

STRUCTURE AND GENESIS OF A BURIED ICE-PUSHED ZONE NEAR ROLD (FUNEN, DENMARK)

J. SCHWAN¹ & A. J. VAN LOON²

ABSTRACT

Schwan, J. & A. J. van Loon 1981 Structure and genesis of a buried ice-pushed zone near Rold (Funen, Denmark). *In*: A. J. van Loon (ed.): Quaternary geology: a farewell to A. J. Wiggers – Geol. Mijnbouw 60: 385-394.

In the Rold area indications have been found for two subsequent Weichselian ice transgressions: an older one from the SE and a younger one from the N or NE.

The older ice advance could be inferred from the presence of partly buried and distorted glacial sediments which are exposed in four sand and gravel pits. The steeply tilted and strongly folded beds share an almost identical NW vergence at all four sites the farthest of which are 2 km apart. Where buried the distorted glaciofluvial beds are unconformably overlain by fine-textured glaciolacustrine deposits, ill-sorted solifluction material or both.

The younger glacierization phase is evidenced by both oriented surface features with roughly NW-SE trend and by scattered glaciolacustrine surface deposits. Together these two phenomena appear to form a time-correlative complex of deglacial origin.

Various glactectonic classes are discussed in order to evaluate the ice-push event associated with the older ice transgression.

INTRODUCTION

The investigated sites are located in a Weichselian dead-ice landscape on the island of Funen, Denmark (Figs. 1 and 2). On the 1 : 200,000 glaciomorphologic map compiled by SMED (1962) this region is delineated as the 'Vissenbjerg area'. This landscape unit is characterized by (1) a disorderly array of kamiform hills (including flat-topped plateau hills) with widely varying height and shape and (2) a centrifugal radial drainage pattern along its margin.

Essentially the Vissenbjerg area consists of stratified ice-contact deposits underlain by a basal till with a highly irregular subsurface topography. Whereas the meltwater beds occupy undisturbed horizontal positions in some places they may show a severe degree of distortion elsewhere.

Geomorphologically the Vissenbjerg area can be considered as a good example of a wholly 'uncontrolled' glacial landscape in the sense of GRAVENOR & KUPSCH (1959). The one single exception is formed by the so-called Fjelsted-Bavnedams bakke zone, a roughly W-E running line of elongated

hills and other directional terrain elements (Fig. 2). According to SMED (1962) this curvilinear zone has its clearest expression near the Rold ridge, the very location of the investigated exposures. By MILTHERS (1940) this remarkable feature of the Vissenbjerg area has been interpreted as a marginal zone of the NE Ice (the forelast Weichselian glacierization phase) formed during a halt of the glacier. When this ice advance resumed its expansion in a southerly direction it overrode its own end moraine. During subsequent deglaciation the better part of the badly distorted end moraine supposedly became buried under a pile of ice contact deposits. In the present paper an alternative to Milthers' interpretation will be put forward.

THE LITHOSTRUCTURAL UNITS

Figure 2 shows the location of the studied gravel, sand and clay pits: Andebølle, Farlebjerghus, Rold and Vestergaard. Representative sections of these exposures are given in figures 3-6. Andebølle and Farlebjerghus were still being worked at the time of investigation; rubble and scrub growth seriously hampered observation in the other pits.

In top to bottom order three lithostructural units could be

¹ Institute for Earth Sciences, Free University, De Boelelaan 1085, 1081 HV AMSTERDAM, The Netherlands.

² C. Vredenburghaarde 2, 1241 AS KORTENHOEF, The Netherlands.

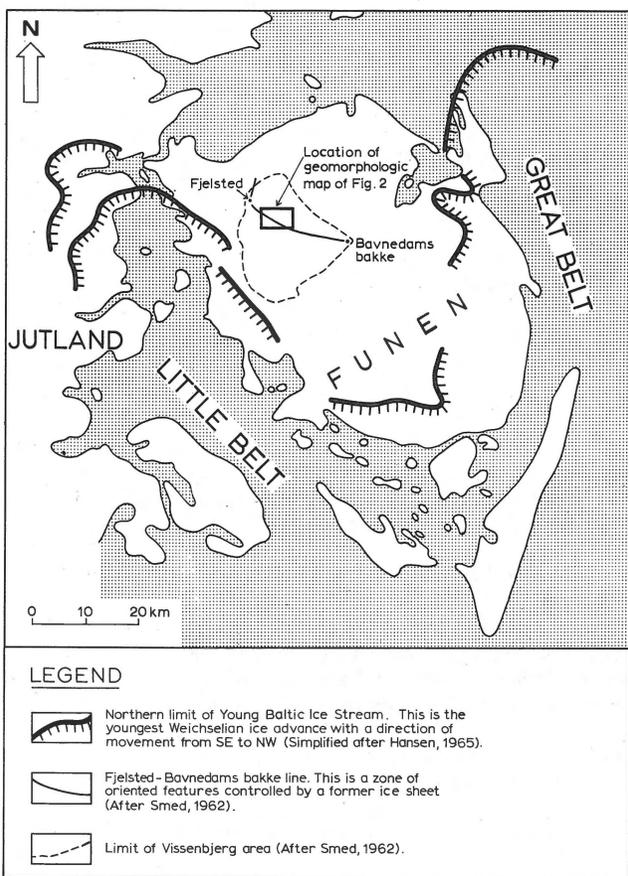


Fig. 1
Location map.

distinguished:

- (3) Glaciolacustrine cover beds;
- (2) Distorted glaciofluvial sediments;
- (1) Basal till.

Since distortion and a concomitant obscuring of the stratigraphic relationships are a primary characteristic of the rock sequence subdivision on a lithostructural basis seems appropriate. The spatial relationship between the three units is shown schematically in figure 3.

Unit I: the Basal till

The Basal till is a stiff and massive stony sandy loam with brownish or bluish colour. Several of its exposures show that at one time the till was subjected to diapirisation. Large-scale evidence for this process is present in the Andebølle sand pit. A tentative reconstruction of the tills' subsurface topography at this site is shown in figure 3. More modest in size but equally characteristic are the wedges and sills of till material which are regularly found squeezed into the tilted beds of unit II (Figs. 3 and 4). These structures are invariably concordant intrusions which used pre-existing zones of weakness (bedding planes, faults, unconformities) to penetrate into the overlying sediments.

