SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 754 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 72 NR 16

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ABSTRACT

Till and moraine forms in central Lappland are described. The purpose has been to define the various genetic processes that have been at work in different areas. The result can be of use in prospecting as the distance that mineralized boulders have been transported is related to the local glacial situation. Interpretations are made in the light of the mechanical properties of glacier ice.

INTRODUCTION

Glaciological studies have been carried out within the Storavan area (map sheet 24 I Storavan) and within parts of adjacent map sheets. The studies formed an integral part of a programme of mineral exploration, and in a separate paper (Minell 1978) the use of glaciological studies in ore prospecting is discussed and illustrated in detail. This paper presents the purely glacial geological part of the investigation. The aim of the investigation has been to clarify the composition and genesis of moraines for the purpose of facilitating prospecting. Since a till in many cases appears in different morphological forms which differ in origin, it is proposed to classify the forms into groups depending on their genesis and sub-bedrock content. It is of great importance for ore-prospecting to know if a mineralization is covered by a till consisting purely of material from another area, or if there has been an extensive contribution of material from the underlying bedrock. With some knowledge about the glacial deposits, results from boulder tracing as well as geochemical investigations can thus be easier to interpret.

The initial stage was to describe the morphology and composition of the moraines. The second stage was to determine their mode of formation with reference to theoretical and experimental studies of glacial processes.

General studies of fluvioglacial marks have also been made. In addition, a small number of ^{14}C age determinations were made and an interpretation of the deglaciation phase has been proposed.

The investigation also entailed an air-photo interpretation of the entire area complemented by field studies of specific limited areas.

METHODS

An aerial photograph interpretation was carried out on those parts of 24 I Storavan that lie north of the Skellefte river, and on the southwestern part of 25 I Stensund (Plate I). Photographs on the scale 1:20 000, made in 1969, were used. The aim was to obtain the best possible subdivision of the morphology, soil types and outcrops.

The results are presented on a moraine-morphology map (Plate II) and a map showing outcrops and fluvioglacial activity (Plate III). Plate II illustrates the moraine forms. Plate III, showing outcrops and fluvioglacial activity, illustrates erosion channels, ridges and glacial stream deposits as well as the exposed bedrock.

A large number of localities have been visited in the field and good correlation between the aerial photograph interpretations and the field observations was obtained. No systematic field mapping has, however, been carried out, and the maps as a whole must be regarded as aerial photograph interpretations with the possible mistakes and shortcomings which can occur.

The choice of localities for investigation was based on those areas with significant morphology over which metal prospecting also had been carried out.

During the follow-up and investigations in the field, more emphasis has been laid on pit studies and levelling than on detailed mapping over a larger area. The levelling was made by pendulum, lath and measuring tape.

About 70 till samples have been taken, primarily from the areas of the aerial photograph interpretations, but also from areas to the north and south and from the nearby Caledonian rocks. The samples were taken mainly from moraines of specific character and form, but also from moraines without distinct morphological features. The samples have been sieved and analysed by the hydrometer method.

Some simple laboratory experiments have been conducted in order to simulate continuity in morphological pattern caused by glacial flow.

Doming is a process which may be effective when ice is overlain by till. The conditions necessary for doming to be initiated were investigated in a theoretical study.

GENERAL DESCRIPTION OF THE AREA

The bedrock (Fig. 1) consists of granites and granitoids of Svecokarelian age (cf. Ödman 1957). Thin belts of metamorphosed supracrustal rocks occur between the intrusions. The supracrustal rocks are mostly terrestrial volcanics of acid composition, although intermediate and basic types are also represented.

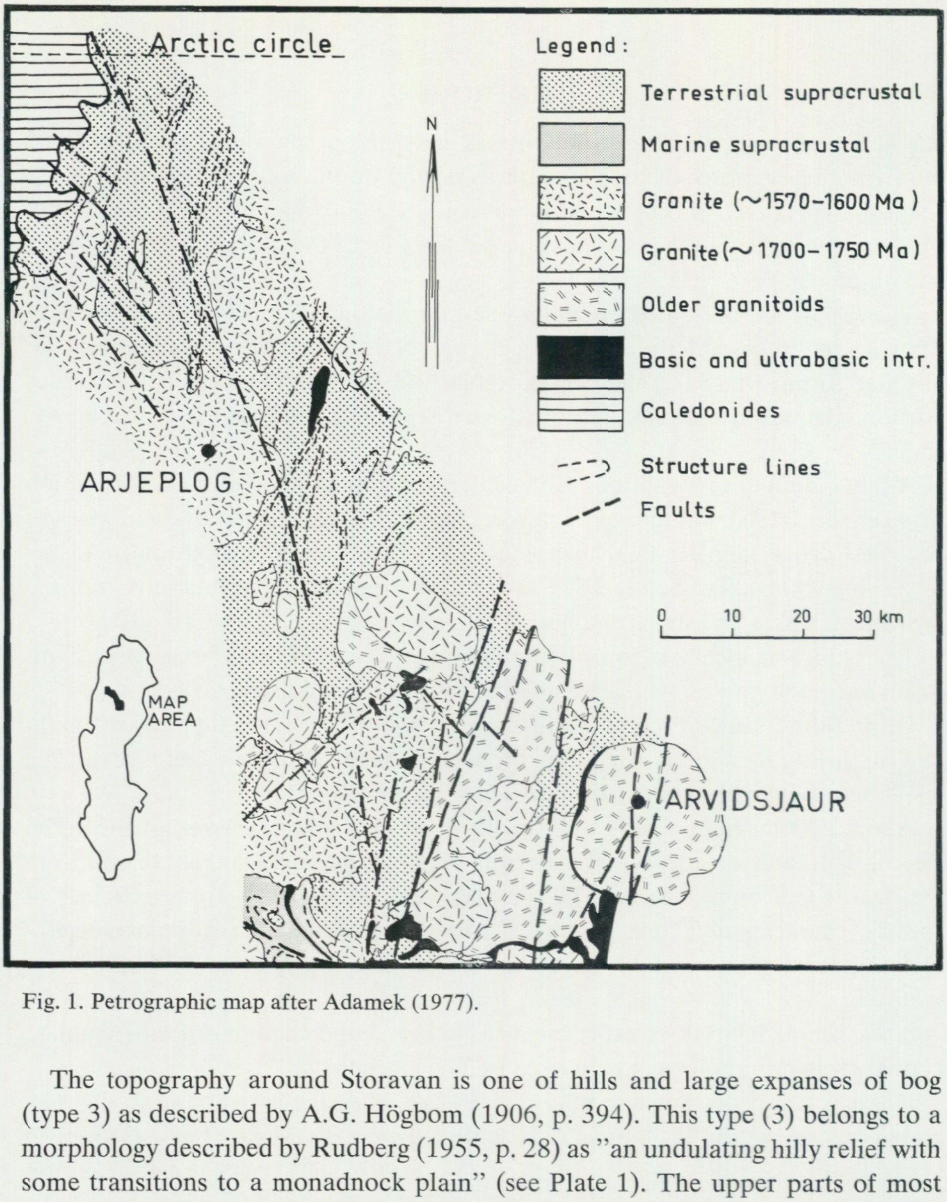


Fig. 1. Petrographic map after Adamek (1977).

The topography around Storavan is one of hills and large expanses of bog (type 3) as described by A.G. Högbom (1906, p. 394). This type (3) belongs to a morphology described by Rudberg (1955, p. 28) as "an undulating hilly relief with some transitions to a monadnock plain" (see Plate 1). The upper parts of most of the hills (500–600 m altitude) form an older "lidpeneplan", while the lower terrain (350–400 m altitude) which separates the hills, is a younger "inland peneplan" (M. Lundqvist 1953, Magnusson et al. 1963). Most of the areas is illustrated in Plate II. In Plate III the extension of bedrock outcrops, the fluvioglacial deposits and the fluvioglacial erosion are illustrated in general. The bedrock is usually exposed on the higher parts of the hills; the fluvioglacial deposits follow the lower terrain especially the valleys.

The glacial and fluvioglacial deposits in the vicinity of Storavan have been investigated earlier only within certain localities (Minell 1978). However, the map sheet 25 J Moskosel northeast of Storavan has been mapped and described by Esko Daniel (1973, 1975). General descriptions and mappings have also been published from areas in Västerbotten (Granlund 1943) and in Norrbotten (Fromm 1965). Many local investigations and general descriptions of Lappland, which are relevant to the Storavan area, have been published by G. Lundqvist (1943, 1952, 1958, 1961), Hoppe (1952, 1957, 1959), A. G. Högbom (1906), and others.

ICE DIRECTIONS

The directions of ice movement in central Lappland have previously been investigated by Fredholm (1892), Gavelin and Högbom (1910), A. Högbom (1931, 1935), Ljungner (1943, 1945, 1949), G. Lundqvist (1961), and Fromm (1965). The latest work by Daniel (1975, p. 13) includes an investigation of ice striations. Daniel found that the majority of striations were oriented NW-SE with some older ones oriented WSW-ENE. In some places the situation was more complicated with striations oriented both NNE-SSW and SW-NE during the last stage of deglaciation.

There are very few good localities in which there is a clear relationship between the different directions of ice movement, and a systematic examination has not been made. Only one locality has been seen which supports a change in direction from S 75° W to N 40° W. This is on an outcrop 1 km southeast of Högåsberget, south of lake V. Kikkejaure. The outcrop slopes to the southeast and is thus in a lee position. The bedrock consists of an acid volcanic rock with a very smooth surface. Four groups of striations can be identified: S 74°–88° W, N 76°–84° W, N 52°–56° W and N 42°–46° W. The age relationships of these striations have not been deduced by comparing stoss- and lee-side positions or different facets. The striations have only been compared with regard to sharpness in relation to secondary abrasion and must thus only be seen as a comparison to the findings of Daniel (1973, p. 20). The results of these comparisons indicate that the striations oriented S 74°–88°W are the oldest, while those oriented N 42°–46° W and N 52°–56° W are youngest. The group N 52°–56° W are probably of approximately the same age as the group N 42°–46° W since there is such a small difference between them. The general topography, the drumlins and the boulder trains correspond very well with the youngest direction of movement from N 42°–56° W.

Closer to the ice-shed, however, the youngest direction of ice movement deviates from that around Storavan and to the southeast of this lake. The youngest striations in the northern part of Hornavan lie around N 20° W, while the youngest striations southwest of lake Storvindeln are oriented N 60°–70°W.

MORAINE MORPHOLOGY FROM AERIAL PHOTOGRAPH INTERPRETATION

The following types of moraine morphology can be clearly distinguished (Plate II).

1. Large-scale flutings
2. Drumlins and drumlinoids
3. Large crag moraines
4. Large transverse ridges and Rogenmoraines, smaller-scale transverse hog's-back moraines
5. Large-scale hummocky moraine and moraine plateaux
6. Hummocky moraines of different types

1. Large-scale flutings. Both flutings and drumlins are elliptical in shape with the long axes parallel to the direction of ice movement. The basal till indicates that they were deposited under an active ice cover. The ridges are a few metres high (Figs. 38 a and 39). They are several hundred metres long, but only 30–40 m wide. The distance between the ridges is the same as their width, a cross-section over the area thus displaying a gentle sine-wave curve.

Large-scale flutings in southern Norrbotten occur in zones on the flattest part of wide valleys or on the level areas which lie either proximally or distally to the larger hills. The zones often have a length of 2–3 km although lengths of up to 5–6 km occur. Their width varies little and is around 1 km.

The large-scale flutings occur most abundantly in swarms east and south of Storavan towards the Skellefte river, and in the southeastern part, east and south of Hedberg (Plate II). The till is sandy to fine sandy with a low boulder content. The large-scale flutings are most probably extended drumlins of the type described by Gravenor and Meneley (1958).

Other forms of extended moraines parallel to the direction of ice-movement are the radial moraines. They have only been found in one place (Plate II) relevant to the part of central Lappland described here, and are thus not treated in this general description. However, these radial moraines are large and distinct enough to warrant treatment within the local description of Ruttjebäcken.

2. Drumlins, "drumlinised till" and drumlinoids have a considerably greater relief than the large-scale flutings. The length and breadth of the drumlins are more proportional, but can vary greatly from a length of 100 m and a width of 40–50 m up to kilometre long forms with widths up to 400 m. The thickness of the till is about 8 m. This type of drumlins is the most common in Norrbotten

(Hoppe 1957, p. 12, Daniel 1973, p. 40) and can be regarded as a type of drumlinised till because of its subdued relief.

Drumlins and ”drumlinised” till occur in southern Norrbotten with a swarmlike appearance within large flat areas of 10–20 km². Within the swarms, the distance between the ridges is the same as the ridge width. These drumlins are regarded as being totally without rock cores, and are thus independent of the underlying surface (Hoppe 1951, Fromm 1965, Daniel 1973).

The drumlinoid forms (which are directly dependent on the underlying surface in the form of rock cores within or outside the drumlins) do not occur in swarms but rather as single entities or smaller groups, then often in association with bedrock knobs (J. Lundqvist 1969, Minell 1973). All the drumlinoid forms have approximately the same length/bredth relationship; whereas the height of the drumlins with rock cores is greater than that of drumlinised moraine. The material constituting the drumlins and the drumlinoid forms is usually a normal basal sandy to fine sandy till with a normal to low boulder content. In some cuttings, a weak lense bearing till has also been found at some metres depth.

Glückert (1973) described drumlins and drumlinoids in central Finland and reviewed the literature on drumlins. Gillberg (1976) has made a subdivison of different drumlins and drumlinoid forms in southern Sweden. The subdivision is based on morphological interpretations of outcrops.

A statement common to all literature is that drumlins are a basal formation, usually of compacted till but sometimes of lensed till, particularly at depth. Drumlins have been interpreted genetically as a deposition of material due to increased friction, which itself is the result of increased pressure (Boulton 1974, cf. Smalley and Unwin 1968), but also as deposition of material during stagnation within an area with low shear stress and low pressure (Minell 1973 and 1975). The shaping of the drumlins can easily be explained if they are dependent on bedrock, but it is not apparent which mechanism is responsible for the outspread drumlins occuring in the flatter areas of Norrbotten and Västerbotten.

3. The large crag moraines (Gillberg 1976) are essentially ”crag and tail” features whose shape is controlled by the rock core. The till is uneven and thin, except in the most distal (postcrag) and proximal (precrag) moraine parts where it may be quite thick. The inclination of the postcrag moraines varies between 4–6°, while the precrag moraines incline approximately 6°.

A type locality for the drumlins and the drumlinoid forms is the area around Lake Naustajaure (Plate II). The low Norrbotten type of drumlins and drumlinised moraine surrounds the lake to the north, west and south. To the east a number of crag moraines occur and to the southeast there is a zone of large-scale flutings. All these formations have their long axes oriented parallel to the last direction of ice movement (Plate II).

4. Large transverse ridges and Rogen moraine can vary from a few hundred metres up to several kilometres in length. The width of the ridges and the distance between them are approximately 200 m. Their height varies considerably but lies around 10 m (Fig. 36). In general, they occur along shallow troughs in the terrain (cf. J. Lundqvist 1969a). The troughs are filled with water and, as a result of this, the characteristic moraine forms are easy to distinguish even on the topographic maps. Most clearly developed are the transverse ridges within a certain depth of break in the trough, with a diameter of over 2–4 km and with a depth of 15–20 m (Plate II). These usually lie in the central part of the trough, but, in certain cases, surround a deeper core without moraine (cf. J. Lundqvist 1958). The ridges are best developed towards the centre but often lose their character of a transverse ridge towards the periphery. On the fringes of the troughs, however, the forms often have the character of large, softly-convex mounds of dead-ice character (cf. J. Lundqvist 1958 and 1969a).

The material within the area of large transverse ridges consists of a grey, fine sandy to sandy, in places lense-bearing till (Fig. 3), with normal to abundant content of boulders, but in some places the till is fine sandy and compressed. The lenses are of decimetre size and consist of silt or sand (G. Lundqvist 1951, Möller 1960, J. Lundqvist 1958, 1969, 1969a). In places, the lenses occur only sporadically, but from a distance the whole till looks like a large mass of thin irregular lenses.

The transverse ridges occur around the northern part of Storavan and are best developed along the lakes Njallejaure, Vaksemjaure and the northern part of V. Kikkejaure. Small groups, though with larger and better developed forms, are found in Storavan from Kallön and upper Storfjärden.

Clearly basal-formed, large transverse ridges occur in southern Järntjärnsdalen and around Mörttjärnarna.

Transverse ridges have so far only been discovered in the areas near to the glacier source, and proximity to the glacier source is therefore thought to be necessary for the formation of all forms of transverse ridge.

In northern Norrbotten, large transverse ridges have been described by Hoppe (1948). These ridges mainly consist of a till with lenses of sorted material (Kalix pinnmo; cf. Fromm 1965, p. 118). These ridges are situated below the highest shore-line.

In Jämtland and Härjedalen, large transverse ridges have been called Rogen moraines by J. Lundqvist (1969, 1969a). The composition and morphology have been described and treated in detail. The Rogen moraines mainly consist of basal till.

At first, the large transverse ridges termed Rogen moraines were only classified as undulating moraine and in some cases as end moraines (Högbom 1920, p. 94, Frödin 1913, 1925). G. Lundqvist (1937, 1943, p. 37, and 1951) described the Rogen moraines as a special type of dead-ice moraine formed in fractures in close connection with a stagnating ice front. G. Lundqvist regarded the fractures as being supraglacial and explained the pressure structures in certain moraines as later reactivation of the ice. Mannerfelt (1945, pp. 155 and 216) regarded the Rogen moraines as both subglacial and surface fracture accumulations. The subglacial theory was taken up by Granlund (1943, p. 46) and explained as a forcing up of till in basal fractures in the ice. This theory was also supported by Hoppe (1952, pp. 34 and 66). J. Lundqvist (1969, p. 64, and 1969a) also explained the Rogen moraines as basal formations, but he regarded the basal fractures as a disintegration of the debrisrich basal sections of the ice (J. Lundqvist 1969a). Simultaneous with the fracturing of the debrisrich basal sections, overlying pure ice filled up the intervening spaces. This process explains the compressed basal tills which often appear in Rogen moraines. However, as the investigations will show in this paper, it is more probable that the Rogen-moraines have been formed within an environment of compression where material was folded and thrust forming large transverse ridges. If the process continued for a long time or in a cooler environment, material was transported to the surface and collected in fractures caused by later tension.

The term Rogen moraine is commonly used in the literature regardless of its composition and is mostly seen morphologically as a large transverse ridge. In the following chapters therefore, the term large transverse ridge is used, subdivided within groups due to composition (Table I–IV).

5–6. During mapping, the following sub-divisions of hummocky moraine have been used, following Daniel (1973, p. 55).

5a. Veiki moraine with plateaux and side ridges. The till is generally sandy to fine-sandy and poor in boulders.
5b. Moraine forms which resemble the Veiki moraine but lack the typical large plateaux and side ridges.
6a. Irregular and abruptly cut-off moraine forms with boulderrich till and angular boulders.
6b. Other forms which lack marked features but which occur within a limited area.

5a. The moraine forms within the hummocky moraine vary considerably in shape and thickness. The diameters of the moraine plateaux exceed a few hundred metres. The moraine plateaux are bounded by irregular troughs with steep sides and depths in most cases amounting to 10–20 m. The troughs have an average width of 200 m. The undulating moraine plateaux occur between the hills within relatively flat areas of 6–8 km^2. Even if the surfaces are not convex, the area as a whole lies higher than the surrounding terrain and valleys.

The moraine plateaux of type 5a are not so clearly represented within the map sheets 24 I Storavan and 25 I Stensund. The moraine plateaux with side ridges are most clearly represented in the Kåbdalis area of map sheet 25 J Moskosel NE and in certain parts of the Abborrträsk area (Figs. 2, 42, 43).

The undulating moraines with plateaux have been treated earlier by Hoppe (1952), Gravenor and Kupsch (1959), Parizek (1969), and Daniel (1973, 1975) among others. Hoppe has interpreted them as phenomena which have been forced-up subglacially while Parizek supports the theory for supra-glacial development.

Undulating moraine of type 5b occurs around Krokberg and Mörttjärnsberget and between Svärdälven and the mountain Akkanålke in the eastern part of 24 I Storavan (Plate II).

Hummocky moraines of type 6a (irregular and abruptly cut-off moraine forms with boulder-rich till and angular boulders) and type 6b (a less distinctive hummocky moraine) are widespread in the area.

A slight indication of drumlinisation of the undulating moraine is apparent between Svärdälven and Akkanålke.

North of Högåsberget along the southern part of Kikkejaure occurs a transition from drumlins to partially developed large transverse ridges.

Hummocky moraines of types 5a, b and 6a, b have in general been described and interpreted as beeing created in the peripheral part of the ice by surface processes (Geijer 1917, Högbom 1932 and G. Lundqvist 1943). However, subglacial origins have been supported by G. Lundqvist (1943), Mannerfelt (1945) and Hoppe (1952).

TILL

The grain size distribution of the matrix in till varies from area to area. The variations depend partly on factors such as the degree of brittleness of the bedrock and the frequency of fractures. The distance to the ice-shed may also be of importance since this is a controlling factor for the presence or absence of long transported material. Genetic processes in the formation of till also effect the frequency of different size fractions (Minell 1977a). The genetic processes concerned are the way in which the glacier-ice acted during erosion, transport and deposition or accumulation. For example, till deposited in an environment of accumulation, where only weak erosion of the bedrock took place, contains larger quantities of silt than till formed in an environment with large supples of locally eroded bedrock material. The grain size distribution of the matrix in till, therefore, like the different moraine forms, is dependent on the various stages which a glacier can undergo from erosion to stagnation.

In order to obtain an idea about the variations of tills in different moraines, samples have been taken from representative moraine forms within an area east of Lake Storavan (Plates I and II) and a few samples from Harrejokk and Storuman. The samples were also representative with regard to homogeneity for example only the homogeneous till between the lenses of a lense-till was taken and not any lense material. The samples were sieved and a number of different grain size distributions have been illustrated on cumulative curves and as frequency curves. Certain values from these cumulative curves have been used in the formulae in the chapter on calculations. The results from these calculations are illustrated on diagrams (Figs. 6, 7, 8), showing that some types of till occupy certain areas in each diagram. It is also possible to distinguish certain trends of development referring to the change from one till, for example "till at birth" with a high content of crushed bedrock material, to a till which has undergone long transport and maturity without mixing of crushed bedrock material during transport.

SUBDIVISION OF TILL TYPES

On the basis of the frequency curves and the diagrams, a particular till type can not always be related to a particular moraine forms. Instead, a general sub-division of different till types has been made, based on field observations and on genetic differences. The field observations inform about boulder content and distinct differences in the grain size distribution. The genetic differences are related to the main process involved in the formation of certain moraine forms. The tills have been classified into seven groups:

a. "Till at birth" has a high content of coarse local bedrock material in such a stratigraphic position that supra-glacial washing could not have been responsible for the coarse material. The till is gravelly with a clay content of 1 % or less. The content of boulders and pebbles is high. All the material which is coarser than granule-size is very local and angular. This type of till is not associated with any particular morphology but generally lies at the base of fairly thin moraines, or constitutes the entire thickness of some hummocky moraines (Table III). This till is very common in many moraines which lie close to the ice-shed.

"Till at birth" is a till which can often influence other tills very strongly (cf. Hörner 1944, p. 715 and Järnefors 1952, p. 198), particularly in areas where a strong upwards transport of till has taken place (Minell 1977), and in till where intensive plucking of bedrock material could have taken place (Hörner 1944, p. 713). The diagrams (Figs. 6, 7, 8) show three examples of "till at birth". These clearly belong to this group due to their rich content of locally crushed material.

b. Basal till exhibits a clear basal origin with regard to both structure and moraine form. Moraine forms, such as plane moraine, large crag moraines, drum-

Fig. 2. Boulder-poor till at Abborrträsk. From north.

lins and in some cases large transverse ridges containing foliated or compacted till, have been classified as containing basal till. The till is sandy, sometimes fine sandy, with a clay content ranging from 3 to 7 per cent. The content of boulders is very low while that of gravel varies considerably. The coarser fragments comprise both local material and long-transported material. Most of the fragments have been abraded, but the proportion of angular and rounded fragments is very variable. The till can be foliated or brecciated, especially in the upper parts. This type of till is mostly associated with the drumlin swarms and with some large transverse ridges (Table III). Basal till is often described in the literature and is sometimes termed lodgement till.

c. ”Englacially derived till” is not mixed with very local bed rock material and was evidently transported within the glacier ice at some distance above the base. The diagnostic features are the loose nature of the material, its considerable thickness, and its tendency to overlie sediments. On the diagrams, this type shows a high degree of maturity. This is a sandy till with a clay content ranging from 2 to 4 per cent. The contents of pebbles and boulders are low to normal (Fig. 2). The fragments of the coarser fraction, cobbles, appear to be more rounded, whereas abraded edges predominate in the pebble fraction. The content of long-transported material is very high. The till looks homogeneous.

