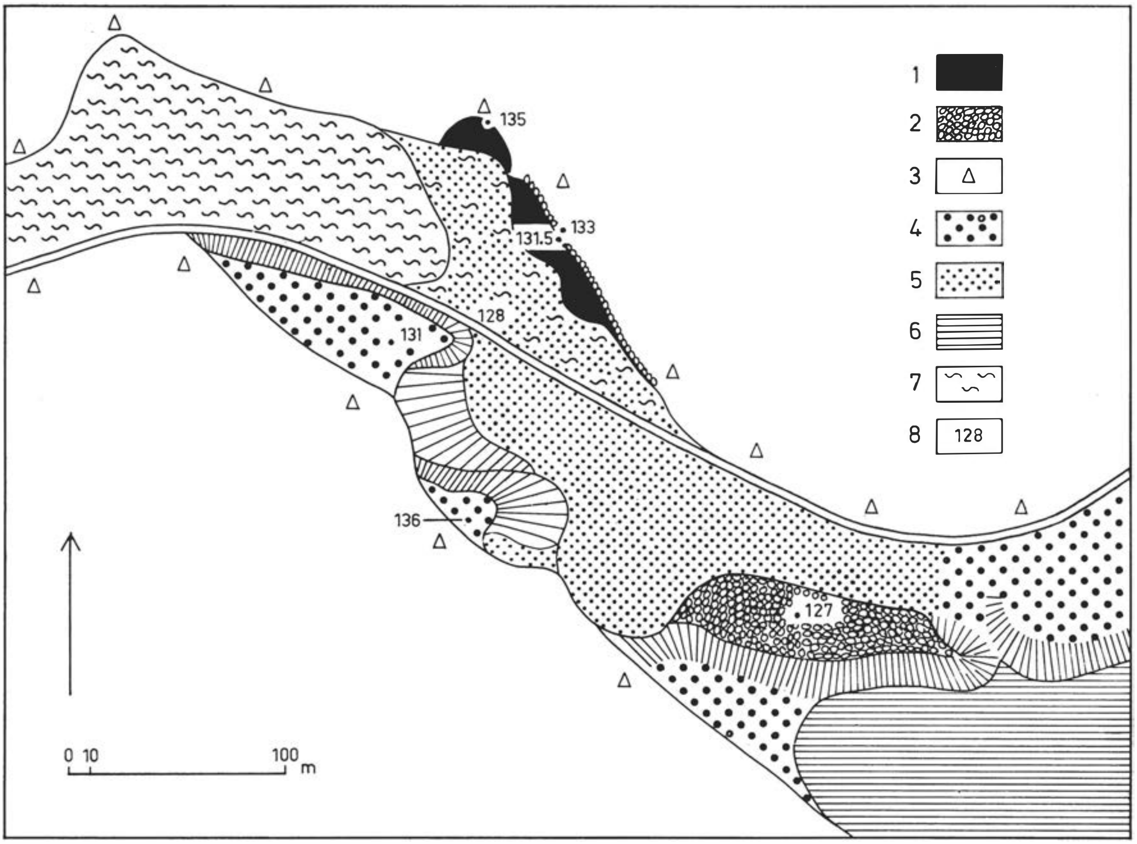


Fig. 32. Accumulation and erosion forms at the eastern outlet of the drainage valley at Millingetorp. 1. Exposed bedrock. 2. Boulder field. 3. Basal till. 4. Stony gravel. 5. Sand. 6. Silt. 7. Peat. 8. Levelled sites.

This outlet is marked by a distinct erosion channel in the till with a vast boulder accumulation at the outlet. The stream was conducted through the stagnant ice in the Oppklacken basin, across Lake Glimmingen and Lake Verveln towards Gullringen.

After the drainage at Haverdalen, only a shallow body of water occurred in the Tidersrum valley, where the pass point northwards is situated at *c.* 157 m a. s. l. The present outlet from the valley, the small river Stenån, follows a long and deep gorge in the leptitic bedrock (Fig. 36; cf. Björnsson, 1937, pp. 77—78), which forms the pass level northwards to the Kättestorp valley.

As the progress of the deglaciation in the deep Kättestorp valley was complicated, a detailed map was compiled (Fig. 37). Around the rock gorge, a vast area of hummocky moraine occurs. The till northward gradually passes over into glaciofluvial deposits.

Fig. 33. Wash limit at the outlet of the erosion channel E. of Millingetorp. The boulder zone shows the border between exposed bedrock and non-washed till (cf. Fig. 32).

Along the western slope of the valley, a sharp

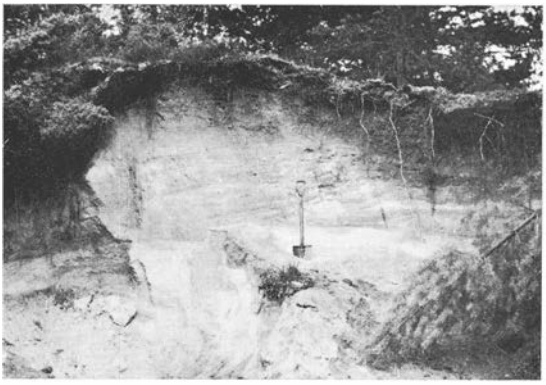


Fig. 34. Curved esker ridge built up of stratified sand. Lake Björkhultsjön, SE. of the Tidersrum valley.

Fig. 35. Dead-ice hollow ("Knipfloen") in an area built up of ablation gravel, SW. of Lake Skolen.

Fig. 36. The rock gorge at Arnebo, N. of Tidersrum (photograph by Stig Nilsson).

esker ridge high above the valley bottom reaches *c.* 175 m a. s. l. An interruption is caused by a steep bedrock cliff, but N. of Misterfall a glaciofluvial terrace is situated on the till slope (172 m a. s. l.) high above the valley bottom, which reaches only *c.* 120 m a. s. l. (Björnsson, 1937, pp. 99—100). These deposits must have been formed between the ice and the high area around Misterfall, reaching *c.* 260 m a. s. l. The level corresponds to the pass point at Haverdalen. The ice damming up the glacial meltwater during the formation of these deposits must be classified as still active, according to J. Lundqvist (1972, pp. 28—29), otherwise the drainage would have been subglacial.

As the melting of the ice tongue in the Kättes-

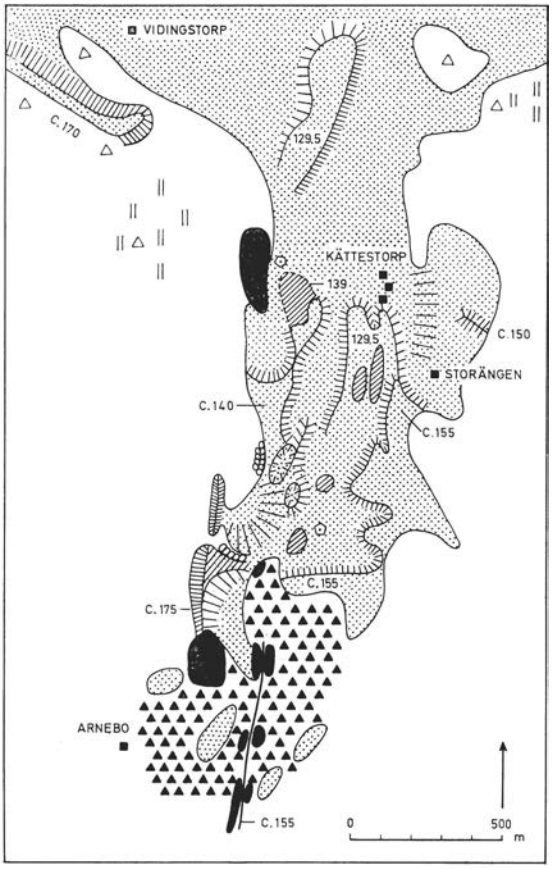


Fig. 37. Glaciofluvial deposits in the Kättestorp valley, WSW. of Kisa. The deposits are surrounded by till, sometimes covered with a thin layer of wind-blown silt. Solid black areas show exposed bedrock and black triangles hummocky moraine. Hatched areas show excavations and the stripes indicate plains and ridges. Levels in metres above sea-level. The line through the hummocky moraine is the rock gorge at Arnebo.

Fig. 38. Excavation in the plain at 139 m a.s.l., SW. of Kättestorp (cf. Fig. 39). Photograph taken June 1971.

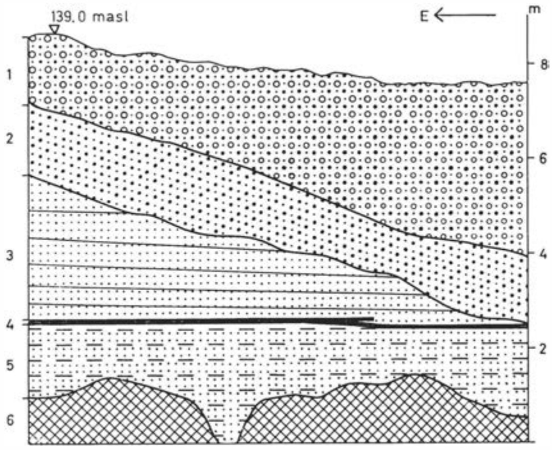


Fig. 39. Stratigraphy in the glaciofluvial plain at 139 m a.s.l., W. of Kättestorp, now entirely excavated. Sequence from below: stratified coarse silt (continues at least 6 m), fine silt with a thin layer of reddish clay, fine sand with distinct stream ripples, sandy gravel and stony gravel.

torp valley proceeded, the water table controlled by the pass point at Haverdalen was lowered to the east at Grässvederna, E. of the valley, where a distinct lateral channel was eroded in the pre-crag accumulation (*c.* 160 m a.s.l.). South of Storängen, a vast and irregular terrace with ice contacts was built up to *c.* 155 m a.s.l. This terrace and the channel at Grässvederna may represent the final drainage of the Tidersrum valley, as the levels approximately correspond to the pass point at *c.* 157 m a.s.l.

A still lower level, 139 m a.s.l., is represented by a small plain with steep slopes W. of Kättestorp, which to the south passes over into a steep ridge. This plane (Fig. 38) was entirely excavated during 1972. A profile in the excavation (Fig. 39) showed that silty, subaquatic strata were cut off and covered by coarse, gravelly and probably supra-aquatic material. The silt, which contains well-developed stream ripples, is divided by a thin zone of clay-banded fine silt. This is interesting, as the level is above the HK. The clay must have been deposited in a completely stagnant body of water surrounded by ice. After the deposition of the clay, the stream increased and finally the body of water was drained.

The valley bottom is occupied by the lowest plain, which is built up of sandy-silty material to 129.5 m a.s.l. The same level is represented by a freely deposited plain at Vidingstorp, a short distance to the north, and thus it may represent the HK.

The outlets from the Sommen basin

Most of the problems treated in this section are briefly mentioned by Björnsson (1940). As better map material is now available, most of his observations have to be revised. As this part of the investigated area shows the most complicated deglaciation pattern, a detailed map was compiled (Fig. 40). This map contains the information given in the maps, Figs. 4 and 18, with some more place-names.

During the first deglaciation stages, the Sommen basin was dained southwards, to the uppermost part of the Stångå valley, which is entirely filled with vast glaciofluvial deposits. The lowest pass point is situated at 172 m a.s.l., N. of Lake Bringen and outside the investigated area (cf. Björnsson, 1940, pp. 56—57). The area is built up of coarse glaciofluvial material, in which plains

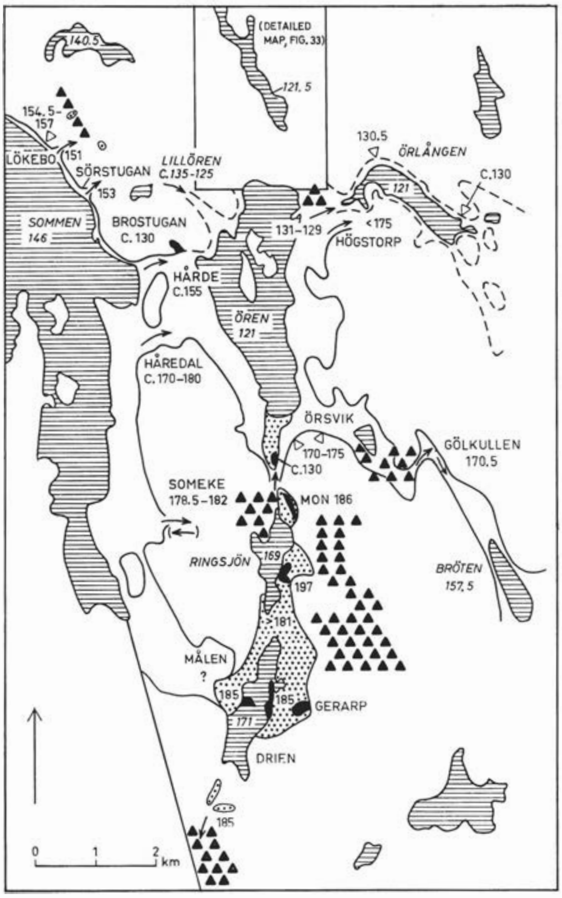


Fig. 40. The outlets from the Sommen basin and associated deglaciation features. Symbols explained in Figs. 3 and 18. In this figure the highest coastline is represented by a dashed line.

and eskers reach 175—180 m a. s. l. These levels give an approximate starting-point for an estimate of the dammed water level in the Sommen basin.

Lake Drien in the south-westernmost part of the area has its outlet, at 171 m a. s. l., westwards to the Sommen basin. The pass point southwards is situated at *c.* 185 m a. s. l. Around the lake, large esker ridges and plains reach this level, indicating that during their formation the lake was filled with stagnant ice and lacked a connection with the water level in the Sommen basin (cf. Björnsson, 1937, pp. 98 and 103).

Lake Ringsjön (169 m a. s. l.) is situated N. of Lake Drien. The lakes are divided by an esker network, the lowest point of which reaches 181 m a. s. l. On the eastern shore of Lake Ringsjön, a plane esker S. of Sjöstugan rises nearly 30 m above the lake or to *c.* 197 m a. s. l. The material, exposed in a vast excavations, is entirely coarse. As the depth of the lake is 25 m immediately outside the deposit (Björnsson, 1937, Pl. V), the thickness of the glaciofluvial material exceeds 50 m, which is the highest value obtained in this region. At Mon, slightly to the N., a plane esker reaches only 186 m a. s. l., indicating a lowering of the dammed water table (cf. below). In the northwestern part of the lake, hummocky moraine occupies a vast area and the Ringsjön basin must also have been filled with stagnant ice.

West of Lake Ringsjön and S. of Someke, a pass point to the Sommen basin reaches 178.5 m a. s. l. This site is represented by vast areas of exposed bedrock in the bottom of the valley, and the upper level of the bare-washed rock reaches *c.* 182 m a. s. l. This level may give an approximate figure for the dammed water table in the Sommen basin, as shorelines are completely lacking in the cultivated till slopes. Through this pass, a drainage westwards must first have taken place, when the water table in the Ringsjön basin was lowered to the Sommen basin.

Lake Ringsjön has its lowest pass point northwards, towards Lake Ören (121 m a. s. l.). This lake also has its outlet at the northern end and thus it was dammed by ice during the deglaciation. The southern pass point is situated at Gölkullen, SE. of the lake (170.5 m a. s. l.). In the deep valley, a vast boulder field reaches a few metres lower. On the slopes SE. of Örsvik, boulder zones, bare-washed rock and a terrace cut in the till occur slightly above this level. These objects were formed by a lateral stream between the slope and the ice in the Ören basin during the drainage eastwards of the Ringsjön basin. Also in the glaciofluvial deposits around Lake Ringsjön a distinct terrace was cut out at *c.* 172 m a. s. l.

When the area between Ringsjön and Gölkullen had become ice-free, the Sommen ice-lake could be lowered eastwards over the pass at Someke (Björnsson, 1942, p. 104). From Gölkullen, the water flow followed the outlet of the Tidersrum valley through the rock gorge at Arnebo and it may to some extent have influenced the development of the deposits in the Kättestorp valley. The synchrony in the evolution is, however difficult to estimate. The comparatively small erosion at these pass points indicates that not all the meltwater from the Sommen basin was discharged through the pass at Someke. Probably the outlet at Bringen was still in use at this time, as the gradient is only at little above 0.5 m/km when the levels are compared. It is impossible that the water level in the Sommen basin should have reached nearly 200 m a. s. l., as was suggested by Björnsson (1940, p. 59).

