LITHOLOGICAL INVESTIGATIONS IN SOME DANISH BOULDER-CLAY PROFILES

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Abstract. About 150 samples, taken from three boulder-clay deposits on Lolland and Fyn in Denmark, have been examined for the grain-size distribution in the sand, silt and clay ranges (fine earth) and for the content of different rocks in the fine-gravel and the coarse-sand fractions. The investigation, which was followed by chemical analyses, was carried out in order to find an easy way of locally dividing boulder-clay deposits into units with different characteristics. The usefulness of the methods of obtaining this result is discussed. It seems that for a particular layer the parameters have a constant size. Finally, using as a basis about 300 samples, representing 35 localities, the possibility of using the contents of palaeozoic limestone for regional correlations is mentioned.

INTRODUCTION

The exact characterization of the different types of glacial earth with regard to grain-size distribution and other properties has often, especially in Sweden, been emphasized in the literature about the Quaternary (for instance, Hörner, 1944, 1946 and 1947, and Gillberg, 1969). In this paper only the properties of boulder clay will be treated. The methods of analysis used are simple and easy to perform and take only a relatively short time.

When Werner Christensen, Principal Geologist at the Geological Survey of Denmark, was examining in the early 1960s the geochemical environments in clay sediments (Werner Christensen, 1962), I had the opportunity of carrying out lithological analyses of sample series from different localities on Sjælland in Denmark. In two of these localities, the samples consisted of boulder clay, which was deposited in layers with visible differences. Within a particular layer, the lithological parameters seemed to have a constant size. If it could be shown that this condition was of general application, lithological investigations might become useful in stratigraphical work. In the following years, an investigation was therefore carried out, using samples from profiles in which the boulder clay showed a clearly visible stratification.

METHODS

Sampling. In order to obtain statistical significance, the samples were as far as possible taken in large numbers. Sampling in this way implies, however, a very small amount of material in each separate sample. Methods which require much material are therefore out of the question.

Granulometric analyses. About 100 g of dry material was washed in sieve No. 230 (0.063 mm). A thousand millilitres of 0.005 *M* sodium-pyrophosphate solution (22.3 g $Na_4P_2O_7$, 10 H_2O in 1000 ml H_2O) was used for the washing of each sample. The solution was collected in a cylinder glass, in which the sedimentation was analysed with a hydrometer. Material which was retained in sieve No. 230 was dried and analysed by dry sifting. Grain curves were drawn for the fine earth only, since the amounts of gravel and stone were not representative in such small samples. The term "fine earth" includes the following grain-size sections: sand (2.00—0.06 mm), silt (0.06—0.002 mm) and clay (< 0.002 mm).

Petrographic analyses. Formerly it was the custom to carry out grain-counting on the sample part, consisting of small stones and coarse gravel (about 60—6 mm), washed out from a 10-kg sample of boulder clay (Ussing and Madsen, 1897). For such small amounts of material as were available in this investigation, that method was naturally not usable, the less so as in all prohability it was not statistically valid for the 10-kg samples either (Marcussen, 1973). Instead, about 300 grains in the fine-gravel and coarse-sand fractions (about 6.00—1.41 mm) were separated into the following rock groups:

Rock group	Abbreviations used in diagrams and tables
Chert	Ch.
Limestone, Cretaceous	Li.Cr.
Limestone, Palaeozoic	Li.Pal.
Igneous and Metamorphic rocks	I.m.r.
Sandstone and Quartzite	S.Q.
Shale	Sh.
Various	Var.

The ratios between thc amounts of these rock groups are practically constant in the fractions studied, whereas they would be modified in the fractions larger than 6.00 mm and totally changed in the fractions smaller than 1.41 mm (medium-and fine-grained sand). In the last-mentioned size ranges, chert will be under-represented and the group of "igneous and metamorphic rocks" will be dominated by monomineralic grains (Søndergaard, 1959).

It was found that it would involve a good deal of trouble to choose a graphical representation which clearly showed the essential relations between the many varying sizes. Finally it was resolved to make the number for the group of "igneous and metamorphic rocks" equal to 100 and to convert the numbers for the other groups proportionally to that. Furthermore, the "sandstone and quartzite", "shale" and "various" groups are omitted in the diagrams, among other things, because the numbers for these groups depend largely on the separation method used.

