TILLS IN DISLOCATED DRIFT DEPOSITS ON THE RØSNAES PENINSULA, NORTHWESTERN SJAELLAND, DENMARK

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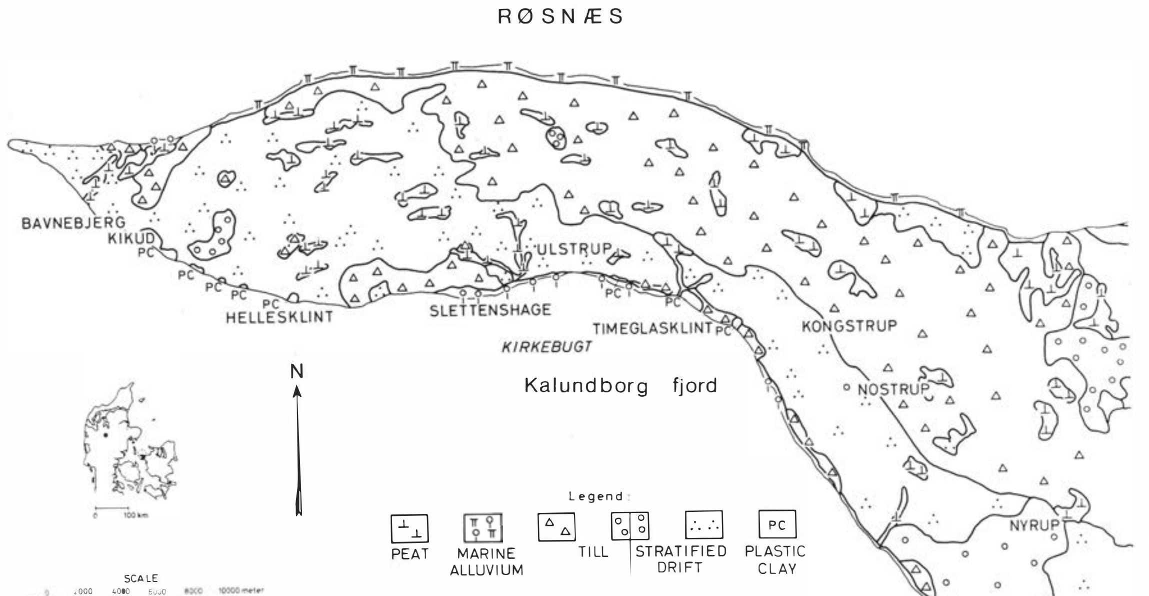

SECTION OF THE GEOLOGICAL MAP FROM 1900

Abstract. A review of the earlier discussions on the Quaternary geology of the area is given briefly, followed by a demonstration of the tectonic and stratigraphic features of the area, as seen in a clay pit (Lower Eocene plastic clay, Røsnœs Clay). The glacial dislocation is from the south. Two tills, an older and a younger one, can be distinguished. The tills are characterized by their spatial positions, their stone contents (using the stone-counting method), their granulometric compositions and, as a stratigraphical indication, the presence (as a floe in one of the tills) of a marine clay, ascribed to the Eem. These methods are applied to two exposures along the southern shore of Røsnœs. The results of these investigations are considered in the light of other investigations in northwestern Sjœlland.

INTRODUCTION

Discussion of the drift deposits on Røsnœs has mostly been concerned with the ice movement at the time when the end moraine of the peninsula was made. Previous authors have disregarded the stratigraphical problems dealt with by K. Rørdam at the turn of the century, but have been influenced by the studies by V. Milthers on indicator boulders and on the morphology of the glacial landscape. On the basis of studies of indicator boulders, V. Milthers (1932) concluded that the ice pressure was *from the north.* This view was contradicted by Andersen (1927, 1929, 1964) and by Gry (1952) from studies of meltwater deposits and tectonic conditions; they concluded that the ice pressure was *from the south.*

The tectonic methods applied to the Lower Eocene, Mo-clay area by Gry (1940) were used by the present author to make a *tectonic analysis of a clay pit* to the southwest of Ulstrup at Røsnœs (Fig. 1). This was recorded in 1969 and 1970, together with other investi-

