Deglaciation models from the Swedish West Coast

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Deglaciation processes within different rock relief types are discussed. The lower parts of the fissure-valley landscape in western Sweden were covered by the late-glacial sea at deglaciation, while the rock plateaux between the valleys formed an arctic archipelago. The glacial movements, deposition activity and recession were intimately dependent on the variations of the topography and on the buoyancy of the seawater in the valleys. The opinion that a piedmont glaciation existed in eastern Halland during the deglaciation stage has been corroborated concerning areas above the marine limit. In the valleys below this limit the ice margin, however, was straight or slightly concave. The western part of the South Swedish Highland, situated high above the marine limit, is characterized by a zonal deglaciation; zone by zone of the ice margin was detached from the actively moving ice and became immobile. Subglacially formed eskers appear together with glaciofluvial deltas which formed extramarginally in ice-dammed lakes. The moraine forms are often dominated by 1–2 km long drumlins with rock cores. Where the ice diverged over a convex bedrock basement, Rogen-like moraine ridges, radial as well as transverse, were formed during the deglaciation stage when the ice was stagnating.

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During recent decades a great deal of interest has been concentrated on the deglaciation pattern and the dating of ice recession in western Sweden. Some old and new models of deglaciation mechanics will be presented.

Piedmont glaciation in Halland

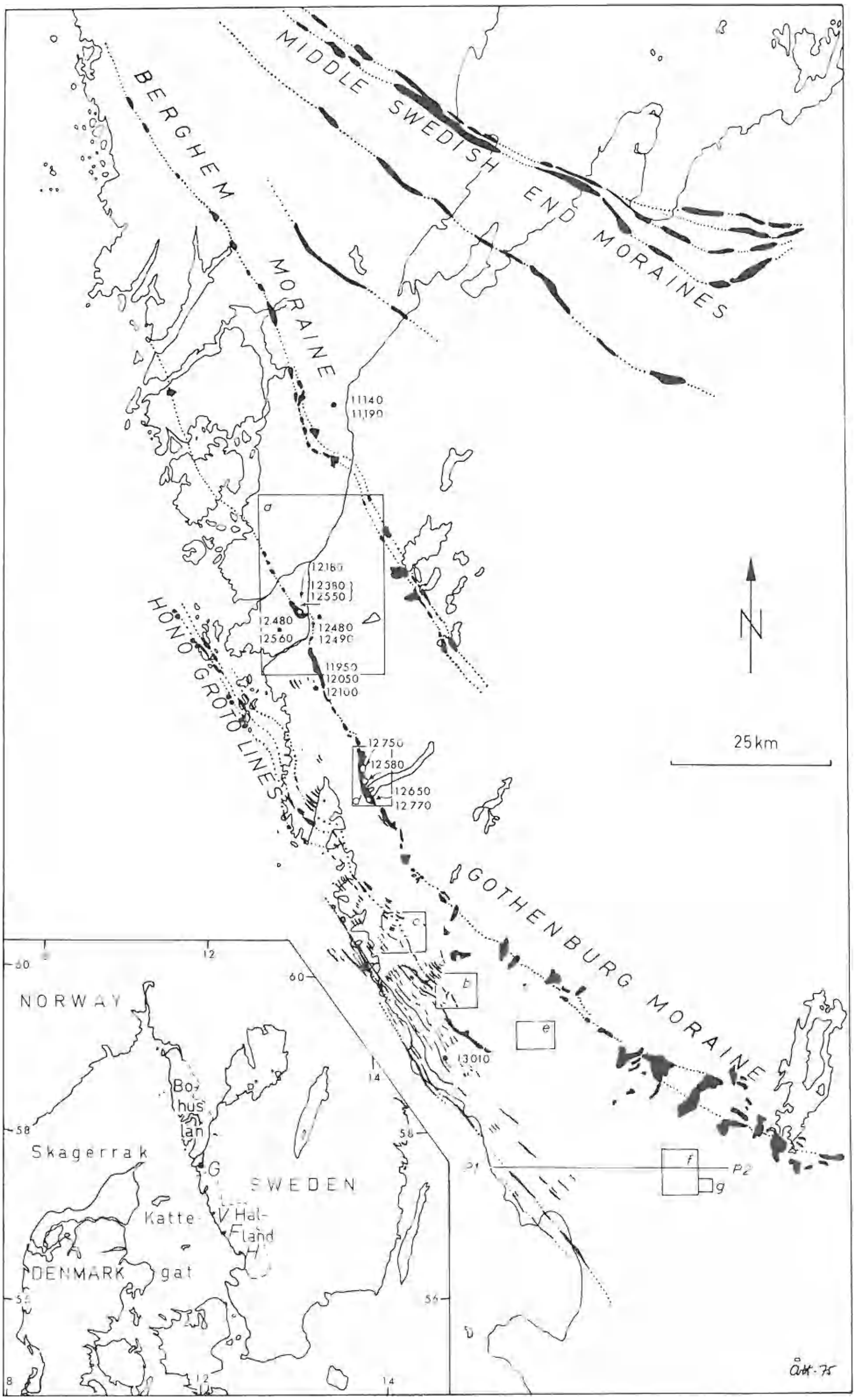
Von Post (1938) found anomalies of the highest marine limit in the Viskan fjord valley. He based the idea of the 'Ice Alps in Western Sweden' (Sw. *den västsvenska isalpen*) on these observations. Caldenius (1942) stated that amphitheatre-like end moraines existed at certain valley mouths and along some valley sides in the Dagsås and Torpa areas. This was later reiterated by Caldenius (1960). New maps of both areas were presented with supposed end moraines of piedmont glaciers in eastern Halland, flowing down the valleys from the South Swedish Highland.

The opinion that valley glaciers existed in western Sweden, where the ice ended in the late-glacial sea, was also expressed by Björsjö (1949), and by Wenner (1952). Gillberg (1956) described the deglaciation in western Sweden, especially within the northwestern part of the South Swedish Highland, and expressed the opinion that valley glaciers flowed down from the ice sheet in the northeast. More recently Mörner (1969) put forward the idea that valley glaciers penetrated long distances from the ice sheet into, among others, the Göta River valley, the Lärje valley, and the Viskan valley. Wedel (1971) agreed with the same fundamental opinion.

Calving bays in the fjord-like valleys and on the coastal plain in Halland

Johnsson (1956) found that in the Gothenburg area the ice moved down the valley sides during the final deglaciation stage and that the ice margin formed calving bays within the fjord-like valleys. The same deglaciation pattern and ice movement development had been suggested by Gjessing (1953), for the Oslo Fjord area. Hoppe (1948:38–41) had pointed to the importance of the water depth in the formation of an ice cliff and the calving from this cliff within the lower coastal regions of Norrbotten, northern Sweden.

Johnsson's investigations formed the basis for further studies by the present author (Hillefors 1969). I mapped the 'general' ice movements, documented by the dominating older inframarginal striae from about NE–ENE, and the younger deviations during the final deglaciation stage, indicated by submarginal striae from about NNE or E–ESE, in southern Bohuslän,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western Västergötland and northern Halland (Figs. 1 and 2). Relief of the rock basement was very significant as regards ice movements during the deglaciation. The *Kammwasserscheiden* thus play the role of 'ice divides' on the plateaux. The deviations are directed towards the lower areas on both sides of these water divides. The ice movements have converged toward the fissure valleys, which had approximately the same direction as the main inframarginal ice movement.

Ice border formations of different geneses and material indicate that the ice formed calving bays in the fjords and fissure valleys. The long coherent ice marginal lines are perpendicular to the inframarginal striae. The submarginal striae are at the same time perpendicular to the ice contacts of frontal deposits (Fig. 3).

The causes of this deglaciation model are the effects of the water depth in the sea, in which the ice ended, and the meltwater streams in layers and channels at the interface between the ice and the rock basement.