Heavy-mineral analyses. All the samples from one of the localities treated (Rødby) were examined for heavy-mineral content. For each sample, the fraction 0.25—0.177 mm was divided by means of Bromoform into a heavy and a light part. About 150 mineral grains from each part were determined. It was, however, not possible in this way to demonstrate a clear difference between the upper and the lower boulder clay. Possibly the locality chosen was unsuitable for this; therefore it was intended some day to try the method at another locality with different conditions.

Chemical analyses. Material from each sample was subjected to an examination of the $CaCO_3$-content, and furthermore selected samples were analysed for a large number of trace elements. The results of these investigations supported, in the cases of certain elements, the lithostratigraphy which was proposed on the basis of other investigations. For the traceelement analyses, a crushed-down part of the total sample was used. Subsequent analyses showed that better results were obtained by using material from the fine-silt and clay fractions solely (Binzer, 1973).

Rødby

In 1961 it was possible to follow several, separate, boulder-clay layers right through the great excavation made during the construction of the harbour at Rødby Ferry. As references were selected a water-sorted gravel layer and a conspicuous colour change from yellow to grey. In each of two ferry berths with a mutual distance of 50 m a vertical series of samples was taken (series A and B). In the latter series, the boulder clay was covered by a 10-cm-thick layer of peat (Atlantic) and by about 3 m of marine deposits, while in the former series both the postglacial layers and the uppermost metre of the boulder clay were missing.

The above-mentioned colour change is accompanied by a change in the relation between sand, silt and clay (see diagrams, Fig. 1), whereas the thin layers of well-sorted gravel, sand and silt separate units that apparently show no essential differences. The grey boulder clay is clearly different from the yellow one, as regards the median grain size (see diagrams, Fig. 2). Also some of the chemical-analysis series show the presence of a sudden change at the point where the colour changes (see diagrams, Fig. 3). This is shown particularly well in the case of the $CaCO_3$ content. The grain-count results (see diagrams, Fig. 4) are very interesting, as they show a conformity between the curves for chert and Cretaceous limestone, thus proving that the differences between the two units depend on their original characteristics and are not merely the result of chemical disintegration (weathering). The quotient for Palaeozoic limestone is rather high but shows no clear difference between two units.

Lindø

The establishment of the Lindø shipbuilding yard in northern Fyn in the years 1957 and 1958 offered good opportunities, as was the case at Rødby harbour, of seeing boulder-clay profiles showing their stratified structure, at this locality alternating with metre-thick layers of sand, silt and clay deriving from meltwater. In the dock excavations, some of the boulder-clay layers were demarcated by glacially striated pavements, the striae of which were measured by the late Dr. K. Milthers, Principal Geologist at the Geological Survey of Denmark, and by G.O. Andrup, the Director of the Odense Waterworks (Nielsen, 1961). Four

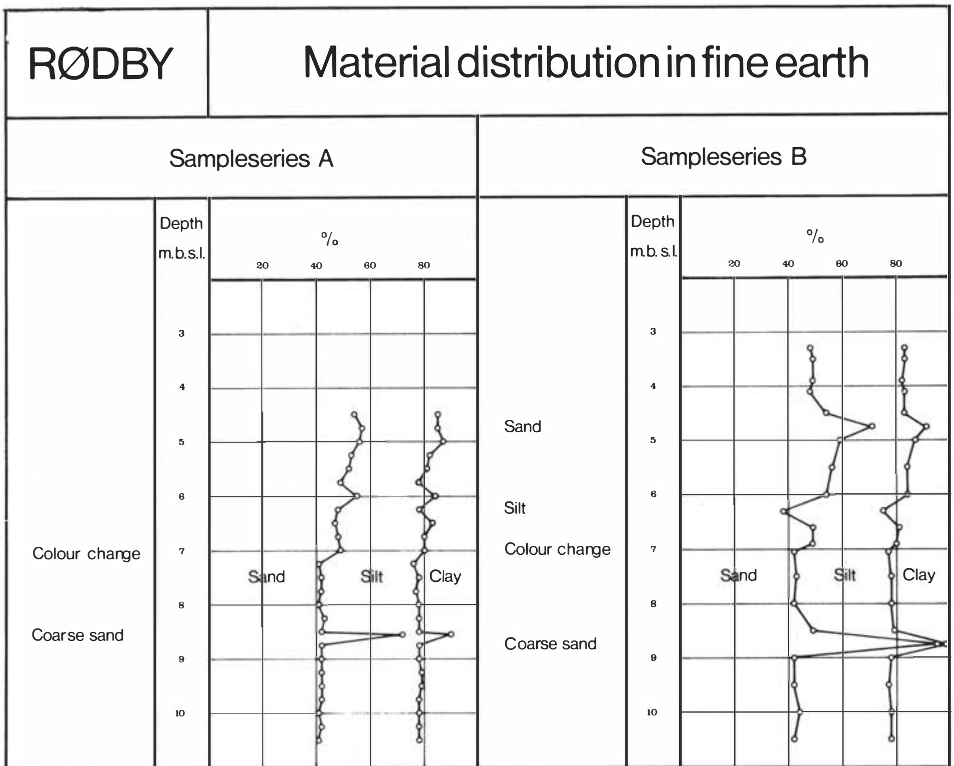
RØDBY
Material distribution in fine earth
Sampleseries A
Sampleseries B
Depth
m.b.s.l.
%
20
40
60
80
3
4
5
6
7
8
9
10
Colour change
Coarse sand
Sand
Silt
Clay

