

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 753 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 72 NR 15

SVEN BJÖRNBOM

CLAYEY BASAL TILL
IN CENTRAL AND NORTHERN SWEDEN

A DEPOSIT FROM AN OLD PHASE OF
THE WÜRM GLACIATION



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ABSTRACT

A dark, clayey basal till underlying the ordinary till is described from central and northern Sweden. The till consists of Precambrian rock material and differs from the ordinary till by a higher content of fines, dark colour, lower stone, and boulder frequency and a higher degree of compaction. The roundness is higher in the clayey till. The clayey till occurs mainly as relicts in topographic positions that have reduced erosion from younger ice movements. The high content of fines is supposed to depend on intermixed older sediments. At some localities pieces of clay and laminated silt have been found in the till. The petrography, shape and roundness of coarse particles suggest that the clayey till is far transported. Particle orientation analyses show that the clayey till has been deposited by an old north-westerly to westerly ice movement. X-ray analyses of the fines show that the clay mineral content is about the same in the clayey till as in the ordinary one. The clayey till most probably dates from an initial phase of Würm II—III.

INTRODUCTION

Different genetic types of clayey till occur in Sweden. The main part is found in areas with sedimentary bedrock. A clayey till of a special type different from these has been reported from several places in Sweden. (E.g. Fegraeus 1890, Ängeby 1951, G. Lundqvist 1951, 1963, J. Lundqvist 1958, 1967, 1969, 1971, Möller 1964, 1965, 1968, 1969, 1974, 1977, Björnbom 1971, Eriksson 1977.) In the County of Västernorrland several occurrences of the clayey till have been found during the reconnaissance for the map of the Quaternary deposits of the county (pers. comm. J. Lundqvist, J. O. Svedlund).

A similar type of till has been reported from Norway by Låg (1948), from Finland by Berghell (1899, 1904), Virkkala (1959), Kujansuu (1974, 1975), Rainio and Lahermo (1976) and from the USSR by Armand et al. (1969).

There are different opinions about the age of the clayey till. A deposition in Würm I is proposed by Armand et al. (1969, p. 11) and J. Lundqvist (1971, p. 32, 1974, p. 329, 1977, p. 82). In the latter work J. Lundqvist also considers it possible that the till in question derives from the initial phase of Würm II. A deposition in Würm II is also proposed by Möller (1968, p. 467), Kujansuu (1975, p. 50) and Rainio and Lahermo (1976, p. 151). Berghell (1904, p. 48) thought that the clayey till derived from the so-called great glaciation which corresponds to Riss. Låg (1948, p. 95) only states that the till is older than the ordinary one.

In Sweden H. Möller has reported several occurrences of a clayey basal till in the vicinity of Stockholm, central Sweden (see above). Two of these localities, *Vada* and *Ullna*, have been investigated in detail (H. Möller 1964, p. 94—97, 1968, p. 467, 1974, p. 42—43). By means of till fabric he identified a transport direction from WNW. H. Möller correlated this direction with an old system of striae in these regions which was supposed to date from an early phase in the Würm glaciation. Petrographic analyses in the stone fraction showed that about 20 per cent of the clasts in the till was transported far, at least 100 km.

Observations on the clayey till in this work have been made during a period of about 10 years. Some of the localities have been found during reconnaissance for soil maps and geochemical prospecting while others have been found in excavations for buildings and roadworks. As the observations have been made during a long period, sampling and methods of analyses are not consequently performed.

No distinction is made between clayey till and clay till in the text although the clay content sometimes exceeds 15 per cent. The reason is that the clay content varies within the same unit and the terms clay till and clayey till could be interpreted as terms denoting different till beds.

The purpose of this investigation was to get more information about the regional distribution, topographic position, reason for the dark colour, content of weathering residual, direction of transport and an age determination (cf. J. Lundqvist 1973, p. 20).

METHODS

Grain-size analyses. About 2 kg of each till sample was analysed by sieving (20—0.063 mm) and hydrometer analyses (< 0.063 mm). In the cumulative curves the interruption at 0.063 mm, caused by different methods of analysis, has not been taken into consideration. The Atterberg's classes have been used.

CaCO₃ content. The analyses were made on material < 2 mm by quantitative analyses on developed CO₂ after treatment with 10 per cent HCl. The accuracy is about ± 0.5 per cent.

Humus content. The humus content was analysed on material < 2 mm by oxidation at 1000°C in oxygen and gravimetric analyses on developed CO₂. The obtained percentage of carbon was then reduced with the CaCO₃-carbon content. The humus content was calculated by multiplying the factor 1.72 with the organic carbon. The accuracy is estimated to about ± 2 per cent.

Heavy minerals. The heavy mineral content was determined on material from the fraction 0.6—0.2 mm by wet-sieving and separation in tetrabromomethane (2.8 g/cm³).

The above mentioned analyses were carried out at the Soil laboratory of the Geological Survey of Sweden (SGU).

Spectrochemical analyses. The content of metal elements in the matrix (< 2 mm) and in the 0.2—0.06 mm fraction was performed in an emission spectrograph at the Geochemical laboratory at SGU. The method is described by Danielsson and Sundkvist (1959). As only Zn and Cr showed defined variations, only these two elements are presented.

X-ray diffraction analyses. The clay mineral analyses and the estimations of the clay mineral content were performed at the Geochemical laboratory, SGU, by Dr Ann-Marie Brusewitz. Only basic results from these analyses are presented in this work.

Particle counts. The petrographic studies were made in the stone and fine gravel fractions (200—20 mm and 6—2 mm respectively). In the fine gravel fraction more than 300 particles from each sample were counted according to the method developed by J. Lundqvist (1952). In the stone fraction 90 to 150 stones were counted from each sample.

Unidentified particles did not amount to 1 per cent. The distinction between some of the petrographic groups is not so clear as the table shows (Table No. 1) and needs some comments: Granites, coarse-grained gneisses, quartz, feldspar

and others are put together in the same group as for example migmatized gneisses may be mixed up with granites. Fine-grained, dark, meta-arenitic gneisses may in some cases have been placed in the graywacke group and vice versa. If a slaty structure was visible the particles were grouped to the graywackes. The leptite group may contain some aplites and dense quartzites. Calcedony has been put in the porphyry and hälleflinta group.

Roundness analyses. The roundness classification was carried out in the stone fraction visually in the field. The roundness of medium sand particles (0.5–0.2 mm) was determined by a method modified after Russel and Taylor (1937). About 400 particles were fractioned out from each sample and examined under microscope. The determination of roundness was then carried out in photographs taken of the samples. Four classes were used: *angular*, *sub-angular*, *sub-rounded* and *rounded*. In the last class *well-rounded* is included as they are very rare in these till fractions.

Microfabric analyses. The grain orientation was determined in oriented till samples employing a method by Björnbom (1977). The three-dimensional orientation of medium sand particles was determined in a stereo magnifier. Measured particles:

Rods $A/B > 3/2$, $B/C < 3/2$

Blades $A/B > 3/2$, $B/C > 2$

A = long axis, B = intermediate axis, C = short axis. Particle size = 0.5–0.2 mm. The measurements are plotted on a polar, equal-area net, lower hemisphere. N = number of measured particles.

Matrix hue: The determinations of matrix hue were made by using Munsell Soil Color Charts (values 2.5 and 5Y; 2.4, 5, 7.5, and 10YR; and 10R).

Compactness: The compaction of the tills was estimated in the field at the localities. Undisturbed samples of the clayey till (volumes between 100 and 450 cm³) from localities Nos. 11, 13 and 16 were submitted to dry density measurements. The samples were air-dried under constant conditions more than a month. After treatment with grease the lifting-power in water was measured. The known weight of the grease was then subtracted from the total weight and the dry density could be calculated.

Six samples of the clayey till gave a dry density between 2.2 and 2.4 g/cm³. The dry density of the ordinary sandy till at locality No. 4 was found to be 2.0 g/cm³. The density measurements were performed only to exemplify the degree of compactness. As Goldthwaite (1948), Floss et al. (1968), Johnson & Sallberg (1962) have pointed out, several factors influence the compactness. The dry density of the clayey till does not tell anything about the conditions when the till was deposited.

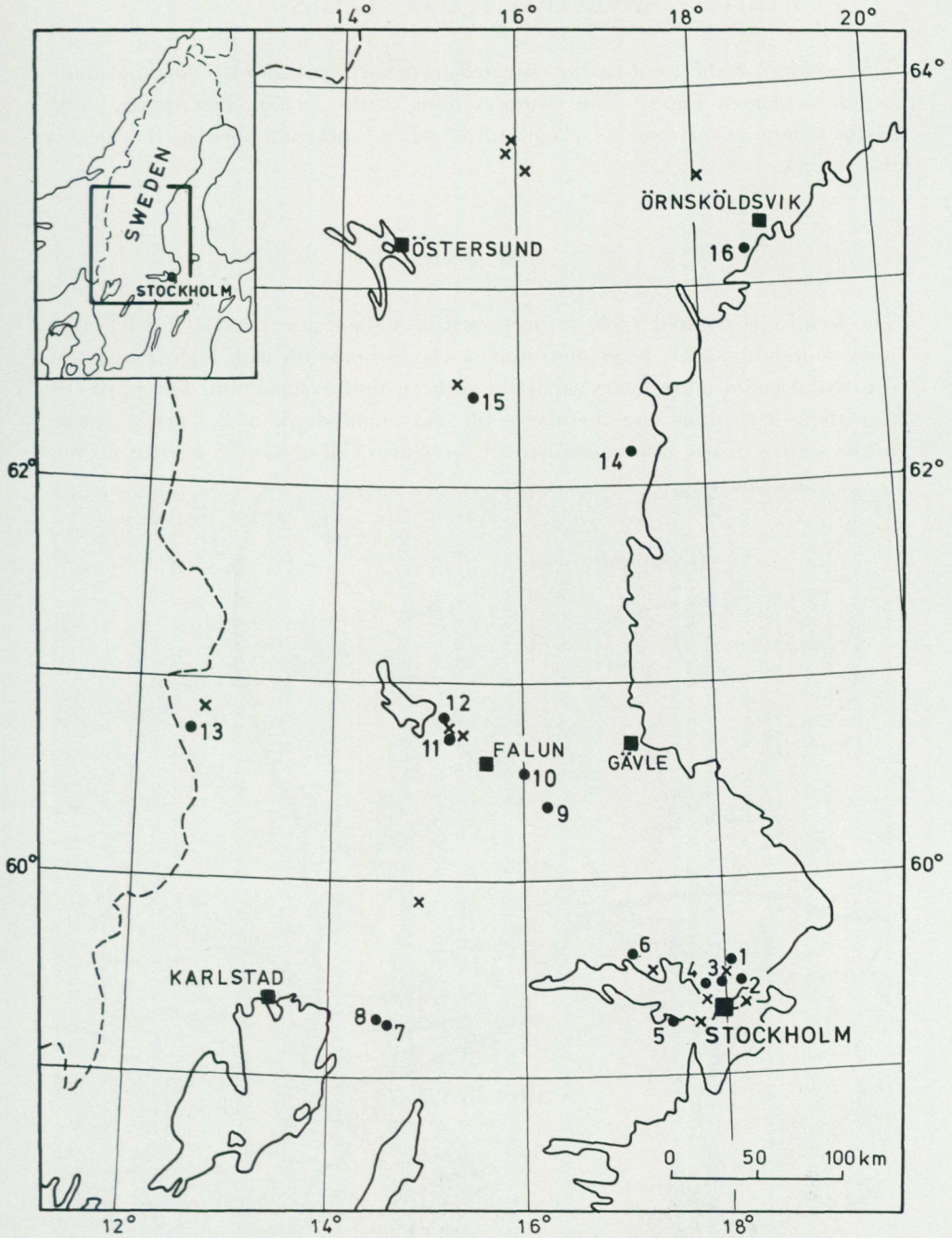


Fig. 1. Map showing the position of old clayey till localities. Dots with numbers refer to the localities described in the text. Cross marks denote inspected occurrences not described in detail in the text.

INVESTIGATED LOCALITIES

The position of the localities investigated in detail, marked with dots and numbered, is seen in Fig. 1. The numbers refer to the locality description. Cross marks denote occurrences of clayey till which are not described in the locality description.

1. ROSENDAL

The locality is situated 1 800 m northwest of Vallentuna church (Fig. 2). In a small foundation shaft (now destroyed) a clayey sandy till with high compaction was found below an ordinary sandy till with medium compaction. The upper till was about 1 m thick and the clayey till was found down to 2.5 m.b.s. (meter below surface). The uppermost part of the clayey till, about 0.5 m, had a grey-



Fig. 2. The position of locality No. 1. Top. map 11 I Uppsala SO.

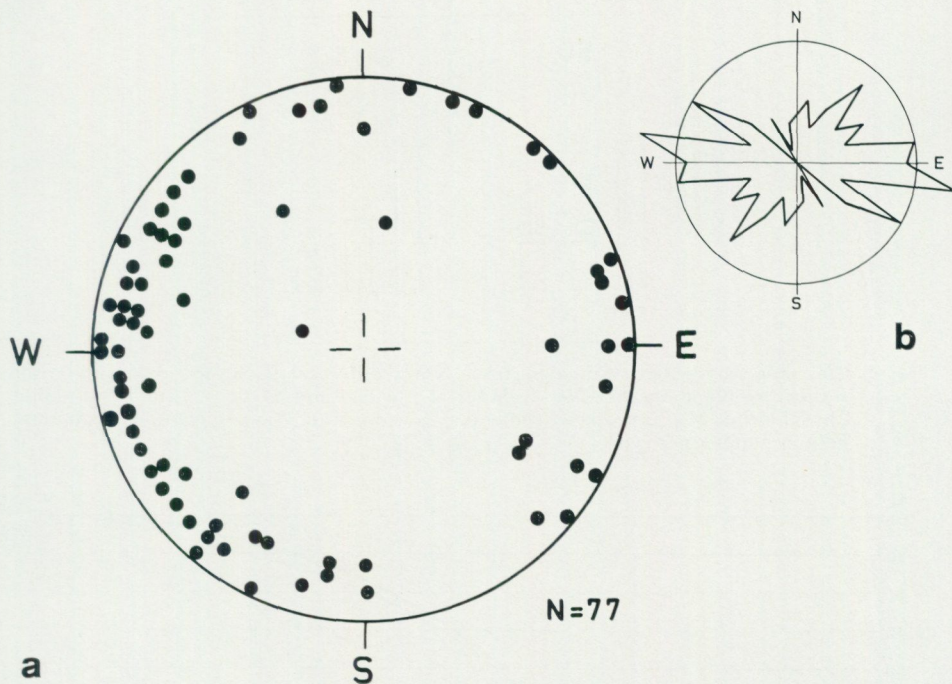


Fig. 3. a = Stereodiagram of particle orientation in the clayey till 2 m.b.s. at locality No. 1. b = Particle orientation in Fig. 3a visualized in a rose diagram. (Circle marks 10 per cent.)

ish brown hue (2.5Y 5/2) while the lower part was dark grey (2.5Y 4/0). The limit between the two tills was sharp while the limit between the two colour zones in the clayey till was indistinct. The frequency of sub-rounded and rounded coarse clasts was higher in the clayey till. A microfabric analysis in the clayey till (2 m.b.s.) showed a preferred orientation from WNW (Fig. 3).

Glacial striae systems from $N60^{\circ}W \rightarrow NW \rightarrow NNW \rightarrow N-S \rightarrow NNE$, from oldest to youngest, have been reported from areas round this locality by H. Möller (1974).

The petrography of the fine gravel fraction in the clayey till (sample 1 B) and in the sandy till (sample 1 A) is seen in Table No. 1. There are no significant differences in the petrography between the two tills.

Two X-ray diffraction analyses were carried out in the clayey till; one in a sample from the greyish brown zone (sample SO 4, 1.2 m.b.s.) and one in the dark grey zone (sample SO 5, 2.0 m.b.s.). The result is seen in Fig. 4. Smectite and vermiculite are lacking in the lower zone. Some kaolinite is indicated in the upper part. The percentage of FeO is higher in the upper zone while Fe_2O_3 shows the converted trend (not seen in Fig. 4).

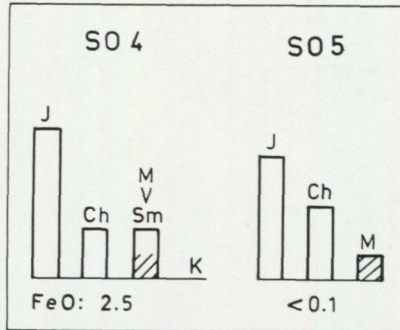


Fig. 4. Clay mineral content estimated from X-ray diffraction analyses in samples from the clayey till at locality No. 1. SO 4, 1.2 m.b.s. and SO 5, 2.0 m.b.s. (J=illite, Ch=chlorite, M=mixed-layer mineral, V=vermiculite, Sm=smectite, K=kaolinite, FeO in number per cent)

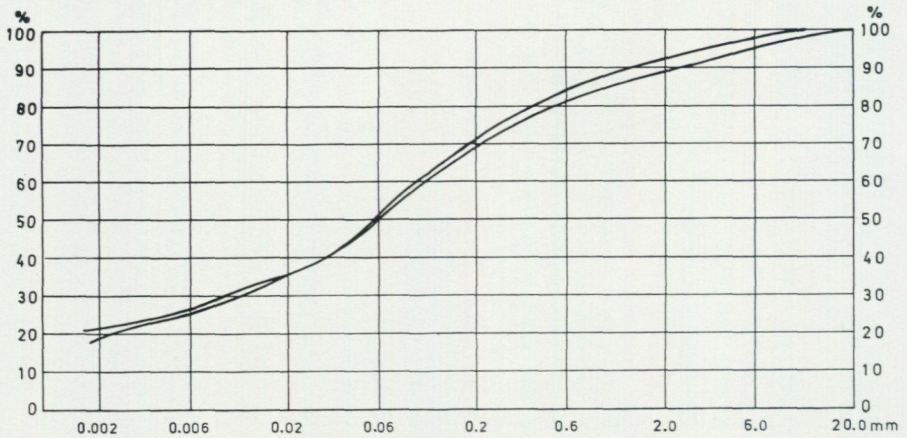


Fig. 5. Grain-size distribution of the two zones of the clayey sandy till at locality No. 1.

The grain-size distribution in the two zones of the clayey till is seen in Fig.5. The curve with the higher clay content represents the dark grey zone.

The two tills are situated in a lee-side position close to a bedrock outcrop at the northern end of the excavation. A smaller occurrence of the clayey till was found 100 m west of the foundation shaft. This till was overlain by a sandy till. In this case also the situation was in a lee-side position.

2. ÖSTRA RYD

Within a limited area four occurrences of a clayey sandy till were found in road cuttings. One of these sites is here described in detail. It is situated 900 m north-west of Östra Ryd church (Fig. 6). In a cutting (now destroyed) a clayey till

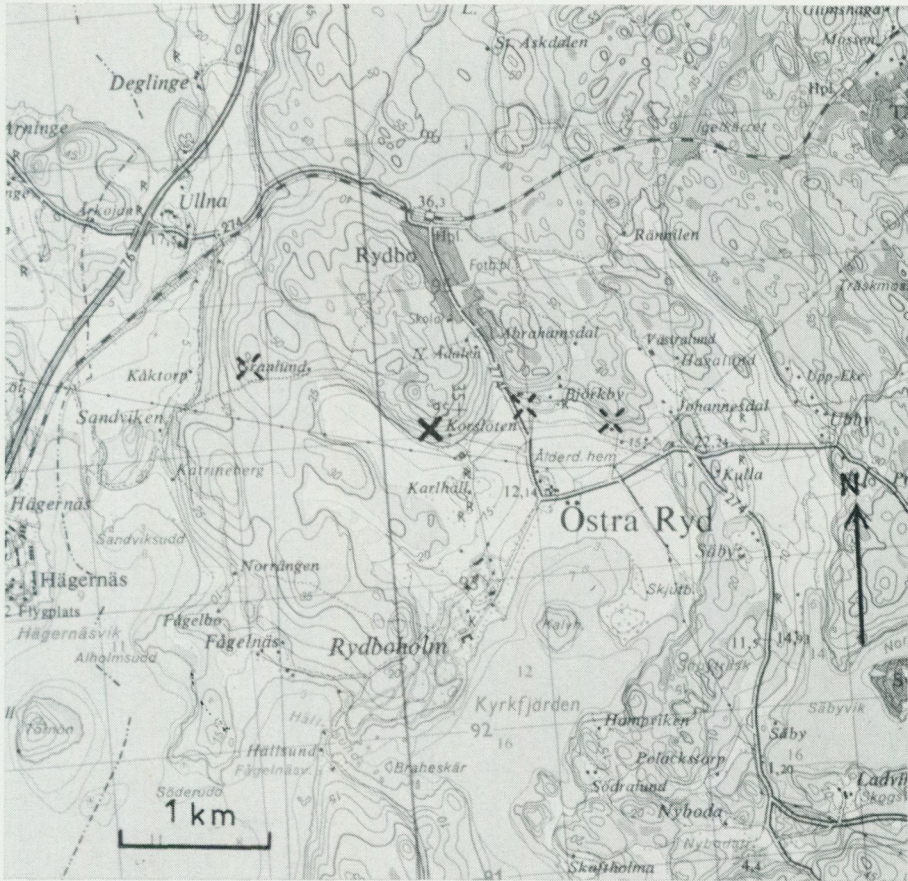


Fig. 6. The position of locality No. 2. Top map 10 I Stockholm NO.