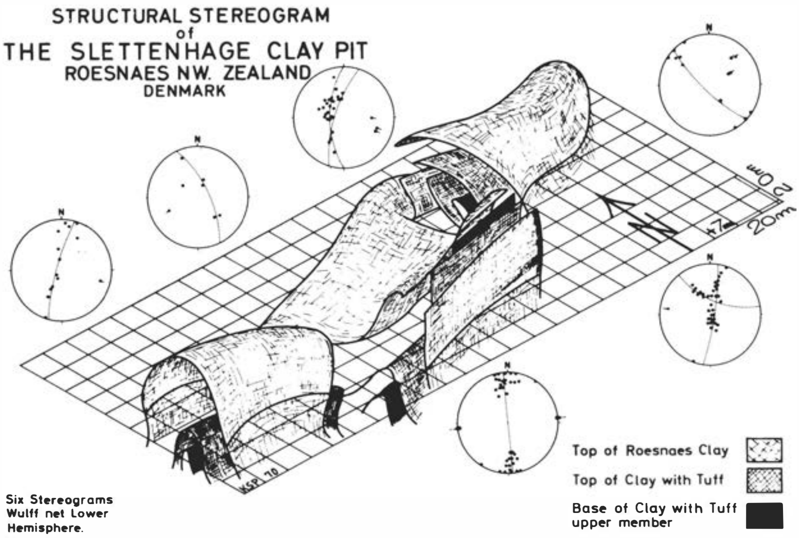

Fig. 1. Strata below the drift.

gations of the locality. The inspiring paper on periglacial phenomena of different ages by Berthelsen (1971) tempted the author to correlate the *stratigraphy of the clay pit* (Fig. 2) with other localities of the area.

Characterization of the tills of the clay pit

The spatial position of the ice-dislocated tills was interpreted by means of a *tectonic analysis*. This was facilitated by the presence of the Røsnæs Clay formation, and the underlying upper member of Clay with Tuff; the graded bedding of the tuff is a reliable top-and-bottom criterion.

The *stone-counting method,* as introduced by Ussing and Madsen (1897), was used (Table I). This method has been strongly criticized when the stone-count quotient (the ratio of the number of flint pebbles to the number of igneous- and metamorphic-rock pebbles) has been used for long-distance correlation (cf. Madsen, 1928); in this case the method was used outside its sphere of application. Correctly (as in 1897) the method should be used in support of the geological mapping of an area.

It was found useful to separate the stones of each sample into three fractions, and to illustrate graphically the stone-count results of each fraction, for the purpose of intercorrelation (Fig. 3). The quantity ratio (in one fraction) of the various kinds of stones was found to be dependent on the grain size. The number of flints was found to decrease with grain size, a phenomenon also noted by Søndergaard (1959) and V. Milthers (1900).

The *granulometric composition* of each sample, in combination with the results of the stone-countings (including Tertiary concretions), show that plastic clay characterizes one of the tills. The position of this till in relation to the other tills, as deduced by the tectonic analysis, indicates that this one is *an older till.*

A floe of marine clay was found in *a younger till.* The molluscs in this floe (Table II) belong to a boreo-lusitanian *Turritella communis* community from a muddy bottom, about 20 m below sea-level, in an environment with a salinity of not less than 30 ‰. All of the genera and most of the species from the floe are known from Eem Sea deposits. The possible dating of the floe shows that the younger till belongs to the Weichselian stage. Shells of Quaternary molluscs also occur sporadically in the younger till of the area.

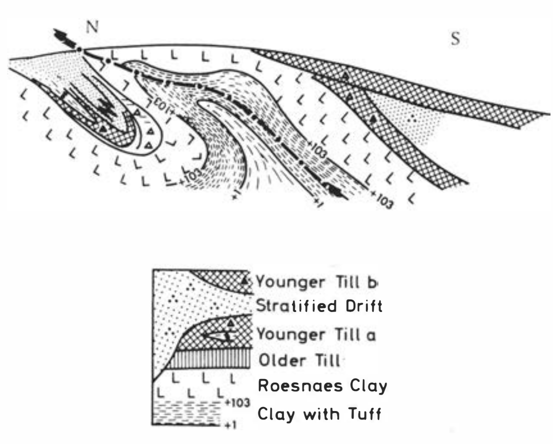

Fig. 2. Compound section (N.–S.) of the Slettenhage clay pit. The sequence of strata is shown below.