Fig. 1.

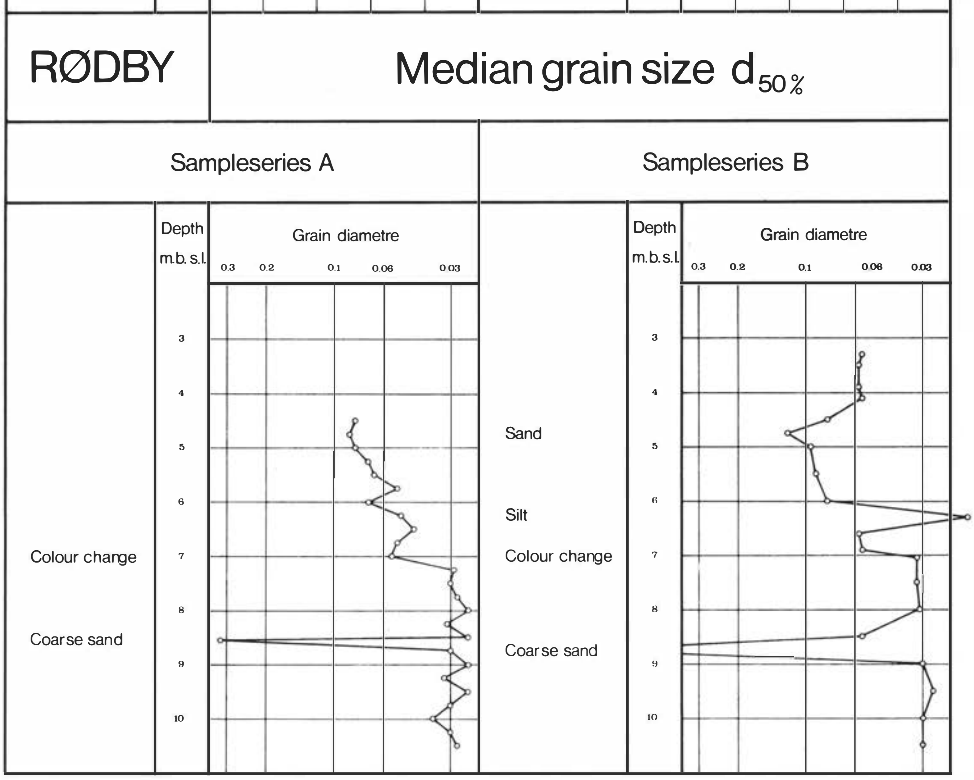
RØDBY
Median grain size d50%
Sampleseries A
Sampleseries B
Depth
m.b.s.l.
Grain diametre
0.3
0.2
0.1
0.06
0.03
3
4
5
6
7
8
9
10
Colour change
Coarse sand
Sand
Silt

Fig. 2.