Fig. 7. The cutting at locality No. 2. North is to the left in the picture. Exposed bedrock is seen to the left.



Fig. 8. A section at locality No. 2 showing the zonal variation of colour in the clayey till. Slumped material at the lower part of the section.

with low frequency of boulders and stones was found overlain by wave-washed sediments. The cutting wall was oriented in a N—S direction and at the northernmost part the bedrock was exposed (Fig. 7). The till had a high compaction, somewhat lower in the upper part. The sediments had a thickness of 0.5 m and the clayey till reached down to 3—5 m.b.s. with decreasing thickness to the south.

The clayey till was divided into three different hue zones, an uppermost one (about 1 m) with a greyish brown hue (10YR 4/2), a middle one (about 1.5 m) with a greyish brown hue (2.5Y 5/2) and a lower zone with a dark grey hue (2.5Y 4/0), Fig. 8. Several thin laminae of silt running subhorizontally through the matrix were visible all over the cutting. One of these silt laminae is seen in



Fig. 9. A thin laminae of silt (above the key) in the clayey till at locality No. 2.

Fig. 9. Two steeply dipping joints, 5–10 cm wide and filled with silt, were found in the till. They dipped southwards at an angle of about 50 degrees. Both of them began in the uppermost part of the till and ended in the middle of the dark grey zone. At this level the surroundings of the joints had a light brownish grey hue while the matrix as a whole was dark grey. An irregular fissility was present in the till down to about 3.5 m.b.s. Precipitation of mangan, especially on joint surfaces, was common in the two upper zones.

Two small bedrock knobs were exposed in the northern part of the cutting. One of them was at the same level as the middle zone and the other at the lower zone. Striae systems from $N55^{\circ}W$ and $N70^{\circ}W$ were found on top parts of the knobs. The $N55^{\circ}W$ -system dominated and the $N70^{\circ}W$ -system occurred in small depressions on the bedrock surface. The latter system is supposed to be the oldest.

Microfabric analyses, one in a sample from the middle zone 1.5 m.b.s. (Fig. 10) and one from the lower zone 2.5 m.b.s. (Fig. 11) show a preferred orientation from the northwest.

The following striae systems have been reported from areas round this locality by H. Möller (1964): $WNW(N80^{\circ}-N60^{\circ}W) \rightarrow NW \rightarrow NW-N$, from oldest to youngest. The WNW -system occurs on facets dipping towards SSW and is separated from the NW -system which occurs on facets dipping towards southwest. These systems are separated from younger system ($NW-N$) which do not appear on facets.

Grain-size analyses were carried out in four samples from the clayey till at

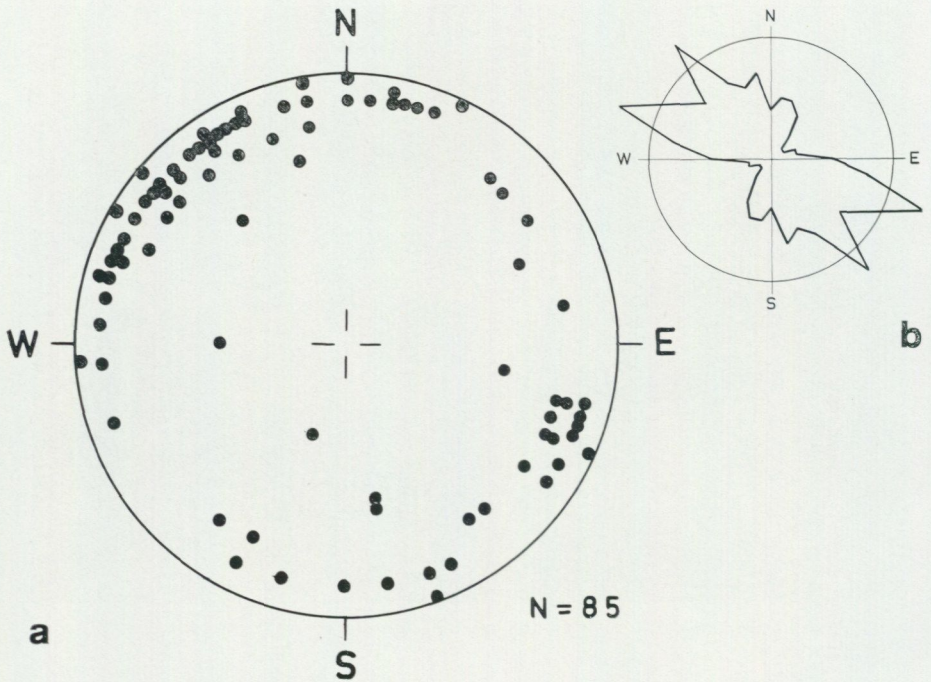


Fig. 10. a=Stereodiagram of particle orientation in the clayey till 1.5 m.b.s. at locality No. 2.
b=Particle orientation in Fig. 10a visualized in a rose diagram. (Circle marks 10 per cent.)

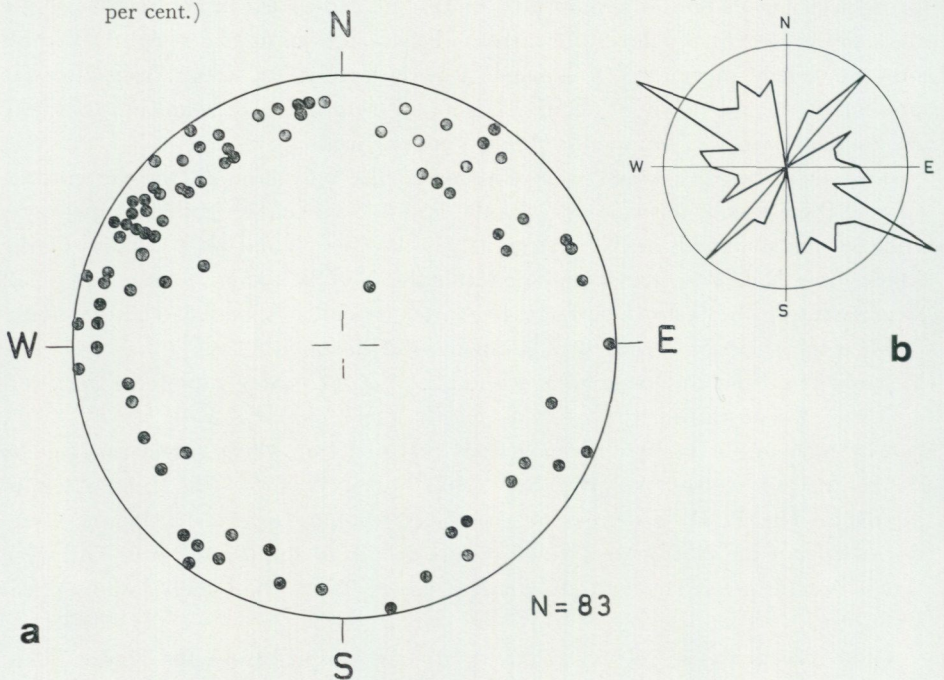


Fig. 11. a=Stereodiagram of particle orientation in the clayey till 2.5 m.b.s. at locality No. 2.
b=Particle orientation in Fig. 11a visualized in a rose diagram. (Circle marks 10 per cent.)

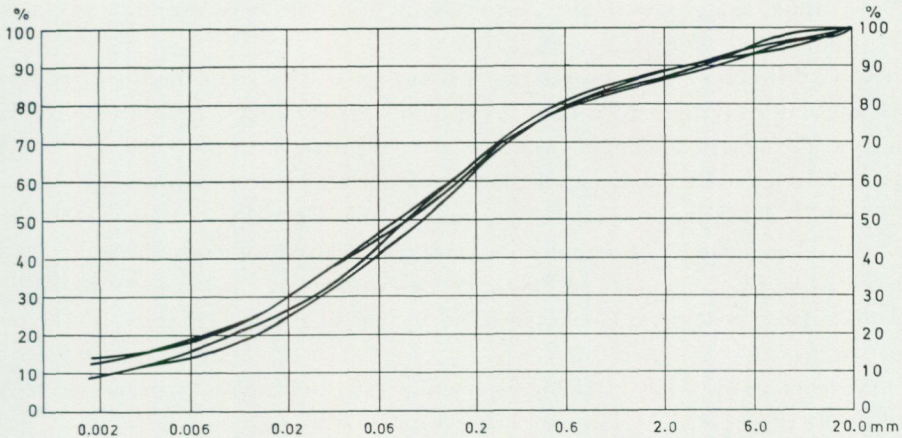


Fig. 12. Grain-size distribution of the upper and lower zone of the clayey till at locality No. 2.

different levels (Fig. 12). The two curves with the highest clay content are from samples in the lower zone and the other two curves represent the mechanical composition of the till in the upper zone. The content of clay is higher in the lower part of the clayey till.

Roundness analyses of sand grains in a sample from the till 2.5 m.b.s. showed that 21 per cent were angular, 72 per cent sub-angular, 6 per cent sub-rounded and 1 per cent rounded. For comparison, an analysis of sand grains from a sample of an ordinary sandy till close to the investigated site showed that 32 per cent were angular, 67 per cent sub-angular and 1 per cent sub-rounded. Rounded grains were lacking. Thus, the roundness is higher in the clayey till.

The petrography of the gravel fraction from samples taken in the upper and lower zone is seen in Table No. 1 (sample 2 B, upper zone, and 2 C, lower zone).

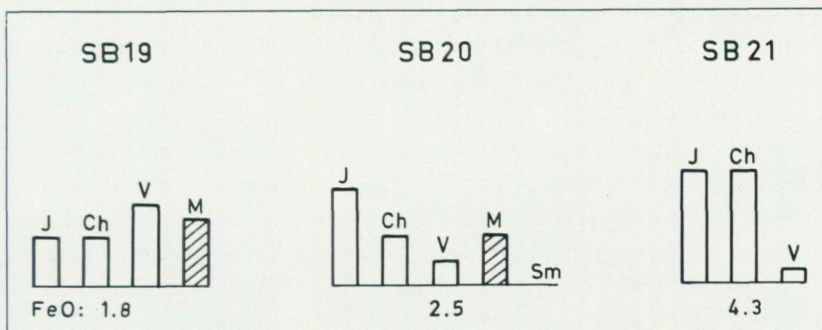


Fig. 13. Clay mineral content estimated from X-ray diffraction analyses in samples from the clayey till at locality No. 2. SB 19, 1.3 m.b.s., SB 20, 2.8 m.b.s. and SB 21, 4.5 m.b.s. (J=illite, Ch=chlorite, V=vermiculite, M=mixed-layer mineral, Sm=smectite. FeO in number per cent.)

Petrographic analyses were also performed in a sample from the ordinary sandy till (sample 2 A, 1.5 m.b.s.).

X-ray diffraction analyses were carried out in samples from the three zones of the till. The clay mineral content is seen in Fig. 13. Analysis SB 19 shows the mineral content in a sample from the greyish brown zone (1.3 m.b.s.), SB 20 shows the mineral content in a sample from the brownish grey zone (2.8 m.b.s.) and SB 21 shows the mineral content in a sample from the dark grey zone (4.5 m.b.s.). The content of vermiculite and mixed-layer minerals decreases with depth while the percentage of FeO increases with depth. The content of Fe₂O₃ in these samples shows a converted trend to that of the percentage of FeO (not seen in Fig. 13).

The content of Cr, Zn, CaCO₃, heavy minerals, and humus from samples 2 A, 2 B and 2 C (see above) is seen in Table No. 2.

The clayey till was situated in a lee-side position to younger ice movements. Three other occurrences of the clayey till, found in the vicinity (Fig. 6), were also in lee-side positions.

3. SOLLENTUNA

The locality is situated 100 m NNE of Tureberg railway-station (Fig 14). In a foundation shaft (now destroyed), with a depth of 6 m and a base of 20 x 40 m, three tills were exposed. The shaft was oriented in ENE—WSW. In the eastern part, the tills were overlain by glaciofluvial material deriving from an esker east of the site. In the western part of the excavation a loose sandy till was underlain by a clayey sandy till. The limit between the two tills was sharp. The clayey till bed was 4—6 m thick in the western part of the shaft and had an average dip of 30 degrees towards northeast. A fine sandy till underlying the clayey till was exposed in the western part of the shaft. The limit between the clayey till and the fine sandy till was sharp and was sub-parallel to the limit between the two upper tills. The grain-size distribution of the three tills is seen in Fig. 15 (curve No. 1 = sandy till 1.8 m.b.s., No. 2 = clayey till 4.5 m.b.s. and No. 3 = fine sandy till 5.6 m.b.s.).

The sandy till had a high frequency of boulders and stones. Most of them were angular. The compaction was low. Lenses of sand and silt were frequent, especially in the eastern part of the excavation, close to the glaciofluvial material. The till had a light grey hue (5Y 7/2) and precipitation of iron was common.

The clayey till with a dark grey hue (2.5Y 4/0) had a low frequency of boulders and stones and a high compaction. The roundness of coarse clasts was markedly higher than in the sandy till. Sub-rounded stones and gravel were frequent. Some of them were faceted, polished and striated. Thin lenses and laminae of silt, mainly conformable to the till beds were very frequent through-

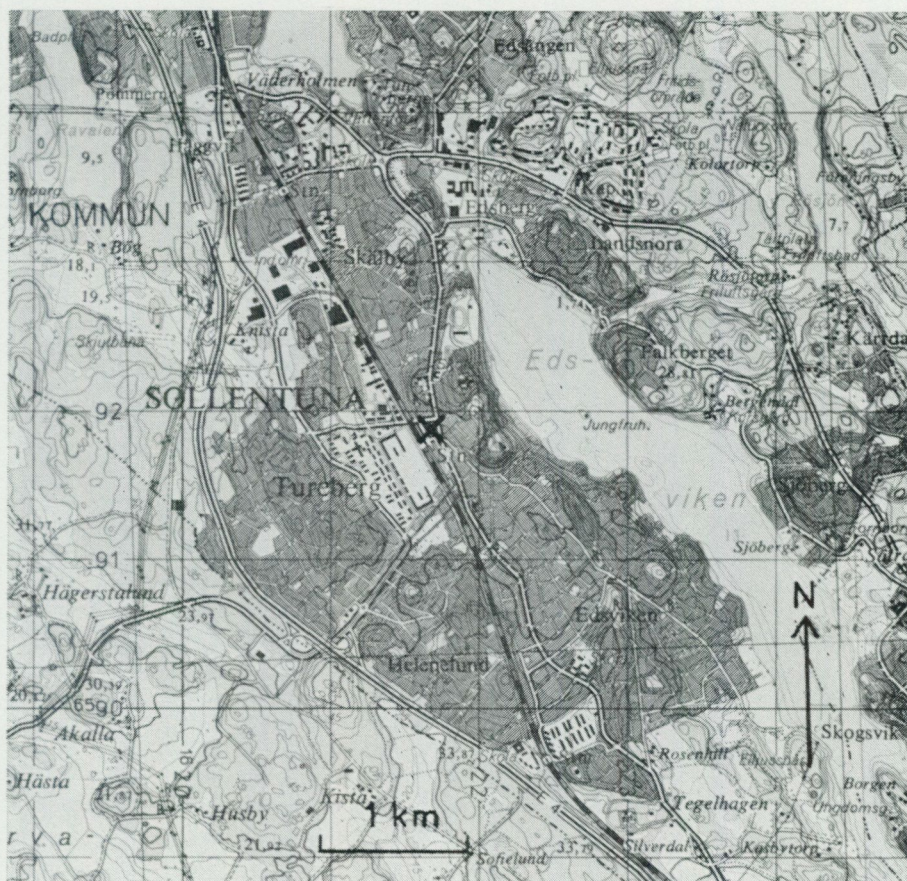


Fig. 14. The position of locality No. 3. Top map 10 I Stockholm NV.

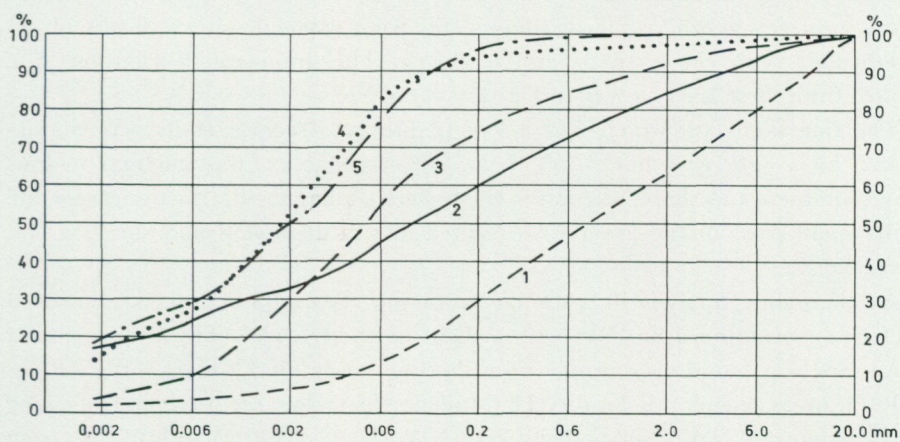


Fig. 15. Grain-size distribution of the three tills and sediment layers at locality No. 3. (1 = sandy till, 2 = clayey till, 3 = fine sandy till, 4 = silty layer in the fine sandy till, 5 = silty layer in the clayey sandy till.)



Fig. 16. The limit between the clayey and the fine sandy tills in a section at locality No. 3. The dark part at the upper right is the clayey till. Note the thin silt laminae in the clayey till conform to the limit of the fine sandy till (light in the picture). NNW is to the right in the picture.

out the whole unit. They were a few millimetres thick and had a length of a few centimetres to some metres. Thin silt laminae in the lower parts were in contact with the underlying fine sandy till. They were undulating and at some sections folded. In some parts, where the contact was irregular but sharp, the silt laminae were parallel to the lower till limit (Fig. 16). In the eastern part of the shaft, in a section where the two lower tills were exposed, several layers of silt interbedded with clayey till layers were seen. The grain-size distribution in a sample from these layers is seen in Fig. 15 (curve No. 5).

The fine sandy till which had a low frequency of coarse clasts was characterized by a light grey hue (2.5Y 7/2). The compaction was medium to low. The roundness and shape of coarser clasts were similar to that in the clayey till. Some small parts of the lower till consisted of stratified sand and silt (Fig. 15, curve No. 4).

A microfabric analysis in a sample from the clayey till 4.5 m.b.s. showed a preferred orientation from NW with a slight northerly trend (Fig. 17). A similar anisotropy was found in a sample from the fine sandy till 5.5 m.b.s. (Fig. 18).

From areas round this locality H. Möller (1965) has reported the following striae systems: WNW (N80°—N60°W)→NW (N50°—N40°W)→NW—N, from oldest to youngest. The two oldest striae systems are found on facets and in

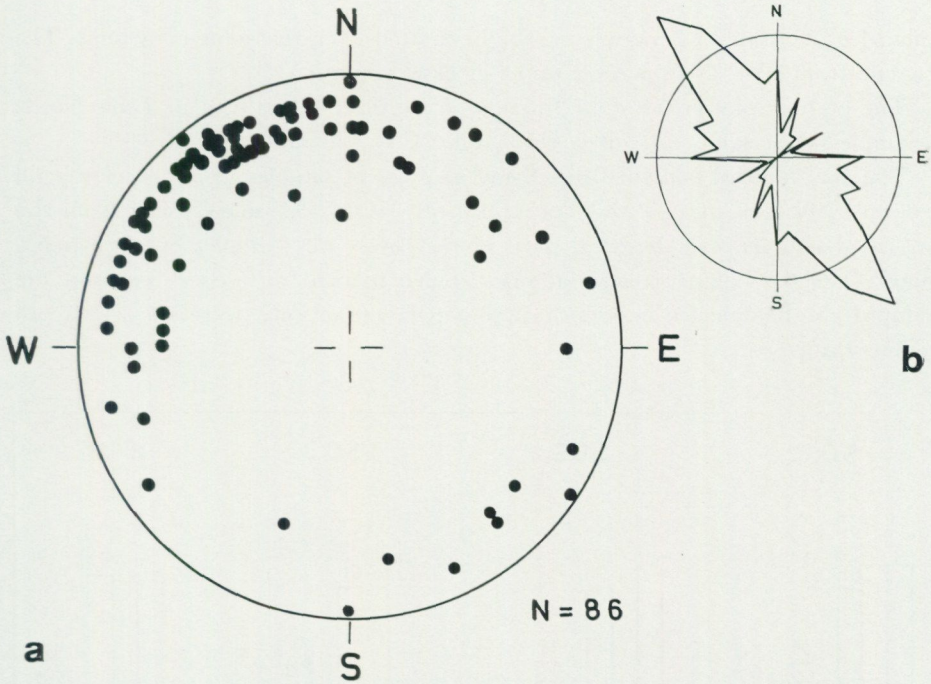


Fig. 17. a = Stereodiagram of particle orientation in the clayey till 4.5 m.b.s. at locality No. 3.
 b = Particle orientation in Fig. 17a visualized in a rose diagram. (Circle marks 10 per cent.)