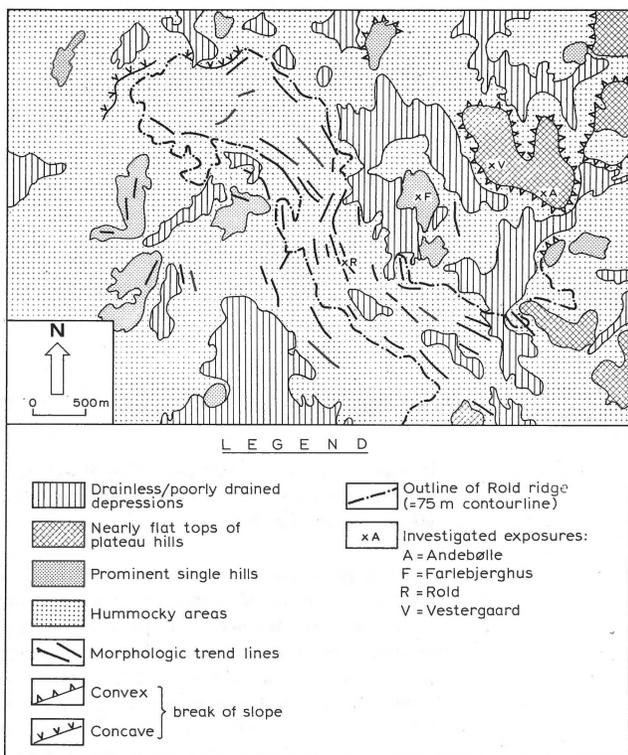


Fig. 2
Geomorphologic map of Rold ridge and surroundings. For location see figure 1.

Unit II: the Distorted glaciofluvial sediments

Unit II shows an alternation of stratified gravels, sands, silts and clays and includes a few flow-till beds with gravelly sandy loam texture and an average thickness of 1 m. Successions of this type are characteristic for meltwater deposits formed in an ice-contact environment. Various types of deformations are present in this unit.

Homoclines – Series of strata with a virtually constant dip direction over a distance of more than 10 m are here referred to as homoclines. The dip value varies from 17.5° to 80°. Homoclines are the most common type of structure encountered in the four exposures (Fig. 4, sections 2-3 & 3-4; Fig. 6).

Folds – Open and nearly symmetric folds with an upright horizontal or slightly plunging attitude are occasionally found. Wavelengths do not exceed 5 m. This fold type is definitely outnumbered, however, by inclined to recumbent folds with tight or even isoclinal geometry (Fig. 5, sections BB' and CC'; Fig. 7). On these folds dimensions are far more difficult to estimate since forelimbs may have been reduced to zero thickness as a result of thrust folding.

Unspecified faults – These are planes on either side of which the dip but not necessarily the strike of the beds changes. The two conspicuous faults of this type occurring in the Rold

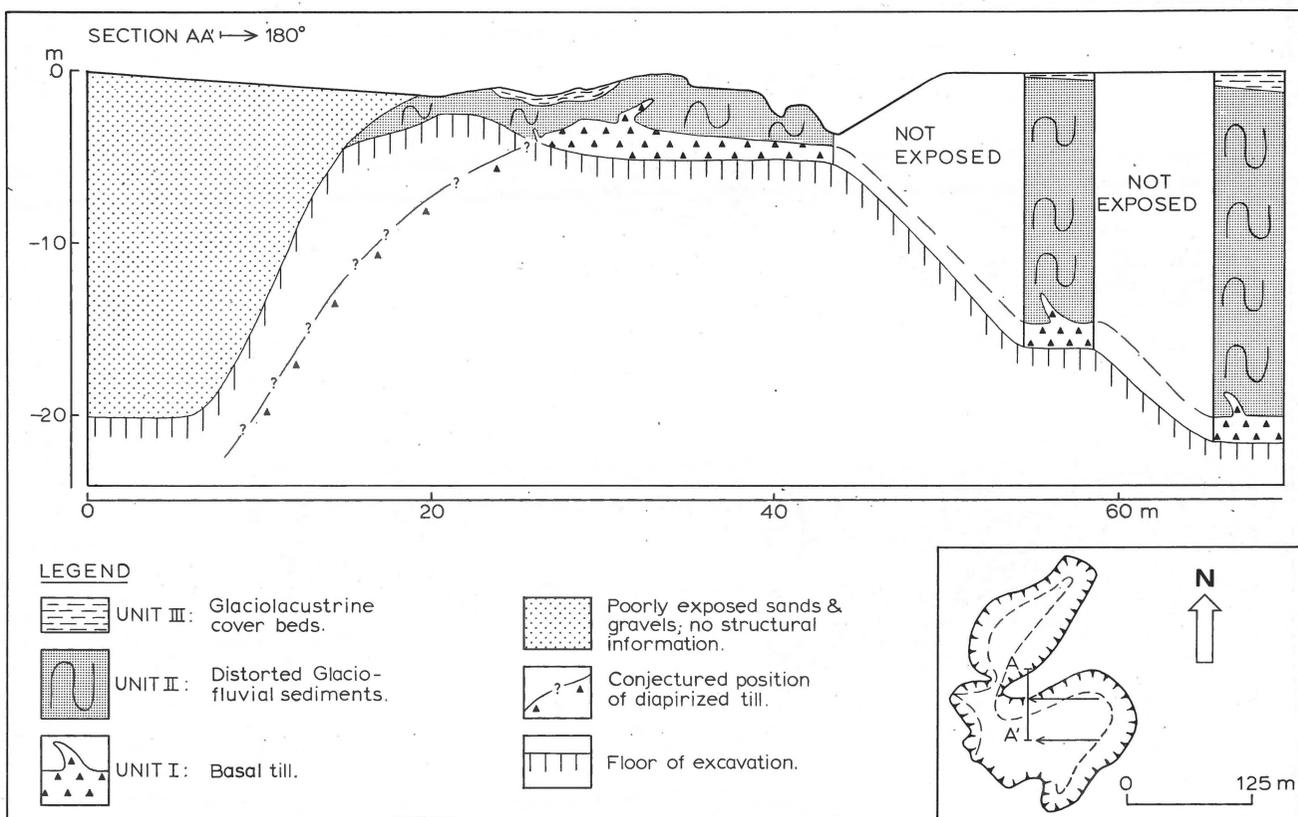


Fig. 3
Schematic section of the Andebølle sand pit.

exposure (Fig. 6) will be commented on at a later stage.

