DANMARKS GEOLOGISKE UNDERSØGELSE
II. Række. Nr. 111
*Geological Survey of Denmark. II. Series. No. 111*

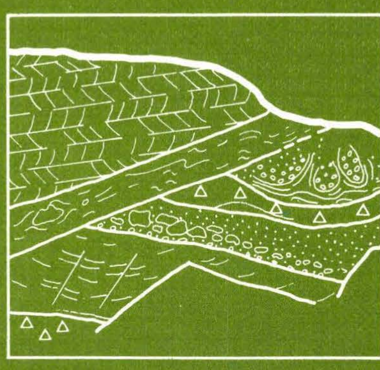
# The stratigraphy, structure and origin of glacial deposits in the Randers area, eastern Jutland

BY

*Gunnar Larsen, Flemming Højgaard Jørgensen and Søren Priisholm*

DANSK SAMMENDRAG:

Glacialaflejringernes stratigrafi og oprindelse i Randers-egnen



*I kommission hos C. A. Reitzels Forlag. København 1977*

Danmarks Geologiske Undersøgelse. II. Række. Nr. 111
*Geological Survey of Denmark. II. Series. No. 111*

# The stratigraphy, structure and origin of glacial deposits in the Randers area, eastern Jutland

*By*

*Gunnar Larsen, Flemming Højgaard Jørgensen and Søren Priisholm*

*Dansk sammendrag:*

Glacialaflejringernes stratigrafi og oprindelse i Randers-egnen

I kommission hos C. A. Reitzels Forlag
København 1977

D.G.U. II. rk. nr. 111
er sat med Fotosats Times
og trykt i offset i 1350 eksemplarer
hos Andelsbogtrykkeriet i Odense.
Bogen er trykt på Thai-Cote, 115 g
fra a/s De forenede Papirfabrikker.
ISBN 87-421-0708-3
ISSN 0366-9130

Date of publication: 1977-11-25

The authors' addresses:

Professor, dr. phil.
Gunnar Larsen
Department of Geology
University of Aarhus
DK-8000 Aarhus C

Cand. scient.
Flemming Højgaard Jørgensen
Norwegian Petroleum Directorate
Lagårdsveien 80
N-4000 Stavanger

Cand. scient.
Søren Priisholm
Geological Survey of Denmark
Thoravej 31
DK-2400 København NV

# Contents

# Abstract

The investigations of the glacial sequence in the Randers area include mapping of the surface layers, study of bore profiles and detailed examination of outcrops, concentrating on the determination of transport directions in the deposits.

The following stratigraphic succession has been established:

Highest: NE till
Tebbestrup Formation (melt water deposits)
SE till
Haldum Formation (melt water deposits)
Lowest: NE till

The two uppermost units can with certainty be referred to Weichselian. Arguments are presented that the three lowermost units are of Saalian age.

The origin of the sequence is discussed. The highest hills in the area (Ølst, Lysnet) were probably formed by the Saalian ice from the NE, since they appear to have influenced flow directions during the deposition of the Haldum Formation. This formation is considered to represent a sandur formed in front of the advancing ice from the SE. In the Weichselian, prior to the formation of the Tebbestrup Formation, the landscape obviously had a varied relief. The formation which infills the lower parts of this landscape is considered as a sandur, formed in front of the advancing ice from the NE. This sandur, together with the prominent hills from the Saalian, formed the substrate for the ice from the NE. This ice modified, but did not destroy the old hills.

# Introduction

Geological mapping of the Quaternary of the Randers map sheet has been carried out by a group from the Department of Geology, Aarhus University, in cooperation with the Geological Survey of Denmark. Some of the work has been done by students as part of projects for their final examination. Apart from actual mapping these projects include sedimentological and glacial-tectonic investigations of the exposed sequences, for example in gravel pits, with the purpose of contributing to the understanding of the structure, stratigraphy and origin of the glacial landscape. Some earlier results of these investigations have been published by Larsen et al. (1972, 1973), Liboriussen (1973, 1975) and Nielsen (1973).

In the two first-mentioned publications a hypothesis is put forward, based on the first results of the mapping, which suggests that landscape remnants from the Saalian glaciation occur preserved within the areal extent of the Weichselian glaciation. The hypothesis is based on the following relations: The landscape in the Randers area is characterised by a plateau, dissected by large valley systems which surrounded for example, the notable hills at Ølst and Lysnet (Fig. 1). The plateau landscape is build up of till resting on thick, widely developed deposits of melt water sand and gravel. Just to the west of the map sheet, at Hollerup in the Gudenå valley, melt water deposits overlie lacustrine deposits from the Eemian interglacial (Andersen, 1965). Thus it is concluded that melt water deposits are the oldest Weichselian deposits in the area. The hills at Ølst and Lysnet, consisting of Eocene clay with tuff horizons (Nielsen, 1973) and strongly disturbed by glacial tectonics, occur as the highest parts of a glacial terraine older than the melt water deposits of the plateau landscape. These hills are therefore considered to have been formed before Eemian, probably in the Saalian glaciation. Structural elements in the melt water deposits and till cover (Larsen et al., 1973; Liboriussen 1973, 1975) strongly support the interpretation that the hills are remnants of an older landscape complex.

In this paper, the earlier published results are extended with those from the examination projects of Flemming Højgaard Jørgensen (1974) and Søren Priisholm (1975).

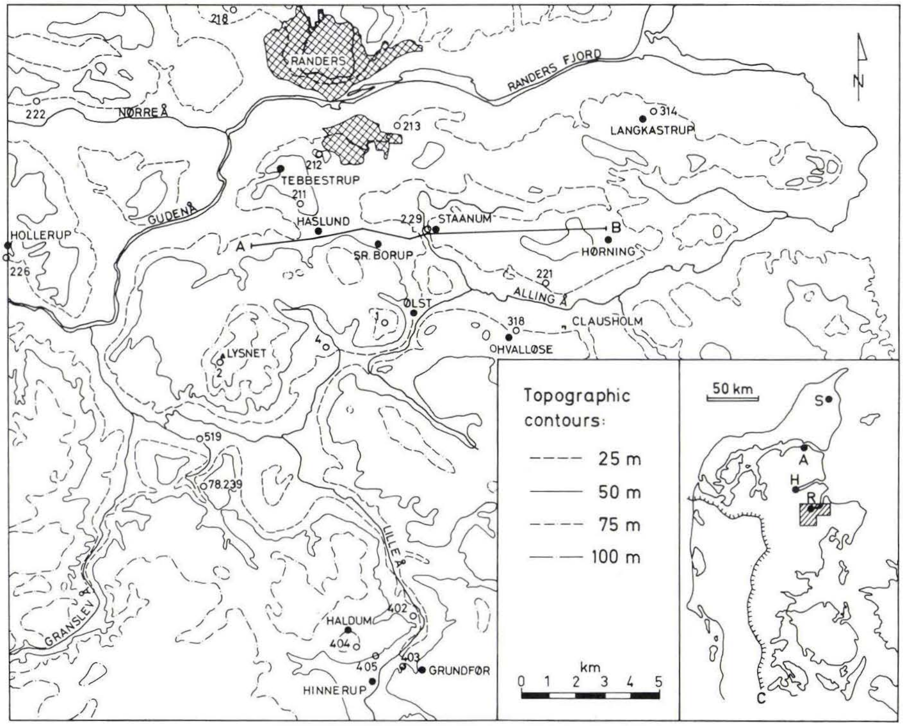



*Fig. 1.* Location map.

Line A-B gives the location of the profile in fig. 3. The numbers represent the localities mentioned in the text.

Regional map: C is the main stationary line for the Weichselian glaciation: R, H, A and S are the localities Randers, Hobro, Aalborg and Skærumhede.

# Main features of the stratigraphy and structure

Investigations of the stratigraphy, structure, and origin of the glacial landscape can be divided into two phases; a general one in which the main elements are established, and a special one which aims at a more thorough illustration of the conditions of origin. The general phase is based on mapping together with examination of wash borings.

## Mapping

The mapping has been carried out using a 1 m long auger which gives information as to the geological relations below the soil profile. The existence of large, usually steep-sided, valleys in the area means that this surface mapping can illustrate major features of the structure of the glacial landscape. Fig. 2 shows the simplified results of the mapping. The simplification includes the non-distinction between Late Weichselian and Flandrian (Mangerud et al. 1974) deposits. The distribution of three types of deposits (till, melt water sand and gravel, sticky Tertiary clay) is indicated for the glacial landscape, without considering composition variations within the individual units.

As mentioned in the introduction and illustrated in Fig. 2 the plateau landscape around Randers Fjord and the Gudenå valley consist of widely developed melt water deposits covered by till, and Tertiary clay makes up most of the prominent hills at Ølst and Lysnet. Tertiary clay also occurs away from these hills, such as below the till in the slopes of the Gudenå valley at Grensten and in the eastern outskirts of Randers. From the latter area, Andersen (1958) has described the occurrence of glacio-tectonically disturbed Eocene clay with tuff horizons.In some places sand occurs above the till, such as on the plateau landscape just west of Lysnet hill.

The plateau landscape continues to the south of the large hills and the Lilleå valley, but with a greater elevation than in the north. The mapping has shown that till also occurs in the south, resting on melt water deposits and, in places, on sticky Tertiary clay.