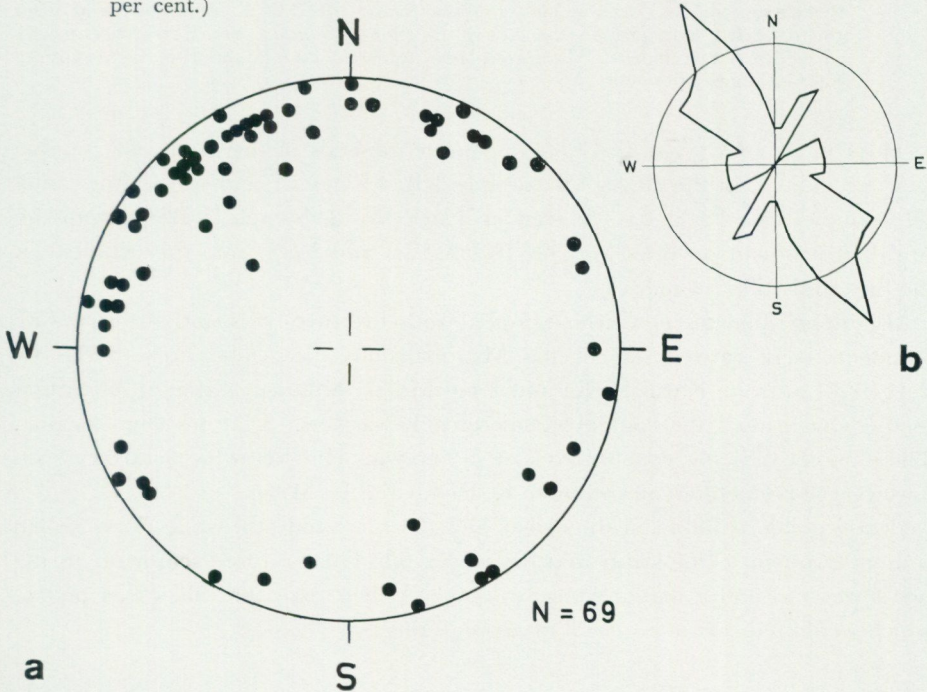


Fig. 18. a = Stereodiagram of particle orientation in the fine sandy till 5.5 m.b.s. at locality No. 3.
 b = Particle orientation in Fig. 18a visualized in a rose diagram. (Circle marks 10 per cent.)

other lee-side positions and are possibly separated from the younger systems. The systems from NW—N show a continuous clockwise rotation.

The petrography in the stone fraction of the three tills is seen in Table No. 1. (Sample 3 A = sandy till, 3 B = clayey till, 3 C = fine sandy till).

The clay mineral content from X-ray analyses of samples from the clayey till (sample SO 2, 3 m.b.s.), the fine sandy till (SO 1, 3.5 m.b.s.) and from the stratified sediments in the clayey till (samples SO 3, 5 m.b.s. and SO 6, 6.5 m.b.s.) is seen in Fig. 19. No marked differences between the samples can be detected besides that the percentage of FeO decreases with depth below surface.

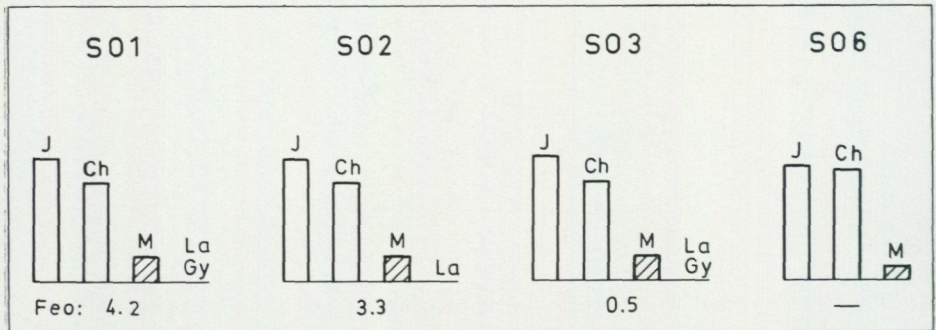


Fig. 19. Clay mineral content estimated from X-ray diffraction analyses in samples from the clayey till (SO 2, 3 m.b.s.), the fine sandy till (SO 1, 3.5 m.b.s.) and from the stratified sediments in the clayey till (SO 3, 5 m.b.s. and SO 6, 6.5 m.b.s.) (J = illite, Ch = chlorite, M = mixed-layer mineral, La = laumontite, Gy = gypsum. FeO in number per cent.)

The content of Cr, Zn, CaCO₃, and heavy minerals in the sandy till (sample 3 A, 1.8 m.b.s.), in the clayey till (sample 3 B, 4.5 m.b.s.) and in the fine sandy till (sample 3 C, 5.6 m.b.s.) is seen in Table No. 2. Sample 3 BS is from the stratified sediments in the clayey till (6.5 m.b.s.) and 3 CS from the sediment in the fine sandy till (5.4 m.b.s.).

Microfossil analyses in fifteen samples from the three tills and the stratified sediments were carried out at the Micropaleontological laboratory, SGU, by Bengt Falkenström, Karin Hedin and Urve Miller. Although different separation methods were used the content of microfossils was low. Diatoms were lacking. Therefore no reliable conclusions can be drawn. The following tendency can, however, be pointed out according to K. Hedin and U. Miller:

Betula pollen is found in the clayey and the fine sandy till while *Pinus* pollen is more frequent in the sandy and the clayey till. The stratified sediments in the two lower tills had a higher concentration of pollen than the tills. *Picea* pollen, which would indicate interglacial material, is rare.

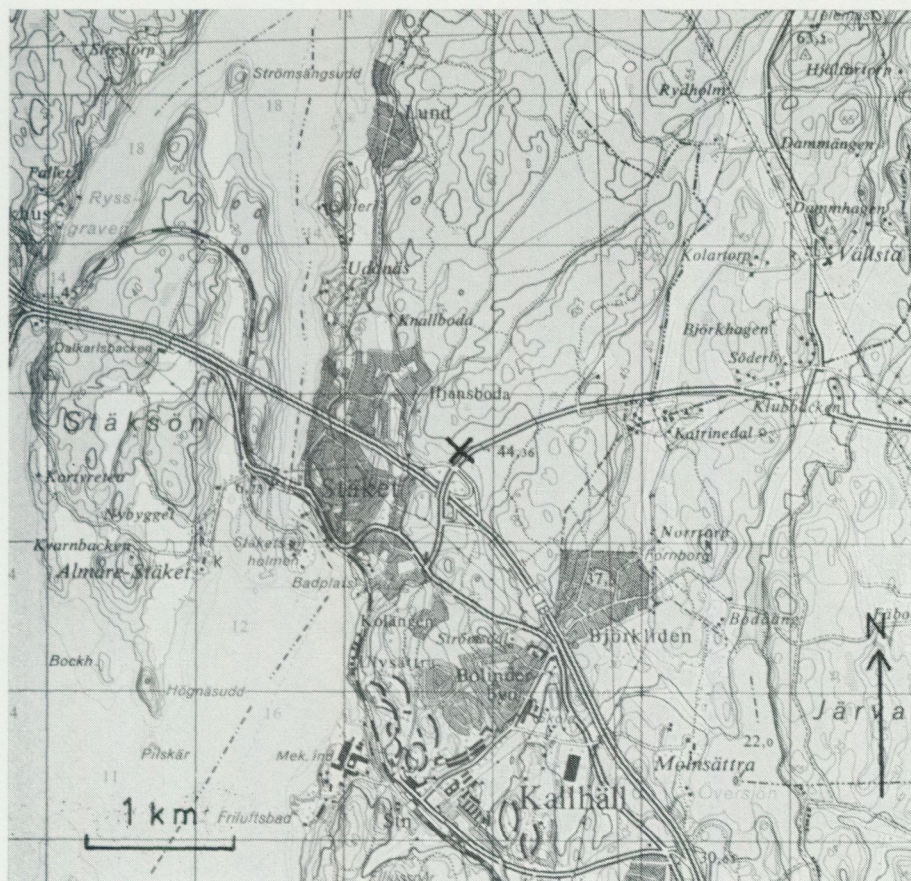


Fig. 20. The position of locality No. 4. Top. map 10 I Stockholm NV.

4. ILJANSBODA

The locality is situated 1 100 m ENE of Stäket railway-station (Fig. 20). Observations were made in a 3 m deep and 100 m long cutting oriented in north-east. A sandy till with light grey hue (10YR 7/1) overlain by wave-washed sediments was observed along the whole cutting. At three sections a clayey sandy till was found below the upper till. At one section the following strata were observed:

- 0—0.6 m.b.s. Wave-washed gravel and sand.
- 0.6—2.2 m.b.s. Sandy till. Fissility in the upper parts.
- 2.2—3.0 m.b.s. Clayey sandy till. Partly with horizontal joints reminding of a fissility.
- 3.0 m.b.s. Bedrock surface.

The grain-size distribution of the sandy till (1.8 m.b.s.) and the clayey till (2.6

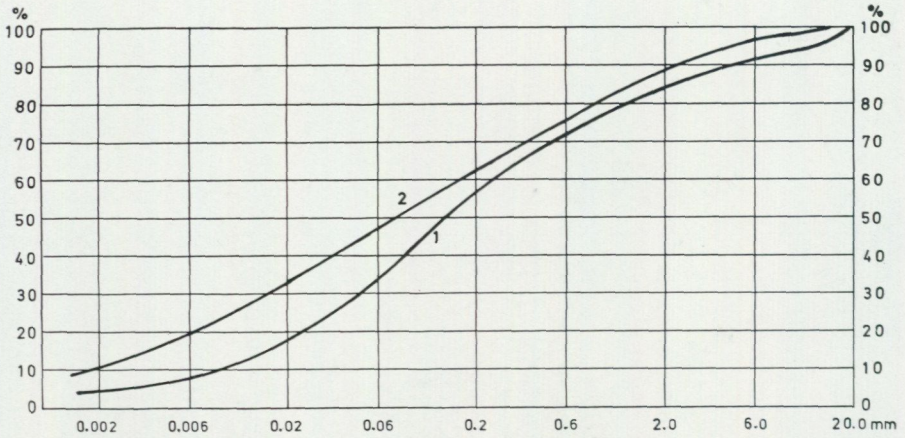


Fig. 21. Grain-size distribution of the two tills at locality No. 4. (1 = sandy till, 2 = clayey sandy till).

m.b.s.) is seen in Fig. 21. The limit between the two tills was at some parts sharp and at others undefined. The clayey till had a dark grey hue as a whole but in an upper zone, close to the sandy till, it was olive grey. Thin silt laminae (some millimetres in thickness and up to a metre in length were visible throughout the clayey till. Usually they were subhorizontal but at some sections they

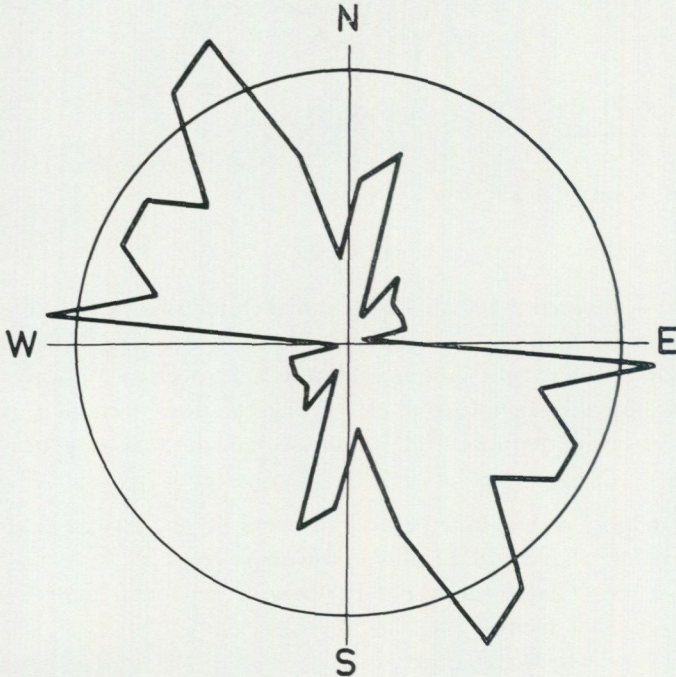


Fig. 22. Rose diagram of particle orientation in the clayey till 2.8 m.b.s. at locality No. 4. (Circle marks 10 per cent.)

were folded. A mantel of silt (some millimetres thick) was found on the bed-rock surface in small depressions.

A two-dimensional microfabric analysis, carried out in a sample from the clayey till (2.8 m.b.s.), showed a weak preferred orientation in NW—SE (Fig. 22). The striae systems described in locality No. 3 also concern areas round this locality.

5. EKEBY

The locality is situated 750 m NNE of Eriksberg (Fig. 23). In a large gravel pit (Underås sandtag) a clayey sandy till was found below glaciofluvial material. The till was exposed in a section extended in NNW—SSE. The clayey till, partly covered with slumped material and artificial fill, was observed within a distance of 150 m and had a thickness of about 5 m.

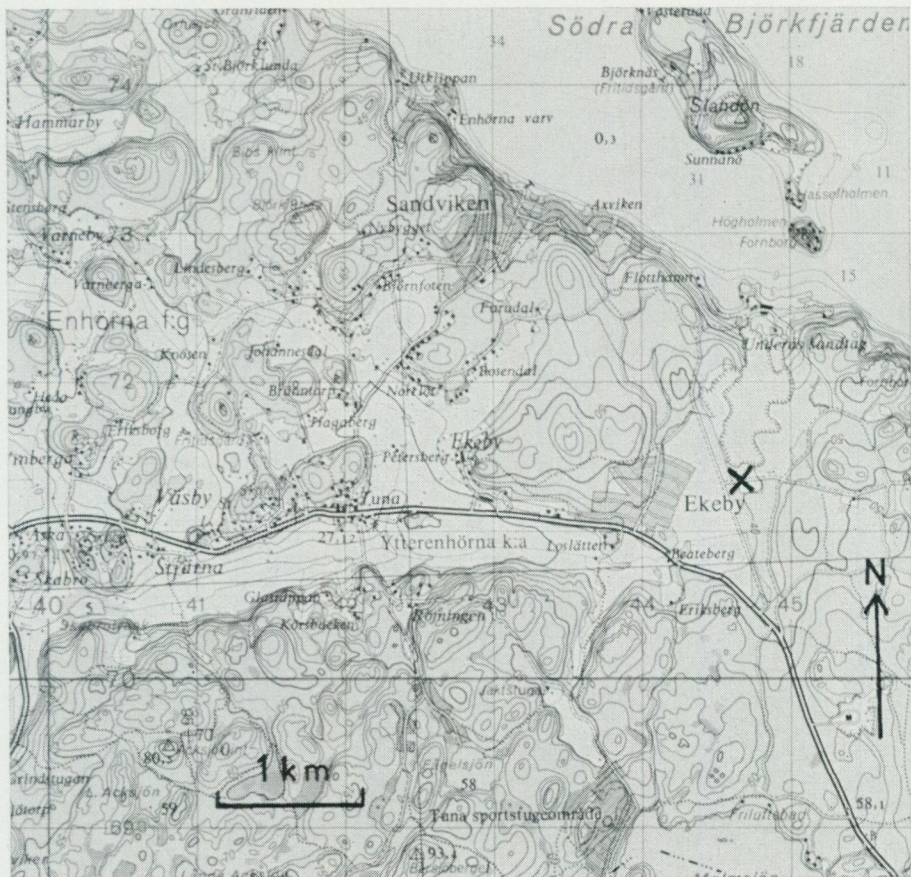


Fig. 23. The position of locality No. 5. Top map 10 H Strängnäs SO.

The frequency of boulders, stones and pebbles was low. The content of sub-rounded, striated, polished and faceted coarse clasts was markedly higher than in the ordinary sandy till in the region.

The clayey till contained several thin, sub-horizontal silt laminae. Some of these laminae were deformed by folding and faulting. The till had a dark grey hue (2.5Y 4/0) and in the uppermost zone close to the contact to the glaciofluvial material an olive grey hue (5Y 5/2).

In the overlying glaciofluvial material, dominated by gravelly coarse sand, small clasts of the clayey till were embedded in a zone just above the limit to the till. This limit was sharp but pronouncedly irregular.

The mechanical composition of the clayey till (1 = 4.5 m.b.s., 2 = 3.0 m.b.s.) and of a part of the till with silt laminae (curve No. 3) is seen in Fig. 24.

A microfabric analysis in a sample from the clayey till (4 m.b.s.) showed a preferred orientation from northwest (Fig. 25). At the same point a fabric analysis of elongated stones was carried out. It showed a weak preferred orientation from northwest (Fig. 26).

Striae observations from areas round this locality have been made during the reconnaissance for the map of the Quaternary deposits, 10 H Strängnäs SO. The following striae systems have been observed: $N60^{\circ}W \rightarrow N40^{\circ}W \rightarrow NNW \rightarrow N-S$, from oldest to youngest. The oldest system ($N60^{\circ}W$) occurs on lee-side facets and the $N40^{\circ}W$ -system in lee-side positions (pers. comm. H. Möller).

Petrographical analyses in the gravel fraction were carried out in the clayey till (sample 5 B, 4.5 m.b.s.) and in a sample of an ordinary sandy till taken 900 m north of this locality (sample 5 A, 1.5 m.b.s.). The result is shown in Table No. 1. In Table No. 2 the content of Cr, Zn, $CaCO_3$, and heavy minerals can be seen (samples 5 A and 5 B as above).

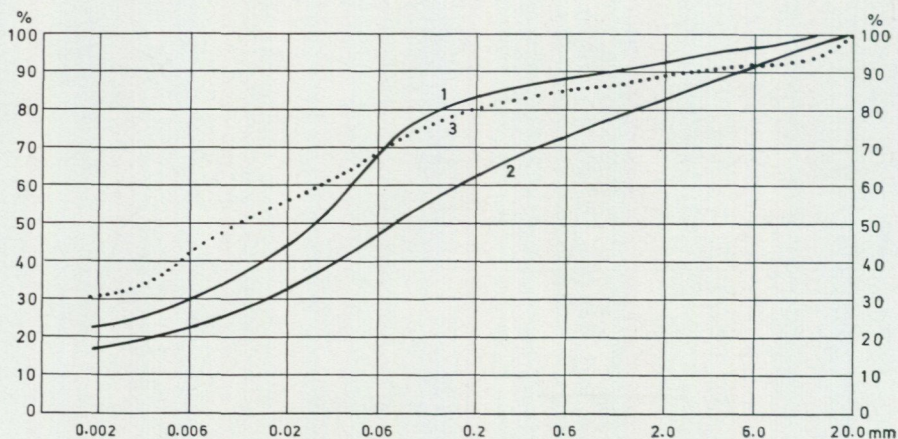


Fig. 24. Grain-size distribution of the clayey till at locality No. 5. (1 = clayey till 4.5 m.b.s., 2 = clayey till 3.0 m.b.s. and 3 = clayey till with silt laminae.)

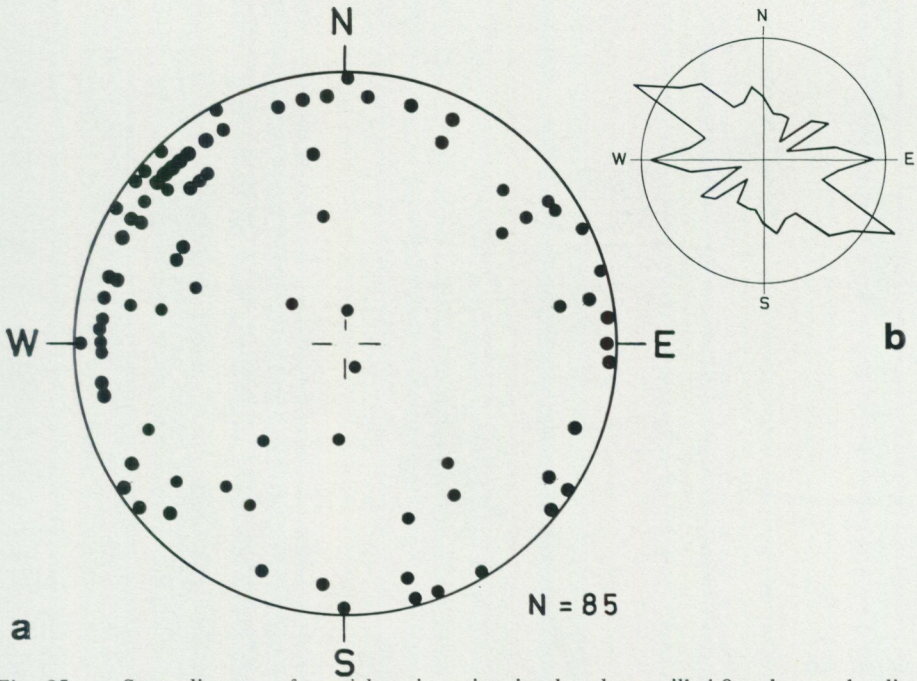


Fig. 25. a=Stereodiagram of particle orientation in the clayey till 4.0 m.b.s. at locality No. 5.
 b= Particle orientation in Fig. 25a visualized in a rose diagram. (Circle marks 10 per cent.)