This type of till is usually associated with very thick moraines such as moraine

Fig. 3. Boulder-rich hog's back moraines at Båtsabäcken. From west.

plateaux, large postcrag moraines and some types of moraine-plain with wide Rogen-like forms (Table III). "Englacially derived till" is often described in glaciological texts as englacial debris.

d. Ablation till is ordinarily a loose till material which obviously melted out on the surface of the glacier and above the basement without being affected by any secondary processes which would result in lenses of sorted material or other heterogeneous features. This is a sandy till with a clay content ranging from 1 to 3 per cent. The content of pebbles and boulders is normal to high (Fig. 3). Angular fragments predominate. The material is local, especially the coarser fragments. Sand is commonly sedimented around the coarser fragments. The till is loosely packed. This type of till is mostly associated with hummocky moraines of different forms and sizes, 6a and b, and with fairly thin moraines or confined forms (Table III).

Ablation till is commonly described in the literature and includes, in general, loosely packed tills which are normal to rich in boulders, and sandy with a low clay content.

e. Lense-till or sediment bearing till is a sandy till with a clay content of 2 per cent or less. The content of gravel is low and that of boulders is low to normal. Fragments with abraded edges predominate but rounded fragments are very common although long-transported material is present in some degree. The till contains lenses and thin layers of sand and silt (Fig. 4). At some distance, the

Fig. 4. Lense-till at V. Kikkejaure. From east.

structure has the appearance of a flowing medium. This type of till can occur in level moraines, rather large hummocky forms, and in large transverse ridges (Table III).

Areas of lense till generally occur within localities of dead-ice, melting in valley bottoms (G. Lundqvist 1940) and lee positions (Möller 1960). The lense moraines are considered to have been formed within intraglacial dead-ice (G. Lundqvist 1940) which was subjected to subglacial drainage on a broad front (J. Lundqvist 1969, Daniel 1973) or to temporary local melt water streams within the border zones of the ice (Charlesworth 1957). Lense-till in the area not overlain by other till are interpreted simply as a form of supraglacial flow-till (cf. Boulton 1972a).

Möller (1960), among others, found that lense-till usually lies directly on the underlying bedrock and in certain places is overlain with a sharp contact by

Fig. 5. ''Ablation gravel'' with glacial stream material at Järntjärnsdalen. From south.

a hard packed and pressed till. The lense till has a lower content of clay and silt than the packed moraine. A subglacial lense till which underlies foliated basal till has only been found in the area in the large crag moraines and larger drumlin formations. The formation of this moraine is interpreted by the author as the result of melting in the basal parts of the ice. Melting was caused by the high speed of the ice in relation to the underlying material. The high shear stress in the basal parts of the ice did not produce large cavities and chanelling of the melt water in pronounced tunnels (cf. Glen 1954, Shreve 1972). The underlying till and the till which was deposited from the ice where therefore subjected to washing and sorting by a relatively thin flowing sheet of water on a broad front. The water velocity could vary depending on different pressure zones within the ice, thus a greater velocity would be expected from high to low pressure zones (Shreve 1972, cf. models in Minell 1973, 1975). This would result in a more thoroughly washed till with a lower water activity producing lenses of accumulated silt and less thoroughly washed till.

f. ''Washed till'' or ''ablation gravel'' is a gravelly till with a clay content of less than 1 per cent. The contents of both pebbles and boulders are high. Most of the material is local and angular. This type of till occurs mainly in some types of hummocky moraine (Fig. 5) and it is not very common.

Water activity, occurring when supragracial till has just melted out, may cause washing which can result in only a gravelly till or ''ablation gravel'' (cf. Agrell 1974, p. 134) being left.

g. "Flow till" is a gravelly to silty till with a very variable clay content and with a clear bimodal distribution of the matrix. Micro-foliation resulting from secondary flow can sometimes be seen. This till is sometimes associated with ablation till which has been washed to a greater or lesser extent, or with lense-till where it occurs as thin undulation layers.

The "flow till" is seen here as a fractionation product from the supraglacial flow of "melt out till" (cf. Boulton 1970, 1971).

As mentioned above, the physical nature of the bedrock is of great importance. The till-types mentioned are, however, all from areas with a basement of granite and metamorphosed supracrustal rocks. Features such as fracture frequency do not appear to have influenced this subdivision of tills.

CALCULATIONS

Ek (1974, p. 26) has carried out investigations of the grain size distribution of the matrix within different tills in relation to the distance of transport and stratigraphic relationship. He found that three parameters gave the best response for the distinguishing of tills, namely the standard deviation (σ), the skewness (sk), and the mean (m). For the calculation of these, values have been taken from the phi-scale of the cumulative curve (Ø) (Krumbein 1938). Modified formulae of Folk and Ward (1957) have been used in these calculations. These formulae are tailored to non-normal distribution, which is the case with till, and are based on a system of Inmans (1952), which was more suited to sediments with normal distribution.

$$\text{Standard deviation } (\sigma) = \frac{\text{Ø}\,84 - \text{Ø}\,16}{4} + \frac{\text{Ø}\,95 - \text{Ø}\,5}{6{,}6}$$

is a measure of sorting and is very poor to extremely poor in tills.

$$\text{Skewness } (sk_1) = 1/2\,\frac{\text{Ø}\,84 + \text{Ø}\,16 - 2\text{Ø}50}{\text{Ø}\,84 - \text{Ø}\,16} + \frac{\text{Ø}\,95 + \text{Ø}\,5 - 2\text{Ø}50}{\text{Ø}\,95 - \text{Ø}\,5}$$

is the predominance of coarser and finer mixtures. A predominance of the coarser mixture results in values in the positive direction, but a predominance of the finer mixture results in values in the negative direction.

$$\text{Mean (m)} = \frac{\text{Ø}\,16 + \text{Ø}\,50 + \text{Ø}\,84}{3} \text{ is the mean size.}$$

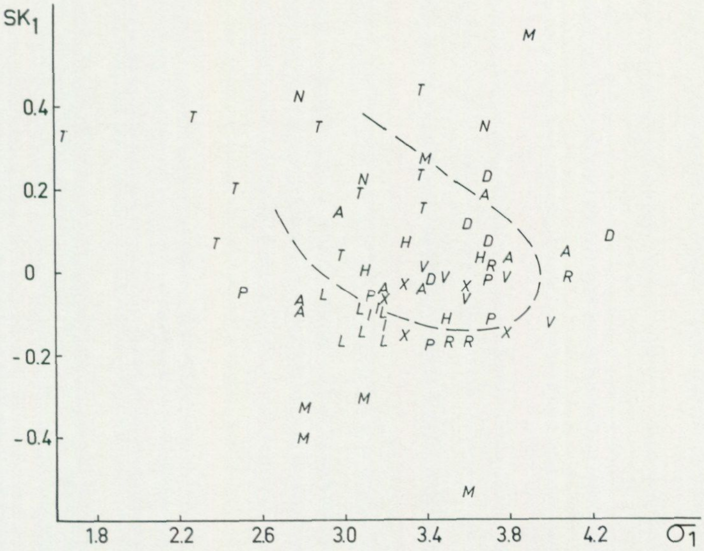


Fig. 6. Diagram with size — distribution parameters, skewness (Sk_1) and deviation (σ). From phi-scale Ø.)

X	basal level moraine
P	crag moraine
V	moraine plateau
A	ablation till
L	lense-till
N	”till at birth”
T	”ablation gravel”
M	”flow till”
I	”englacially derived till” in large transverse ridge
H	ablation till in large transverse ridge
R	basal till in large transverse ridge
D	drumlin

The results can be seen in Figs. 6, 7, 8 and Tables I, II, III. These tills are also presented on a triangle diagram in Fig. 9. Some of the most typical tills have been illustrated on cumulative diagrams in Figs. 10, 11, 12, 13.

Frequency curves are taken from histograms where each column is the percentage value between each phi-value Ø on the cumulative curve. The frequency curves are only illustrated to show the trends of the different tills. The character of the frequency curves and a subdivision of the till on the basis of these is shown in Figs. 14a, b, c and Tables I, II, III.

The diagrams in Figs. 6–9 and Tables I, III represent till from an area with relatively homogeneous bedrock mostly within a limited area around Lake Storavan. The formation of these moraines, however, varies considerably, some being clearly basal, while others are thought to be englacial. The latter have accumulated in an environment with flat glacier surfaces, whereas still others have accumulated from sloping or, in places, fragmented glacier surfaces. The

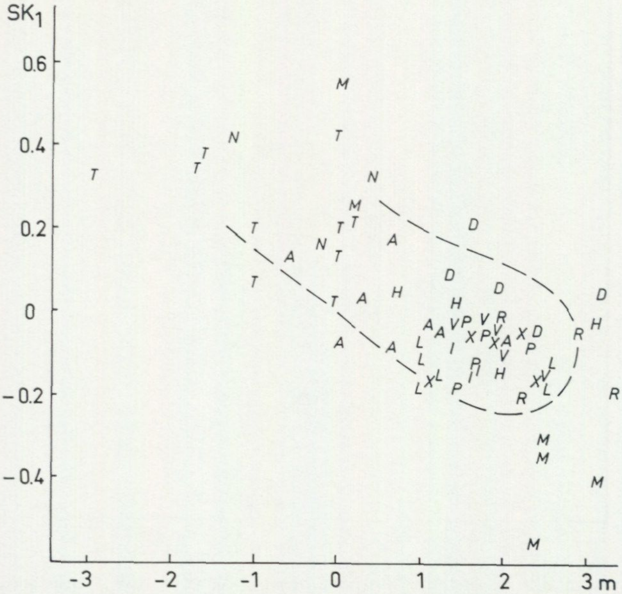


Fig. 7. Diagram with size − distribution parameters, skewness (SK_1) and mean (m). (From phi-scale Ø.) See Fig. 6 for symbols.

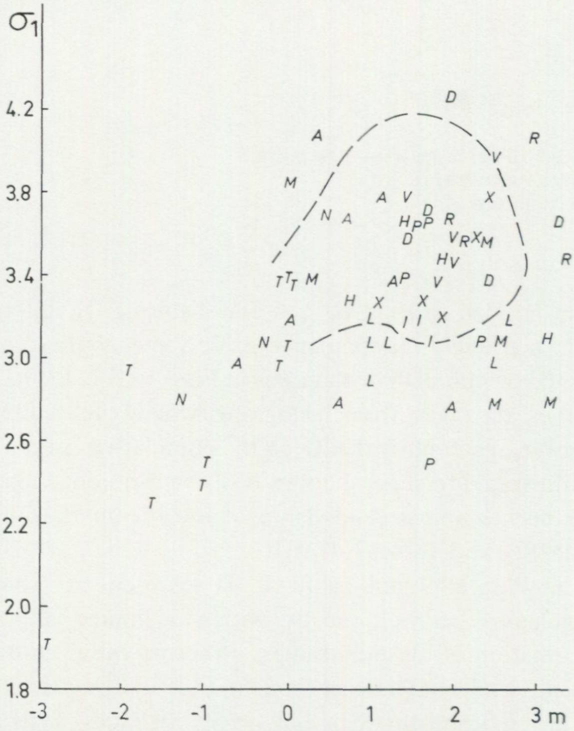


Fig. 8. Diagram with size − distribution parameters, deviation (σ) and mean (m). (From phi-scale Ø.) See Fig. 6 for symbols.

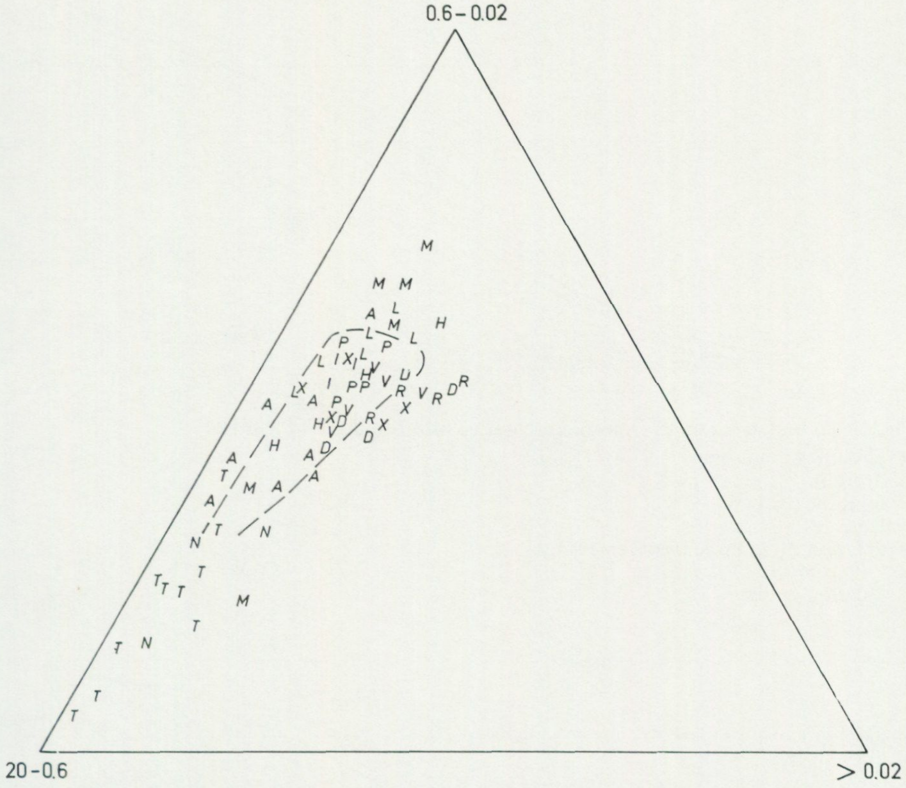


Fig. 9. Triangular diagram showing size — distribution in the till samples with respect to sizes <0.02 mm, 0.02–0.6 mm, 0.6–20 mm. The same samples as in Figs. 6, 7, 8 have been used here. See Fig. 6 for symbols.

clearest differences are apparent from the topography but even the diagrams in Figs 6–8 and Tables I–III clearly illustrate the subdivision of some types of till. A further feature apparent in the diagrams is the degree of maturity of the tills, where a line in all the diagrams can be followed from the till at birth (N) to till in drumlins (D) and further to till in other basal formations; (P), large crag moraines, and (R), large transverse ridges. With the basal formations, the line is often bent in order to go through more mature "englacially derived till" in moraine plateaux (V), large perpendicular ridge (I) or other basal level till surface (X), where it can be continued in the same direction through lense-till, ablation till and other tills with different degrees of washing. One deviation is the extreme bimodal till: this one can, such as the lense-till, be divided into two different groups. The division into groups is not geographically controlled.

The samples from "till at birth" have a considerably greater spread in the diagrams than, for example, those of "englacially derived till" which lie rela-

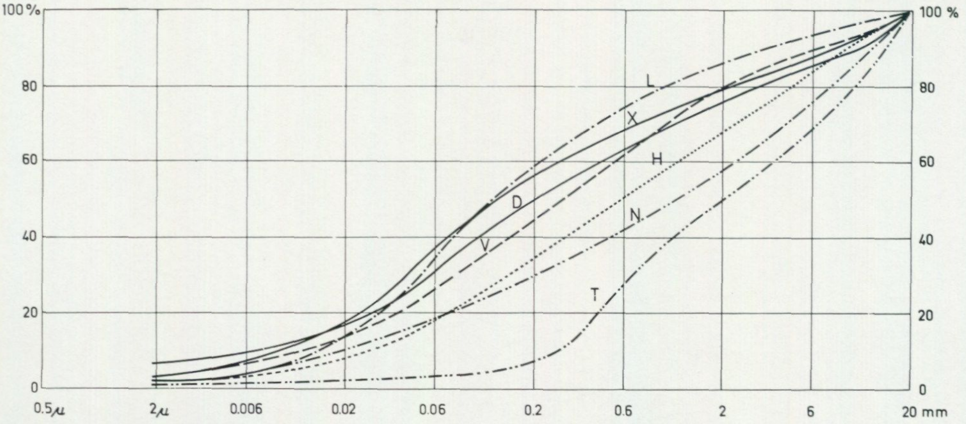


Fig. 10. Cumulative curves from representative tills. See Tables I and III.

X basal level moraine
D drumlin
V moraine plateau
L lense-till
H ablation till in large transverse ridges
N "till at birth"
T ablation gravel

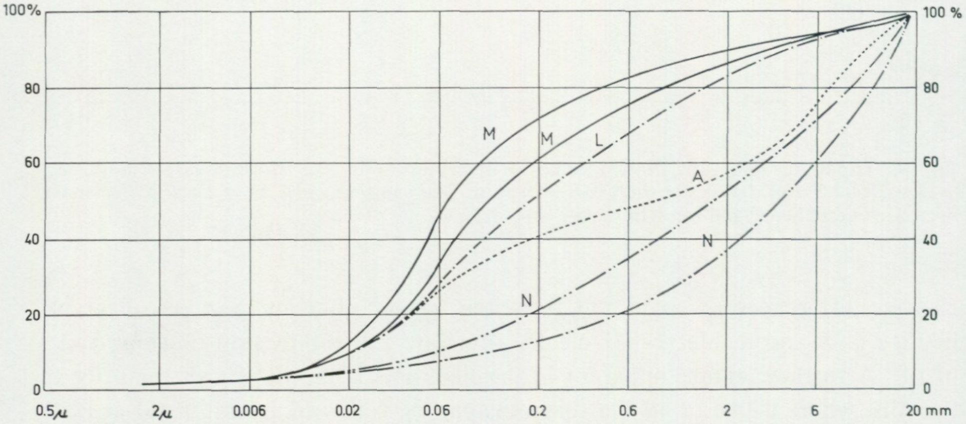


Fig. 11. Cumulative curves from representative tills. See Tables I and III as well as Fig. 6.

A ablation till
L lense-till
N "till at birth"
M "flow till"

tively concentrated. Ablation till and the washed till samples show a poor concentration; some samples lie in the area for "till at birth".

The tills which have been presented have varying transitions. Tills also have a very variable dominance in different areas, the commonest in central Lappland being c, d and e. Close to the Caledonian front, type a is also relatively common.

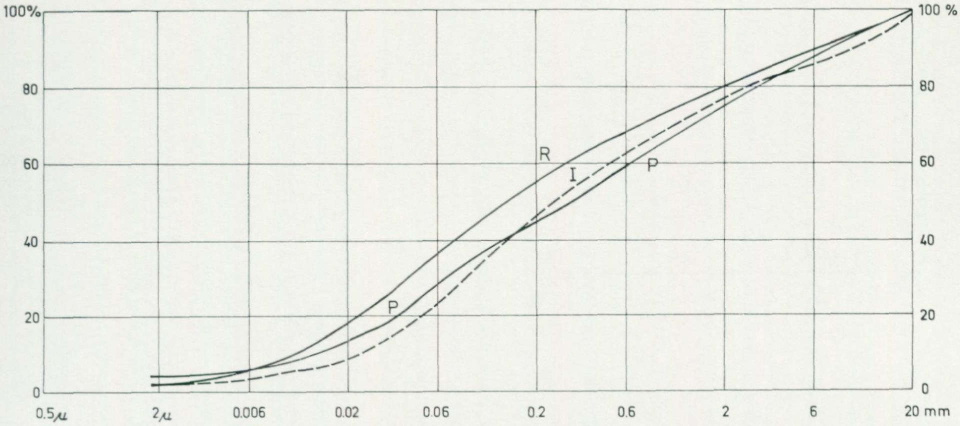


Fig. 12. Cumulative curves from representative tills. See Tables I and III as well as Fig. 6.
P crag moraine
R basal till in large transverse ridge
I "englacially derived till" in large transverse ridge

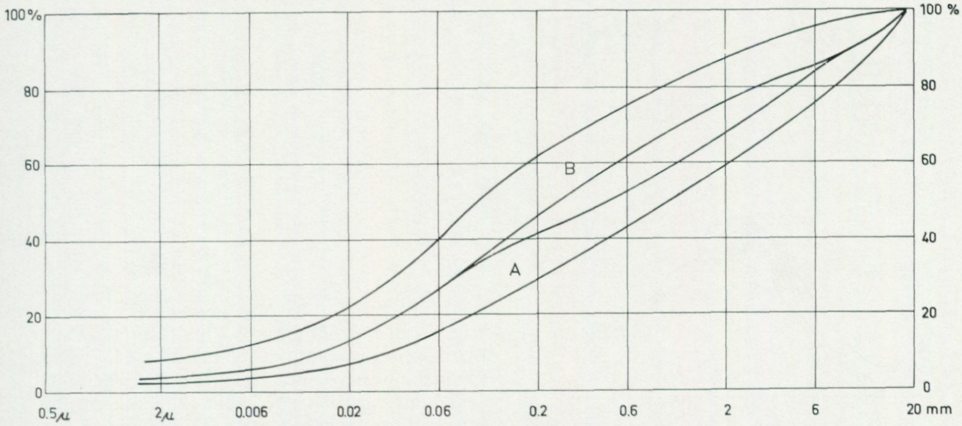


Fig. 13. Cumulative curves of the most common till types of basal origin (B – X, P, R, D) and (A – A, H) from ablation origin. See Tables I and III as well as Fig. 6.

Fig. 15 shows a zone where an attempt is made to illustrate the stratigraphic position of the tills. The figure is schematic and one can expect to find accumulations within several areas which are older than the last deglaciation in certain deeper parts.

As mentioned earlier the grain size distribution of the matrix in till varies also according to the composition of the bedrock and probably also to the distance to the ice-shed. In order to obtain an idea of how distinct these variations are, samples have been taken from different moraine forms. The moraine forms are situated in widely separated areas with different bedrock and different distances

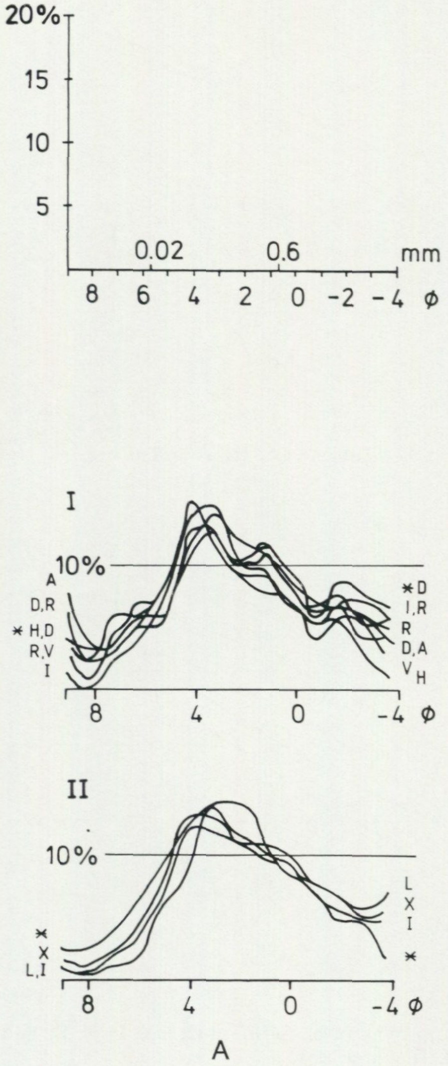
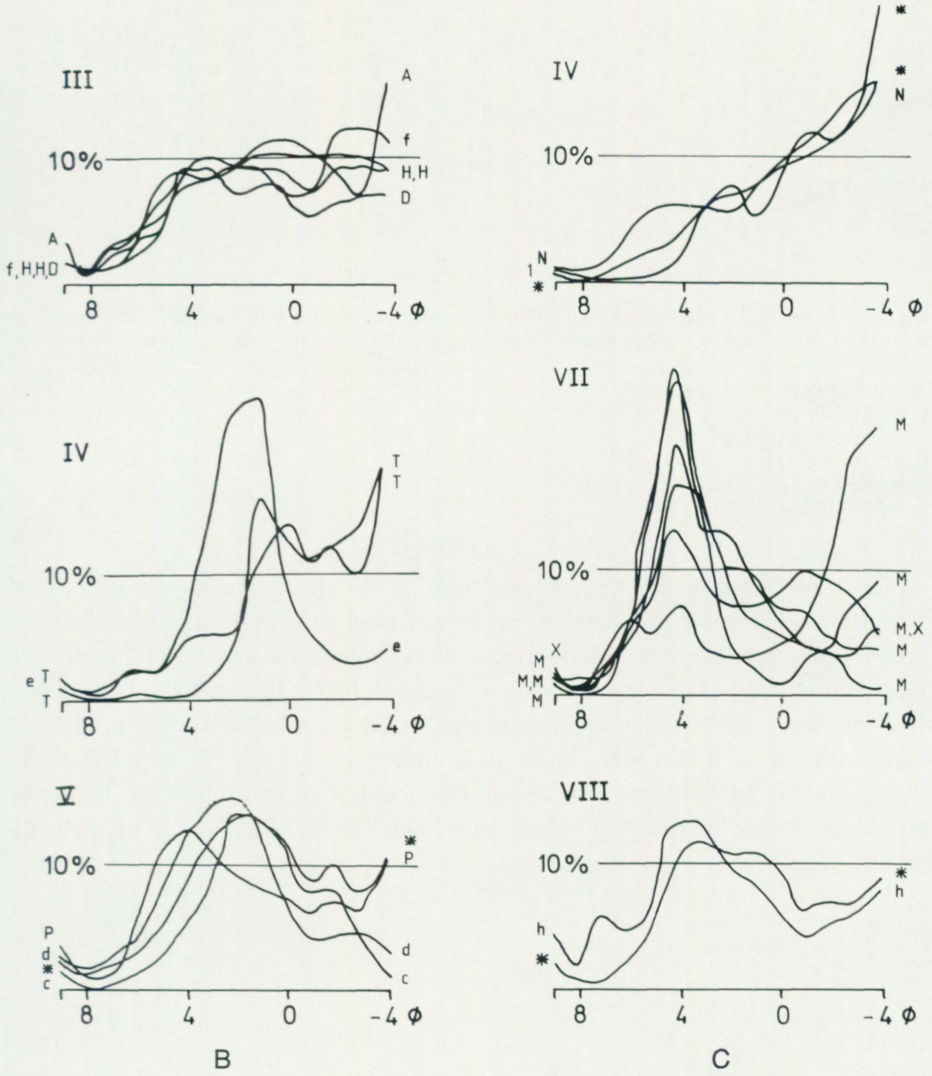