The water within the late-glacial valleys in northern Halland and in Bohuslän has often reached a depth of a hundred metres, generally lower in the south and greater in the north because of the uneven downpressing by the ice. In some of the largest valleys, e.g. the Göta River valley, the water depth could be 150 m or more. As the land surface slopes towards the west (the coastal flexure) the water depth decreases to the east. The fissure valleys, however, also continue above the highest limit of the late-glacial sea. In regions such as these, other modes of deglaciation have developed (see below).

The water depth of the sea has affected the ice by its buoyancy effect (Fig. 4). This caused the ice front to crack parallel to the margin. In the zone between the valley ice and the ice upon the rock plateaux there was a heavy shearing caused by the difference in movement velocity of the ice masses. Consequently the bedrock in the valleys as well as within the plateaux was characterized by topographic irregularities, ridges, hills, basins, hollows, etc., which also caused crevassing in the ice. Thus calving of the valley ice could be intensive, especially where this ended in deep water basins 'behind' rock thresholds. This also helped the ice debris to flow away from the ice cliff so new blocks of ice could loosen. Catabatic winds, here directed from the east towards the west, could have carried the calving ice away from the ice cliff, so that the delivery of new ice blocks could continue unhampered.

Meltwater streamed downwards through the ice and met basal meltwater, and together both meltwater masses found their way to lower and lower levels. So there could quite definitely have been fairly large quantities of meltwater within the marginal zone of the valley ice, particularly in the basal layers during summer seasons. This meltwater contributed to breaking up the ice by enlarging crevasses and widening subglacial meltwater channels, especially those located in the shearing zones along the valley sides.

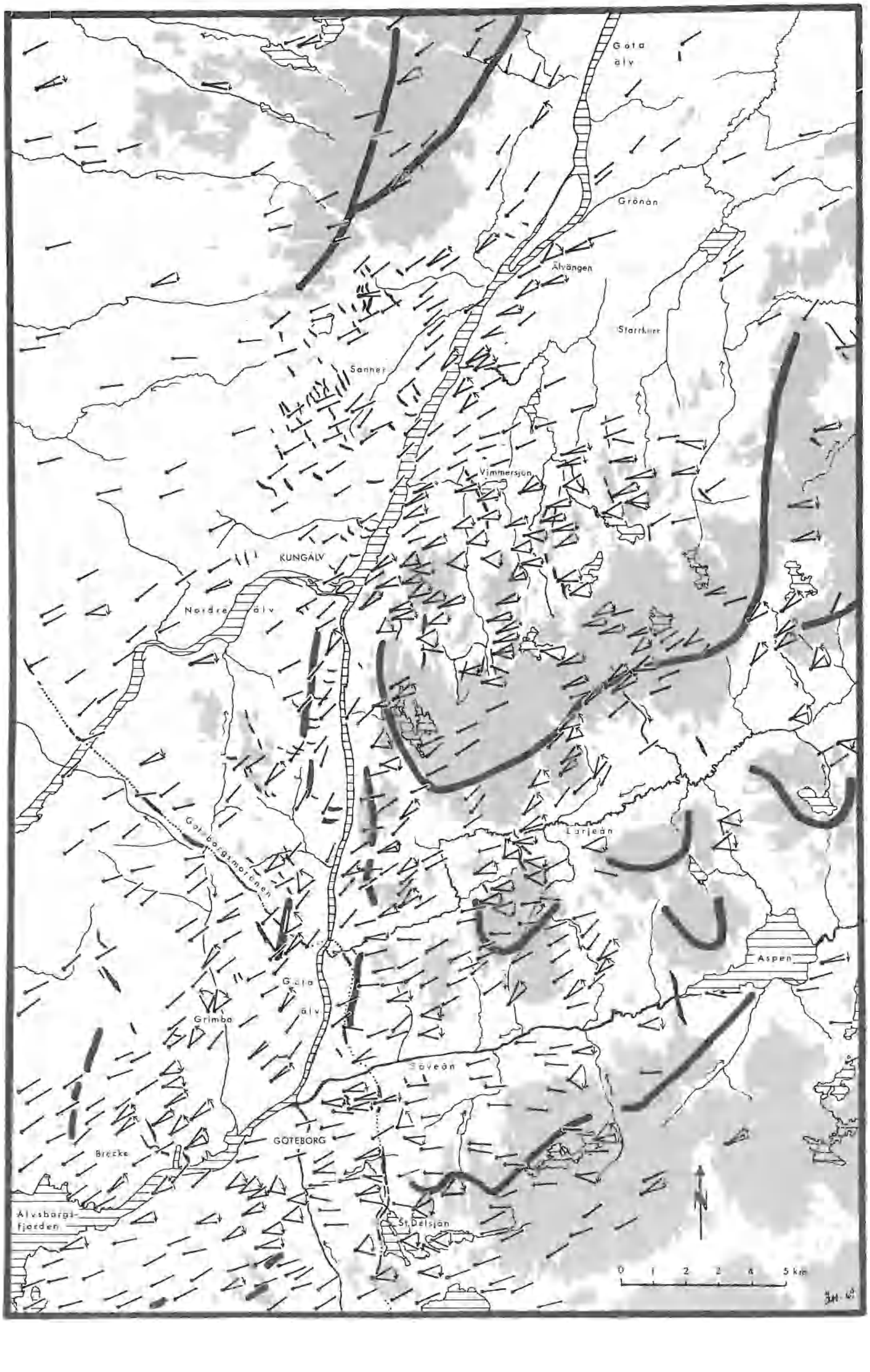
Below large areas of the ice masses moving down the fissure valleys, especially those fairly parallel to the general slope of the land surface, an extended sheet of meltwater streamed toward the sea, here and there concentrated to tunnels and channels, particularly during the melting season. This subglacial meltwater was under high hydrostatic pressure, higher than that of the sea water. It has actively contributed to the calving and breaking up of the ice.

Within the fissure valley landscape in Bohuslän, western Västergötland and northern Halland the late-glacial sea could inundate parts of the rock plateaux, but the water depth was about 10–20 m with the heights forming low islands.

The large quantities of meltwater at the interface between the ice and its rock basement caused the ice in the valleys to move with a high velocity in relation to conditions on the plateaux. Thus the fissure valleys acted as draining channels for the ice masses. Such 'jet streams' in continental ice sheets are known from Antarctica and Greenland.

Upon the rock plateaux with structure valleys and ridges and hills in about a N–S direction, the shear strains within the basal layers of the relatively thin ice were considerably greater than down in the valley bottoms where the uplift of the seawater lowered the shear strains. The content of far-transported material in the till is much higher in the valleys than upon the plateaux.

Fig. 1. Map of western Sweden with ice-marginal lines. For framed areas see detail maps. (a) the Gothenburg area, Fig. 2 (and 3); (b) the Dagsås area, Fig. 5; (c) the Torpa area, Fig. 6; (d) the Fjärås bräcka and Svedaskogen area, Fig. 7; (e) the Sjönevad–Sjösgärdesjö area, Fig. 9; (f, g) the Esmared and Härsängaryen areas, Figs. 12 and 15. Profile P1–P2, see Fig. 16. – ^{14}C-datings have been marked (cf. Fig. 8).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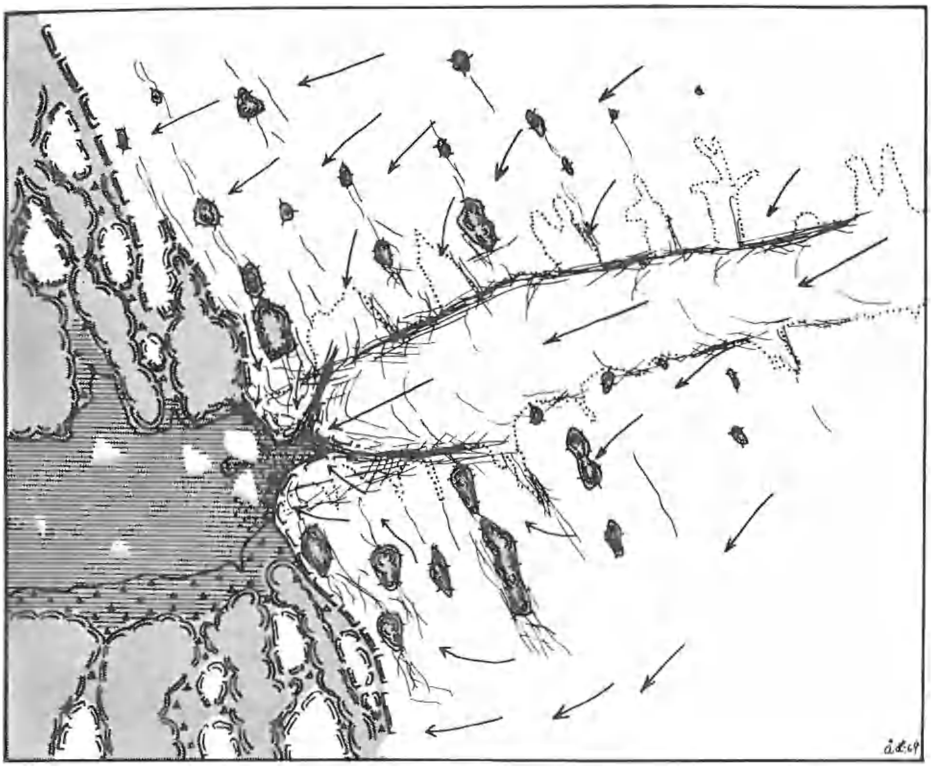