The water flow from the melting ice remaining in the Ringsjön basin must have continued for a relatively long time. At the outlet S. of Lake Ören, an accumulation of sandy and gravelly material reaches *c.* 130 m a. s. l., which is the supposed level of the HK in this area. The strata dip northwards, indicating that the accumulation was deposited by a water flow from the south.

When the vast till ridge SE. of Håredal became ice-free, a pass point at *c.* 170 m a. s. l. was opened (cf. Björnsson, 1940, p. 59). The abrasion, indicated by exposed bedrock, reaches *c.* 180 m a. s. l. The Bringen pass was now entirely drained. The outlet at Gölkullen was probably at this time replaced by a drainage across the till ridge at Högstorp, where the Ören basin was lowered to the Baltic ice-lake in the Örlången valley. A deep dry valley slopes from 131 to 129 m a. s. l. with large boulder accumulations in the bottom and a distinct boulder scarp at the eastern outlet. To the north, this channel was bordered by some remaining stagnant ice, indicated by a hummocky moraine area. This valley, the level of which is due to the HK, is not mentioned by Björnsson.

At Hårde, slightly N. of Håredal, the eastern pass point of the Sommen basin reaches only *c.* 155 m a. s. l., and thus there was a sudden lowering of the water table here, as is indicated by the areas of exposed bedrock. A vast accumulation W. of Brostugan, entirely built up of boulders (Fig. 41), reaches with its plane surface *c.* 130 m a. s. l. This accumulation was built up where the outlet at Hårde ended at the HK.

Fig. 41. Boulder field on the highest coastline c. 130 m a. s. l., E. of the outlet from the Sommen basin at Hårde (photograph by Stig Nilsson).

North-west of Hårde, pass points were opened at slightly lower levels, 153 m a. s. l. at Sörstugan and 151 m a. s. l. at Lökebo. This area has been described in detail by Björnsson (1940, pp. 60—64) and the map compiled by Björnsson is shown as Fig. 42. As no obvious errors have been found, this map has not been revised. Slightly N. of the outlet at Lökebo, a distinct shoreline was developed as a cobble wall (Fig. 43). This is quite natural, as the water table here must have been at the same level for a long time. The cobble scarp (154.5—157 m a. s. l.) may represent the mean water table in the late Sommen ice-lake, which thus reached 3.5—6 m above the pass level (cf. Björnsson, 1940, p. 63, who suggests a mean depth of 5 m).

The pass points are represented by short rock gorges and further to the E. vast boulder fields occur. Much of the boulder material is now covered with peat. The discharge was collected in the rock gorge E. of Lake Lillören at 134 m a. s. l. (Björnsson, 1940, p. 64). This gorge, with a length of *c.* 400 m and a depth exceeding 20 m, is the largest in this region, and a profile has been made across it (Fig. 44). The profile was made by measuring the length and slope of rows, but a tube levelling was made to a fixed point so that the height above sea-level could be used in the profile. The valley, which is eroded in a leptitic rock, has an asymmetrical cross profile. This shows that the profile has been influenced by glacial erosion and thus the valley cannot have been entirely formed by the outlet from the Sommen basin. Probably this rock gorge was an ice-lake outlet during several glaciations (cf. Persson, 1969, p. 95).

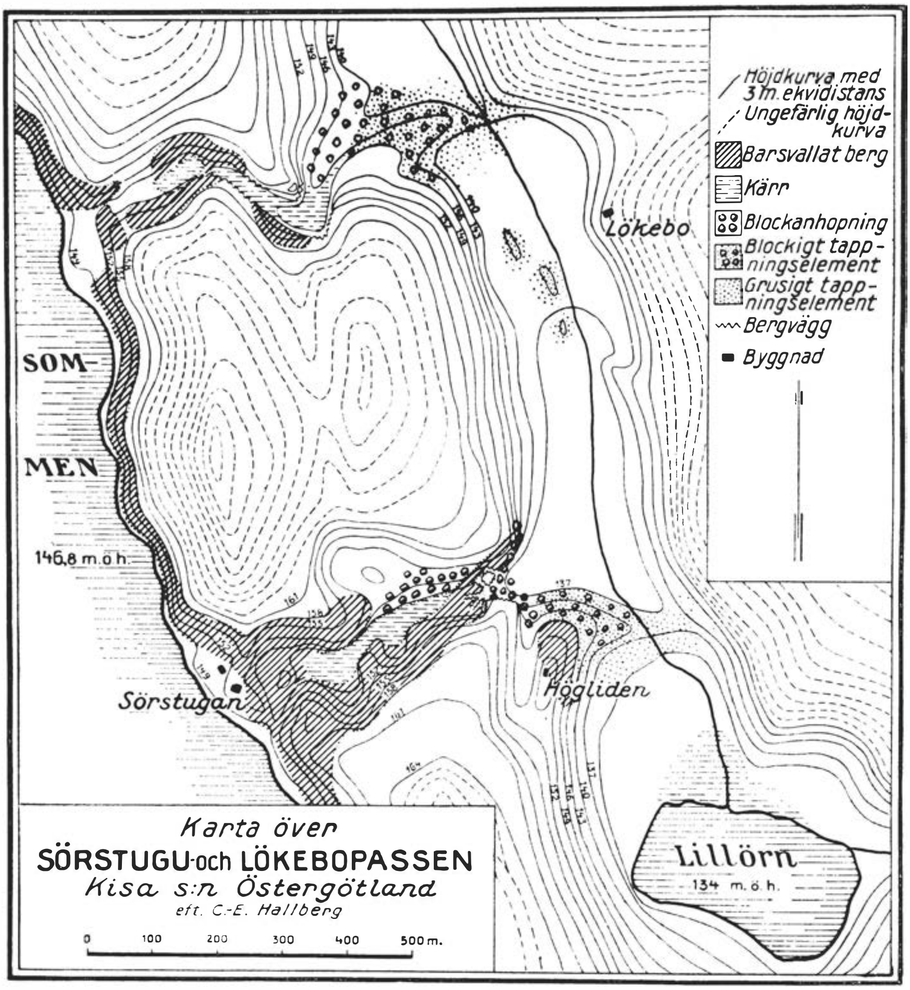


Fig. 42. The outlets from the Sommen basin at Sörstugan and Lökebo. From Björnsson 1940, p. 62. Legend from above: Level curve with 3-m interval, approximative level curve, bare-washed rock, fen, boulder accumulation, gravel, rock wall, building. Compiled by C. E. Hallberg in 1939.

As the outlet through the Lillören valley was used for a long time after the ice margin left this area, it is eroded below the HK, down to the present water table in Lake Ören (121 m a. s. l.). Probably the Sommen basin was still discharging eastwards when Lake Örlången, situated at the same level E. of Ören, was isolated from the sea. Vast rock areas were bare-washed around the pass point at Örneström and a little below 125 m a. s. l. large potholes were developed (Fig. 10).

To this description may be added some information about the deposits formed by the late Sommen ice-lake outside the investigated area. The large delta at Malexander in the north-eastern part of the lake has been described in detail by Björnsson (1942). In the valleys northwards from the delta, Björnsson made investigations which were never published, but some data appear in reports of undergraduate work done at the Department of Geography, University of Lund. These data were used in the construction of the map (Fig. 45).

The distal part of the delta at Malexander reaches 154 m a. s. l., which corresponds to the nearby outlet and shoreline at Lökebo. The level quickly rises to 160 m a. s. l. (cf. the detailed map compiled by Björnsson, 1942), and this indicates that the upper parts of the delta were supra-aquatically deposited. Excavations are lacking in

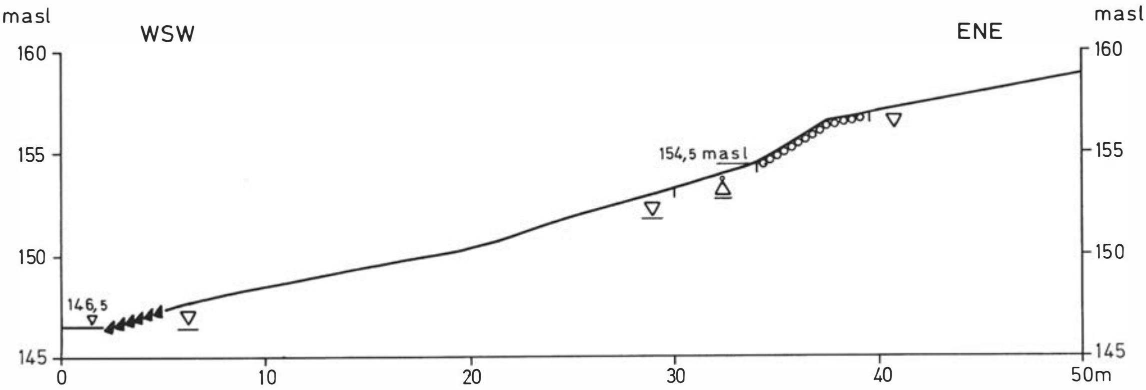


Fig. 43. The highest shoreline of the Sommen ice-lake immediately N. of its main outlet at Lökebo. The profile, which is not enlarged, starts at the present water level in Lake Sommen (146.5 m a. s. l.).

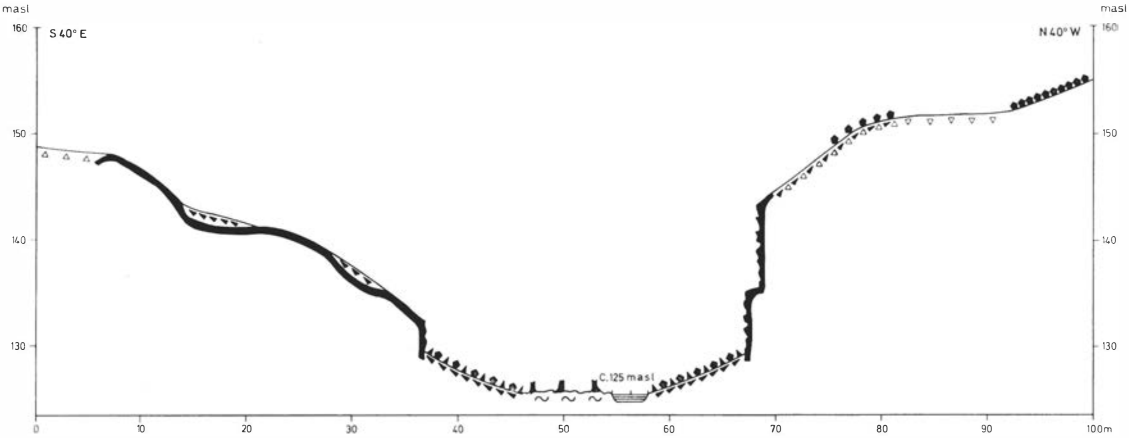


Fig. 44. Profile across the rock gorge at Lillören. No enlargement.

the delta, the central part of which is occupied by the village.

The glaciofluvial deposits N. of the delta form plains in the valley towards Lake Öjaren, rising gradually to *c.* 175 m a. s. l. on the large kettle field at Basteberg. The bedrock surface, however, sinks to the N. from the area slightly N. of the present Lake Sommen and Lake Öjaren is situated only 141 m a. s. l. The irregular shape of the plains indicates that the valley was filled with stagnant ice during their formation. Also in the valley towards Lake Asplången (149 m a. s. l.), plains occur at slightly lower levels. From the northern end of the lake, a sharp-ridged esker of stony material follows the narrow valley towards Enshult. A profile has been levelled along the crest, which reaches around 160 m a. s. l. The ruined farm at Enshult is situated on a lateral terrace with coarse surface material, reaching 167 m a. s. l. The terrace has a steep slope eastwards to the valley bottom, which is situated *c.* 20 m lower down (Fig. 46).

These deposits show that no open ice-lake occurred N. of Lake Sommen, as was suggested by Björnsson (1940, p. 65). The dammed water table in the stagnant ice margin reached only slightly above the bedrock surface, increasing northwards to a little below 167 m a. s. l. at Enshult, *c.* 12 km N. of Malexander. In the flat area further northwards, glaciofluvial deposits are almost totally lacking, but hummocky moraine, rich in boulders, covers wide areas. The problems concerning the final lowering of the dammed water table in the Sommen basin will be treated in the last section.

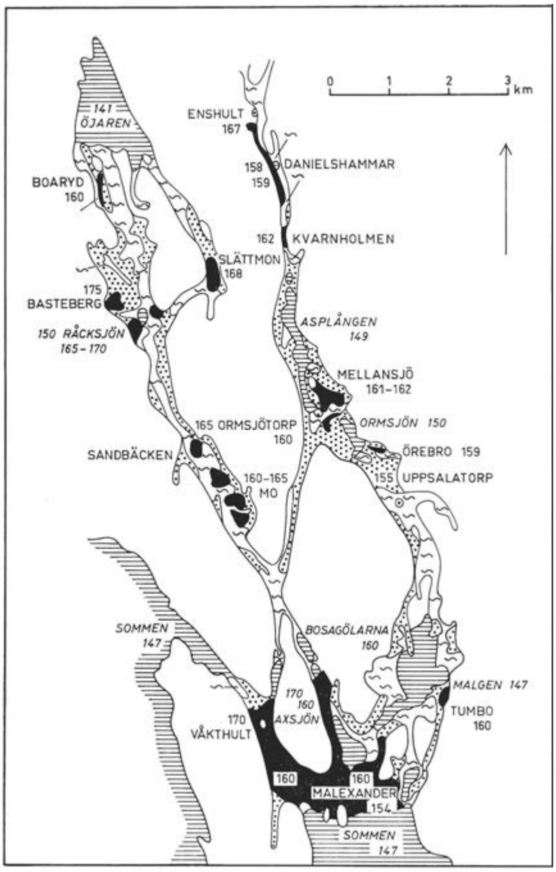


Fig. 45. Glaciofluvial deposits in the north-eastern part of the Sommen basin. Plains and ridges solid black, other glaciofluvial deposits dotted. The peat is only marked where it is supposed to cover glaciofluvial material. Some of the levellings were made by Björnsson (unpublished).

The Svalsjö valley

The valley from Lake Ören and *c.* 3 km to the NNW. forms a basin overdepressed by glacial erosion (Björnsson, 1937, p. 70). It is entirely occupied by a large glaciofluvial delta complex, with plains surrounding Lake Svalsjön (121.5 m a. s. l.). The plains are surrounded by steep walls of exposed bedrock, which reach 80—100 m above the lakes, thus giving a broad relief to the whole area (Fig. 47). The area was mapped in detail as an undergraduate task by Svante Rindetoft (Fig. 48) and profiles were levelled along and across the deposits (Figs. 49 and 50). Grain-size analyses were made on a large number of soil samples and some type soils are shown in Fig. 51. The description of the area follows the detailed map.

The southern part of the delta is slightly lowered towards Lake Ören. A scarp a little above the lake represents the old shoreline before a lowering of about 2 m in 1918 (Svalsjön and Örlången were also lowered at this time). A vast plain occurs between Svalsjö and Örsebo and its flat surface, 129.5—130 m a. s. l., indicates that it was built up to a water table. The plain eastwards, at Stora Vassgärdet, reaches 129 m a. s. l. and probably a single plain 129—130 m a. s. l. was formed and later divided by an erosion valley. At the southern end of Lake Svalsjön, the plains are bordered by steep slopes and immediately offshore the lake is *c.* 20 m deep. This indicates a proximal contact with stagnant ice and a thickness of the deposits of nearly 30 m. These plains, which are situated in a free position, may represent the HK in this area.

The central part of the delta complex is divided by a large area of till and exposed bedrock. In the south-western part of the delta, plains occur at a slightly lower level. These plains have been very much transformed by deep erosion channels. A great deal of meltwater was discharged through the valley at Perkels hål, at the mouth of which a badly sorted till-like material occurs. South-west of this area, the till slope is covered with wind-blown silt (cf. Fig. 72).