Fig. 14 a, b, c. Diagrams illustrating size – distribution of samples in Tables I–IV. The frequency curves are based on the size-content between each phi-value Ø in the cumulative curve. See Tables I–II and Fig. 6 for signs. The frequency curves are only illustrated to show the trends of the different tills.

from the ice-shed. The values sk, σ, and m have been calculated from Ø results obtained from samples after sieving as earlier described. The values have also been placed on sk, σ, and m diagrams in order to compare with previously illustrated diagrams (Figs. 16, 17, 18). Samples a–c are from an area north of Hornavan–Harrejokk, situated near to the ice-shed. In spite of proximity to the Caledonian front, granitic material is markedly dominant in the till. The morphology consists of hog's-back moraine. The different characteristics of the moraines are due to secondary processes. Samples d–e are from a moraine in Kåbdalis between the ice-shed and highest shore-line. The bedrock consists mainly of



granites of the Lina-Arjeplog type with an area of deformed acid volcanics. The till occurs in an area of moraine plateaux, and consists of material transported very considerable distances. Sample e represents material from a side ridge and sample d represents material from a moraine plateau. Samples f–i are from the moraines at Giltjaur, west of Sorsele in the vicinity of the Caledonian front. The difference in the till depends on the fact that two samples (f, g) were taken from a large transverse ridge in an area with Revsund granite, one sample (h) from a large transverse ridge in an area with Caledonian rocks, and one till (i) from a fairly level large postcrag moraine in the Caledonian. Samples j–l are tills in

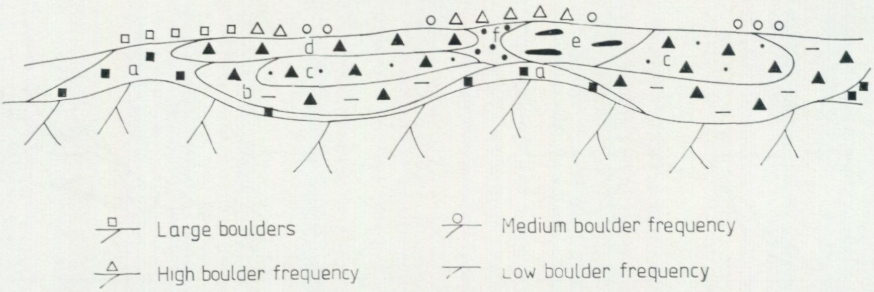


Fig. 15. A general profile illustrating the stratigraphic relationship between tills described in text and in Tables I–IV. There is not supposed to be any age relation between the different deposits.
a, "till at birth"
b, basal till
c, "englacially derived till"
d, ablation till
e, lense-till
f, "ablation gravel"

Abborrträsk between the ice-shed and the highest shore-line, in the vicinity of Arvidsjaur. The bedrock consists mainly of acid and intermediate volcanics, apart from a few granites. The moraines occur in an area with thick till deposits where moraine plateaux and side ridges are developed in places. Sample j belongs to a moraine plateau and samples k and l to a till which overlies a delta of sorted fluvioglacial material. These diagrams, Figs. 16, 17, 18 and Table IV, display tills from different environments of formation, from different bedrocks and from areas which lie at great distance from one another. The same maturity

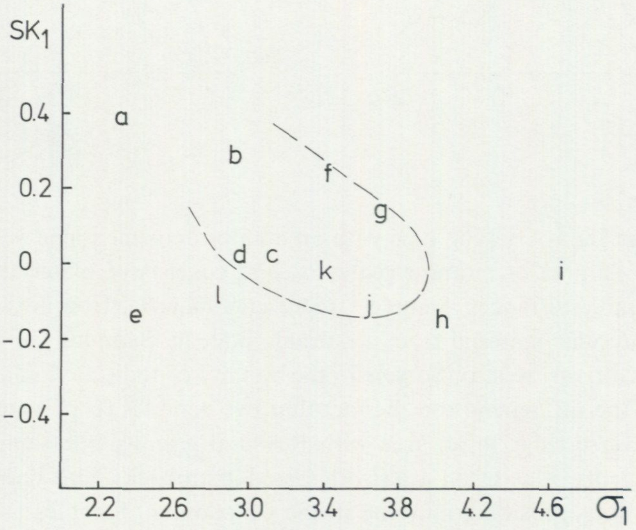


Fig. 16

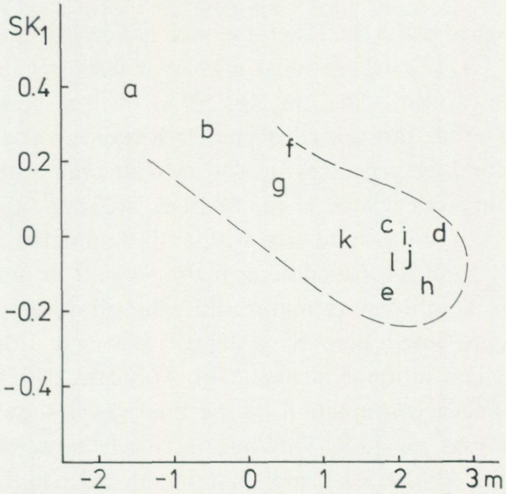


Fig. 17

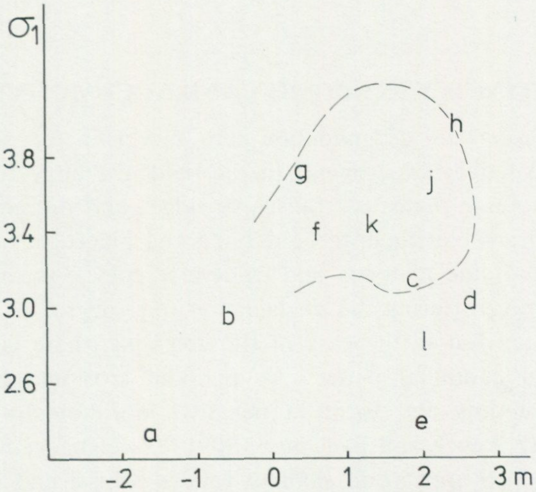


Fig. 18

Figs. 16, 17, 18. Diagrams with size — distribution parameters (from phi-scale Ø). Samples have been taken over a wide area, from different types of localities, between the ice-shed and about 50 km west of the highest shore-line. Fig. 16 shows skewness (Sk_1) and deviation (σ), Fig. 17 skewness (Sk_1) and mean (m), Fig. 18 deviation (σ) and mean (m).

	Area	Sample object, see Table IV
a	Harrejokk	”ablation gravel”
b		”till at birth”
c		ablation till
d	Kåbdalis	moraine plateau
e		”ablation gravel”
f	Giltjaur	ablation till in large transverse ridge
g		do
h		do, (in Caledonian bedrock)
i		crag moraine (in Caledonian bedrock)
j	Abborrträsk	moraine plateau
k		ablation till
l		do

trend can be distinguished as in the diagrams in Figs. 6, 7, 8 and Table IV. In Harrejokk (Figs. 16, 17, 18), where local granite material is dominant in the till, the ablation till lies towards the area for till at birth a, b, while till slopes with a mixture of material transported a greater distance, or a till which has been subjected to secondary processes lie towards an area with more mature till C. In Giltjaur, differences related to the bedrock are more apparent, f and g are large transverse ridges in a granite area with a till dominated by local granite material, while the till from the Caledonian bedrock is of an entirely different character giving a considerably more mature till. The till developed from Caledonian bedrock is represented here by a large transverse ridge (h) and an postcrag moraine (i). The moraine plateaux of Abborrträsk (j) and Kåbdalis (d) respectively lie along a continuation of the line which should be followed from the diagrams in Figs. 6, 7, 8. This line is clearly terminated by the till overlying the sediment in Aborrträsk k and l and the side ridge in Kåbdalis (e).

CONTINUITY IN EROSION AND ACCUMULATION

Continuity in erosion and accumulation can be seen in the field, predicted in theory and simulated by experiment. In the field, the large forms of accumulation such as moraine plateaux, transverse ridges and drumlins, usually have a size scale which enables them to be defined and placed in certain groups. In the case of the moraine plateaux and transverse ridges, secondary alterations are probably involved during the deglaciation (e.g. degree of supraglacial fissure formation etc.) but in the case of the drumlins, there is a basic process causing a certain continual pattern. A periodic erosional pattern which is broader than drumlins and forms a negative morphological feature is the ”zweigbäcken” (cf. Penck and Brückner 1909). ”Zweigbäcken” is a large-scale erosional form which appears in shallow valleys behind end moraine systems in the Alps. The distance between these negative form is approximately 8—9 km and the valley length is of the same order.

In theory, a longitudinal continuity in erosion may be expected (Nye 1967). This erosion could be associated with the slip-line field which can be created in glacier ice flowing over bedrock with some degree of undulating topography. In these types of topographies, preferential erosion should occur in connection with the slip-lines producing a more pronounced concave form in the terrain.

Continuity in morphology where certain defined scale forms appear can be demonstrated by experiment for erosion and even for fissure systems and folding. Some experiments using different media will now be presented. In the first experiment, a cylinder of plastic or viscous material is rolled over silty or fine granular material. In the second experiment two media flow as a system with a normal density gradient. In the third experiment a medium covered with

Fig. 19. Expanded tongues in the less heavy part of two flowing mediums.

a thin skin is flowing. These media of course can not be exactly equivalent to glacier ice, but processes may be seen which can be compared to the processes operating in glacier ice in certain environments. In the first experiment, where a cylinder of rubber clay, or any other soft medium, is rolled over dry silt or sand, the fine granular material is redistributed into longitudinal ridges with no fine material between them (cf. Anketell et al. 1970, p. 19). When the sub-layer is thin, the crests are very narrow and lie close together. The crests become wider, however, and further apart when the sub-layer becomes thicker. Crests are not formed if the velocity of the cylinder is too slow. A fairly high velocity giving rise to high shear stresses seems to be necessary for crests to be formed.

The interesting feature of this experiment is the distribution of the crests without the influence of dilatation or cohesion, or as in flowing media the influence of capillary forces or circulating cells. In the second experiment, both longitudinal and transverse ridge patterns can develop due to acceleration or retardation of the overflowing medium. In this experiment, a lighter less-viscous syrup flowed over glycose with a higher density. The experiment produced a longitudinal negative pattern when flow was constant or accelerating, and a transverse pattern when flow was retarded (cf. Dzulynski and Simpson 1966). These patterns resemble the longitudinal and transverse score marks which usually develop in granular material covered by flowing water and resulting in some types of turbidite pattern (cf. Sanders 1965). The interesting feature of

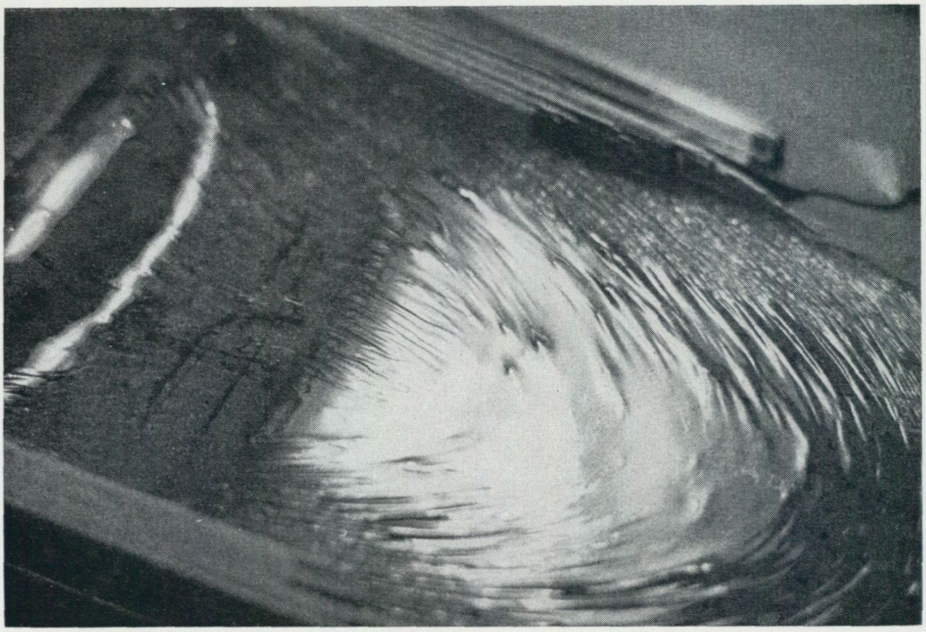


Fig. 20. Folding in a stiffer part of two flowing mediums.

this experiment is the production of these patterns without co-transported tools, without reversed density gradient, or without any form of liquid phenomena, circulating cells or turbidites.

At the beginning of this experiment, a much larger pattern was created in the front of the faster flowing medium. Broad tongues with 12 cm amplitude, grew out from the front, and after flowing approximately 10 cm two new tongues grew out from each of the first tongues (fig. 19). The development of this process requires a much higher longitudinal velocity in the tongues than between them, and the process is probably accentuated by scouring down into the lower medium. Each of the media was less than 1 cm thick, so that the cohesion of the media may probably be a factor determining the scale of each tongue.

This experiment may not be strictly applicable to glacier ice, but it demonstrates the effects of variation in strain rates or velocity distribution in a very wide front of a flowing medium. The location of fast flowing zones is initially dependent upon the primary topography (cf. Robin 1969), but once the zones are established the erosional effects within the zones will accentuate the topography, forming valleys with certain scales which correspond in scale to the zones. Perhaps this large scale model of erosion in transverse section may be related to Nye's (1967) erosion model with slip-lines in a longitudinal direction. Another aspect of morphological interest is the creation of folds in a medium incorporated within another moving medium. Experiments have been conducted using glycose flowing across an undulating surface. The surface of glycose was dried a little, and folds appeared on the skin reflecting areas of extension and compression (fig. 20). Transverse folds appeared at the peripheral parts of the medium, and in some cases proximal to large obstacles or between two adjacent large obstacles. Longitudinal folds appeared in the lee of large obstacles, or on very flat areas, where the medium diminished in volume. This experiment demonstrates the possibility of folding between two media during flow, where the orientation of the folds is dependent upon the topography of the environment.

THE EXPERIMENT IN RELATION TO MORPHOLOGY IN THE FIELD

How do the patterns obtained from the experiments fit in with the actual glacial morphological patterns?

Longitudinal ridges oriented parallel to the direction of flow movement occur between two media where the differences in speed are large, or where high shear stresses develop between the media as a result of acceleration. It is probable that drumlins have formed in such an environment. (See, *e.g.,* Charlesworth 1955, Smalley and Unwin 1968, Minell 1975, 1976.) Shaw and Freschauf (1973) also claim the formation by a secundary flow mechanism. Drumlin swarms and swarms of large fluting usually consist, at least in their upper layers, of a fine-grained till, which in places is compressed or foliated (see following description of area Skidnäsberget).

Transverse ridges, however, occur in environments with restricted flow and reduced speed. Transverse folds occur on a medium which is retarded. Transverse features are therefore thought to occur where ice stagnates and is compressed (Minell 1976). Certain types of transverse ridges give an indication of basal folding or "barcan-like" development (Minell 1977a; see following description of large transverse ridges at Giltjaur, Nimtek and V. Kikkejaure.) Other ridges indicate a strong upwards transport of material in the glacier ice, which, during melting, accumulates in open fractures (Minell 1977; see following description of N. Dötternåive and Nimtek), or is distributed transversally due to the gravitational effects of the actual melting process (see following description of Krutaberget).

With regard to longitudinal erosion on a large scale, it is probably important to make comparisons with the experiment where faster flowing tongues developed at the front of the flowing medium. The only comparison which can be made in this case is the relation in size existing between the breadth of a tongue of ice in "stato surge" and the thickness of the glacier in which it occurs. It is possible that the tendency of glacier ice to produce ice tongues in "stato surge" has contributed to the controlled distribution of the valleys along the Caledonian front. The width of the valleys along the Caledonian front is approximately the same as the "Zweigbäcken"-type lakes of the alpine valley glaciers, that is, 2–4 km wide.

It is important to note that the large-scale topography resulted from older processes. The process concerned with the distribution of faster flowing parts in the glacier ice must only be seen as a controlled distribution which influenced the valley forms and, at the final stage, the distribution of drumlin fields.

REGIONAL DESCRIPTION OF THE AREAS V. KIKKEJAURE, N. DÖTTERN, LÅNGTRÄSKET, AND NJALLEJAURE

INTRODUCTION

The area under investigation lies between valley basins with lake V. Kikkejaure (365.4 m altitude) in the northeast and Långträsket (402.4 m altitude) in the southwest (Plate I, Fig. 21). The valleys are connected by Järntjärnsdalen, which is relatively flat and several kilometres wide. North of the valley lies a 6–8 km wide hill massif with the summits N. Döttern, Liessetjäkke, and S. Döttern, all lying at about 700 m altitude, further Granberget and Tallberget at over 500 m. South of the valley lies an unbroken hill massif with summits at 500–600 m.

The topography of the moraine is dominated by level moraine surfaces in the western part of the area (Långträsket), while the eastern part has a considerably stronger relief. The moraine morphology in the northern part of V. Kikkejaure, Vaksemjaure and Njallejaure consists of large transverse ridges. The southern side of Järntjärnsdalen, in its central and eastern parts, consists of hummocky moraine type 6 a. Proximal to N. Döttern, there is also a large area of hummocky moraine with hog's-back moraines which lie transverse to the direction of ice movement. A number of large postcrag moraines and drumlinoids have been developed in association with the mountains Granberget and Tallberget.

Ice lake deposits in the form of current-bedded sand and silt together with sandy gravel and "ablation gravel" are found to the west of the cross roads at V. Kikkejaure. The ice lake deposits belong to the transition to hummocky moraine. In the sketch map (Fig. 21), the material has been divided into sorted and unsorted types only. The sorted material includes sedimented and water sorted material. The unsorted material includes sandy gravel and "ablation gravel". Some of the large postcrag moraines have been eroded by fluvioglacial activity to a depth of 12–14 m in the form of 100 m wide dry valleys. The fluvioglacial valleys have constituted a drainage system for many kilometres,

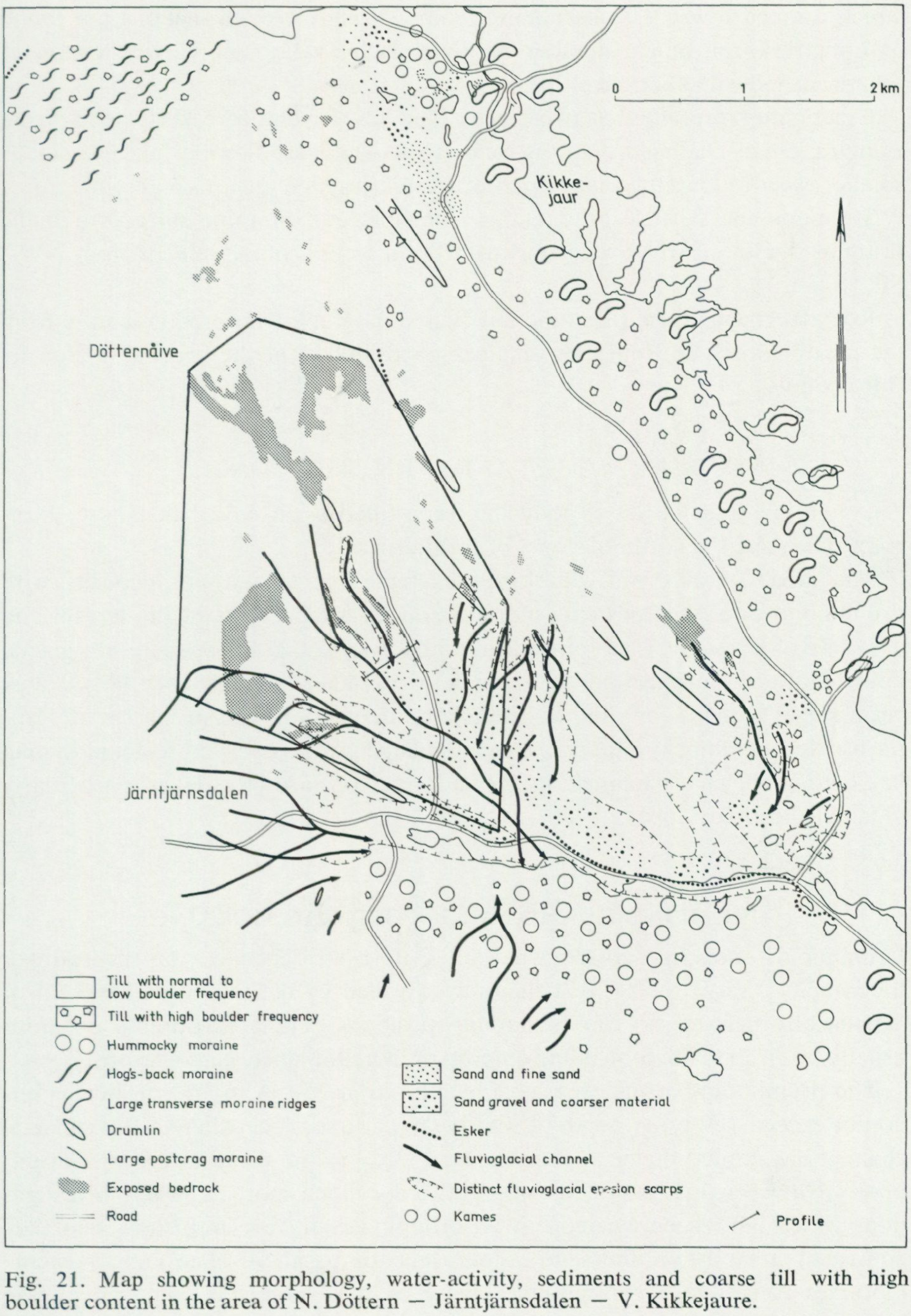


Fig. 21. Map showing morphology, water-activity, sediments and coarse till with high boulder content in the area of N. Döttern – Järntjärnsdalen – V. Kikkejaure.

which drained towards Vaksemjaure. Some strongly eroded sections are found at Långträskbron and a number of fluvioglacial valleys of varying character are associated with Gierkåive.

Eskers are represented at two places. The best developed esker extends from Långträsket to Njallejaure and it follows the southeast flowing lake system. A smaller esker follows the central part of Järntjärnsdalen towards Vaksemjaure.

Striations and particle orientations from the level moraine surfaces and the drumlin shapes clearly correspond with the direction of movement from NW–SE.

Rock fragments from till in the low lying topography are predominantly from the local bedrock and one can obtain a good picture of the bedrock region by stone counts.

V. KIKKEJAURE AND JÄRNTJÄRNSDALEN

The area investigated lies close to the basin filled by lake V. Kikkejaure, Järntjärnsdalen and the northern slopes of Järntjärnsdalen.

The area contains well developed examples of Quaternary deposits with drumlinoids and large postcrag moraines on the raised parts of the terrain and a variety of hummocky moraines in the hollows. In the north, there are glacial lake deposits with transitions to hummocky moraine. Long series of large transverse ridges extend along the V. Kikkejaure depression, and in the lee of Järntjärnsdalen hummocky moraine is accumulated. An extensive erosional system has cut fluvioglacial channels in the moraines of Järntjärnsdalen, particularly along the northern slopes.

DRUMLINOIDS AND LARGE POSTCRAG MORAINES

Drumlinoids and large postcrag moraines are both dependent on the bedrock topography, that is to say, that they have formed by deposition of basal till or ”englacially derived till” in favourable positions. These favourable positions usually lie distal to the protruding outcrop or in hollows between outcrops.