Fig. 3. Sketch map of the presumed appearance of the ice border during deglaciation within the fissure valleys below the marine limit (shaded area) in western Sweden. On the whole the model is derived from the Lärjeå valley and a reconstructed position of the ice border at the formation of the Äspered–Gunnilse ose. From two converging feeding eskers a glaciofluvial deposit was formed in a constriction of the fissure valley. The arrows show the direction of ice movement, more precisely in the striating basal layers of the ice. Icebergs are floating away in the fjord. On the southern side, turned towads the ice movement, till has accumulated. The northern side is characterized by ice-plucked precipices.

The content of Hunne-diabase, a local indicator rock type, makes up about 5–10% in the northern parts of the Göta River valley but less than 1% upon the plateau to the west nearby. The valleys have functioned as draining channels for the ice.

The greater shear strain rates upon the plateaux and much lower shear strain rates in the valley bottoms have also resulted in the ice surface forming cupolas over the rock plateaux and troughs over the valleys (see Fig. 4c). These conditions are also reflected in the ice movement patterns, shown by the striation and indicating that the ice converged towards the valleys from the plateaux. Within the shallow basins on the rock plateaux, where lakes and bogs now occur, more motionless ice blocks were situated and with the continuous thinning of the ice they transformed into completely dead ice masses.

This deglaciation model has been tested within the areas investigated by Caldenius (1942), Wenner (1952) and Mörner (1969).

The results of these tests can be seen in Figs. 5 and 6. In his mappings, Caldenius only considered the glacial deposits. It is not easy to find glacial striae within the Dagsås area, which is very rich in till and glaciofluvial deposits. Nevertheless some observations of striae were possible. Within the Torpa area both striae and

Fig. 2. Map of ice movements in the Gothenburg area and in the southern parts of the Göta River valley. The bow-bent arrows show the age relationship between different generations of striae. The long thick lines denote the watersheds of the rock massives. Shaded area is situated above the marine limit (M.L.). The convergent movement of ice towards the large fissure valleys was more pronounced the longer the thinning of the ice continued. Note the course of the Gothenburg Moraine – an ice bay in the Göta River valley.

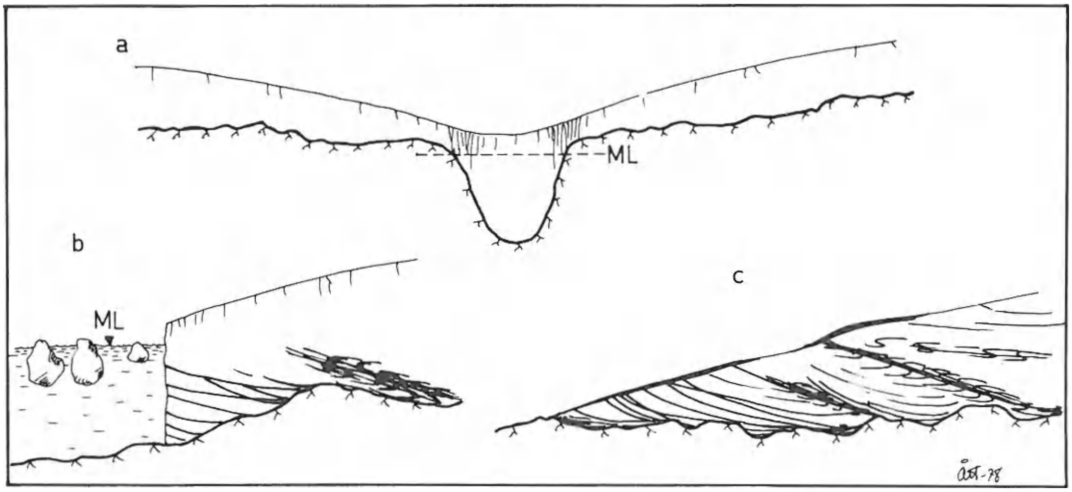

Fig. 4. Profiles of the ice terminus within the fissure-valley landscape (see Fig. 3). (a) A cross profile (M.L. = marine limit). The ice sheet is separated into one fast-moving stream in the valley with heavy crevassing in zones along the two valley sides towards the ice on the rock plateaux (b) Profile of a calving ice cliff with shear zones within the ice front; the buoyancy of the seawater causes the ice to flow relatively fast because of decreased shear strain rates at the interface between the ice and the rock basement. (c) Profile of a tapering snout of the ice sheet upon the rock plateaux; high shear strain rates within the basal layers of the ice cause this to move slowly and shear plains to develop, so till could be transported up to the ice surface and form ablation till.

end moraines show that the ice here formed calving bays instead of valley lobes. Caldenius has connected transverse and radial form elements, like end moraines and drumlins, into ice border lines. From these elements he concluded that the ice-border formations consisted of amphitheatre-like end moraines, indicating piedmont glaciers advancing from the high bedrock plains in the east downwards to the coastal plain in the west. The conditions within the Dagsås area are the same where glacial morphology is concerned. However, Caldenius has not noted the remarkable drumlins. Obviously he interpreted them as lateral moraines.

Mörner (1969:pl. 3) has not analysed the ice movements, neither has he discussed the mechanisms of the deglaciation. The ice marginal lines, showing ice tongues ending in the sea and advancing long distances from the main ice sheet down into the fissure valleys, seem to have been drawn from the old mappings of Caldenius and Wenner.

The Gothenburg Moraine

Here only the main stages of the formation of the Gothenburg Moraine will be discussed, mainly illustrated by the two largest formations, Fjärås bräcka and Svedaskogen (cf. Hillefors 1975, 1977).

Fjärås bräcka consists of a transverse ridge, the base of which was formed during the gradual retreat of the ice from which several meltwater streams debouched simultaneously. These streams found their way along the steep sides of the fjord-like Lygnern valley. At this stage deposition took place at the mouth of the Lygnern valley, where the rate of ice retreat gradually decreased, so the deposition of sand and gravel continued for a relatively long period. The valley drained large ice masses, and the bedrock of the valley itself contributed considerably to the debris content in the ice sole, which was washed by the subglacial water streams. This explains the huge quantities of sand and gravel in the ridge. The tunnel mouths were gradually forced toward the centre of the valley as the deposition continued. The fjord-like valley was consequently finally dammed (Fig. 7).

Then an ice-free stage set in, and varved clay was laid down. The ice was surely not far away. After that the ice readvanced, pushing sand and gravel, clay and till into end moraines which now cover the glaciofluvial basement, which was glaciotectonically disturbed in its uppermost layers.