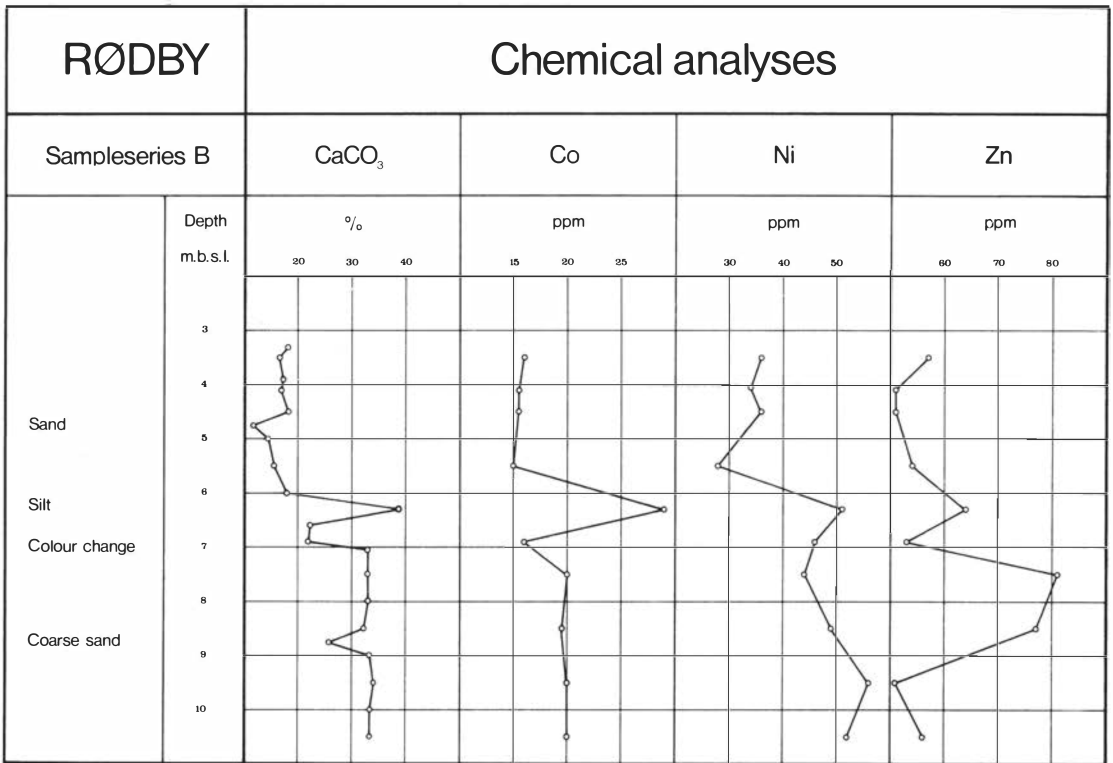
RØDBY
Chemical analyses
Sampleseries B
CaCO3
Co
Ni
Zn
Depth
m.b.s.l.
%
ppm
ppm
ppm
20 30 40
15 20 25
30 40 50
60 70 80
3
4
5
6
7
8
9
10
Sand
Silt
Colour change
Coarse sand

Fig. 3.

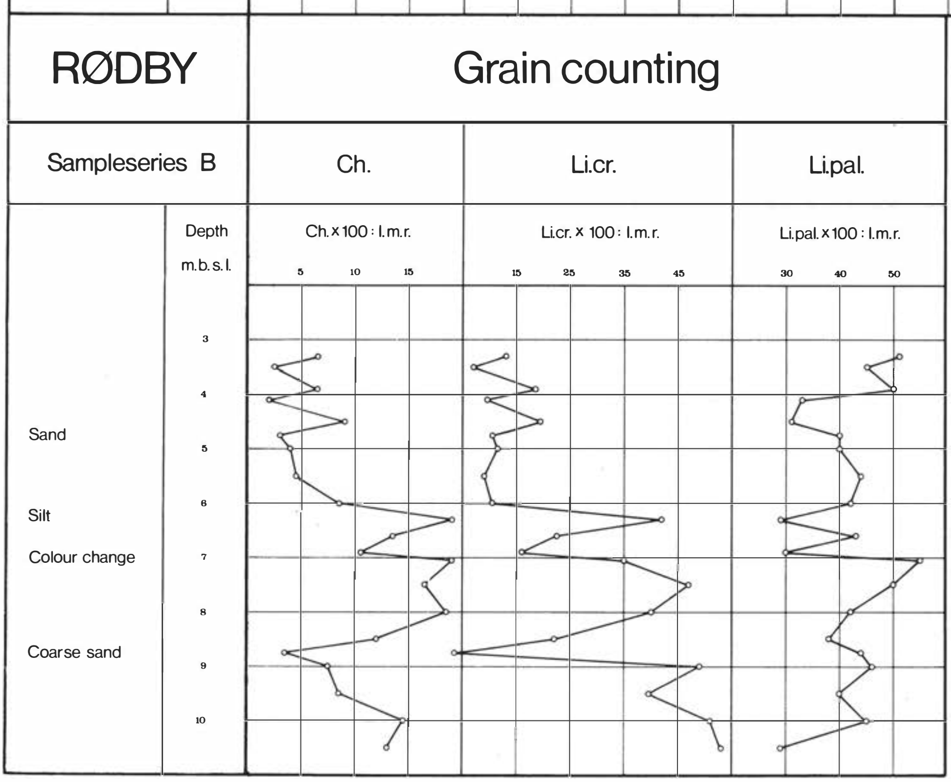
RØDBY
Grain counting
Sampleseries B
Ch.
Li.cr.
Li.pal.
Depth
m.b.s.l.
Ch. × 100 : l.m.r.
Li.cr. × 100 : l.m.r.
Li.pal. × 100 : l.m.r.
5 10 15
15 25 35 45
30 40 50
3
4
5
6
7
8
9
10
Sand
Silt
Colour change
Coarse sand