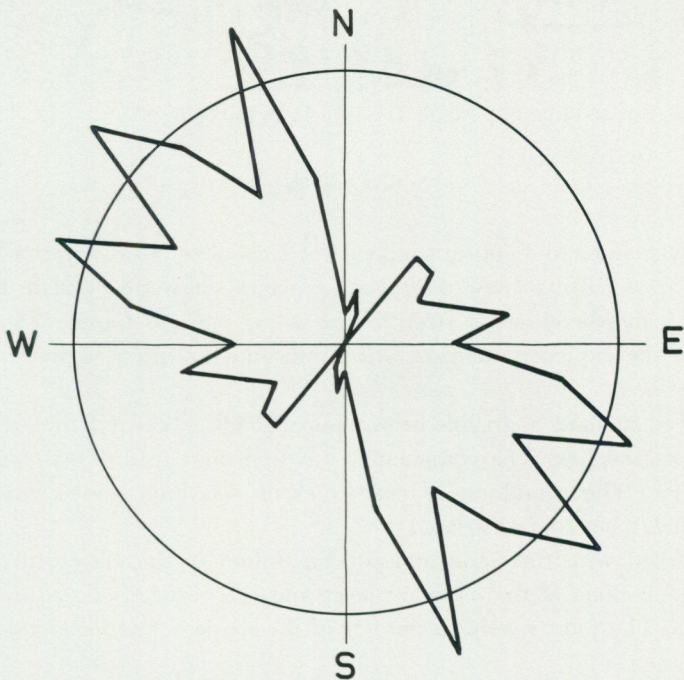


Fig. 26. Rose diagram of the two-dimensional orientation of elongated stones in the clayey till 4.0 m.b.s. at locality No. 5.



Fig. 27. The position of locality No. 6. Top map 11 H Enköping SV.

6. FANNA

The locality is situated 1 700 m southeast of Enköping railway-station (Fig. 27). In a small road cutting (now destroyed) a clayey sandy till overlain by a sandy till and with interbeddings of stratified sand and silt was found (Fig. 28). The thickness of the sequence of strata was 1.7 m and the limits between each layer was well defined.

The clayey till had a greyish brown hue (10YR 4/2) and the frequency of coarser clasts was low. The compaction was high and fissility was found in the whole matrix. The roundness of coarser clasts was high and several of them were polished, faceted and striated.

A joint filled with fine sand and silt was found in the clayey till. The joint began at the contact of the sediment layer and ran vertically down in the clayey till (Fig. 28. The joint is seen to the left of the spade). The lower till was inter-



Fig. 28. The cutting at locality No. 6. NNW is to the right in the picture. Partly exposed bedrock is seen to the right. Note the layer of sediment between the two tills, and the different boulder and stone frequency in the upper and lower till.

sected with thin silt laminae (some millimetres thick and lengths varying between some centimetres and a metre). The majority of the laminae were in horizontal positions. Some of them were folded and small-scale faultings appeared in some parts of the section.

The silty layer upon the lower till showed current bedding and infusions of stones and pebbles were common in the lower parts of the layer.

The sandy till had a light grey hue (5Y 7/2) and the frequency of stones and boulders was high. Most of them were angular and sub-angular. A fissility was visible through the whole matrix.

The grain-size distribution of the sandy till (curve No. 1, 0.6 m.b.s.), the sediment layer (curve No. 2, 0.9 m.b.s.) and the clayey till (curve No. 3, 1.2 m.b.s.) is seen in Fig. 29. The petrography in the stone fraction of the two tills is seen in Table No. 1 and the content of Cr, Zn, CaCO₃, and heavy minerals in Table No. 2.

A two-dimensional microfabric analysis in a sample from the clayey till (1.3 m.b.s.) shows a weak preferred orientation in NW—SE (Fig. 30).

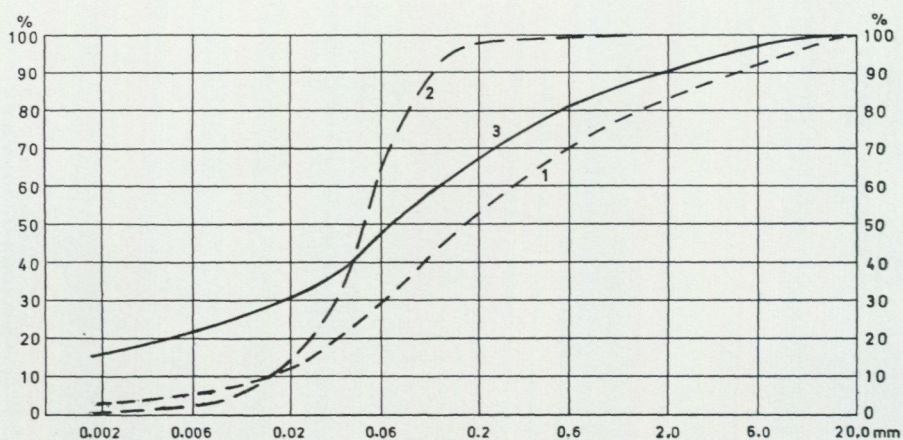


Fig. 29. Grain-size distribution of the two tills and the sediment layer at locality No. 6. (1 = sandy till, 2 = sediment layer, 3 = clayey till.)

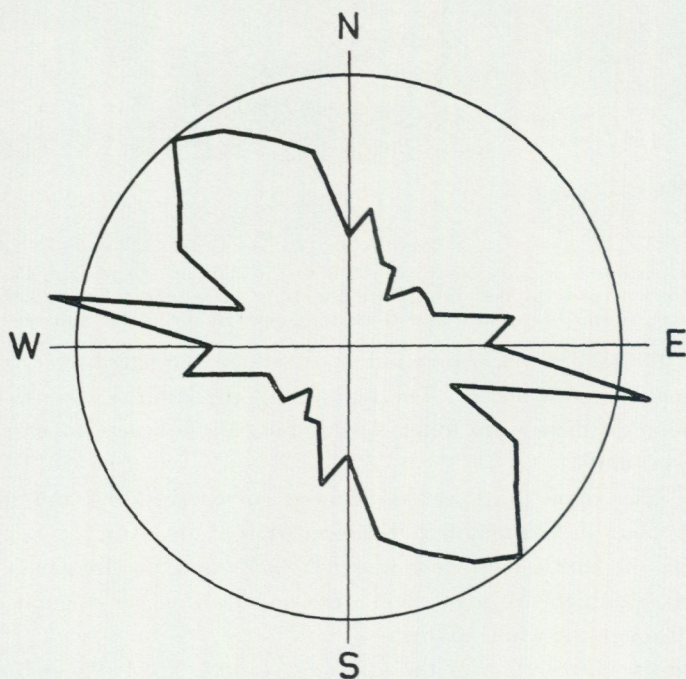


Fig. 30. Rose diagram of particle orientation in the clayey till 1.3 m.b.s. at locality No. 6.

Striae observations from areas round this locality have been made during reconnaissance for the map of the Quaternary deposits, 11 H Enköping SV. The following striae systems have been observed: $N60^{\circ}W \rightarrow NW \rightarrow NNW \rightarrow N-S$, from oldest to youngest. The oldest system occurs on facets towards SSW and

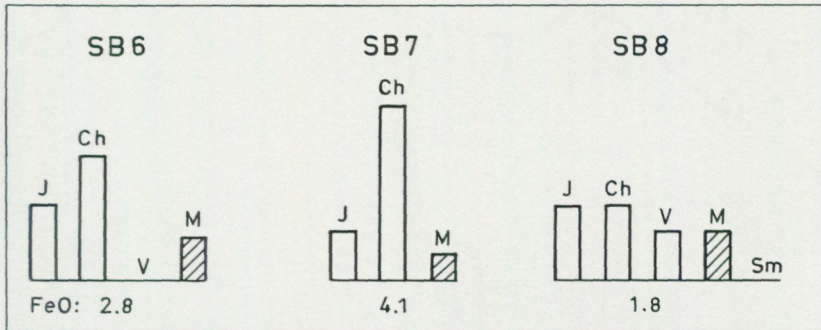


Fig. 31. Clay mineral content estimated from X-ray diffraction analyses in samples from the sandy till (SB 6, 0.6 m.b.s.), the sediment layer (SB 7, 0.9 m.b.s.) and from the clayey till (SB 8, 1.2 m.b.s.) at locality No. 6. (J=illite, Ch=chlorite, V=vermiculite, M=mixed-layer mineral, Sm=smectite, FeO in number per cent.)

the NW-system on facets towards SW (pers. comm. H. Möller).

Roundness analyses of sand grains in a sample from the sandy till (0.6 m.b.s.) showed that 16 per cent were angular, 80 per cent sub-angular and 4 per cent sub-rounded. In a sample from the sediment layer (0.9 m.b.s.) there were 20 per cent angular, 75 per cent sub-angular and 4 per cent sub-rounded. The distribution of roundness classes in a sample from the clayey till (1.2 m.b.s.) was: 14 per cent angular, 76 per cent sub-angular and 11 per cent sub-rounded. The roundness was higher in the lower till while the stratified sediments and the upper till had a lower roundness.

X-ray diffraction analyses were carried out in samples from the two tills and the sediment layer. The clay mineral content is seen in Fig. 31. Analysis SB 6 shows the clay mineral content in the upper till (0.6 m.b.s.), SB 7 shows the clay mineral content in the sediment layer (0.9 m.b.s.) and SB 8 shows the clay mineral content in the lower till (1.2 m.b.s.). The content of vermiculite is higher in the clayey till compared with the sandy till while it is lacking in the interbedded sediments.

The clayey till was situated in a lee-side position and after further excavations, when the clayey till was removed, the bedrock surface under the till could be inspected. A thin silt mantle covered small areas of the bedrock surface, mainly in small depressions. The clayey till had a dark grey hue (2.5Y 4/0) in a narrow zone close to the bedrock (about 2 m.b.s.).

7. NYSÄTER

The locality is situated 100 m south of Nysäter (Fig. 32). A clayey sandy till (1.0–2.2 m.b.s.) was found in a small road cutting. The till was overlain by wave-washed material (0–1.0 m.b.s.), partly till-like. The clayey till had a

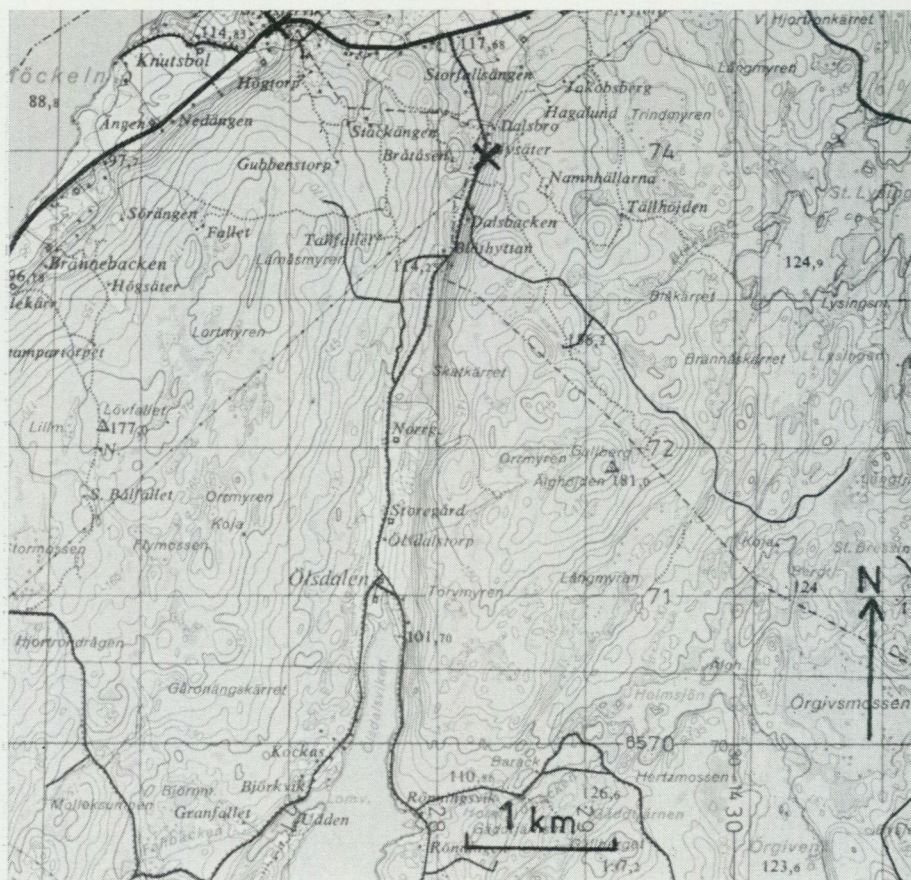


Fig. 32. The position of locality No. 7 and No. 8. Top. map 10 E Karlskoga SO.

greyish brown hue (10YR 4/2) and low frequency of boulders and stones. The roundness of coarser clasts was high. The matrix was homogeneous without any lenses or laminae. A fissility in the till was visible in some parts (Fig. 33). The matrix in narrow zones in the surroundings of the joints had a very light grey hue, 10YR 7.5/1 (Fig. 34).

The grain-size distribution in a sample from the clayey till (1.7 m.b.s.) and in the wave washed layer (0.8 m.b.s.) is seen in Fig. 35.

A microfabric analysis in the till (1.8 m.b.s.) shows a weak preferred orientation from northwest (Fig. 36).

Striae observations from areas round this locality (mainly south and east of it) have been made during the reconnaissance for the map of the Quaternary deposits, 10 E Karlskoga SO. The following striae systems have been observed: NNW → N → NNE, from oldest to youngest (pers. comm. B. Ericsson).

The distribution of roundness classes in the medium sand fraction in a sample

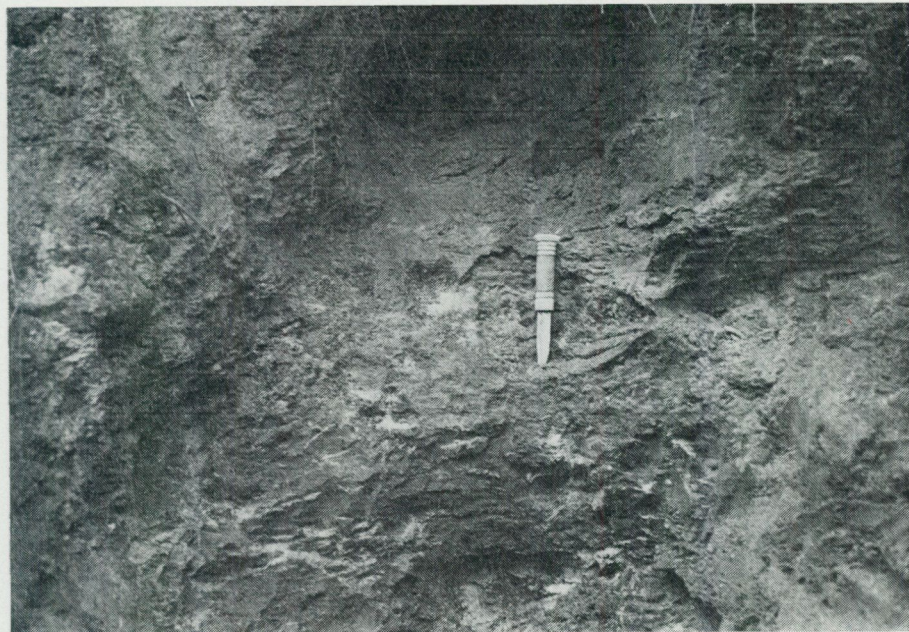


Fig. 33. The clayey till at locality No. 7. Wave-washed and till-like material above the handle of the knife.



Fig. 34. Light grey surroundings of the fissility joints in the clayey till at locality No. 7. (The key length is 6 cm.)

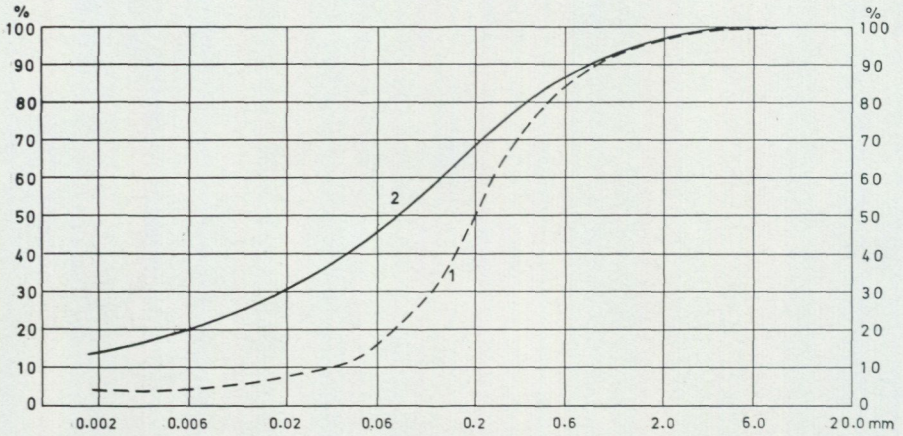


Fig. 35. Grain-size distribution of the wave-washed sediments and the clayey till at locality No. 7. (1 = wave-washed sediment, 2 = clayey sandy till).

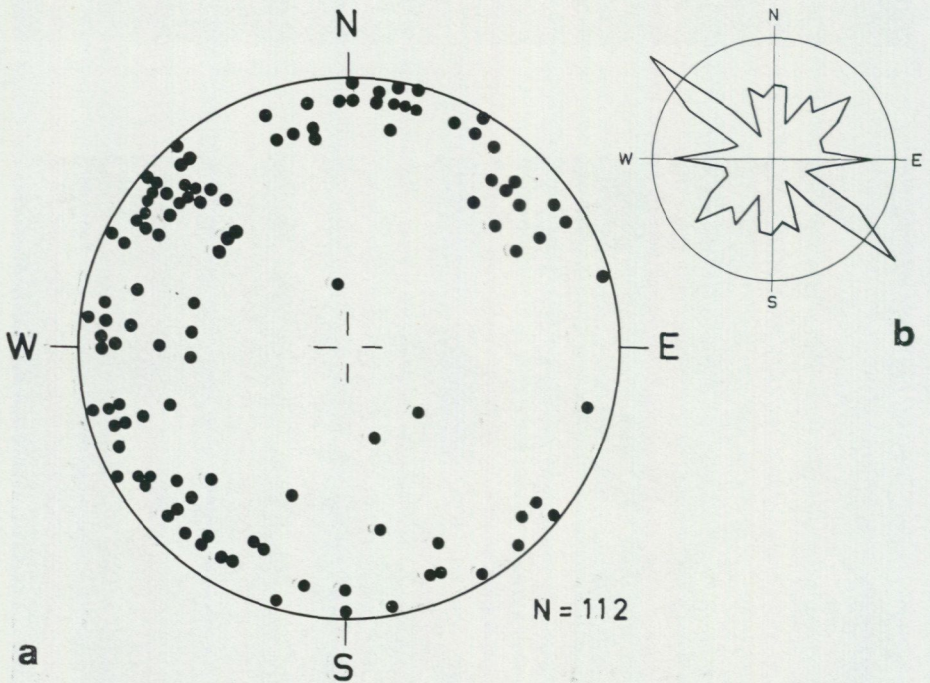


Fig. 36. a = Stereodiagram of particle orientation in the clayey till 1.8 m.b.s. at locality No. 7.
b = Particle orientation in Fig. 36a visualized in a rose diagram. (Circle marks 10 per cent.)

from the wave-washed sediment (0.8 m.b.s.) was: 15 per cent angular, 72 per cent sub-angular, 11 per cent sub-rounded, and 1 per cent rounded. In a sample from the clayey till (1.7 m.b.s.) 13 per cent were angular, 69 per cent sub-angular, 16 per cent sub-rounded, and 2 per cent rounded. The roundness was slightly higher in the clayey till than in the wave-washed layer.

The petrography in the gravel fraction from samples in the wave-washed sediment (sample 7 A, 0.8 m.b.s.) and in the clayey till (sample 7 B, 1.7 m.b.s.) is seen in Table No. 1.