The drumlinoids of the area have lengths from 250 m to 700 m, but widths do not exceed 100 m. A depth of 9 m is seen at one place where a fluvioglacial channel has eroded down to bedrock very close to the central part of a drumlinoid. However, it is assumed that depth vary much more. The few investigations which have been carried out on drumlinoids in this area show that they consist of a sandy or fine sandy, homogeneous basal till. The large postcrag moraines consist to a considerable extent of very large hill outcrops, on the distal side of which till has been deposited. The thickness of till is usually inconsiderable but thicknesses of up to 20 m can occur. The large postcrag moraines are usually up to two kilometres long and between 500 and 100 m wide. They are often covered by an uneven layer of thin ablation till, due to their lee position. At a depth of a few metres appears a grey sandy till of the "englacially derived" type or the basal type. In an other area, south of Storavan and close to the Granliden massif (Plate II), good road cuttings through large post-crag moraines and drumlinoids are to be seen. All these forms contain a weakly washed till, in places lense-bearing, which is overlain by a few metres of foliated till.

LARGE TRANSVERSE RIDGES

Large transverse ridges are thick ridges of till which lie transverse to the direction of ice movement. They occur in large systems with ridges occurring one after the other. The distance between the ridges and the width of the individual ridges are generally constant at about 200 m. The thickness of till in the ridges corresponds to the depth of the basin which is filled by the large transverse ridges. Often this is several tens of metres. The basin in V. Kikkejaure which is filled with large transverse ridges has an area of 2×4 km. The primary requirement for the formation of large transverse ridges is thought to be a flat trough-shape of only a few tens of metres depth within a large concave area (cf. J. Lundqvist 1969a). A few of the large transverse ridges in the area have a weak indication of barchan or crescent shape. Towards the periphery, the ridges show transitions to hummocky moraine type 6a. The southern part of Järntjärnsdalen is covered by this hummocky moraine, which passes successively eastwards into large transverse ridges at Vaksemjaure. The large transverse ridges of this area are generally composed of a light grey, sandy, supraglacially formed lense-till or in the central part of the basin an "englacially derived till" (Figs. 6–9, Tables I–IV).

The lenses in the lense-till generally consist of sorted sand or silt. In places the lenses are abundant and can vary in size from a few centimetres to several decimetres. Particle orientation studies have been carried out on this type of lense-till at Njallejaure (Plate I and Fig. 31a) and Långträskbron (Plate I and Fig. 31b). At Långträskbron, the particles tend to lie oriented parallel with the last direction of ice movement, or perhaps in this case down the slope of the pre-ice surface.

In the southeastern part of Järntjärnsdalen, immediately southeast of V. Kikkejaure at Mörttjärn, there are quite flat broad transverse ridges. The ridges consist of homogeneous basal till. A particle orientation study from the ridge in Järntjärnsdalen gives a maximum value of N 50° W and a high value in the transverse direction (Fig. 25b).

TILLS

Five categories of tills have been distinguished within the area. The tills belong to those described in the earlier chapter on subdivision of till Tables I–IV.

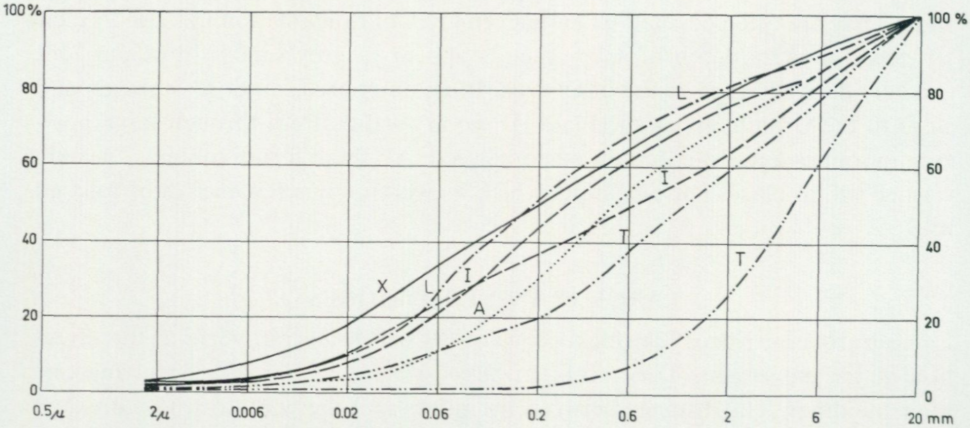


Fig. 22. Cumulative curves from some representative tills in the area of N. Döttern — Järntjärnsdalen — V. Kikkejaure. See Tables I—III.

X basal level moraine
I "englacially derived till" in large transverse ridge
L lense-till
A ablation till
T "ablation gravel"

Type a. "Till at birth" is not found in this area, but in places till type d (ablation till) is so mixed up with local bedrock material that it is very similar to "till at birth".

Type b. A fine sandy till with a certain content of clay. In places the till has a clear basal character. The boulder content is usually normal to poor (cum. curve X, Fig. 22). The till predominates at higher altitude in the drumlinoids but also in level moraine and in transverse ridges in the southeastern part of Järntjärnsdalen.

Type c. Fine sandy till with a low pebble content and a clay content of a few per cent. The surface is usually poor in boulders. This till is found in the central basin in V. Kikkejaure and in some large postcrag moraines (cum. curve I, Fig. 22).

Type d. The ablation till consists of fine sandy to gravelly till. The pebble fraction is often high. The boulder content is normal to rich often with large boulders. Within certain areas, the till is thought to be intermixed with the "till at birth" (type a). The ablation till predominates in the central and southern part of Järntjärnsdalen (cum. curve A, Fig. 22).

Type e. A lense-till which consists of a sandy to fine sandy till with lenses of sand or silt. The pebble fraction is low. In the larger pits, a form of compressed or large "flow structure" is apparent. The boulder content is usually normal to rich, but boulder-poor moraine does occur. Some of the large transverse ridges are built of lense-till (L, Fig. 22). The till predominates in the northwestern basin of V. Kikkejaure.

Type f. ”Ablation gravel”, probably unsorted and washed till transported a short distance. The grain size of the matrix is greater than sand. The till is very similar to gravelly, sandy glacial stream material. The ”ablation gravel” occurs often in association with the lense-till and overlies it (T, Fig. 22). The till is found in the ice-lake deposits in the northwestern part of V. Kikkejaure.

GLACIAL LAKES AND FLUVIOGLACIAL DEPOSITS

An area with glacial stream deposits is found along the lower, northeasterly slopes of N. Döttern. The slopes of N. Döttern have formed the southwestern boundary of a glacial lake, while the rest of the lake was bounded by a fragmented, decaying tongue of ice along V. Kikkejaure (Fig. 21). The glacial lake belongs to the type described by J. Lundqvist as a transitional form between glacial lake and dead ice (types 3 and 7, J. Lundqvist 1972 and 1973, p. 162).

The clearest indications of glacial lakes are terraces of fluvioglacial material, kames with abundant well-rounded cobbles, and sediments of silt and sand. Fluvioglacial material can vary from ”ablation gravel” (a strongly washed moraine) to a gravelly sand. The terraces associated with the rock slopes in the southwest consist of ”ablation gravel” of almost till character, while the terraces associated with the kames in the north consist of sandy gravel. The kames below the terraces have a gravelly — sandy character and are thought to originate from the esker. The gravelly sand overlies a grey sandy till of the lense-bearing type.

The western and central parts of the glacial lake area have a more complex stratigraphy. Many of the flat, fluvioglacial deposits which consist of sandy, gravelly material, can sometimes have a thin cover of a few decimetres of till. In places, this till can be quite boulder-free over large areas. The till is sandy to fine sandy. In some more hummocky areas, some very rounded boulders are to be found in places, particularly on the slopes, and they cover the underlying fluvioglacial (Fig. 5) material (cf. Mannerfelt 1945). Zones of cobbles also occur higher up on the southwest mountain slope where they cover ”ablation gravel”.

The thickest formations in the area are the terraces, which attain the same heights as the zones of cobbles deposited along the southwestern mountain slope. The terraces have ice contact slopes, which can be up to 8 m in height above the surrounding terrain. The smallest formations of the area do not exceed a few metres thickness and consist of silt or sand. The silt has probably been deposited during quieter conditions, while the sand, often together with silt, forms current bedding in the deposits. One formation in the southern part of the glacial lake area shows clear current bedding (Fig. 5). The surrounding terrain exhibits in places a very quiet environment with fine silt of flaky character (cf. J. Lundqvist 1972). The fine silt does not form any topographic feature above the surrounding terrain.

Two more areas of glacial lake character are to be found within the map sheet area (Plate I). These areas consist of sandy, gravelly material which builds up kames. All these glacial lakes appear to have had a brief existence, with fluvially transported material being deposited in fractures in the decaying ice (cf. J. Lundqvist 1972 and 1973, p. 162).

In some areas, sandy gravel or "ablation gravel" have been deposited in established lakes on the ice. Where the fluvioglacial streams emerged from the ice, sand and silt was deposited in current bedding, while the fine silt and flaky sediments were transported further to a quieter environment. In places, till could be deposited on top of the fluvioglacial stream deposits from nearby decaying ice blocks. During melting, the till flowed out over the fluvioglacial stream deposits (cf. Boulton 1972).

Fluvioglacial streams in other areas have left fewer traces in the form of thin layers of silty sediments (G. Lundqvist 1943, p. 84). Sediments of such character occur south and east of Ledfatsfjället (southeast of Skidnäsberget). These sediments were probably deposited in weakly concave surfaces on a relatively flat glacier surface (cf. Gillberg 1956, p. 406).

FLUVIOGLACIAL CHANNELS AND ESKERS

The fluvioglacial channels form a strongly eroded drainage system on the northern slopes of Järntjärnsdalen (Figs. 21, 23, 24, and 26). At high altitudes within the area, the erosion has been strong and outcrops are exposed in places, and in some cases small canyons occur. The canyons generally have a depth of 6–8 m and are not usually more than 10—15 m wide. Their length is very variable and dependent on the topography, but usually they do not exceed 80–100 m. The canyons are generally oriented from N 40°–50° W or in some cases from

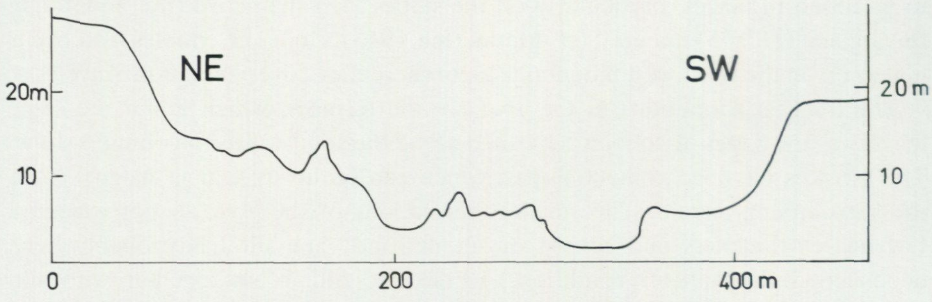


Fig. 23. Profile drawn across the fluvioglacial system at Järntjärnsdalen (Fig. 21).

Fig. 24. The fluvioglacial erosion system at Järntjärnsdalen (the profile in Fig. 21). From northeast.

N 30°–40° E and N 75° W. These directions correspond with the direction of water flow at each locality prior to erosion. However, these directions also correspond with the most common directions of fissure boundary planes and other weak zones in the bedrock. Deep erosion into the bedrock could therefore take place because of the coincidence of high water pressure and strong material transport with the presence of weak zones in the rock. These canyons described here are probably a smaller variant of those described by Rudberg (1949, p. 443), Fromm (1965a, p. 134) and Daniel (1975, p. 93).

At higher levels, the till is also washed out beyond the clear channel formations while further down, where the erosion has not been so strong in the fluvioglacial channels, the normal sedimentary frequency is an ablation till or ”ablation gravel” overlying a grey, sandy till.

Further east, where the valleys are less steep, one can distinguish a greater degree of accumulation. Here ”ablation gravel” till, sandy gravel, gravel or areas of small boulders overlie the gentle slopes of grey sandy till.

With the formation of the fluvioglacial channels, the glacier had reached the height at which the valleys begin. Here the supraglacial streams cut down under the ice and initiated erosion.

An esker occurs within the area. It runs from a fluvioglacial channel down to lake Vaksemjaure (Fig. 21). The material in the esker is largely gravelly sand but sorted finer material also occurs. The ridge of esker material and sand is

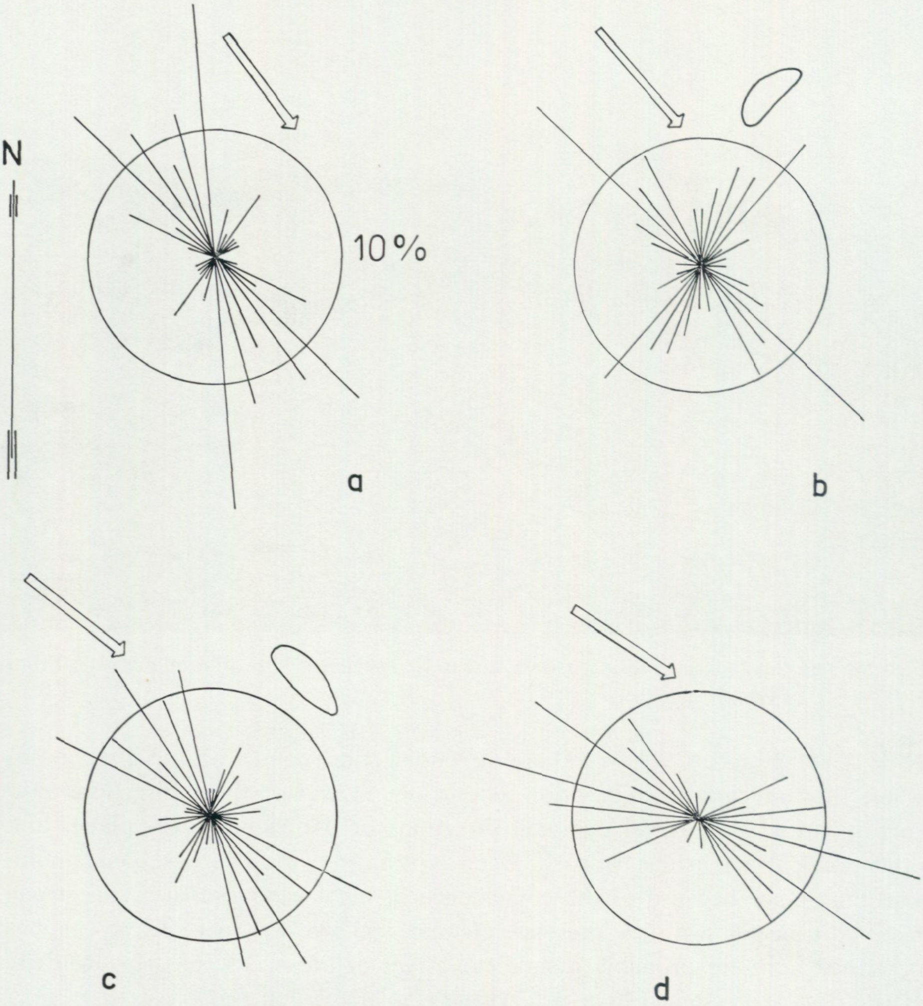


Fig. 25. Orientations of pebbles from

a, an even till surface at a depth of 1 m close to V. Kikkejaure,

b, a large transverse moraine ridge of basal origin at a depth of 1 m to the southeast of Järntjärnsdalen,

c, a drumlin on high level. Depth 1 m,

d, an even till of basal origin at a depth of 1.5 m at Långträskbron. The locality is at the bottom of a fluvioglacial channel.

overlain by till, which in turn is overlain by silt. The ridge was clearly formed sub-glacially. In places the roof of ice must have collapsed, causing any till on the surface of the ice to accumulate on top of the esker. Between these areas of till, sedimentation could take place under quieter conditions.

The initial deposition of the esker took place when the living ice front stood on a level with the northern part of Vaksemjaure and the sub-glacial drainage began further along the valley. The ridge was formed sub-glacially very close

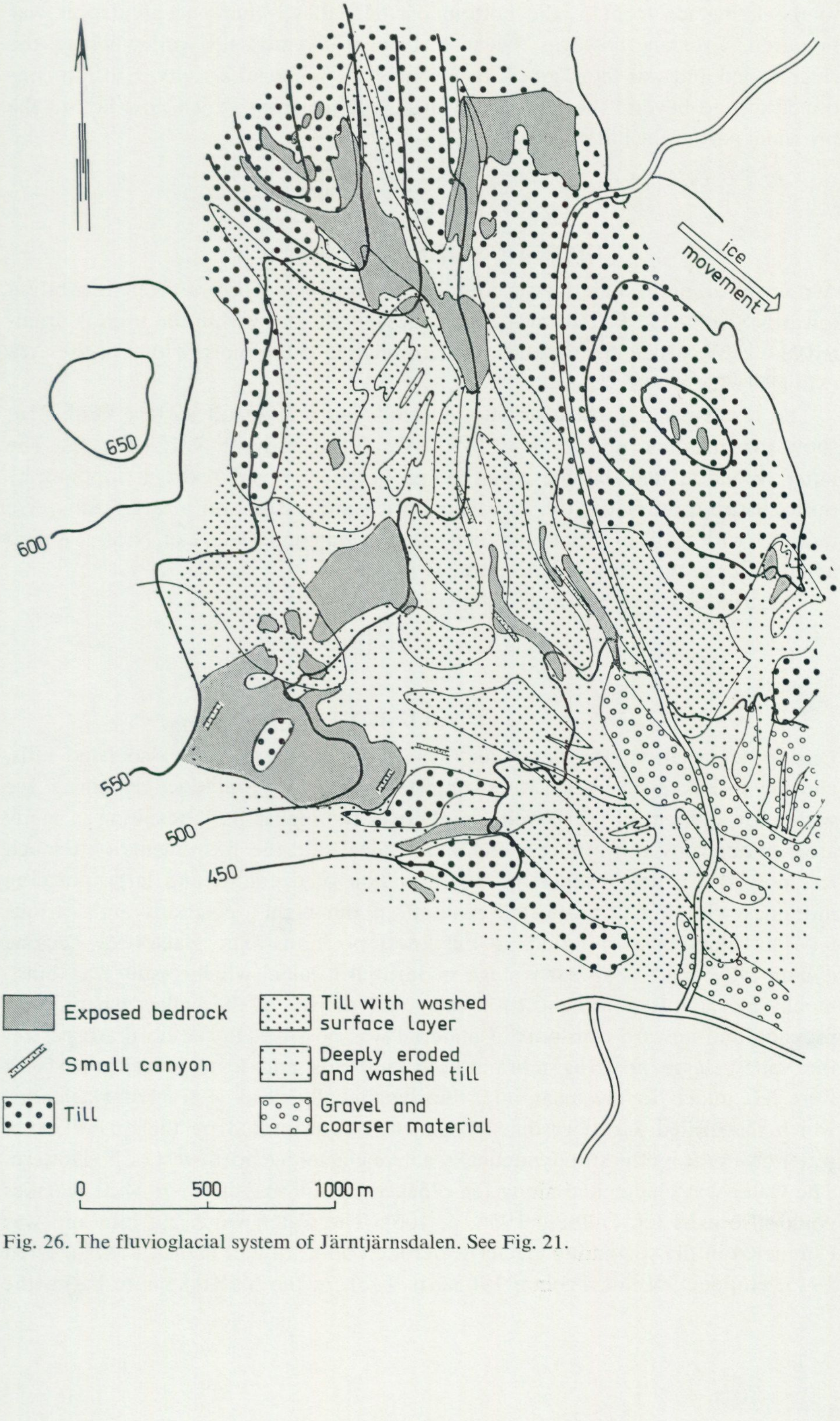


Fig. 26. The fluvioglacial system of Järntjärnsdalen. See Fig. 21.

to the living ice front in the bottom of the valley, where accumulation was favoured. Erosion, however, became stronger towards the valley where the ridge ended and was later cut off by stronger fluvioglacial activity. Erosion continued at and beyond the margins of the living ice front which now lay on the proximal part of the hill massif.

DIRECTION OF ICE MOVEMENT

A train of uranium mineralized boulders exhibits as a whole a clear orientation towards S 20°–25° E. However, the longest single unit within the train is oriented N 40° W, which corresponds to the direction of the morphology of the area (Minell 1978).

The results of a particle orientation study on a level till surface (Fig. 25a) show two maxima, one at N 40°–50° W and another at N 1°–10° W. The latter direction may be the result of influence by local bedrock topography during deposition of the till. A particle orientation study on a large transverse moraine with a till of basal character gives a maximum value of N 50° W and a high value in the transverse direction (Fig. 25b).

The striations show a youngest direction from N 45° W.

CONCLUSION

During deglaciation, Järntjärnsdalen, the Döttern massif with associated hills, and the V. Kikkejaure basin were subjected to highly variable ice dynamics. Ice with a low content of till moved rapidly over the higher parts resulting in many areas of outcrops. Lower down, and on the distal side, the movements were much less powerful which resulted in the formation of drumlins and large postcrag moraines with long transported materal in the higher positions and various types of hummocky moraines in the lower positions. The glacier ice became dynamically dead at an early stage in Järntjärnsdalen, which resulted in hummocky moraine (type 6a and b) in the southern part of the valley, where compression and upward transport of material was possible. In the northern part of the valley, large postcrag moraines, drumlinoids and level moraine surfaces were left intact. In the meantime, the dynamically dead section of glacier ice which then filled Järntjärnsdalen began to be perforated by the quantities of water given off by the still dynamically active glacier ice northwest of N. Döttern. The water was channelled along the blocked up hill massif where wide icelakes could also exist (cf. Gillberg 1956, p. 406). The water which cut into and was channeled in the stagnating glacier ice eroded both till and bedrock (Mannerfelt 1945, Hoppe 1950, cf. Fromm 1965a, p. 132). In the V. Kikkejaure basin, the glacier ice was not constricted but could flow freely. This glacier flow was possibly obstructed by dynamically dead ice in basins such as Njallejaure, Vaksemjaure and Kikkejaure, and thus caused strong compression. Compression resulted in upward transport and mixing of the local material and the long transported material. It is also probable that the basal parts underwent folding which resulted in large transverse ridges. Along the peripheral parts of the stagnating, but still dynamically active ice, temporary glacial lakes could develop.

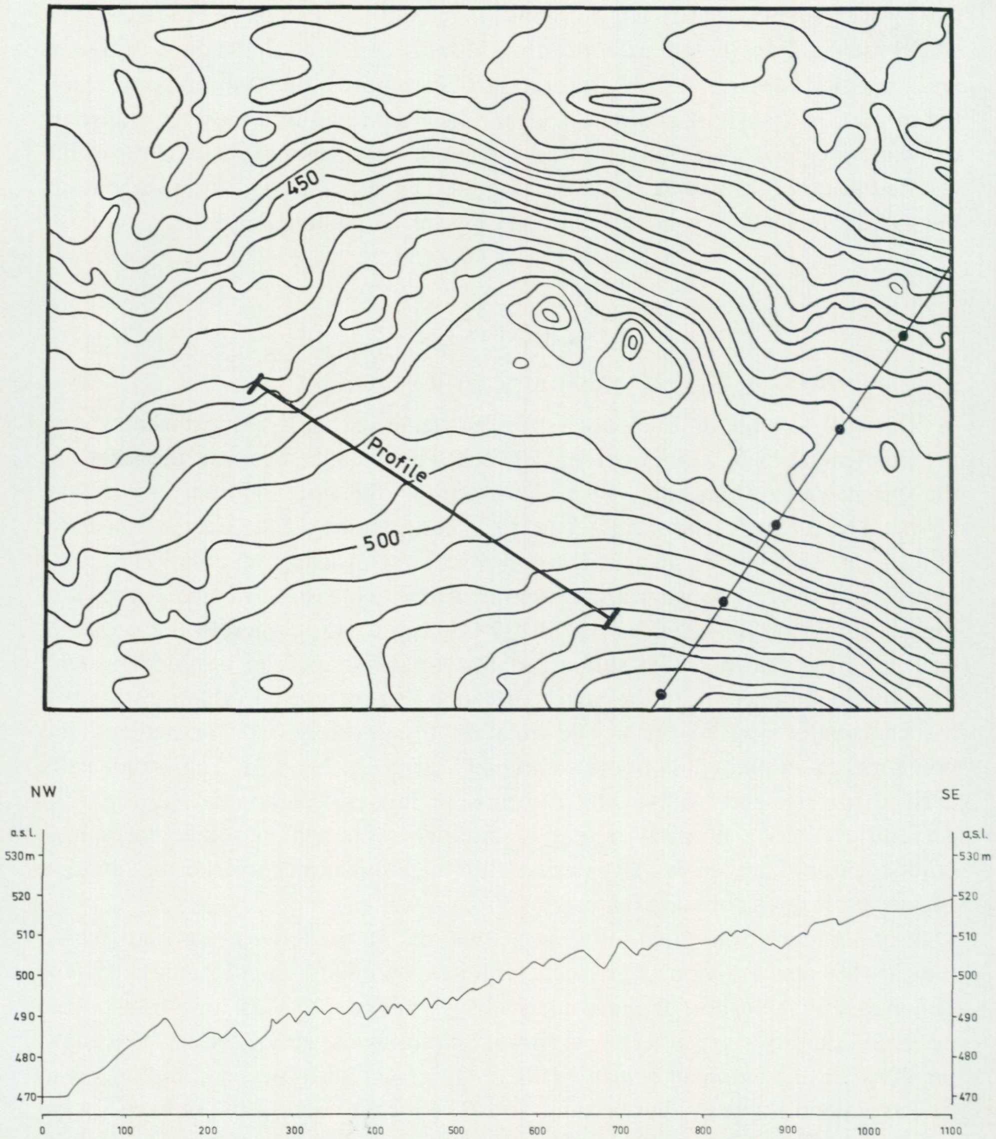
N. DÖTTERN

HOG'S-BACK MORAINES

A 600–800 m wide zone of hog's-back moraines extends along the northern, proximal slope of N. Döttern (Figs. 27, 28). The distance between the ridges of the system varies from 20 to 40 m. The width of the ridges is rarely more than 25 m. Their length and height can vary considerably, but length is usually 30–100 m and height 3–6 m. Moraine ridges consisting of ablation till are always hog's-back shaped with a summit. Ridges consisting of till type c (I in Fig. 22) are usually steeper on the distal side (up to 45°) whereas the proximal side is flatter, and no clear summit or hog's-back shape can be distinguished. Two tills dominate within the area, corresponding to types d (ablation till) and c ("englacially derived till"). The ablation till is sandy, rich in pebbles and boulders and in places the boulders are very large (A, Fig. 22). The "englacially derived till" is sandy, silty with a normal to low pebble content (I, Fig. 22). The surface has a normal content of boulders although in some places it is boulder-poor. The "englacially derived till" can sometimes overlie the ablation till but this is not a common feature.