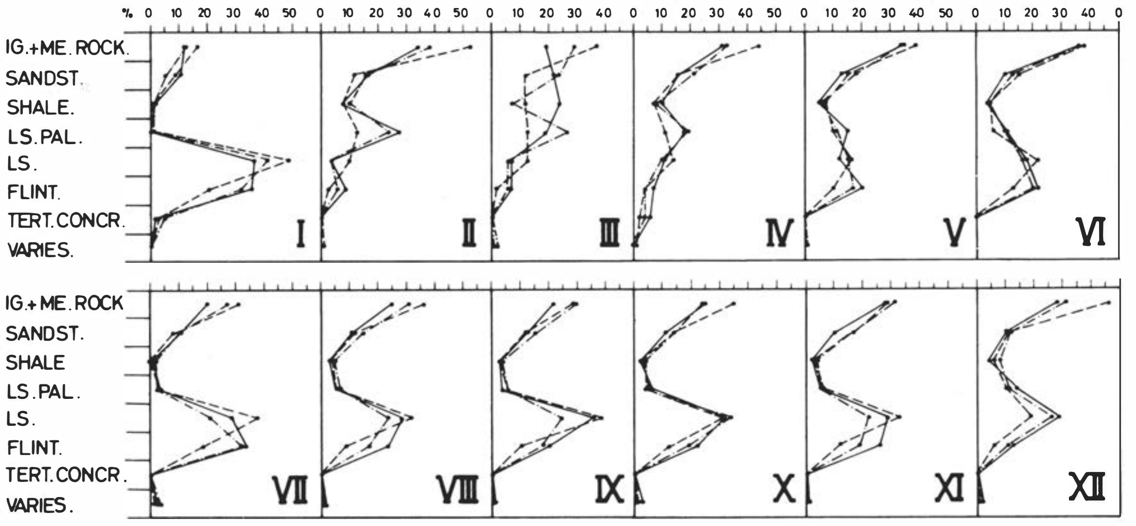

Fig. 3. Graphical representation of the stone-count results. Numbers I and VII: the older till. The other numbers: the younger till.

Table 1. Stone-count table. Weights of stones in one fraction in italics means that stone-counting has been carried out on a subsample. The generally applied size interval for correlation purposes is: a hen's egg – 6 mm.

	Slettenhage clay pit								
Till-sample number	I (368/69-I)			II (368/69-II)			III (368/69-III)		
Fraction	>6 mm	6–4 mm	4–2 mm	>6 mm	6–4 mm	4–2 mm	>6 mm	6–4 mm	4–2 mm
Weight of sample, grams		10110			9760			5250	
Weight of stones, grams	276.0	67.4	*92.7*$^{+}$	739.0	*119.1*$^{+}$	*206.1*$^{+}$	233.0	64.7	*104.1*$^{+}$
Number of stones: N	124	382	704	203	345	911	82	321	526
In % of N									
Igneous and metamorphic rocks	12.1	13.1	16.8	33.6	38.5	52.7	19.5	29.3	47.0
Sandstone	10.5	5.5	8.9	17.3	16.5	11.6	21.9	23.9	12.3
Shale	1.6	1.5	0.6	7.9	10.3	7.7	24.4	7.5	11.6
Limestone Palaeozoic	0.0	1.3	0.8	28.1	24.1	13.2	19.5	27.4	12.7
Limestone	37.1	41.8	48.6	4.4	4.4	10.5	7.3	5.6	13.3
Flint	36.3	32.2	20.9	8.9	6.4	3.1	7.3	5.6	1.5
Tertiary concretion	2.4	4.7	3.0	0.0	0.0	0.0	0.0	0.0	0.0
Varies	0.0	0.3	0.4	0.0	0.0	1.2	0.0	0.6	0.0
Stone-count quotient	2.98	2.46	1.24	0.26	0.19	0.06	0.37	0.19	0.03