Contents of Cr, Zn, CaCO_3 , humus, and heavy minerals in samples from the sediment layer (7 A, 0.8 m.b.s.) and from the clayey till (7 B, 1.7 m.b.s.) are seen in Table No. 2.

X-ray diffraction analyses were carried out in samples from the wave-washed sediment (SB 3, 0.8 m.b.s.), from the clayey till (SB 4, 1.7 m.b.s.) and from a joint zone with a very light grey hue in the till (SB 5, 2.0 m.b.s.). The clay mineral content from these analyses is seen in Fig. 37. An indication of kaolinite is found in the two layers and the content of mixed-layer minerals is highest in the wave-washed sediment and the very light grey joint zone. The percentage of FeO decreases with increasing depth. Fe_2O_3 shows the opposite trend (not seen in Fig. 37).

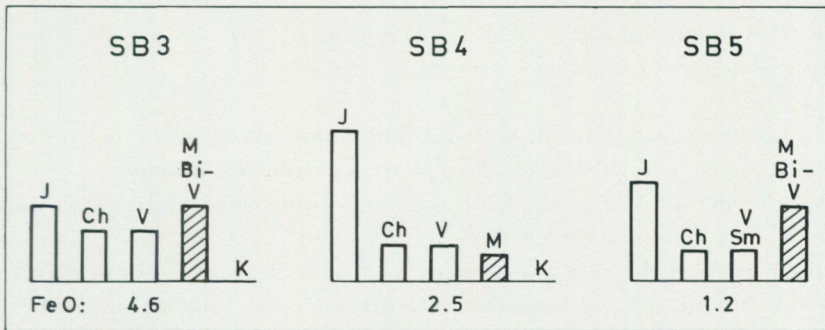


Fig. 37. Clay mineral content estimated from X-ray diffraction analyses in the wave-washed sediments (SB 3, 0.8 m.b.s.), the clayey till (SB 4, 1.7 m.b.s.) and in a light grey joint zone (SB 5, 2.0 m.b.s.) at locality No. 7. (J=illite, Ch=chlorite, V=vermiculite, Bi=biotite, M=mixed-layer mineral, Sm=smectite, K=kaolinite. FeO in number per cent.)

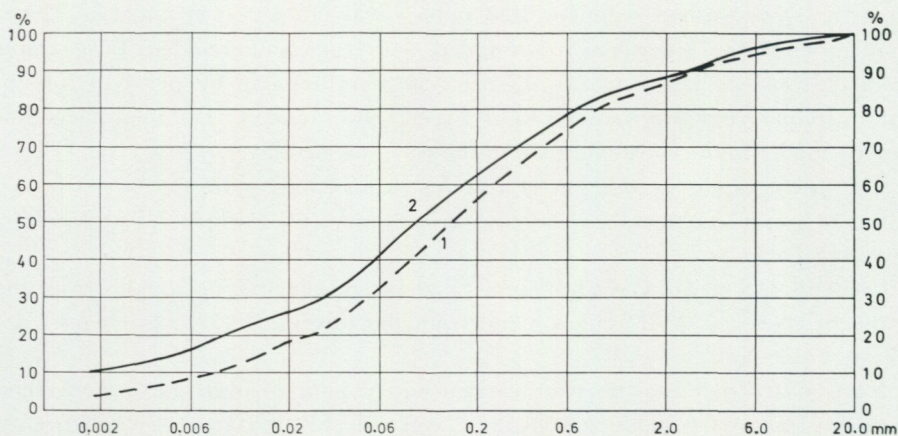


Fig. 38. Grain-size distribution of the upper till and lower till at locality No. 8. (1 = sandy till, 2 = clayey sandy till.)

8. KNUTSBOL

The locality is situated 250 m NNE om Högtorp (Fig. 32). In a road cutting the following sequence of strata was observed:

- 0—1.8 m.b.s. Sandy till with medium compaction and a light grey hue (10YR 7/1). Precipitation of iron was common.
- 1.8—4.0 + m.b.s. Clayey sandy till with high compaction and a greyish brown hue (10YR 4/2).

The limit between the tills was difficult to observe because of the slumped material, but it seemed to be indistinct. The frequency of boulders and stones was lower in the clayey till. The roundness of stones and gravel was markedly higher in the lower till. Thin laminae of silt and fine sand were common in the clayey till.

The grain-size distribution of the two tills is seen in Fig. 38 (curve No. 1 = sandy till, 1.5 m.b.s.; No. 2 = clayey till, 3.0 m.b.s.).

Microfabric analysis in a sample from the clayey till 2.8 m.b.s. shows a preferred orientation from northwest with a westerly trend. A secondary peak from the north is noticeable (Fig. 39).

The petrography in the gravel fraction of samples from the sandy till (8 A, 1.5 m.b.s.) and the clayey till (8 B, 3.0 m.b.s.) is seen in Table No. 1.

The contents of Cr, Zn, CaCO₃, heavy minerals, and humus from samples of the sandy till (8 A, 1.0 m.b.s.) and of the clayey till (8 B, 2.8 m.b.s.) is seen in Table No. 2.

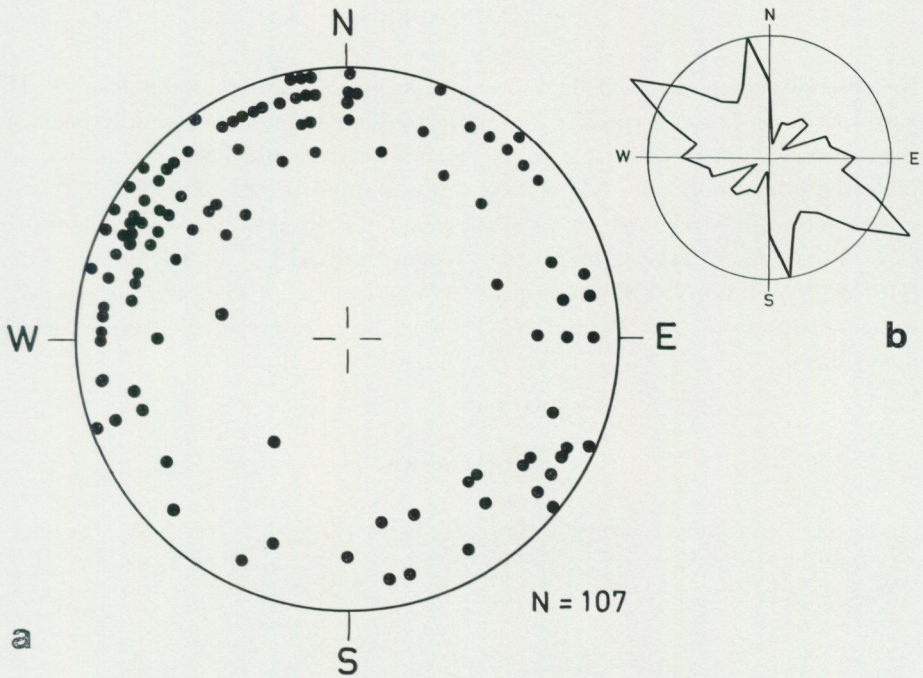


Fig. 39. a = Stereodiagram of particle orientation in the clayey till 2.8 m.b.s. at locality No. 8.

b = Particle orientation in Fig. 39a visualized in a rose diagram. (Circle marks 10 per cent.)

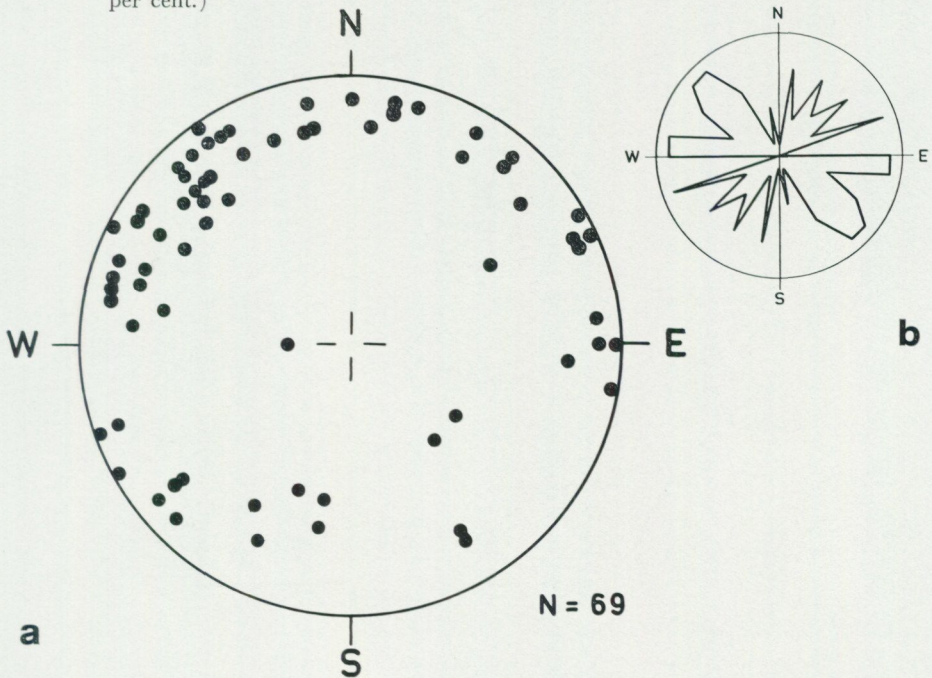


Fig. 40. a = Stereodiagram of particle orientation in the clayey till 1.0 m.b.s. at locality No. 9.

b = Particle orientation in Fig. 40a visualized in a rose diagram. (Circle marks 10 per cent.)

9. GARPENBERG

No observations in the field have been made by the author at this locality. Dr Karin Eriksson found a clayey till overlain by a sandy one. In a sample taken in the clayey till about 1.0 m.b.s., a microfabric analysis has been carried out. A preferred orientation from NW with a westerly trend is seen (Fig. 40).

The following striae systems in areas round this locality have been described by G. Lundqvist (1941): a main striae system from $N25^{\circ}$ — $30^{\circ}W$. Systems from $N10^{\circ}W$, $N-S$ and $N55^{\circ}E$ also appear. At one locality (3 km north of Hovran) striae systems from $N25^{\circ}W$ and $N5^{\circ}W$ have been observed. The latter one is the youngest.

10. GÖTMYRAN

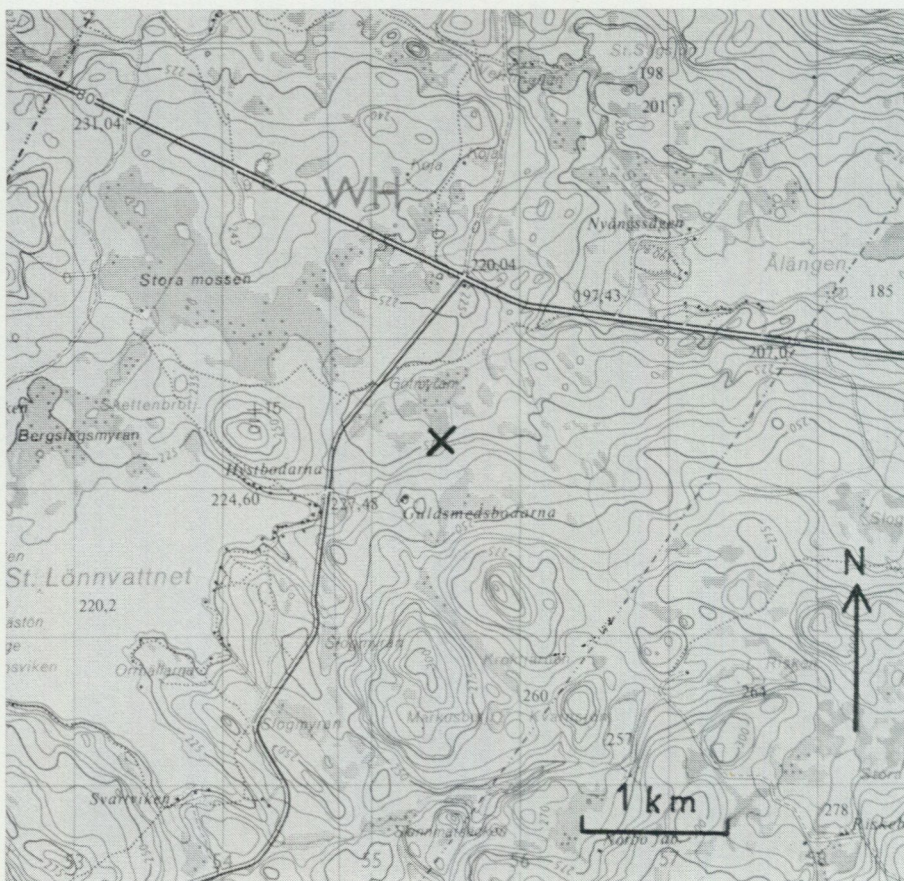


Fig. 41. The position of locality No. 10. Top. map 13 G Hofors SV.

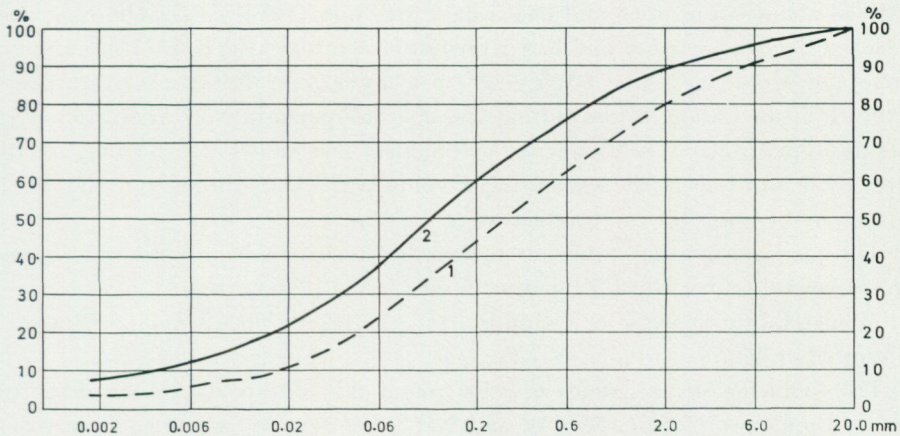


Fig. 42. Grain-size distribution of the upper and lower till at locality No. 10. (1 = sandy till, 2 = clayey sandy till.)

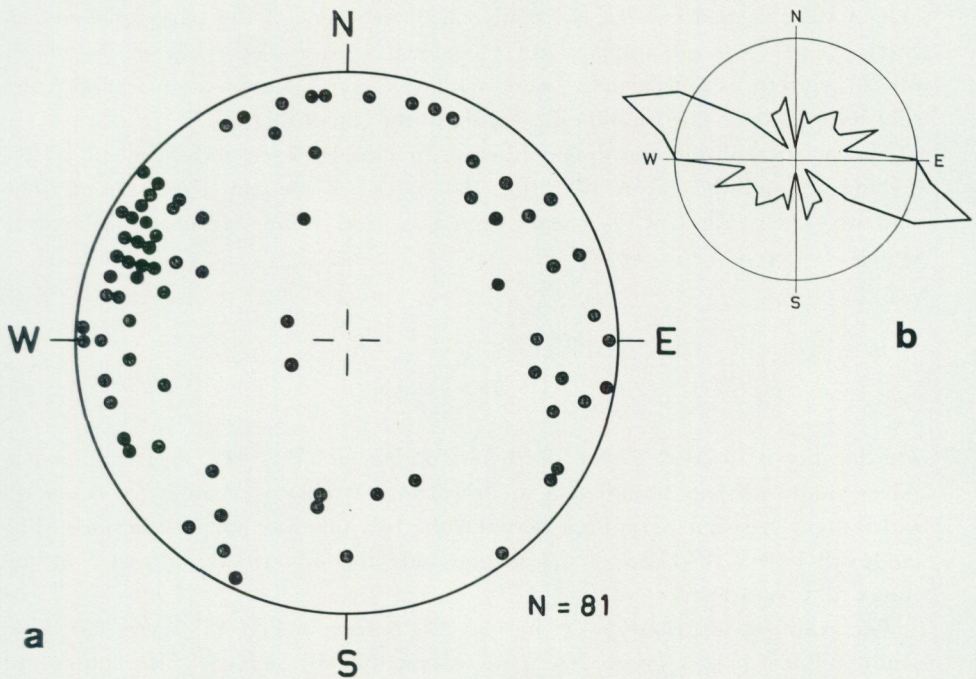


Fig. 43. a = Stereodiagram of particle orientation in the clayey till 2 m.b.s. at locality No. 10.
b = Particle orientation in Fig. 43a visualized in a rose diagram. (Circle marks 10 per cent.)

The locality is situated 500 m NNE of Guldsmedsbodarna (Fig. 41). In a small road cutting a sandy till underlain by a clayey sandy till was exposed. The sandy

till was about 0.5 m thick and had a light grey hue (10YR 7/2). The clayey till reached down to 3 m.b.s. and had a greyish brown hue (10YR 4/2) in an upper zone and a dark grey hue (2.5Y 4/0) in a lower zone. A bedrock surface was exposed at the bottom of the cutting and a striae system in N50°W was observed on the top surface. The frequency of boulders and stones was medium in the upper till and low in the clayey till. Fissility was found throughout the whole matrix in the lower till and was lacking in the sandy one.

The mechanical composition of the sandy till (curve No. 1, 0.4 m.b.s.) and the clayey till (curve No. 2, 2.0 m.b.s.) is seen in Fig. 42.

A microfabric analysis in a sample from the clayey till (2 m.b.s.) showed a preferred orientation from NNW (Fig. 43).

The following striae systems in areas round this locality have been described by G. Lundqvist (1951): N50°W and N10°W → N30°W → N10°E, from oldest to youngest. The age relation between the N50°W-system and the N10°W-system could not be determined.

Roundness analyses in the sand fraction in samples from the sandy till (0.4 m.b.s.) were carried out. In the sandy till 33 per cent of the particles were angular, 65 per cent sub-angular and 1 per cent sub-rounded while in the clayey till 20 per cent of the particles were angular, 77 per cent sub-angular and 4 per cent sub-rounded. The roundness is higher in the clayey till.

The petrography in the gravel fraction in samples from the sandy till (10A, 0.4 m.b.s.) and the clayey till (10B, 2.0 m.b.s.) is seen in Table No. 1. The content of Cr, Zn CaCO₃, heavy minerals, and humus from corresponding samples is seen in Table No. 2.

11. ÖRATJÄRN

The locality is situated 650 m northwest of Hagen (Fig. 44). A greyish-brown clayey sandy till was found in a ditch cutting. It was overlain by a sandy till with a light grey hue. The limit between the two tills was not well defined. The sandy till had a thickness of 0.7 m and only the uppermost halfmetre of the clayey till was exposed.

The grain-size distribution of the two tills is seen in Fig. 45 (curve No. 1 = sandy till 0.5 m.b.s., curve No. 2 = clayey till 0.8 m.b.s.). The content of CaCO₃, heavy minerals and humus from the same samples is seen in Table No. 2. (11A = sandy till, 11B = clayey till).

A microfabric analysis was carried out in the clayey till 0.7 m.b.s. and it shows a preferred orientation from W (Fig. 46). Striae observations from areas round this locality are described by G. Lundqvist (1951). General observations of striae systems from NW and N—NNE were made. The NW-system is the oldest.

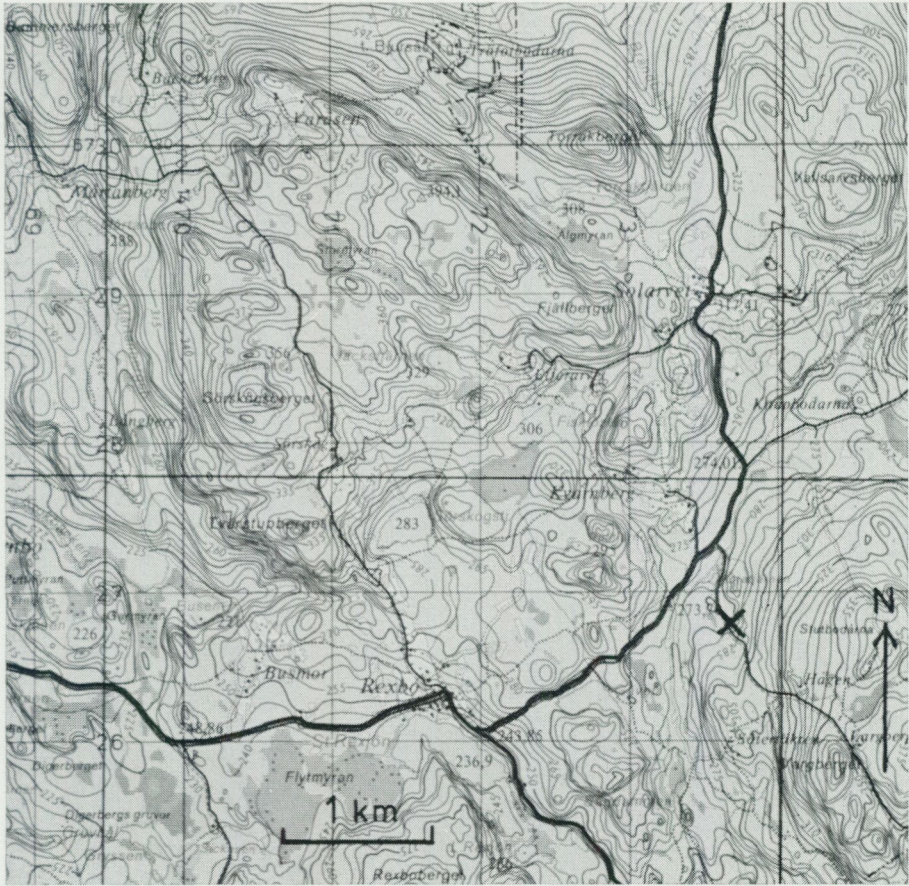


Fig. 44. The position of locality No. 11. Top. map 13 F Falun NV.