In the eastern part of the map, where the plateau character of the land-

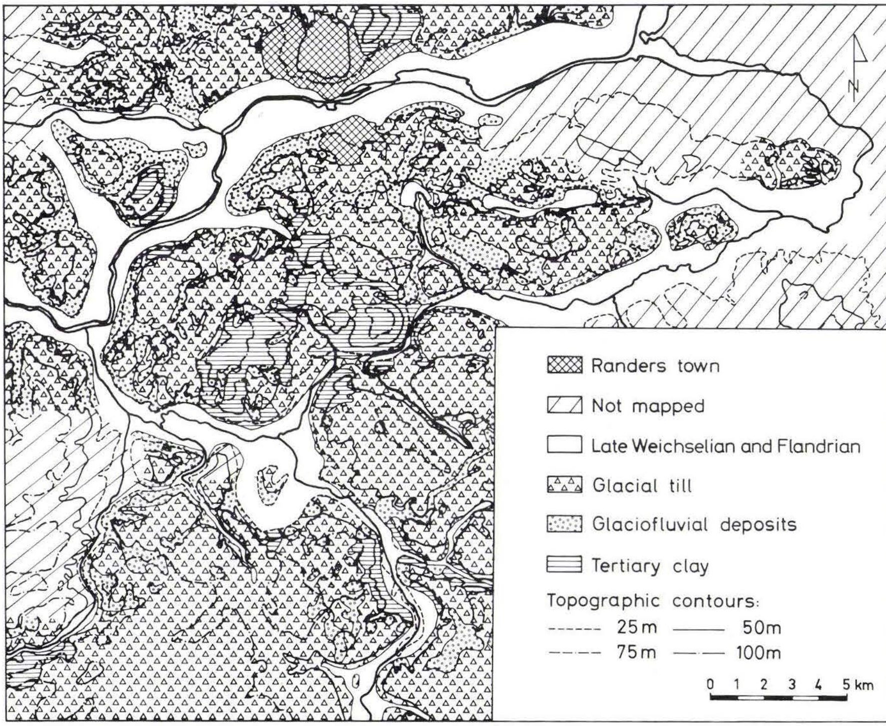



*Fig. 2.* Geological map.

scape is not so well developed, the till cover is less continuous, such that the underlying melt water sand and gravel often occur at the surface.

The mapping has therefore revealed a simple picture for the major structure of the glacial landscape. It should be stressed that mapping alone cannot distinguish, for example, whether the melt water deposits beneath the till belong to one or more units throughout the area.

## Borings

In 1973, Dansk Undergrunds Consortium carried out a series of shot hole borings along a line through the northern part of the map sheet. Colleagues from the Department of Geology, Århus, have had the opportunity of following 73 of these, located along a 13 km long line from Haslund to Hørning (line A-B on map fig. 1). The borings were carried out as wash borings with a rotating drill, bore diameter 8 cm, depth 25–30 m. The results of the borings are compiled in the cross section of fig. 3.

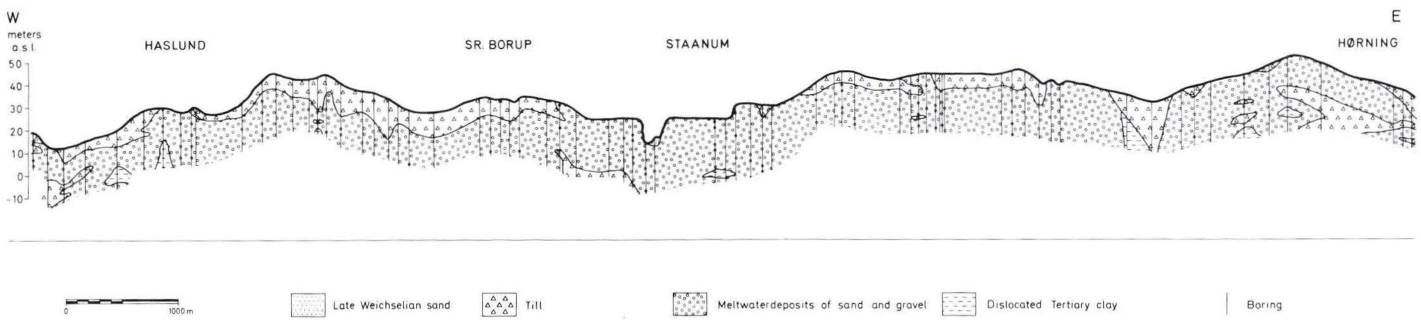



*Fig. 3.* Profile through the glacial landscape from Haslund to Hørning, based on wash borings; see fig. 1 for location of profile. Vertical exaggeration × 20.

It is apparent that melt water sand and gravel are the dominant deposits in the cross section. In addition there occurs till of varying thickness, in the west over a wider area, and in the east as smaller isolated units. The contact of the melt water deposits with the underlying material is only reached in a few places. Deeper horizons of till have been found west of Haslund, between Sr. Borup and Staanum, and at Hørning. Slices of Tertiary material occur in the west as Eocene, plastic clay, and in the east as marl of likely Paleocene age.

The results of the borings have therefore supported those of the mapping as regards the structure of the glacial landscape, and have provided new evidence concerning the lower boundary of the melt water deposits.

# Investigation and interpretation of outcrops

As mentioned above, the mapping and examination of bore material have revealed a general picture of the landscape structure. In order to establish a deeper understanding of the topic, exposures in gravel and clay pits in the area have been investigated in detail.

Study of these profiles has concentrated in part on an analysis of the lithology and partly on an analysis of the features which can give information as to the directions of movement of the melt water and the glacier ice. The orientation of cross-bedding directions has been measured for melt water deposits, and the grain orientation (fabric) in gravel horizons. The directions of ice movement has been investigated by measuring deformation structures (plunge of fold axes and dip directions of thrust planes) and partly by fabric studies of tills; both the macrofabric method and the radiography method for microfabric investigation (Liboriussen, 1973) have been used.

The results of these investigations for a series of exposures (localities given in Fig. 1) are given below.

*Loc. 229. Staanum (Fig. 4)*

The locality is situated on a small terrace. The uppermost sand layers, ca. ½ m, are therefore considered to be Late Weichselian. Planar cross-bedding occurs in this sand, showing a transport direction towards 150°. Sorted polygon structures and a fossil ice wedge occur in the sand.

Beneath this occurs 0.5 m of layered sandy till containing gravel and a few boulders bigger than 200 mm; the layering wraps around these. Macrofabric analysis shows a marked preferred A-axis orientation of 45°, with a northeasterly plunge. The sandy till passes gradually downwards into a 0.5 m thick laminated sand horizon. This feature, together with the layered character of the sandy till, may indicate that we are dealing with a flow till (Marcussen, 1973). In a flow till, particle orientation will normally be poor or absent (Lundqvist, 1948; Drake, 1971; Marcussen, 1975). However, a flow till can achieve a marked fabric if pronounced gravitative flow has occured (Boulton, 1971; Marcussen, 1975). Another possibility is that the layering is a glaciodynamic structure (Lavrushin, 1970 a). In this case the till can be considered to be a lodgement till which, according to the fabric analysis, was deposited by ice from the NE. The question cannot be decided with certainty but it should be mentioned that the latter interpretation fits in well with the picture of the region as a whole – see later. The locality has been visited by Dr. Yu. A. Lavrushin, Moscow, who supported the latter interpretation.

The laminated sand rests discordantly on strongly deformed sand and gravel horizons. The deformations are of both box- and isoclinal fold types. The fold axes group around N–S; overturning to the west indicates ice movement from the east. The direction of tabular cross-bedding indicates that transport of melt water took place towards 310°.

