Sedimentological and geochemical features of Weichselian tills and pre-Quaternary sediments in Denmark

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Binzer, Knud: Sedimentological and geochemical features of Weichselian tills and pre-Quaternary sediments in Denmark. *Danm. geol. Unders., Årbog 1973,* pp. 111–131. København, 7. oktober 1974.
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Tills and pre-Quarternary sediments have been analysed. The results of the sedimentological analysis show that the granulometrical composition of the tills is very uniform. With a few exceptions they can be characterized as clayey tills. The chemistry of the tills also shows homogeneity in composition, except in two localities where more than one till is present. Comparison with analyses of pre-Quarternary clays and calcareous sediments shows that the analysed tills have probably inherited most of the element content from local pre-Quarternary sediments.

To provide values from which the heavy-metal contamination of soils can be evaluated, a project supported by Statens teknisk videnskabelige Fond was initiated at the Geological Survey of Denmark and the Mineralogical Institute (Technical university of Denmark) to analyse Weichselian tills, collected from localities all over the country. Besides this pollutional aspect, the aim was to estimate to what degree it is possible to distinguish between tills deposited by glaciers moving from different directions. A further aim was to try to make out from what source the trace element content in the tills was derived.

On the map (fig. 1) the sample localities are shown. Among the investigated localities where tills occurred there have been 4 with more than one till observed and investigated (7: Hven, 9: Feggeklit, 12: Ristinge and 13: Halk Hoved).

Regional geology

The basement for the Quaternary deposits in Denmark consists mostly of soft unconsolidated sediments. In contrast, the pre-Quaternary rocks in Scandinavia consist of hard metamorphic and igneous rocks, but the

Quaternary deposits reveal geological relationships with the neighbouring countries to the north, east and south. A continuation of the Quaternary deposits can be followed from Scandinavia through Denmark to Poland, Germany and Holland. These deposits witness the erosion, transport and sedimentation during the Glacials. Although these deposits do not form a continuous and homogeneous cover, there is good evidence of a common origin.

In Denmark the stratigraphical age of the pre-Quaternary sedimentary series at the base of the Quaternary becomes younger from northeast to southwest (Sorgenfrei and Buch 1959). This distributional pattern of the pre-Quaternary sediments can be explained as an erosional cut through the stratigraphic column by the glaciers. "Pockets" with Cretaceous and Paleocene sediments in Swedish basement rocks (Halland and Scania) show that the borders of the pre-Quaternary sedimentary basins at least sometimes have been more to the northeast than the borders between the sediment series show today.

Quaternary Geology

Geological processes in the Weichselian have been important agents in forming the Danish landscape. Mainly on evidence from indicator boulder analyses (Milthers 1909) and stone countings (Madsen 1928) a hypothetical glacial stratigraphy of the country has been established (K. Milthers 1942, V. Milthers 1948, Hansen 1965). This hypothesis includes glacier advances from different directions at different times in the Weichselian resulting in till-deposits with characteristic stone content. Milthers (1942) tried to divide the tills into three main types, characterised by a stone-content from Norway, Sweden and the Baltic, respectively. The till-types should thus represent glacier movements from north, east and southeast respectively. Lately doubt has arisen as to whether the indicator boulders and stone countings are sufficient basis for the hypothesis of a Weichselian glacial stratigraphy (Marcussen 1973, 1974).

Besides the stone content, tectonic analysis of dislocated cliffs with tills have contributed to the establishment of supposed icepressure directions (Hartz, Madsen and Nordmann 1908, Rosenkrantz 1944, Jessen 1930, Gry 1940, Aabo Rasmussen 1973 and Strand Petersen 1973).

Depositional environment of the tills

The tills were probably deposited in a cold and moist environment. Water has been important as a transporting agent especially in the deglaciation period. The dispersed calcareous material in the tills suggests that the pH of the depositional environment was relatively high. Measurements in unaltered tills show pH-values between 7 and 8 (W. Christensen pers. comm.). The cold and moist depositional environment probably did not increase a chemical alteration that could lower the pH. This suggests that the pH in the environment was alkaline or neutral during the deposition of the tills.

Weathering

The surface deposits have been subject to weathering and soil-forming processes. Under the soil profile the weathering can be seen as a red colouring due to oxidation of the iron compounds in the sediments. Besides the oxidation the sediments are often washed out by percolating rainwater. The calcareous material and to some degree also the iron and manganese are normally washed out to a certain depth under the surface. It is possible to measure within a narrow horizon to what depth the calcareous material has been washed out by the shift from low pH-value to a high pH-value between upper layers without calcareous material and underlying layers rich in calcareous substance. This horizon has been called the "acid front" (W. Christensen 1962).

Material

The analysed samples have been taken from two groups of deposits. One group consists of Weichselian tills and the other of pre-Quaternary sedimentary rocks. The till samples chosen were as little altered as possible by secondary processes (weathering and soil-forming processes). From the tills present at the localities up to 5 samples were taken of 5 kg each. The pre-Quaternary samples were taken in sediment series which had been touched by the glacial erosion and thus constitute the basement of the Quaternary deposits. From each of these sediment series up to 7 samples were taken.

All the samples were collected in cliffs or in open pits, and were taken with a plastic spoon and kept in plastic bags until further treatment. The sediment types and sample localities are shown in fig. 1. The numbers of the different types of sediments which are analysed are listed in table 1.

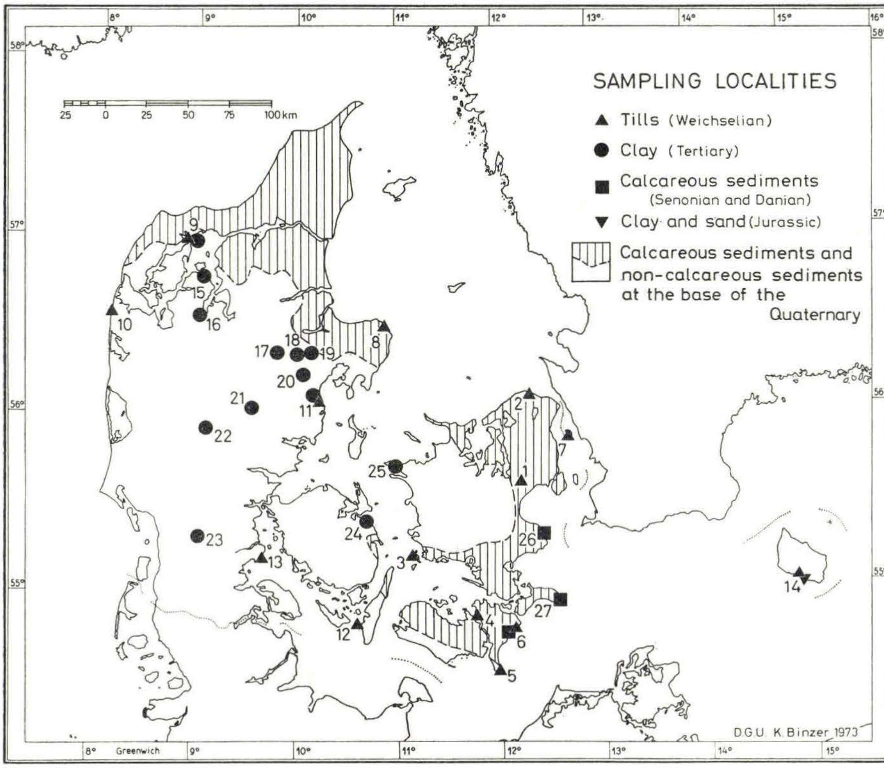

Fig. 1: All sampling localities, except loc. 22 and 23, are placed within the Weichselian glaciated area.