	Slettenhage clay pit			Helleskint					
Till-sample number	IV (368/69-X)			V (368/69-XI)			VI (368/69-XII)		
Fraction	>6 mm	6–4 mm	4–2 mm	>6 mm	6–4 mm	4–2 mm	>6 mm	6–4 mm	4–2 mm
Weight of sample, grams		35477			14100			14270	
Weight of stones, grams	1239.0	*316.4*$^{+}$	*713.9*$^{+}$	586.0	137.5	*224.9*$^{+}$	842.8	131.7	*219.9*$^{+}$
Number of stones: N	725	511	849	250	780	558	345	763	727

Table 1. (continued)

	Slettenhage clay pit			Hellesklint					
In % of N									
Igneous and metamorphic rocks	31.3	32.9	44.5	34.8	33.8	40.0	36.2	35.8	38.2
Sandstone	16.0	21.4	15.9	13.2	18.2	15.4	9.6	12.7	15.0
Shale	10.4	8.4	7.2	5.2	5.8	7.5	3.5	5.2	4.9
Limestone Palaeozoic	17.9	19.2	10.8	14.8	10.8	10.1	11.3	10.0	6.0
Limestone	11.4	9.6	14.3	11.6	14.7	16.3	18.0	16.0	21.9
Flint	7.0	4.3	4.2	20.0	16.7	10.4	21.7	19.7	13.3
Tertiary concretion	5.9	4.3	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Varies	0.0	0.0	1.3	0.4	0.3	0.5	0.0	0.3	0.7
Stone-count quotient	0.22	0.13	0.09	0.57	0.49	0.26	0.60	0.55	0.35

	Hellesklint			Kongstrup					
Till-sample number	VII (368/69-XIII)			VIII (31-12-71-I)			IX (31-12-71-II)		
Fraction	>6 mm	6–4 mm	4–2 mm	>6 mm	6–4 mm	4–2 mm	>6 mm	6–4 mm	4–2 mm
Weight of sample, grams	12590			10000			10000		
Weight of stones, grams	261.9	87.7	*145.4*+	634.0	134.6	*254.2*+	821.1	123.0	*253.7*+
Number of stones: N	205	571	737	430	742	694	472	661	806
In % of N									
Igneous and metamorphic rocks	20.0	27.5	30.6	24.6	30.6	35.8	22.1	30.1	29.4
Sandstone	10.7	9.8	8.2	11.2	15.3	12.4	12.7	15.7	12.2
Shale	1.0	2.5	0.0	3.5	5.0	4.2	2.8	4.2	3.4
Limestone Palaeozoic	3.9	3.2	3.7	6.0	6.9	5.9	4.2	6.5	6.1
Limestone	29.2	21.4	37.6	29.3	24.1	32.3	36.1	25.4	38.8
Flint	33.7	33.3	18.8	23.9	17.4	9.2	20.4	18.0	9.9
Tertiary concretion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Varies	1.5	2.5	1.2	1.4	0.8	0.3	1.3	0.6	0.3
Stone-count quotient	1.68	1.20	0.62	0.97	0.57	0.26	0.93	0.59	0.34

	Timeglasklint						Nostrup		
Till-sample number	X (31-12-71-III)			XI (31-12-71-IV)			XII (24-2-72-I)		
Fraction	>6 mm	6–4 mm	4–2 mm	>6 mm	6–4 mm	4–2 mm	>6 mm	6–4 mm	4–2 mm
Weight of sample, grams	10000			10000			10000		
Weight of stones, grams	601.9	123.6	*246.5*+	693.5	120.5	*255.5*+	325.0	108.7	*177.0*+
Number of stones: N	371	773	924	453	661	1065	187	661	731
In % of N									
Igneous and metamorphic rocks	24.8	24.4	34.6	27.7	31.2	28.5	28.4	31.4	46.4
Sandstone	11.1	13.9	13.9	10.2	16.9	17.1	9.6	12.4	10.9
Shale	1.9	4.3	2.9	2.2	3.6	2.9	4.3	8.0	6.0
Limestone Palaeozoic	6.5	3.9	5.2	4.6	5.1	6.0	13.9	10.9	10.1
Limestone	31.8	33.6	31.2	29.1	22.4	32.8	28.8	25.8	19.2
Flint	21.6	18.9	11.9	26.1	19.4	12.1	13.4	10.7	6.2
Tertiary concretion	0.0	0.0	0.0	0.2	0.6	0.6	0.0	0.0	0.1
Varies	2.5	0.9	0.3	0.9	0.7	0.0	1.6	0.8	1.9
Stone-count quotient	0.87	0.78	0.34	0.94	0.62	0.43	0.47	0.34	0.13