A preliminary non-quantitative rock type determination was carried out on the 20–80 mm fraction. The local granites dominate in all sample groups although long-transported material is always abundant. This long-transported material comprises greenstones, granites, amphibolites, grey gneisses, volcanics, phyllites and Caledonian schists. This mixture of rock types is common up to the large pebble and smaller boulder size. The local granite is the only rock type to occur in the large boulder fraction. The striations indicate that the ice had its last movement from N 35°–50° W.

It is suggested that the ridges were formed in open fissures in stagnating ice on the proximal slope of a hill mass. Crevassing of the ice occurred during melting whereby the water-saturated till, which was released, successively filled the crevasses (cf. Boulton 1972 and Minell 1977). Ridges with "englacially derived till "possibly belong to the type of ridge which is folded basally but not transported up to the ice surface (Minell 1977a, cf. Kupsch 1962, p. 592, and Moran 1971, p. 138).



Figs. 27, 28. Profile drawn across the hog's-back moraines at the proximal part of N. Döttern.

LÅNGTRÄSKBRON

The area investigated lies between Långträskbron and Nordanås where Järntjärnsdalen joins Långträskdalen (Plate I). The area between Långträskbron and Nordanås is strongly eroded down into an originally level moraine surface (Fig. 30). The surface of till is level and can generally be regarded as boulder-

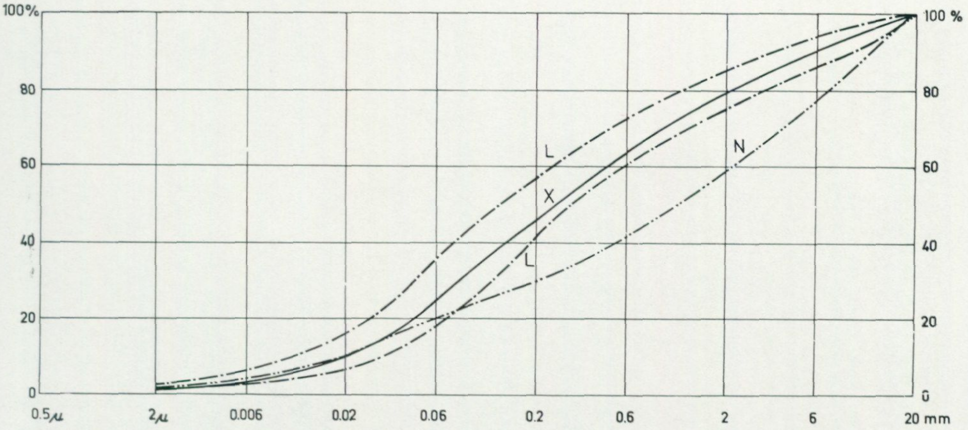


Fig. 29. Cumulative curves from some representative till samples in the area of Långträsket. See Tables I – III.

X basal level moraine
L lense-till
N "till at birth"

poor, even though many small boulders are abundant in some places. Four categories of tills have been distinguished in the area. The tills belong to those described in the chapter on subdivision of tills and Tables I–IV.

a. "Till at birth" is a gravelly till with a high content of locally-derived material.
b. Basal till is compacted sandy to fine sandy with a low content of boulders.
e. Lense-till is sandy with a low boulder content. The till contains lenses and thin layers of sand and silt.
f. "Ablation gravel" is a gravelly till with a high boulder content.

Stratigraphically, the lense-till (cum. curve L, Fig. 29) overlies a fine-sandy, compacted till. Due to local fluvio glacial erosion, however, the lense-till has been eroded away and, closer to the shore, it is replaced by "ablation gravel" and pebbly–sandy gravel. The strongly washed material lies only on compacted till or lense-till. The transition from the overlying till can go successively from fine-sandy till to "ablation gravel" and then, at a depth of about 1.5 m, to gravel. A reddish, gravelly–sandy, compacted till can be regarded on the basis of this strictly local appearance to be a "till at birth" (cum. curve N, Fig. 29).

Measurements of particle orientation were carried out on three level till surfaces. Between 50–60 particles where measured at each place. These tills all have a dominant orientation approximately N 50° W. A sandy to fine-sandy, hard packed till (Fig. 25d) exhibits two clear orientations, one from N 50°–60° W and one from N 70°–80° W. A reddish gravelly–sandy, hard packed "till at birth" (Fig. 31 c) shows two clear orientations, one from

Fig. 30. Fluvioglacial erosion scarps at Långträsket. From southeast.

N 40°–50° W and one from N 10°–30° W. A lense-till (Fig. 31b) exhibits a clear maximum orientation from N 50°–60° W. The overall maximum orientation of N 50° W is easily explained because the final ice movement was probably channeled along Långträsket, which in general has this orientation. The two differing directions were obtained from tills whose distance from the underlying bedrock is so slight that irregularities in the bedrock probably caused these divergences.

Striations were only found on strongly eroded outcrops on the floor of the eroded valley. Only coarse, 0.5 cm wide, older striations could be distinguished, indicating movement from N 38°–59° W. The clearest direction is from N 41° W–S 47° W.

Rock type determinations were carried out for the pebbles of the 2–6 cm fraction. The determinations were made from two sampling pits in each till. 80–90 pebbles were determined from each pit. The average contents in percentages were calculated from each till.

Till N, cum. curve Fig. 29, constitutes a special case of "till at birth" as only two rock types are present. The main constituents are acid to intermediate volcanics (68 per cent), and the remainder (28 per cent) consists of porphyritic granite (Table VI). Probably these high contents of local rocks are caused by a crush zone in the bedrock, which could release considerable quantities of crushed material. Low and variable amounts of red and grey gneiss, ultra-

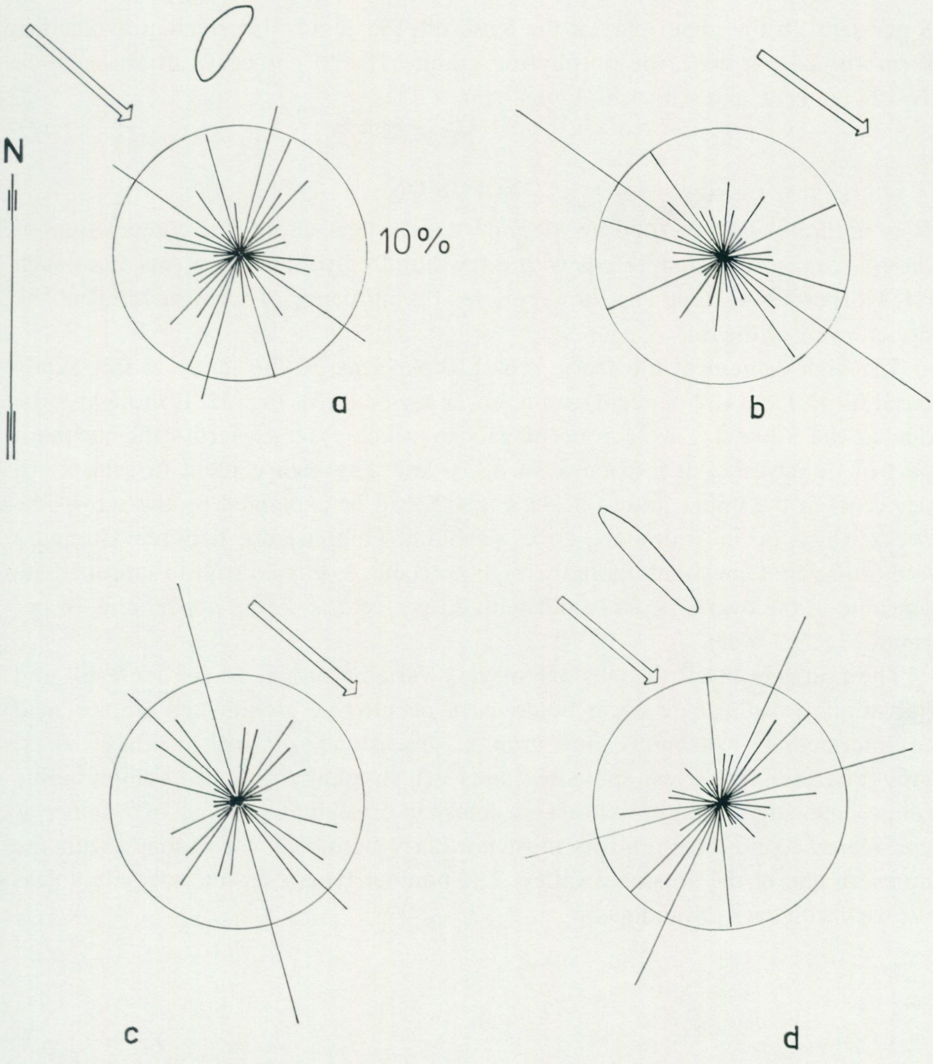


Fig. 31. Orientations of pebbles from
a, a large transverse ridge of till with sediment lenses at Njallejaure. Depth 2 m,
b, an even till surface with sediment lenses at Långträsket. Depth 1 m,
c, a basal till consisting of "till at birth", Långträsket. Depth 1 m,
d, an esker with sediment lenses at Långträsket. Depth 1 m.

basic rock, grey granite and quartzite are common features of all the other tills. A local red granite forms 4–14 per cent of all the tills.

For till X, cum. curve Fig. 29, no great variations were apparent as the sampling was only made in two adjacent holes. The result gives a high content (30 per cent) for the local acid–intermediate volcanics and 14 per cent for the porphyritic granite, which is also local. Greenstones represent 24 per cent and schists

8 per cent. In the upper part of the lense-till, the acid to intermediate volcanics form 16–22 per cent, the porphyritic granite 18–26 per cent, ultrabasic rock 16–24 per cent, and schists 8–18 per cent.

CONCLUSION

It is naturally unwise to draw definite conclusions about the composition of the till from so few sample pits with a few hundred pebble fragments from each (cf. Hörner 1944). One can, however, see the influence of local material in the upper layers of the till.

The high content of ultrabasic rock (20 per cent) in the sandy to fine sandy basal till (X) and (22 per cent) in the lower lense till (3), Fig. 32, is thought to be due to the kilometre wide zone of gabbro which extends across the northern part of Långträsket at a distance of 8–10 km. The high content of schists (18 per cent) in the upper lense-till (4), Fig. 32, can be explained by the schist-like rocks which occur within the zone Vaxholm–Gubblisjaure between Uddjaure and Storavan. One should note the high percentage of local acid to intermediate volcanic in the overlying lense-tills with 22 per cent in 4 (the upper) and 16 per cent in 3 (the lower).

The boulders in all the tills are of very variable origin. In the lense-till and "ablation gravel", there occur boulders of porphyritic granite, red granite, acid to intermediate volcanics, grey granite, greenstone, diorite, ultrabasic rock, grey quartitic sandstone, phyllite, mica schist, quartzite schist, amphibolitic schist, and augen granite with large feldspar crystals. One type of boulder is considered to be local, and its most northerly boundary corresponds with the northern end of the erosional valley. The boulder type is an intermediate volcanic rock with dark groundmass.

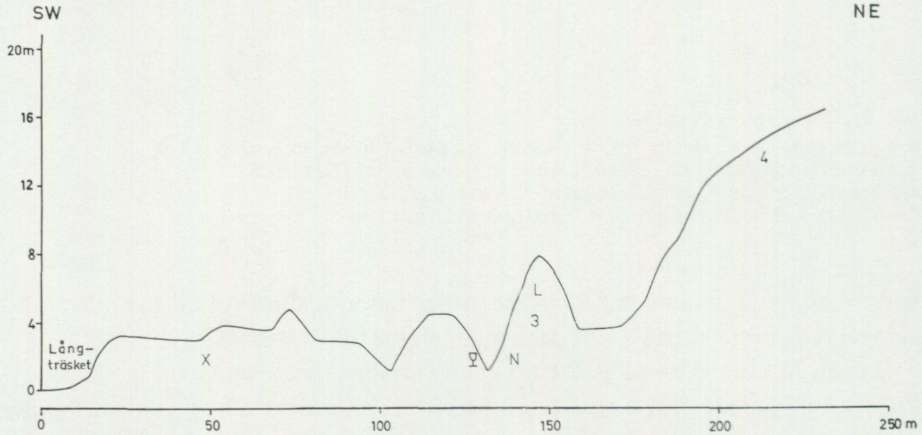


Fig. 32. Profile drawn across a fluvioglacial channel and a subglacially engorged esker at Långträsket.

The outer configuration of the till is strongly modified by water erosion. The erosion was primarily subglacial and in places cut down to bedrock. At the time of erosion, the ice ought to have been very thin, and the subglacial melting well advanced because the erosion valley begins suddenly at about 35 m above the surface of Långträsket and cuts down in places to more than 10 m in the till. This late erosion during deglaciation was probably due to the damming of water in the southern part of Långträsket. Fluvioglacial erosion was prevented until the main drainage of the area began. Large quantities of gravelly, sandy material and till have been deposited in close proximity to Långträsket and later eroded somewhat by periglacial streams.

The ridge in Fig. 32 consists of the typical lense-till of the surrounding area and should therefore not be regarded as an esker but as a section of the other till which has been isolated by erosion. The lense-till has been interpreted as the result of upwards transport of material due to compression in the glacier ice. The upwards transport has caused a strong mixing of local material with the other debris layers. Weak flows of watersaturated till along flat glacier surfaces caused the superimposition of till over sorted material. The sorted material, which accumulated in water pools on this glacier surface, appears now as lenses in the thin layers of till (Boulton 1971 and 1971a).

When the drainage began, the tills lost their high water content. The water was channeled within the ice and till and cut down deeply. During the final melting, proglacial drainage caused the final erosion of the fluvioglacial channels.

NJALLEJAURE

At Njallejaure (Plate I) some observations of the rock content were made within a large transverse ridge consisting of lense-till.

The till is a grey, sandy, loosely packed lense-till (L) with normal boulder content on the surface. The lenses consist of sand or silt. In places the well-sorted sediments lie on larger stones. The till belongs to the same type of lense-till as is found in Långträsket and V. Kikkejaure. The lense-till is interpreted as having the same mode of formation as that in Långträsket, but in this case accumulation occurred within fractures in the glacier ice.

The area lies in the centre of a region with grey granite, which is bounded to the northwest by a marked zone of porphyritic granite, acid volcanics and red granite. A simple pebble count gives a good impression of the proximal-lying dominant rock types. Several hundred rock type determinations were carried out on a couple of sample pits. The determinations were made in the lense-till on pebbles with a long axis of 2–6 cm. The results obtained are acid volcanics 24 per cent, porphyritic granite 24 per cent, grey granite 22 per cent, greenstones 12 per cent, red granite 10 per cent and grey gneiss 10 per cent.

The grey gneiss is probably only a variant of the grey granite, which in smaller fragments appears to be more gneissic than it really is. What is clear, however, is the high percentage of local grey gneiss and granite (over 30 per cent) and the dominance of acid volcanics and porphyritic granite, both over 20 per cent within a distance of about 1 km from a 5 km wide subglacial outcrop.

LARGE TRANSVERSE RIDGES

The larger types of transverse ridges described from Krutaberget, Nimtek, Båtsabäcken, and Giltjaur all belong to a type of ridge which is similar to Rogen moraines in form. The ridges from these localities are not, however, attributed solely to sub-glacial formation but to genesis where the till melted out from a water-rich environment. All these formations lie within concave basins.

KRUTABERGET

The transverse moraine ridge consists of a typically lense-bearing, supra-glacially formed till. The site of its formation was a low, quite flat area on the very distal part of large postcrag moraine (Plate I and Fig. 33).

The area is situated immediately northeast of lake Storavan with one locality north of and another southeast of Krutaberget. The transverse ridges occur on quite flat areas (460 m altitude) in the immediate prolongation of large postcrag moraines (600 m altitude), Fig. 33. The whole of this area is characterised by a typical landscape of hills with a slight incline to the northwest. To the east and northeast, however, the terrain lies at a slightly higher level (i.e. 510 m altitude). The glacial geology of these two plains is quite different. On the lower plain with the transverse ridges, ablation moraines of hummocky and Rogen-like moraines predominate. The till is sandy and in some places rich in boulders. On the higher plain, drumlinised moraine predominates, especially in the lee of the hills. At one place in Allejaure, 8 km north of Krutaberget, transverse ridges have been formed on a slightly concave surface.

The ridges north of Krutaberget in the lee of Vollegielas have a Rogen-like form (Figs. 33, 34c). The ridges are 300–500 m long with heights of 8–12 m. The distances between the ridges vary from 220 to 240 m. The till is sandy with lenses of silt and fine sand (cf. Hoppe 1948, Fromm 1965, p. 118). There are many large boulders in the till, but as a whole, the boulder content is normal. The till in the vicinity of the transverse ridges is of finer material at depth, especially around Allejaure.

This moraine type has been formed by large quantities of till being carried up into a slightly sloping glacier surface. This glacier has had abundant water on the surface, as a result of which the moraine easily became a flowing medium. In places, sorted material of silt and sand was preserved as lenses in the over-

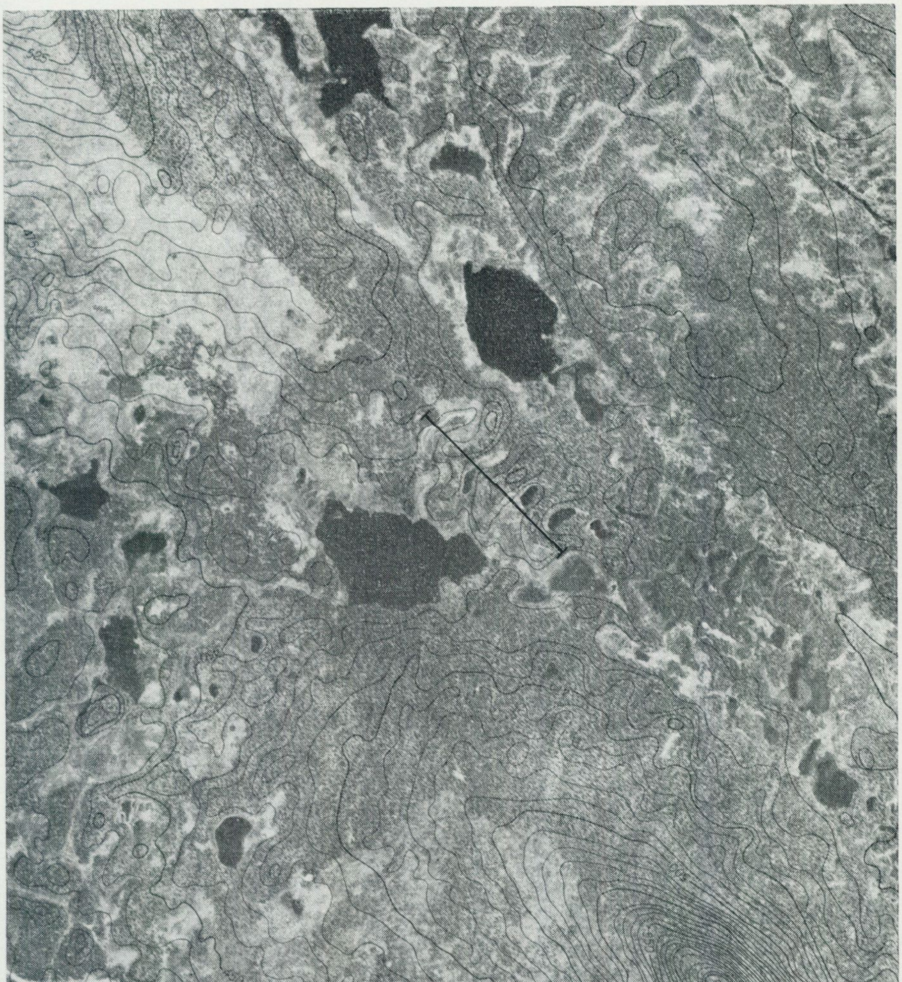


Fig. 33. Aerial photograph, scale 1:30 000, over Krutaberget area with large transverse ridges (Fig. 34c).

flowing till. Channeling of the material into certain zones by transport along slip planes up towards the surface can have contributed to the marked accumulations of moraine which lie at right angles to the direction of ice movement (Boulton 1972). Poorly developed side ridges give the impression that these accumulations have sunk into the ice to a certain degree during melting and caused forcing up and transport up on the sides.

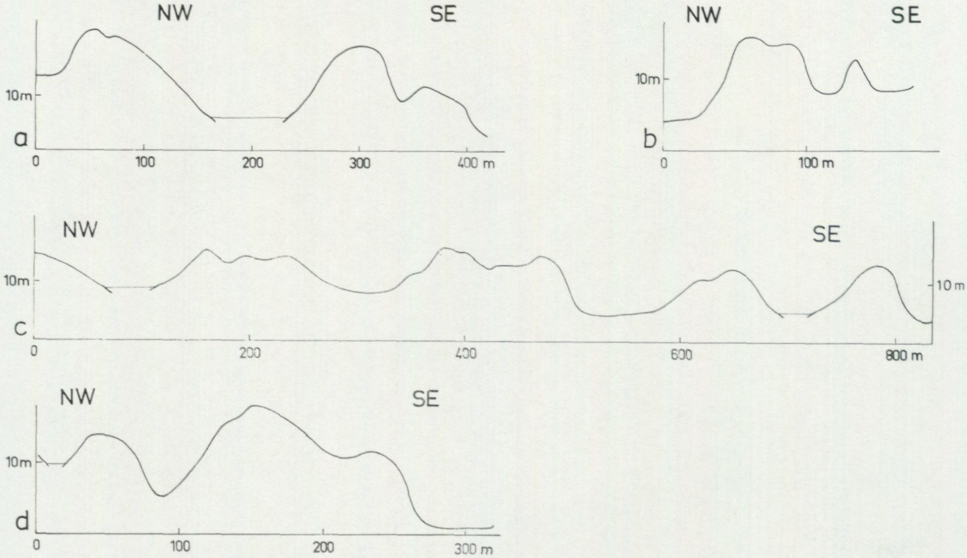


Fig. 34. Profiles drawn across
a, b, large transverse ridges in concave terrain at Giltjaur,
c, large transverse ridges at Krutaberget in lee of a mountain,
d, transverse ridges of large and medium size in concave terrain at Nimtek.

NIMTEK

At Nimtek, 25 km southeast of Arjeplog, a system of strongly pronounced transverse ridges has been investigated (Plate I).

Nimtek is a lake situated in a slightly concave area (Fig. 35) at about 500 m altitude with hills only a few km away: Jäknatjavelk to the northeast and Nimtekberget to the south, both at altitudes of little more than 650 m. The terrain to the northwest and southwest, which lies along the direction of ice flow, has an altitude some 50 m above that of Lake Nimtek. The area around Lake Nimtek is covered with strongly pronounced transverse ridges (Fig. 34d). These are usually about 10–15 m high, 250 m long and 80 m wide and have thus not the same size as the previously described transverse ridges. The width corresponds to the distance between each ridge. The orientation of the individual ridges, and of the ridge system as a whole, is N 20° E. Thus they deviate some 20°–30° from the true transverse position. To the south and northeast, the ridges are bounded by areas with ridges of more Rogen-like dimensions (cf. J. Lundqvist 1969a). These lie closer to the true transverse position. Geochemical investigations and diamond drilling were made on one of these large ridges (Minell 1978).