North of Haga, plains occur on both sides of Lake Svalsjön, sloping steeply towards the lake. The cross profile (Fig. 50), reveals that the plains at Haga and Mogård were built up to the same level (131.5 m a. s. l.). They might have been divided by stagnant ice in the lake basin, through which the water communicated. The coarse and badly sorted surface material probably forms a supra-aquatic superimposition. In its northern part, the Mogård plain passes over into a well-developed lateral terrace between the rock and the lake and in the steep rock side a hollow form was eroded by a lateral stream (Fig. 9).

The plains at Skördefall, Sjöhaga, Näs and S. of Tällstugan all reach about 135 m a. s. l. They show the same type of composition, with irregular ice-contact slopes, especially towards the lake. Deep

Fig. 46. Lateral glaciofluvial terrace (167 m a. s. l.) in the Sommen basin at Enshult, N. of Malexander.

Fig. 47. Lake Svalsjön (121.5 m a. s. l.) towards the NW. The plain in the front of the lake reaches 129 m a. s. l. (photograph by Svante Rindetoft).

excavations occur in the plains at Näs and Sjöhaga. They show an irregularly stratified, sandy-silty material on which a coarse, badly sorted gravel, 1—2 m thick, is superimposed (cf. the analyses, fig. 51). By drilling, the thickness of the glaciofluvial deposits at Näs has been estimated as *c.* 26 m. The sand and the silt must be interpreted as subaquatic sediments and the gravel was superimposed when the bodies of water in the ice were entirely filled with sediments (cf. J. Lundqvist, 1972, p. 32).

The northernmost part of the delta is characterized by a coarse material with numerous dead-ice hollows, some of which are very distinctly developed. The area N, of Näs may be characterized as a kettle field. In the narrow valley to the NNW., the coarse material gradually passes over into ablation till. From this valley, the glaciofluvial deposits can be followed outside the mapped area, from Fagersjön (144 m a. s. l.) towards Månhult. The other main discharge valley is situated NE. of Tällstugan and here the valley bottom consists of exposed bedrock. Also here the glaciofluvial deposits can be followed outside the area, towards the Ulrika basin.

The uniform levels of the plains indicate that they were formed at about the same time around a large area of residual stagnant ice in Lake Svalsjön. Thus the lake can be regarded as a gigantic dead-ice hollow. The southern plains were built up to the HK while the northern plains were dammed to a slightly higher level by the ice (cf. the profile, Fig. 49). These plains were covered with coarse material, probably to the level of the ice surface. The delta is entirely surrounded by higher terrain, especially northwards. It is thus possible that a large body of stagnant ice was separated in the Svalsjö basin during the deglaciation. The main part of the glaciofluvial material must have been subglacially deposited. The upper parts of the delta were formed during the last phase of the melting of the stagnant ice. At this time, however, the surrounding areas must have been ice-free and thus the delta was formed as an extra-marginal deposit outside the continuous ice margin. A strong indication of this develop-

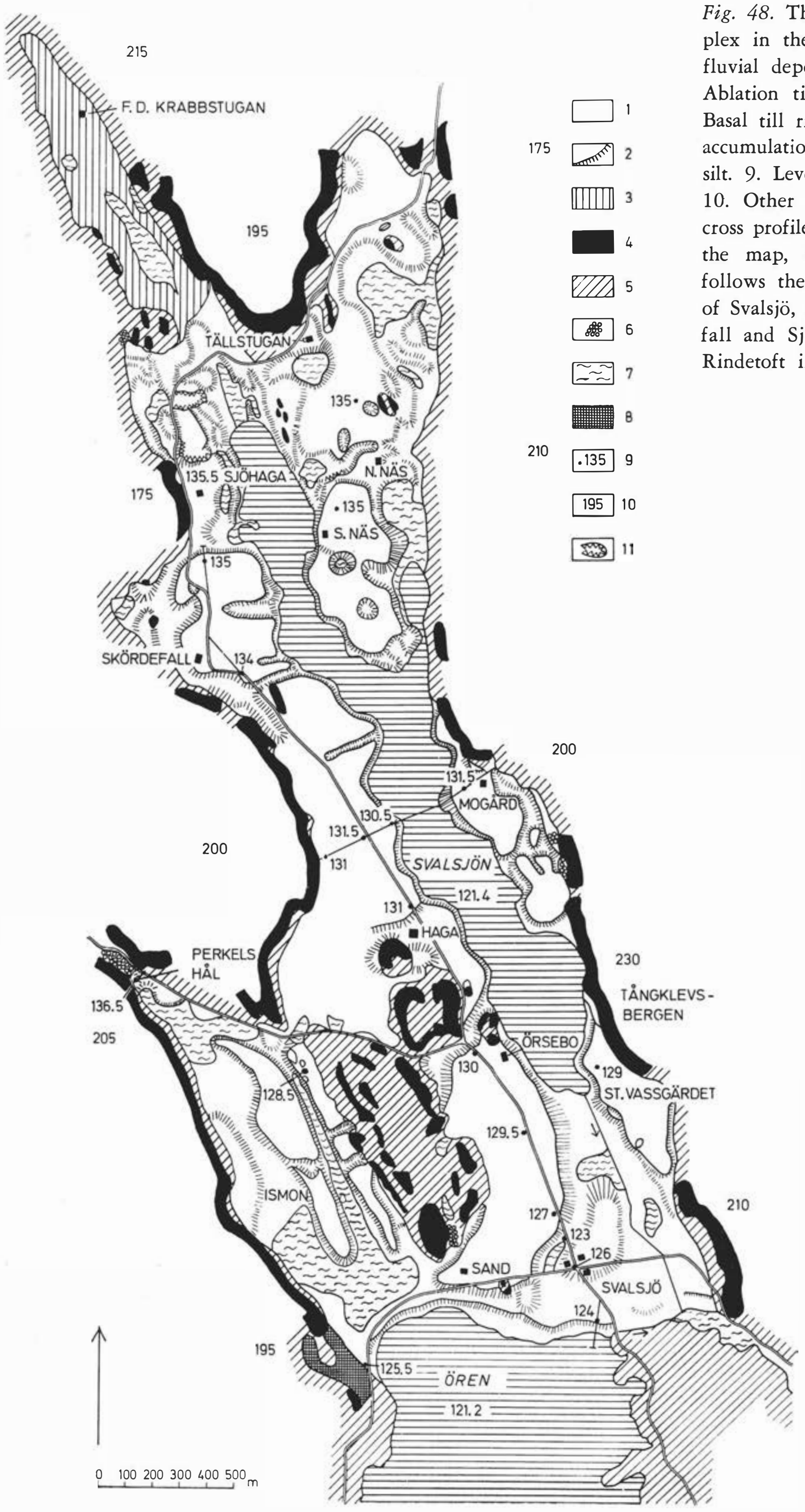


Fig. 48. The glaciofluvial delta complex in the Svalsjö valley. 1. Glaciofluvial deposits. 2. Slope direction. 3. Ablation till. 4. Exposed bedrock. 5. Basal till rich in boulders. 6. Boulder accumulation. 7. Peat. 8. Windblown silt. 9. Level measured by instrument. 10. Other level. 11. Excavation. The cross profile Haga-Mogård is shown on the map, the length profile mainly follows the road from Lake Ören, S. of Svalsjö, to a point between Skördefall and Sjöhaga. Mapping by Svante Rindetoft in 1971.

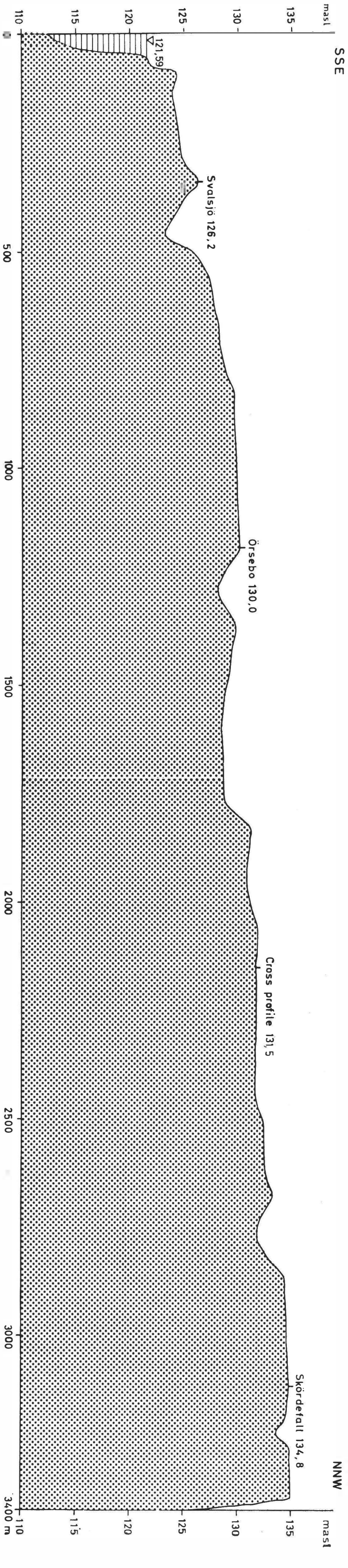


Fig. 49. Levelled profile across the glaciofluvial delta at Svalsjö.

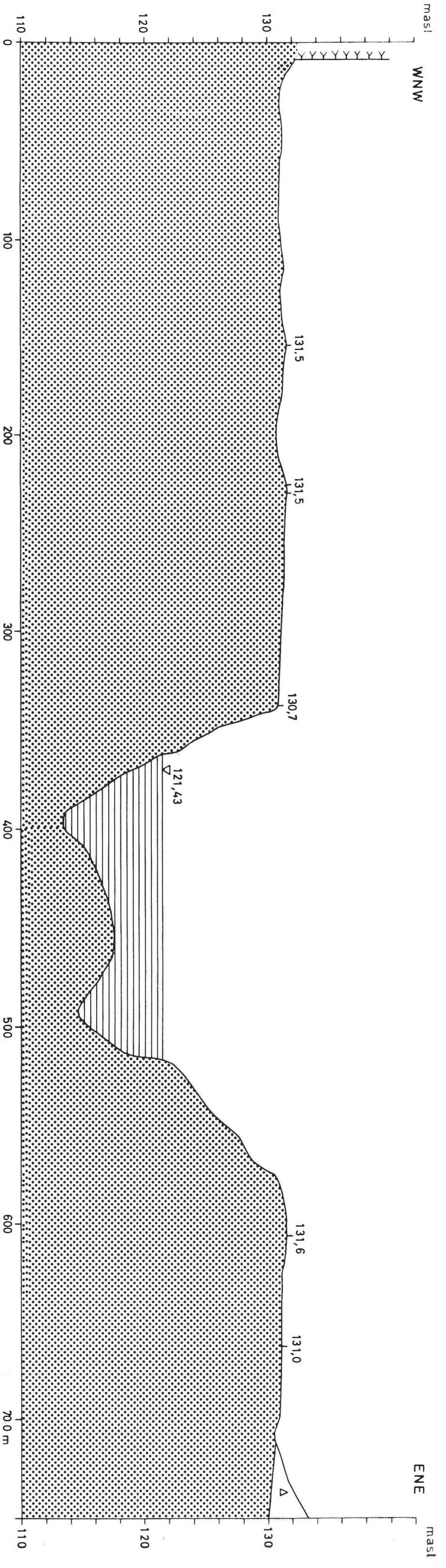


Fig. 50. Levelled profile across the glaciofluvial delta at Svalsjö (soundings in the lake).

ment of the area is the projection of the HK (Fig. 27), which shows that this level in the Svalsjö area is situated lower than the corresponding level along Lake Åsunden.

The Mjölsefall valley and the surrounding uplands

The glaciofluvial deposits in the Tidersrum-Kättestorp valley continue on the northern side of the valley from Kisa to Lake Sommen. North of Lake Övre Föllingen, the distinct Mjölsefall valley runs *c.* 5 km northwards, where it suddenly ends towards higher terrain. The southern part of the valley, S. of Lake Mjölsjön, is narrow and is mainly filled with hummocky moraine, reaching *c.* 20 m below the HK. Sandy glaciofluvial deposits occur at Hylta, where a small plain 131.5 m a. s. l. occurs N. of the farmhouse. This level corresponds to the wash limit SE. of the farm.

The glaciofluvial deposits can also be followed from Kättestorp towards Örneström and Lake Stora Gigeln (142.5 m a. s. l.). In the valley south of the lake and along its eastern shore, the glaciofluvial material is replaced by hummocky moraine, with coarse ablation till, rich in boulders. (The following description refers to the map in Fig. 52. This map contains the information given on the maps in Figs. 4 and 18). Coarse glaciofluvial gravel covers the cultivated area from Lake Lillgigeln (143 m a. s. l.) to Långebråta, slightly W. of the mapped area. From Långebråta and further to the NNW., the glaciofluvial material follows a narrow valley with its pass point at *c.* 190 m a. s. l.

North of the Gigeln valley, the terrain quickly rises to maximum heights of 200—225 m a. s. l. However, these heights decline further northwards. The lowest pass point, *c.* 175 m a. s. l. at the crest of the slope, is represented by a distinct rock gorge with a length of *c.* 100 m and a cross-section of *c.* 15×15 m. To the south, a vast boulder zone appears in the steep slope and to the north the gorge is immediately followed by a sharp esker ridge. This location of a rock gorge, at a pass point where it replaces glaciofluvial material at lower levels, has been pointed out by many authors, for example, Rudberg (1949, p. 474) and Persson (1969, p. 93). When the rock gorge was formed, a stagnant ice mass must have remained in the Gigeln basin. Probably the glaciofluvial material transported through the gorge was superimposed on the ice and, as the ice melted, formed an irregular mixture with the ablation till, now appearing as the boulder-rich areas between the Gigeln lakes.

North of the gorge, the glaciofluvial material follows the valley towards Mansgölen (154 m a. s. l.). At Hasenberg the ridge passes over into a lateral terrace *c.* 100 m long, with a slope *c.* 20 m high to the east. The surface level, *c.* 175 m a. s. l., corresponds to the base level of the gorge.

When the area SE. of Mansgölen became ice-free, a pass point was opened at *c.* 155 m a. s. l. towards the northern part of the Mjölsefall valley. The water table was now lowered about 20 m and the slope down to the Mjölsefall valley, where the glaciofluvial deposits reach *c.* 135 m a. s. l., was filled with an irregular boulder train.

In the Mjölsefall valley, sandy areas covered with peat appear N. of Lake Mjölsjön. A thin cover of glacial silt with clay zones shows that a free water table occurred in the valley. In the northern part of the valley, the glaciofluvial deposits become more pronounced, forming several plains separated by hills of till and exposed bedrock. The irregular distribution of the plains indicates that to some extent they were bordered by stagnant ice. The glaciofluvial deposits end suddenly at Svensbo, where a hummocky moraine area covers the slope up to Fagerhult *c.* 190 m a. s. l.

The manor house at Mjölsefall is situated on a glaciofluvial plain which rises distinctly above the surrounding sandy areas (cf. Björnsson, 1940, p. 65). On the *c.* 100-m-wide surface, the level sinks from 131.1 to 130.5 m a. s. l. towards the SE. Glacial silt reaches nearly to the top level, thus indicating that the plain was built up to a free water table. To the NW., the plain has a steep slope towards an erosion valley, c. 15 m deep. Also to the SE. a slope of similar height occurs and the slopes show that the plain was entirely built up of sandy material. In the bottom of the valley, exposed bedrock occurs, giving an approximate thickness of the deposits. The remainder

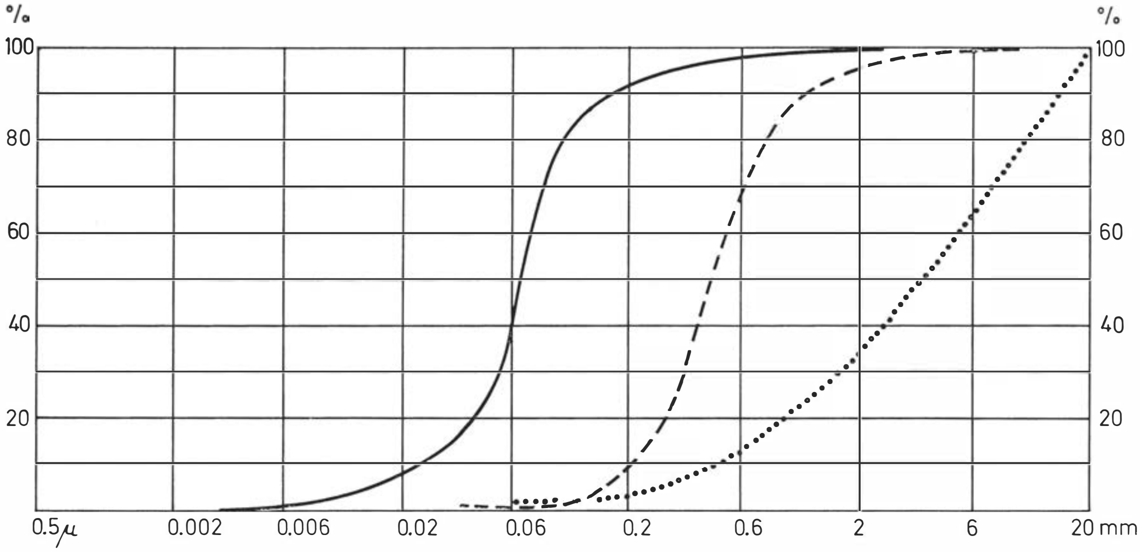


Fig. 51. Grain-size composition of glaciofluvial material from the delta at Svalsjö. Continuous line: silt from the lower part of the excavation W. of Norra Näs; dashed line: sand from the upper part of the same excavation; dotted line: gravel near the surface in excavation N. of Skördefall.

of the plain NW. of the valley reaches higher, a little above 131 m a. s. l.