In some places the varved clay, deposited

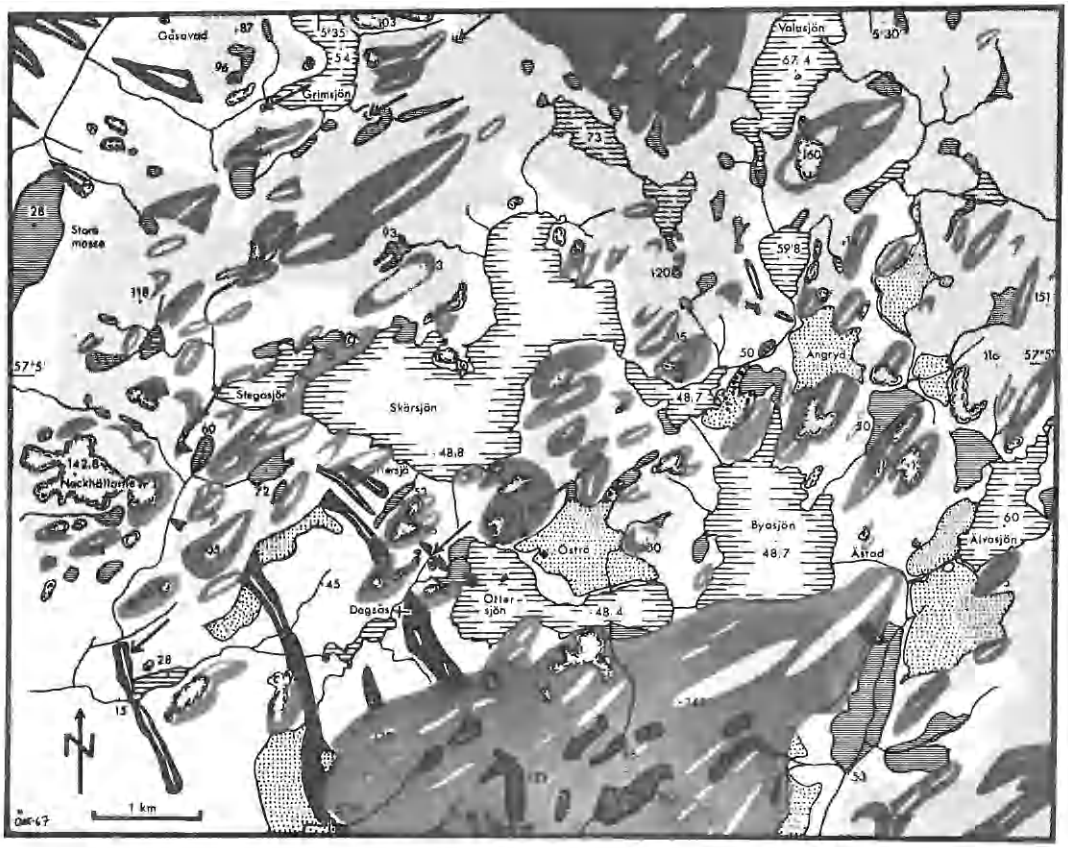

Fig. 5. Map of the Quaternary deposits of the Dagsås area in middle Halland. Light tone shows area above the marine limit. Darker tone is moraine (stoss-side and lee-side moraines and drumlins) below the marine limit. Above this level these phenomena are indicated by the darkest tone. The crests of the drumlins etc. have been indicated. Note how the end moraines form straight ridges over the valleys. The ice has not formed valley glaciers.

during the ice-free stage, contained shell fragments which were found on the glaciofluvial deposits. Even till with shell fragments was found within the lowest parts of the cresting end moraine in the northern part.

The end moraines are straight and not scimitar-like as Wenner (1952:15) reproduced them on his map. The observations of striae are few. They indicate, however, that the ice within this region also slid down from the plateaux towards the Lygnern valley.

Svedaskogen is an imposing end moraine. It is formed of basal till, glaciofluvial sand and gravel and of glaciomarine clay. In the first stage the ice retreated and then sand and glaciomarine clay containing shell fragments were deposited. After a halt the ice readvanced. Proglacial sand and gravel were then pushed and dragged by the ice which formed an end moraine of this stuff together with basal till. Many interesting glaciotectonic features were observed here and at least a threestage formation history has been stated by analyses of the stratigraphy. This is also typical of other constituents of the Gothenburg Moraine.

Radiocarbon dates of shell fragments suggest an age of ca. 12,700 years B.P. for the Gothenburg Moraine (Fig. 8).

Valley glaciers within the steep-sloping zone in eastern Halland

Some areas within the steep-sloping zone in eastern Halland have been mapped in detail by

Fig. 6. Map of the Quaternary deposits of the Torpa area in Halland. Symbols as Fig. 5. The end moraines form straight ridges in this area also. They do not cross the valley because the calving in the deepest part was obviously too intensive to form an ice front stationary enough to allow till to be heaped up and form a continuous ridge. According to the striation there has been a bay in the ice front from V. Derome (upper left corner) to Bönarp (towards the southeastern part of the map).

the present author in order to elucidate the deglaciation process. Such studies have also been carried out by Johnsson (1956:309). Recently Bjelm (1976) gave a report on the deglaciation pattern for a similar part of the South Swedish Highland.

The steep-sloping zone (also called the fall zone) is characterized by its high relative relief. It forms the transition between the extremely flat bedrock plain in the east, belonging to the South Swedish Highland, and the Hallandic coastal plain in the west. Preglacial fluvial erosion and glacial excavation during the Quaternary have formed deep valleys and basins in which lakes now often lie (Fig. 9).

The Sjösgärde area to the east of Falkenberg will be presented as a type region of the deglaciation process within the steep-sloping zone.

The heights consist of rocks covered by till, often forming drumlins. In flat areas between the drumlins more irregular till forms appear, probably ablation moraine.

Glaciofluvial deposits are quite common within the valleys. It seems that the larger valleys, parallel or subparallel to the main ice movement direction, housed ice-tongues, from which the meltwater streams transported sand and gravel to form sandur plains. These valleys drained the surrounding areas for a relatively long time during the deglaciation. This draining was characterized by occasional torrential streams, 'jökulhlaups'. This will be elucidated further.

As can be seen from Fig. 9 there is a straight

Fig. 7. Map of Fjärås bräcka and Svedaskogen. (1) rock contour; (2) glaciofluvial material (mainly); arrows show the directions of the transporting meltwater streams; (3) end moraines; (4) boulders; (5) striae; (6) peat bogs and wet grounds; (7) gravel pits.

fissure valley, running NNE–SSW deviating rather strongly (about 25°) from the main ice movement direction in NE–SW. In this valley the glaciofluvial sand and gravel have formed a segmented esker ridge. Within the saddle part of this valley, the esker ridge has branched into an esker network, parallel ridges and cut-off ridges. Glaciofluvial terraces with flat and evened surfaces have formed along the sides of the valley, where this is wider and more open. Dead-ice hollows are frequent in glaciofluvial fields around the lake.