These medium sized ridges are somewhat similar to the ridges in Harrejokk (Minell 1977) and are thus given a similar interpretation, that is, formation in

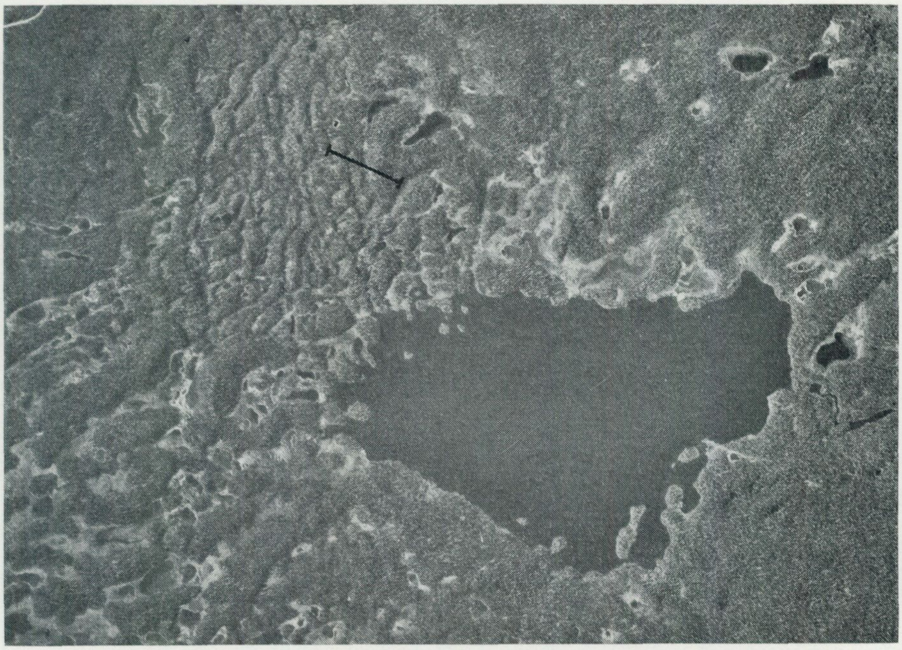


Fig. 35. Aerial photograph, scale 1:30 000, over Nimtek area with transverse ridges (Fig. 34d).

an environment of compression which caused strong upwards transport and further washing of the material on the surface of the glacier ice. When the ice stagnated, stress conditions in the ice due to the topography and possible variations in groundwater conditions can have caused a supraglacial fracture pattern, in which the till collected. The larger Rogen-like ridges in the peripheral parts of the area are thought to be dependent on weaker compression during a shorter period, which caused a system of folds in the till in the base of the glacier (Minell 1977a and b, cf. Kupsch 1962 and Moran 1971).

BÅTSABÄCKEN

In the Båtsabäcken area, 6 km east of Mellanström, (Plate I), a system of hog's-back moraines of the Harrejokk type (Minell 1977) are to be found (Fig. 3). East of this system and northwards on the eastern shore of Båtsasjön, the ridges are of the large transverse type (Fig. 36). The ridges occur on a flat area at approximately 470 m altitude. The hills to the northwest and north, 4–5 km away, reach from 600 m to 700 m altitude. To the south and southeast, the hills reach the same altitude but over distances of more than 6 km.

The hog's-back moraine consists of sandy till of the ablation type. The till is loose and the boulder content is high. In the larger transverse ridges the boulder

Fig. 36. The distal side of a large transverse ridge at Båtsabäcken.

content is also high, but the till is of a sandy to fine sandy type (H, Figs. 6–9, Tables I–IV). Sediments are subordinate but there has been a very strong erosion in an E–W direction in the vicinity of Båtsabäcken.

These ridges have been formed by compression within the glacier ice. In the region where the glacier was cold, due to slower movement caused by the strong compression, material was frozen at the base and transported up into the ice (cf. Weertman 1961). When the glacier stagnated and melted away, debris collected in crevasses on the ice surface (Minell 1977). In areas where the glacier was temperate or warm at the base, material accumulated and was folded at the base of the glacier.

GILTJAUR

An area of large transverse ridges lying very close to the Caledonian mountain chain is found approximately 20 km west of Sorsele (Plate I). The bedrock consists of Revsund granite.

The hummocky moraines in Giltjaur are situated very close to the peripheral parts of the mountain range. This area covers a wide zone at an altitude of approximately 430–450 m. The terrain to the east is quite flat with only a few hills reaching up to approximately 550 m altitude. In the west a dissected landscape dominates, where the terrain rises steeply from hills at approximately 600–650 m up to a few summits at approximately 800 m 15–20 km further west.

The large transverse ridges are mostly developed on flat and slightly concave areas. In this terrain the till is probably quite thick. Giltjaurälven and a deep channel not far from Giltjaur indicate till deposits between the ridges of at least five metres, contrary to the plain moraines on the convex terrain where outcrops of bedrock can be found. The form of the large transverse ridges and the distance between them correspond with the large transverse ridges in other areas (cf. Fig. 34a, b). However, southwest of Staburträsket, extremely large forms exist with distances up to 250 m and a thickness of probably more than 20 m.

A very characteristic feature to be found in those areas is the limited form of the large transverse ridges. The transverse ridges are best developed on slightly concave terrain but decrease abruptly when meeting strongly concave or convex terrain.

In the areas where the bedrock consists of Caledonian rocks, the till is fine sandy to silty with rich content of pebbles and gravel (Figs. 16–18, Table IV).

In the areas of crystalline bedrock, the till is sandy to gravelly and boulder-rich (Figs. 16–18, Table IV). Coarser fragments in the till are very local. Only a few kilometres from the Caledonides, material from the crystalline bedrock predominates. The tills in the large transverse ridges of the Caledonian area show a greater tendency to bimodality compared to the tills from relatively flat moraines in the same area.

The ridges are interpreted as having formed in the basal part of glacier ice with compressive flow. When the ice was retarded because of the compressive flow, the basal till and the till saturated ice became folded (cf. Kupsch 1962) and were later stacked up as barchan forms (cf. Moran 1971, Minell 1977a).

RUTTJEBÄCKEN — RADIAL MORAINES

The radial moraines in the area investigated consist of a type of large moraine ridges (Fig. 37) extended in the direction of ice flow. The radial moraines appear on a quite flat area at 460 m altitude that extends into a valley on the same level. This area is bordered by high hills: Tjipko to the WNW, Dalvetesåive to the south and Hornliden to the northeast, all at an altitude of approximately 700 m. The moraine deposits in the vicinity consist of a flat drumlin-field between Tjipko and Hornliden, and drumlin-like moraines on the flat area east of Dalvetesåive and southeast of Hornliden. The till is sandy to fine sandy (Tables I, II and Figs. 6–9).

The radial moraines appear between these two drumlin-like fields in a constricted valley between Hornliden in the northeast and Dalvetesåive in the south. The extent of the radial moraine-field is limited to less than 1 km.

The radial moraines give the impression of an increase in height and length of the drumlins to the northwest. The distance between the radial moraines

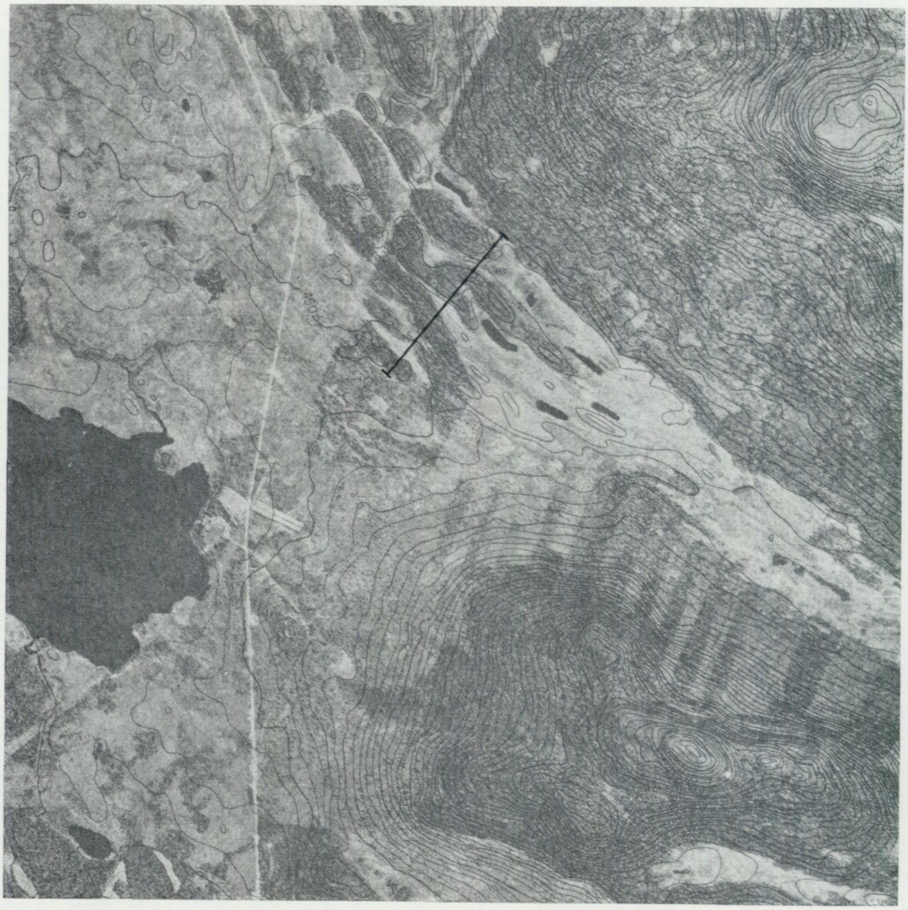


Fig. 37. Aerial photograph, scale 1:30 000, over Ruttjebäcken area with radial moraines (Fig. 38a).

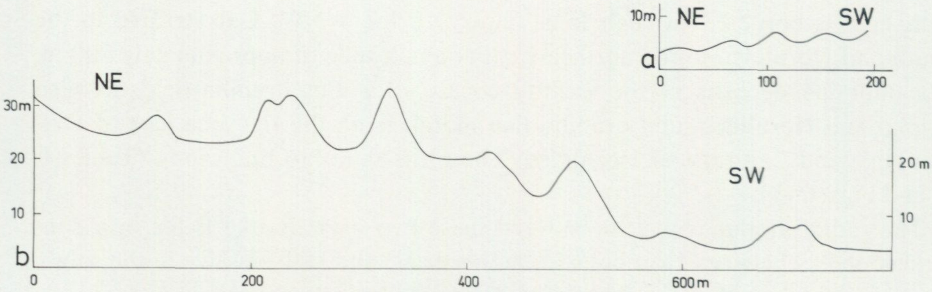


Fig. 38. Profile drawn across

a, large-scale flutings proximal to Skidnäsberget. See Fig. 39,
b, radial moraines at Ruttjebäcken.

varies between 90 and 120 m (Fig. 38b). The ridges are from a few up to 12 m high and with lengths up to several hundred metres. They are most pronounced in their central parts.

The till is sandy to fine sandy, rich in gravel but with a low boulder content. In some places the radial moraines are covered with silty and sandy sediments.

The most appropriate interpretation of these radial moraine forms is that the moraine accumulated in supraglacial fractures in the ice. It is also possible that the ridges were formed subglacially, and shaped by longitudinal folding as in the case of experimentally produced structures (see earlier description in Continuity in erosion and accumulation) and as suggested as a possible process in the formation of drumlins. In this case, the folding must be dependent on an area of extending flow or at least transport of ice from the surrounding proximal parts of the area. This transport would be due to the narrowing valley and results in folding of media with higher viscosity than that of pure glacier ice. The material transported at the base of the ice would thus be shaped due to pressure differences created by folding around axes parallel to the direction of ice movement. The forming of longitudinal ridges must therefore be seen as a continual process within which the basal material is not transported as fast as the moving ice and therefore the ridges become elongated parallel to the main direction of ice flow.

SKIDNÄSBERGET — LARGE-SCALE FLUTINGS

Immediately southeast of lake Storavan (418 m), the terrain is quite flat and lies at approximately 420 m altitude, covering an area of more than 100 km^2 (Plate IV). To the southwest, the terrain consists of hills only a few km wide and rising only approximately 200 m over the surrounding areas. In the flat area to the southwest, the terrain is dominated by drumlins of the ordinary Norrbotten type. In the area to the southeast, zones of large-scale flutings appear proximally or in the lee of many of the hills. The most pronounced flutings, which lie proximal to Skidnäsberget, cover an area of 1 by 4 km. They can be up to many hundreds of metres long but are very narrow with widths sometimes less than 40 m (Figs. 38a and 39). Their height is never more than a few metres. The till is fine sandy with a fairly high clay content, over 4 per cent (Figs. 2–5, Tables I–IV). The boulder content is low. Sediments or washed material have not been found in the vicinity. This type of fluting and the similar swarm-like drumlin field occurrence are interpreted as the result of folding of a moraine layer in the basal part of a glacier. The folding with a longitudinal fold axis ought to be dependent on an area of extending flow in the glacier ice.

This area included all the hills east of the Skellefteälven valley, where freeflow occurred from a glacier ice with a steeper inclination in the northern part

Fig. 39. Large-scale fluting at Skidnäsberget. From east. Photo P. Edmark. Cf. Fig. 38a.

of the Storavan basin. The extending flows were strengthened around the hills, resulting in a higher speed and transport from the surrounding proximal parts of the area. The longitudinal folding, which appeared, resulted in zones with higher and lower pressure in which the moraine material was distributed. The large-scale flutings reflect the same direction as the main ice-flow since the process was continuous and did not proceed with the same velocity as the ice movement.

BRUNBERGET AND MÖRTTJÄRNSBERGET — MORAINE PLAIN

Between Grundträskliden and Hedberg in the southeast part of 24 I Storavan, there is a level moraine region with transitions to plateaux-like moraines to the southeast.

The level moraine has accumulated at an altitude slightly higher (480–500 m) than in the surrounding areas (400–450 m), further in the lee and between the hills Brunberget, Surliden, Mausberget, and Alderliden (all four approximately 600 m). These moraines cover an area of approximately 25 km^2 with probable till thicknesses of 10–25 m and perhaps more in some cases.

There is a morphological transition from the proximal area with the highest altitude between Brunberget and Surliden to a lower and more distal area between Surliden and Mausberget. At the higher altitude, the moraine consists of

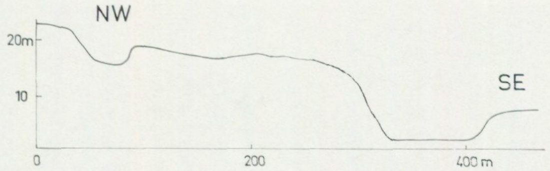


Fig. 40. Profiles drawn across a fairly level till with distributed kettles in lee of Brunberget.

a plain with waterfilled holes with a diameter of about 200 m (Fig. 40). Such holes or lakes appear south of Brunberget within drumlin-like forms, giving the impression of collapsed drumlins. From these holes or lakes, erosion channels leads away, especially from the leeside of Brunberget and south of Brunberget, where the terrain slopes steeply to the southwest. A system of fluvioglacial channels leads from the level moraine southeast of Brunberget down to the lower Lappbäcken valley.

The morphology at the lower altitude and in the lee positions passes over into more closely lying lakes and moraine forms. The till is of the sandy to fine sandy ”englacially derived type” poor in boulders (Figs. 6–9, Tables I–IV). There is no visible structure and no special form of packing to be observed.

Sediments occur but without any pronounced morphology, generally as thin gravelly and sandy layers on the till.

The water-filled holes and erosion channels are interpreted as a result of karst-like processes in the ice (Clayton 1964). The karst-like formation indicates that the water transport from the area was very weak at the beginning. This suggests drainage from a nearby water covered area which continued subglacially beneath the water-table. The subglacially transported water was not canalized due to the weak difference of water pressure in relation to the outer part of the area (Glen 1954). However, when a stronger drainage system developed in the surrounding deeper terrain, the difference of water pressure became larger, resulting not only in a sub-aerial channeling out from the sinkholes but also a sub-glacial channeling of water into a now quite thin ice. The contribution of debris and sediments to the sinkholes was not large enough to be accumulated but was preferentially transported away.

SKIDTRÄSKET AND SUNDNÄSSJÖN — KAME AREA

The Storavan esker varies very much in character with strongly eroded zones and more tranquil zones. The strongly eroded zones consist of fluvioglacial channels in moraine and bedrock (small canyons) and in the less eroded zones different sediments appear as high and narrow eskers (Fig.41). The erosive environment can be seen in the vicinity of Jan-Svensamössa between Gullön and Avaviken. The tranquil zone with channeled areas and areas of sediments

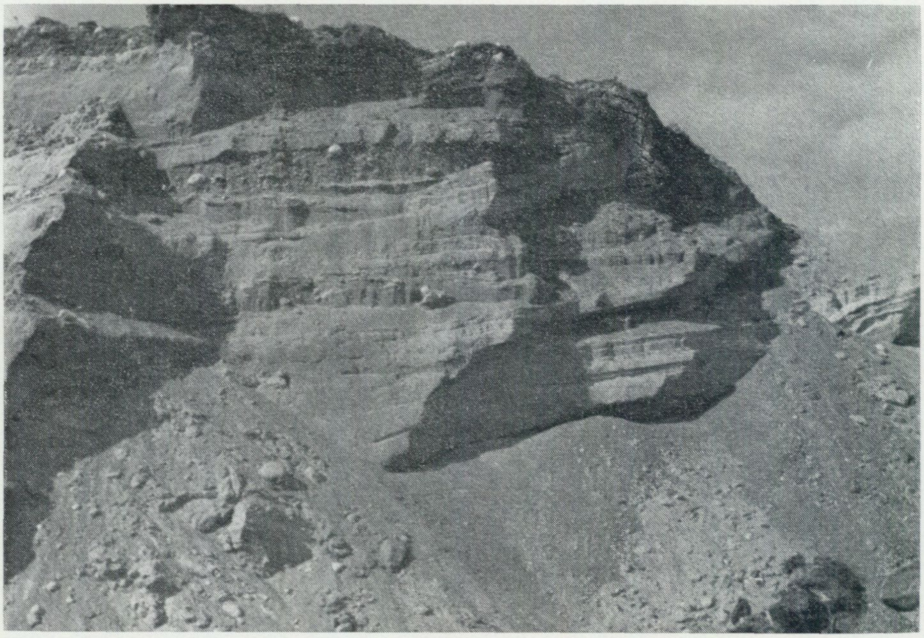


Fig. 41. The esker of Jan-Svensamössa. From south.

such as silt and sand, and even coarser material, is well pronounced at Skidträsket, 6 km southeast of Avaviken, and Sundnäs, 11 km southeast of Avaviken. This kame area is a few kilometres long and up to 500 m in width. The thickness probably varies between 25 and 35 m. Skidträsket is situated in a flat area at 430 m altitude with large postcrag moraines more than 3 km away, while Sundnäs is situated between Holmberget (530 m) immediately to the north and Bålkaberget (630 m) only 1 km to the south.

Those two kame areas have strongly undulating surface topographies consisting of a network of hillocks. The distance between the hillocks is usually about 40 m and the height of the hillocks around 5–10 m. The material consists of silt and sand between the hillocks and in the low part, while coarse gravelly fractions with cobbles and pebbles exist on the eskers and hillocks.

The kame area is interpreted as the result of flooding of sediment over a flat area: the fluvioglacial stream was channeled originally from dynamically living ice. When this body of ice stagnated on the flat terrain, the water could escape other ways, partly because the ice was dynamically dead and partly because the ice was thoroughly fractured. The fracturing is thought to be primarily caused by the undermining action on a broad front of the water in this flat area. In this later stage, the major part of the accumulation took place.

The damming effect was not due to a more moderately inclined basement, since this was much more depressed eastwards in the Baltic sea than in the inner parts of Skandinavia. It seems more likely that the transport of water away from the kame area was not enough to drain away the melt water from large areas.

KÅBDALIS — MORAINE PLATEAUX

Northeast of Kåbdalis, there is a region with (Fig. 42) typical moraine plateaux of the so-called Veiki moraines (Hoppe 1952). The moraines have accumulated and formed at quite a high altitude, 400 m, with the hills Kåbdalisvare and Pajenisvare, at over 500 m altitude, situated in a proximal position. The moraine cover an area of approximately 7 by 9 km.

Morphologically the Veiki moraines can be classed as large areas of till that have become separated from each other. Each area of moraine plateau has a thickness of approximately 15–25 m and a diameter of approximately 250 m (Fig. 43a, b). The boundaries of these plateaux slope steeply down to a lobe; bogs or in many cases a channel-like valley separating the individual plateaux. These steep lakes or valleys usually have a diameter of 200–250 m (Fig. 43c).

At the periphery of the plateaux, there sometimes occur moraine ridges composed of washed till or ”ablation gravel”. These ridges usually have their steepest flank towards the valley side, while the flank facing the centre of the plateaux is more gentle. This gives some of the plateaux a very pronounced shape with steep sides and a concave upper surface (Fig. 43a, b).

The till is of the sandy to fine sandy ”englacially derived” type with a low boulder content. There is no visible structure, and no special form of packing was observed. However, in some places, lenses or layers of a metre or more of fine sediments can appear overlyings as well as intercalating the till.

Hoppe (1952, p. 54, and 1957) believes that the moraine plateaux were created subglacially where blocks of ice sank down into water-saturated till. This could have resulted in till being pressed up into large cavities under the ice. The moraine ridges and the moraine crests may thus be directly related to the ice contact. Parizek (1969), however, supports a supraglacial process in which till and sediments accumulated in basins on the glacier ice. These basins were characterised by a high rate of accumulation. Considerable water activity and the shores of the basins produced the ridges.

An alternative explanation is that these types of moraine plateaux have formed as a result of doming (Minell 1976) or by the rising of dikes of relatively clean ice between large blocks of till (Fig. 45). One can also visualise the process as the sinking of thick deposits of till into the ice. To investigate the possibility of this process some theoretical studies with reversed density gradients have been made.

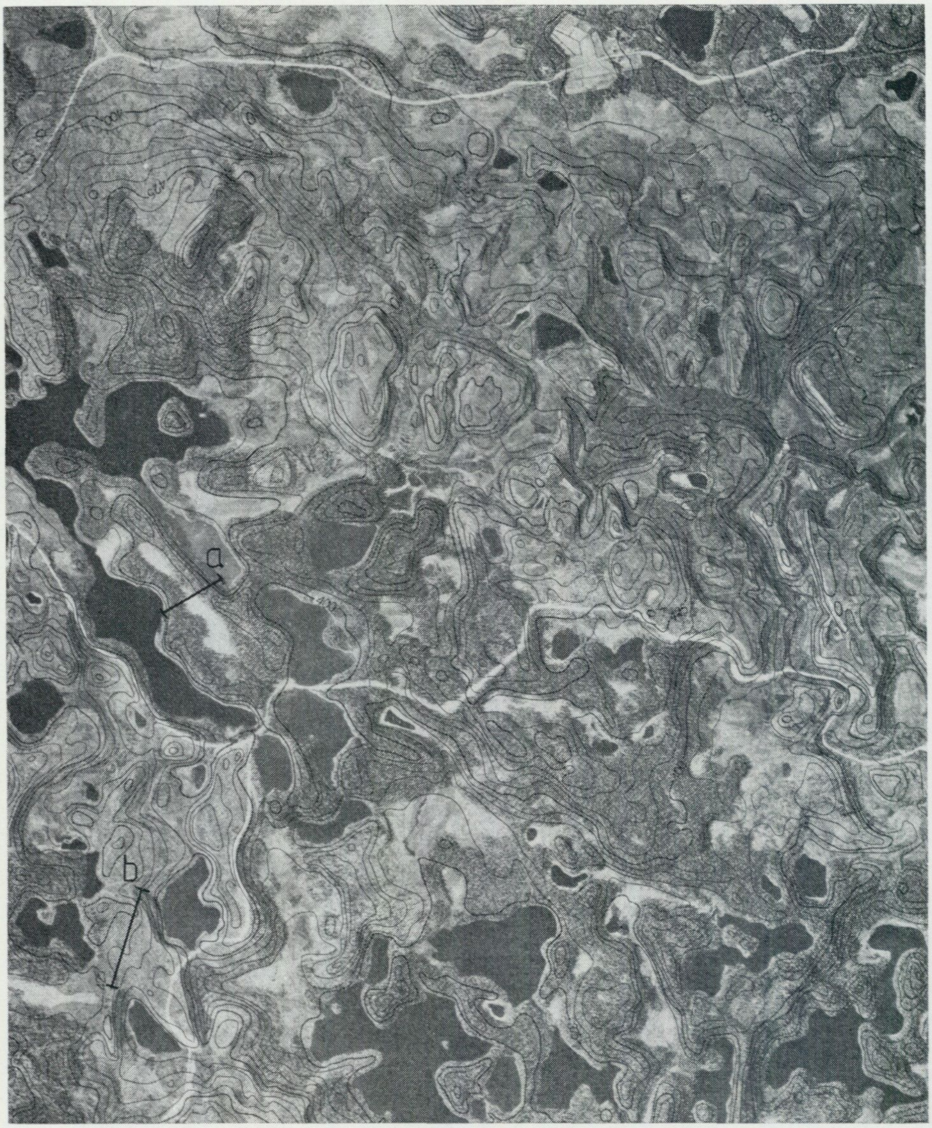


Fig. 42. Aerial photograph, scale 1:30 000, over Kåbdalis area with moraine plateaux (Fig. 43a, b).