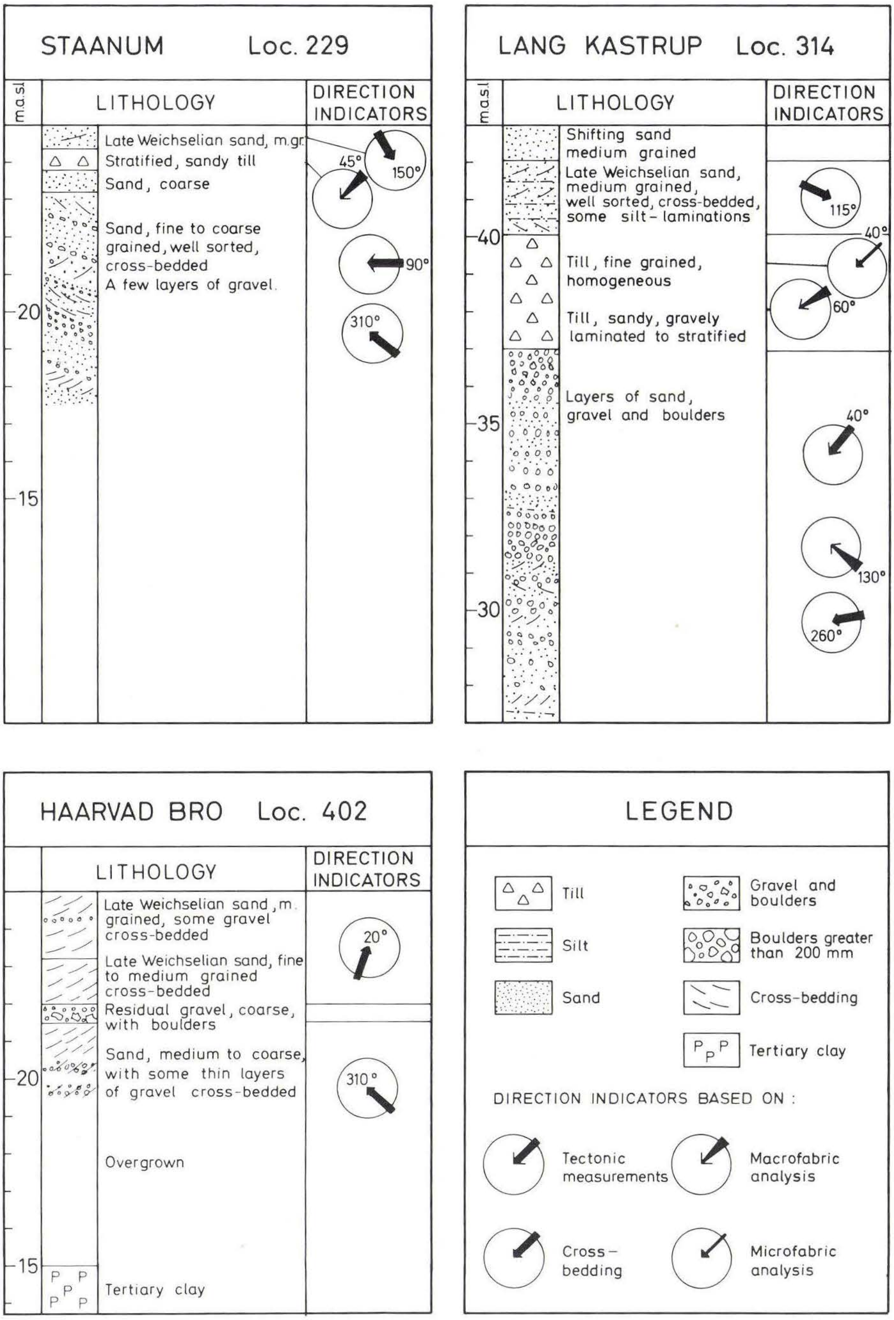

STAANUM Loc. 229
m.a.sl
LITHOLOGY
DIRECTION INDICATORS
Late Weichselian sand, m.gr.
Stratified, sandy till
Sand, coarse
Sand, fine to coarse grained, well sorted, cross-bedded
A few layers of gravel.
45°
150°
90°
310°
20
15
LANG KASTRUP Loc. 314
m.a.sl
LITHOLOGY
DIRECTION INDICATORS
Shifting sand medium grained
Late Weichselian sand, medium grained, well sorted, cross-bedded, some silt-laminations
Till, fine grained, homogeneous
Till, sandy, gravely laminated to stratified
Layers of sand, gravel and boulders
115°
40°
60°
40°
130°
260°
40
35
30
HAARVAD BRO Loc. 402
LITHOLOGY
DIRECTION INDICATORS
Late Weichselian sand, m. grained, some gravel cross-bedded
Late Weichselian sand, fine to medium grained cross-bedded
Residual gravel, coarse, with boulders
Sand, medium to coarse, with some thin layers of gravel cross-bedded
Overgrown
Tertiary clay
20°
310°
20
15
LEGEND
Till
Gravel and boulders
Silt
Boulders greater than 200 mm
Sand
Cross-bedding
Tertiary clay
DIRECTION INDICATORS BASED ON :
Tectonic measurements
Macrofabric analysis
Cross-bedding
Microfabric analysis

*Fig. 4.*

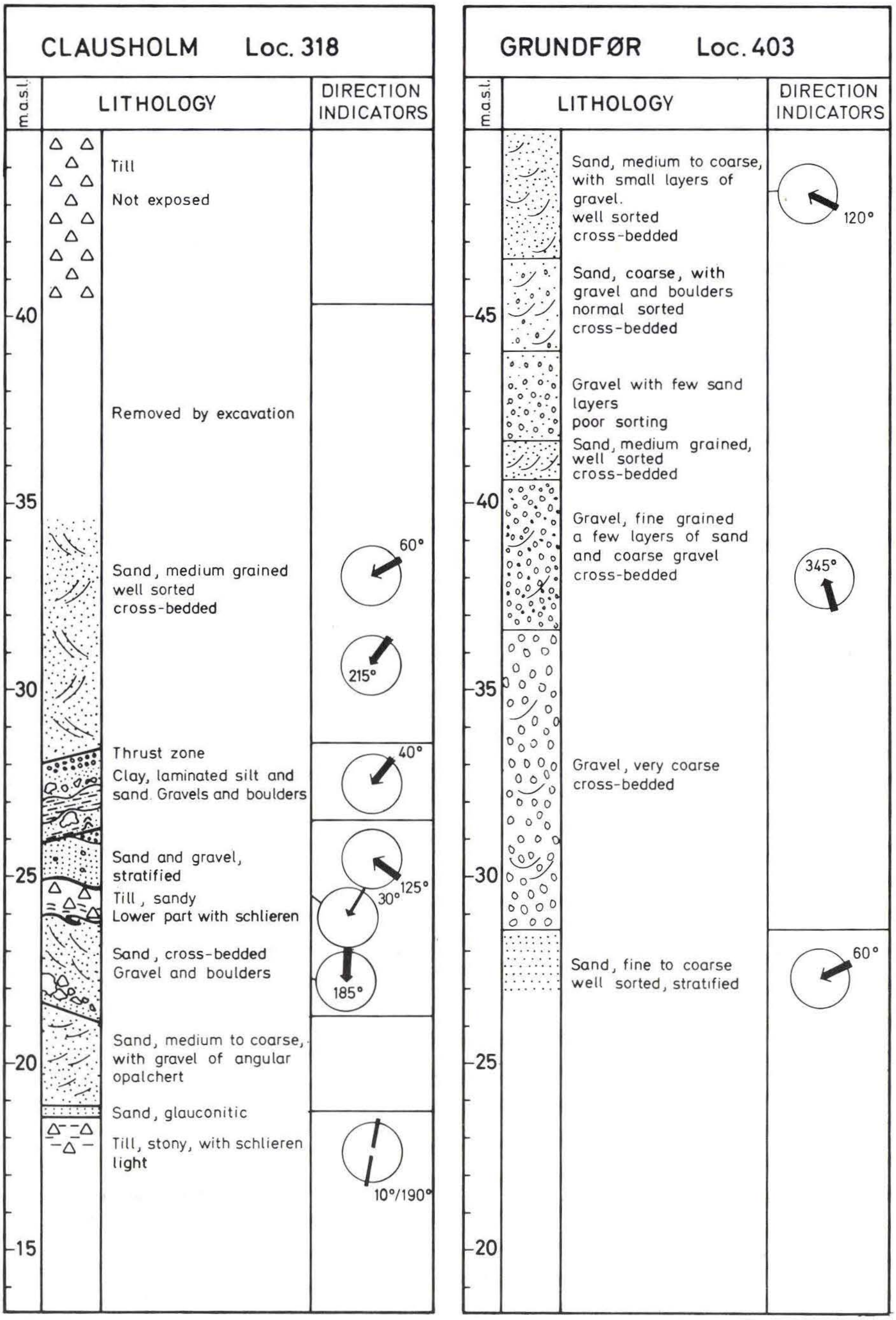



*Fig. 5.* For legend see fig. 4.

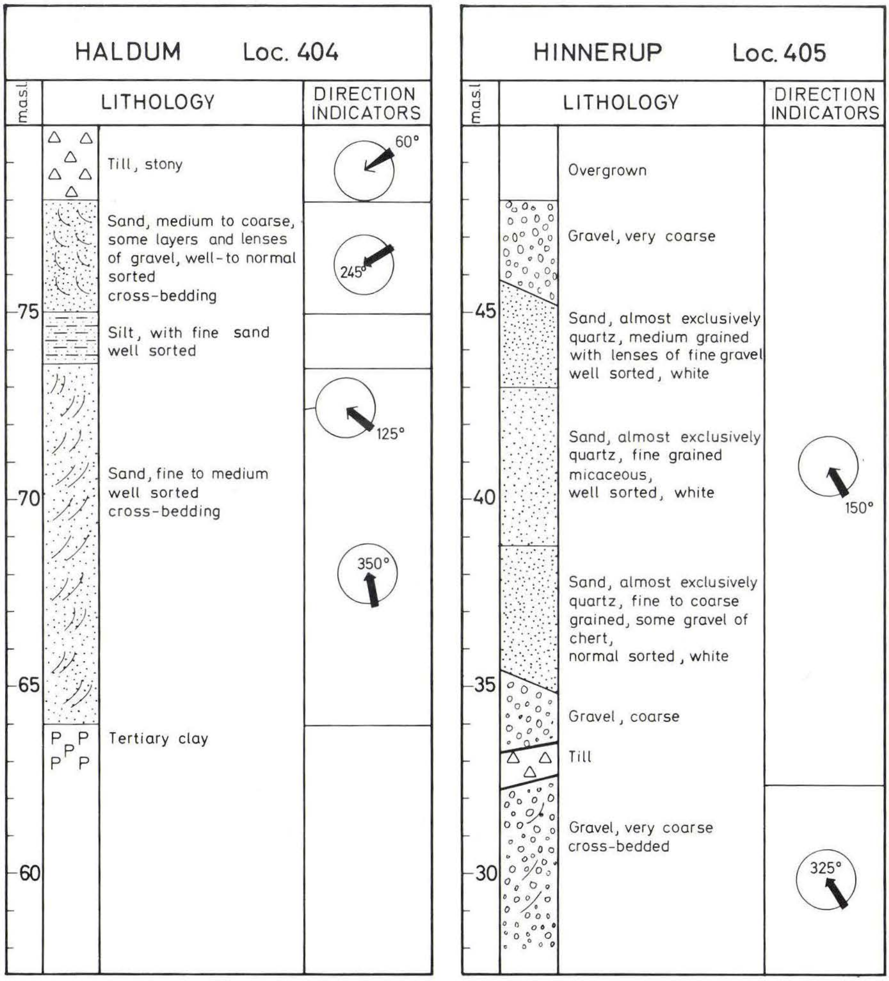



*Fig. 6.* For legend see fig. 4.

*Loc. 314, Lang Kastrup (Fig. 4)*

The locality is a large gravel pit, 150×250 m in area and 15-20 m deep. The exposed sequence can be subdivided into four units.

Uppermost occurs a c. ½ m thick medium grained, well sorted, structureless sand, considered to be a wind blown sand deposit. Below this occurs 2 m of sand with through cross-bedding which indicates a transport direction towards 115°. Two fossil ice wedges have been noted, and the sand is interpreted as being of Late Weichselian age.

The next unit is a 3 m thick till, the upper ½ m of which is sticky and fragmented while the lower 2½ m is sandy and gravely with microshearing and "gneissic" structures (Lavrushin, 1970 b). This till unit can be followed throughout the locality with a constant thickness and without noteworthy variations in structure. The till is classified as a lodgement till, and this is supported by the fabric investigations. The macrofabric analyses reveal a preferred orientation of elongated elements in a direction of 60°; the A/B planes of flat particles dip towards the NE. Microfabric investigations give a direction of 40°, with a smaller maximum at 130°, for elongated particles.

Below the till there is a deposit, at least 10 m thick, consisting of 0.2–2 m thick units of sand, gravel and boulder horizons. Cross-bedding shows a transport direction towards 260°; fabric analyses give a direction of 310°.

The sand and gravel deposits are strongly deformed with fold axes at 130° and with thrust planes dipping to the NE. The deformations can therefore readily be ascribed to pressure from the ice which formed the overlying till.