Names of localities: 1 Hedehusene (W), 2 Gilleleje (W), 3 Agersø (W), 4 Alstrup (W), 5 Gedser (W), 6 Pomle Nakke (W and Senonian), 7 Hven (W), 8 Gjerrild (W), 9 Feggeklit (W and Eocene "Moler"), 10 Bovbjerg (W), 11 Århus (W and Eocene), 12 Ristinge Klint (W), 13 Halk Hoved (W), 14 Bornholm (W and Jurassic), 15 Branden (Oligocene), 16 Gammelgård (Eocene), 17 Sofienlund (Oligocene and Miocene), 18 Hinge (Eocene), 19 Ølst (Eocene), 20 Grundfør (Eocene and Oligocene), 21 Salten (Miocene), 22 Brande (Miocene), 23 Gram (Miocene), 24 Lundsgård (Paleocene), 25 Ulstrup (Eocene), 26 Stevns (Senonian and Danian), 27 Møn (Senonian).

"W" indicate Weichelian tills.

Table 1.

No. of samples	Sediment type
72	till
23	Tertiary clay
5	Danian and Senonian limestone
2	Jurassic clay and sand
102	

Methods

The flow-sheet diagram of the analytical procedure of the tills is shown below:

Sample
|
fractionation
/ \
separation — grain size analysis
| |
0.032 mm — 1.40 – 6 mm
| |
chemical analysis — stone countings

To avoid contamination of the fraction finer than 0.032 mm for the chemical analysis, this fraction was obtained by wet sieving with distilled water through an 0.06 mm nylon sieve and by sedimentation and decanting. The separated fraction for the chemical analysis was dried at 100° C.

The stone countings

After grain size analysis the 1.4–6 mm fraction of the sieved till samples was used for stone counting analysis. The procedure described by Bahnson (1973) was followed, and the analyses were carried out by Sedimentlaboratoriet, D.G.U.

Grain size analysis

The grain size analysis was carried out on the till samples after removal of the material coarser than 2 cm. The grain size distributions for the material bigger than 0.064 mm were found by sieving. The distribution of the smaller fractions was determined by hydrometer analysis. These analyses were also carried out by Sedimentlaboratoriet, D.G..U

Chemical analyses

The major elements Al, Fe, Ca and Mg and the trace elements Mn, Sr, Cr, Ni, Zn, Cu, Co, Li and Pb were determined by atomic absorbtion spectrophometry employing a Perkin-Elmer A.A.S. model 303. TiO_2 was determined by spectrophometry with a Beckman DB spectrophometer. Na_2O and K_2O were determined on an EEL Flame Photometer. SiO_2 was determined by gravmetrical analysis. The rock samples were evaporated with

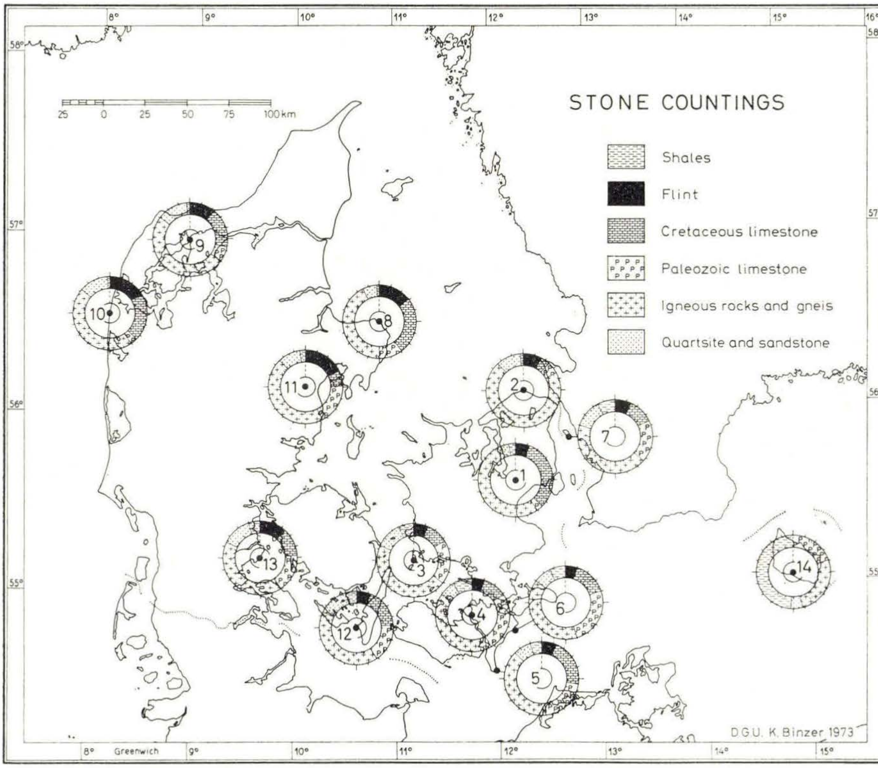

Fig. 2: Each circle represents the relative frequency of six rock types, expressed in percent. The shown distributions are averages from several countings in samples from the localities. In cases of more than one till (loc. 7, 9, 12 and 13), only countings from the uppermost till are shown.

a mixture of HF and $HClO_4$. The residue left, after fuming to dryness, was dissolved in dilute HCl. All the analyses were carried out at the Mineralogical Institute, Technical university of Denmark.

Statistical analysis

The values of the trace-element content and the figures for content of $CaCO_3$ and content of 0.032 mm fractions in the till-samples were analysed statistically by a program edited by J. Thuesen, 1973. The program is written in UNIVAC ALGOL *V*, version NUALGOL, and processes principal component analysis.

Results and discussion

Stone countings

Stone counting analyses primarily provide information about the rock content of the tills. In fig. 2 the results of the analyses are summarised. The rocks have been divided into 6 types and the content of each type is recalculated as percentage of the total counted stones.

Except for locality 14 (Bornholm) there is a suprisingly uniform content of the rock types on the localities. However, Paleozoic limestone, shales and clay-ironstones show a distributional pattern with decreasing content from southeast toward northwest, in accordance with the so-called baltic-ice hypothesis (Milthers 1909, Madsen 1928).

The very high shale content in locality 14 comes from the nearby Paleozoic and Mesozoic sediments in the basement. The content of shales and clay-ironstone in the samples from the localities in the southern part of the country (3, 4, 5, 6, 12 and 13) can be derived from the Tertiary sediments north and northeast of the localities and thus indicate glacier movements from northeast as well as from southeast.