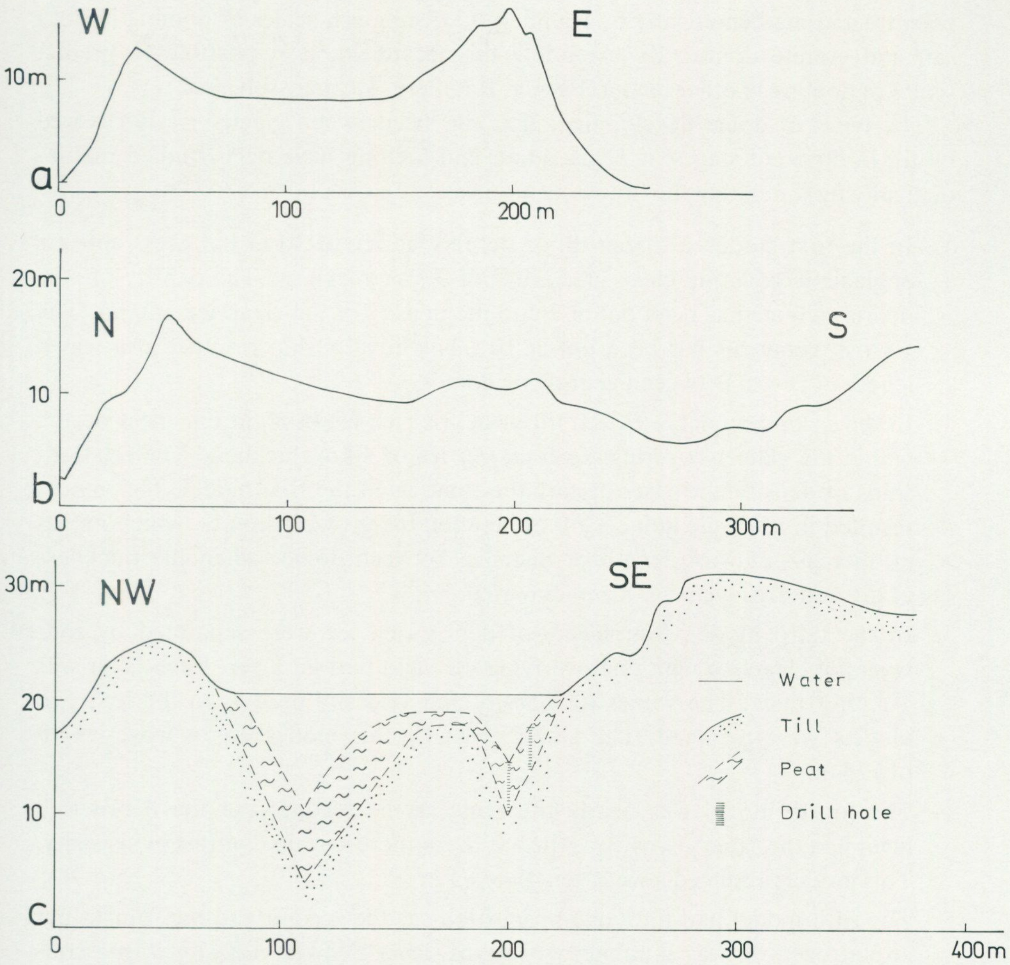


Fig. 43. Profiles drawn across.
a, b, moraine plateau with rim ridges at Kåbdalis,
c, moraine plateau without rim ridges but with kettles in the deep part between the plateaux.

MODELS OF ICE DIAPIRISM THROUGH TILL

A series of strata in which denser layers overlie lighter layers is essentially unstable. Given the opportunity, the layers will try to change places. The lighter medium will tend to move upwards and the heavier medium will tend to sink to form a stable density system. This process called dome development is well known in the science of fluids. Examples from the earth sciences include intrusive diapirs and salt domes. Investigations using various media have shown that the scale of doming is basically dependent on density contrast, thickness of layers and viscosity contrast (Ramberg 1965). These experimental investigations have been treated mathematically by Ramberg to distinguish scales of doming in both salt and granite domes. By extending this treatment, it is possible to predict scales of doming in other media (Berner, Ramberg, Stephansson 1972).

The types of dome development that can occur when glacier ice is covered by till in different stages of deglaciation and melting have been studied mathematically by simulating the following models.

1. In the first model, a frozen till or debris-rich ice of 30 m thickness appears englacially covering clean glacier ice of 30 m thickness. The density of the debris-rich ice has been put at 2 and the density of the clean ice at 0.95. The viscosity contrast has been put at 10^2. This relationship resulted in a wavelength of 200 m between the growing domes.
2. In the second model, a frozen till or debris-rich ice of 30 m thickness occurs within the glacier covering clean glacier ice of 40 m thickness. The relationships of density and viscosity are the same as in the first model. This model resulted in a wavelength of 240 m between the growing domes, which means an increase of wave-length or distance between domes when the thickness of the underlying glacier ice is increased.
3. In the third model, four layers of debris rich ice were separated by four layers of clean ice with one overlying the rigid bottom layer. Each layer was 7 metres thick. The values for density and viscosity used as in the first two models were assumed. The result given by this model was a wave-length of 175 m.
4. The fourth model was nearly the same as the second, but the debris-rich layer had the same viscosity as the ice. Thus there was no contrast in viscosity. This model produced a wave-length of 94 m.
5. The fifth model had the same proportions as the second and the fourth, but an unfrozen till was simulated giving this layer a lower viscosity with a contrast of 10^5 in relation to the pure ice. The surface of the unfrozen till was open and free. The result of this model gave a wave-length of 85 m.

The form of the dome is dependent on the viscosity contrast between the two media. If the covering layer with higher density has a much lower viscosity than the underlying medium, the growing domes will become broader while the sinking softer medium forms thin narrow basins. If the rising medium has a lower viscosity, the domes will become narrower and the overburden will sink down as wide basins (Ramberg 1965). In an extreme case the rising material will have the form of dikes (Anketell et al. 1970).

The velocity for the rising dome is dependent on the wave-length thickness ratio, the density contrast, the thickness and viscosity of the rising layer, and of possible amplitudes in the rising layer (Ramberg et al. 1972). The velocity of doming, when using Ramberg's (1972) formula and putting the viscosity of ice at 10^{14} pois, gives a result of approximately 36 m in 1500 years, and when using a viscosity of 10^{13} pois, 36 m in 150 years. This shows the strong dependence on the viscosity value for estimating the velocity of doming, which is therefore very hard to determine in glacier ice. However, the figure known for convection doming in Antarctica is 7 cm/year in Wilkes Land (Hughes 1976) or 35 m in 500 years which is the value obtained when using a viscosity between 10^{13} and 10^{14} pois.

Very rapid velocities have been found when doming of temperate ice up through cold ice has taken place due to thermal convection (Hughes 1976). From calculations, on processes from the Antarctic ice cap, Hughes obtained a velocity of 2.1 km/year on rising dikes with a width of 0.2 km. This means that the rising dikes take only 6 days to rise 36 m. The sinking cool ice table, however, has a velocity of 64 m/year which is 32 m in 6 months. These are rapid velocities comparable with surge and might be analogous to turbulent convection in fluids.

MORAINE PLATEAUX – CONCLUSION AND DISCUSSION

There are two problems to be tackled in connection with moraine plateaux. The first is the mechanism of accumulation, which probably took place during glaciation, and the second is the shaping process which very likely had its strongest influence during deglaciation.

There are strong indications that most of the primary accumulation in the area took place englacially. The till bears no indication of basal genesis, and the thick layers of sediment, which appear in some moraine forms, indicate sedimentation in supraglacial pools in a water-saturated environment.

The primary, englacial accumulation should be due to stagnation as a result of retarded movement (Fig. 44a). Retardation can, in particular, be due to topographic conditions, but also temperate circumstances. If a rock massif protrudes in the area, it can cause proximal compression, which is not followed by large scale extension due to the height and length of the rock massif. Weak movements therefore result in an ice flowing off the rock plateaux, whereas debris-bearing ice stagnates.

The primary process of accumulation can be strengthened if cold conditions prevail within the glacier ice, which could well be the case during glaciation as well as during deglaciation (Schytt 1974), particularly on a raised plateau where the geothermal heat was negligible and movement greatly reduced (Nobles and Weertman 1971, Clarke 1976).

The author therefore interpretes accumulation as the result of stagnant, debris-saturated ice which was transported mainly from an area with compression, where the till was incorporated and transported up into the ice. If cool conditions exist, the up-transport could be strengthened (cf. Boulton 1972). A doming

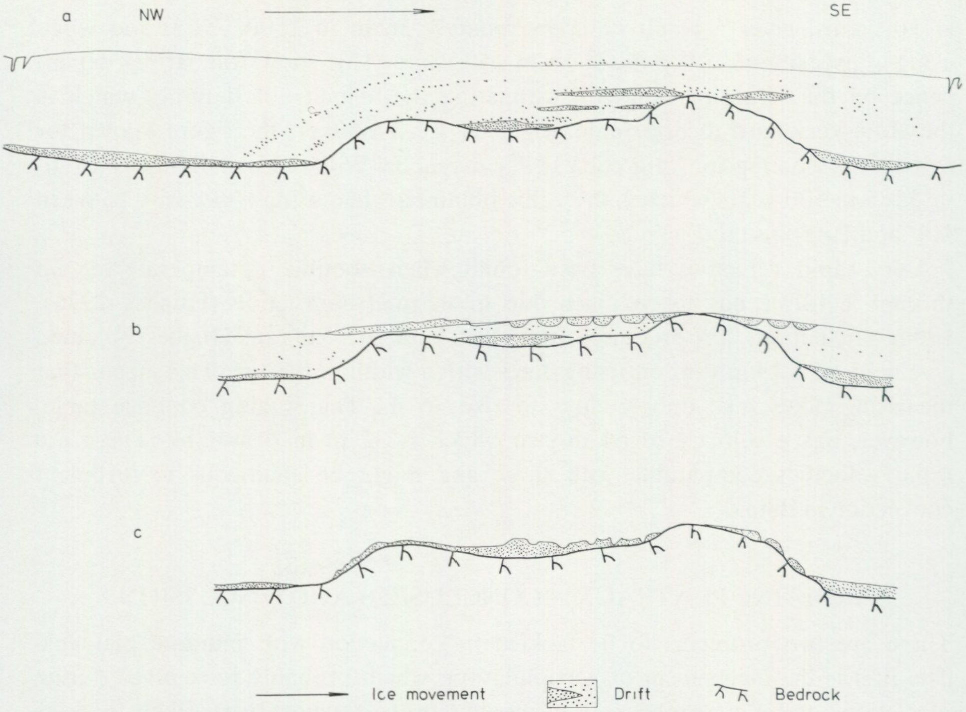


Fig. 44. Sketch illustrating the possible formation of moraine plateau.
a. An early stage in the deglaciation with stagnation of englacial till.
b. A late stage in deglaciation with sinking of heavier till and rising of lighter ice.
c. Results when ice melted away.

of pure ice through till-saturated ice could, when the glacier-ice reached total stagnation, initiate strong uneveness in the debris-saturated ice. This first initial doming was probably in some degree dependent on irregularities in the basal conditions (Stephansson 1972).

During the deglaciation, the debris melted out onto a horizontal and very even glacier surface. The melt water produced accumulated to a certain extent in the quiet environment, but drained away in the peripheral parts of the plateau area. In the central part of the plateau area, the circulation of water was poor and did not contribute to any increased melting at depth along the contact between thawed till and ice. A ”karst formation” in the underlying glacier ice, due to the flowing meltwater and precipitation (Clayton 1964), can have commenced at an early stage and caused the formation of sink holes. These were so extensive that the moraine, where it was thickest, sank into the underlying ice and at the same time ice forced up around it. In the sinking, water-saturated moraine pools, sedimentation from flowing water could take place at times (Fig. 45). These sediments could be overlain in places by ”melt-out till” (Boulton 1971).

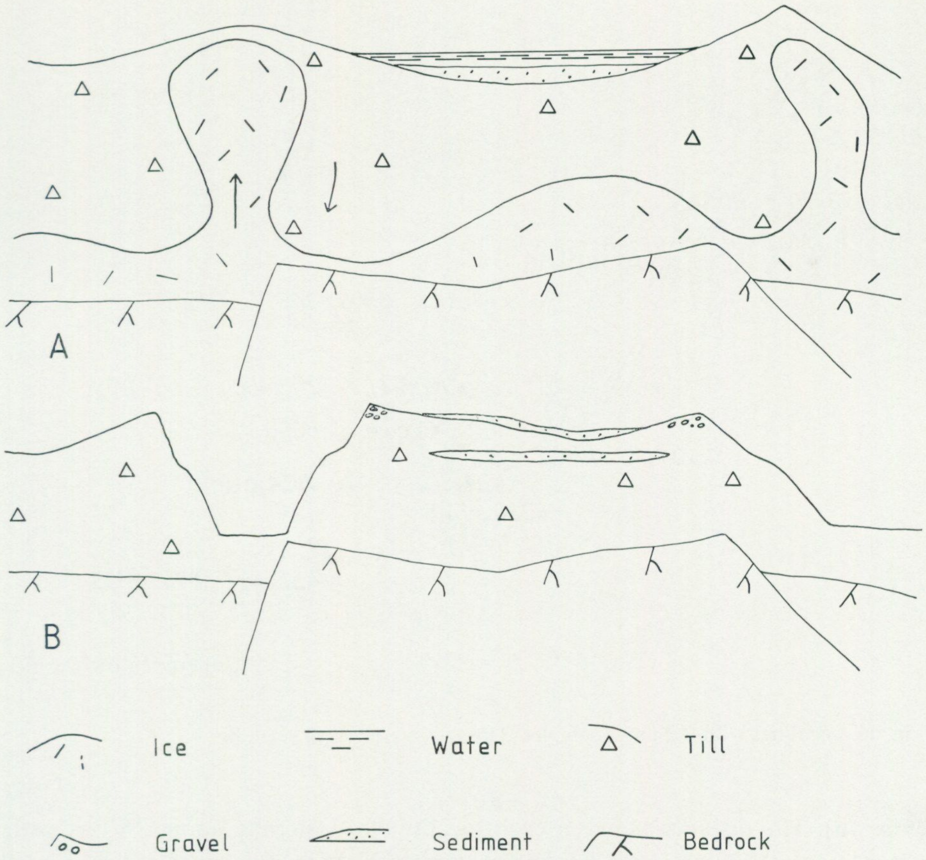


Fig. 45. Hypothetical model for formation of a moraine plateau.

In areas where thick till covered relatively thick glacier ice, distinct moraine plateaux were thus formed with side ridges where the ice was most clearly forced up (Fig. 44b, c). The side ridges consist of washed material, where they were developed in a water-saturated environment, that is to say, on the shores of till-filled pools. In areas where the till or ice was thin as in the peripheral parts, no complete moraine development could take place. Instead hummocky moraines were formed, and in some cases only isolated sink holes through which drainage could take place.

^{14}C-DATING

Eight samples for ^{14}C-dating were taken from different localities each along a traverse from Glommersträsk, 30 km from the highest shore-line, to Grutaure in the vicinity of the ice-shed. The localities between Glommersträsk and Grutaure were Abborrträsk, Julträsk, Vaksemjaure, Kikkejaure, Plättik, Akkelisjaure

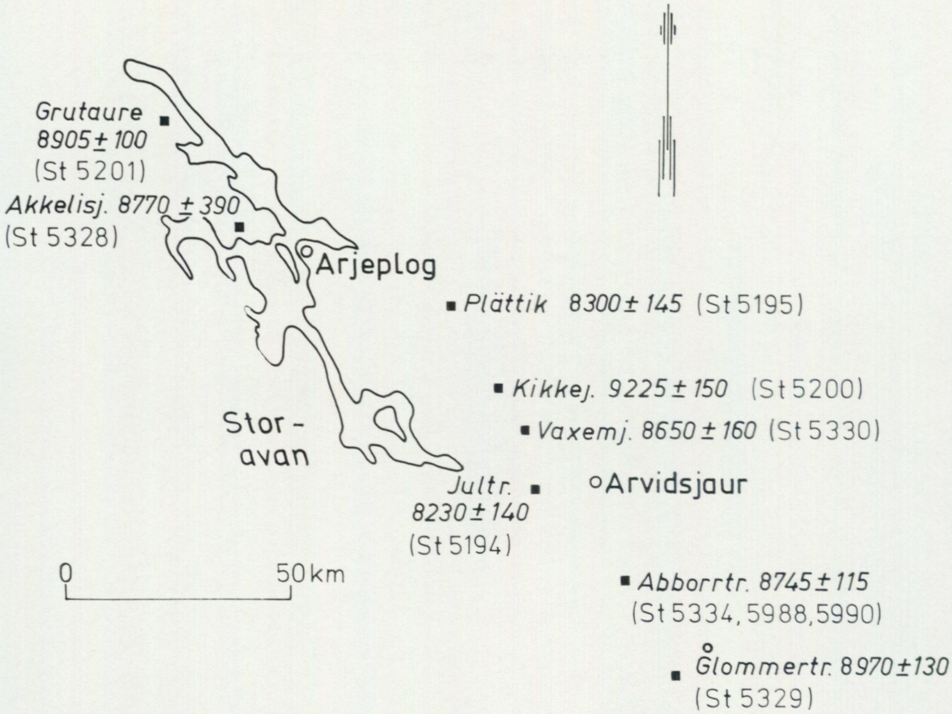


Fig. 46. Localities with ^{14}C-dated samples. The ages are given in years BP.

(Fig. 46). The distance between each locality was generally about 25 km, with a maximum of 30 km and a minimum between Vaksemjaure and V. Kikkejaure of 11 km.

The samples were taken from the bottom sediments of the lakes in undisturbed sedimentation environments, lakes large enough not to be influenced by dry periods, that is, with diameters of 100–200 m and depths of 5–15 m.

The samples were taken in early spring in order to use the ice as a solid foundation when boring. This operation was carried out with a Livingstone sampler through holes in the ice. Samples were taken from the deepest parts of the lakes. For ^{14}C-analysis, samples were taken of the first organic material upon contact with the underlying minerogenic soil. Only 2–3 cm of the cores were used for dating. Six or seven samples of the minerogenic contact had to be taken to obtain enough material. All samples were taken from boring cores within a few metres of each other. The depth of sediments varied from 1 m to 4 m. A complete core for pollen and diatom analysis was taken from all the localities except Julträsk.

The ^{14}C-analyses were made by the laboratory for isotope geology, Swedish museum of Natural History.

The pollen analyses were made at the micropaleontological laboratory at the Geological Survey of Sweden. The descriptions of the pollen analytical results have been written by Ann-Marie Robertsson.

Glommersträsk. A lake approximately 80 m wide lying in a drumlinised terrain 5 km southwest of Glommersträsk (Fig. 46). The water had a maximum depth of 4.80 m and the organic sediments a maximum depth of 1.04 m. The lake has a very small inlet and outlet. The sample was 2 cm thick and consisted of green gyttja above a silt layer. The gyttja becomes more brown and loose towards the surface.

The ^{14}C-dating gave a result of 8 970 ± 130 BP, (St 5329) 1 cm above the contact silt/gyttja, which gives a positive margin of error of another 75 years.

Pollen analyses were made on eight samples, three from the silt and five from the gyttja at 10 cm intervals from the contact and upwards. *Betula* (birch) and *Pinus* (pine) occur with 40–60 per cent each. *Alnus* (alder) was not represented in the silt but reaches frequencies around 10 per cent in the gyttja. According to the pollen analyses, the ^{14}C-dating would correspond to the beginning of the *Alnus* curve (A°).

Abborrträsk. 1 km south of Abborrträsk, samples were taken in a very deep part of a lake (Fig. 43c). The lake seems to form a hexagonal pattern between moraine plateaux. The distance between each deep hole in the lake is approximately 100 m and the diameter and distance between each moraine plateau is approximately 250 m (Fig. 43c).

The samples were taken in a sinuous lake connecting holes of a depth of approximately 15–20 m from the water surface to the till. The lake has no inlet or outlet. The part of the lake where the samples were taken has a diameter at the surface of 25 m and a depth of 5.80 m. The deepest sediment was 4.85 m.

Stratigraphy was:
depth (cm) below water surface

950– 993	peat (brown mosses with some admixture of *Sphagnum* and *Equisetum)*
993–1000	gyttja
1000–1005	muddy peat (brown mosses and some *Sphagnum)*
1005–1029	*Equisetum* peat (with brown mosses and *Carex)*
1029–1055	coarse detritus gyttja with *Equisetum*
1055–1063	coarse detritus gyttja, silty
1063–1065	till, with plant fragments *(Equisetum, Betula)*

Pollen analyses were made on 30 samples from the Abborrträsk core. *Betula* dominates the tree pollen spectra between 990 and 1065 cm with frequencies around 80–90 per cent. *Pinus* is represented with 10–20 per cent. At 995 cm depth, *Alnus* increases from 0.5 to 12 per cent. Above 990 cm *Pinus* and *Betula* have alternating maxima. Two ^{14}C-datings were made according to the composition of the tree pollen spectrum at 1035–1045 *(Betula* maximum frequencies around 95 per cent) and at 993–1000 cm (the beginning of the *Alnus*-curve). The results were 8 320 ± 115 B.P. (St 5988) for the *Betula* maximum and 8 270 ± 185 B. P. (St 5990) for the rise of the *Alnus* curve.

The datings show that the coarse detritus gyttja with *Equisetum* (1029–1055) and the peat (1000–1029) were formed during a rather short period (50–350 years).

The deepest ^{14}C-sample was 3 cm thick and was taken from the bottom layer of till with plant fragments.

The ^{14}C-dating gave a result of 8 745 ± 115 (St 5334) 1.5 cm above the bottom contact, which gives a positive margin of error of another 50 years.

Julträsk. 10 km west of Arvidsjaur, samples were taken in a round lake in a small moraine plateau-like hummocky terrain. The lake is approximately 80 m in diameter with a maximum depth of 2.70 m and organogenic sediments up to 180 m. The lake has no inlet or outlet. The sediments consist of a muddy loam on silt. Twenty cm over the silt is a 5–6 cm thick layer of brown peat above which the muddy loam becames successively more loosely packed.

The ^{14}C-sample of 3 cm muddy loam was taken between 6 and 9 cm above the contact with the silt. This was because the first centimetres of muddy loam in contact with the silt were always lost. The ^{14}C-dating gave result of 8 230 ± 140 B.P. (St 5194).

To obtain an idea of the stratigraphic value of dating one needs to know the rate of sedimentation. In this case it is probably about 1 cm per 50 years. This sample of 3 cm was deposited during about 150 years, and the date obtained will give the approximate age of the middle part of the sample, which is situated 1.5 cm over the underlying contact, thus making it 75 years younger than the real bottom stratigraphy. This age falls on the positive side of the margin of error.

From these values it is possible to make a general approximation of the age of the contact between the silt and brown peat. The actual contact lies 7.5 cm below the dated sample and therefore has an age of about 8 600 B.P. The brown peat lies 12.5–17.5 cm above the dated sample and therefore has an age of 7 605–7 355 B.P.

Vaksemjaure, 20 km northwest of Arvidsjaur. The lake has an area of 150 by 400 m and is situated between large transverse moraines with ablation till. Samples were taken from the deepest, southwestern part, where the water was 2.40 m deep and the organic sediment 1.80 m thick. The lake has no inlet or outlet.

The core consists of silt overlain by clay gyttja and a light brown, loose gyttja.

Samples for ^{14}C-dating were taken from the base of the clay gyttja in contact with the silt. The results give an age of 8 650 ± 150 B.P. (St 5330) 1 cm above the contact, which gives a positive margin of error of 50 years.

V. Kikkejaure, 45 km northwest of Arvidsjaur. This is a kame area situated close to a group of large transverse ridges of ablation till on the northwestern part of lake V. Kikkejaure. The lake has a small inlet and outlet. The lake is 40 by 150 m with a maximum depth of 2.30 m and maximum thickness of organic sediments of 2.40 m. The core consists of silt covered by gyttja. The result from a ^{14}C-sample taken 0–2 cm above the silt contact gives an age of 9 225 ± 150 B.P. (St 5200). This age is too old and is probably due to an old faulted calcite-bearing zone in the Archean rocks which extend right through the area.

Pollen analyses around the contact silt/gyttja confirm that the age of the radiocarbon dating is too old. A° can be placed 5–10 cm above the contact.

Plättik. A lake between an esker and moraine, 25 km southeast of Arjeplog. The lake is 100 by 200 m with a maximum depth of 5.96 m and thickness of organic sediments of 0.80 m. The lake has neither inlet nor outlet. The core consists of a gyttja resting on silt. At 6–11 cm above the silt contact, a piece of *Betula* wood was found, 11 cm above the contact a piece of *Pinus* wood, and at 12 cm a piece of *Pinus* bark.