The area is characterized by stream furrows and emptying channels for the dammed meltwaters that gradually flowed from higher towards lower levels accessible as the ice thinned out and decayed. Torrential subglacial, and consequently confined streams, as well as subaerial,

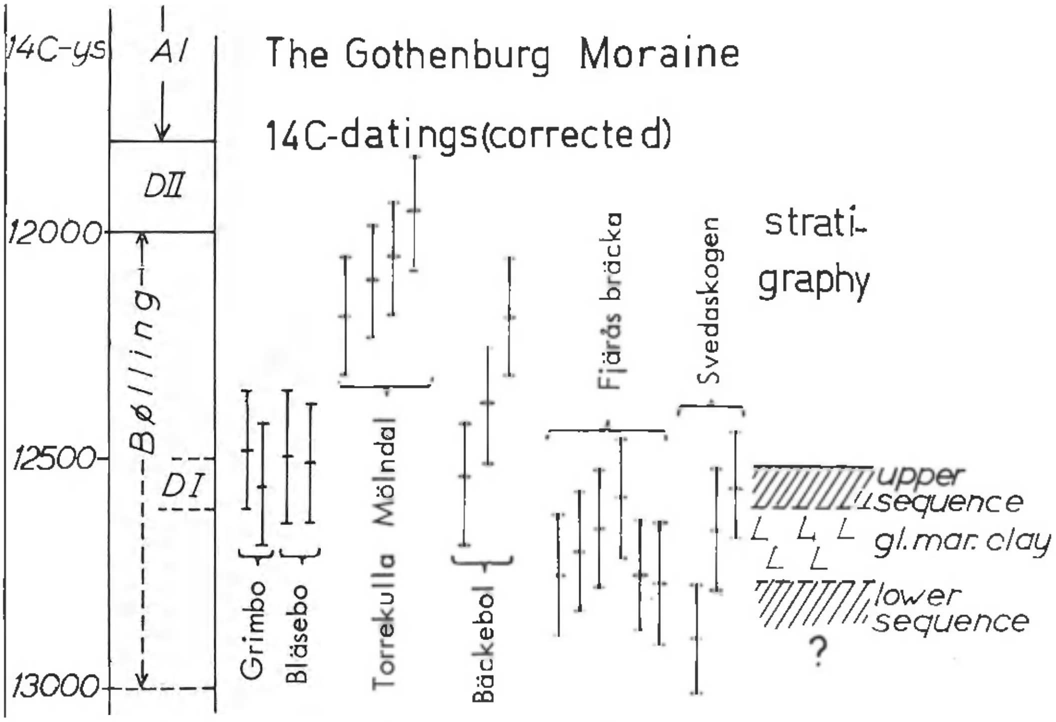

Fig. 8. Diagram of the stratigraphy and datings of the Gothenburg Moraine.

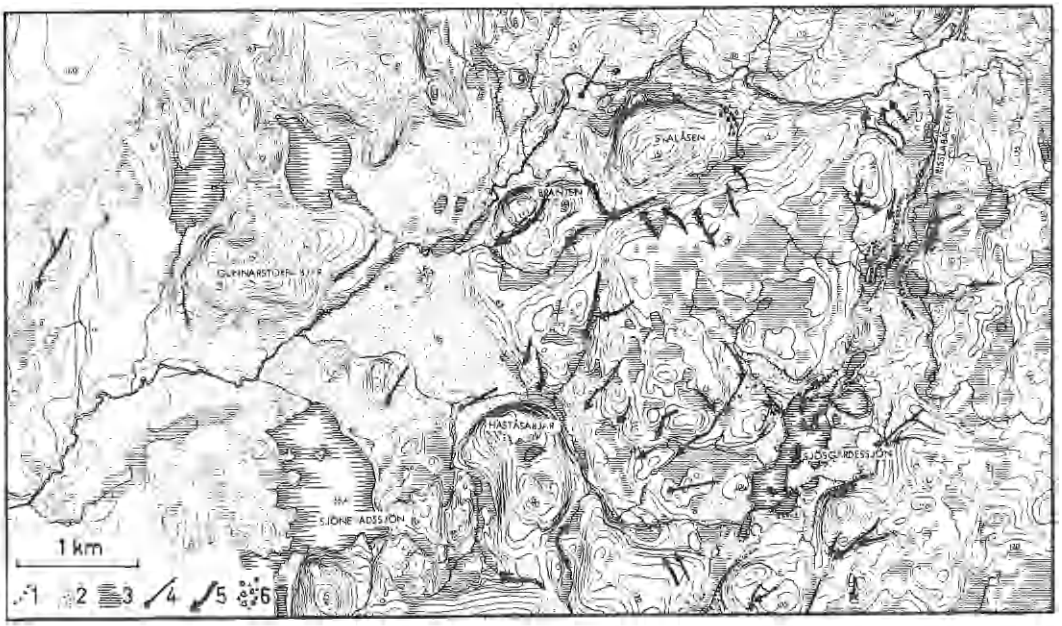

Fig. 9. Map of the Sjönevad–Sjösgärdesjö area. (1) esker ridge; (2) glaciofluvial deposit in the form of terraces, deltas, etc.; (3) peat bogs; (4) striae; (5) glaciofluvial drainage channel; (6) heaps of boulders (washed by meltwater streams).

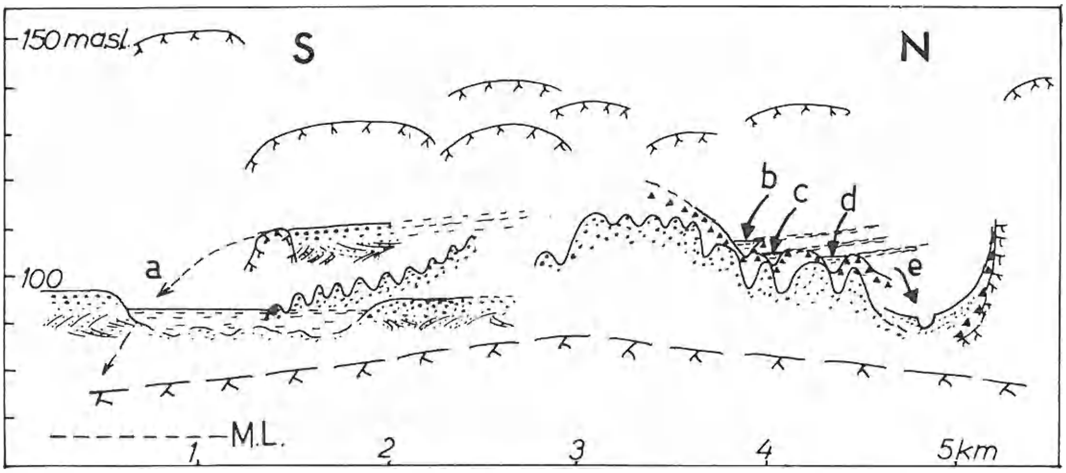

Fig. 10. Profile along the esker ridge in the Sjösgårdesjö valley. The supposed rock bottom of the valley in the lower part. Heights on both sides of the valley (of rock and till) in the upper part. (a) Overflow from a lateral terrace for meltwater forming a hydraulic pressure level in the ice. (b)–(d) Gradual emptying channels for meltwater in the ice. (e) The final drainage course for the meltwater, now the Lillå valley.

unconfined streams forced their way over moraine ridges and along valley slopes. So real 'boulder squares' or boulder strongholds have been formed, not uncommon in the area. Ablation till accumulations, bordering the valley slopes, often show the effect of running water both morphologically and stratigraphically.

Apart from the sandur plains, there are no frontal deposits showing an active ice margin. The ice melted by gradual thinning. The rock hills with drumlins must therefore have lost their ice-covers very early and formed nunataks. Because of differences in albedo, channels with meltwater and lateral ice lakes have originated between the stagnating ice and the rock hill sides. Here small calving ice cliffs could be formed, but they must have been very short-lived. The water masses often formed hydraulic pressure surfaces within the decaying ice. Ice and rock thresholds resisted the pressure for some time, but when such dammings yielded the meltwater masses violently streamed downwards, submarginally and/or subglacially (Figs. 10 and 11).

A deglaciation model for the western part of the South Swedish Highland

The area here considered as typical of the deglaciation processes within a very flat plain of Precambrian rocks – a peneplain of probably Mesozoic age – is situated well above the marine limit and to the west of the southern end of Lake Bolmen (see Fig. 1). Johnsson (1956) previously studied parts of this area. Persson (1972) also investigated parts of the South Swedish Highland with a similar topography.

The till is fairly thick, on an average about 4–5 m. However, because of the flat topography, the peat bog area is very conspicuous. The heights consist of drumlinized rock hills and drumlins with rock cores. The area also contains transverse moraine ridges (Fig. 12). Probably there are no end moraines within this area except in some very special cases (cf. Johnsson 1956:335–440; Mörner 1969:134–135).