Normal faults – Faults of this type are not numerous and unlike the reverse faults they never exhibit any preferred attitude. Where local concentrations of normal faults occur (e.g. in the Vestergaard exposure) they are probably due to melting of buried dead ice.

Reverse faults – This kind of structure occurs regularly especially in association with tight overturned folds (Fig. 5, section BB'; Fig. 6). Displacements appear to be on the dm scale only. With regard to this class of faults two points must be raised.

In the first place a good deal of bed-parallel reverse faulting must have taken place in the homoclines. This is deduced from the internal deformations on cm or dm scale which are frequently found in the finer-grained strata of the homoclines. Here, bed-parallel displacements are suggested by small drag folds, irregular bedding planes and thin brecciated zones.

Secondly it is possible that principal thrust planes have remained concealed below the base of the generally shallow exposures. A principal thrust plane in the present context is a glactectonic surface along which horizontal displacement of ice-thrust blocks of substratum has taken place over some unknown distance (e.g. BERTHELSEN, 1979; LAVRUŠIN, 1978; MORAN, 1971). In that case the structures described would only

represent subsidiary and minor features of a much larger glactectonic phenomenon.

Strike-slip faults – These faults were found in the Andebølle sand pit. Here a flow-till bed with uniform texture, colour and thickness could be traced over a distance of 30 m. This stratum served as a marker bed for the reconstruction of the strike slip faults which are shown in figure 8.

Attitude readings on planar structures in unit II have been compiled in figure 9, diagram A to E. From the five diagrams the prevalence of structures with a dip direction of 130-145° is evident. This direction persists over a length of at least 2 km between the two exposures that are farthest apart.

Only the data from the Vestergaard exposure (diagram E) demands some further comment. Unlike in the other locations the bedding displays a rather diffuse pattern with three separate maxima and a correspondingly lower density value. Whereas the 130°/75° dip fits in neatly with the general trend, the other two concentrations do not. Possibly they are associated with structures due to the melting of buried dead-ice.

Unit III: the Glaciolacustrine cover beds

Typically the glaciolacustrine cover beds are well-sorted silty or clayey sediments with fine lamination though coarser-

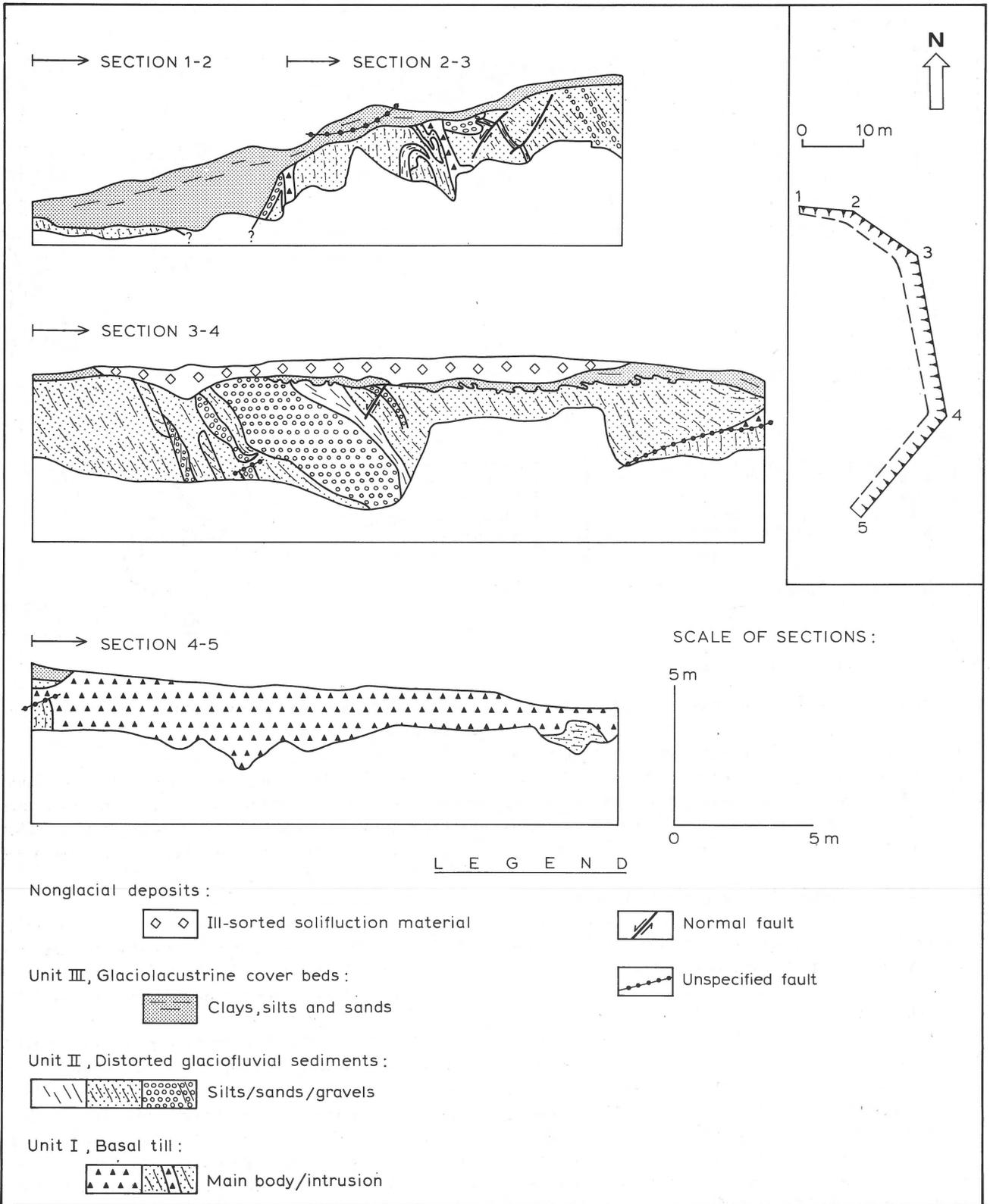


Fig. 4
Sections of the Farlebjerghus pit.