The small farm of Grönhagen, *c.* 1 km to the NW., is situated on a small plain with a medium level of 133.5 m a. s. l. and a plain SE. of Grönhagen reaches *c.* 1 m lower. These levels show that the plains in the northern part of the Mjölsefall valley slope continuously towards the SE. and thus that they were built up from the NW. by the glacial meltwater stream which had branched off from the Hasenberg valley. The lowermost level of the Mjölsefall plain corresponds to the HK in the valley, which thus has a lower level than at Hylta, *c.* 4 km to the south. This is an indication that stagnant ice melted away some time later in this sheltered valley.

The glaciofluvial stream can be traced along the valley from Mansgölen towards the NNE., where it is represented by boulder trains south of the pass point to the Drögen basin (*c.* 175 m a. s. l.). South of Bäckhult, a distinct eske ridge was built up to the pass level. However, the coarse deposits around Bäckhult at Lake Drögen show no distinct surface form and neither do the deposits continuing on the other side of the lake, at Isnäset. This is an indication that no ice-dammed water table occurred in the Drögen basin.

The Yxefall valley

The Yxefall valley, with a length of *c.* 5 km, runs NNW. from Lake Hargsjön, N. of Kisa (115 m a. s. l.), towards the pass point to the Drögen basin (*c.* 160 m a. s. l.). As the Drögen basin, the recent water level of which was situated at *c.* 158 m a. s. l. (Sundelin, 1917, p. 166), had its recent outlet northwards lowered by glacial erosion, it has been supposed that in pre-glacial time the lake was drained southwards through this valley (Björnsson, 1937, p. 83). The central part of the valley is occupied by a large drumlinoid ridge, along the eastern side of which glaciofluvial deposits occur. The ridge is bordered on the east by two small lakes, the Eksjö lakes, which are situated in a basin overdepressed by glacial erosion. The glaciofluvial deposits in the valley were examined as an undergraduate task by Rolf B. Bergström in 1970.

Immediately NW. of Lake Hargsjön, the valley is very narrow and the till bottom forms the pass level of the lakes, slightly above 125 m a. s. l. The area between the pass point and Lake Hargsjön is occupied by glaciofluvial deposits, which form a plain *c.* 200×50 m in a N.—S. direction immediately W. of the lake, at Östorp. The plain is bordered by steep, 10-m-high slopes and the

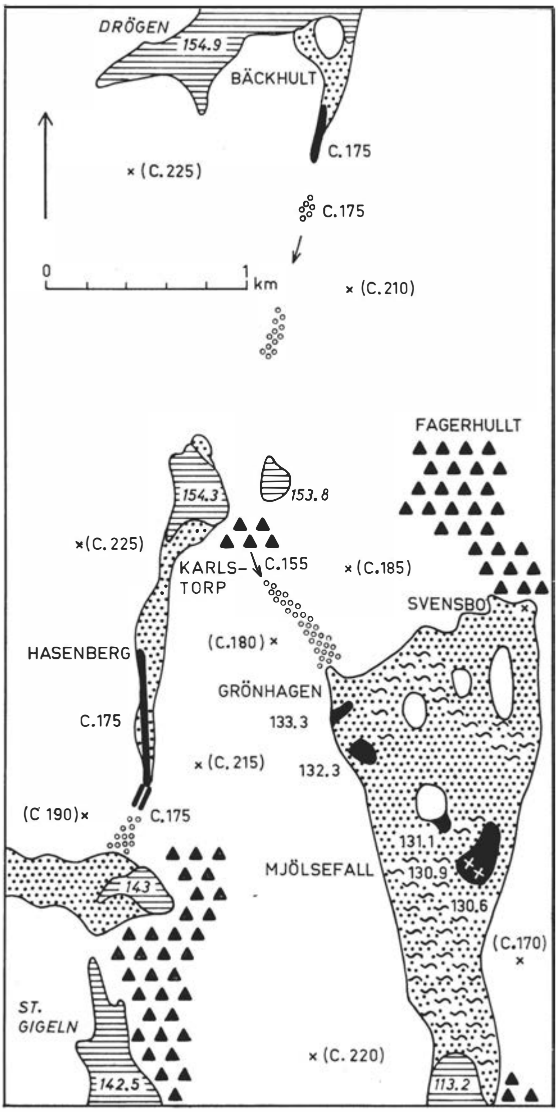


Fig. 52. Deglaciation features in the Gigeln and Mjölsefall valleys and their continuation northwards to the Drögen basin. The small circles indicate boulder wash zones; the other symbols are explained in Figs. 4 and 18. Note the position of the rock gorge *c.* 175 m a. s. l., S. of Hasenberg.

material is sandy. The completely flat surface reaches 130 m a. s. l. This plain, which must have been bordered by stagnant ice during the formation, represents the water level at the mouth of the Yxefall valley, probably the HK (cf. the levels obtained at Millingetorp in Fig. 33.

The glaciofluvial deposits W. of Lake Nedre Eksjön form a distinct plain, bordered by the lake and the till ridge (Figs. 53 and 54). The surface slopes towards the SSE. from 134 to 133 m a. s. l. over a distance of 200 m, which indicates supra-aquatic sedimentation. The distal slope, which was destroyed by excavation during 1971, was slight and seemed to indicate a distal body of free water. An excavation in the distal scarp (Fig. 55) shows that sandy strata dipping 30—35° towards the SW. were covered by horizontal layers of gravelly sand and an uppermost layer of stony gravel. The sandy layers form the foreset bed towards the body of free water and the steep dip indicates a rapid deposition. When the delta was built up towards the water table, the stream increased in the shallow water and the uppermost layer must be regarded as a supra-aquatic superimposition. Fig. 56 shows the granulometric composition of the main soil types.

Along a cross profile (Fig. 57), motor drillings and seismic measurements with a MD-3 hammer seismograph were made. This investigation revealed that the subaquatic material became coarser with increasing depth, which indicates that the initial part of the sedimentation took place subglacially. The glaciofluvial deposits reach a thickness of 18 m below the surface along the profile and south of Lake Övre Eksjön and the border towards the till corresponds to the deepest part of Lake Nedre Eksjön (—12.6 m). The depth indicates that the lake basin was filled with stagnant ice and thus the delta was formed in a small, lateral, water basin between the ice and the till ridge.

Further to the north, the lakes are separated by a ridge of silty sand, reaching 133 m a. s. l. This ridge was probably built up between the remains of stagnant ice in the lakes by a stream from a valley to the NNE. Along the western side of Lake Övre Eksjön, a terrace follows the till ridge. Its northernmost part, with a length of 130 m, is well developed in the open area, forming a 30-m-wide, plane surface at 136 m a. s. l., with a 10-m-high scarp to the valley bottom. The continuous lateral plain indicates that a synchronous residue of stagnant ice remained along the whole till ridge. The terrace was thus formed at the same time

Fig. 53. The glaciofluvial delta, at Yxefall W. of Lake Ned. Eksjön, 126 m a. s. l., NNW. of Kisa.

as the delta and the transversal ridge between the lakes. The top levels were directed by the ice surface, sloping *c.* 3 m/km. The dammed water table in the valley probably reached a little above the HK, towards which the plain at Östorp was built up at the same time.

The surface level rises N. of the lakes and the valley becomes narrow. A large accumulation of very coarse glaciofluvial material is situated here and the irregular surface reaches *c.* 140 m a. s. l. This accumulation was formed when the stream suddenly decreased at the opening of the valley and thus it may be classified as a "proximal delta", according to G. Lundqvist (1940, p. 52). The coarse glaciofluvial deposits can be traced to the pass point at Boxhult *c.* 160 m a. s. l. where the erosion in the till bottom was intense. It is quite possible that the proximal delta was formed at the same time as the lateral deposits described above. All the glaciofluvial deposits in the valley are thus supposed to have been formed synchronously when the uplands around and north of it were already deglaciated.

The area West and North-west of Slätmon

The large lowland area below 100 m a. s. l. south of Slätmon was formed by the intersection of several large valleys. The lower parts are covered by thick clayey and silty deposits and, S. of Hag, erosion valleys with a depth exceeding 20 m were formed in the silt during Post-Glacial time. A vast glaciofluvial accumulation occurs at Hag, but, as it has now been mainly destroyed by a large gravel pit, the surface form is difficult to reconstruct. The highest parts at the southern end of the deposit reach 133.5 m a. s. l. Sandy and gravelly strata with a thickness exceeding 15 m dip 25—30° towards the SE., thus indicating that the distal part of the accumulation was deposited as a delta in a free water table. As fine sediments cover the vast valley downslope, this water table must be the Baltic ice-lake and the top level gives an approximate figure for the HK. Northwards, coarse glaciofluvial material, supra-aquatically deposited around bedrock knobs, reaches *c.* 140 m a. s. l and *c.* 1 km WNW. a plain reaches 133—134 m a. s. l. (cf. Sundelin, 1917, p. 208). The topographical position of this accumulation is typical of a delta formed at the HK (cf. G. Lundqvist, 1940, p. 49).

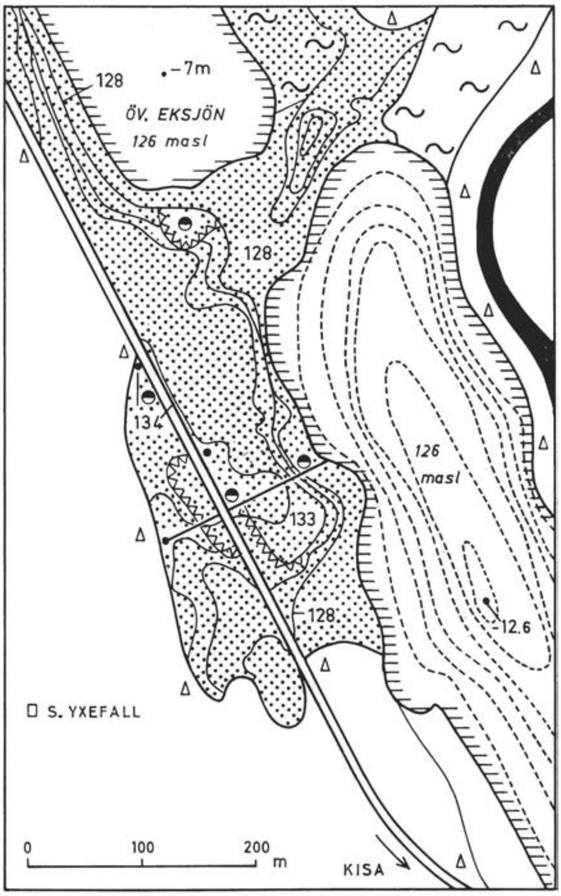


Fig. 54. The glaciofluvial delta at Yxefall. A distance of 2 m between the level curves in the glaciofluvial material and in the lake. Note the position of the profile (Fig. 57) and the drilling points.

The glaciofluvial deposits can be followed towards the NNW., where a distinct esker ridge appears in the deep and narrow valley towards Lake Flatsjön (129 m a.s.l.). The core of the ridge is visible in the gravel pit at Hag, showing that the material is coarse and stony. The esker has a length of *c.* 500 m and, as the crest is followed by a small road, a length profile was levelled (Fig. 58). The profile shows two crests, at 137 and 138 m a.s.l. A cross profile was levelled at the southern crest (Fig. 59). To the west, the esker is bordered by a steep rock wall and to the east by a lateral terrace with a length of *c.* 200 m, reaching nearly the same level as the esker crest. This indicates that the esker was formed in a very thin, stagnant ice, probably in an open crevasse. The crest levels indicate that the esker was formed at the same time as the accumulation at Hag. This large deposit must thus have been finally developed when the proximal uplands were almost free from ice.

A few kilometres NW. of Hag, a deep valley runs towards the WNW. from Lake Ösjön (130 m a.s.l.). This valley forms the eastern outlet from the Drögen basin, the pass level of which is situated at 160 m a.s.l., S. of Persbo. Vast boulder fields occur in the deep rock gorge and also at the outlet in Lake Ösjön a vast boulder field was formed. This boulder field reaches some metres below the HK, nearly to the present water table of the lake, as the water flow must have continued for some time through this valley. The recent pass point of the Drögen basin is situated at Viggedal, NE. of the lake, where a boulder field reaches 139 m a.s.l. This boulder field may represent the final lowering of the ice-dammed water level in the Drögen basin and the level of the field was governed by the HK. As I mentioned in the preceding section, the ice-dammed body of water in the Drögen basin had a level which only slightly exceeded that of the present lake. No deposits formed in the supposed ice-lake have been found and the small plain *c.* 165 m a.s.l. at Valvik was deposited in a local body of water. It is probable that the basin was entirely filled with stagnant ice. The water discharged from the melting ice mass through the outlet at Persbo is supposed to have built up most of the glaciofluvial deposits W. of Slätmon.

Glaciofluvial deposits also occur in the deep valley from Lake Flatsjön northwards to Lake Järnlunden. This valley slopes northwards and the narrowest part is situated S. of Lake Valvikssjön

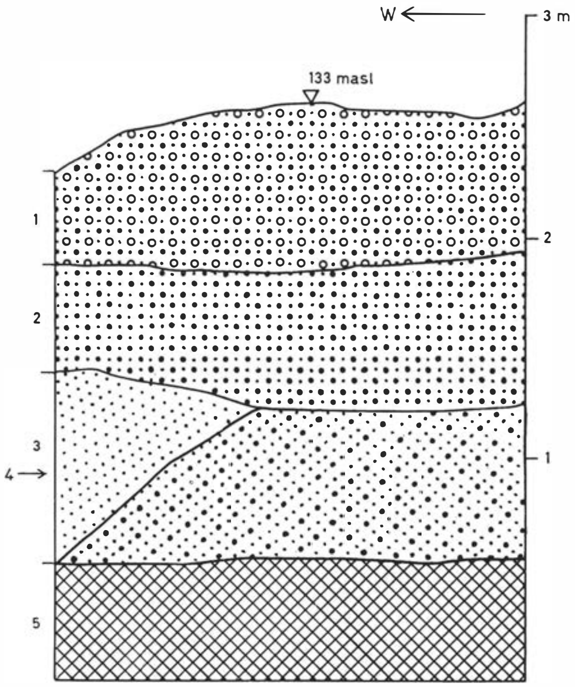


Fig. 55. Stratigraphy in the distal slope of the delta at Yxefall. Sequence from below: slide material, coarse sand and medium sand dipping *c.* 30° towards the SW., gravelly sand with irregular horizontal banks, stony gravel without stratification.