The drumlins seem to be of at least two different types. One type is characterized by being long (often 1–2 km), fairly high (20–30 m) and having even surfaces. The surfaces may, however, also be rather rough, in which case it seems as if the original evened drumlin surfaces have been covered with fairly bouldery ablation till.

The other type of drumlin has much smaller dimensions – length about 100 m, height about 5–10 m – and the surface is irregular and bouldery, characterized by ablation till. These small drumlins have sometimes been 'cut off' at their distal ends, thus resembling the form of roches moutonnées.

The large drumlins may appear in groups in

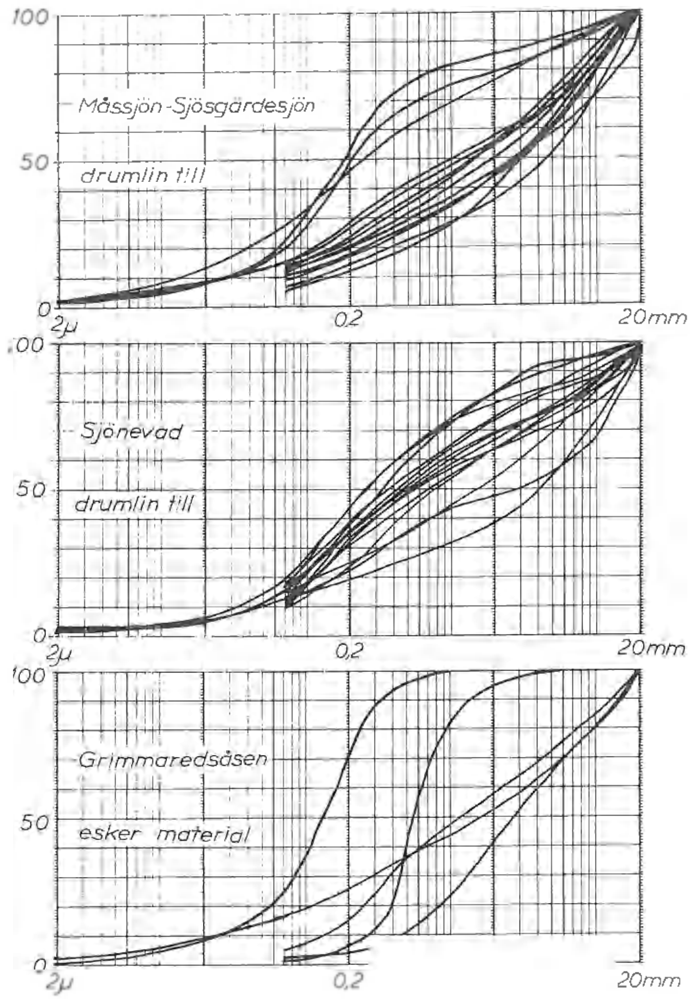

Fig. 11. Grain-size diagrams from drumlins and from an esker ridge, Grimmaredsåsen, a continuation to the south of the Sjösgärdesjö esker ridge. The grain-size composition of the drumlin till varies considerably. The coarse till belongs to the superficial layers of the drumlins. Probably it has been washed by meltwater. The more fine-grained samples belong to deeper layers in the drumlins, i.e. basal till, unaffected by meltwater. The content of fines is nevertheless low. The esker material also varies considerably; some samples show a very good sorting, other samples are rather badly sorted and one sample shows till material (from the side of the ridge).

special areas and simultaneously be lacking in other areas (Johnsson 1956:342; Persson 1972:47–48, fig. 22). Within the present area mapped (Fig. 12) the small drumlins seem to be connected to the transverse moraine ridges as mentioned above and often make up parts of these (see below).

The transverse moraine ridges occur in groups where the rock basement is convex, as e.g. from Långhulten in the southwest to Sävsered in the northeast (Fig. 12). The rock hill of Långhulten (in the southwest corner of the map) is slightly drumlinized, but no large drumlins exist within this special area, which seems to be significant for the till deposition processes.

The transverse moraine ridges are parallel to each other and perpendicular to the ice movement. They are hilly and about 3–10 m, sometimes 25 m high and 100–300 m long, slightly winding or fairly straight, often with small drumlins with 'cut-off' distal ends connected. They may consist of basal till throughout, or they may contain layers and laminae of silty-sandy water-transported material together with basal or water-washed till in beds and lenses (Fig. 13). There are, however, few pits in these ridges, so their inner structure is not very well known. They have a cover of ablation till with large boulders. Sometimes they continue as transverse eskers according to Johnsson (1956:318, 331, 334).

The glaciofluvial accumulations are

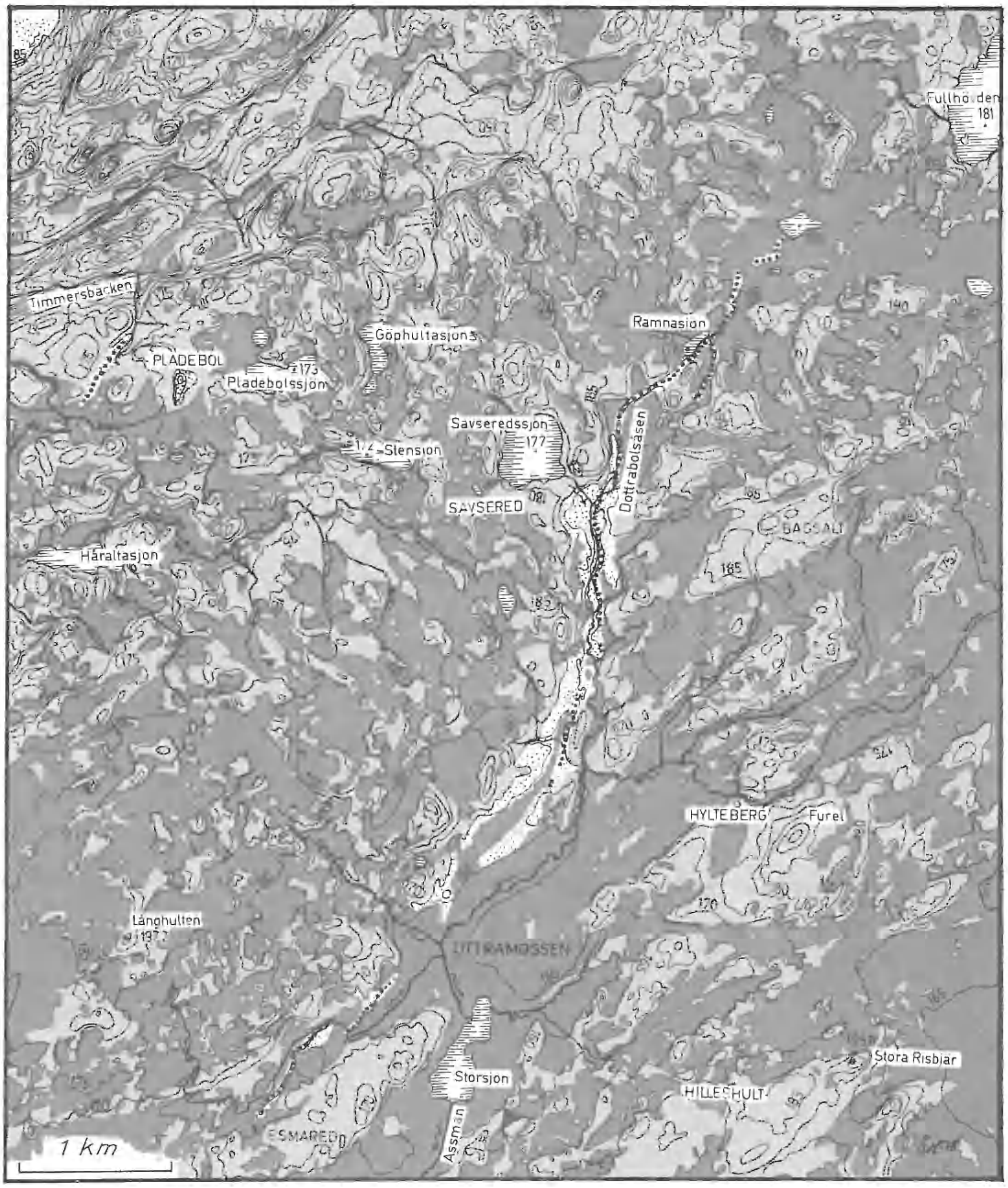

Fig. 12. Map of the Esmared area and surroundings. The moraine in grey, hatching indicates peat bogs. The streamlining of the till appears as radial moraine forms, occurring together with transverse moraine ridges (see the southwestern part of the map). Part of the fall zone is visible in the northwestern part of the map. Large quantities of meltwater have washed away the till so rock hills are now covered only by residual till boulders. Large drumlins appear in the eastern part of this area. Cf. Fig. 14.

characterized by delta-like fields, kames and radial segmented or even-crested eskers.