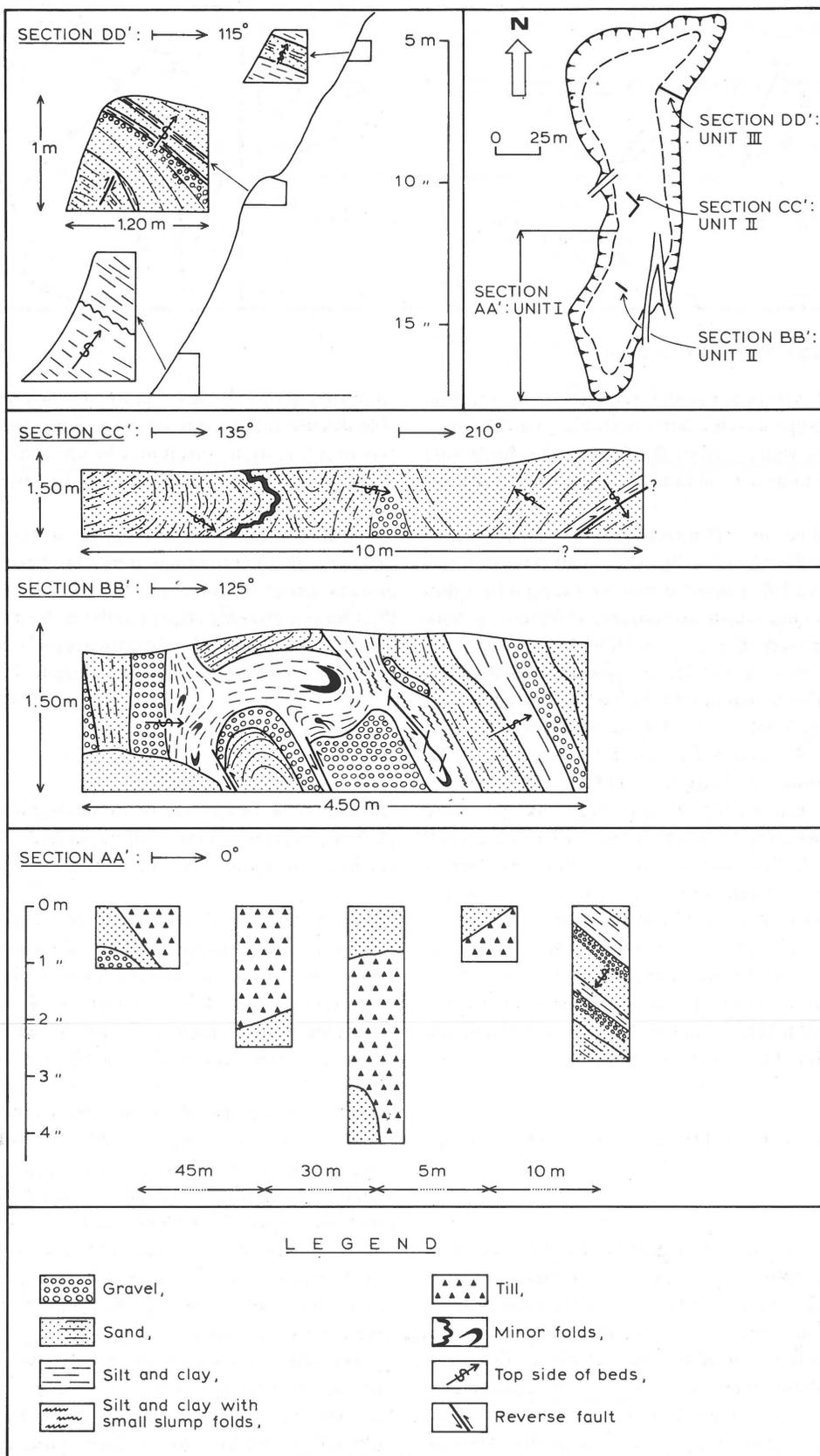


Fig. 5
Sections of the Vestergaard pit.

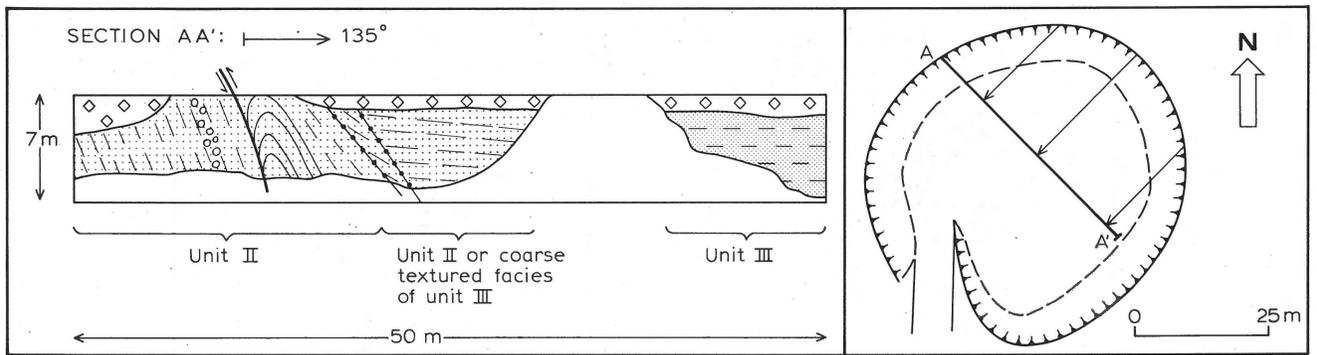


Fig. 6
Section of the Rold pit. For legend see figure 4.

grained intercalations are not at all rare. In the thicker section of unit III a fining-upwards tendency is normal. The thickness of unit III varies widely: from 0-1.5 m in the Andebølle exposure (Fig. 3) to over 15 m in the Vestergaard pit (Fig. 5, section DD').

Where observable unit III forms a surface deposit which covers the distorted deglacial sediments of unit II unconformably (Figs. 3, 4 and 10). Locally it may be overlain by a thin layer of gravelly sand which presumably represents a non-glacial solifluction deposit (Fig. 4, section 3-4; Fig. 6).