*Loc. 318, Clausholm (Fig. 5,7)*

This locality, a large gravel pit, lies 1.5 km west of Clausholm castle and 0.4 km west of the classic locality for the Danian-Paleocene boundary, Hvalløse 1 (Ødum, 1926; Gry, 1935). The gravel pit measures about 200 × 200 m, and consists of several smaller pits at different levels. The original land surface lay at 44 m above sea level. A section through the gravel pit is shown in Fig. 7, and it can be seen that the outcrop has a complex structure. Two major units can readily be identified – an older "core" consisting of till and melt water deposits, and a younger "mantle" of melt water deposits which surround and overlie the "core". Uppermost occurs a till horizon which has been removed during excavation such that it is not exposed in the pit profile itself.

In the "core" occur a lower and an upper till. Between these, and above the upper till there are sand and gravel horizons. The lower till is gravely and layered, is very light coloured and has a carbonate content of about 20%. Microfabric analyses show a preferred orientation of elongate particles in a direction of 10°, with a secondary maximum at 90°. Therefore the ice movement was either from N or S, and it cannot be decided which of these two directions should be preferred.

Above the till follows 0.5–1 m of laminated to micro cross-bedded glauconite-bearing sand. The glauconite is interpreted as being reworked form glauconitic Paleocene deposits which have been reported from the area (Ødum, 1926; Gry, 1935).

Above this occur cross-bedded, medium to coarse grained sand with coarse, angular opal flint fragments.

Discordantly resting on these sandy deposits are about 3 m of gravel and sand horizons with big boulders, some of which are derived from Norway (rhomb porphyry, larvikite). Cross-bedding structures in the sand and gravel layers reveal a transport direction towards 185°.

Next there follows sandy till containing layering in the lower part. Microfabric analysis, together with studies of the glaciodynamic structures of isoclinal folds and joints (Lavrushin, 1970 b) give a direction of ice movement from 30°. The till is concordantly overlain by melt water sand and gravel. The facts that the till and the underlying melt water deposits have almost the same transport directions and that the overlying sand rests concordantly on the till may indicate that the three units have a common origin, and belong to a single "kineto-stratigraphic" unit (Berthelsen, 1973).

This sequence is deformed by folds, faults and thrusts. The orientations of fold axes and thrust planes indicate ice pressure from the SE.

The contact between the "core" and the "mantle" consists of thrust planes. In the SE-NW-trending part of the profile (Fig. 7) the thrust plane is sharp, while in the N-S part it appears as a 2 m thick zone consisting of sand, gravel and till layers with small folds. Fold axes and bedding plane orientations indicate that the thrusting occurred with ice pressure from 40°.

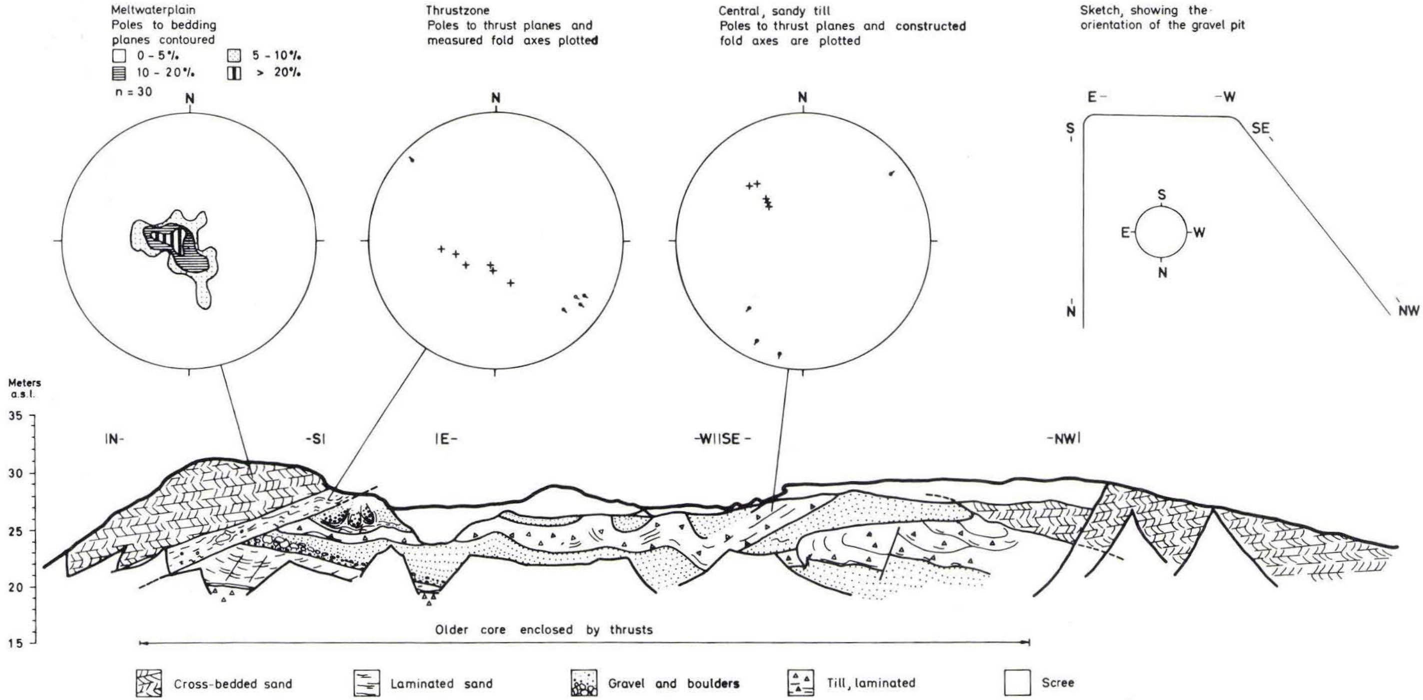



*Fig. 7.* Profile through locality 318, Clausholm, drawn from photographs in 1974. Left diagram – Lambert net; others Wulff net; all lower hemisphere.

The "mantle" consists of more than 10 m of sand and gravel horizons with trough-formed cross-bedding. Measurements of these reveal a transport direction towards 215°. Weak deformations in the layers indicate ice pressure from 60°. It is presumed that the thrusts between "core" and "mantle" and the deformations in the "mantle" were produced by the same event, probably with pressure from the glacier which deposited the overlying till which, as mentioned earlier, is not exposed in the gravel pit profile.

The three localities described above are all situated in the northern part of the map sheet. Information from earlier studies of several other gravel pits in the area, together with the data from Staanum, Lang Kastrup and Clausholm, is summarised in Fig. 8. In addition to the lithology, transport directions of melt water and glacier ice have been given. Information concerning transport directions from localities described elsewhere has been taken from Larsen et al. (1973) and Liboriussen (1973, 1975).

The natural starting point for consideration of Fig. 8 is loc. 226 (Hollerup) where Eemian interglacial deposits occur. It is believed that the melt water sand above the Eemian in loc. 226 can be followed in all the other localities; current directions are westerly with variations between NW and SW. Melt water deposits in localities 229 and 314, together with the "mantle" in loc. 318 clearly belong to this unit.

The deposit occurs as a sedimentary body with an extremely irregular form, presumably controlled to a large extent by the underlying topography and the surface erosion.

It is natural to consider the sequence from a lithostratigraphic point of view. The melt water deposit described above can be considered as a lithologic and lithogenetic unit. Since this unit is a major feature of the sequence over a larger area, it seems practical to give it a name. The deposit is more than 20 m thick at loc. 212 near the village of Tebbestrup, and the name Tebbestrup Formation is appropriate.

The overlying till shows the same transport directions in all localities – namely from NE-ENE. It is undoubtedly the same till in all the profiles, and will be referred to as the NE till.

Both the Tebbestrup Formation and the NE till clearly belong to the Weichselian. In loc. 226 the Tebbestrup Formation is underlain by Eemian, while in loc. 218, 211 and 318 by glacial material. Whether these belong to the Weichselian or Saalian will be discussed below. It will just be mentioned here that in loc. 318 the underlying material, the "core", has a highly complex structure, effected by several glacial events of which those caused by pressure from ice from the SE are the youngest. The results of pressure from SE ice are also evident in the material immediately below the Tebbestrup Formation in loc. 211.

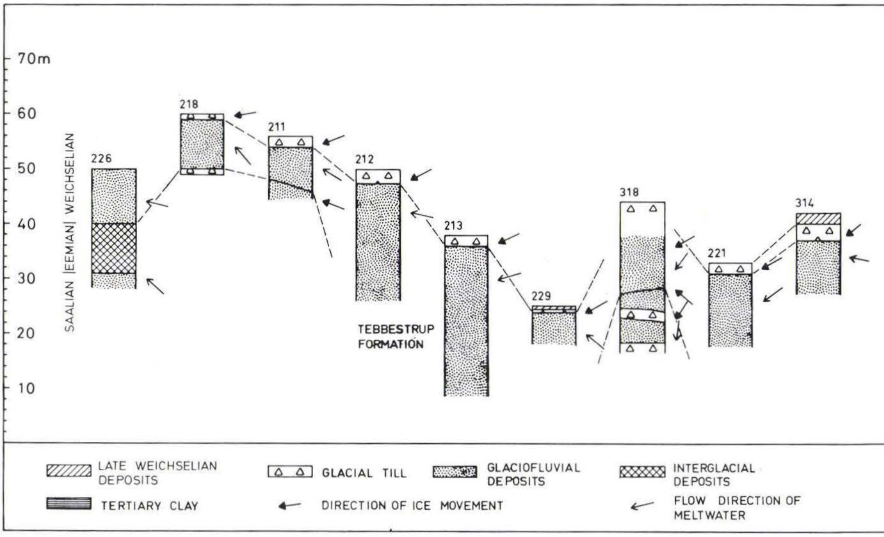



*Fig. 8.* Compilation of locations in the northern part of the area. Location numbers on the profiles are from fig. 1.

*Loc. 402. Haarvad bro (Fig. 4)*

The locality is a small gravel pit situated on a terrace surface in the Lilleå valley. The uppermost layer (c. 3 m) is considered as Late Weichselian; it consists of cross-bedded sand layers, showing a transport direction towards 20°.

A ½–1 m thick coarse flat-lying gravel horizon separates the Late Weichselian sand from an underlying sand deposit. The gravel horizon clearly represents a Late Weichselian erosion level. The underlying cross-bedded sand shows a transport direction of 310°. Petrographically the sand below the gravel is very different from the overlying Late Weichselian sand (Table 1). Eocene plastic clay occurs below the sand.