Fig. 4.

Table 1. Grain-counting table. Rødby: Profile B.

m.b.s.l.	Ch.	Li.Cr.	Li.Pal.	I.m.r.	S.Q.	Sh.	Var.	Total
3.30	10	21	83	159	35	17	0	325
3.50	5	15	95	210	27	22	0	374
3.90	9	26	70	139	34	23	0	301
4.10	4	17	59	180	24	42	0	326
4.50	18	38	61	196	53	36	0	402
4.75	6	20	77	191	47	43	0	384
5.00	7	19	68	169	37	40	0	340
5.50	11	23	112	254	55	61	0	516
6.00	14	17	69	165	30	44	0	339
6.30	26	57	39	136	32	21	0	311
6.60	29	48	92	212	42	39	0	462
6.90	25	38	71	239	46	21	0	440
7.05	32	58	91	167	37	35	0	420
7.50	26	74	70	158	52	21	0	401
8.00	29	64	66	159	50	49	0	417
8.50	42	77	132	348	85	92	0	776
8.75	69	66	858	1937	195	264	0	3389
9.00	17	111	103	226	88	37	0	582
9.50	15	68	69	173	45	37	0	407
10.00	28	98	87	193	43	41	0	490
10.50	30	124	68	234	49	44	0	549

metres below sea-level, there was a pronounced pavement striated from the southeast, a little deeper down an uncertain pavement with striations from due north and 6 m below sea-level again a regular pavement, striated from the east. The same direction was found on boulders below the lowermost pavement. Dr. Sv. Th. Andersen, Principal Geologist at the Geological Survey of Denmark, has made an attempt to classify the layers by means of pollen analysis (Andersen, 1965). For the sediment analyses in the present work, samples were used which came from the same profile and boring (profile B and boring No. 8, located 25 m from profile B) as were used for the pollen analyses. Unfortunately the results of the sediment analyses did not bear comparison with the efforts expended. This was mainly because the number of samples from within the particular layers was too small to be statistically significant, but also because of difficulties in correlating the two localities. Nevertheless there seem to be some indications of homogeneous units in the very varying sample series. The boulder clay situated over the uppermost pavement makes up a homogeneous unit as regards the grain-size distribution and the median grain size (see diagrams, Fig. 5). The next unit, between pavements No. 1 and No. 2, differs from the first one, but from this unit we have only one sample. In the section between pavements No. 2 and No. 3, several samples were taken. However, only the uppermost part (two samples) of this section consists of boulder clay, the remaining part being water-sorted sand, silt and clay. The two boulder-clay samples are rather uniform and their properties differ from those of the overlying boulder clay. On the other hand, they show in their grain-size distribution a similarity to the boulder-clay samples taken from below pavement No. 3 and right down to 17 m below sea-level. This is the case, in spite of the fact that the boulder clay in this region is divided by several sand layers up to 2 m in thickness. Still, variations in the median grain size suggest that we have to do with more than one unit. About 18 m below sea-level, the boulder clay is a little more clayey (one sample), while the following 3 m consist of a homogeneous, sandy, boulder clay, interrupted by a thin sand layer and underlain by a sand layer about 10 m thick. In the boulder clay below the thick sand layer, a single sample was taken, which had an intermediate grain-size distribution. In the figures, the profile is divided, on the basis of the analyses performed, into a series of boulder-clay horizons which only partly accord with the division made on the basis of pollen analysis. Any division is, however, to be taken with a certain caution by reason of the few samples. Nevertheless the division made on the basis of grain-size distribution seems in the main to be confirmed by the chemical analyses and the grain countings (see diagrams, Fig. 6). The $CaCO_3$ analyses and the quotient for Palaeozoic limestone are particularly useful, while the quotients for Cretaceous limestone and chert vary independently of the divisions.