In this case the delta-like fields are represented by the Härsängaryen field (Fig. 15). This has a fairly flat surface in the southwest with some broad stream channels and steep proximal ice-contact slopes in the north-northeast, where numerous kettleholes show that ice blocks have been detached from the decaying ice and more or less buried under sand and gravel.

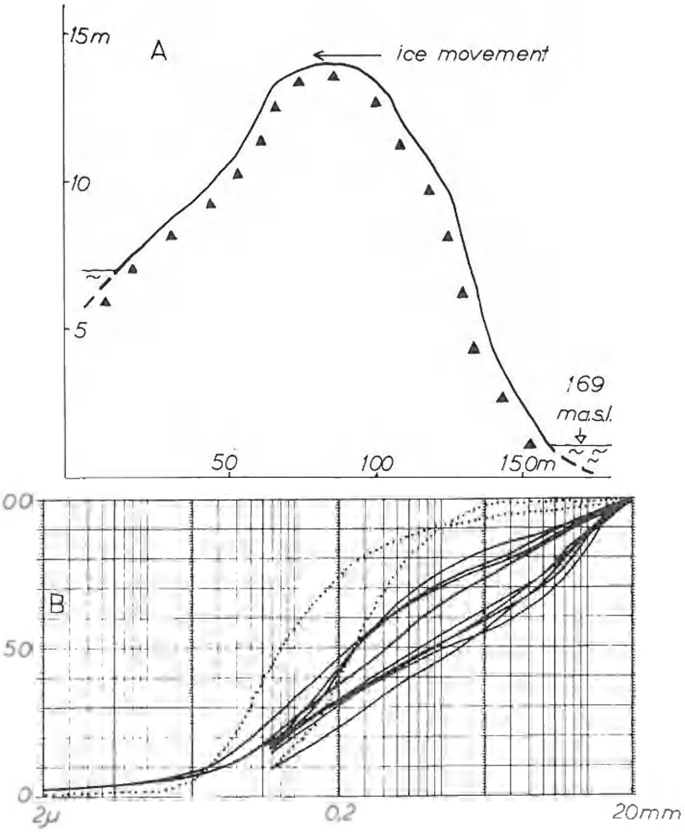

Fig. 13. A. Profile of a transverse moraine ridge. B. Grain-size composition of soil samples of a transverse moraine ridge. Pointed curves show samples from water-transported materials in lenses and layers. Other curves show the composition of different layers and beds of till.

The glaciofluvial material is well sorted and layered and has been transported by running water.

Because of the delta-like surface and the kettle topography in proximal parts of the field the sedimentation seems to have taken place mainly subaerially and not subglacially. The field gradually slopes towards Lake Hillesjö, so this depression was probably occupied by a disintegrating dead-ice body, which directed the meltwater streams. Also the small valley northeast of the lake was filled with dead ice. Thus it is not a meltwater erosion valley.

The Härsängaryen field also shows a zonal formation (dashed lines in NW–SE in Fig. 15), which was probably caused by a rhythmic retreat of the ice. An ice-dammed lake opened here step by step or crevasse by crevasse. The meltwater streams were probably directed by these ice-walled crevasses transverse to the ice movement. In the later stages however they could stream over the delta-like surface more or less unhampered by ice blocks, guided only by the low slope towards SW.

When the surrounding dead-ice bodies gradually decayed, e.g. in the valley southeast of the Härsängaryen field, the meltwater streams flowed over the moraine areas at Glamshult and covered them with sand, so till boulders are not visible now; they are in any case not common in these areas. The same applies to the moraine areas west of the glaciofluvial field.

According to Johnsson (1956:332–335) transverse eskers also exist which may gradually change into transverse till ridges, showing that the meltwater streamed in frontal channels or crevasses parallel with the marginal zone of the ice sheet. As there are very few gravel pits within the investigated area, I have not been able to study the relationship between glaciofluvial and till deposition, but Johnsson's conclusion is corroborated by the zonal formation, characteristic of the Härsångaryen field.

Kames exist 500 m to the west of Lake

Pladebolssjön and at Singeshult, just outside the Esmared map area to the northeast. At Pladebolssjön the mounds are covered with ablation till and at Singeshult a pit showed crossbedding and ripples in the sand and collapse faults.

The radial eskers are sometimes regularly segmented with about 80 m between the hills (Dottrabolsåsen), sometimes even-crested. They obviously follow fracture zones in the bedrock which also function as drainage courses now (Fig. 12). Their material varies between well-sorted and layered sand and gravel and almost till-like matter, lacking structures (Fig. 14). Channel and fill structures have been observed in a sand pit in the esker NE of Esmared – the sand being well sorted.

These radial eskers are also surrounded by moraine areas which, according to a pit in the south of Lake Sävseredssjön, have been inundated by meltwater, so the till has been washed. The moraine boulders have been covered by sand and the usually rough moraine surfaces have been evened. The stones in road cuttings are fairly well rounded and the matrix is gravel and sand. As the ice decayed, the tunnel obviously began to leak and meltwater and sand streamed out into adjacent areas.

In this peneplain area the meltwater in the terminus of the ice sheet was affected by the small topographic differences of the rock basement. The longitudinal strains in the ice resulted in subglacial tunnels. Sand and gravel were deposited in these tunnels as the esker sediments contain heavy boulders which must have melted free from the roof of the tunnel and fallen down. Sometimes the meltwater was also loaded with large masses of till which in some way would pile up in the channels during the decaying process of the ice. This material could then be deposited as till-like matter. The eskers may also have a cover of till on the (lower parts of the) sides.

The retreat within the areas above the marine limit and with such a flat topography meant a gradual thinning-out of the ice sheet. This thinning-out then caused one frontal zone after another to be disconnected from the dynamically moving ice behind. Ice masses behind such frontal immobile zones then moved over these dead-ice bodies. Till was transported upwards along shear planes so ablation till could form upon the surface of the ice terminus (cf. Fig. 4c). This ablation till could easily be oversaturated by meltwater so that it formed a flow till.

When the thin ice moved over convex rock basement areas, it was crevassed in a fairly regular pattern, parallel and transverse to the flow direction of the ice, giving rise to the transverse moraine ridges with connecting small drumlins, very much resembling the Rogen Moraine (Lundqvist 1969).