*Loc. 403. Grundfør (Fig. 5)*

This locality consists of two gravel pits which converge, lying on the slope of the Lilleå valley about 1 km NW of Grundfør. In the main pit there is a 20–25 m section through melt water deposits. The upper 6 m are chiefly sand and the following 15 m mainly gravel. The sequence is built up of trough cross-bedded units. Measurements of these give an average direction of transport towards 345°. Two asymmetric folds occur near the top of the profile, produced by deformation by ice pressure from the SE (120°).

The gravel rests on white, fine to medium grained sand of unknown thickness. Two asymmetric folds in the sand indicate pressure from 60°.

In the shallower pit only the upper part of the sequence is exposed. Measurements reveal the same transport and deformation directions as in the main pit.

*Table I.* Petrographic composition (per cent) of the size fraction 16–32 mm.

| Locality no. | 229 | 229 | 314 | 402 | 402 | 403 | 404 | 404 | 405 |
|---|---|---|---|---|---|---|---|---|---|
| Sample depth ............ (m above sea level) | 24.5 | 19 | 34 | 23 | 20 | 38 | 70 | 76 | 31 |
| Flow direction ........... | 150° | 310° | 260° | 20° | 310° | 345° | 350° | 245° | 325° |
| Magmatic and metamorphic rocks ........ | 10.1 | 10.7 | 14.3 | 6.9 | 20.6 | 22.1 | 34.5 | 15.4 | 24.4 |
| Sandstone, claystone and limestone ............ | 5.7 | 9.4 | 11.0 | 9.0 | 11.3 | 14.0 | 14.4 | 14.0 | 25.0 |
| Flint ..................... | 84.0 | 79.7 | 74.5 | 78.2 | 61.0 | 61.1 | 50.4 | 70.6 | 47.2 |
| Miscellaneous ............ | 0.2 | 0.2 | 0.2 | 5.9 | 7.1 | 2.8 | 0.7 | 0.0 | 3.4 |

*Loc. 404, Haldum (Fig. 6)*

This locality is an extensive gravel pit, measuring c. 500×200 m and about 15–20 m deep, situated ½ km SE of Haldum town. During the period of our investigations, the pit was under intensive excavation; it was apparent that the appearance of the profile did not alter much during the time, about a year, in which the locality was being studied.

About 1–2 m of till occurs at the top of the pit. Macrofabric analyses have shown that the plunge of A-axes has a marked maximum at about 60°.

Beneath this occurs 3–4 m of cross-bedded melt water sand and gravel. Measurements give an average transport direction towards 245°. Deformation structures in the layers indicate pressure from the NE. The ice responsible for this deformation is undoubtedly the same as that which deposited the overlying till. A fossil ice wedge, 60 cm wide at the top, has been observed in the uppermost part of the melt water sand.

This upper sand and gravel horizon is separated from a lower one by a c. 1–2 m thick layer of silt and fine sand. This lower deposit is 8–10 m thick and consists of light, almost white melt water sand built up of trough cross-bedded units with an average transport direction towards 350°. Deformation structures, both faults and an asymmetrical fold with a fold axis striking 35°, occur in the uppermost part of this deposit. The asymmetry of the fold indicates deformation pressure form 125°. The melt water deposits lie on Eocene plastic clay, which may be a glacial tectonic slice.

*Loc. 405, Hinnerup (Fig. 6)*

The locality is an abandoned gravel pit situated in the northern part of Hinnerup town on the slope of the Lilleå valley.

The sequence consists of cross-bedded melt water gravel. In the undeformed lower part, transport directions towards 325° have been measured. The upper part is strongly deformed, and measurements of strike and dip of slices of till and white quartz sand indicate pressure from 150°.

Localities 403, 404 and 405 are situated close to each other and they all have predominant SE directional features. Fig. 9 illustrates the main features of these localities, together with loc. 402.

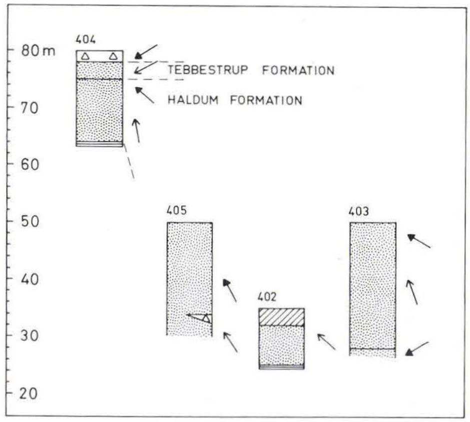



*Fig. 9.* Compilation of locations in southern part of the area. Location numbers on the profiles are from fig. 1. For legend see fig. 8.

In loc. 404 the overlying till is unquestionably the NE till which has been described in the northern area. The underlying melt water deposit, with current directions towards SW, probably belongs to the Tebbestrup Formation, and this discordantly overlies melt water deposits with a dominant current direction towards NNW.

This is probably the same deposit which was encountered in the three other localities where similar transport directions occur. Since this deposit occurs as a significant lithostratigraphic unit, it is practical to give it a name and in loc. 404 (Haldum) both the upper and lower boundaries are exposed; consequently the unit is named the Haldum Formation. Deformation structures show that a glacier from the SE has effected the area after the Haldum Formation had originated. The till associated with this event has not been demonstrated in the area, but it should be mentioned that SE deformations are apparent in localities 211 and 318 (Fig. 8) at the appropriate level in the sequence. Thus traces of ice from the SE can be found over a wide area.

The Haldum Formation lies on Eocene plastic clay in loc. 404 and 402; in 403 it rests on sand deformed by pressure from the NE which suggests that an "old" NE-glacier has been operative. Equivalent NE-directions have been found in the "core" at loc. 318.

*Loc. 519, Svejstrup*

A profile of about 7 m is exposed in a gravel pit on the Lilleå valley terrace south of the Bidstrup-Svejstrup road. The top 2½ m are of an undisturbed layer of cross-bedded sand and gravel, with an average transport direction towards 265°. This deposit is considered to be Late Weichselian, and has a discordant lower boundary.

Cross-bedded melt water sand and gravel also occur beneath the discordance, and measurements give a current direction towards 250°. At one place at the top of this horizon a fold has been noted which is cut by the discordance at the base of the Late Weichselian deposit. The

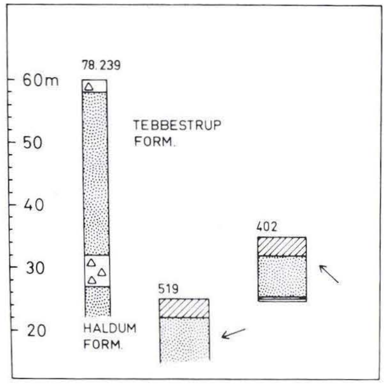



*Fig. 10.* Compilation of locations 402, 519 and boring 78.239. For legend see fig. 8.

orientation of this fold has not been measured because of collapse of the wall of the gravel pit, but it is estimated to be roughly E-W.

The profile in loc. 519 closely resembles that in loc. 402 which is likewise situated on the Lilleå valley terrace. As shown above, the glacial sequence in loc. 402 belongs to the Haldum Formation, while the westerly transport direction in loc. 519 would suggest that it is part of the Tebbestrup Formation. Fig. 10 attempts to illustrate the affinities of the two localities. Here they are compared with 78.239, which is a water supply boring situated in the glacial terrain just to the south of loc. 519 (see Fig. 1). It should be pointed out that this terrain forms the most southerly part of the 60 m plateau which surrounds the Ølst-Lysnet hills; it is the internal structure of this terrain which is shown in Fig. 8. A short distance to the south of the bore locality begins the higher, southern plateau landscape.

The following deposits occur in the boring from the top to bottom; c. 2 m of till; 26 m of melt water deposits; 5 m of till; and finally meltwater deposits, the base of which was not reached. No information of transport directions were obtained from the bore profile. Comparison with the area to the north (Fig. 8) suggests that the uppermost till is the NE till, and the underlying sand and gravel belong to the Tebbestrup Formation. The layers below the lower till can therefore reasonably be referred to the Haldum Formation (Fig. 9).

According to Fig. 10, it seems extremely likely that the glacial layers in loc. 519 represent the Haldum Formation. The deformation noted in loc. 519 therefore persumably results from the glacier which deposited the lower till in boring 78.239. It is probably the effects of this ice from the SE which can be traced in several places throughout the area investigated.

The localities which have been described and discussed above have been selected from a much larger number, and they have been chosen to illustrate the main features in the structure of the glacial sequence. The inclusion of more localities would allow the examination of more details, but not many which would shed new light on the subject. A single significant detail will be mentioned here. At loc. 222 (Fig. 1). where the Tebbestrup Formation and the NE till are present, a large fossil ice wedge occurs in the uppermost part of the former; its width at the base of the till is 1½ m.

# The age and origin of the sequence

The results of geological mapping and the investigations of bore profiles and outcrops have been presented above. Correlations have allowed the following glacial sequence to be proposed:

Highest: NE till
Tebbestrup Formation (melt water deposit)
SE till
Haldum Formation (melt water deposit)
Lowest: NE till

It can be stated with certainty that the two uppermost units belong to the Weichselian glaciation, since the Tebbestrup Formation rests on Eemian deposits in loc. 226 (Hollerup). On the other hand there is no direct evidence as to the age of the SE till and the older units, but several lines of reasoning can be followed to shed light on this question.

## The older deposits

The transport directions recorded from horizons older than the Tebbestrup Formation are presented on a map (Fig. 11) as background for the following discussion. The information has been obtained from the descriptions above and from the publication of Larsen et al. (1973). The SE till can belong to either the older part of Weichselian or to Saalian. In this connection it should be noted that in southern Denmark there are numerous traces of an ice from the SE, called "Old Baltic" and referred to Early Weichselian (Berthelsen, 1973). Jessen et al. (1910) have also reported a till from the Skærumhede boring in North Jutland which, according to its petrographic composition, is clearly of Baltic parentage. It occurs at the base of the marine Eemian deposits and must therefore presumably belong to the Saalian glaciation, and probably to its closing stages. Late Saalian or Early Weichselian are thus two realistic possibilities when the age of SE till in the investigated area is to be considered.