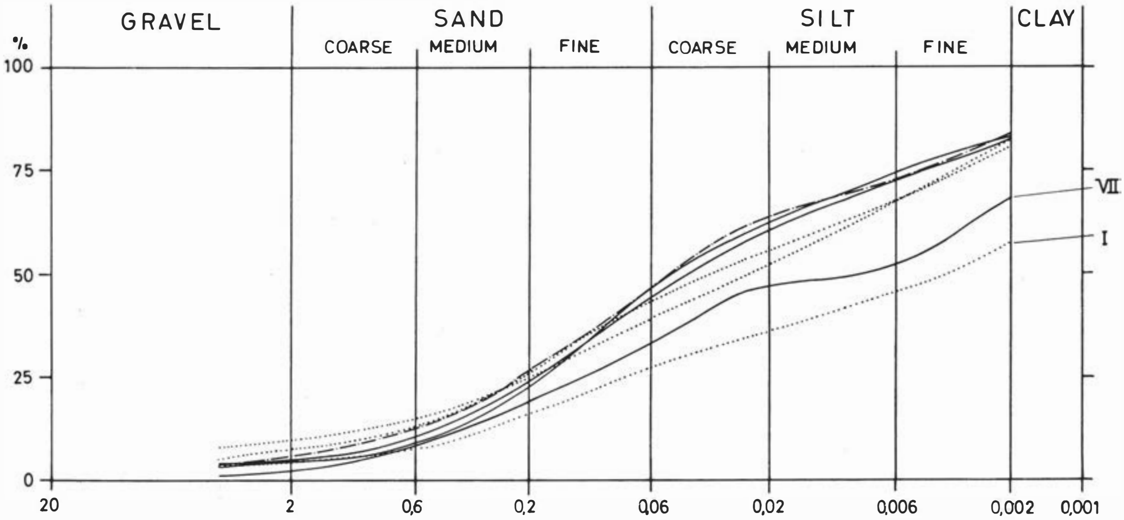

Fig. 4. Granulometric composition of the tills from the Slettenhage clay pit (dotted lines and in IV broken line) and from the Helleskint (continuous lines). Numbers I and VII: the older till. Analyses by Statens Vejlaboratorium.

The *stratigraphy* of the clay pit is demonstrated in Fig. 2. The till overlying the plastic clay is different from the other dislocated tills (Fig. 3 I, II and III and Fig. 4), as is shown by the content of shale and Palaeozoic limestone. The large amount of Cretaceous and Palaeocene limestone ("Limestone" in the diagrams) was picked up by the glacier outside the area, in contrast to the Tertiary concretions, which may be con-

Table 2. The molluscs from the floe in the younger till *a* of Slettenhage clay pit.