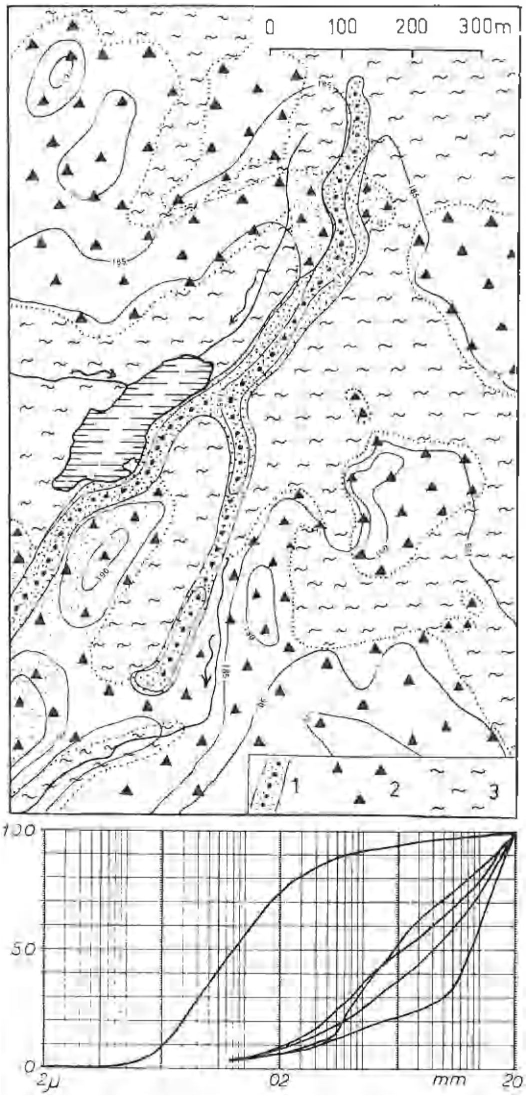

Fig. 14. Map of the Dottrabolsåsen esker ridge (at the top) and grain-size composition of samples from this esker (below). (1) esker ridge; (2) till; (3) peat bogs. The material in the esker is composed of coarse and fairly badly sorted gravel and sand and of lenses of a till-like matter. Note how the esker divides. Probably it follows two sides of a valley in the rock basement. Parallel eskers are not uncommon in this area.

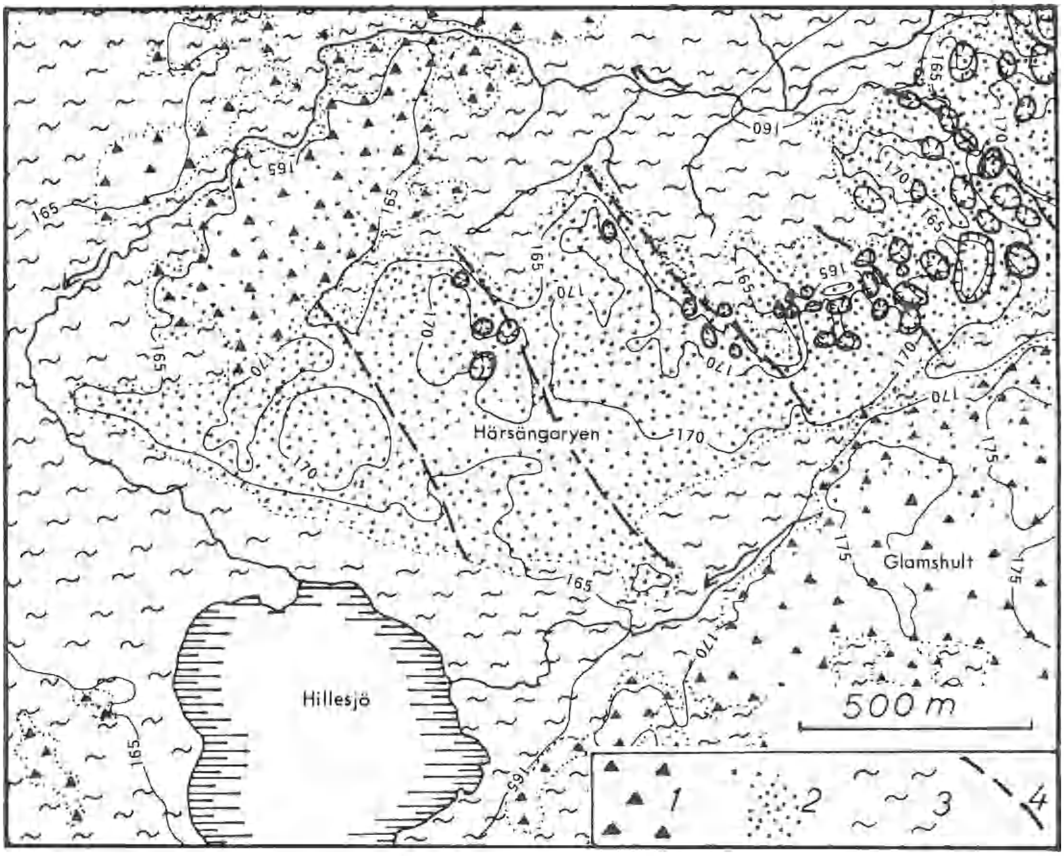

Fig. 15. Map of the Härsängaryen delta. (1) till; (2) glaciofluvial sand and gravel; (3) peat bog; (4) zones of the delta. Note how the kettles are more frequent in the northeastern parts, where filling may not have taken place to the same degree as within the southwestern parts, which may indicate that the latter areas were free sedimentation areas for quite a long time.

Concluding remarks

The different deglaciation models considered here are summarized in Fig. 16.

Within the open coastal plain in western Halland the ice front ended in deep seawater. In this case the ice front consisted of an ice cliff which was long and coherent and formed calving bays over deep water and promontories over rock ridges and hills. Within the fissure-valley landscape in e.g. southern Bohuslän calving bays or incisions were formed. On the rock plateaux above the marine limit or with shallow water (10–20 m) in between the ice gradually stagnated and melted as dead ice. This deglaciation model was due to the water depth in the sea and different shear strain rates in the ice in the valleys and on the rock plateaux.

The Gothenburg Moraine was formed mainly in three stages. During the first stage the ice retreat was gradually retarded. Then a basement of till and/or glaciofluvial material was deposited. The next stage was ice-free and deposition of glaciomarine clay took place. During the final and third stage, the ice readvanced and pushed up end moraines upon older deposits. The Gothenburg Moraine was left by the ice at about 12,700 B.P.

Within the areas that are highly intersected and well above the marine limit as for example in middle eastern Halland, the so-called fall zone, the hill tops first formed nunataks, where the till has sometimes been channelled by lateral meltwater streams. In these high areas the ice stagnated early, while it was fairly active in the large valleys for long periods. Subglacial and

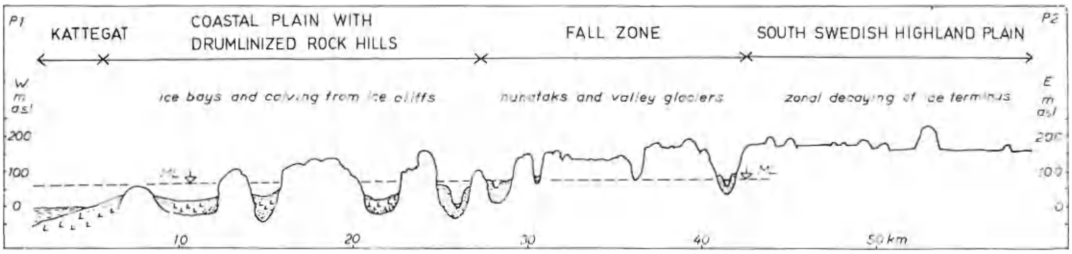

Fig. 16. Profile in west-east (P1–P2 in Fig. 1). Here the different deglaciation models have been summarized. (L indicates clay and points sand.)

lateral deposition of glaciofluvial material was common in the valleys. Consequently eskers and lateral terraces were formed. Sandur deposition took place within the largest valleys. Catastrophic emptying of dammed water seems to have been rather common. The water easily cut its way down into water-soaked till and glaciofluvial material and formed channels.

Within the peneplain of Precambrian rocks of the western part of the South Swedish Highland, fairly large drumlins were formed subglacially during a somewhat earlier stage of the deglaciation. By the gradual thinning of the ice, zone by zone of the ice margin was detached from the dynamically moving ice and became immobile. When the margin stagnated, glaciofluvial material could form kames, eskers and deltas in ice-dammed ponds and lakes. Where the stagnating ice diverged over a convex rock basement, Rogen-like moraine was deposited as transverse and radial ridges. Parts of these forms obviously began to form subglacially beneath a moving ice sheet. They were then covered by ablation till from a dead ice.

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