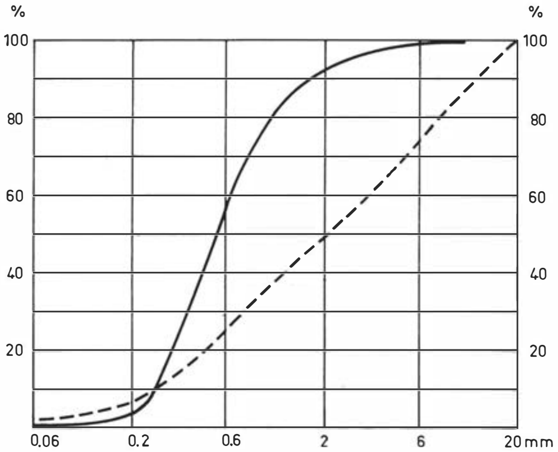


Fig. 56. Grain-size composition of stratified sand and surface gravel (dashed line) in the distal slope of the delta at Yxefall.

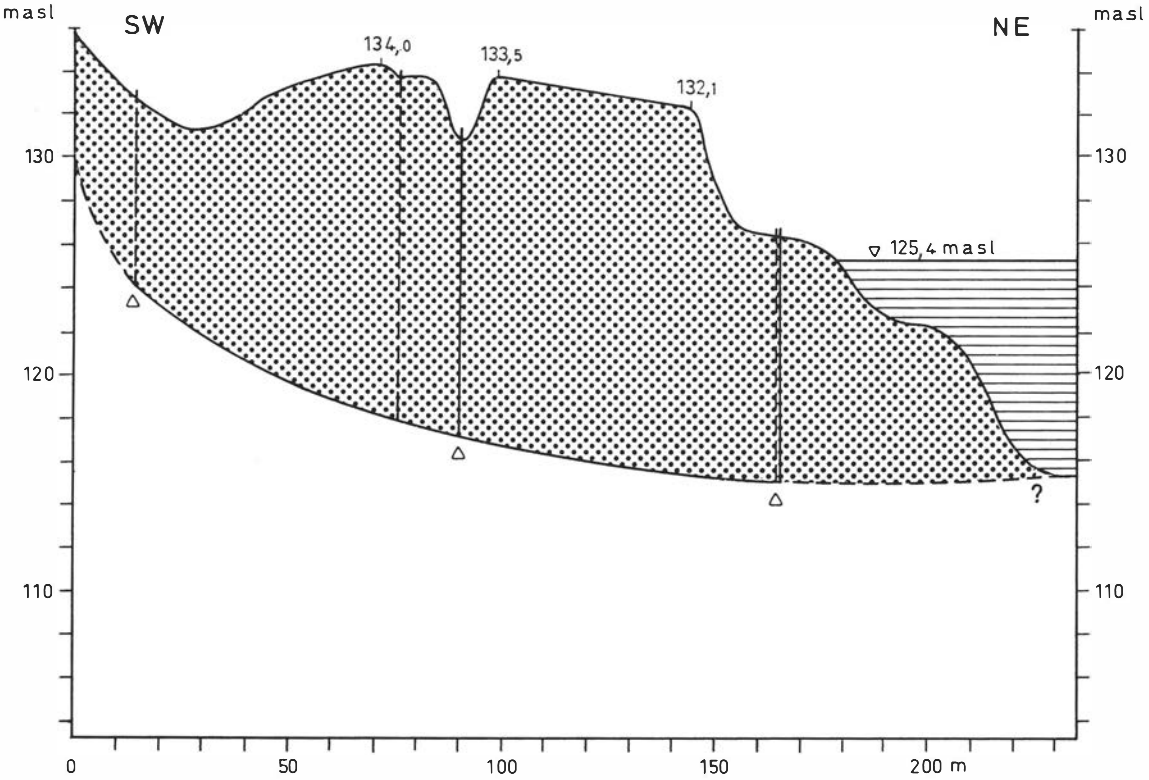


Fig. 57. Levelled profile across the glaciofluvial delta at Yxefall. The thickness of the glaciofluvial material was examined by drillings (continuous lines) and by hammer seismograph (dashed lines). Compiled by Rolf B. Bergström in 1970.

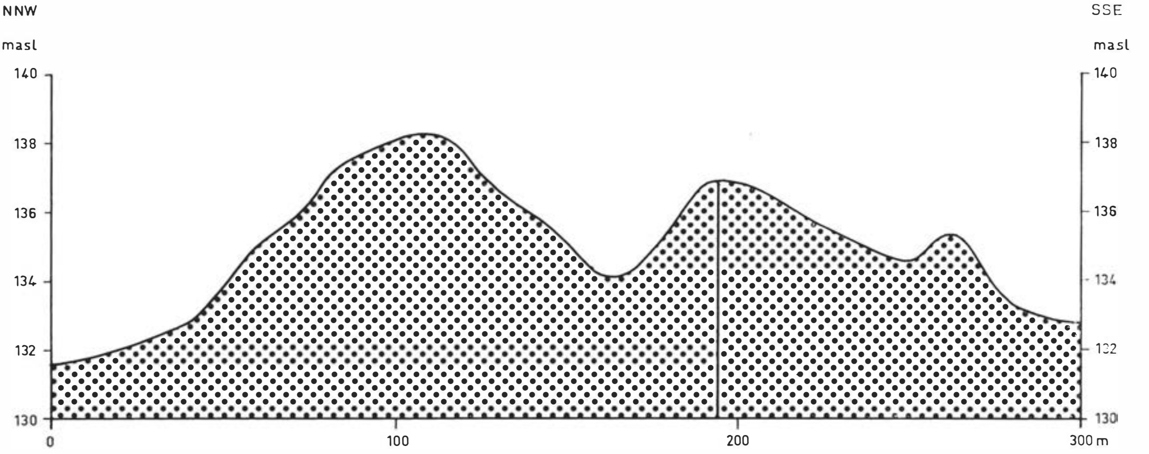


Fig. 58. Levelled profile along the esker S. of Lake Flatsjön and W. of Slätmon, enlarged 10 ×. Note the position of the cross profile at the southern crest.

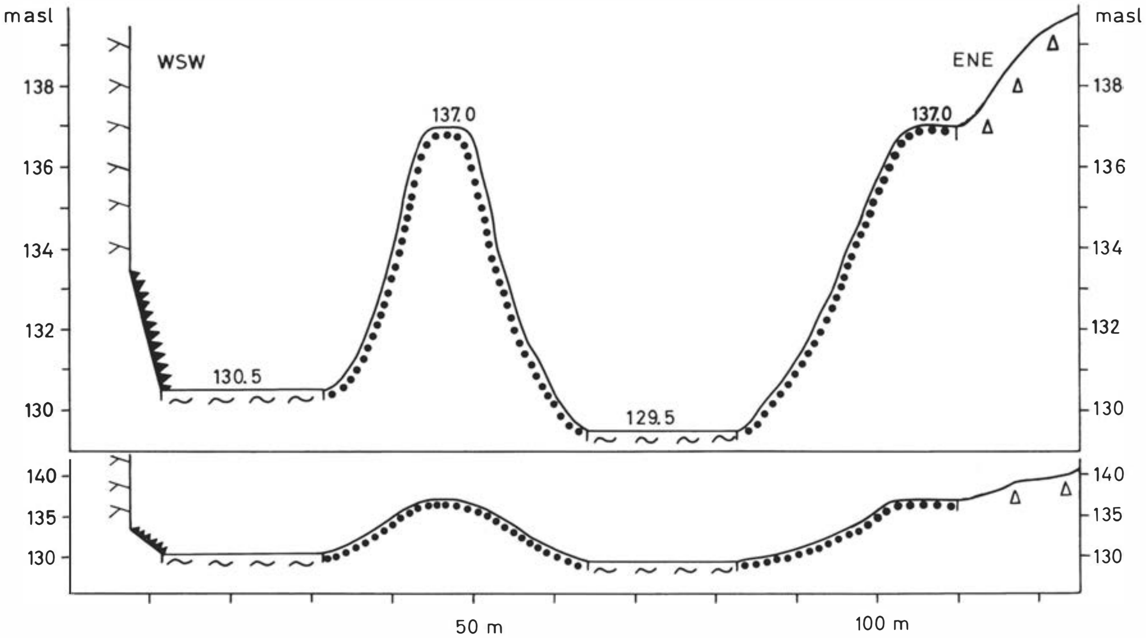


Fig. 59. Levelled profile across the esker S. of Lake Flatsjön and W. of Slätmon, above with 5 × enlargement and below without enlargement.

(122 m a. s. l.). Westwards, a steep rock slope reaches *c.* 80 m above the valley bottom. An esker ridge surrounded by the lake reaches 138 m a. s. l. and it continues to the S. as an irregular accumulation with the surface *c.* 139 m a. s. l. A large excavation shows that the material is coarse and dips irregularly and the accumulation may be interpreted as a proximal delta. The transition to the proximal delta indicates that also this esker was formed in a very thin ice. The level is around the HK and the subaquatic deposition with a high water pressure may be one reason for the great amount of coarse material.

Also in the eastern part of the Slätmon area, glaciofluvial deposits occur. Around the former railway station, they have been abraded and wide areas of silty sediments are covered with sand. Further to the NW., at Svartmålen, a plain 400 m long and 100—150 m wide, which was bordered on the sides by stagnant ice, slopes from 134 to 133.5 m a. s. l., giving an indication of the highest water table in the area (cf. the boulder terrace at Ulvesund, 134.5 m a. s. l.).

The Ulrika basin

The circular depression at Ulrika is filled with sandy glaciofluvial deposits, dominated by the large plain *c.* 179 m a. s. l. on which the village is situated (cf. Ekström, 1924, pp. 42—43, Munthe, 1940, pp. 45—46). The surrounding area, which is rich in exposed bedrock, is flat compared with the areas to the S. and W. The plain and its surroundings have been mapped (Fig. 60) and two profiles have been levelled, along the delta (Fig. 61) and across it (Fig. 62).

The delta, *c.* 500×900 m, has an irregular form, rising with steep slopes *c.* 6 m above the small and shallow (−3 m) lakes surrounding it. A drilling at the crossing of the profiles showed that the sandy material reaches a thickness of 16 m and that it is distinctly bordered towards the till. The profile in the WSW.—ENE. direction is almost flat, while the profile in the NNW.—SSE. direction slopes 0.8 m/200 m towards the SSE. From the central basin, glaciofluvial deposits can be followed towards the NNW., NNE., ESE. and SW., where, as a rule, they are coarse and were supra-aquatically deposited. An orientation analysis of the elongated pebbles in the gravel pit in the south-easternmost part of the mapped area showed that the coarse material was deposited from the WNW.

The glacial drainage from a large area must have been concentrated in the Ulrika basin during the deglaciation. The thickness of the deposits indicates that the accumulation must have started subglacially. The slope of the plain indicates that the surface was built up by a stream from the NNW. At this time the plain must have been entirely surrounded by ice and the slope may have been governed by the ice surface (*c.* 3 m/km). This is probable, as the lowest pass point towards the SW. only reaches 173 m a. s. l. and thus it must have been blocked by ice during the deglaciation. No ice-lake shorelines corresponding to the level of the plain were found on the till slopes, but lateral wash zones occur at different levels.

Some of the glacial drainage from the area further to the N. and NW. was, however, directed W. of the delta, through the *c.* 20-m-deep joint valley at Rönnäs with the pass point at *c.* 175 m a. s. l. This pass point governs the level of the distinct Ycke esker, the main direction of which is NNE. The direction of the esker is independent of the small valleys in the NNW.—SSE. direction and this may have been due to the influence of stagnant ice in the flat-surfaced area. The esker can be followed to Norrstugan, where it forms a distinct plane esker, 225 m long, sloping from 181 to 180.5 m a. s. l. towards the SW.

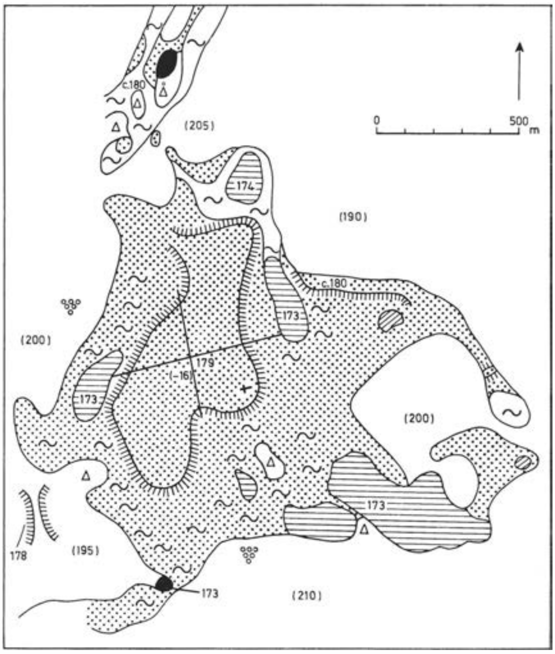


Fig. 60. The glaciofluvial delta at Ulrika (179 m a. s. l.) and its surroundings. The top levels around the basin are marked. Note the position of the levelled profiles on the delta plane.

The Tyrsbo area

The northernmost part of the investigated area has a very flat rock surface, sloping northwards from *c.* 175 to 140 m a. s. l. with joint valleys in the NNW.—SSE. To the NE., the area is bordered by the HK *c.* 140 m a. s. l., which forms an approximate limit to the lower terrain northwards. The flat rock surface continues S. and SW. of the area. This area is dominated by a distinct and continuous esker running N.—S., the Tyrsbo esker, which is a continuation of the Ycke esker. A transversal esker, the Helgeslund esker, runs *c.* 2.5 km towards the ENE. from the central part of the Tyrsbo esker. This esker is bordered to the S. by a vast area of hummocky moraine, rich in boulders. Hummocky moraine is, however, common in the whole area.

The Tyrsbo area is known from the literature as the supposed final drainage area of the Sommen ice-lake. According to Björnsson (1946, p. 11), this event took place as a catastrophic drainage E. of Tyrsbo to the Baltic ice-lake. The field work supporting the statement by Björnsson was an unpublished report on an undergraduate task carried out by D. Davidsson in 1943. A "boulder delta" at Opphem, E. of Tyrsbo, was supposed to indicate the lowering of the Sommen ice-lake (178—179 m a. s. l.) to the Baltic ice-lake (163 m a. s. l.) (Davidsson 1943, pp. 31—34). Nilsson (1953, p. 198) has accepted Björnsson's theory of a sudden drainage at Tyrsbo, where he also supposed the Tida-Vättern ice-lake to have been lowered. In a later paper (1958, p. 182), he mentions a "drainage varve" in a clay sequence from Rimforsa, which is supposed to indicate this event.

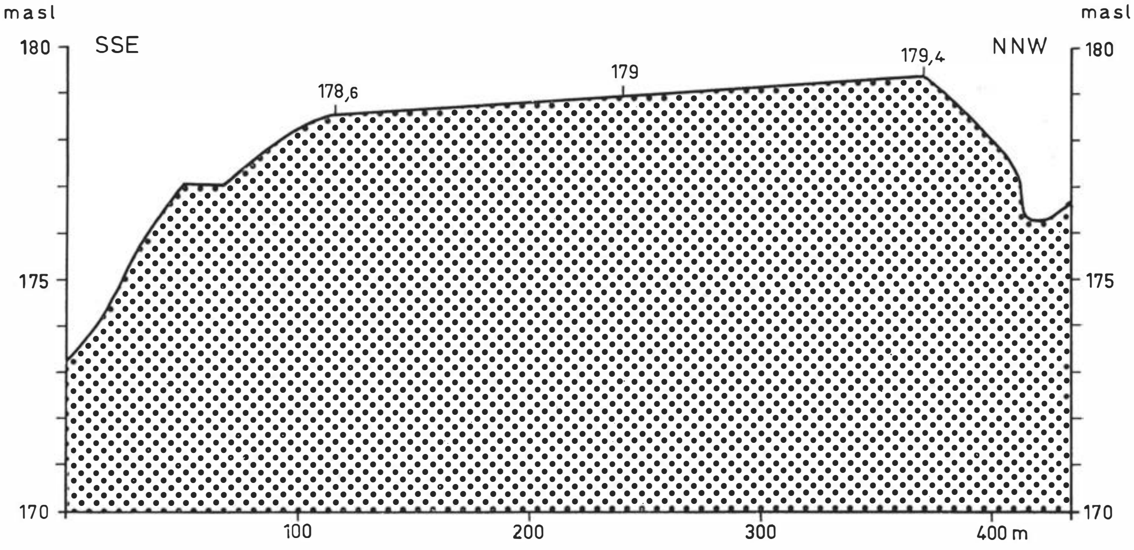


Fig. 61. Levelled profile along the glaciofluvial delta at Ulrika.