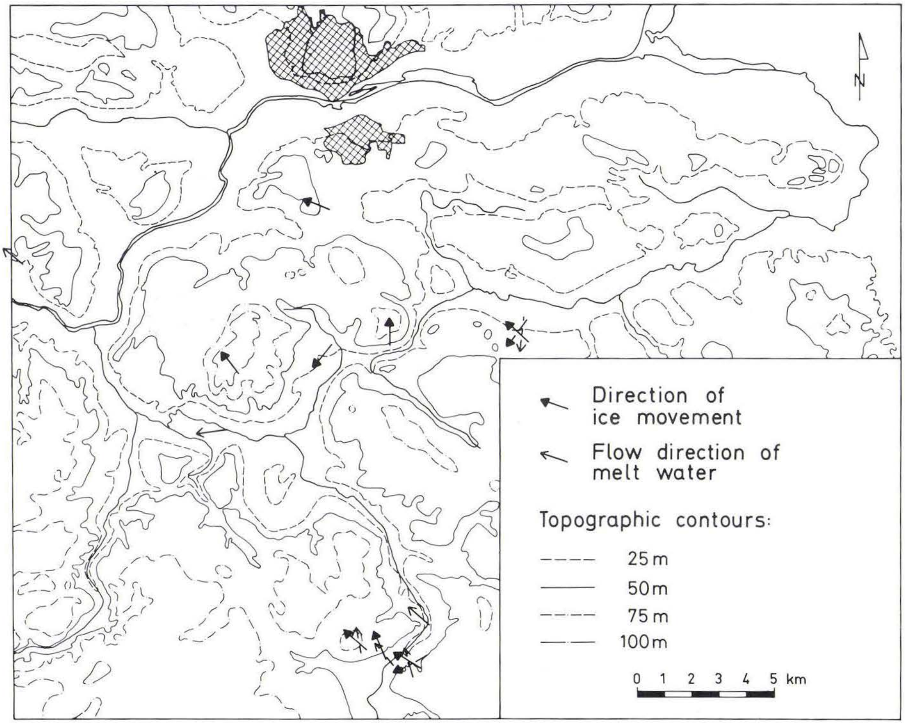



*Fig. 11.* Direction indicators in glacial deposits older than the Tebbestrup Formation.

Only sparse evidence concerning the SE till is available in the area studied; boring 78.239 is apparently the only place where it can be demonstrated. However, deformations are encountered in many places which can be ascribed to the ice responsible for the formation of the SE till – localities 211, 318, 403, 404, 405 and 519. In the latter four, the deformations occur in the Haldum Formation, in which in localities 403, 404 and 405 the transport direction is towards NNW. This is practically the same direction as that for the movement of the SE ice as indicated by the orientation of the deformation structures. It therefore seems obvious to interpret the Haldum Formation as a sandur formed in front of the advancing ice from the SE. In this case the age of the SE ice can be established by dating the Haldum Formation.

The Haldum Formation has been demonstrated with certainty as far north as loc. 519, but it undoubtedly has an even wider extent. It is believed that the SE-deformed sand deposits in loc. 211 belong to this formation, such that it is directly overlain by the Tebbestrup Formation. The same situation occurs in loc. 404 and presumably also in many other places, possibly also near loc. 226 (Hollerup). At this locality, the Eemian lies between the Tebbestrup Formation and an older sand deposit. Since the Eemian here consists of a fresh water deposit of limited areal extent, the Tebbestrup Formation probably rests directly on this older sand a short distance from loc. 226. This situation is so similar to that in loc. 404 that it is very tempting to refer the sand below the Eemian to the Haldum Formation. The transport direction in the sand agrees very well with this correlation (Fig. 11).

By way of these indirect lines of evidence the conclusion is reached that the SE ice is probably Late Saalian. The result is by no means certain, but it is the best which can be achieved. It is relevant to add that a Late Saalian ice from the SE in North Jutland must almost certainly have passed over this area, while it is by no means sure that an Early Weichselian ice from the SE, demonstrated in southern Denmark, reached this far.

The traces of ice from the NE, established in loc. 318 and 403, are older than the SE ice and the Haldum Formation. As a consequence of the assumption above, the NE ice can also be referred to the Saalian, and an earlier stage than the SE ice.

The foregoing considerations have been concerned with the sequence in the landscape surrounding the prominent hills of Ølst and Lysnet. Those hills have previously been dealt with by Larsen et al. (1973) and Nielsen (1973). The hills consist mainly of plastic clay of Eocene age which has been strongly effected by glaciotectonic deformation. The earlier investigations have considered the deformation relations in three localities; these are shown in Fig. 1 as nos. 1, 2 and 4. In loc. 1 and 2 ice pressure from the S and SE respectively has been recorded. Both can naturally be referred to the influence of the presumed Late Saalian SE ice. It has not been possible to determine precisely the direction of ice pressure in loc. 4; it was either from NE or SW, Larsen et al. (1973) tentatively preferred the SW pressure direction. In the light of our present knowledge that an older NE ice has been active in the area, loc. 4 might be reinterpreted such that the traces result from ice from the NE. This interpretation is given in the map of fig. 11.

With this as background, the possibility can be mentioned that the hills may have been formed by the Saalian NE ice and only modified by the later SE ice. In this case, the hills existed when the Haldum Formation was deposited. Current directions in this formation in loc. 519, immediately S of Lysnet hill, are almost westerly which is notably different from those in the outcrops further south (loc. 402, 403, 404, 405). This might imply that Lysnet hill formed a prominent feature which effected the current directions of the melt water.

Some of these conclusions as to the events in the older part of the sequence are uncertain, being based on a limited number of observations. They have nevertheless been presented to illustrate the problems which further studies must attempt to solve.

## The Weichselian deposits

Figs. 12 and 13 show respectively the measured transport directions in the Tebbestrup Formation and the NE till, and these are to a large extent the basis for the following discussion. The information on the map is taken from the account above, together with earlier publications by Larsen et al. (1973) and Liboriussen (1973, 1975) as well as unpublished reports (Jørgensen, 1974; Priisholm, 1975).

As mentioned several times before, it is certain that these two deposits belong to the Weichselian. It is not, however, immediately apparent which part of the Weichselian they represent, though different lines of evidence can be applied to the question.

The NE till must reasonably be referred to the main episode of the Weich-

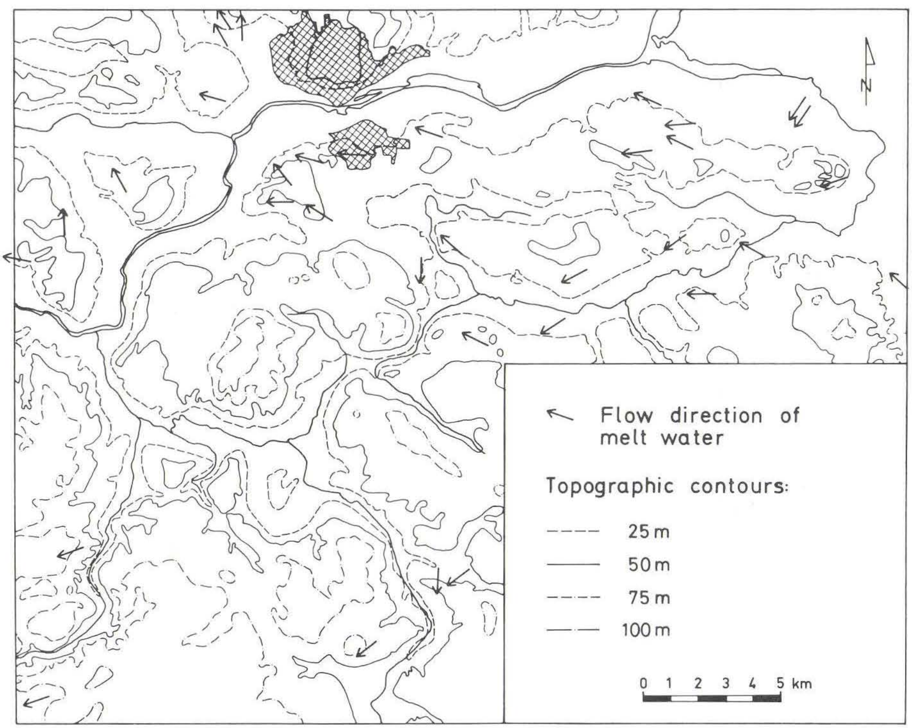



*Fig. 12.* Deposition directions in the Tebbestrup Formation (Weichselian).

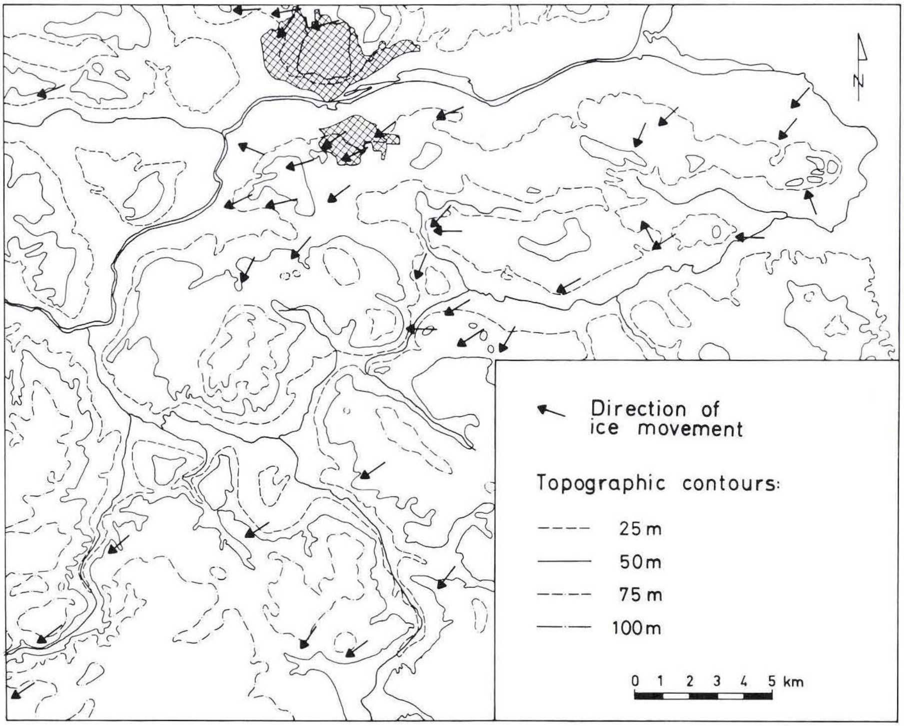



*Fig. 13.* Direction indicators for the ice from the NE (Weichselian).

selian advance in which glaciers from the N, NE and E reached the main stationary line in central Jutland (see amongst others, Milthers, 1942). If the ice from the N and NE reached the main stationary line at about the same time, it must have been in late Middle Weichselian. This statement is based on studies of the sequence at Skærumhede in north Jutland (Bahnson et al., 1974). Here it has been shown that marine conditions prevailed continously in northernmost Jutland from Eemian to Early and Middle Weichselian, and it is concluded that "The Weichselian glaciers do not appear to have reached Vendsyssel until the main Weichselian advance about 18.000–20.000 years ago" (Bahnson et al., 1974, p. 57). This can be supplemented with the information given by Lundqvist (1974) that the glacial Weichselian III phase, during which the ice attained its greatest extent, occurred about 20.000 years ago.