The ^{14}C-sample was taken from 2 cm of gyttja 2–4 cm above the silt contact due to the loss of the bottom part when taking up the core. Results from dating give an age of 8 300 ± 145 B.P. (St 5195) for a level of approximately 2–4 cm above the silt contact. This gives a very approximate age at the contact of 8 600 B.P. The approximate age is due also to the thin sediment cover with a rate of sedimentation of less than 1 cm per 100 years.

Akkelisjaure. A wide round lake lying 15 km west of Arjeplog. The lake is 200 m in diameter and the water has a maximum depth of 2.60 m with 2.93 of organic sediments. The lake has a small inlet and outlet.

The core consists of clayey and silty layers at the bottom. A 13 cm layer of gyttja rests on silt.

The brown peat is covered by gyttja and muddy loams with a thickness of 25 cm and in two cores these are overlain by brown peat. Three cm above the silt a piece of bark was found.

Samples for ^{14}C-dating were taken from the silt contact and 3 cm upwards in the gyttja. The results give an age of 8 770 ± 390 B.P. (St 5328) for 1.5 cm above the contact with a positive margin of error of 50 years.

Grutaure. A wide and round lake 40 km northwest of Arjeplog. The lake is 150 by 200 m in diameter and has a depth of 3.30 m and 1.80 m of organic sediments in its deepest part. The lake is situated in a peat bog area where the circulation of ground water is only slight.

The cores consist of clay covered by gyttja. Samples for ^{14}C-dating were taken from the clay contact and 2 cm upwards in the gyttja. The results give an age of 8 905 ± 100 B.P. (St 5201) for 1 cm above the clay contact with a postive margin of error of 50 years.

CONCLUSIONS

The results of the ^{14}C-dating strongly indicate an invasion of vegetation at about 8 600–8 700 B.P. in the areas between Arjeplog and Arvidsjaur. One cannot draw any conclusions concerning the higher ages towards the ice-shed and towards the coast on the basis of the few samples taken. Samples of lake sediments taken in similar areas (Donner and Jungner 1974) have, in some cases, given excess ages and have thus been explained by re-deposition of older organic material or the effects of hard water or graphite. The two high values of over 8 900 B.P., obtained for Grutaure near the ice-shed and Glommersträsk near the highest coast-line, can be due to re-deposition of older material.

In Abborrträsk the datings and pollen analyses of the bottom part with till and plant fragments of *Equisetum, Betula* (8 745 ± 115 B.P.), coarse-detritus gyttja with *Equisetum* (8 320 ± 115 B.P.) and peat (8 270 ± 185 B.P.) indicate that ice covered by a till was melting when the organic material was carried in (cf. Florin and Wright 1969).

In the Abborrträsk pollen diagram, the first vegetation that occupied the land after the ice is reflected by high frequencies of herbs, shrubs and *Betula.*

According to the pollen analysis the ^{14}C-datings of the contact minerogenic/organic material can be summarized in the following way:

They all represent sediments deposited before the rise of the *Alnus* curve (A°). The rise of the *Alnus* curve (A°) has been dated in adjacent areas in northern Sweden:

Coastal area of Ångermanland	(Fromm 1938):	6 450–6 350 B.C.
	(Wenner 1968):	6 500–6 400 B.C.
Jämtland, eastern part	(Wenner 1968):	6 715–6 600 B.C.
	(Lundqvist, J., 1969):	6 500–6 000 B.C.
Västerbotten, Adak	(Lundqvist, G., 1957):	6 620 ± 125 B.C.

With corrected ^{14}C-ages $T_{\frac{1}{2}} = 5\,730$ and corrected varve-chronology Wenner assumed A° to be about 6 850 B.C. According to the dating from Adak, which is situated about 40 km WSW of Abborrträsk, A° can be placed at 6 750–6 500 B.C. within this area. The ^{14}C-datings in the present work agree with the pollen-analytical results.

GENERAL CONCLUSIONS

BEFORE DEGLACIATION

At the maximum stage of the last glaciation there was little or no erosion of bedrock or modification of till in central Norrland. This was due partly to the extremely low temperature, which caused the ice to be frozen to the basement (Schytt 1974), partly to the high pressure of glacier ice, which resulted in high friction between bedrock and till material (Boulton 1974), and partly to the low ice velocity in the vicinity of the ice-shed. Even in the early stage of deglaciation there was little erosion.

PROCESSES AT THE TIME OF DEGLACIATION

When the glacier ice became thinner, with the ice-margin in the vicinity of the highest shore line, the deglaciation had gone so far that large parts of the glacier ice had only very slight surface gradients less than 2° (cf. Nye 1951, 1952). Movement of the ice mass was thus very much reduced, especially in concave basins and in connection with large elevated areas or plateaux. In open terrain such as valleys and around free-lying hill-tops, movement of the ice mass was still continuing (Daniel 1975, p. 109). The strong ablation and the vicinity of the input area resulted in extensive variation in flow within the glacier ice. Living ice could meet completely stagnant ice. The glacier ice could thus go through extension and compression (Robin 1969).

LESS COOL OR TEMPERATE AREAS WITH EXTENDING FLOW

Drumlinoids, drumlin-fields and large crag moraines mainly appear in areas with steady state or extending flow (Minell 1976). The till is basal with a fine-sandy matrix and boulder-poor content. At a few metres depth, the till can change with a sharp contact into a water-affected till with, in some cases, lenses of sorted material (cf. Hoppe 1952, p. 162). The till has a very low content of local rock material. Because high speed between the glacier ice and the underlying medium is thought to be a prerequisite, the basal part of the ice should have been temperate, resulting in the production of water which could not be channeled because of the high pressure and shear stresses (Glen 1954). However, the till was subjected to washing, sorting and redeposition by a thin water sheet, which varied in velocity due to differences in pressure (Shreve 1972). Incorporation of new material into the glacier was weak; however, transport of already incorporated material could take place. At the last stage of deglaciation, when a permeable bed was created and when the drainage of water was more effective in the stagnant parts of the glacier, the watertable became lower and transport of material by traction could take place (Boulton 1974).

The mechanical state of till during traction was probably very variable due to the strong variation in water pressure, pressure and shear stresses (Boulton 1974). The till material could thus be easily mobilised in extended forms. The drumlins are thus seen to be formed as a continuation of deposition by bottom melting at the first stage of deglaciation and wider deposition by lodgement when an effective drainage began. At the final stage, stress variations at the basal part of the ice caused a differential continual movement by traction. The stress variations could be a consequence of longitudinal folding due to extension in the glacier ice. (See earlier description of continuity in erosion and accumulation). This last process continued until the glacier stagnated.

COOL AREAS WITH COMPRESSIVE FLOW

In areas where the glacier was in compression, a very variable final morphology was produced, varying from common hummocky moraine to small transverse ridges and large transverse ridges. The till consists of varying types of ablation till with grain size varying from fine to coarse. The boulder content is normal to high. The content of local material varies from a very high to a quite low percentage.

The moraine and till have formed in environments where ice of steady state flow or extending flow have met with ice masses of low velocity resulting in compressive flow. The latter resulted in folding, (cf. Kupsch 1962, p. 588, Moran 1971, p. 138, and Minell 1977a), incorporation and upwards transport of large quantities of till (cf. Weertman 1961, Boulton 1972a, Minell 1977). The final moraine forms and tills were dependent on the time during which the process continued and how temperate the environment was (Boulton 1972a). The folding without upward transport into the glacier ice resulted in basal large transverse ridges. If refreezing due to low velocity took place, low pressure and low shear stresses existed (Weertman 1962, p. 971), and there was an upward transport of material to the glacier surface (cf. Boulton 1972 and 1972a). If this process continued for a long time, large quantities of long-transported material as well as local material could be deposited.

The melting of stagnant and fragmented glacier ice produced a very variable final morphology from common hummocky moraines to small transverse ridges and large transverse ridges. The till during this last stage of supra-glacial melting and accumulation was exposed to different types of flow and water activity (cf. Boulton 1968 and 1971).

In connection with moraine plateaux and very large crag moraines, large deposits of till can exist. These usually have a topography varying from large moraine-plains, accompanied by large dead-ice holes, to very pronounced disintegrated moraine plateaux.

The till is homogeneous and loosely packed. It is rich in fine sandy matrix and poor in boulders. However, sediment layers of a few metres thickness with sharp contacts to upper and lower tills may exist. The till contains little or no rock-material of local origin in the uppermost layer.

Large deposits of "englacially derived till" have been preserved in elevated areas. The elevation and the cooler zones at a higher altitude seem to have caused a compression (cf. Boulton 1972) resulting in upward transport of till within a retarding and stagnating ice mass (cf. Boulton 1972) around and between hills. This transport, stagnation and accumulation on the high altitude resulted in an ice mass with large quantities of englacial debris. If there was a large distance between the proximal and distal part of the elevation, the compression was not followed by an extending flow as in other convex areas with smaller size (cf. Robin 1969).

During the final stage of deglaciation when till melted out, water activity and secondary movement of till and ice became possible. Large deposits of till can have sunk into the glacier ice resulting in moraine plateaux.

FINAL MELTING

At the time of the final melting of glacier ice, large areas between the Caledonian mountains and the highest shore-line were covered by stationary stagnant ice (cf. Mannerfelt 1945, Hoppe 1950, G. Lundqvist 1961, p. 125). Evidence of fluvioglacial activity, results from ^{14}C-dating and the lack of evidence of peripheral processes support this.

WATER ACTIVITY

Zones with intense water activity appear at intervals of several tens of kilometres. The water activity has resulted in well-developed eskers, washed moraines, strongly eroded thresholds, fluvioglacial channels and in rare cases canyons. The pattern of water activity is that of channeling towards and along lower zones in the terrain. Around the larger hill massifs there are swarms of fluvioglacial channels with, in places, clear eskers.

The fluvioglacial channels developed when the glacier was climatically dead and when the subaerial water had a temperature and content large enough to hold an ice tunnel open by pressure and melting (Glen 1954, Paterson 1969, p. 134, Shreve 1972). The glacier must have stagnated. In other case the fluvioglacial channels would have been destroyed. In areas with effective drainage, the fluvioglacial channels began to erode during the time of ice-stagnation. The stagnation took place when the ice stopped flowing at a level of approximately 200 m above the valley bottom, where the highest fluvioglacial channels begin.

This level is comparable with Nye's flow model (1951) where a glacier stops flowing when decreasing at an angle of 2° on a thickness of approximately 200 m. On a thickness of 100 m the gradient for a flowing glacier would be very steep and there are no indications that such a situation existed. The only fluvioglacial lateral channels with a gentler gradient than 2° have been found at Dötternåive. An effective drainage system, however, did not necessarily develop because of stagnant ice. Sediments from dammed water and fluvioglacial channels on very different and lower levels are evidence for this.

It seems that the drainage capacity of water was not enough to transport away large quantities of meltwater, which collected on the extensive level ice-surface (cf. Gillberg 1965, p. 406, Fromm 1965a). The most effective drainage system from such areas appears to have initiated when the stagnant ice was thin and the water was able to be easily transported away. At this stage the pressure and plasticity of ice was low, whilst the volume, temperature, pressure, pressure differences, and velocity of the water were high (Glen 1952, Paterson 1969, p. 134, Shreve 1972).

^{14}C-DATING

^{14}C-dating of samples taken from bottom sediments of lakes and also from dead ice holes associated with moraine plateaux indicate a re-establishment of vegetation in central Lappland at about 8 600–8 700 B.P. Unfortunately the number of samples studied is statistically insignificant, but all the values obtained are very similar with differences of only a few hundred years. These small differences support a quite sudden re-establishment of vegetation all over central Lappland after the last ice areas melted away in less than a few hundred years (cf. Fromm 1965, p. 209, Daniel 1975, p. 111). In Abborrträsk the datings and pollen-analyses indicate that ice covered by a till was melting, when the organic material was carried in (cf. Florin and Wright 1969).

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GFF = Geologiska Föreningens i Stockholm Förhandlingar

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The author wishes to draw attention to the following newly published book which makes an important contribution to this field of study.

Sugden, D. F., and John, B. S., 1976: Glaciers and Landscape. A geomorphological approach. — Edward Arnold, London. 376 pp.

TABLE I. Reference table for diagrams and curves (Figs. 6 – 18, 22, 29) with statistical treatment of till samples from different environments (pp. 12 – 28). All symbols refer to the diagrams in Figs. 6 – 9. The same types of symbols are used in the cumulative curves illustrated in Figs. 10 – 12, 22, 29 and in the frequency curves Figs. 14a – c.

Sample object	Sample no.	Frequency curves in Tab. II	Cumulative curves in	Symbol in figure (left), area (right)	
Basal level moraine-surface	7383: 929		Fig. 10	X	Björklund
	851	II	Fig. 29	X	Långträsk
	875		Fig. 22	X	V. Kikkejaure
	888	VII		X	Harrejokk
	7482: 707			X	V. Kikkejaure
Large crag moraine	7383: 816	V		P	V. Kikkejaure
	7482: 735			P	,,
	741			P	,,
	768		Fig. 12	P	,,
	753			P	Brunberget
Moraine plateaux	7482: 701			V	Abborrträsk
	712			V	Holmtjärn
	716		Fig. 10	V	,,
	717			V	,,
	7580: 561	I		V	Abborrträsk
Ablation till	7482: 705			A	Björklund
	708		Fig. 11	A	V. Kikkejaure
	720	III		A	Ruttjebäcken
	7476: 036			A	Dötternåive
	059			A	V. Kikkejaure
	7580: 565			A	Abborrträsk
	566			A	,,
Lense-till	7383: 850			L	Njallejaure
	856		Fig. 29	L	Långträsk
	862	II	Fig. 29	L	,,
	7482: 814		Fig. 11	L	Mörttjärn
	7476: 030		Fig. 10	L	V. Kikkejaure
	031		Fig. 22	L	,,
”Till at birth”	7383: 861	VI	Figs. 10, 25	N	Långträsk
	7476: 045		Fig. 11	N	Storuman
	053		Fig. 11	N	,,
”Ablation gravel”	7383: 842	IV	Fig. 10	T	V. Kikkejaure
	846	IV	Fig. 22	T	,,
	876		Fig. 22	T	,,
	892			T	Harrejokk
	895			T	,,
	962			T	,,
	444			T	,,
	7482: 703			T	Skellefte älv
	785			T	V. Kikkejaure
	896			T	,,
”Flow till”	7482: 884	VII		M	Harrejokk
	894			M	,,
	940	VII		M	,,
	954	VII		M	,,
	7476: 037	VII	Fig. 11	M	V. Kikkejaure
	032	VII	Fig. 11	M	,,
”Englacially derived till” in large transverse ridges	7383: 874		Fig. 22	I	V. Kikkejaure
	7476: 057	II	Fig. 12	I	,,
	058	I		I	,,
Ablation till in large transverse ridges	7383: 817	I		H	Dötternåive
	7476: 035	III	Fig. 10	H	V. Kikkejaure
	7580: 543	III		H	Båtsabäcken
	546			H	,,

TABLE I, continued

Sample object	Sample no.	Frequency curves in Tab. II	Cumulative curves in	Symbol in figure (left), area (right)	
Basal till in large transverse ridges	7482: 733			R	V. Kikkejaure
	788			R	,,
	842	I	Fig. 12	R	Mörttjärn
	7580: 575	I		R	Allejaure NW
Drumlins	7476: 040	I	Fig. 10	D	Skidnäsberget
	7482: 719	I		D	Ruttjebäcken
	7476: 065			D	Julträsk
	066	III		D	,,
	067	I		D	,,

TABLE II. Reference table for frequency curves (Figs. 14 a—c) and other curves and diagrams (Figs. 6—13, 16—18, 22, 29) with statistical treatment of till samples from different environments in Figs. 6—9 and 16—18. The cumulative curves are illustrated in Figs. 10, 11, 22, 29. Symbols with asterisks have frequency curves very similar to other till samples of the same type. They are not illustrated in the frequency curves in order to prevent confusion.

Frequency curves	Sample no.	Cumulative curves in	Symbol in figure	Area
I	7383: 459*		A	Harrejokk
	817		H	Döttern
	7476: 040		D	Skidnäsberget
	058		I	V. Kikkejaure
	067		D	Julträsk
	7482: 719		D	Ruttjebäcken
	842		R	Mörttjärn
	7580: 561		V	Abborrträsk
	575		R	NW Allejaure
II	7383: 951		X	Långträsk
	862	Fig. 29	L	,,
	7476: 041*		L	Skidnäsberget
	057		I	V. Kikkejaure
III	7476: 035		H	V. Kikkejaure
	066		D	Julträsk
	7482: 720		A	Ruttjebäcken
	7580: 543		H	Båtsabäcken
	553		f	Giltjaur
IV	7383: 842	Fig. 10	T	Björklund
	846	Fig. 22	T	,,
	7580: 603		e	Kåbdalis
V	7383: 816		P	V. Kikkejaure
	820*	Fig. 22	A	Döttern
	960		c	Harrejokk
	7580: 602		d	Kåbdalis
VI	7383: 861	Figs. 10, 29	N	Långträsk
	899*		N	Harrejokk
	955*		N	,,
VII	7383: 884		M	Harrejokk
	888		X	,,
	940		M	,,
	954		M	,,
	7476: 032	Fig. 11	M	V. Kikkejaure
	037	Fig. 11	M	,,
VIII	7580: 556		h	Giltjaur
	547*		H	Båtsabäcken

TABLE III. Reference table for statistically treated till types (pp. 12—28) from moraine forms (pp. 8—12) illustrated in diagrams and curves (cf. Figs. 6—18, 22, 29).

Subdivision of till types	General morphology	Symbol in figure	In frequency curves
a, ”till at birth”	Thin till	N	VI
	4. Hog's - back moraines	N, b	
	6. Hummocky moraines of different types	N	
b, basal till	1. Large-scale flutings. 2. Drumlins	D	I, III
	3. Large crag moraines	P	
	4. Large transverse ridges	R	I
	Level marine surface	X	II
c, ”englacially derived till”	5. Moraine plateaux	V, d, j	I, V
	3. Large crag moraines	P, i	V
	4. Large transverse ridges	I	I, II
d, ablation till	4. Large transverse ridges	H, f, g, h	I, III, VIII
	and hog's-back moraines	A, c	
	5. Large scale undulating moraines	A	III
	6. Hummocky moraines of different types	A, k, l	
e, lense-till or sediment-bearing till	2, 3. Within interior of some drumlins and large crag moraines	L	II
	4. Large transverse ridges	L	
	6. Rather large hummocky moraine forms of different types	L	
	Level moraine surface	L	II
f, ”ablation gravel”	4. Hog's-back moraines	T	
	6. Hummocky moraines of different types	T, a, e	IV
g, ”flow till”	4. Hog's-back moraines	M	VII
	6. Hummocky moraines of different types	M	

TABLE IV. Reference table for diagrams and curves (cf. Figs. 6—18, 22, 29) with statistically treated till samples from different areas and with different bed rocks in diagrams Figs. 16, 17, 18.

Sample no.		Frequency curves in Tab. II	Symbol in figure	Area and bed rock types	
7383:	961		b	Harrejokk	Immediately east of ice-shed in
	962		a	„	crystalline bedrock
	960	V	c	„	
7580:	602	V	d	Kåbdalis	Between ice-shed and highest shore
	603	IV	e	„	line in crystalline bedrock
7580:	553	III	f	Giltjaur	Main ice-shed in crystalline
	554		g	„	bedrock
	555		i	„	Caledonian rocks
	556	VIII	h	„	„
7580:	561	I	j	Abborrträsk	Between ice-shed and highest
	565		k	„	shore line in crystalline bedrock.
	566		l	„	

TABLE V. Reference table for moraine forms (pp. 8–12) and till types (pp. 12–28) illustrated in diagrams and curves (cf. Figs. 6–18, 22, 29).

Moraine type	General till types	Symbol in figure	In frequency curves
1. Large-scale flutings	b, basal till probably lense-till at depth	D	I
2. Drumlins and drumlinoids	b, basal till, in some cases at depth lense till	D	I, III
3. Large crag moraines	b, basal till	P	
	c, ”englacially derived till”,	P i	V
	in some cases at depth lense till	L	II
4. Large transverse ridges (Rogen-like moraines)	b, basal till	R	I
	c, ”englacially derived till”	I	I, II
	d, ablation till	H f, g, h	I, III, VIII
	e, lense-till		
Hog's-back moraines	a, ”till at birth”	N b	VI
	d, ablation till	A c	V
	f, ”ablation gravel”	T a	IV
	g, ”flow till”	M	VII
5. Large-scale undulating moraine and moraine plateaux	c, ”englacially derived till”	V d, j	I, V
	d, ablation till	A	III
6. Hummocky moraine of different type	a, ”till at birth”	N	VI
	d, ablation till	A e	IV
	f, washed till	T	IV

TABLE VI. The bedrock content in different till types at Långträsket.

Bedrock content in per cent	”Till at birth”	Basal till	Lense-till (lower)	Lense-till (upper)
Acid to intermediate volcanics	68	30	16	22
Porphyritic granite	28	14	26	18
Ultrabasic rock		24	24	16
Red granite	4	10	10	14
Red and grey gneiss		12	8	6
Schists		8	8	18
Grey granite			6	2
Quartzite		2	2	4

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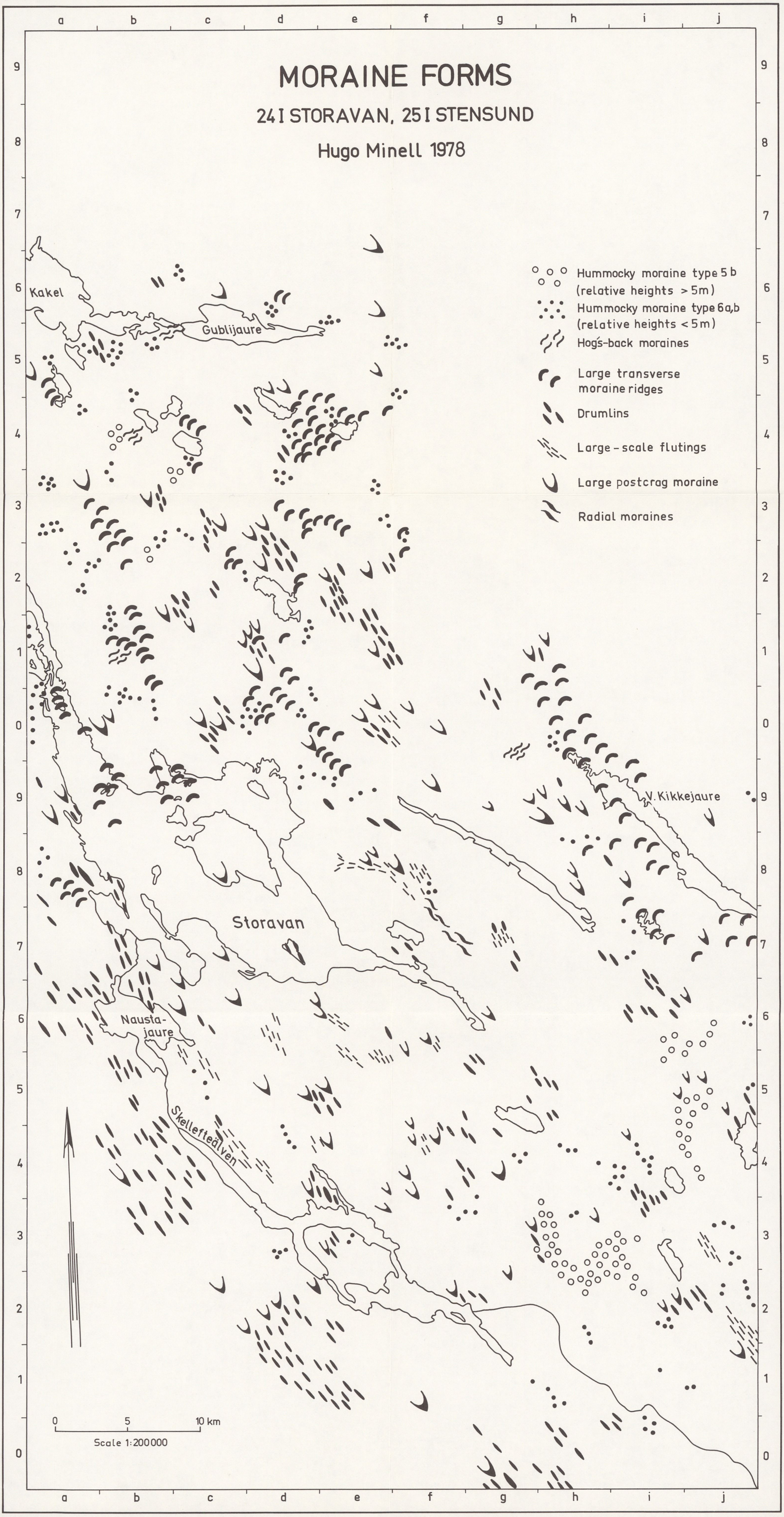

FLUVIOGLACIAL TRACES AND EXPOSED BEDROCK

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