Mollusca	No.	Lowest mean salinity, ‰	Lusian	Boreal	Arctic	Depth, meters 0 20 40 60 80 100
Nucula sulcata Bronn	3	33				+
Amonia sp.	Fragments					
Modiolus sp.	2					
Acanthocardia echinata (L.)	Fragments	25				+
Cerastoderma edule (L.)	8	6				
Arctica islandica (L.)	Fragments	15				
Venus striatula (da Costa)	2	30				
Spisula subtruncata (da Costa)	1	20				
Mya truncata (?) L.	Fragments	15				
Hydrobia ulvae (Pennant)	14	10				?
Turritella communis Risso	304	25				
Clathrus clathrus (L.)	22	30				
Clathrus turtonis (Turton)						
Cirsotrema commutatum (Monterosato)						
Rissoda abella Lovén	1	15				
Odostomia eulimoides Hanley	41	30		?		
Odostomia umbilicaris (Malm)		33		?		
Odostomia plicata (Montagu)						
Natica montagui Forbes	3	30				+
Buccinum undatum (?) L.	Fragments	15				+

Fig. 5. View of Hellesklint from the west.

sidered as local. The Eocene deposits are at the base of the Pleistocene in this part of northwestern Sjælland (Sorgenfrei and Buch, 1964, Plate 13).

According to the stone content, the till overlying the stratified drift deposits (*b* in Fig. 2 and Fig. 3 IV) belongs to the same glacier as the till immediately below the stratified drift deposits. (*a* in Fig. 2 and Fig. 3 II and III). This situation may be interpreted in several ways. It is considered most likely here that the uppermost till (*b*) represents the ground moraine of the dislocating ice *from the south*. This is in accordance with the data obtained by the geological mapping of the area by Rørdam and Milthers (1900): to the south of the clay pit, between this and the Kalundborg Bay, the range of hills is indicated as "till". The content of Tertiary concretions was derived from floes of plastic clay as the ice passed over dislocated strata to the south. It may be concluded that the younger till (*a+b*) belongs to the Younger Baltic Ice stream, and that the stratified drift deposits were laid down during a stage of ice retreat. Melting of the ice was then interrupted by a re-advance of the glacier through the Store Bælt onto the Røsnæs peninsula. The area was not subsequently overridden by the ice.

Investigations on the tills of two other localities

From samples of tills along the southern shore of Røsnæs to the west of Hellesklint, it is seen that the same till is traceable from place to place within a distance of 1.5 km. This till resembles the younger till. The stone-count quotient of the 6–4 mm fraction are as follows (from west to east, Bavnebjerg to Hellesklint): 0.36; 0.42; 0.31; 0.38; 0.29; 0.26/0.94; 0.43; 0.45. The two quotients 0.26/0.94 are from tills separated by a boulder pavement at the Kikud locality. The older till (stone-count quot. 0.94) below the pavement was exposed by land-sliding, which raised the foreshore as the hinterland subsided.

The older till is also present at *Hellesklint* (Fig. 5), here as an ice-dislocated outcrop. Three samples of tills from this locality (Fig. 3 V, VI and VII) indicate that the same till (the younger one) is duplicated so as to both underlie and overlie stratified drift deposits. This has been explained as a *tight synforme* by Asger Berthelsen. The third till is different from the two others. Its stone content and its position in close contact with plastic clay show it to be identical with the older till (Fig. 3 VII and Fig. 4 VII). No all-covering till has been found at this locality.

The other investigated locality along the shore of Røsnæs, *the Konstrup area* (Fig. 6), is situated to the west of Kongstrup, between the Timeglaslint and an exposure to the west of Nostrup. The direction of the shore is NNW.-SSE. To the south of the coastal area