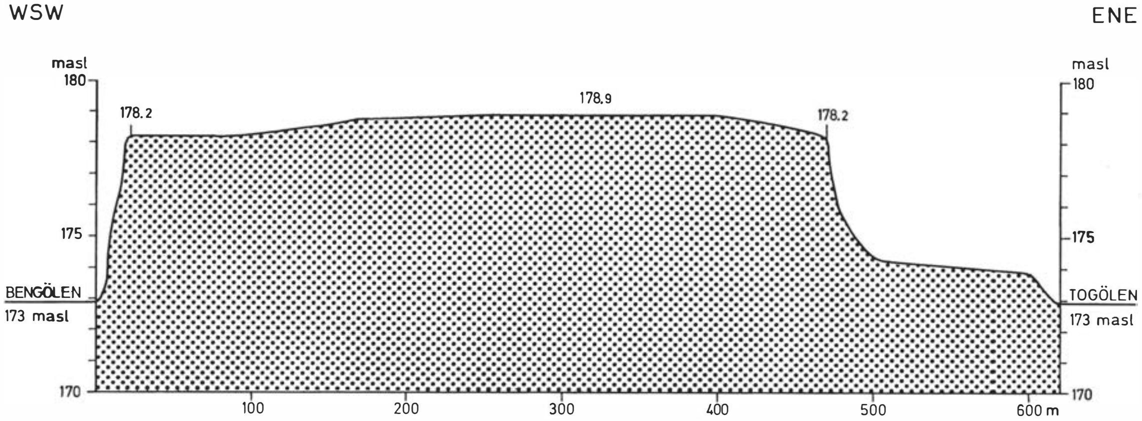


Fig. 62. Levelled profile across the glaciofluvial delta at Ulrika.

On the map compiled by G. Lundqvist (1961), the drainage at Tyrsbo is marked with the Baltic ice-lake reaching 160 m a. s. l. and the Sommen ice-lake 175 m a. s. l. However, it is not dealt with in the description.

A detailed interpretation of the supposed "drainage area" is especially easy to make, as it is covered by the south-westernmost part of the geological map Linköping SO (Johansson & Gorbatschev, 1973). This part was mapped on a scale of 1:10 000 and published on a scale of 1:20 000 (Johansson, 1973, pl. I and pp. 40—45). The map, Fig. 63, is a simplification of the map published by Johansson. This simplification was necessary, in order to make room for the levelled figures obtained in this investigation.

In the south-western part of the area, a plain at Skuggebo reaches 169.5—171 m a. s. l., sloping towards the SW. This plain was built up of slightly dipping sandy strata and is bordered by steep slopes rising *c.* 10 m above the flat, peat-covered, valley bottom. This indicates that the plain was built up in stagnant ice in the same way as the delta at Ulrika. The plain shows that

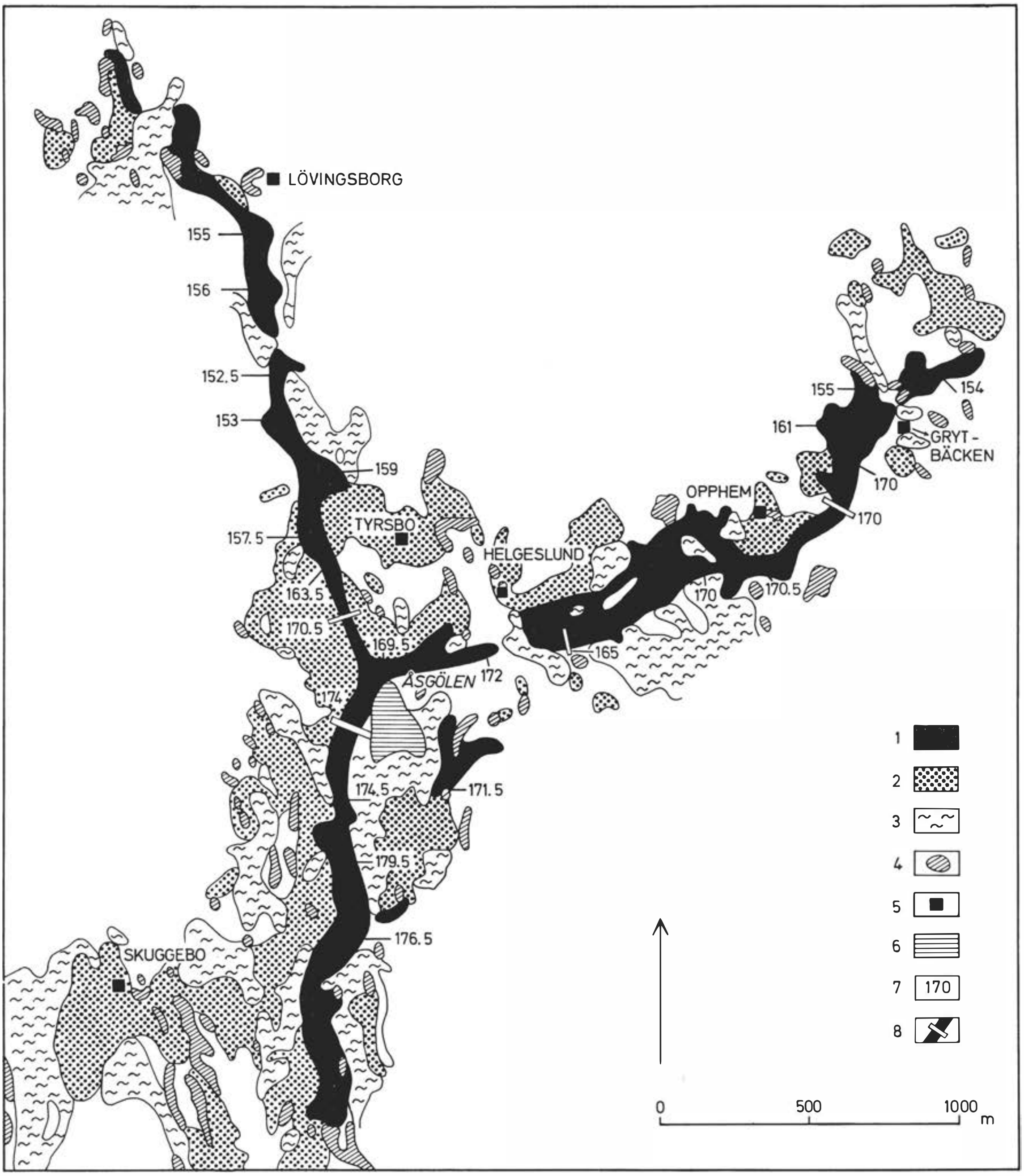


Fig. 63. The Tyrsbo area. Simplified geological map from Johansson 1973, pl. I. Legend: 1. Ridges of coarse glaciofluvial material (esker). 2. Glaciofluvial sand. 3. Peat. 4. Rock outcrop. 5. Farmhouse. 6. Lake. 7. Esker crest in m a. s. l. 8. Cross profile. The areas without other symbols consist of till.

the dammed water level in the ice was lowered *c.* 10 m after the formation of the plane esker at Norrstugan, 1.5 km to the south.

The high and distinct Tyrsbo esker, E. of Skuggebo, has a sharp ridge form, rising to a maximum of *c.* 180 m a. s. l. This indicates that the esker was deposited some time before the plain at Skuggebo. West of Lake Åsgölen, the ridge gradu-

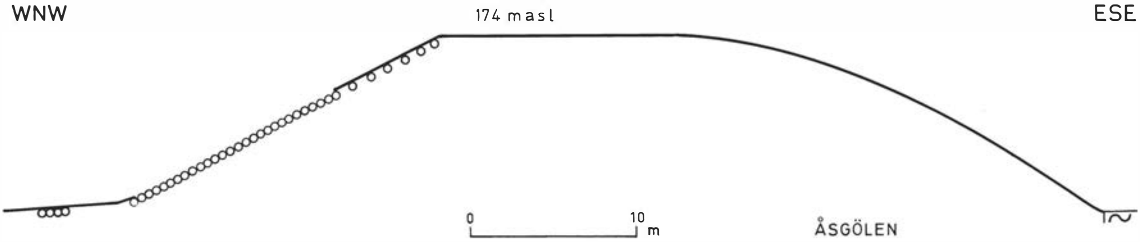


Fig. 64. Profile across the Tyrsbo esker, W. of Åsgölen. The rings indicate boulder wash zones. The profile, which has not been enlarged, was not levelled by instrument.

Fig. 65. An excavation through the transversal esker SE. of Helgeslund in the Tyrsbo area.

Fig. 66. Hummocky moraine rich in boulders N. of Stensjön in the Tyrsbo area.

ally passes over into a plane esker, *c.* 200 m long. The plane esker reaches 174 m a. s. l. (cf. the cross profile, Fig. 64) and the slopes are covered with boulder accumulations. Such boulder fields occur on the sides of the eskers at several sites in the area, for example, at Opphem. They may have been formed by lateral wash some time after the formation of the ridge.

The transition from a ridge to a plane esker is important. The plane esker must have been developed in an open crevasse, and in that case the ice cannot have been thicker than approximately the width of the plane, otherwise a tunnel would have been formed. It is most likely that the ice surface just reached the level of the plane. The ridge parts of the esker, which were formed at the same time, must thus also have been developed in a very thin marginal zone of the ice, which was entirely stagnant. The deposition in a stagnant front zone explains the irregular distribution of the glaciofluvial material.

North of Lake Åsgölen, the Helgeslund esker separates from the Tyrsbo esker. The levels of the eskers suddenly sink just at the branch, but they soon reach the previous level, *c.* 170 m a. s. l. The Tyrsbo esker declines gradually northwards, reaching 155 m a. s. l. at Lövingsborg, where it no longer forms a continuous ridge. The level is governed by the bedrock surface, above which the esker rises *c.* 10 m. A large pit S. of Fridhem shows that the esker core was built up of very coarse material. The core is bordered on the sides by stratified, silty, fine sand, probably occurring in local dammings between the core and the ice.

The level of the Helgeslund esker, 165—172 m a. s. l., also seems to be governed by the bedrock surface, above which it rises *c.* 10 m. A gravel pit SE. of Helgeslund shows a cross-section with a material similar to the Tyrsbo esker (Fig. 65). Also here silty fine sand occurs at the sides. The esker is bordered proximally and distally by vast areas of hummocky moraine (Fig. 66), which N. of Grytbäcken, reach slightly below the HK. East of Helgeslund, towards Opphem and Grytbäcken, an esker network with parallel ridges was formed proximally to the esker. The esker is interrupted by deep valleys S. of Helgeslund and N. of Grytbäcken. These are probably erosion valleys, formed when the stagnant ice remaining south of the esker melted away some time later.

At Grytbäcken the ridge crest quickly sinks from 170 to 154 m a. s. l., which seems to be due to the sloping surface level. Further towards the NE, the ridge disappears completely. A stone-orientation analysis at *c.* 160 m a. s. l. at Grytbäcken (Fig. 67) shows a maximum transversal to the esker. This indicates that the Helgeslund esker was continuously built up as a normal esker by a glaciofluvial stream from the ENE., not as a real transversal esker along the ice margin.

The topographical conditions favoured the development of large areas of stagnant ice in this area and the glaciofluvial deposits were formed in a thin, stagnant, frontzone. The levels of the eskers were governed entirely by the bedrock surface sloping towards the N. and NE. (cf. Persson, 1971, p. 89). The direction of the Helgeslund esker indicates that the ice was drained towards the WSW. not towards the SSE. This is quite natural, as the area to the east is situated *c.* 50 m lower. When the ice in the Tyrsbo area had amalgamated, so that it was not much higher than the ridges, it was still thick in the low land E. of the area. This ice was still active, which means that the hydrostatic pressure was enough to prevent glacial drainage in this direction (cf. J. Lundqvist, 1972, pp. 28—29, 1973, p. 6). Some time later, the water table in the Tyrsbo area was gradually lowered eastwards and no "catastrophic drainage" took place here.

To this account of the deglaciation of the Tyrsbo area may be added some information about the final deglaciation of the Sommen basin. At Enshult, *c.* 13 km SW. of Lake Åsgölen, the dammed water table in the Sommen basin reached *c.* 165 m a. s. l. The synchronous gradient of the ice-lake shorelines discussed in a following chapter (*c.* 0.5 m/km), indicates that the local water table in the Tyrsbo area reached a higher level than the water level in the Sommen basin.

The "Sommen ice-lake" thus never reached this area. A well-developed esker network at Flathult, *c.* 2.5 km N. of Enshult, reaches only *c.* 160 m a. s. l. and the sharp and curving Haddebo esker, 7.5 km NNE. of Enshult, reaches 150—155 m a. s. l. These levels were governed by the bedrock surface, but they indicate a gradual lowering of the water table at the ice margin. This lowering must have taken place eastwards, before the present outlet from the Sommen basin in the Svartå valley became ice-free.

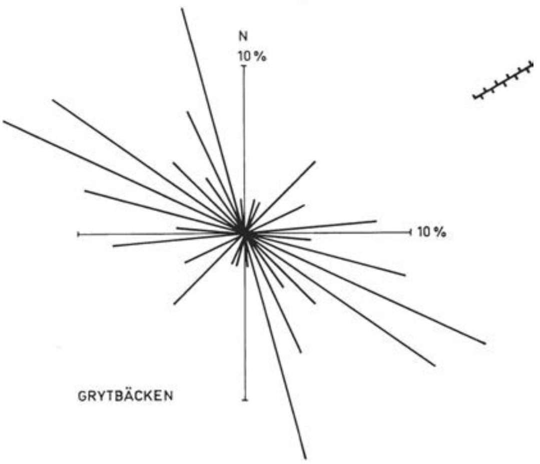


Fig. 67. Orientation of elongated pebbles in the Helgeslund esker, N. of Grytbäcken.

The main part of the meltwater collected in the Sommen basin was discharged through the outlets eastwards all the time until the Svartå valley became ice-free, as is indicated, for example, by the levels of the glaciofluvial deposits in the valley from Boxholm to Strålsnäs. No free water table occurred in the area N. of the present Lake Sommen, which was entirely filled with stagnant ice. The distance between the bottom and the dammed water table seldom exceeded 10 m in this area and thus the dammed water masses were comparatively small. When they were gradually discharged in the irregular terrain eastwards, they were unable to leave any important drainage marks.

THE PERIGLACIAL DEPOSITS

The periglacial deposits in this region are defined as ground structures and soils which were formed by nonglacigenic processes under arctic or subarctic climate conditions. These deposits mainly consist of patterned ground and wind-blown silt.