The content of Cretaceous calcareous sediments in tills shows variations that seem to be related to the thickness of the Quaternary deposits at the locality and/or the distance from the locality to Cretaceous sediments at the base of the Quaternary. On fig. 1, the borders between calcareous sediment and non-calcareous sediment at the base of the Quaternary are shown. At the localities 1, 5, 6 and 8 the content of Cretaceous sediments is relatively high, in accordance with the thin Quaternary deposits (25–50 m) resting on Cretaceous sediments (fig. 1). At localities 2 and 7 the content is relatively low and here the Quaternary deposits resting on Cretaceous sediments are very thick (more than 75 m). Localities 9 and 10 have high contents, relating to nearby Cretaceous sediments north of the localities and to the ice-pressure direction or glacier movement from north to south (Gry 1940, Nørregaard 1912). At localities 11, 12 and 13 the Quaternary deposits rest on non-calcareous sediments and are situated far from Cretaceous sediments, which results in a relatively low content of these sediments in the tills. At locality 14 there have not been found any Cretaceous calcareous sediments among the stones counted.

The content of Cretaceous sediments in the tills from localities 3 and 4 are unexpectedly low, considering the thin Quaternary deposits (less than 25 m) resting on the Cretaceous. A possible explanation can be that the tills are deposited by glaciers moving from north and north-east across large areas with Tertiary non-calcareous sediments. This suggestion is in opposition to the distributional pattern of Paleozoic limestones, which show spreading from south-east. However there is no evidence against the possibility that the different limestones in the same till can show distributional patterns that reflect glacier movements from north-east as well as from south-east.

The importance of the stone content for evaluation of the chemical Analyses.

In this investigation the grain-size (Søndergaard 1959) and the number of stones counted (Lundquist 1952) should ensure that the apparent tendency of distributions of the rocks in the tills is reliable. Only limestones and shale- and clay-ironstones show regional variations. It has been shown that limestones contribute trace-elements at a level below the analytical precision worked with (Binzer 1973). The content of shale- and clay-ironstones are very low (less than 10 %) with one exception (locality 14) and can be ignored.

The stone content in the tills can thus be regarded as being so uniform that no essential source of variation in the element content has been excluded by analysing chemically only the 0.032 mm fraction of the tills.

Grain size distribution

The till samples were grain size analysed and the distribution curves are summarised in fig. 3. The figure shows that only two samples contain less than 10 % clay. For the comparability of the chemical analyses it is important to know how much the fraction less than 32 μ constitutes of the tills. In fig. 4 the distribution of the ÷ 32 μ fraction of the samples is shown. The samples can be divided in three groups and it appears that in most of the samples the ÷ 32 μ fraction constitutes about 50 % of the tills.

Besides granulometrical distribution the grain size curves also provide information of a change in nature of the tills from dominance of rock fragments to dominance of mineral grains. (Beaumont 1971). In this investigation this change appears in the grain size range 0.1–0.7 mm as a break of slope in the grain size curves. Another break of slope appears at 0.064 mm and is ascribed to difficulties in connecting the results of the sieve analysis with the results of the hydrometer analysis. Examples showing breaks of slopes in the curves at different grain sizes are shown in fig. 5.

The grain size analyses have shown that all the samples except 2 are clayey tills, that the chemically analysed fraction (÷ 32 μ) constitutes about

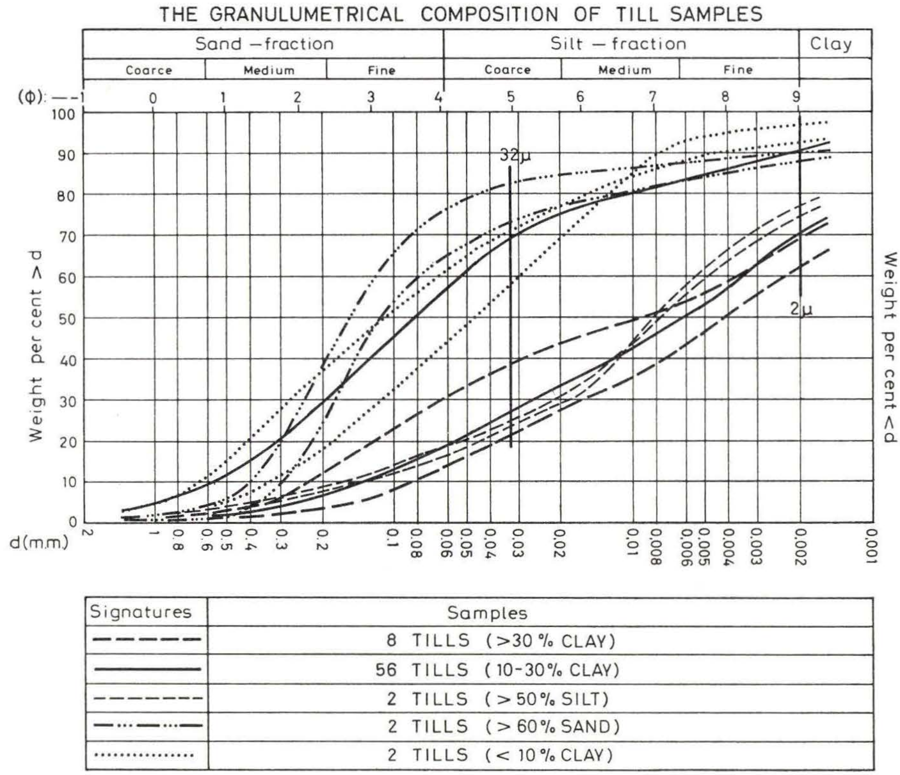

Fig. 3: The full lines show the area within which run distributional curves for 56 samples. The same applies to 8 samples within the thick dashed lines.

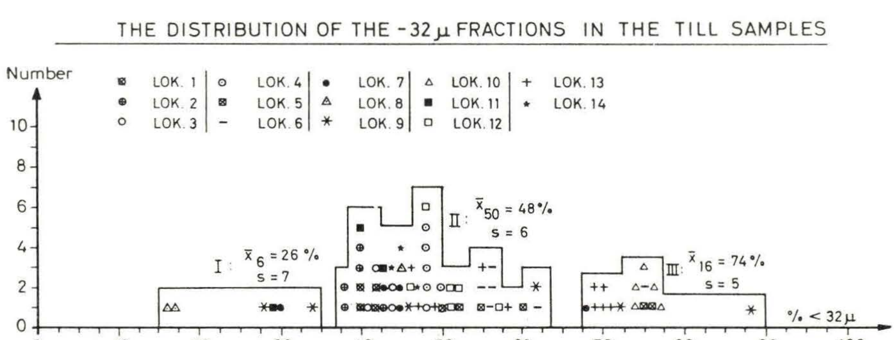

Fig. 4: The diagram shows the proportion of the till samples constituted by the fraction less than 0.032 mm. It is seen that the fraction less than 0.032 mm constitutes more than 40 % of most of the samples.