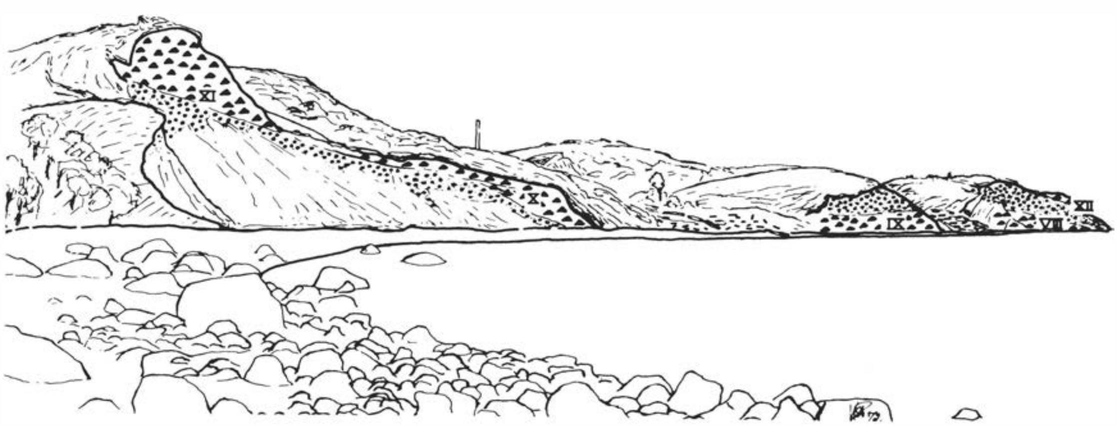

Fig. 6. Sketch of the southern coast of the Røsnæs peninsula, viewed from Timeglasklint to the east as far as Nostrup. The Roman numerals refer to the till samples. Stratified drift is shown by dots.

(Fig. 6), southwards from the till marked XII, the stratified drift depsits are interbedded between tills, exactly as was demonstrated by Berthelsen (1971) for the Grœsmarken area in the southeastern part of the Asnœs peninsula (south of Røsnœs). According to Berthelsen's explanation, the till marked X and XI (Fig. 6) may be considered to be due to a glacier which advanced over the stratified drift deposits and *overrode* the hilly part of the Røsnœs peninsula (this "hilly part" is identical with the area indicated as "stratified drift deposits" on the map of Røsnœs). Another theory may explain the structure at this locality as described in the following pages.

The dip of the stratified drift deposits is southwards (Fig. 7). Between the exposures of till and stratified drift, plastic clay spreads onto the beach. The plastic clay is interbedded between drift deposits (below) and till (above). On the beach, in front of the cliffs, the plastic clay acts as a rigid mass, projecting as a small reef into the bay. Planes of this plastic clay have a steeply southward dip. It should be noted that all measurements must be taken with a certain amount of reservation, as sliding may occur.

From the stone content and the graunulometric composition of till samples VIII–XI (Figs. 3 and 8), it may be concluded that all the tills were derived from the same glacier. The tills resemble the younger till of the clay pit. The analyses of till XII show that this till belongs to the overridden area to the south of this outcrop, mentioned above and not dealt with in this paper.

A possible interpretation of the position of the layers is that they form an *imbricated structure*. Support for this theory is also to be found in (1) the "disturbances" in the bottom part of the tills (fragments of layered sand and gravel from the drift deposits below have been absorbed in the overriding sequence (Fig. 9)), and in (2) the plastic clay coming up as a lubricant during the imbricating process (Fig. 10).

Imbricate structure is a well-known phenomenon of

Fig. 7. Kongstrup area. Cliff exposure viewed towards the north. The author is standing on the limit between younger till (below) and stratified drift (above). The dip of the stratified drift is to the south.