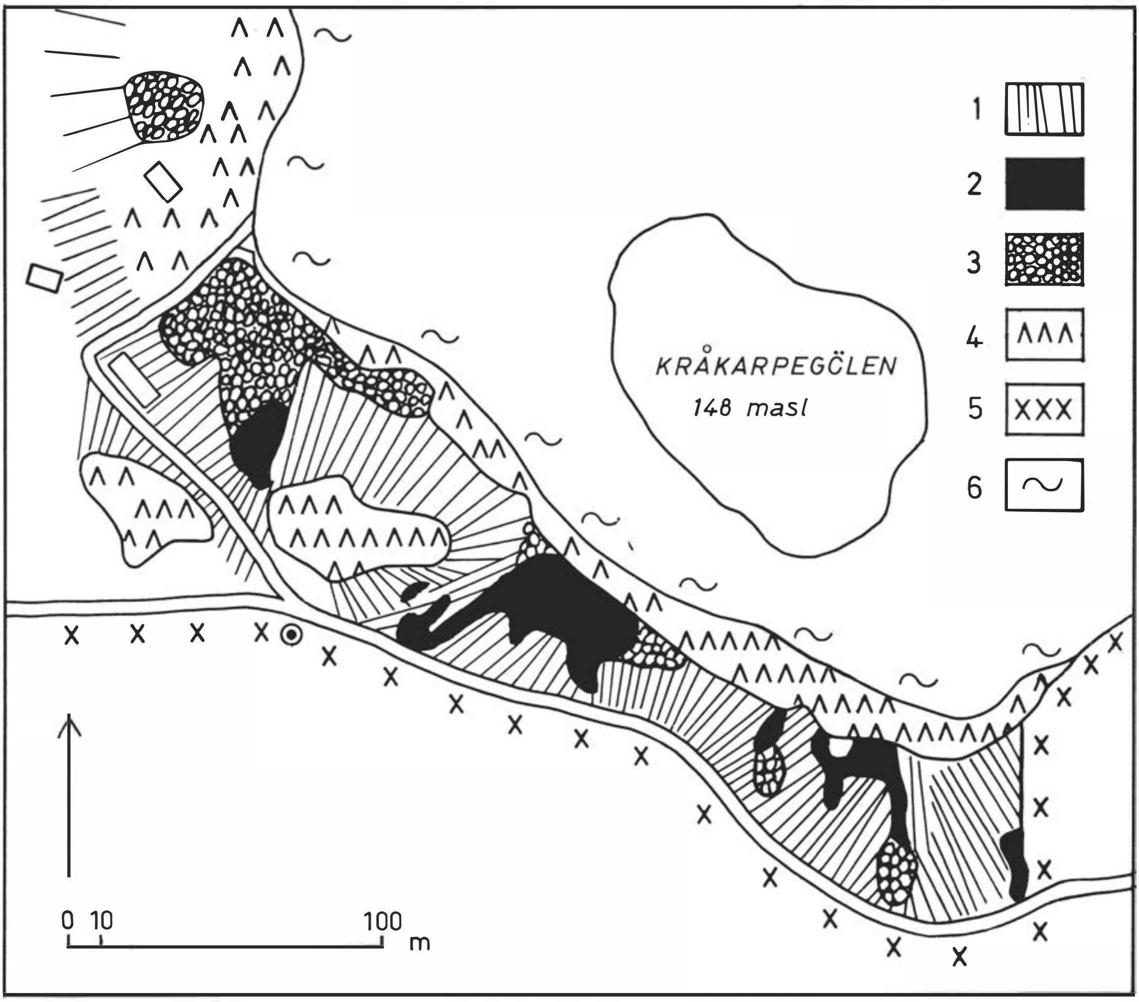


Fig. 68. Periglacial boulder forms at Kråkarp SE. of Lake Ören. 1. Sloping till ground. 2. Boulder accumulation. 3. Till rich in boulders with patterned ground structures. The isolated area in the NW, is shown in Fig. 69. 4. Till ground which has been cultivated. 5. Spruce wood. 6. Peat.

Such deposits have not previously been described from this part of the country. This material has been presented in a separate report by the author (Agrell, 1973 *a*), which sums up two brief reports (Agrell, 1971, Agrell & Hultman, 1971), and thus only a brief summary is presented in this thesis. It must, however, be stated that the identification of the periglacial deposits is of great importance in order to avoid misinterpretation of the objects formed by glacigenic processes.

Patterned ground of supposed periglacial origin, mainly boulder depressions, have been found at nine sites in the investigated area (cf. Agrell, 1971). The main locality is situated at Kråkarp, SE. of Lake Ören, where boulder depressions are connected with welldeveloped sorted streams and net works (Fig. 68, cf. J. Lundqvist, 1962, p. 97). According to Rapp (1967, p. 238), such objects are good indications of fossil periglacial activity. A part of the sorted net work structure was mapped in detail (Figs. 69 and 71) and a digging revealed that this material, which is rich in frost-broken fragments, becomes finer with increasing depth.

Stone-orientation analyses (Fig. 70) have revealed that solifluction has occurred on the steep till slopes in this region (cf. Rudberg, 1958, p.

123). The solifluction identified at the HK has been treated already. The boulder forms are often difficult to identify, because of old cultivation and dense vegetation cover (cf. Rapp, 1967, pp. 237—238).

Wind-blown silt occurs at seven localities — the first to be described from southern Sweden — above the HK in the area (cf. Agrell & Hultman, 1971). The largest accumulation, which was mapped in detail, is situated SW. of the glaciofluvial delta at Svalsjö (Figs. 48, 72 and 73), where the sediments are exposed along a timber trail. This distribution is typical of silt derived from glaciofluvial deposits by winds from the ice during the deglaciation (cf. Hjulström, 1955, pp. 90—91). The material is relatively coarse (fine sand), mainly because the deposits are situated near the source of the material. Wind-blown sand, however, seems to be completely lacking in the area.

Large talus fields were found at four sites on steep slopes of leptite rocks (Fig. 74). Some recent activity still occurs on the talus slopes, but large trees show that most of the material is fossil (cf. J. Lundqvist, 1962, p. 77). The doubtful structures sometimes found in the excavations in the glaciofluvial deposits can be explained in other ways and it is not certain that they indicate periglacial processes.

The periglacial deposits were probably formed under arctic or subarctic conditions during and shortly after the deglaciation. They thus indicate a cold climate with tundra vegetation during the deglaciation.

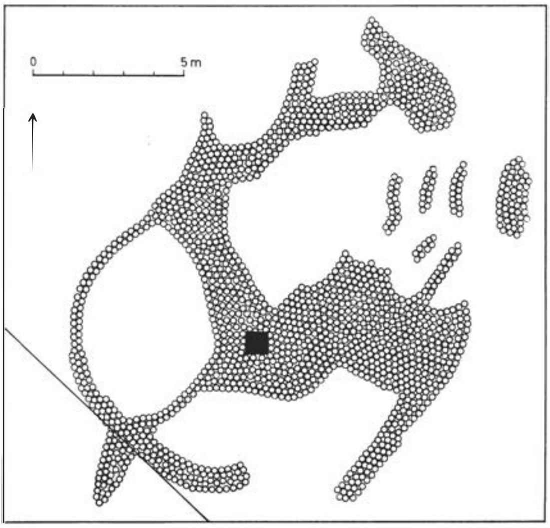


Fig. 69. Sorted network structure at Kråkarp. Digging at the black spot.

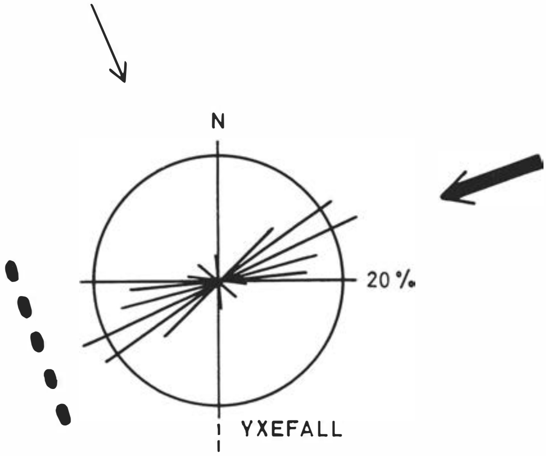


Fig. 70. Orientation of elongated pebbles near the surface in a till slope NE. of Yxefall. A boulder front occurs at the lower end of the slope.

Fig. 71. Fossil patterned ground at Kråkarp, the same site as Fig. 69.

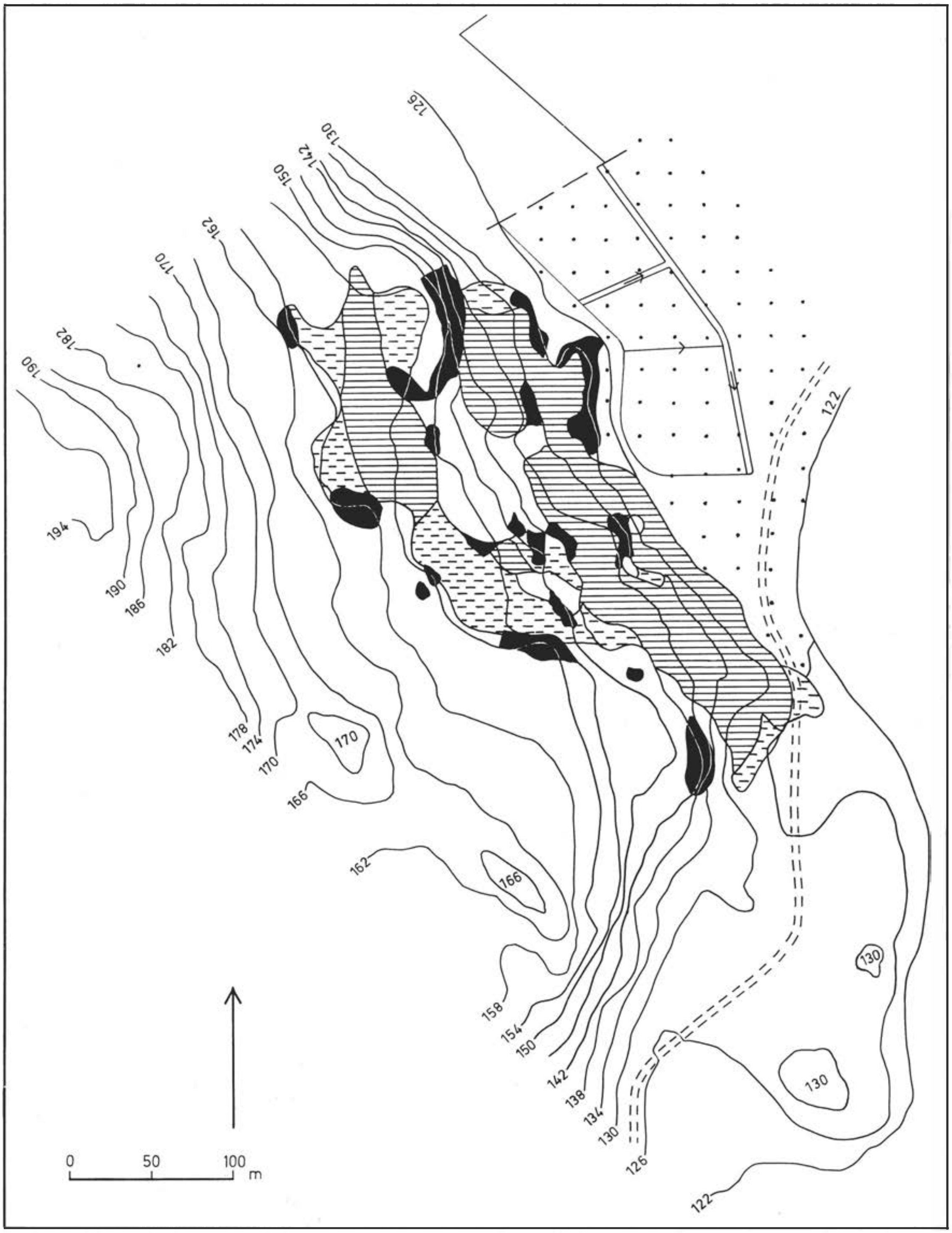


Fig. 72. Wind-blown silt in the till slope SW. of the glaciofluvial delta at Svalsjö (the position marked on Fig. 48). Solid black: exposed bedrock; stripes: wind-blown silt, thickness exceeding 0.5 m; dashed lines: thin cover of wind-blown silt. The level curves with 4-m intervals, according to a photogrammetric map made by RAK in 1970. Mapping by Rolf Hultman in 1970.

Fig. 73. Wind-blown silt SW. of the glaciofluvial delta at Svalsjö (photograph by Rolf Hultman).

Fig. 74. Talus slope in leptitic bedrock N. of the rock gorge at Lillören.

Fig. 75. Cobble wall a little below 120 m a. s. l., S. of Krogsfall and W. of Lake Järnlunden.

THE SHORE-LEVEL DISPLACEMENT AND THE CHRONOLOGY OF THE DEGLACIATION

The problems of the shore-level displacement and the chronology of the deglaciation have not been studied in detail during this investigation. This chapter is thus mainly a discussion of results obtained by other authors, which must be presented as a background for the final discussion of the deglaciation.

The shore-level displacement

In some of the profiles across the wash limit, distinct shore marks at slightly lower levels have been noted. From the Törnevik area, Cato & Lindén (1973, p. 34) describe a distinct shore level represented by wave-cut terraces and cobble walls 116—118 m a.s.l. (Fig. 75). Some glaciofluvial plains have been abraded to a level below the HK, for example, 117 m a.s.l. at the former railway station in Slätmon. However, it has not been possible to connect these scattered observations with synchronous stagnation levels of the Baltic ice-lake. Nilsson (1953, p. 242) presents a large number of shoreline observations from this region with gradients a little above 0.6 m/km (Pl. 1). All the shoreline observations made by Nilsson in this area seem to be quite hypothetical.

The amount of shore-level displacement can be calculated by different methods and often the deposition of glacial clay is used. At Nygärdet, N. of Kisa, a clay sequence containing 434 varves was measured by Nilsson (1968, Pl. V). The locality is situated *c.* 107 m a. s. l. and the HK cannot have exceeded 130 m a. es. l. The shore-level displacement at this locality cannot exceed 5 m/100 years, as at least 434 years must have passed for the shore level to sink from 130 to 107 m a. s. l. This is a low figure compared with the results obtained by Hörnsten (1964, p. 191), who estimated the uplift of land in the coastal area of Ångermanland as 11—13.5 m/100 years. The ice recession in this area is *c.* 300 m/year (Hörnsten, 1964, p. 193). In eastern Blekinge, Ringberg (1971, p. 90) has obtained a rate of shore-level displacement of about 6—7 m/100 years and the ice recession in this region was estimated at *c.* 100 m/year (Ringberg, 1971, p. 95). These investigations indicate that the rate of ice recession in the investigated area was comparatively small.

When the shore-level displacement and the rate of ice recession are approximately known, the gradient of the oldest synchronous shorelines can be estimated. As the ice recession cannot have exceeded 100 m/year (1 km/10 years) (cf. below) and the shore-level displacement was not more than 0.5 m/10 years, this gradient cannot have exceeded 0.5 m/km over longer distances (cf. the gradients of 0.3—0.4 m/km for Post-Glacial time calculated by Sundelin, 1917, pp. 86 and 155. It may be noted that the gradient of the Vimmerby ice-lake, from the outlet at Solnehult to the glaciofluvial plains near the southern border of the area, reaches approximately this value. Björnsson (1940, p. 65), however, suggests a much steeper gradient, 1.2 m/km, for the shorelines from the older Sommen ice-lake. This estimate is supported by Nilsson (1968, p. 65). The pass levels and plains of the Sommen basin, however, exclude gradients much steeper than 0.5 m/km and it is possible that Björnsson has misinterprested lateral wash zones as shore marks.

The metachonous gradient of the HK, 0.4 m/km, is steep compared with this synchronous gradient. This may indicate that the ice recession proceeded at a steep angle to the isobases of land uplift, which means that the Åsunden valley quickly became ice-free from the east at a time when stagnant ice still remained further to the west. The level differences of the objects plotted on the distance diagram, Fig. 27, support this statement. They indicate that stagnant ice remained for *c.* 100 years in the inner part of the valley from Kisa to Lake Sommen, when the corresponding levels along Lake Åsunden were ice-free.

The varve chronology

Morphological indications on the rate of ice recession, such as esker ridges with mounds, systems of glaciofluvial channels and systems of transversal accumulation ridges are almost entirely lacking in this area. The only transversal till ridges found below the HK cannot be used as indications of the ice recession. Björnsson (1937, pp. 99—100) estimated the distance between esker mounds in the southern part of the Sommen basin at *c.* 100 m, which he supposed to indicate the yearly ice recession. However, no morphological indications of the ice recession are expected to be found in a region where the last phase of the deglaciation was characterized by large masses of stagnant ice.

In the low land along the river Stångån and Lake Åsunden, glacial clay with well-developed varves was deposited during the deglaciation (Fig. 76). The thickness may exceed 10 m and several hundreds of varves may occur in a single profile. The progress of the deglaciation, with numerous outlets from ice-dammed areas, has, however, influenced the clay sedimentation. This makes varve connections over wide areas uncertain, especially between localities situated in separated sediment basins.

At the beginning of the century, varve measurements were made by Dr. R. Lidén in the numerous clay pits along Lake Åsunden. This material, which was collected by Professor G. De Geer, was never published, but it is briefly referred by Sundelin (1917, p. 90). The average ice recession from Horn to Rimforsa was supposed to be almost exactly 100 m/year. As I supposed in the preceding section the ice recession may have been directed to the W. and thus the connection between the localities was made at steep angles to the ice front. The real rate of ice recession may thus have been a little slower. In the Ukna valley, E. of the area, Sandegren (1926, p. 63) obtained a recession rate of *c.* 85 m/year and these connections were made at right angles to the ice margin. Slightly N. of the area, Kristiansson (pers. comm.) has estimated by foil core sampling a recession rate of between 80 and 100 m/year.