In general the beds of unit III are gently inclined with a mean dip of 20° (Fig. 9, diagram F). In the Farlebjerghus sand pit the beds of unit III closely follow the sloping surface topography (Fig. 4, section 1-2 and 2-3). Likewise in the Vestergaard exposure the thick unit-III bed (Fig. 5, section DD') dips in a direction 210° i.e. towards the margin of the plateau hill in which the pit is located (Fig. 2). The lithostructural relationships in the Rold sand pit are somewhat ambiguous (Fig. 6; Fig. 9, diagram D). Here the dip value of the beds decreases from 80° in the NW to 17.5° and less in the SE without any appreciable change in strike. The beds assume an increasingly central-lacustrine character in that both their granular composition and lamination become finer. Consequently in the Rold pit the boundary between unit II and unit III cannot be defined as sharply as in the other exposures.

INTERPRETATION OF THE STRUCTURAL DATA

Unit I

In the four exposures diapirization of the basal till has manifested itself in a twofold manner: in the first place as a large protuberance with a height of approximately 15 m (Fig. 3) and secondly in the form of much smaller wedges and sills which have concordantly intruded into the overlying beds of unit II. Most probably these two types of diapiric structures not only differ in size and shape, but also in time of formation.

The large bulge of diapirized till in the Andebølle exposure must have come into being *before* the deposition of unit II. The unit-II beds would otherwise have been folded into a

large anticline the basic structure of which remained recognizable despite subsequent ice push. Since there is no observation to substantiate this, it may be safely assumed that the till protuberance at the Andebølle site already existed before the deposition of unit II.

A different interpretation applies to the wedges and sills. They are mainly concordant intrusions into pre-existing zones of weakness of the tilted unit-II beds. This could suggest that their formation came after or at the earliest coincided with the ice-push event. For a further discussion of glaciadiapirism in the Vissenbjerg area reference is made to SCHWAN ET AL. (1980-a, b).

Unit II

As with rock deformations of endogenous origin various glacitectonic classes may be distinguished. Here the following glacitectonic features will be considered.

Imbricate thrust structures – These structures represent a large-scale glacitectonic feature of common occurrence. Alternative terms are stacked thrust sheets, stacked thrust slices (BERTHELSEN, 1979), ice-drift scales (RÜHLE, 1961) or Glazigene Press-Schuppen (GRIPP, 1979) in German. The stacked slices may consist of basal till, substratum material, or both.

In the opinion of many authors the major plane of décollement coincides with the base of the subglacial permafrost layer. From this it follows that the glacier bed may become affected by thrusting to a depth of several tens of metres. The thrusting is normally accompanied by a sometimes considerable horizontal displacement of the thrust slices. Terms such as glacial floes, large-scale block inclusions (MORAN, 1971) or glacio-olistoliths (LAVRUŠIN, 1978) emphasize the aspect of long-distance transport.

Manifold repetition of intact sedimentary sequences, the presence of originally deep-seated layers at an anomalously high level (e.g. Eemian marine beds in the study area) and large recumbent folds are features normally associated with the glacitectonic style discussed here. In unit II none of them was observed.

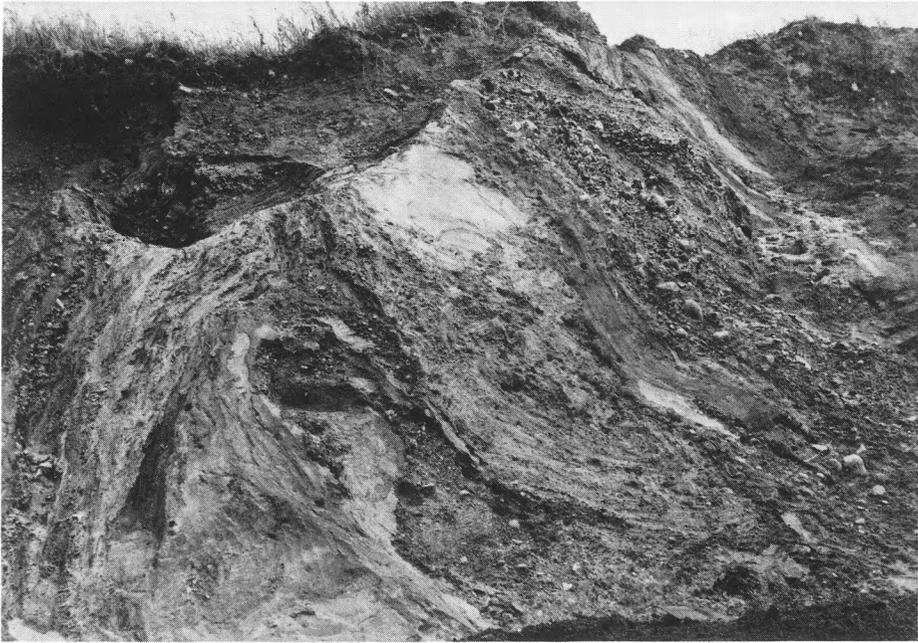


Fig. 7
Asymmetric and tight folding in beds of unit II (Andebølle sand pit).