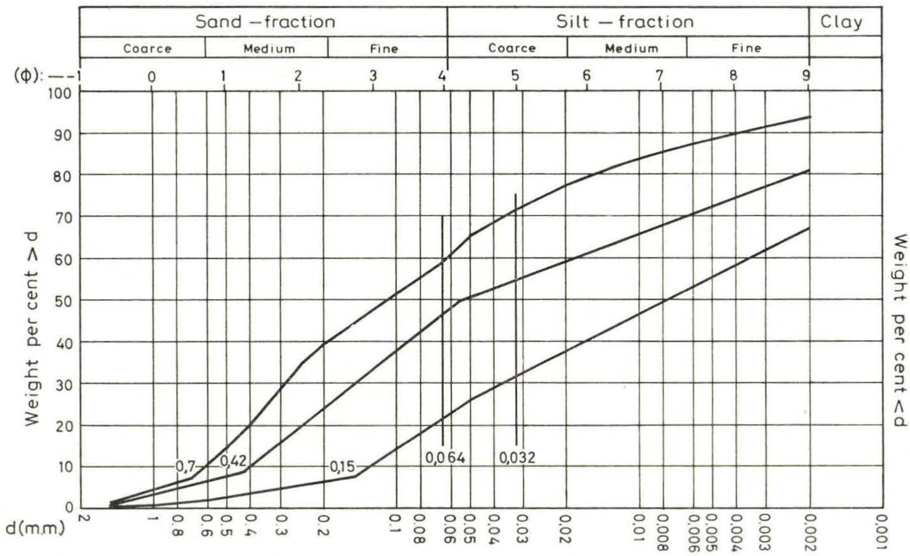

Fig. 5: Distributional curves with breaks of slope for 3 samples from loc. 7, shown as examples. The breaks in the coarse end are ascribed to a change in nature of the tills from dominance of rock fragments to dominance of mineral grains. The breaks of slope around 0.064 mm are ascribed to difficulties in connecting sieve analyses with hydrometer analyses.

50 % in most of the samples, and lastly that this fraction will be free of rock fragments.

Chemical analyses

The results of the chemical analyses are given in table 2. In table 3 the average composition of the tills for major elements is shown. The average trace element content of the tills, recalculated on $CaCO_3$ free basis, and the average contents of the pre-Quaternary formations are given in table 4.

Major elements. The figures from table 2 for K_2O, Na_2O, MgO, Fe_2O_3 and Al_2O_3 have been recalculated and plotted in triangular diagrams (fig. 6 and 7) to facilitate comparison. All the chemical data plotted are recalculated to mol percentages of basic oxides.

In fig. 6, besides Danish tills, Norwegian till analyses (E. Roaldset 1972) have been recalculated and plotted. Furthermore, analyses of Swedish basement rocks (granite and gneiss), Bredvad porphyry (Törnebohm 1901), and Rapakivi porphyry (Sahama 1945) are plotted together with mineral analyses (Deer, Howie and Zussman 1966), an earthcrust average (Krauskopf 1967) and the mean values of Norwegian loams (Goldschmidt 1954).

The Danish tills (except one analysis) plot within an area (the rhomboidal figure) of less than 2 percent of the triangular diagram and thus vary negligibly. The Norwegian tills are more scattered, and except for three analyses plot outside the Danish tills. The rock analyses plot outside the rhomboidal area, though the granite and gneiss lie closer than the porphyries. The earthcrust average (E on the figure) and the Norwegian loams (G on the figure) also plot outside the rhomboidal area, but lie among the Norwegian tills.

The analysis of the clay fraction (sample OlB) of one of the till samples plots close to the middle of the rhomboidal figure showing no difference in chemical composition between the clay fraction and the – 32 μ fraction of the till. This is consistent with studies on factors affecting the composition of argillaceous sediment (Englund and Jørgensen 1973), which concluded that moderate variations in grain size distribution have only a small effect upon the bulk chemistry. Among the mineral analyses plotted it is noteworthy that illite (7 in the figure) plots close to the till analyses and within the rhomboidal area.

In the triangular diagram fig. 7 the rhomboidal figure, the granite- and gneiss analyses and the earthcrust average from fig. 6 are shown together with plots of the analyses of the pre-Quaternary samples.

World averages of analyses of carbonate rocks (C), basalts (B), sandstones (S), granite (G) and shales (Sh) taken from Krauskopf (1967) are shown. The average of 68 analyses of Danish tills are also plotted (▲).

The plots of the analyses of the pre-Quaternary samples are more scattered than the till analysis, but three groups can be distinguished. One group of 5 samples, to the left of the till analyses, consists of 2 samples from loc. 17 and 20 containing glauconite; one sample from loc. 19 contains volcanic ash, and 2 samples from loc. 9 consist of marine diatomit (Moler). Another group of 6 samples to the right of the till analyses consist of 2 samples from Jurassic limnic sediments in loc. 14, 2 samples of limnic sediments from loc. 17 and 21 and 2 samples from loc. 22 taken outside the Weichselian glaciated area. In general most of these samples are taken from layers with a small stratigraphic or regional distribution.

The last group of 14 samples lies close to or inside the rhomboidal figure containing the till analyses. The samples consist of marine clay sediments taken from localities within the Weichselian glaciated area, with the exception of 2 samples from loc. 23. It seems from these plots that the till analyses resemble the pre-Quaternary analyses, with respect to the elements

Table 2 Chemical composition of tills and pre-Quaternary sediments. Major elements in percent and trace-elements in p.p.m.