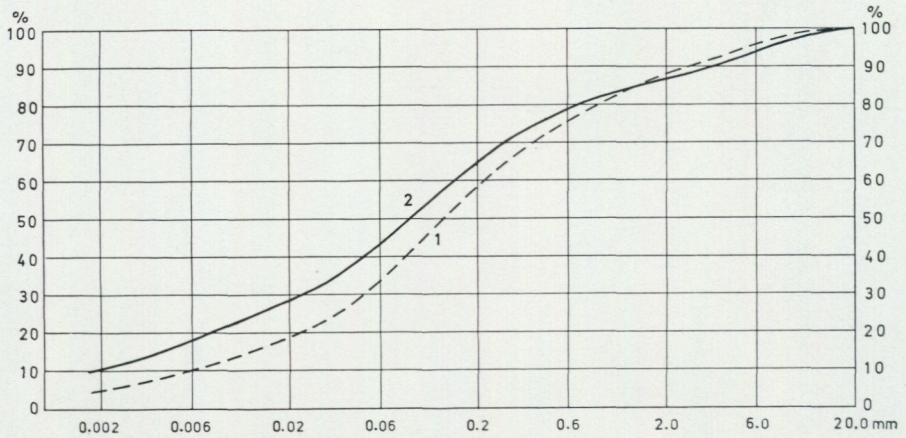


Fig. 45. Grain-size distribution of the upper and lower till at locality No. 11. (1 = sandy till, 2 = clayey sandy till.)

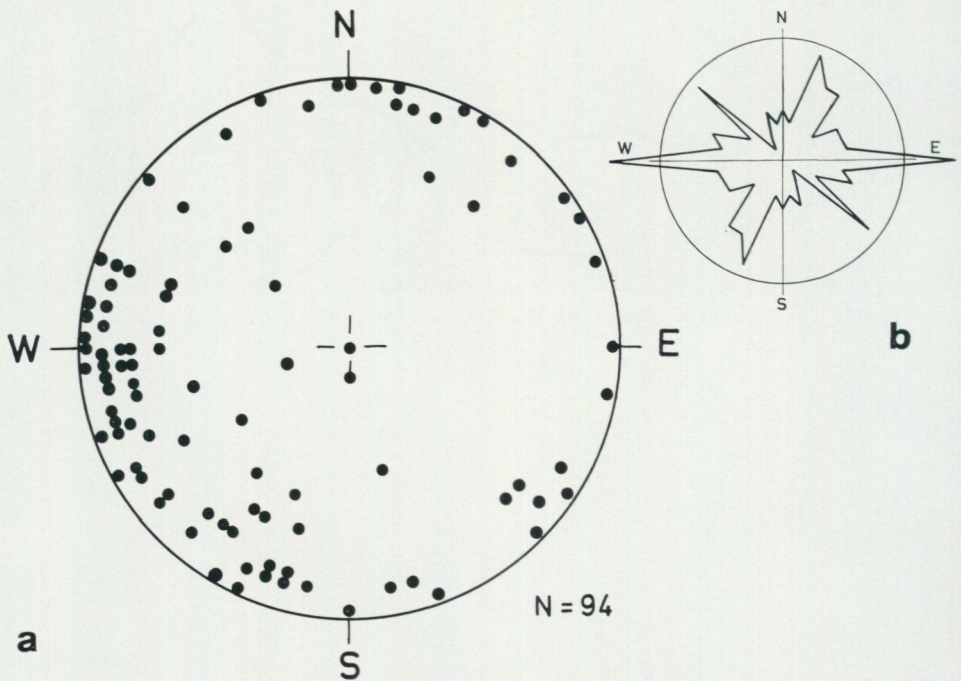


Fig. 46. a = Stereodiagram of particle orientation in the clayey till 0.7 m.b.s. at locality No. 11.
 b = Particle orientation in Fig. 46a visualized in a rose diagram. (Circle marks 10 per cent.)

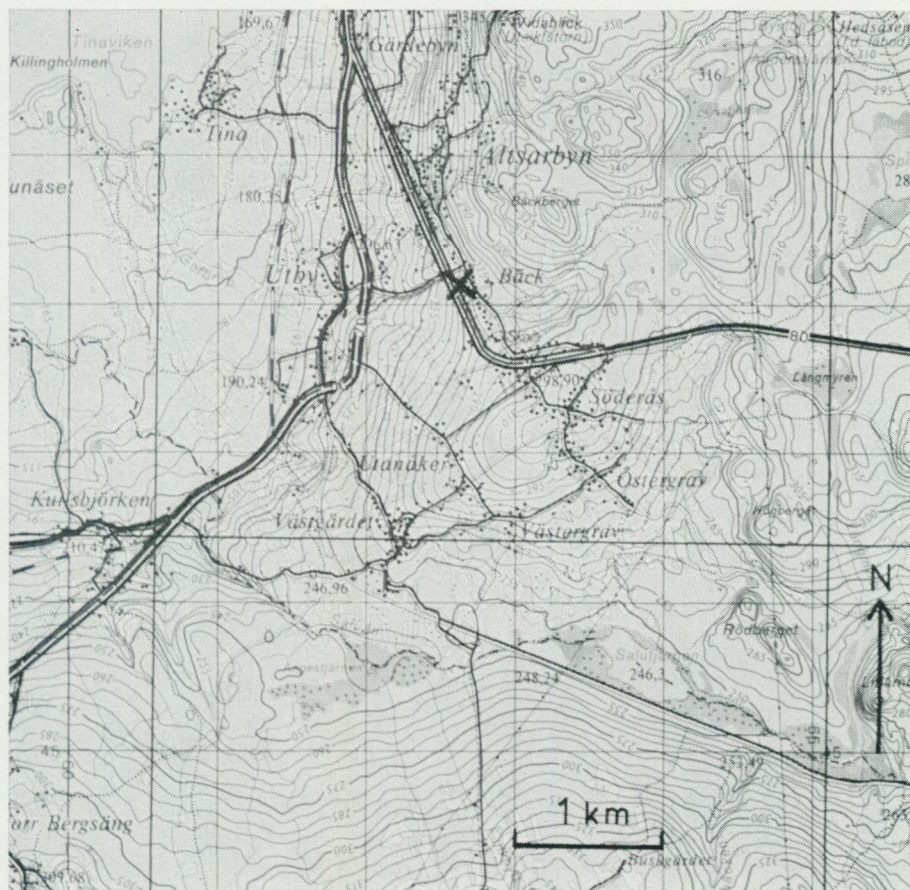


Fig. 47. The position of locality No. 12. Top. map 13 F Falun NV.

12. BÄCK

The locality is situated 200 m west of Bäck (Fig. 47). A clayey sandy till was found in a road cutting. The cutting had a depth of 2 m. Fissility was visible in the till, which had a brown hue (7.5YR 5/4). Precipitations of manganese on the joint surfaces were common. The mechanical composition of a sample 1.5 m.b.s. can be seen in Fig. 48.

A microfabric analysis in a sample from the till 1.9 m.b.s. shows a preferred orientation from NNW (Fig. 49). The striae informations are the same as for locality No. 11.

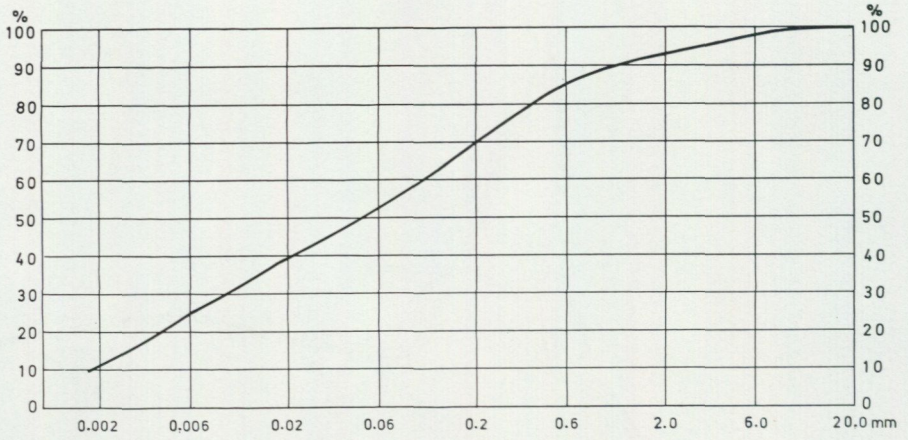


Fig. 48. Grain-size distribution of the clayey till at locality No. 12.

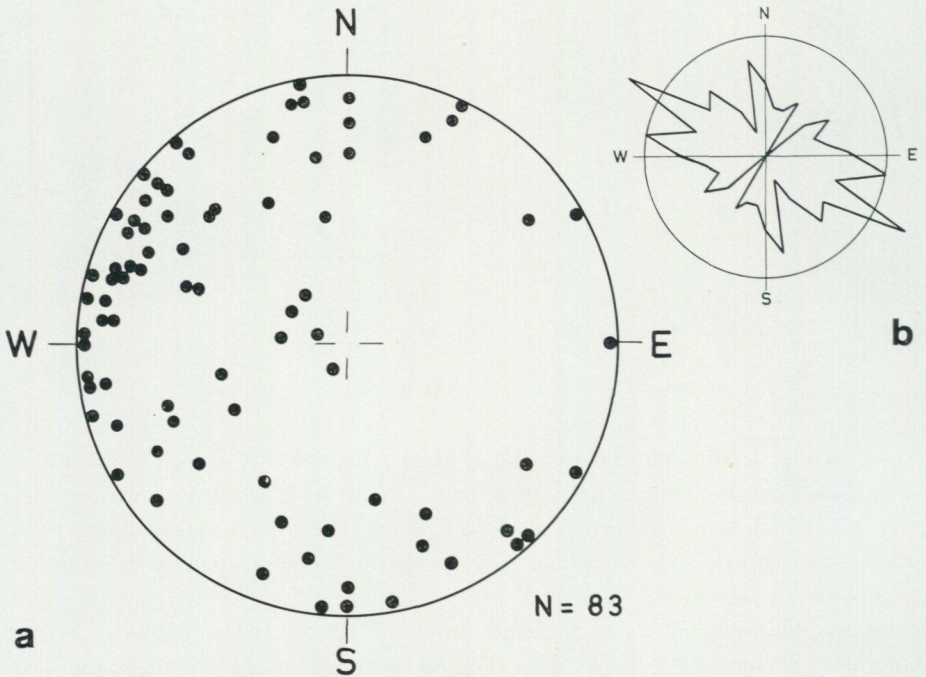


Fig. 49. a = Stereodiagram of particle orientation in the clayey till 1.9 m.b.s. at locality No. 12.
 b = Particle orientation in Fig. 49a visualized in a rose diagram.



Fig. 50. The position of locality No. 13. Top. map 13 C Dalby NO.

13. BOGRANGEN

The locality is situated 650 m SSE of Embret (Fig. 50). A clayey sandy till overlain by a sandy till was found in a large excavation. The occurrence has earlier been described by J. Lundqvist (1958). Almost the whole excavation is now covered by slumped material. A profile in the southern part showed the following strata:

- 0—2.5 m.b.s. Sandy till with medium compaction.
- 2.5—12.0 m.b.s. Clayey sandy till with high compaction.

The upper till had a grey hue (5Y 6/1) and the frequency of boulders and stones was medium. The clayey till had a lower frequency of coarser clasts and a very dark grey hue (2.5Y 3/0). Roundness of coarser clasts was slightly higher

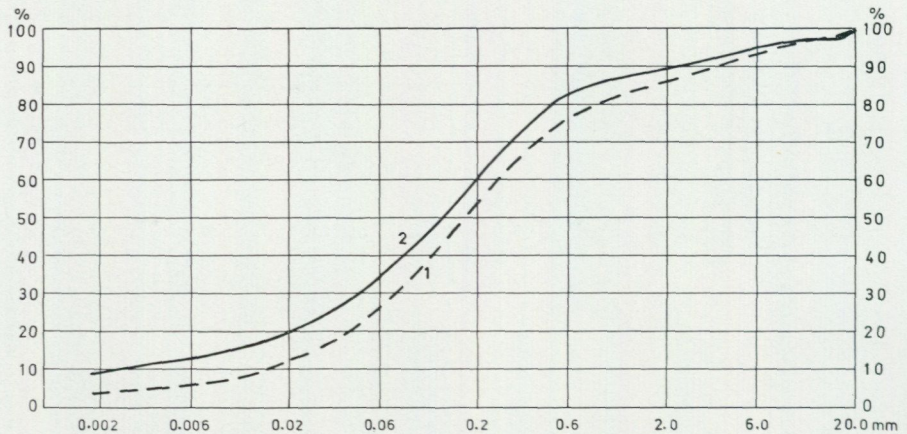


Fig. 51. Grain-size distribution of the upper and lower till at locality No. 13.

in the lower till. Subhorizontal fissility joints were frequent in the clayey till and precipitations of iron common on joint surfaces.

The mechanical composition of the sandy till (curve No. 1, 1.5 m.b.s.) and the clayey till (curve No. 2, 4.5 m.b.s.) is seen in Fig. 51. From one sample in the sandy till (13 A, 1.5 m.b.s.) and one in the clayey till (13 B, 4.5 m.b.s.) the content of Zn, Cr, CaCO_3 , heavy minerals, humus, and the gravel petrography were determined (Tables Nos. 1 and 2).

X-ray diffraction analyses were carried out in the two tills. The clay mineral content in the sandy till (SB 9, 1.5 m.b.s.) and in the clayey till (SB 10, 4.5 m.b.s.) is seen in Fig. 52. The content of mixed-layer minerals is higher in the upper till.

Roundness analyses in samples from the two tills (samples 13 A, 13 B) were carried out in the medium sand fraction. In the sandy till 45 per cent were angular and 55 per cent sub-angular while in the clayey till 21 per cent were angular, 77 per cent sub-angular and 2 per cent sub-rounded. The roundness is higher in the clayey till.

A microfabric analysis in the clayey till (3.8 m.b.s.) shows a preferred orientation from west (Fig. 53).

Striae systems in areas round this locality have been described by J. Lundqvist (1958). He reports striae systems between N and NW. The NW-systems are best developed in the northerly and westerly parts of the province of Värmland.

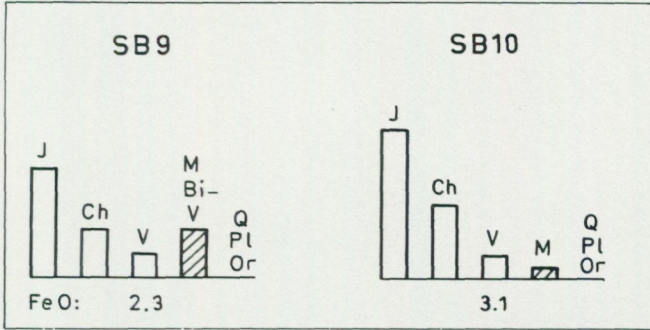


Fig. 52. Clay mineral content estimated from X-ray diffraction analyses in samples from the sandy till (SB 9, 1.5 m.b.s.) and the clayey till (SB 10, 4.5 m.b.s.) at locality No. 13. (J=illite, Ch=chlorite, V=vermiculite, Bi=biotite, M=mixed-layer mineral, Q=quartz, Pl=plagioclase, Or=potassium feldspar. FeO in number per cent.)

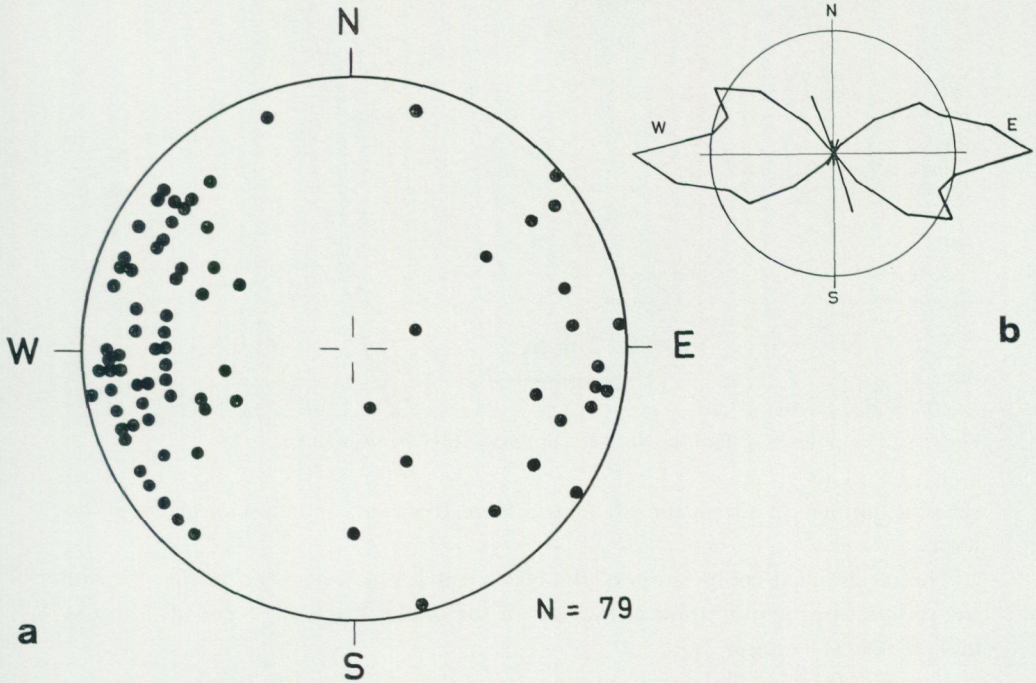


Fig. 53. a=Stereodiagram of particle orientation in the clayey till 3.8 m.b.s. at locality No. 13.
b= Particle orientation in Fig. 53a visualized in a rose diagram.

14. ARMSJÖN

The locality is situated 500 m WSW of Armsjön railway-station (Fig. 54). A clayey sandy till with a dark grey hue (2.5Y 4/0) was found at the bottom of a gravel pit about 2 m.b.s. Only small parts of the till were exposed. Thin subho-

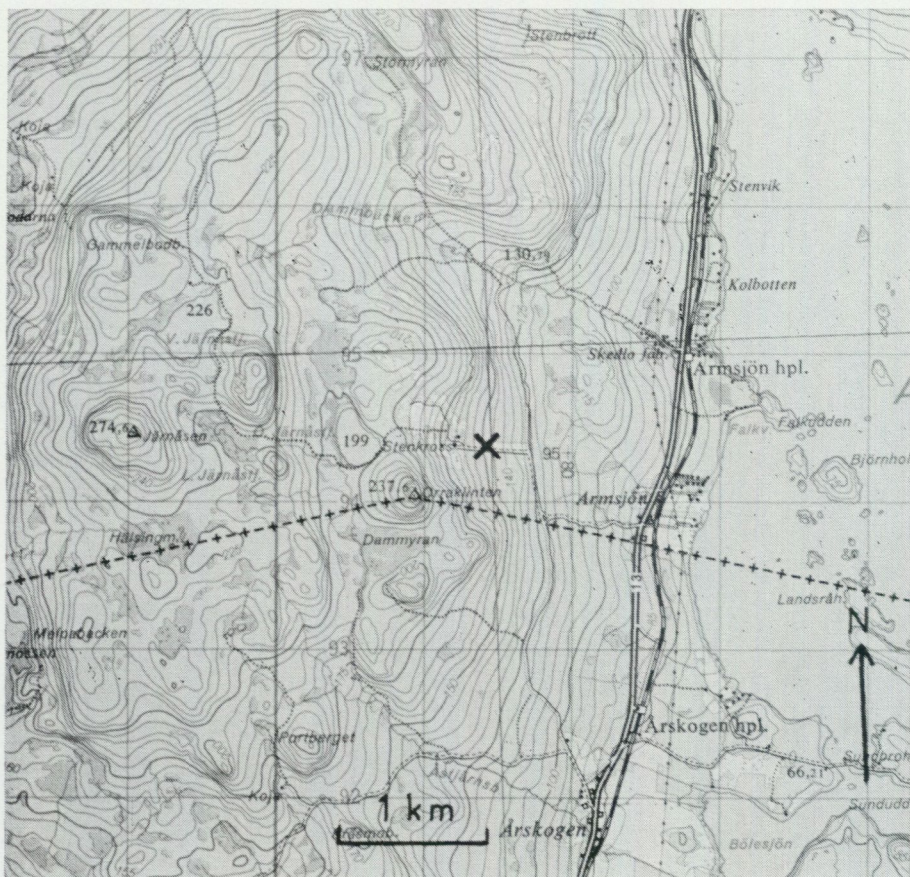


Fig. 54. The position of locality No. 14. Top. map 16 H Bergsjö NO.

horizontal laminae of silt in the till matrix were frequent, and the compaction was high.