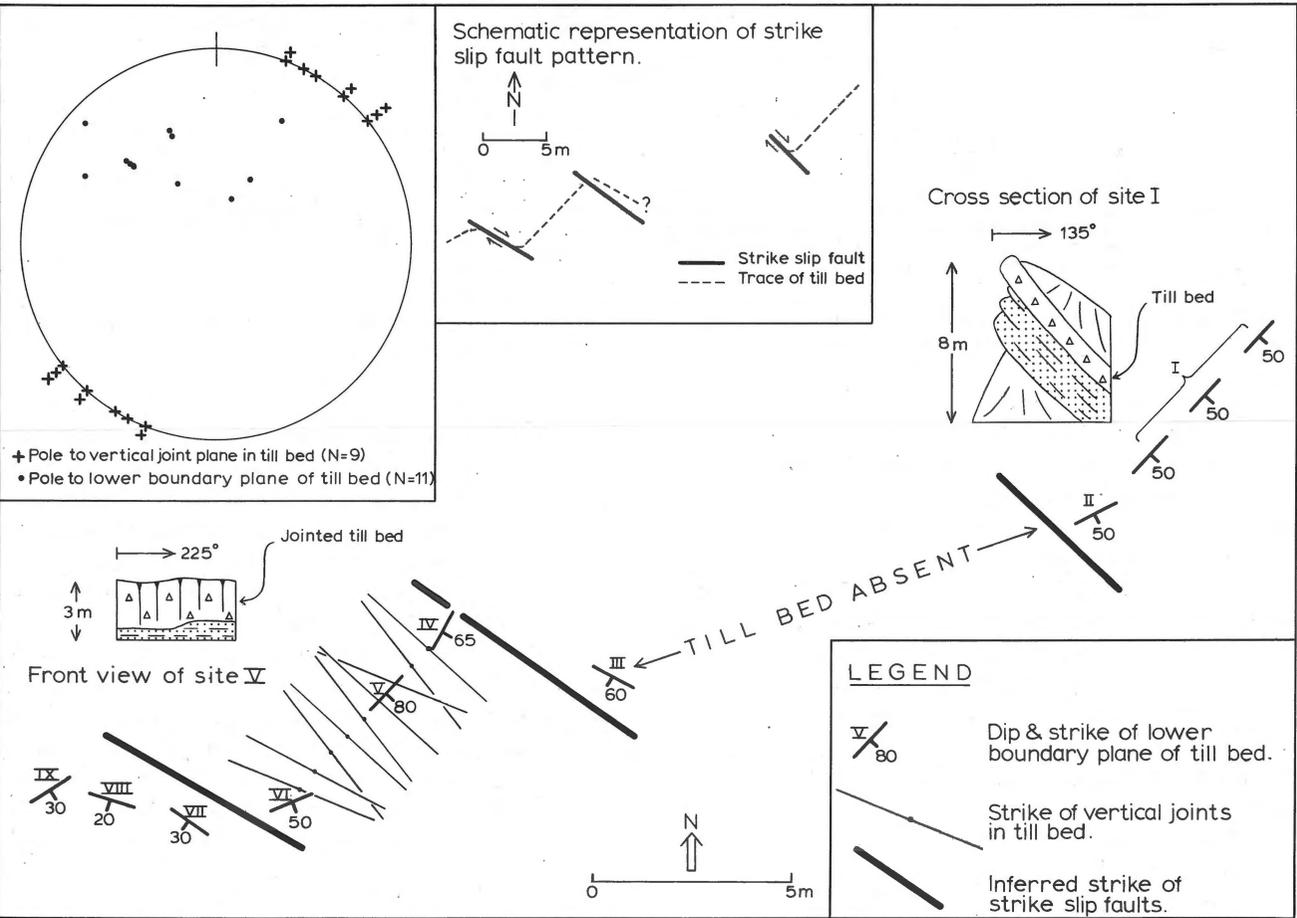


Fig. 8
Andebølle exposure. Reconstruction of strike-slip faults in till bed.

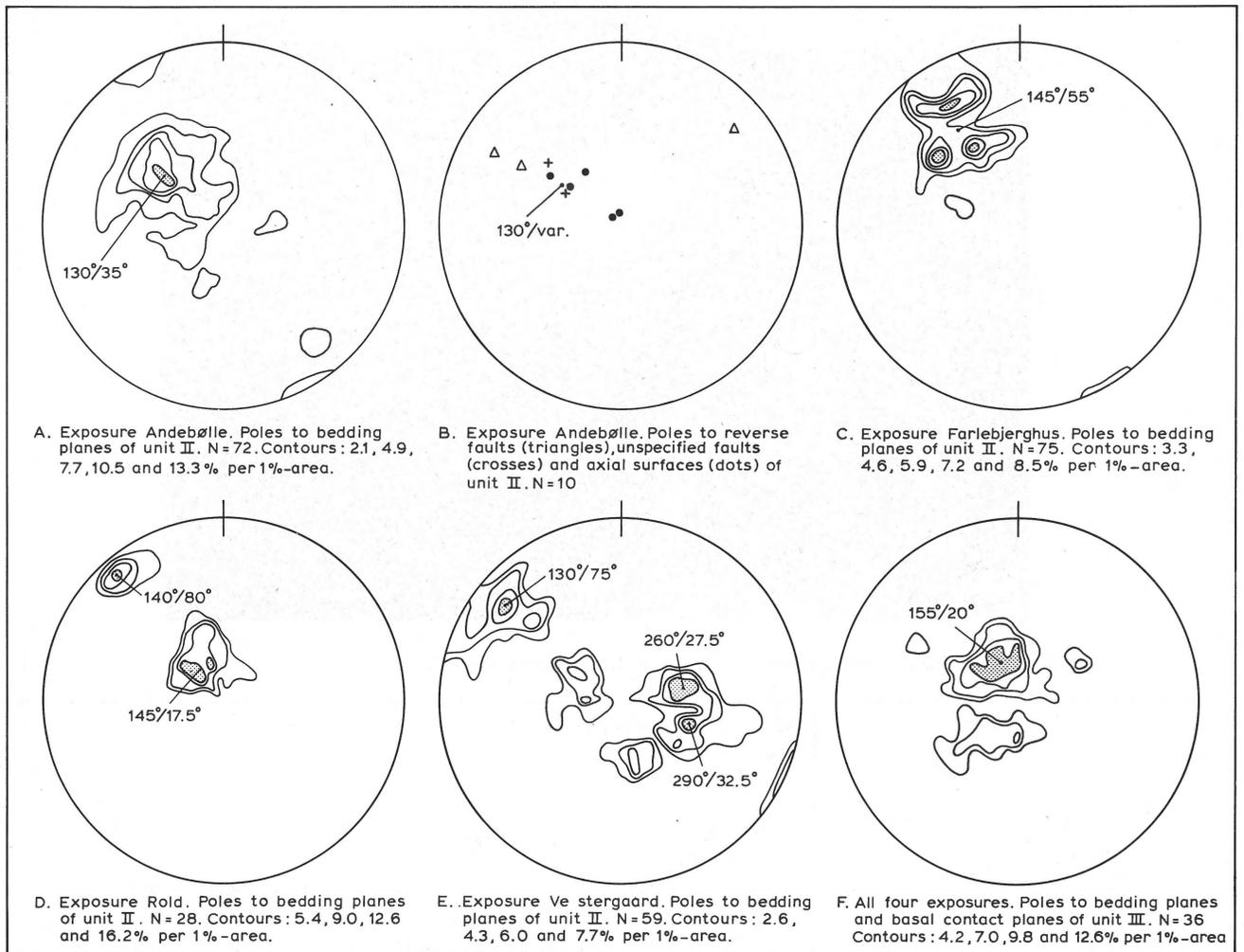


Fig. 9
Structural data of investigated exposures. Equal-area projection, lower hemisphere. Areas of maximal density shaded. The degree values indicate mean dips determined as centres of gravity of these areas.