TILL SAMPLES Loc.	Smp.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	CO_2	Li	Cr	Mn	Co	Ni	Cu	Zn	Sr	Pb
1	1A	43.00	0.42	9.00	4.06	1.24	20.92	0.87	1.80	17.79	17	45	374	< 5	30	18	32	505	39
	1B	30.00	0.56	12.00	3.89	1.74	22.65	0.93	2.28	18.94	31	71	438	10	37	29	83	504	46
	80	43.97	0.56	11.52	4.15	1.96	17.84	1.10	2.31	13.88	39	67	443	17	52	28	82	328	28
	81	45.28	0.55	10.72	3.82	2.07	18.44	1.14	2.29	13.98	26	66	486	8	51	27	65	313	20
	82	43.91	0.59	10.95	3.86	1.92	18.13	1.16	2.47	14.12	26	60	458	34	39	27	73	332	21
	83	42.08	0.55	11.30	4.20	2.01	18.26	1.09	2.47	14.72	28	67	535	28	47	30	70	334	29
2	75	52.48	0.70	14.25	5.48	1.43	8.51	1.47	2.90	7.08	32	65	509	20	35	29	20	221	35
	77	56.48	0.74	13.51	4.80	2.14	9.25	1.77	2.63	6.57	33	75	431	17	35	31	97	206	31
	78	55.31	0.72	14.50	5.26	2.21	8.62	1.57	3.25	6.16	36	76	404	15	31	33	106	197	15
	79	55.56	0.74	13.51	3.42	1.56	8.62	1.67	2.80	6.46	33	71	425	16	41	29	77	194	15
3	4	39.71	0.46	10.27	3.70	1.77	20.33	0.88	2.16	17.30	24	48	319	7	25	22	87	353	15
	7	39.81	0.49	10.32	3.73	1.72	20.17	0.83	2.14	17.20	23	44	365	10	28	23	26	316	25
4	9	36.37	0.49	11.03	4.13	1.48	20.37	0.73	2.22	17.90	25	57	351	5	29	23	51	314	20
	10	36.00	0.53	12.00	3.66	1.62	20.62	0.69	2.30	17.94	23	63	366	< 5	23	27	71	299	55
	11	47.25	0.61	13.36	4.95	1.76	12.21	0.92	2.52	10.74	27	60	377	10	31	26	63	226	15
	12	37.63	0.49	11.01	4.10	1.71	19.87	0.78	2.27	17.38	28	41	333	18	30	26	51	330	30
5	13	40.50	0.69	11.50	3.08	1.86	17.93	0.81	2.30	15.08	25	62	373	5	28	25	56	268	38
	14	42.50	0.57	11.50	3.71	1.18	17.77	0.84	2.40	15.46	26	33	332	9	22	24	64	287	45
	15	42.50	0.75	11.00	2.96	2.07	17.45	0.83	2.36	13.83	26	69	414	4	27	22	64	266	30
	16	43.00	0.53	11.00	3.69	1.66	16.49	0.89	2.36	13.99	24	59	355	5	21	30	91	235	50
	17	44.50	0.63	11.50	3.72	1.99	15.12	0.91	2.42	15.08	26	68	386	5	28	28	67	263	37
6	18	43.00	0.64	12.00	4.70	2.13	17.76	0.88	2.54	13.83	30	63	388	9	16	25	62	300	45
	19	46.00	0.64	12.00	4.49	2.36	18.05	0.77	2.53	14.32	32	58	427	9	22	25	65	286	50
	20	43.50	0.62	11.50	4.21	1.96	15.60	0.83	2.40	13.96	28	54	430	5	17	31	90	264	57
	21	43.00	0.56	11.50	3.72	2.19	21.53	0.80	2.42	15.08	28	64	443	4	23	24	56	251	43
	22	47.00	0.68	11.50	3.64	2.30	13.47	0.80	2.48	12.82	27	67	531	8	27	21	58	199	43
	25	43.00	0.63	11.50	4.05	2.07	18.14	0.75	2.44	15.58	28	67	505	4	34	24	60	314	-
7	70	45.50	0.60	12.00	3.62	1.53	14.76	0.87	2.33	12.20	25	68	405	12	24	23	77	407	-
	71	41.00	0.66	12.50	3.96	1.54	16.26	0.63	2.26	12.82	21	86	346	6	24	23	81	391	-
	72	41.00	0.67	12.00	3.45	1.66	15.89	0.90	2.21	12.68	20	75	319	< 5	28	16	90	194	-
	73	55.88	0.77	14.77	5.72	1.79	5.85	1.41	3.12	5.53	38	70	474	14	38	25	34	167	20
	74	50.00	0.74	15.50	4.75	1.55	7.44	1.37	3.15	5.46	36	90	652	21	39	26	89	505	-
8	39	36.00	0.73	12.50	4.26	3.20	20.47	0.63	2.53	17.06	34	71	468	< 5	30	29	59	316	40
	40	39.50	0.54	10.50	3.75	2.21	25.41	0.73	1.97	20.74	25	59	418	< 5	19	26	56	414	25
	41	20.78	0.26	5.32	1.36	0.93	37.51	0.30	0.93	30.35	15	40	260	19	24	20	47	819	41
	42	29.50	0.49	8.00	3.75	1.14	25.41	0.52	1.44	22.68	18	63	399	< 5	15	18	37	616	50
9	26	66.50	0.87	14.50	5.83	1.68	0.81	0.86	1.93	0	33	42	381	11	21	44	181	156	40
	27	61.89	0.86	15.76	7.15	1.67	0.35	1.16	2.82	0	30	62	518	12	44	43	128	119	30
	28	60.00	0.96	15.50	7.66	2.03	0.94	1.26	2.74	0	35	76	450	21	37	61	162	136	40
	29	59.50	0.96	17.00	9.00	1.65	0.98	1.17	2.25	0	39	79	532	23	48	57	103	130	65
	30	47.00	0.92	13.00	5.22	2.18	15.55	1.08	2.28	11.22	33	63	427	< 5	28	38	69	300	45
	31	40.00	0.51	14.50	5.23	2.09	17.60	0.77	3.12	13.22	40	70	545	9	27	32	78	342	200
10	34	46.00	0.69	11.50	4.46	2.20	18.56	0.88	2.66	11.45	34	82	469	8	43	29	70	294	36
	35	46.00	0.72	14.00	5.23	2.36	14.80	0.93	2.63	11.40	42	68	497	< 5	34	28	59	340	55
	36	45.50	0.92	14.00	5.23	2.40	14.80	0.88	2.58	11.06	37	74	570	< 5	39	34	79	314	55
	37	45.50	0.83	14.00	5.23	2.36	14.80	0.93	2.64	11.66	39	70	464	< 5	37	27	89	316	50
	38	48.00	0.75	13.50	4.85	2.45	14.80	0.91	2.65	10.52	35	66	557	< 5	31	26	66	334	45
11	44	59.00	0.98	19.00	7.99	2.36	0.85	1.07	3.15	0.08	40	107	850	< 5	62	51	190	96	20
	46	62.00	0.91	18.00	5.42	1.89	1.16	1.66	3.72	0.16	36	83	498	16	44	32	98	119	37
	47	51.70	0.68	14.50	4.71	1.99	11.69	0.87	2.38	10.14	38	85	877	14	56	34	98	225	37
12	48	37.50	0.57	12.00	3.91	1.99	18.56	0.64	2.36	16.02	29	73	412	< 5	34	26	68	339	51
	50	31.00	0.51	9.50	2.16	1.72	24.41	0.56	1.65	21.35	15	76	392	9	24	22	96	535	-
	52	35.50	0.75	9.00	2.23	1.79	25.87	0.62	1.45	20.24	11	74	362	6	13	10	99	334	-
	53	44.16	0.61	12.19	4.43	2.47	15.40	0.78	2.73	13.10	33	50	424	12	33	23	44	255	40
	54	44.47	0.58	10.88	3.89	2.19	15.36	0.84	2.61	13.26	27	58	440	16	28	21	65	279	35