Thus it can be inferred that the NE till in the Randers region probably formed during late Middle Weichselian. According to the deposition relations, the Tebbestrup Formation is older than the NE ice, but how much older?

If the transport directions in the two deposits are compared (Figs. 12 & 13) it is apparent that the main orientations are so similar that it seems reasonable to consider the Tebbestrup Formation as a sandur formed in front of the advancing NE ice. In this case the Tebbestrup Formation also belongs to the younger part of the Weichselian. The occurrence of fossil ice wedges in the top of the melt water deposits in loc. 222 and 404, however, indicates that at least part of the sandur was effected by permafrost conditions for a while before being overridden by the ice.

So the Tebbestrup Formation is considered to have been formed as a result of the flow of melt water from the NE ice. The topography in the landscape at that time must have been another controlling factor for the form of the sandur. The nature of the lower surface of the Tebbestrup Formation must reflect this palaeo-topography, but the observation material is insufficient to allow the objective construction of a map of this surface. Fig. 8 can perhaps suggest some trends in the form of the palaeo-topography, lying deep close to the E-W section presented by Randers Fjord (loc. 212, 213), while it is high both to the north (loc. 218) and to the south (loc. 211). Even further south, at the hills of Ølst and Lysnet, the formation is absent, since these hills are old structures formed in Saalian and existing as high areas during Weichselian. A transport direction, in strong contrast to the normal, occurs immediately E of these hills (Fig. 12) and can be naturally explained as a deflection of the flow direction caused by the presence of the hills. It appears obvious that there was a valley depression in the Weichselian landscape along the inner part of Randers Fjord, and Sorgenfrei (1951) has shown that there is a marked depression in the pre-Quaternary here. This may be a coincidence, but they can just as well reflect a common cause; in this case tectonic, or maybe salt-tectonic, movements were involved in controlling the development of the Quaternary landscape in this area.

Fig. 12 shows that just W of Randers, transport directions are towards the N. Normally, river systems are considered as transport routes which lead eventually to the sea. At the time of the deposition of the Tebbestrup Formation, the northern part of Jutland was clearly beneath the sea; it may be transport toward this which is indicated here. It can be mentioned here that the glacial deposits at Hobro, described by Ødum (1969), may presumably indicate that the Tebbestrup Formation can be traced at least as far north as this. Northerly current directions in melt water deposits of uncertain age between Randers and Aalborg (Andersen, 1965; 1967) may also be related to the same events.

There are also indications that the formation can be followed to the west. Baand (1976) has shown that sandurs W of the Weichselian main stationary line in Central Jutland can be divided into an upper and a lower unit. At the top of the lower unit there is a well developed fossil ice wedge horizon. This lower unit may possibly be a westerly continuation of the Tebbestrup Formation. This, together with the significance of the northerly current directions, is to be investigated in our future studies.

The landscape over which the ice from the NE advanced thus consisted of widespread sandurs, infilling the earlier surface depressions, and prominent hills representing remnants of the landscape of the Saalian glaciation. The hills at Ølst and Lysnet were obviously of this type, as indicated by the local divergences in directions of ice movements which can be observed around the hills (Fig. 13). Ølst and Lysnet hills seem therefore to be remnants of the Saalian landscape which were not destroyed during the Weichselian glaciation.

During the retreat of the ice from the NE from the main stationary line there were clearly many pauses. These events and their effects will not be discussed here. The same applies to the later events during Weichselian, where, amongst others, the Late Weichselian valleys were filled.

Trace of Early Weichselian deposits have not been considered here. It is to be expected that such traces would occur in the lower part of the landscape at that time. They should therefore be sought in the sequence below Randers Fjord.

# Concluding remarks

An attempt has been made here to describe and interpret the development of the glacial geology in the Randers area. While some points remain unclear, it is apparent that the geology is considerably more intricate than has been recognised before.

It would appear that some earlier interpretations concerning the geology of the area are incompatible with the evidence presented here, such as the ice border line indicated by Gripp (1964). The suggestion of the existence of a "Friisenborg nunatak" by Schrøder (1974) cannot be confirmed, and his idea that the Late Weichselian deposits in the Lilleå valley are very thick can be rejected.

The geographical area dealt with undoubtedly comprises only a small part of total extent of the deposits occurring here. The investigations are therefore continuing with the aim of establishing a larger regional geological picture.

# Acknowledgements

Throughout the duration of the project, numerous students have carried out geological mapping which forms a major part of the basis for this paper. We have profited from discussions with colleagues form the Department of Geology, Aarhus and from the Geological Survey of Denmark during preparation of this paper. Colleagues from these two institutes have likewise assisted with the practical completion of the manuscript and figures. Translation into English has been carried out by Dr. *J. R. Wilson,* Department of Geology, Aarhus. We would like to thank warmly all those who have helped.

# Dansk sammendrag

## Glacial aflejringernes stratigrafi og oprindelse i Randers-egnen

Den geologiske kortlægning af kvartæret på kortbladet Randers udføres for Danmarks Geologiske Undersøgelse af medarbejdere ved Geologisk Institut, Aarhus Universitet. I arbejdet medvirker ældre studerende som udfører eksamensprojekter indenfor emnet. Herunder suppleres karteringen med sedimentologiske og glacialtektoniske undersøgelser af blottede lagserier. Formålet er at søge glaciallandskabets opbygning og dannelsesmåde belyst. Nogle resultater er tidligere offentliggjort (Larsen et al., 1972, 1973; Liboriussen, 1973, 1975; Nielsen, 1973). I de to førstnævnte publikationer er bl.a. det synspunkt fremført, at de store bakker ved Ølst og Lysnet er rester af landskaber fra saale nedisningen. De tidligere resultater er i denne afhandling udbygget med resultater af to senere specialeopgaver: Flemming Højgaard Jørgensen (1974) og Søren Priisholm (1975).

### *Hovedtræk af lagseriens opbygning*

Det forhold, at glaciallandskabet i det foreliggende område er gennemskåret af store dale med ofte stejle sider bevirker, at man allerede ved overfladekarteringen, der udføres med 1-m sonde, får væsentlige oplysninger om glaciallandskabets bygning. Fig. 2 viser karteringens resultater i en forenklet udgave. Forenklingen går bl.a. ud på, at der ikke er gjort nærmere rede for de sen- og postglaciale aflejringer. Af kortet ses bl.a., at plateaulandskabet omkring Randers fjord og Gudenådalen er opbygget af vidt udstrakte smeltevandsaflejringer dækket af moræne. De store bakker ved Lysnet og Ølst består fortrinsvis af tertiært ler (eocæn). Syd for de store bakker fortsætter plateaulandskabet men med større højde end i det nordlige område. Også her optræder der moræneler hvilende på smeltevandsaflejringer.

Det billede, der tegner sig gennem karteringens resultater, finder bekræftelse i fig. 3, en sammenstilling af 73 boreprofiler, lokaliseret i linien A-B på kortet fig. 1. Foruden at bekræfte karteringen føjer boringerne også ny viden til, idet underlaget for de udstrakte smeltevandsaflejringer stedvis er nået;

det drejer sig dels om moræneler, dels om tertiært ler optrædende som flager.

Karteringen og boringerne kan tyde på, at i hvert fald plateaulandskaberne har en ret simpel bygning. Det skal dog understreges, at hverken karteringen eller boringerne kan oplyse, hvorvidt f.eks. de udstrakte smeltevandsaflejringer er en og samme dannelse i hele området eller flere forskellige. Dette o.l. spørgsmål er søgt belyst gennem detailundersøgelser af blotninger.

*Undersøgelse og tolkning af blottede lagserier*

Det er talrige grusgrave, der i tidens løb er beskrevet som et led i disse undersøgelser. Ved hver enkelt lokalitet har man søgt at klarlægge specielt de forhold, som kan oplyse om transportretningen for det smeltevand og/eller den gletscheris, som dannede aflejringerne. I smeltevandsaflejringer er benyttet måling af skrålagsretning, samt i meget grovkornede forekomster kornorienteringen (fabric). Isbevægelsesretning er søgt bestemt ud fra morænelersfabric samt deformationsstrukturer i morænernes underlag.

Et lille antal af de mange lokaliteter er udvalgt til nærmere omtale i denne afhandling. De væsentligste informationer om lithologi og transportretning ses af illustrationerne fig. 4, 5, 6, 7. Lokaliteternes beliggenhed er vist i fig. 1.

Tre af lokaliteterne (229, 314, 318) er beliggende i den nordlige del af kortbladet. Fra tidligere undersøgelser i dette område foreligger oplysninger om en række andre grusgravsprofiler. I fig. 8 er et udsnit af disse sammenstillet med de her foreliggende tre. Ved betragtningen af fig. 8 er lok. 226 (Hollerup) det naturlige udgangspunkt p.gr.a. forekomsten af eem aflejringer. Smeltevandssandet over eemet synes at kunne genfindes i alle de andre lokaliteter. Transportretningen er vestlig med svingninger mellem SV og NV. Det er fundet naturligt at anlægge en lithostratigrafisk betragtningsmåde på lagserien. Da smeltevandsaflejringen over eem'et tager sig ud som en lithologisk og lithogenetisk enhed, der dækker et større område, er den af praktiske grunde navngivet. Den betegnes Tebbestrup Formationen efter landsbyen Tebbestrup beliggende nær lok. 212, hvor aflejringen er mere end 20 m mægtig. Den dækkende moræne ser ud til at være samme aflejring i alle profilerne; den er aflejret fra NØ eller ØNØ og betegnes i det flg. NØ-morænen.