The mechanical composition of the clayey till 2.5 m.b.s. is seen in Fig. 55, and the results from petrographical analyses in the gravel fraction of the till are seen in Table No. 1 (sample No. 14).

A microfabric analysis in a sample from the clayey till 2.2 m.b.s. shows a strong preferred orientation from west (Fig. 56).

Striae systems in this region have recently been observed by J. Lundqvist during the reconnaissance for the map of the Quaternary deposits of the Väster-norrland County. The following systems have been found: W—E, N45°W, N30°E, N10°E, N30°W and N70°W. The W—E system is the oldest and N70°W the youngest. The relationship in age between the other systems is complicated, showing both clockwise and counter-clockwise changes of the ice movements (pers. comm. J. Lundqvist).

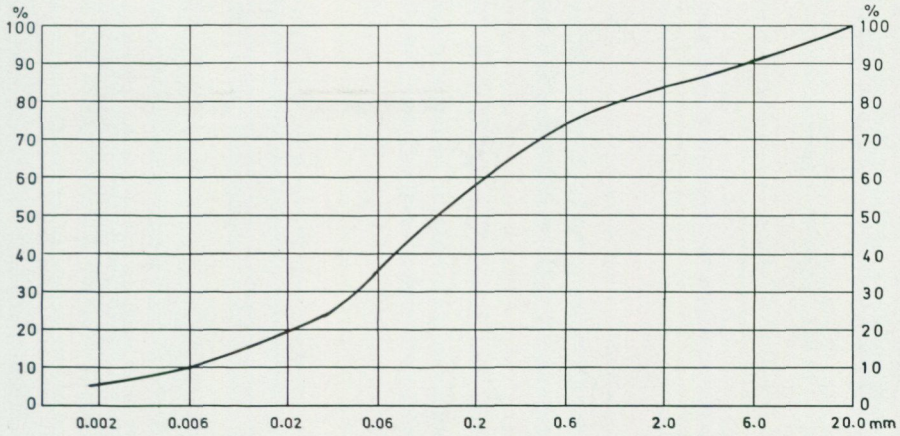


Fig. 55. Grain-size distribution of the clayey till at locality No. 14.

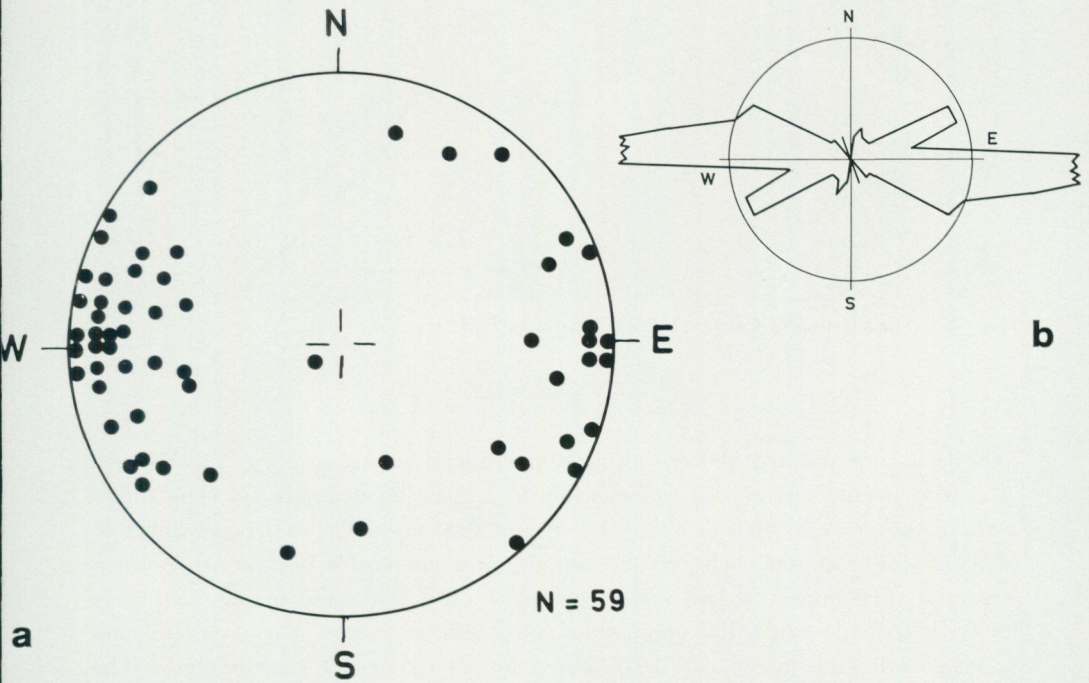


Fig. 56. a = Stereodiagram of particle orientation in the clayey till 2.2 m.b.s. at locality No. 14.
 b = Particle orientation in Fig. 56a visualized in a rose diagram.

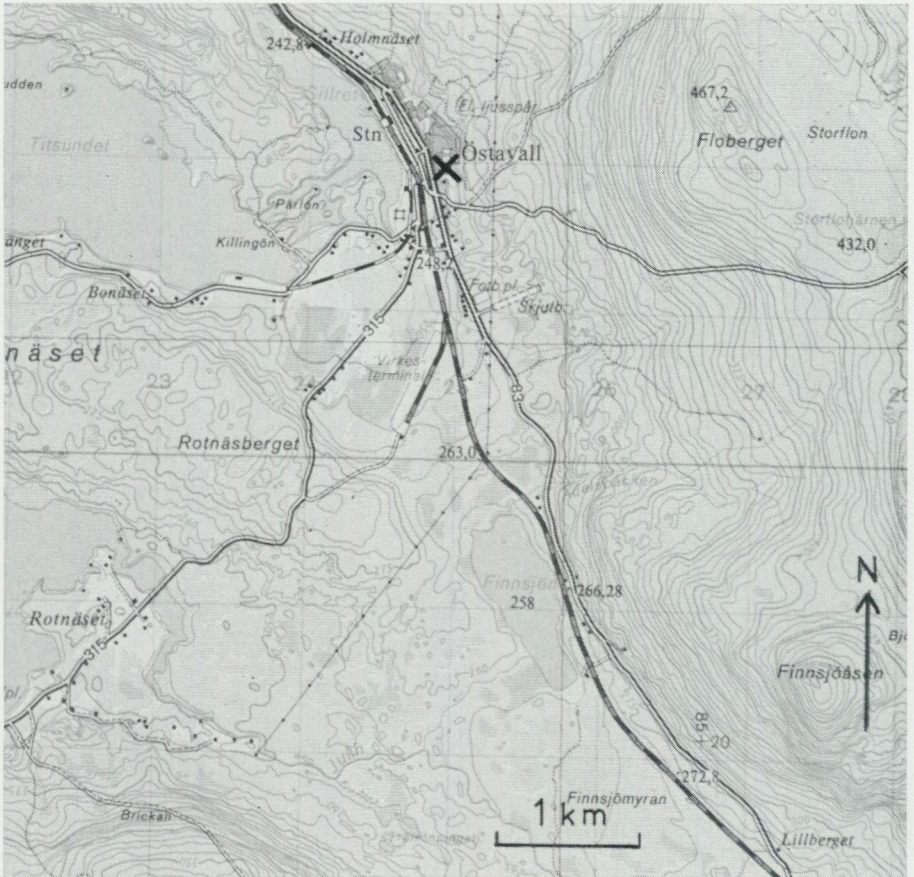


Fig. 57. The position of locality No. 15. Top. map 17 F Ånge SO.

15. ÖSTAVALL

The locality is situated 500 m southeast of Östavall railway-station (Fig. 57). In a cutting a clayey sandy till was overlain by a gravelly to sandy till. The thickness of the gravelly till was about 1.5 m and the clayey till was found down to 3.8 m.b.s. The contact between the two tills was not visible because of slumped material. The upper till had a light grey hue (10R 7/2) and a high frequency of boulders and stones. The compaction was medium to low. The clayey till had a very dark grey hue (2.5Y 3/0) and a low frequency of coarser clasts. The compaction was high. The roundness of coarser clasts in the clayey till seemed to be higher than in the gravelly one.

Thin laminae of silt, running subhorizontally in the matrix of the clayey till, were frequent.

The grain-size distribution of the two tills is seen in Fig. 58. (curve No. 1 =

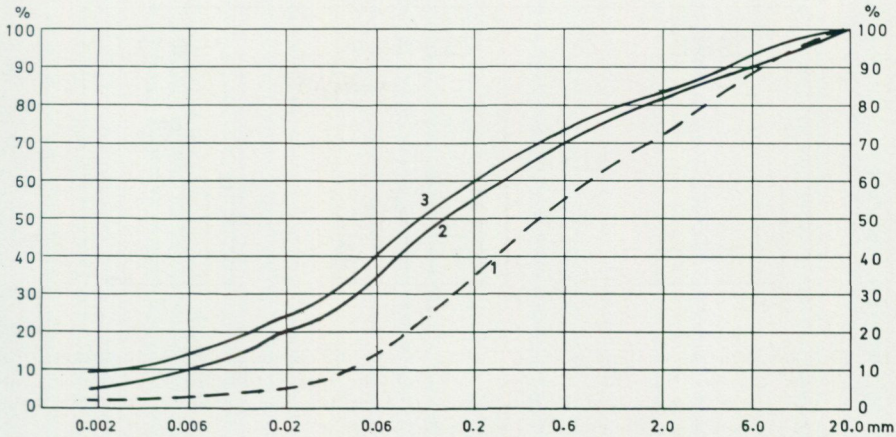


Fig. 58. Grain-size distribution of the upper and lower till at locality No. 15.

gravelly till, 1.2 m.b.s. and curve No. 2 = clayey till, 2.5 m.b.s., No. 3 = 3.2 m.b.s.).

Roundness analyses in the medium sand fraction in one sample from the gravelly till 1.2 m.b.s. and one in the clayey till 2.5 m.b.s. were carried out. In the gravelly till 31 per cent were angular and 69 per cent sub-angular while 26 per cent were angular, 70 per cent sub-angular and 4 per cent sub-rounded in the clayey till. The roundness was higher in the lower till.

The petrography in the gravel fraction in one sample from the upper till (15 A, 1.2 m.b.s.) and in one sample from the lower till (15 B, 2.5 m.b.s.) is seen in Table No. 1. The content of Zn, Cr, CaCO_3 , heavy minerals, and humus from samples 15 A and 15 B is seen in Table No. 2.

X-ray diffraction analyses were carried out in samples from the gravelly and from the clayey tills. The clay mineral content in the gravelly till (SB 15, 1.0 m.b.s.) and in the clayey till (SB 16, 1.5 m.b.s. and SB 17, 2.0 m.b.s.) is seen in Fig. 59. The content of vermiculite and mixed-layer mineral is lower in the gravelly till. In the clayey till vermiculite and mixed-layer mineral decrease with depth. The percentage of FeO increases with depth while Fe_2O_3 shows the opposite trend (not seen in Fig. 59).

A microfabric analysis in a sample from the clayey till 2.2 m.b.s. shows a preferred orientation from west (Fig. 60).

Striae systems from W—E → WNW → N—S, from oldest to youngest, have been observed in areas round this locality during the reconnaissance for the map of the Quaternary deposits of the Västernorrland County (pers. comm. J. Lundqvist).

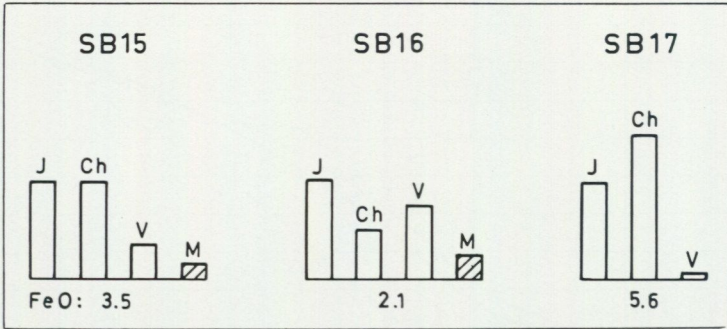


Fig. 59. Clay mineral content estimated from X-ray diffraction analyses in samples from the gravelly till (SB 15, 1.0 m.b.s.) and the clayey till (SB 16, 1.5 m.b.s. and SB 17, 2.0 m.b.s.) at locality No. 15. (J=illite, Ch=chlorite, V=vermiculite, M=mixed-layer mineral. FeO in number per cent.)

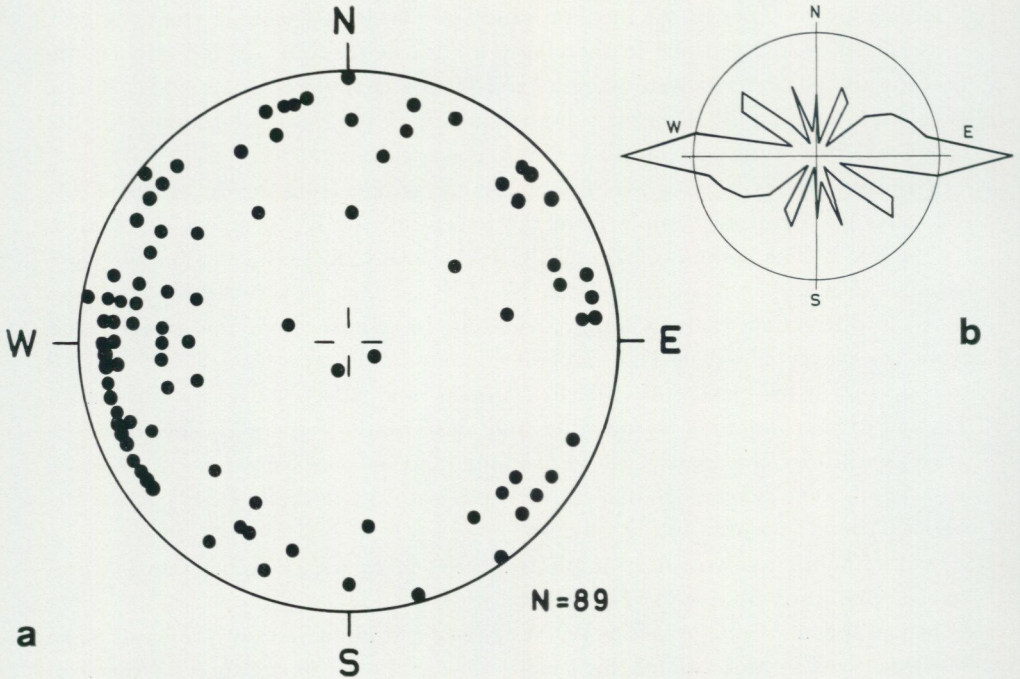


Fig. 60. a=Stereodiagram of particle orientation in the clayey till 2.2 m.b.s. at locality No. 15.
b= Particle orientation in Fig. 60a visualized in a rose diagram. (Circle marks 10 per cent.)



Fig. 61. The position of locality No. 16. Top. map 19 I Örnköldsvik SO.

16. HUMMELVIK

The locality is situated 850 m ESE of Hummelvik (Fig. 61). In a 4.5 m deep cutting a clayey sandy till overlain by wave-washed sediment was found. The clayey till reached from 0.3 m.b.s. down to 4.5 m.b.s. It had an upper zone (between 0.3—1.3 m.b.s.) with a light brownish grey hue (2.5Y 6/2) and a lower zone with a very dark grey hue (2.5Y 3/0). Precipitation of iron and manganese was common in the upper zone. Subhorizontal fissility joints were visible in the whole matrix. The frequency of boulders and stones was low and the roundness of the coarser clasts was high. The clayey till was also characterized by a high compaction. The grain-size distribution of the clayey till at different levels is seen in Fig. 62 (curve No. 1 = 1 m.b.s., No. 2 = 2.5 m.b.s. and No. 3 = 3.5 m.b.s.).

The petrography in the gravel fraction of the clayey till 1.5 m.b.s. is seen in

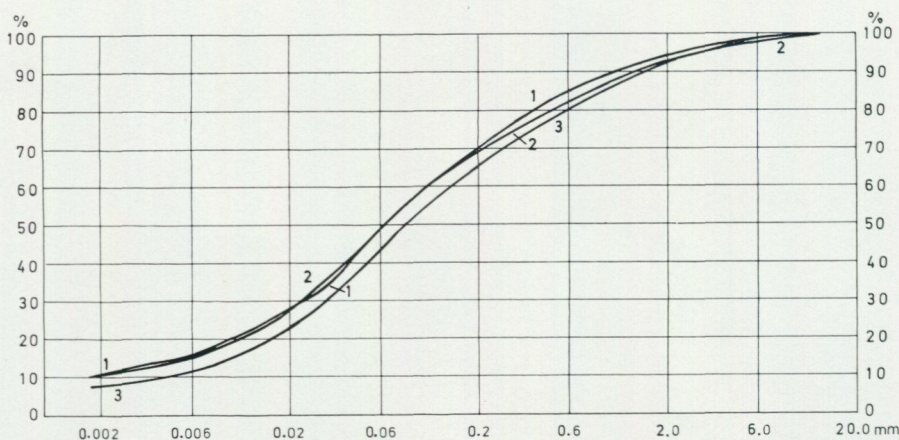


Fig. 62. Grain-size distribution of the clayey till at locality No. 16. (1 = 1.0 m.b.s., 2 = 2.5 m.b.s., 3 = 3.5 m.b.s.)

Table No. 1 (sample 16 B). Petrographic analysis was also performed in a sample from an ordinary sandy till (sample 16 A, 2.0 m.b.s.).

The content of Zn, Cr, CaCO_3 , heavy minerals, and humus in the ordinary till (16 A, 2.0 m.b.s.) and in the clayey till (16 B, 1.5 m.b.s. and 16 C, 3.5 m.b.s.) is seen in Table No. 2.

The results from X-ray analyses in samples from the ordinary till (SB 11, 2.0 m.b.s.) and from the clayey till (SB 12, 1.0 m.b.s., SB 13, 2.0 m.b.s. and SB 14, 3.5 m.b.s.) can be seen in Fig. 63. Vermiculite is present only in the upper zone of the clayey till. The percentage of FeO increases with depth and the content of Fe_2O_3 is higher at lower levels (not seen in Fig. 63).

A microfabric analysis in a sample from the clayey till 2.5 m.b.s. shows a preferred orientation from WNW (Fig. 64).

Striae systems in areas round this locality have been observed during the reconnaissance for the map of the Quaternary deposits of the Västernorrland County. The following striae systems have been found: W—E, $\text{N}35^\circ\text{W}$, $\text{N}45^\circ\text{W}$, $\text{N}60^\circ\text{—}70^\circ\text{W}$. The system from W is the oldest and the age relationship between the younger systems are uncertain but most probably: $\text{N}35^\circ\text{W} \rightarrow \text{N}45^\circ\text{W} \rightarrow \text{N}60^\circ\text{—}70^\circ\text{W}$ (pers. comm. J. Lundqvist).

Some other occurrences of the clayey till need some brief comments.

In a road cutting at Nockeby, about 10 km west of Stockholm, pieces of clay were found in the dark grey clayey till. Also some joints in the underlying bedrock were injected with clay. Some of the clay clasts were varved as though they originated from glacial clay. Clay clasts have also been found in the clayey till 15 km northeast of Leksand, in the County of Kopparberg.

At Koberget, 12 km northwest of Östavall and at Njurunda, Västernorrland County, clasts of varved clay have been found in the dark grey clayey till (pers. comm. J. Lundqvist and J.O. Svedlund, SGU).

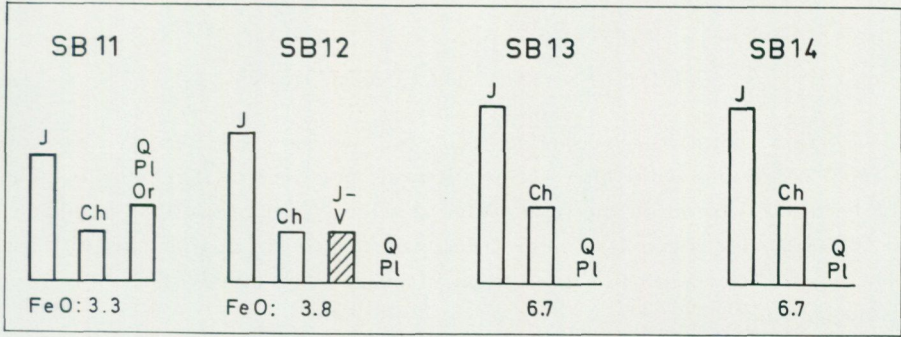


Fig. 63. Clay mineral content estimated from X-ray diffraction analyses in samples from the ordinary till (SB 11, 2.0 m.b.s.) and the clayey till (SB 12, 1.0 m.b.s; SB 13, 2.0 m.b.s. and SB 14, 3.5 m.b.s.) at locality No. 16. (J=illite, Ch=chlorite, V=vermiculite, Q=quartz, Pl=plagioclase. FeO in number per cent.)