Loc.	Smp.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	CO_2	Li	Cr	Mn	Co	Ni	Cu	Zn	Sr	Pb
13	55	56.49	0.90	17.55	8.71	1.81	0.56	0.80	2.88	0	55	109	978	29	88	38	51	108	25
	56	67.42	1.00	14.94	5.92	1.39	0.42	1.32	2.66	0.14	33	87	588	20	63	30	76	75	30
	57	38.00	0.73	10.50	3.17	1.33	19.88	0.53	1.46	17.32	18	74	1163	14	39	22	100	391	-
	58	33.64	0.56	10.28	4.03	1.03	20.31	0.57	1.74	17.21	28	63	365	13	40	29	23	370	25
	59	37.97	0.54	10.30	3.58	1.04	20.36	0.57	1.81	17.32	28	62	387	11	30	25	65	389	20
	60	39.00	0.61	10.50	3.20	1.33	19.34	0.60	1.72	17.06	25	67	1261	14	47	27	82	390	-
	61	38.00	0.67	11.00	3.50	1.34	19.29	0.57	1.67	17.14	22	66	1167	12	41	25	80	329	-
	62	31.50	0.59	10.50	2.67	1.61	22.64	0.51	1.70	19.67	22	64	398	12	28	14	67	384	-
	63	42.00	0.59	11.00	3.25	1.87	17.46	0.66	1.94	14.52	21	68	426	13	27	14	67	313	-
	64	39.00	0.59	10.50	3.32	1.77	19.98	0.60	1.96	17.64	27	63	447	19	32	15	63	378	-
14	65	47.50	0.87	13.50	4.55	2.17	12.12	0.97	2.59	8.00	22	85	473	16	41	26	100	216	-
	66	52.00	0.69	12.50	4.16	1.82	9.39	1.04	2.80	6.22	28	80	426	15	34	20	88	268	-
	67	51.00	0.81	14.00	4.75	1.77	8.09	0.97	2.74	6.22	25	92	420	15	36	29	101	185	-
TERTIARY																			
Loc.	Smp.																		
9	32	53.06	1.96	10.67	7.69	2.02	2.97	1.02	1.36	0	69	82	124	24	34	170	98	122	8
	101	58.80	2.37	12.73	10.73	2.12	1.78	2.01	1.21	0	62	74	99	20	20	220	125	83	< 5
11	43	32.62	-	10.66	4.29	1.07	-	0.24	1.66	-	64	93	377	39	116	50	198	756	-
15	102	59.71	0.83	17.00	7.31	1.84	1.39	0.60	2.71	0.52	63	105	110	16	56	19	58	114	10
16	103	57.95	0.83	17.46	7.51	1.82	0.81	0.87	4.12	0	46	137	102	21	40	20	101	168	15
17	104	56.34	1.19	26.79	3.22	0.98	0.15	0.35	2.46	0	62	87	59	16	50	15	48	67	35
	105	47.59	0.86	17.10	23.62	1.82	0.49	0.49	3.38	0	44	238	99	17	47	18	81	109	10
	106	65.13	0.84	11.98	6.55	1.84	2.32	0.87	2.12	0.63	26	101	225	26	45	18	105	135	10
18	110	54.04	1.23	14.73	9.35	1.97	0.42	0.56	2.69	0	39	84	98	21	25	175	104	806	10
	111	54.21	2.67	14.67	11.95	3.12	2.04	1.10	2.07	0	74	56	270	35	65	200	178	1213	10
19	107	53.76	0.84	20.66	10.07	2.32	0.73	0.47	3.18	0	59	108	593	54	136	49	139	239	15
	108	52.26	1.32	20.24	11.78	2.42	1.58	0.58	2.81	0.24	65	88	3832	52	171	80	131	299	10
	109	49.94	3.66	17.78	14.73	10.00	2.88	1.44	1.71	0.11	38	74	129	98	127	280	231	736	5
20	112	22.71	0.40	9.06	4.05	1.33	29.23	0.59	1.05	24.94	29	42	547	23	64	38	92	1033	10
	113	47.46	0.80	16.77	7.18	2.06	9.74	1.01	2.59	7.20	44	99	188	22	39	23	97	525	15
	114	45.96	0.64	13.01	19.71	1.68	0.46	0.85	3.60	0.10	36	200	181	25	62	10	80	96	30
21	115	33.64	1.02	17.95	6.01	1.08	0.28	0.26	2.50	0	42	77	185	11	44	17	47	41	15
22	116	48.63	0.96	27.99	6.22	1.06	0.15	0.37	2.09	0.20	79	80	148	18	67	28	65	48	30
	117	50.22	1.04	20.22	6.25	1.03	0.20	0.35	2.07	0	79	90	145	20	69	29	64	84	25
23	118	59.89	0.96	18.45	8.52	1.58	0.80	0.54	2.29	0.46	60	90	200	18	41	19	83	122	15
	119	55.28	0.98	21.94	8.81	1.58	0.99	0.57	2.31	0.52	70	98	208	23	50	21	80	157	15
24	120	14.80	0.06	6.32	1.94	0.76	40.26	0.42	0.47	33.91	5	24	932	14	27	16	31	992	25
25	122	45.84	1.05	19.31	11.71	2.27	5.67	0.81	2.47	4.34	73	66	5374	42	126	85	113	325	10
CALCAREOUS																			
Loc.	Smp.																		
6	24	1.22	-	0.21	0.02	0.31	-	0.09	0.11	-	2	< 5	261	< 5	< 5	6	16	615	-
26	Stevns 1	1.38	-	0.20	0.10	0.66	-	0.24	0.14	-	2	< 5	215	< 5	8	7	88	599	-
	Stevns 2	1.31	-	0.12	0.08	0.36	-	0.07	0.07	-	< 1	< 4	166	< 5	< 5	7	65	839	-
27	Møn 1	1.49	-	0.16	0.04	0.21	-	0.09	0.09	-	< 1	< 5	96	< 5	11	7	31	628	-
	Møn 2	1.37	-	0.11	0.04	0.19	-	0.09	0.07	-	< 1	< 5	94	< 5	< 5	6	26	698	-
JURASSIC																			
Loc.	Smp.																		
14	68	67.00	1.21	16.00	1.17	0.58	0.34	0.27	1.26	0	77	114	98	20	37	15	69	97	-
	69	90.00	0.68	3.00	0.27	< 0.05	< 0.05	0.12	0.25	0	4	41	41	< 5	10	< 5	26	37	-

Missing analyses are indicated by a stroke.

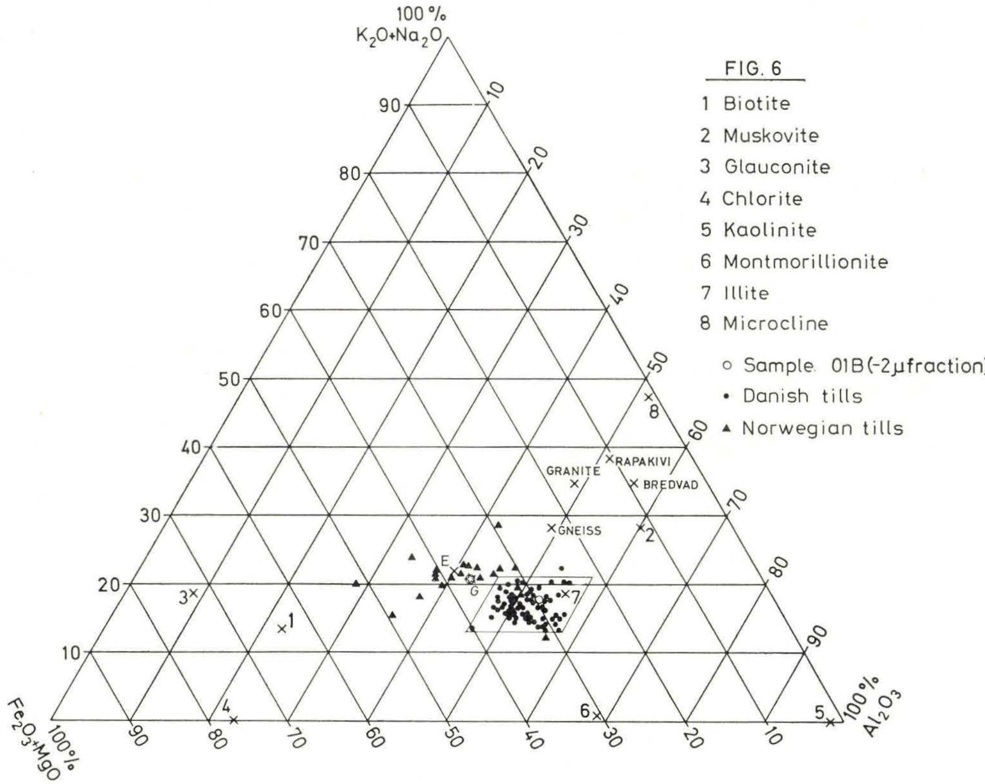

Fig. 6: The relative frequencies of the shown oxides reveals that the Danish tills (68 analyses) plot within a small area (the rhomboidal figure), while the Norwegian tills (22 analyses) are more scattered and plot outside the rhomboidal area. The mineral analyses, except illite, also plot outside the area. The rock analyses of granite, gneiss and Bredvad porphyry from Sweden and Papakive porphyry from Finland also plot outside, through the granite and gneiss lie closer to the rhomboidal figure. An earth-crust average (E) and Norwegian loams (G) also plots outside the area of the Danish tills.

used in the triangular diagram, more than they resemble Scandinavian basement rocks. Lastly it should be noted that the world average of shales lies within the area of the till analysis.