En-bloc tilting – WIENBERG RASMUSSEN (1967) describes deformations in hat-shaped hills in NW Zealand (Denmark) characterized by strongly tilted glaciolacustrine beds. The bedding planes are intersected by both reverse and normal faults which have caused displacements on a cm scale only. Thus homoclines are the dominant structures. The tilted strata which form these homoclines do not show any internal deformation. This probably led Wienberg Rasmussen to the inference that the sequences of glaciolacustrine beds (with an estimated thickness of 200 m) were tilted *en-bloc* by a slight glacier advance. Following this concept, the *en-masse* rotation of the sediment bodies was an ice-marginal event with minimal horizontal displacement.

In contrast with this situation the homoclines of unit II in the Rold area do show a considerable degree of internal deformation.

Simple in situ deformations – MORAN (1971) has proposed a

threefold classification of glacitectonic structures. His first class is called 'simple *in situ* deformation' and refers to folds and faults of small displacement. These generally small-scale structures are produced by subglacial bed shear or subglacial/proglacial ice push. As they normally involve lithologically contrasting strata the simple *in situ* deformations are valuable indicators of the direction of glacier movement.

The deformations in unit II of the study area are generally modest in size and characteristics indicative of either imbricate thrusting or *en-bloc* tilting appear to be absent. It is therefore concluded that the structures of unit II are simple *in situ* deformations in the sense of MORAN (1971). It is tentatively suggested that the distortion of unit II took place in a proglacial environment and resulted from a minor recessional readvance, i.e. from a temporary advance of an actively receding ice mass.

In the study area the direction of ice movement was towards 310°-325°.

Unit III

The strata of unit III (the glaciolacustrine cover beds) unconformably overlie unit II and rather than being horizontal, dip with angles ranging from 5° to 55°. These deviations from the horizontal can be accounted for by assuming deposition in supraglacial lakes. In that case the originally horizontal beds would be slowly let down by melting of the underlying ice. Ultimately the subsiding layers would touch upon the clastic substratum and then drape its surface topography. The present attitude of the unit-III beds has thus been controlled by both their originally ice-floored position and the subglacial topography at the time of ablation.

The variation in surface expression of unit III can be interpreted as clear evidence of its supraglacial origin. Within the study area (see Fig. 2) unit III is found in the flat tops of plateau hills (Andebølle and Vestergaard exposures), near the top of a roughly conical single hill (Farlebjerghus exposure) and as a featureless surface deposit of the Rold ridge (Rold exposure). Also MARCUSSEN (1975) reported that the distribution of glaciolacustrine clay (and other surface deposits) in the Vissenbjerg area is independent of the topography of the terrain.

With regard to the ice mass from which the glaciolacustrine beds were let down two alternatives can be envisaged:

- (1) It represents the deglacial phase of the same ice sheet which at an earlier time advanced from the SE and bulldozed the beds of unit II.
- (2) It is associated with a new ice stream which succeeded the advance from the SE.

The second option is preferred since in and around the Rold exposure the glaciolacustrine beds of unit III (at least 5 m in thickness) form the surface material of the Rold ridge (Fig. 2). As already explained the Rold ridge constitutes part of the Fjelsted-Bavnedams bakke end moraine (Fig. 1). Thus it is most likely that unit III and the Fjelsted-Bavnedams bakke zone (F-B zone) are associated with one and the same ice advance from the North or Northeast. In several exposures near Fjelsted the nontectonized appearance of the sediments indicates that the F-B zone is a *Satzendmoräne* (depositional end moraine) rather than a *Stauchendmoräne* (push end moraine). This implies that the F-B zone could well have been formed during the deglaciation of the ice advance from the N or NE. It furthermore implies that the F-B zone is not necessarily an end moraine in the strict sense as it might have developed in a large structurally controlled crevasse which ran parallel to the ice margin proper.

CONCLUSIONS

(1) In the study area evidence of two successive ice transgressions has been demonstrated. The older advance was directed towards the NW and the younger one to the S or SW. Since the latter is represented by oriented surface features it probably

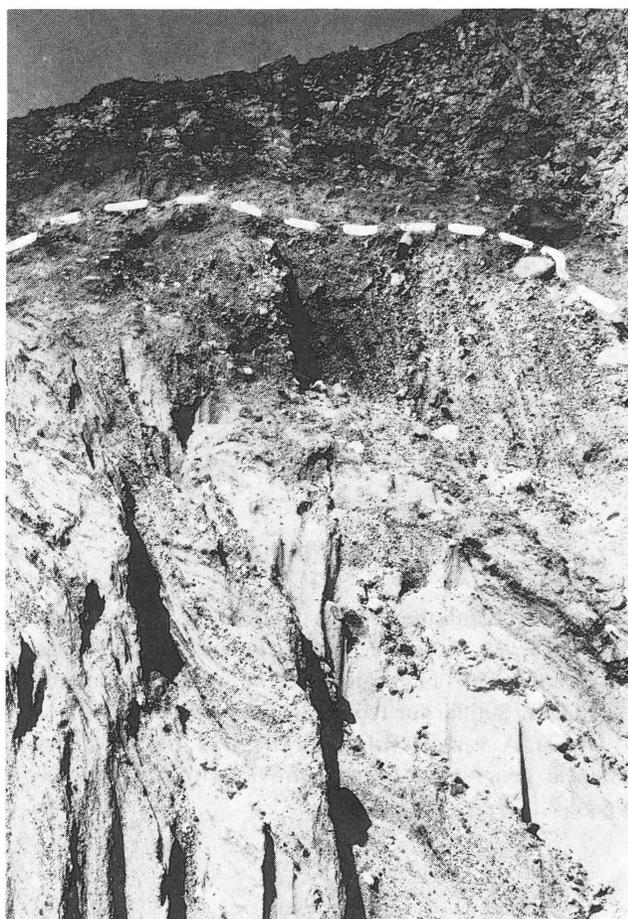


Fig. 10
Glaciolacustrine cover beds unconformably overlying tilted strata of unit II (Andebølle sand pit).

corresponds to the youngest glacierization phase in the study area.