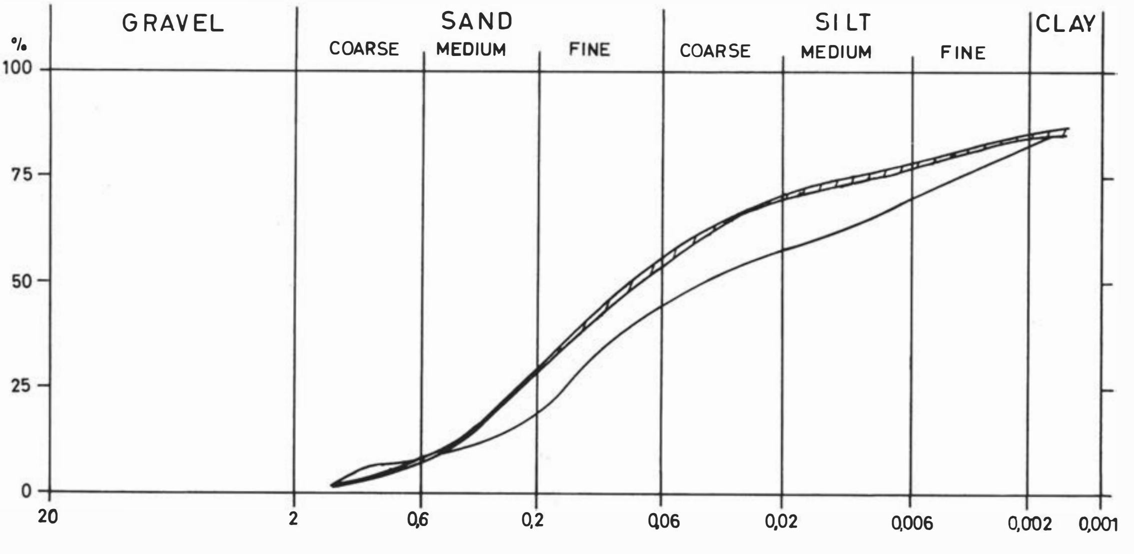

Fig. 8. Granulometric composition of the till samples VIII–XII from the exposures along the shore (numbers in the sketch, Fig. 6). Analyses by D.G.U.

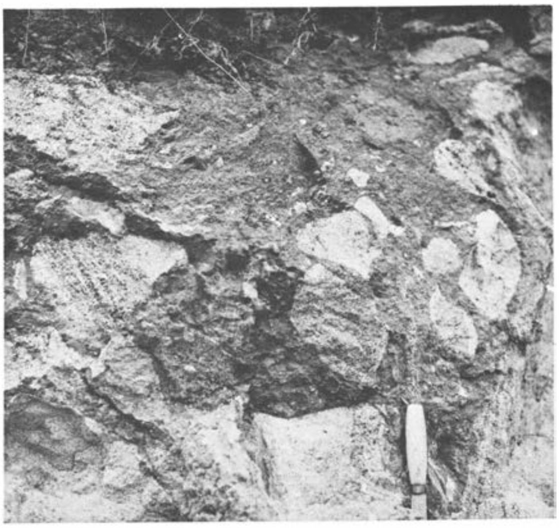

Fig. 9. Contact between stratified drift deposits (below) and the superjacent till: fragments of layered sand and gravel distorted in the till matrix.

the Danish region. It should be emphasized, however, that such a structure may extend over several kilometers, repeating the same sequence of strata many times (Jessen 1931). The imbricated structure is generated in front of the glacier.

DISCUSSION

At each of the three localities (the clay pit, Hellesklint and the Kongstrup area), certain samples may be grouped together on the basis of a correspondence between the stone-count quotient and the granulometric-composition medians, for example, samples V and VI at Hellesklint, while other samples VIII clearly have a different composition. However, samples from the different localities cannot be correlated on this basis, owing to regional variation in composition.

	Sample	Stone-count quotient	Median, mm
	I	2.98	0.0035
Slettehage	II	0.26	0.025
clay pit	III	0.37	0.036
	IV	0.22	0.052
	V	0.57	0.054
Hellesklint	VI	0.060	0.046
	VII	1.68	0.009
	VIII	0.97	0.080
	IX	0.93	0.084
Kongstrup	X	0.87	0.085
	XI	0.94	0.077
	XII	0.47	0.043

However, it will also be seen that the correlation between localities as close as 4 km (the distance from Hellesklint to Konstrup) must take account of the whole assemblage of rocks in the till. It should not be based solely on the stone-count quotient, which takes account only of flint in proportion to igneous and metamorphic rocks.

The stone-counting method is supported by the fact that the localities with a predominance of Norwegian indicator boulders mentioned by K. Milthers (1942) and the localities where the older till is found on the basis of the stone-counting method of the present author are the same.

It is important that, in future, *in situ* till should be studied as a whole, so that the true proportions and degree of mixing of the rock types in the till can be evaluated.

The older till most likely antedates the Weichselian Glaciation (K. Milthers, 1942) and the younger till dates from the Weichselian.

The only rock type ocurring in sufficient quantity in the stone counts to be used as an indicator boulder is the white-spotted flint. It does not occur in the older till, while in the younger it is accompanied by large quantities of Palaeozoic limestone derived from the Baltic.

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Fig. 10. Plastic clay (by the lighter), which acted as a lubricant for the overthrusting sequence.

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