Nilsson (1968, Pls. I and V, pp. 14—15, 104—105 and 109) made three varve measurements with a foil core sampler in this region. The localities are situated at Älö clay pit, slightly S. of the area, Nygärdet clay pit, N. of Kisa, and the former clay pit between Hackel and Hallstad, NNW. of Rimforsa. The distant connections between these three localities seem very dubious, which is to be expected in this region (cf. above). The varve measurements made by Nilsson are of little use for a reconstruction of the ice recession in this region.

The varve sequence at Rimforsa has been remeasured in a new excavation (Fig. 77). The "drainage varve from Tyrsbo" (cf. the preceding chapter) was easily re-found and it consisted of three varves situated *c.* 43 varves above the bottom. At this time, the Tyrsbo area must still have been covered with ice and the varves probably represent the final lowering of the dammed water table in the Drögen basin at Viggedal (cf. Fig. 18).

Nilsson (1968, p. 15) suggests that the Taberg re-advance, indicated by the delta at Malexander, took place in the investigated area, but no signs of a re-advance (or stagnation) of the ice-front have been found during this investigation. Nilsson considers this re-advance to have occurred in Late Alleröd time, while Mörner (1970, p. 11) states that this occasion formed the beginning of the Younger Dryas stadial. South of the area, a supposed stagnation of the ice margin at Vimmerby has been investigated by Friberg (1955, unpublished). For 100 years the ice recession may not have exceeded 25 m/year (Friberg, 1955, p. 30), as is indicated by the varved clay. Similar observations, made by R. Lidén, are referred by Sundelin (1917, p. 156). North-west of Vimmerby, the large delta, mapped by Friberg, is bordered to the north by till ridges, which cover glaciofluvial material (Agrell, 1973 *c*, p. 11).

The stagnation at Vimmerby might correspond to the Taberg re-advance (ibid.) and, if this suggestion is correct, the area investigated was deglaciated during Younger Dryas times. The varve chronology indicates that the rate of ice recession was 80—100 m/year without regional stagnations or re-advances. A slow rate of ice recession in a cold climate is also indicated by the vast glaciofluvial deposits, the periglacial activity and the slow rate of land uplift. No years for the deglaciation can be presented, as the connection between the Taberg re-advance and the present time is being revised (Mörner, pers. comm.). It must, however, be stated that the recession lines presented by Nilsson (1968, Pl. I) probably have to be corrected by several hundreds of years.

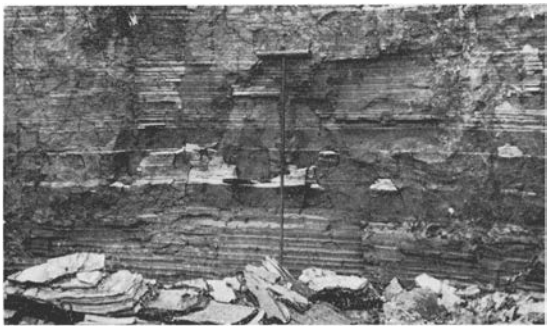
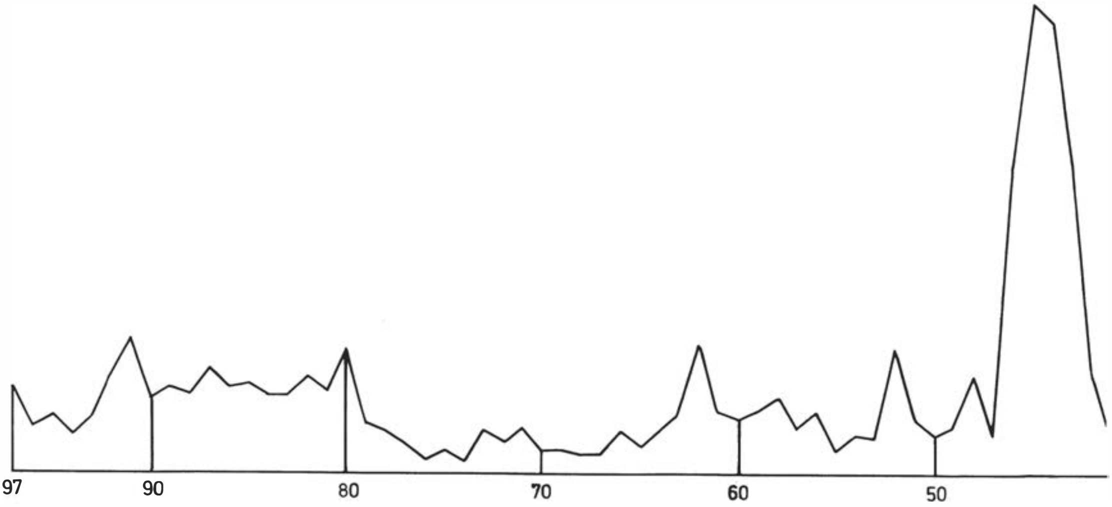


Fig. 76. Varved glacial clay SW. of the railway station at Rimforsa. Note the three thick "drainage varves" (cf. Fig. 77).

SOME FINAL REMARKS

The general principles of deglaciation in the Fennoscandian glaciation area have been treated by a large number of authors in studies covering limited regions. Although several general aspects are discussed in this chapter, it is impossible to give references to all the important works dealing with the same type of problems. J. Lundqvist (1973) has presented the most up-to-date work on deglaciation problems in Sweden. In all important points, the morphological classification (pp. 6—13) and the genetic discussion (pp. 151—163) presented by Lundqvist can be applied to the deglaciation of the investigated area. The general morphological classification and conclusions by Mannerfelt (1945, pp. 8—27 and 211—218) also form an important base for the following discus-



sion. It may be pointed out that the conclusions presented here are valid only for the Sommen-Åsunden region, although in the author's opinion, they may be applied to most other parts of the southern Swedish Uplands.

In this region, the moving ice mass had a selective influence upon the present surface. The valleys parallel to the ice-movement were strongly eroded, but on higher levels pre-glacial disintegration material could be preserved. The ice seems to have been poor in till, as exposed bedrock predominates in the area. On the bedrock surface sloping in the direction of the ice-movement, the till accumulated as pre-crags around bedrock knobs. Hummocky moraine regions were formed in sheltered positions. The glacial striae indicate the ice-movement in the basal parts of the ice, where it was slightly deflected by the valley directions. The large till ridges give a better indication of the main ice-movement. No local striae, indicating active ice lobes in the valleys during the deglaciation, have been found.

Most authors dealing with the deglaciation in the southern Swedish uplands state that the accumulation forms from the deglaciation indicate a stagnant margin zone of the ice. This statement is fully confirmed in this region. The valley bottoms were filled with glaciofluvial material of variable composition. Transitions between till and coarse glaciofluvial gravel ("ablation gravel") are common in sheltered position.

The glaciofluvial planes are more or less bordered by ice-contact slopes. The general stratigraphy starts with a coarse, subglacially formed, bottom layer, covered by the main layer of horizontally stratified sand and coarse silt. This material was deposited in an open water table surrounded by the ice. Finally, the body of water was entirely filled with sediments, which were covered by

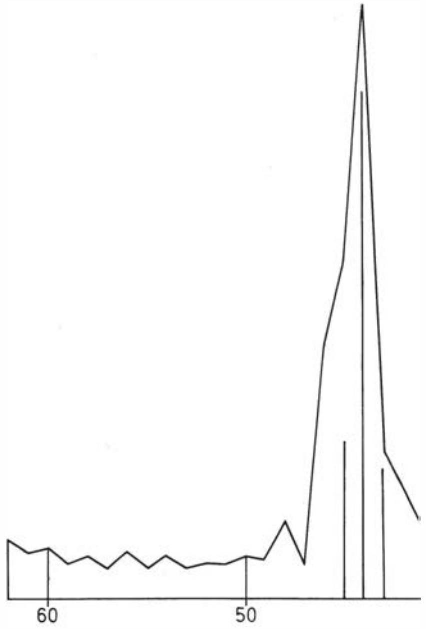
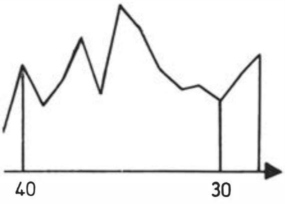


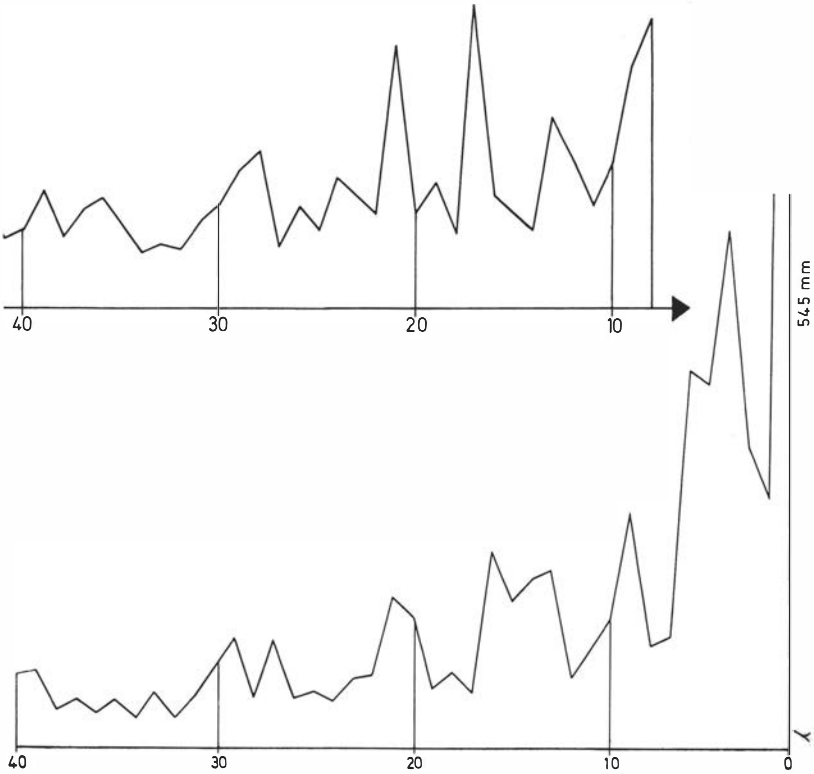
Fig. 77. Varve diagrams from excavations in glacial clay SW. of the railway station at Rimforsa. The three "drainage varves" are connected with the bottom varve. The varves in the figure show about half the natural thickness.

coarse, stony-gravelly material up to the level of the ice surface (cf. Norrman, 1971, p. 224, J. Lundqvist, 1972, pp. 32—33). Drainage channels on the surface have in most cases been destroyed by cultivation. Other types of plains, more similar to common "deltas", were formed under special conditions, for example, the plains built up to a free water table at the HK.

The eskers are of two different types. Small and short ridges with curving directions, often appearing in net works, are built up of stratified sand. These eskers must have occurred as crevasse fillings in stagnant ice (cf. Mannerfelt, 1945, for example, pp. 25, 148 and 196). The other esker type is built up of coarse, stony material of larger dimensions. For topographical reasons also, these ridges must have been built up in a thin, stagnant ice sheet. The supply of material seems to be the only reason for this difference in material composition.

On higher, freely exposed levels, glaciofluvial deposits are almost totally lacking. The only exception is the Misterfall area (Fig. 37), where





the deglaciation conditions were very special. This fact indicates that the glacial drainage took place subglacially already as the highest peaks in the area became ice-free. Subglacial drainage of this extent can only have occurred in a stagnant ice mass. The lack of lateral erosion forms and shorelines from nunatak ice-lakes also indicates subglacial drainage (cf. Mannerfelt, 1945, p. 16). In the higher-situated till slopes, only subglacial chutes were observed. All the accumulation forms are situated in the lowermost part of the area. To some extent, however, this fact is due to the abundance of the exposed bedrock. In sheltered positions, the till is often strongly abraded by glacial meltwater, forming real boulder fields. Such boulder deposits have often been misinterpreted as indications of the highest coastline (Fig. 78).

No real, open ice-lakes could be formed under such conditions. This is confirmed by the almost total lack of fine sediments above the HK (cf. G. Lundqvist, 1942). Dammed water tables, however, occurred around the melting ice margin in the valleys, as is indicated by the levels of the glaciofluvial deposits. Where the dammed bodies of water were lowered at topographic pass points, forms similar to real ice-lake outlets could be created. At many pass points, however, the drainage must have been entirely englacial, as no morphological indications were observed. The only distinct ice-lake shoreline found in the entire area is situated immediately N. of the main outlet from the Sommen basin (Fig. 43).

The surface forms were the main factors governing the formation of vast areas of stagnant ice. This is especially obvious where a low area proximally rises to higher elevation, for example, in the valley system from Kisa to Lake Sommen. The ice almost ceased to move when it became thinner than c. 30 m (which is obvious from many observations at recent glaciers) but, when loaded with till, even a thicker ice may become stagnant. The extent of the stagnant areas also depends on the marginal slope of the ice surface. This is very difficult to estimate, especially in this region where lateral channels are lacking. Many investigations of deglaciation problems, even by modern workers, do not deal at all with this problem. In this region, the slope and the position of the icelake outlets indicate that also the stagnant frontzone as a rule sloped in the direction of the last icemovement (cf. J. Lundqvist, 1973, p. 63).

Fig. 78. Lateral abrasion in a till slope *c.* 175 m a. s. l. at Vadstugan, N. of Lake Hemsjön.

When objects indicating stagnant ice, for example, esker net works, were formed at a site, the connection with the active ice may have been broken by the surface forms. Some approximate calculations of the extent of the stagnant zone can be made, for example, in the Tidersrum and Gullringen valleys. It seems probable that the marginal slope of the active ice did not exceed 10 m/km (cf. Hillefors, 1969, p. 265), but it is not impossible that the marginal ice surface was even flatter (cf. Gillberg, 1956*b*, p. 428, where a slope of *c.* 3 m/km is suggested at the western border of the uplands). In the isolated areas of stagnant ice, the surface might have been rather flat. The lateral accumulations, however, indicate that the slope cannot have been less than *c.* 3 m/km.

The general progress of the deglaciation in the Sommen-Åsunden region, by the isolation of large areas of stagnant ice in the valleys, was pointed out by Björnsson (1937, p. 100). The stagnant ice margin must have been very irregular, with ice-free rock areas between ice-covered valleys. The surface forms and the supposed slope of the ice margin indicate that the stagnant zone was approximately *c.* 10 km wide. The glaciofluvial deposits in the valley bottoms were often finally built up outside the continuous ice margin (cf. Hörnsten, 1964, p. 188) and this explains the irregular distribution of the glaciofluvial material (cf. Ringberg, 1971, pp. 63, 65 and 67).

Of course, synchronous ice margins and lines of ice recession cannot be reconstructed in an area with this type of deglaciation pattern. The inland valleys, for example, were covered with stagnant ice for at least 100 years after the subaquatic lowland in the Åsunden basin became deglaciated. Only where a detailed net work of levelled objects is available is it possible to estimate the synchrony between different valleys and pass levels. When the objects indicating the deglaciation are lacking, the suggested development must remain hypothetical.

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MAPS USED IN THE INVESTIGATION

Geological survey maps

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Topographical maps, scale 1:100 000

No. 36 Vimmerby (1948) and no. 45 Linköping (1926).

Topographical maps, scale 1:50 000

No. 6 G Vimmerby NV (1967), 7 F Tranås SO (1966), NV (1965), NO (1965), 7 G Västervik SV (1966), NV (1966), 8 F Linköping SO (1965).

Economical maps, scale 1:10 000

No. 7 F 5 *f* Svenningeby (1948), 5 *g* Misterfall (1948), 5 *i* Råstorp (1947). 6 *f* Örsebo (1947), 7 *f* Måla (1947), 8 *f* Ulrika (1948), 9 *f* Solltorp (1948), 9 *i* Rimforsa (1949).

Aerial photographs, scale 1:30 000

68 *Ff* 068 nos. 13—21, *Fg* nos. 8—22, *Fh* nos. 7—24, *Fi* nos. 4—19, *Fj* nos. 4—15. (The photographs were taken in 1968.)