Fire lokaliteter (402, 403, 404, 405) er beliggende i den sydlige del af undersøgelsesområdet. Fig. 9 viser en sammenstilling af disse. Den vigtigste lokalitet er nr. 404. Her genfinder man øverst NØ-morænen og Tebbestrup Formationerne. Under denne ligger en anden smeltevandsaflejring med strømretning mod NNV; den er også tilstede i de tre andre lokaliteter. Denne smeltevandsaflejring betegnes Haldum Formationen efter byen Haldum, beliggende ved lok. 404. Formationen er deformeret ved tryk fra SØ. Dette tilskrives en SØ-is, som er yngre end Haldum Formationen men ældre end Tebbestrup Formationen. Nederst i lok. 403 findes deformationer frembragt af et tryk fra NØ.

I fig. 10 er lok. 402 sammenstillet med to lok. (519, 78.239) beliggende kort syd for Lysnet bakken (se fig. 1). 78.239 er et boreprofil, hvis lagserie er tolket lithostratigrafisk som angivet i fig. 10. Moræenen mellem Tebbestrup Formationen og Haldum Formationen tilskrives den SØ-is, hvis deformation ses i Haldum Formationen i det sydlige område.

*Om lagseriens alder og oprindelse*

På grundlag af de forannævnte lokalitetsundersøgelser kan den glaciale lagserie inddeles på følgende måde:

Øverst: NØ-moræne
Tebbestrup Formation (smeltevandsaflejring)
SØ-moræne
Haldum Formation (smeltevandsaflejring).
Nederst: NØ-moræne.

De to øverste enheder tilhører med sikkerhed weichsel, idet Tebbestrup Formationen hviler på eem aflejringer i lok. 226 (Hollerup). Alderen af SØ-moræenen og de underliggende lag kan diskuteres.

Haldum Formationen må rimeligvis opfattes som en smeltevandsslette dannet foran den fremrykkende SØ-is. Det antages, men egentlige beviser foreligger endnu ikke, at sandet under eem aflejringerne i lok. 226 (Hollerup) tilhører Haldum Formationen. Med denne antagelse henføres SØ-moræenen, Haldum Formationen og den underliggende NØ-moræne til saale nedisningen. Kortet fig. 11 viser transportretningerne i disse ældre aflejringer. Det ser ud til, at Lysnet-Ølst bakkerne kan være anlagt af den gamle NØ-is; strømretningerne tyder på, at Lysnet bakken har eksisteret, da Haldum Formationen blev aflejret. Den efterfølgende SØ-is har øjensynlig påvirket bakkerne.

Fig. 12 og 13 viser transportretningerne i henholdsvis Tebbestrup Formationen og NØ-moræenen. Tebbestrup Formationen opfattes som en smeltevandsslette dannet foran den fremrykkende NØ-is. Denne henføres til weichsel nedisningens hovedstadium, hvorunder gletscherne nåede frem til hovedopholdslinien i Midtjylland. Under henvisning til bl.a. Skærumhede-boringen (Bahnson et al., 1974) antages dette at være sket sent i weichsel. Et påfaldende træk ved Tebbestrup Formationen er, at den er meget mægtig langs den indre, øst-vestlige del af Randers Fjord, medens den både N og S for dette strøg er af mere beskeden tykkelse. Dette leder tanken hen på den sænkning, der er konstateret i undergrunden under Randers Fjord (Sorgenfrei, 1951). Dette kan tyde på, at salttektoniske bevægelser har været med til at forme det kvartære landskabsbillede i denne egn. Bakkerne ved Ølst og Lysnet har øjensynlig raget op over smeltevandssletten. Smeltevandets strømningsretning må til dels have været kontrolleret af det daværende landskabs topografi. Den nordlige strømningsretning lige V for Randers antages at afspejle en afdræning mod Skærumhedehavet. Smeltevandsaflejringen kan øjensynlig også følges mod V, hvor den muligvis er repræsenteret i den nedre del af smeltevandssletterne V for hovedopholdslinien. Den efterfølgende NØ-is har som underlag haft denne smeltevandsaflejring samt de over denne opragende bakker, således Ølst-Lysnet bakkerne; disse er nok blevet omformet men ikke udslettet af weichsel-isen.

# References


Andersen, L. J. 1958: Nye forekomster af eocæne askelag ved Randers. – Meddr. dansk geol. Foren., 13, pp. 449–470.

Andersen, S. A. 1965: Isens bortsmeltning i egnen mellem Viborg og Grenå. – Meddr. dansk geol. Foren., 15, pp. 589–594.

Andersen, S. A. 1967: Isens bortsmeltning i Limfjordsegnen. – Meddr. dansk geol. Foren., 17, pp. 138–144.

Andersen, S. Th. 1965: Interglacialer og interstadialer i Danmarks kvartær. Et overblik. – Meddr. dansk geol. Foren., 15, pp. 486–506.

Baand, P. 1976: Brikker til Haldområdets geologi. – Dansk Natur Dansk Skole, Aarsskrift 1975–1976, pp. 3–21.

Bahnson, H., Petersen, K. S., Konradi, P. B., Knudsen, K. L. 1974: Stratigraphy of Quaternary deposits in the Skærumhede II boring: Lithology, molluscs and foraminifera. – Danm. geol. Unders., Årbog 1973, pp. 27–62.

Berthelsen, A. 1973: Weichselian Ice advances and drift successions in Denmark. – Bull. Geol. Inst. Univ. Uppsala, 5, pp. 21–29.

Boulton, G. S. 1971: Till genesis and fabric in Svalbard, Spitsbergen. – *In:* Goldthwait, R. P. (ed): Till. A symposium, Ohio State Univ. Press, Columbus, pp. 41–72.

Drake, L. 1971: Evidence for Ablation and Basal Till in East-Central New Hampshire. – *In:* Goldthwait, R. P. (ed): Till. A Symposium. Ohio State Univ. Press, Columbus, pp. 73–91.

Gripp, K. 1964: Der Verlauf der Eisrandlagen zwischen Grenaa und Viborg. – Meddr. dansk geol. Foren., 15, pp. 346–358.

Gry, H. 1935: Petrology of the Paleocene Sedimentary Rocks of Denmark. – Danm. geol. Unders. II række, 61, 172 p.

Jessen, A., Milthers, V., Nordmann, V., Hartz, N., Hesselbo, A. 1910: En Boring gennem de kvartære Lag ved Skærumhede. – Danm. geol. Unders. II række, 25, 175 p.

Jørgensen, F. H. 1974: Glacialgeologiske og sedimentologiske undersøgelser i området mellem Lilleådalen og Granslev Å-dal. – Unpublished Thesis, Aarhus Universitet, 74 p.

Larsen, G., Liboriussen, J., Nielsen, O. B. 1973: Opbygningen af Weichsel- og formodet Saale landskaber ved Randers i Østjylland. – XI Nordiska Geologiska Vintermötet Oulu, 1974, pp. 22–30.

Larsen, G., Liboriussen, J., Villumsen, A. 1972: Kvartærgeologiske undersøgelser på kortbladet Randers. – Dansk geol. Foren., Årsskrift for 1971, pp. 27–40.

Lavrushin, Yu. A. 1970 a: Reflection of the dynamics of glacier movement in the structure of a ground moraine. [Translated from Russian]. – Litologiya i Poleznye Isokopaemye, 1.

Lavrushin, Yu. A. 1970 b: Recognition of facies and subfacies in ground moraine of continental glaciation. [Translated from Russian]. – Litologiya i Poleznye Iskopaemye, 6.

Liboriussen, J. 1973: Till fabric analysis based on X-ray radiography. – Sediment. Geol., 10, pp. 249–260.

Liboriussen, J. 1975: A study of gravel fabric. – Sediment. Geol., 14, pp. 235–251.

Lundqvist, G. 1948: Blockens orientering i olika jordarter. – Sver. geol. Unders. Ser. C, 497, pp. 1–29.

Lundqvist, J. 1974: Outlines of the Weichsel Glacial in Sweden. – Geol. För. Stockh. Förh., 96, pp. 327–339.
Mangerud, J., Andersen, S. T., Berglund, B. E. Donner, J. J. 1974: Quaternary stratigraphy of Norden, a proposal for terminology and classification. – Boreas, 3, pp. 109–128.
Marcussen, I. 1973: Studies on flow till in Denmark. – Boreas, 2, pp. 213–231.
Marcussen, I. 1975: Distingushing between lodgement till and flow till in Weichselian deposits. – Boreas, 4, pp. 113–123.
Milthers, K. 1942: Ledeblokke og Landskabsformer i Danmark. – Danm. geol. Unders. II række, 69, 137 p.
Nielsen, O. B. 1973: Eocæne aflejringer i Ølst-området og deres indpasning i områdets Kvartærgeologi. – Dansk geol. Foren., Årsskrift 1972, pp. 100–110.
Priisholm, S. 1975: En sedimentologisk og tektonisk undersøgelse af glaciallandskabet mellem Alling Å-dalen og Randers Fjord. – Unpublished Thesis, Århus Universitet, 133 p.
Schrøder, N. 1974: De geofysisk-geologiske undersøgelser af området nord for Aarhus. – *In:* Undersøgelser af Århusegnens undergrund. Laboratoriet for Geofysik, Aarhus Universitet, pp. 15–55.
Sorgenfrei, Th. 1951: Geologiske og hydrologiske erfaringer fra Randers og omegn. – Vandteknikeren, 2, pp. 1–7.
Ødum, H. 1926: Studier over Daniet i Jylland og på Fyn. – Danm. geol. Unders. II række, 45, 306 p.
Ødum, H. 1969: Kvartæret omkring Hobro. – Danm. geol. Unders. IV række, 4, 10, 19 p.