The major elements analysis has shown that the till samples analysed are very simiiar in composition and that the Weichselian tills in Denmark may be regarded as a chemically rather well-defined rock type. In table 3 the average composition of the tills has been calculated.

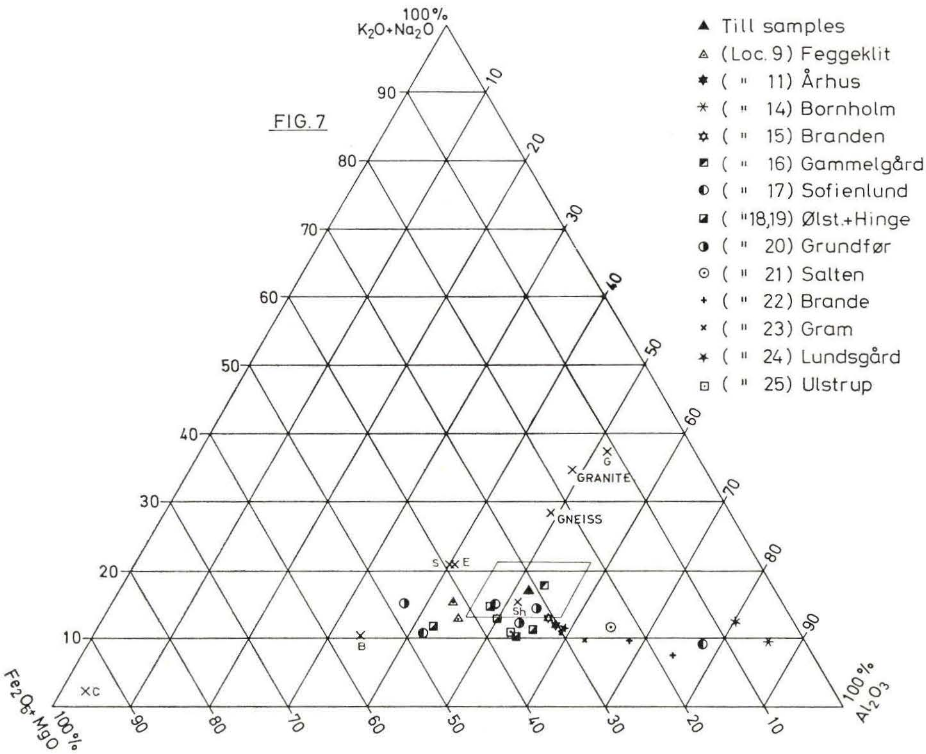

Fig. 7: The rhomboidal figure of the till analyses, the granite and geniss analyses and the earthcrust average from fig. 6 are shown together with world averages of carbonate rocks (C), basalts (B), granite (G), sandstone (S) and shales (Sh). The average of 68 analyses of Danish tills is also shown (▲).

The rest of the plots are pre-Quaternary local non-calcareous sediments. Roughly 3 groups of analyses can be distinguished: One group of 5 samples to the left, and another group of 6 samples to the right of the rhomboidal area. A larger group of 14 samples plots closer to or within the rhomboidal area and thus resembles the till analyses.

Table 3. Average composition of ÷ 32 μ fraction of the till samples.

	$\bar{X}_{68}$ %	s %
SiO_2	44.81	8.95
TiO_2	0.67	0.15
Al_2O_3	12.30	2.23
Fe_2O_3	4.28	1.37
MgO	1.84	0.40
CaO	16.54	10.94
Na_2O	0.89	0.30
K_2O	2.40	0.47
CO_2	12.50	6.31

From the figures in table 3 the content of calcite in the avarage till has been calculated to 28.4 %. On the basis of the Al_2O_3 and SiO_2 content of an illite analysis (Deer *et al.* 1966) the possible content of this mineral in the average till has been calculated. Based on these contents of calcite and illite the relative frequency of possible minerals of the tills has been estimated as follows:

Calcite	3
Illite	6
Quarts and other silicates	1

Illite seems to constitute an important part of the till; this is also indicated by the illite analysis shown in the triangular diagram fig. 6. Preliminary X-ray investigations of the clay fraction of the samples also show that clay minerals from the illite-group possibly form the major clay minerals in the tills.

Trace elements. The sedimentological investigations and the major element analyses have shown that the analysed till samples vary only little and that they constitute a uniform background on which regional and stratigraphical variations of the trace elements can be evaluated.

In table 4 are listed figures from table 2, showing the trace element content in Cretaceous (Møn 2) and Paleocene, and the average contents for Eocene, Oligocene and Miocene. The average trace element content of the tills recalculated on $CaCO_3$ free basis is also shown. This is done because the $CaCO_3$ content in most of the samples is high and variable, and it has been shown (Binzer 1973) that the pre-Quaternary calcareous sediments from which the $CaCO_3$ in the tills is predominantly derived do not contribute significantly to any of the trace elements analysed for, except for Sr. Furthermore it is expedient to exclude the $CaCO_3$ for the sake of comparisons with similar materials poor in $CaCO_3$.

The tendency of regional distribution of trace elements has previously been discussed (Binzer 1973) and it was shown that there is a little higher content of Li, Cr and Ni in the northern part of the country. It was also shown that in loc. 9 with more than one till the content of Co, Ni, Cu and Zn in the uppermost till was higher than in the underlying tills. Likewise in loc. 13 it was shown that the content of Mn and Ni in the one upper till present was significantly higher than in the lower till. The Cu content in the upper till was also slightly higher.

In fig. 8 the values from table 4 have been represented graphically to

Table 4

Avarage trace-element content in tills and pre-Quaternary sediments. Values in p.p.m.