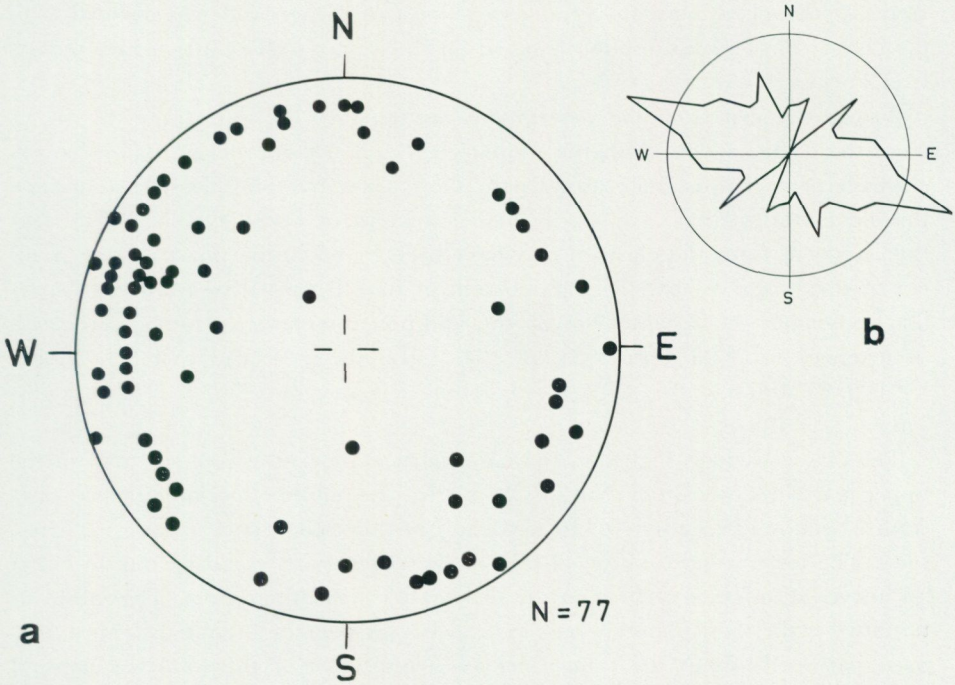


Fig. 64. a=Stereodiagram of particle orientation in the clayey till 2.5 m.b.s. at locality No. 16.
 b=Particle orientation in Fig. 64a visualized in a rose diagram.

DISCUSSION AND CONCLUSIONS

In the following text the investigated clayey till will be called the *old clayey till* to avoid confusions with other clayey till types discussed in the following text. The term old is based on the results from this investigation and thus anticipates the following discussion. It is nevertheless appropriate to separate this till from other types of clayey till in the investigated area, which mainly derive from the last deglaciation.

The old clayey till mainly occurs on the bedrock surface as relicts in topographic positions that can have protected this till against erosion during younger ice movements. Sometimes it is also found in more exposed positions (cf. H. Möller 1965, 1968, 1969, 1974, Rainio & Lahermo 1976, Eriksson 1977). Mostly the old clayey till is overlain by the ordinary till of the area. In the Väster-norrland, Värmland and Kopparberg Counties the cover of ordinary till is sometimes lacking.

The regional distribution of the old clayey till has not been established, but it seems as though at least in certain areas most of the ground was covered with the clayey till. This assumption is based on the author's observations and reports from borings, buildingworks etc.

As can be seen from the descriptions of the sites, the old clayey till differs from the ordinary one. Both the ordinary till and the old clayey till consist exclusively of crystalline rock material in the coarser fractions. Despite that fact, the old clayey till has a markedly higher content of fines (Fig. 65). The fact that layers of fines and clasts of clay have been found in the till at a large number of sites, suggests that the high content of fines is caused by reworked water-laid sediments (cf. locality No. 3; the additional remarks on other clayey till occurrences; G. Lundqvist 1951, p. 162, J. Lundqvist 1958, p. 58, H. Möller 1964, p. 95, 1968, p. 467, 1974, p. 43, Rainio & Lahermo 1976, p. 150, K. Eriksson 1977, p. 395).

The clay content is higher in the basal parts of the old clayey till than in the upper parts (cf. localities Nos. 1, 2, 5, 15). Unpublished granulometric data from a section at locality No. 10 also confirm this trend (pers. comm. K. Eriksson). The lower concentration of clay in the upper parts could be due to either an uneven admixture of fines in the drift or by a leaching effect. The latter alternative is the most plausible one, as a lower clay content is limited to an uppermost part with about the same thickness irrespective of the total thickness of the till bed. A weathering in the upper parts of the old clayey till is also indicated by clay mineral analyses. Illite and chlorite have in the upper parts been altered to mixed-layer minerals, vermiculite and smectite (cf. Droste & Tharin 1958, Jørgensen 1966, Quigley & Ogunbadejo 1976). This is also the reason

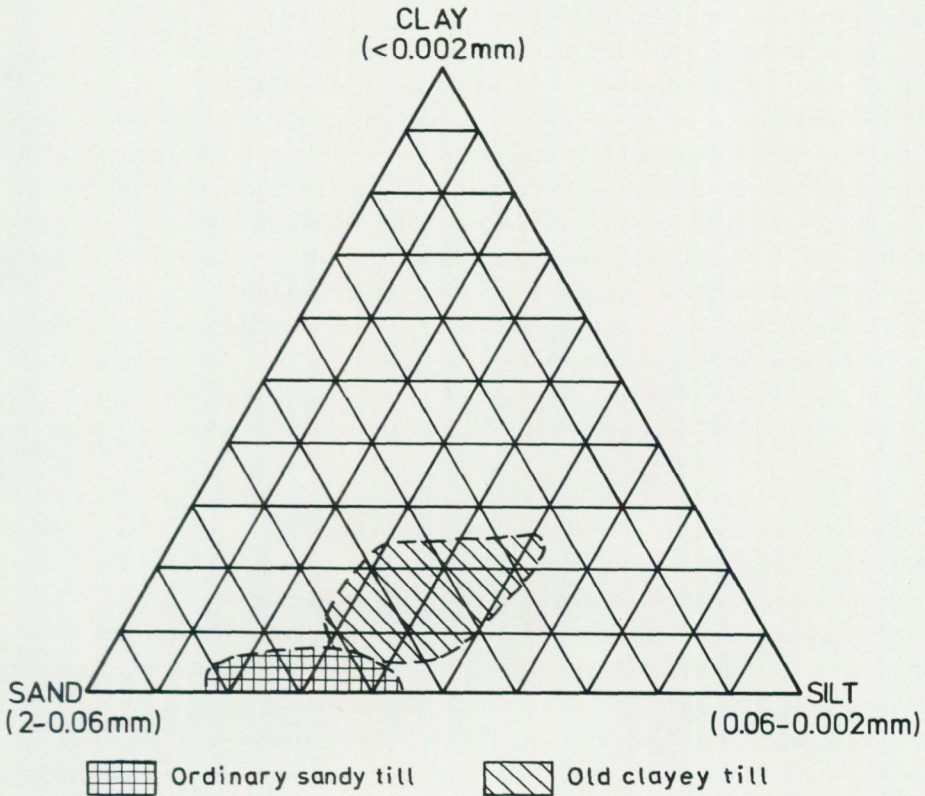


Fig. 65. The grain-size distribution of the old clayey till and the ordinary till from 57 samples.

for the higher content of these minerals in the very light grey surroundings of joints in the old clayey till in locality No. 7.

In general the old clayey till and the ordinary till show similar clay mineral content (cf. J. Lundqvist 1973). There is no trend that one till type is more weathered than the other. The clay minerals in the old clayey till do not indicate any content of deeply weathered rock material.

The dark grey hue of the old clayey till is noticeable at several of the occurrences. The old, dark grey, clayey till has formerly been called *bluish* (cf. J. Lundqvist 1973) but that is only a subjective term of the real hue. The lower, dark grey zone has a darker hue in western and northern parts of the investigated area than the corresponding zone in the southeast. The greyish brown upper zone has not been observed in the westerly and northerly parts of the area and is lacking at some occurrences in southeast (cf. Rainio & Lahermo 1976, p. 150).

The colour and its zonation in the old clayey till is not specific for this type of till. Other authors in Sweden have reported similar colour zonation in other clayey tills (e.g. G. Lundqvist 1940, Ringberg 1975, 1976), but in general the

grey hue of these tills seems to be paler.

The facts that altered clay minerals and a high percentage of Fe_2O_3 is associated with the greyish brown zone and that there is a higher content of FeO in the dark grey zone, where weathered clay minerals are almost lacking, indicate that the colour zonation is due to weathering in the upper parts of the old clayey till. As the upper zone has a markedly higher content of ferric iron and the lower zone more ferrous iron, the zonation is almost certainly caused by oxidation (cf. Rainio & Lahermo 1976). Ferric iron in the upper zone probably covers the darker ferrous iron and gives rise to the greyish brown hue.

The author cannot explain the fact that the dark grey hue is often darker on the old clayey till than on other clayey till types in Sweden. J. Lundqvist (1973) found that the dark colour could not be caused by iron sulphide while Rainio & Lahermo (1976) suggested that sulphates are reduced to ferrous sulphide by the organic material in the till.

The humus content of the old clayey till does not show any tendency to be higher than in ordinary tills. Perhaps this could be explained by a reduction of the humus content when sulphates are reduced to ferrous sulphide. The humus determinations need, however, to be more exact (see Methods).

The preferred orientation from the microfabric analyses is assumed to correspond to the direction of transport by the ice when the till was deposited (cf. Seifert 1954, Harrison 1957, Gravenor & Meneley 1958, Ostry & Deane 1963, Penny & Catt 1967, Evenson 1971, Lineback 1971, Kujansuu 1976). This fact is also verified by the striae found on the underlying bedrock surface at localities Nos. 2 and 10.

The fabric diagrams show an up-glacier dip and this fact in combination with the lithology, shape and roundness of clasts, mechanical composition, compaction, silt laminae and fissility at the sites described, indicate that the old clayey till is a *lodgement till* type (cf. Dreimanis 1976).

Transport directions, concluded from fabric analyses of the old clayey till at the investigated localities, are shown in Fig. 66. The transport was from the west in the northern and western parts of the investigated area and became more northwesterly in the southeast.

The fact that directions of transport turn gradually from the west to the northwest makes it most probable that the ice movement at the sites corresponds to one glacial phase only.

The higher roundness of the coarser clasts and medium sand grains in the old clayey till, conferred with ordinary tills, may be explained by long transport and/or incorporation of water-laid sediments. The coarser clasts show concave surfaces, facets and striation. Thus it is most probable that their higher degree of roundness is caused by ice transport (cf. Holmes 1960, p. 1653, Drake 1972, Bergersen 1973). It is an open question, however, if this is due to long ice transport or another mode of transport in the ice. The first possibility is more

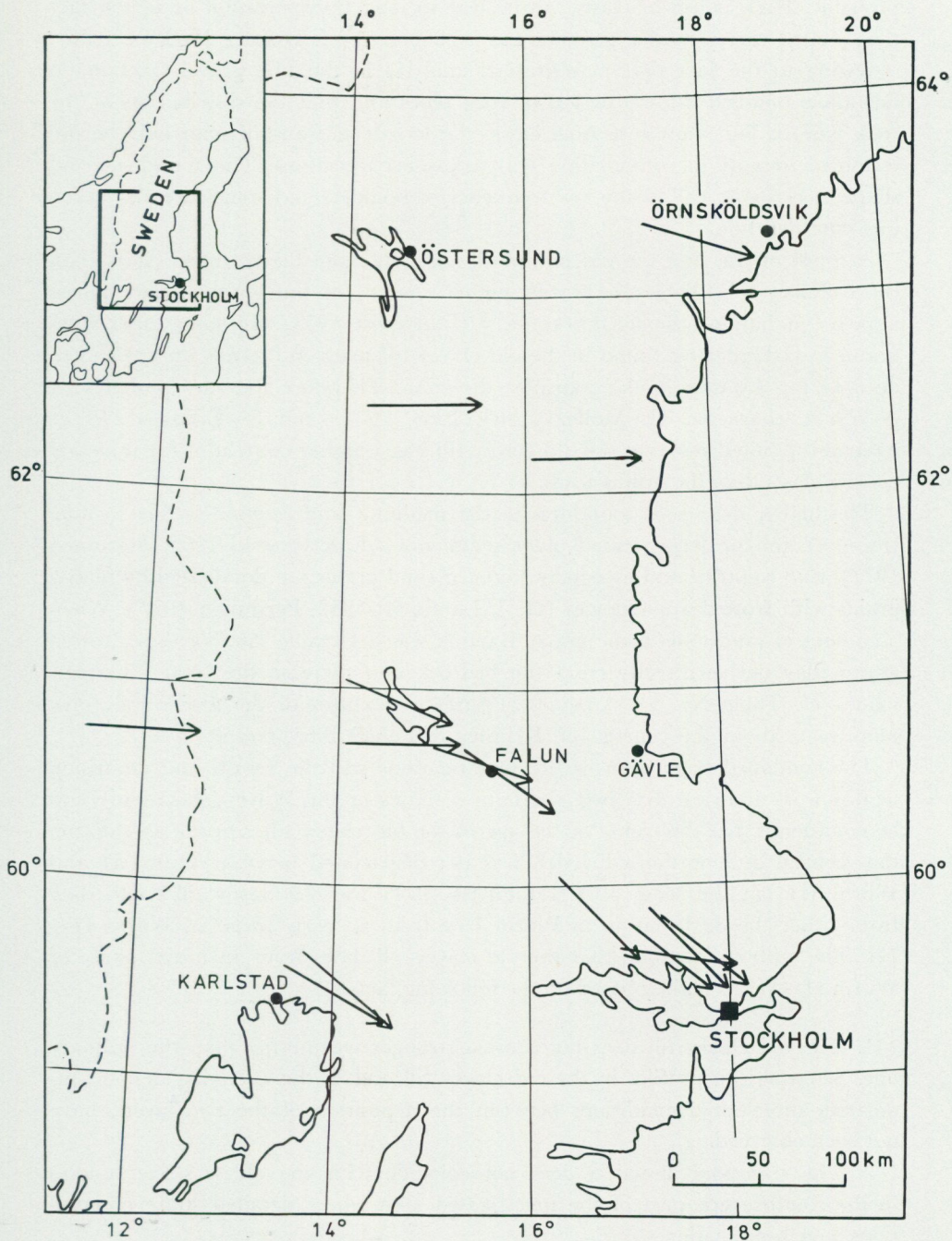


Fig. 66. Sketch indicating the transport directions of the old clayey till as obtained from microfabric analyses.

probable. High polish of clasts can be due to long transportation or to the fact that a silty, clayey matrix gives rise to high polish (cf. Holmes 1960, p. 1656).

Owing to the fact that petrographic analyses in the fine gravel fraction do not allow detailed differentiation of rock types and that the distribution of the rock types is less known in some cases, the length of transport can only be determined broadly in combination with transport directions. The roundness and shape of clasts as well as the low frequency of boulders and stones are also taken into consideration.

At most of the sites the old clayey till contains more far travelled clasts than the ordinary till (Table No. 1). A higher content of fine-grained, dark gneiss appears in half of the localities (cf. J. Lundqvist 1973). In some cases fine-grained, dark gneiss is found in the old clayey till where no source area is known even at far distance in the transport direction. Therefore they are probably of polycyclic character. H. Möller (1964, 1968, 1974) and K. Eriksson (1977) have also pointed out that the old clayey till has a higher content of far travelled coarser clasts than the ordinary till.

The higher degree of roundness in the medium sand fraction is due to long transport and/or incorporated older sediments (cf. Krygowski 1965, Perttunen 1977). *Sub-rounded* and especially *rounded* sand grains are dominated by quartz grains with frosted appearances (cf. J. Lundqvist 1952, Perttunen 1977). When a content of sandstone in the gravel fraction was detectable some of these frosted grains may derive directly from the bedrock and increase the total roundness value (cf. Table No. 1). Analyses of surfaces textures of the grains may give more facts about the genesis (cf. Krinsley & Funell 1965, Granlund 1972).

The combined facts from earlier investigations and the results and discussion in this work indicate that two alternative phases of the Würm glaciation could be considered in a discussion of the age of the old clayey till. On the assumption that central and northern Sweden was not deglaciated between Würm II and Würm III (in the sense of J. Lundqvist 1974) the old clayey till could date from either the deglaciation in Würm I or from an early phase of Würm II—III. The author's opinion, that the old clayey till dates from an initial phase of Würm II—III, is mainly based on the following facts.

1. The old clayey till does not show a stronger weathering than the ordinary one. Separate soil profiles in the old clayey till and in the overlying deposit, indicating interstadial conditions between the deposition of the two layers, have not been observed.
2. The transport direction does not coincide with the oldest striae systems in the southeastern part of the investigated area where detailed striae observations have been made.
3. The absence of any interstadial deposit between the old clayey till and the ordinary one even in sheltered positions.

4. The stratigraphic position of the old clayey till and the fact that only this till unit has a pronounced content of reworked material favours a deposition after the Jämtland Interstadial.

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 SGU = Sveriges geologiska undersökning

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TABLE 1. Petrography of the stone and fine gravel fractions in number per cent.

Sample No.	Granites, coarse-grained gneiss	Fine-grained, dark gneiss	Gray-wacke	Alum shale	Lime-stone	Leptite	Porphyry, hällflinta	Quartzite	Sandstone sparagmite	Greenstone	Number of counted particles
1 A	89	2				2	4	1		2	414
1 B	93	2				1	3				605
2 A	98						1				470
2 B	88	7				3	3				472
2 C	85	9				2	3				474
3 A	71	15					6			9	155
3 B	77	13				5				4	112
3 C	66	15				4	5			11	138
5 A	85	12				1	2				453
5 B	77	23									538
6 A	90	10					1				92
6 B	51	30					13			6	97
7 A	94		1				4	1		1	545
7 B	89		2				5		1	1	567
8 A	90	1	2			2	5				499
8 B	90	4				2	4				406
10 A	79					10	3	4	1	4	380
10 B	70	1				4	14	5		6	604
11 A	70	1				5	18		4		369
11 B	77	1				4	13	4			638
13 A	92	1	1					3	2		574
13 B	87	3	2					6	1		504
14	95	4					1				473
15 A	91	6						3		1	525
15 B	94	5									611
16 A	84	13						2	1	1	520
16 B	68	28	1					1	2		459

TABLE 2. Parts per million of Cr and Zn in the matrix and in fraction 0.2—0.06 mm. Heavy mineral content in fraction 0.6—0.2 mm in number per cent and the contents of CaCO₃ and humus in fractions < 2 mm in number per cent.

Sample No.	Cr in matrix (ppm)	Cr in 0.2 - 0.06 mm fraction (ppm)	Zn in matrix (ppm)	Zn in 0.2 - 0.06 mm fraction (ppm)	CaCO ₃ (per cent)	Heavy minerals (per cent)	Humus (per cent)
2 A	15	16	10	9	0	6.2	0.7
2 B	30	14	40	12	1.0	7.6	0.3
2 C	42	15	59	13	1.5	9.6	0.5
3 A	70	125	19	13	0.6	9.8	-
3 B	97	108	37	16	0.6	11.7	-
3 C	110	106	15	5	0.2	11.3	-
3 BS	70	240	40	10	1.3	10.9	-
3 CS	98	183	38	13	1.3	8.6	-
5 A	37	-	38	-	0	5.0	-
5 B	44	-	52	-	0.1	12.4	-
6 A	35	-	27	-	0	10.8	-
6 S	-	-	-	-	0	16.8	-
6 B	39	-	51	-	0	6.7	-
7 A	13	-	10	-	0	6.7	0.3
7 B	19	-	31	-	0	6.0	0.1
8 A	15	9	22	6	0	6.4	0.2
8 B	20	13	34	13	0	10.4	0.2
10 A	22	16	28	26	0	7.3	1.8
10 B	23	18	32	16	0	5.4	0.1
11 A	-	-	-	-	0	7.3	0.3
11 B	-	-	-	-	0	9.2	0.1
13 A	16	10	16	7	0	3.2	0.2
13 B	22	15	38	12	0	7.0	0.3
15 A	28	25	26	18	0	10.5	0.1
15 B	40	24	47	20	0	8.8	0.3
16 A	20	23	14	14	0	7.8	0.1
16 B	50	22	40	14	0	6.2	0.3
16 C	54	24	46	15	0	7.1	0.3

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