(2) Evidence of the older ice transgression comes from buried ice-pushed beds having a consistent NW vergence over a distance of at least 2 km. It is not known whether this recessional readvance distorted its own extramarginal sediments (the dominal case) or rather those deposited during a still older glacierization phase (the extra-dominal case).

Evidence for the younger and locally youngest ice transgression is present in the form of both the glaciolacustrine cover beds and the oriented surface features collectively referred to as the F-B zone. Since these two phenomena appear to be time-equivalent they have been ascribed to one and the same glacierization phase and more specifically to the dead-ice stage of that event.

(3) Rather than being overridden and distorted by an ice transgression (MILTHERS, 1940) the F-B zone seems to result mainly from deposition in a stagnant or disintegrating ice environment.

(4) Would it be justified to extrapolate the SE Denmark kineto-stratigraphy of BERTHELSEN (1978) to NW Funen, then the older ice transgression might tentatively be correlated with the Old Baltic Advance and the younger one with the NE Ice. Kineto-stratigraphic evidence for the NE Ice being the forelast Weichselian ice advance in the whole of Southern Denmark (including Funen) is quite strong (PETERSEN, 1978). Regarding the still older Weichselian advances on Funen however recent information is scarce.

(5) It is remarkable but by no means exceptional that the younger advance neither disturbed the spatial attitude of the underlying ice-pushed beds nor left behind a basal till. BERTHELSEN (1978) quotes nine literature sources in which this nondestructive behaviour of glaciers is discussed.

ACKNOWLEDGEMENTS

We wish to thank the geologists Dr. H. A. van Lunsen and Drs. M. E. M. de Smet for their constructive comments; Mr A. Heine and Mr. H. A. Sion for drafting the illustrations and Mrs G. B. Snijder for typing the manuscript.

Drs. H. A. van den Brink and Drs. G. J. van Dijk, who are physical geographers, kindly provided the photograph of figure 7.

REFERENCES

- Berthelsen, A. 1973 Weichselian ice advances and drift successions in Denmark – Bull. Geol. Inst. Univ. Uppsala N.S. 5: 21-29.
- 1978 The methodology of kineto-stratigraphy as applied to glacial geology – Bull. Geol. Soc. Denmark 27 (Special Issue): 25-38.
- 1979 Recumbent folds and boudinage structures formed by subglacial shear: an example of gravity tectonics. In: W. J. M. van der Linden (ed.): Fixism, mobilism or relativism: Van Bemmelen's search for harmony – Geol. Mijnbouw 58: 253-260.
- Gravenor, C. P. & W. O. Kupsch 1959 Ice disintegration features in Western Canada – J. Geol. 67: 48-64.
- Gripp, K. 1979 Glazigene Press-Schuppen, frontal und lateral. In: Schlüchter (ed.): Moraines and varves. Origin/Genesis/Classification – Balkema (Rotterdam): 157-166.
- Hansen, S. 1965 The Quaternary of Denmark. In: K. Rankama (ed.): The geologic systems. The Quaternary. Vol. 1: Denmark, Norway, Sweden, Finland – Interscience Publ. (New York): 1-90.
- Lavrušin, J. A. 1978 Texturen, Fazies und stoffliche Zusammensetzung der Grundmoränen – Schriftenr. geol. Wiss. Berlin 9: 161-177.
- Marcussen, I. 1975 Distinguishing between lodgement till and flow-till in Weichselian deposits – Boreas 4: 113-123.
- Milthers, V. 1940 Beskrivelse til geologisk kort over Danmark: Kortbladet Vissenbjerg – Danm. Geol. Unders. I. Række 19: 143 pp.
- Moran, S. R. 1971 Glacitectonic structures in drift. In: R. P. Goldthwait (ed.): Till: a symposium (Columbus): 127-148.
- Petersen, K. S. 1978 Anwendung glaziotektonischer Untersuchungen bei der geologischen Kartierung in Dänemark – Eiszeitalter u. Gegenwart 28: 126-132.
- Poortman, H. H. 1980 Verslag doctoraal veldwerk, Fyn, Denemarken – Unpubl. M.Sc. thesis Free Univ. Amsterdam: 17 pp.
- Rühle, E. 1961 Fifteen years of Quaternary research in Poland. In: J. Czaplicka & W. Rühle (eds.): Quaternary of Central and Eastern Europe – INQUA, VIth Int. Congr. (Warsaw): 589-665.
- Schwan, J., A. J. van Loon, P. G. van der Gaauw & R. Steenbeek 1980-a The sedimentary sequence of a Weichselian intraglacial lake at Ormehøj (Funen, Denmark) – Geol. Mijnbouw 59: 129-138.
- Schwan, J., A. J. van Loon, R. Steenbeek & P. van der Gaauw 1980-b Intraformational clay diapirism and extrusion in Weichselian sediments at Ormehøj (Funen, Denmark) – Geol. Mijnbouw 59: 241-250.
- Smed, P. 1962 Studier over den fynske ø-gruppens glaciala landskabsformer – Meddr. dansk geol. Foren. 15: 1-74.
- Stierman, A. 1977 Verslag doctoraal veldwerk Denemarken – Unpubl. M.Sc. thesis Free Univ. Amsterdam: 91 pp.
- Van den Brink, H. A. & G. J. van Dijk 1979 Verslag van een doctoraal veldwerk op het eiland Fyn (Denemarken) – Unpubl. M.Sc. thesis Free Univ. Amsterdam: 83 pp.
- Van der Gaauw, P. G. & R. Steenbeek 1978 Enkele glacio-tektonische verschijnselen in de omgeving van Årup (Funen, Denemarken) – Unpubl. M.Sc. thesis Free Univ. Amsterdam: 56 pp.
- Wienberg Rasmussen, H. 1967 Undersøgelser og tolkninger af dislocerede issøbakker – Meddr. dansk geol. Foren. 17: 37-57.