		Li	Cr	Mn	Co	Ni	Cu	Zn	Sr	Pb x)
WEICHSELIAN TILLS N=68	max	67	122	1931	49	88	88	193	819	43
	$\bar{x}$	38	92	680	15	45	41	105	292	28
	s	8	19	279	9	13	19	32	113	8
	min	21	22	447	5	21	20	23	75	15
MIOCENE N=5	max	79	98	208	23	69	29	83	157	13
	$\bar{x}$	66	87	177	18	54	22	67	90	20
	s	13	7	26	3	11	4	12	44	6
	min	42	77	145	11	41	17	47	41	15
OLIGOCENE N=7	max	63	238	225	26	62	23	105	525	35
	$\bar{x}$	45	138	137	20	48	19	81	173	17
	s	12	54	55	3	7	2	20	146	9
	min	44	87	59	16	39	15	48	67	10
EOCENE N=8	max	74	108	5374	98	171	280	231	1033	15
	$\bar{x}$	54	74	1367	93	140	139	139	591	9
	s	19	19	1915	52	83	42	42	385	3
	min	29	42	99	21	25	38	92	83	5
PALEOCENE		5	24	932	14	27	16	31	992	25
CRETACEOUS		< 1	< 5	94	< 5	< 5	6	26	698	-

The values of the tills are recalculated on $CaCO_3$-free basis, except Sr.

x) Pb values of the tills are calculated on analyses of 30 samples.

show the trace element variation in the stratigraphic column from the Cretaceous to the Quaternary. It appears that the Tertiary includes formations which have a higher trace element content than the Quaternary tills. This together with the major element analyses, supports the idea, that the tills have inherited most of their element content from local Tertiary clay formations in the same way that they have inherited the $CaCO_3$ content from the local pre-Quaternary calcareous sediments (Binzer 1973).

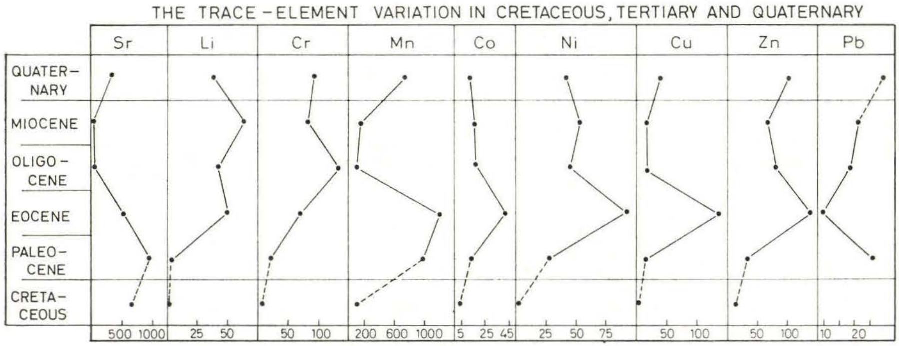

Fig. 8: The variation in the content of trace elements of the stratigraphic colum from Cretaceous to Quaternary is shown. It appears from the graph that the Tertiary includes formations with a trace element content higher than the Quaternary tills. Only Pb shows a slightly higher value in the Quaternary.

Summary of the chemical analyses. This investigation shows that the clayey tills analysed here have a surprisingly uniform chemical composition though the tills reveal a confusing mess in appearance as well as genetically. It appears furthermore that the Danish tills are to a great extent a sediment of local origin with only a low content of exotic material. This observation is consistent with analyses of clays from Fennoscandia (Soveri 1950) showing relationship between the local basement rocks and the clay mineral composition in the Quaternary clays.

Statistical analyses

The 9 trace elements analysed for (Sr, Li, Cr, Mn, Co, Ni, Cu, Zn and Pb), the $CaCO_3$ content and the -32 μ fraction of 67 till samples were statistically treated by correlation analysis. The strong correlation between Sr and $CaCO_3$ previously shown (Binzer 1973) was confirmed.

Acknowledgements. This work was carried out during the period August 1971 to February 1973. Statens teknisk videnskabelige Fond made it possible to make the investigations and is gratefully thanked.

I wish to express my graduate to prof. dr.phil. *H. Pauly* of the Mineralogical Institute, Technical university of Denmark and to director, dr.phil. *O. Berthelsen* of the Geological Survey of Denmark, who took personal interest in the project. A special word of thanks is due to lecturer, mag. scient. *Troels V. Østergård* for discussions and fruitful criticism during the work. I am also indebted to members of the staff of the Geological Survey of Denmark for help and suggestions, especially to State Geologist dr.phil. *Helge Gry*.

Dansk sammendrag

Sedimentologiske og kemiske undersøgelser er blevet udført på prøver af moræneler fra weichsel-istiden og prøver fra præ-kvartære aflejringer (se fig. 1). Undersøgelsens omfang og forløb er skitseret i diagrammet side 115.

De sedimentologiske undersøgelser bestod i stentællinger og kornstørrelsesanalyser. Resultaterne af disse undersøgelser er fremstillet grafisk i fig. 2, 3, 4, og 5. Det konkluderes at det undersøgte moræneler er af så ensartet beskaffenhed at det er tilladeligt at drage sammenligninger mellem kemiske analyser af prøverne.

De kemiske undersøgelser har omfattet analyser af morænelerets finfraktion (mindre end 0,032 mm) og, til sammenligning, af udvalgte prækvartære ler- og kalk aflejringer (se fig. 1). Følgende hovedelementer er blevet bestemt: Si, Al, Fe, Mg, Ca, Na, K samt følgende sporelementer: Sr, Li, Cr, Mn, Ni, Cu, Co, Zn og Pb (se tabel 2). I trekantdiagrammet fig. 6 er de relative mængder mellem K_2O, Na_2O, MgO, Fe_2O_3 og Al_2O_3 for hver af de analyserede morænelerprøver blevet indsat. Desuden er til sammenligning indsat analyser af norske morænelersanalyser og andre bjergarts- og mineralanalyser. Diagrammet viser at det danske moræneler ligger indenfor et område der udgør mindre end 2 % af hele trekantdiagrammet og de analyserede prøver må således siges at variere ubetydeligt. Det norske moræneler ligger udenfor det danske moræneler og mere spredt. De øvrige anførte analyser bortset fra lermineralet Illit (nr. 7 i diagrammet) ligger ligeledes udenfor. I trekantdiagrammet fig. 7 sammenlignes morænelersanalyserne med analyser af de prækvartære leraflejringer. Yderligere er der indsat analyser af andre bjergarter, bl.a. granit og gnejs fra det skandinaviske grundfjeldsområde. Det fremgår af diagrammet at der er større lighed mellem morænelerет og de lokale, danske præ-kvartære lersedimenter end mellem moræneleret og de skandinaviske bjergarter.

Den gennemsnitlige sammensætning af de analyserede morænelersprøver er anført i tabel 3. På grundlag af dette gennemsnit og på grundlag af en analyse af Illit er det mulige indhold af dette mineral blevet beregnet. Ligeledes er indholdet af $CaCO_3$ (Kalkspat) blevet beregnet. Forholdet mellem følgende mulige mineralsammensætning i moræneleret er derefter blevet estimeret til: Kalkspat 3, Illit 6, Kvarts og andre silikater 1.

Sporelementindholdet i moræneleret har vist sig at være meget ensartet, bortset fra et lidt højere indhold af Li, Cr og Ni i den nordlige del af landet. På lokalitet 9 og 13 kunne der vises en vis forskel i sporelementindholdet mellem 2 morænelersbænke. I fig. 8 er sporelement-variationen (taget fra tabel 4) i prøver taget i formationer der repræsenteter tidsrummet fra kridt til kvartær blevet grafisk afbilledet. Det fremgår heraf at tertiæret indeholder formationer, der har et højere sporelementindhold end moræneleret. Dette, sammen med hovedelementanalyserne, støtter tanken om at moræneleret har arvet det meste af sit sporelementindhold fra de lokale tertiære lerformationer.

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