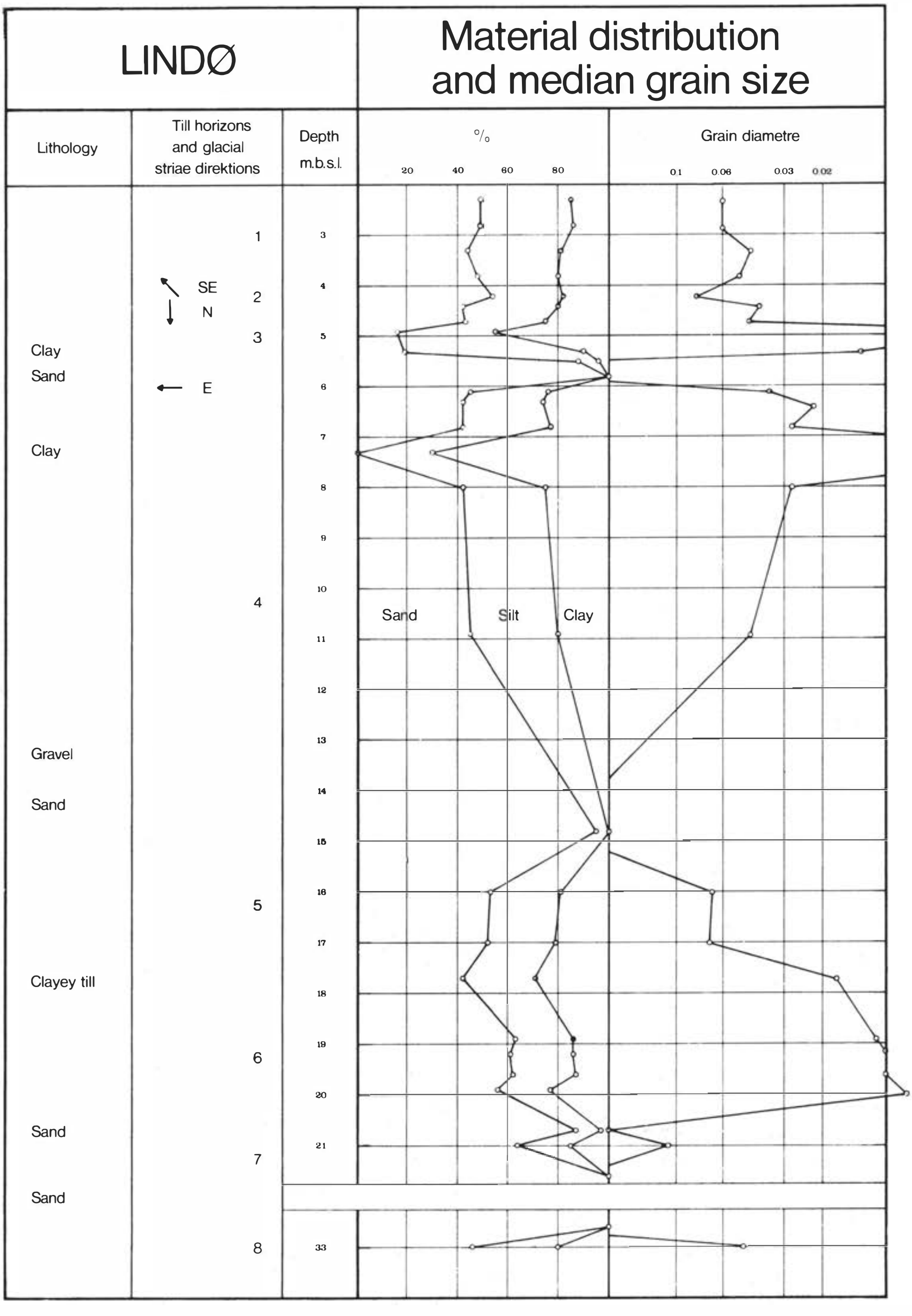
LINDØ
Material distribution and median grain size
Lithology
Till horizons and glacial striae direktions
Depth m.b.s.l.
%
Grain diametre
20
40
60
80
0.1
0.06
0.03
0.02
Clay
Sand
Clay
Gravel
Sand
Clayey till
Sand
Sand
SE
N
E
1
2
3
4
5
6
7
8
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
33
Sand
Silt
Clay

Fig. 5.

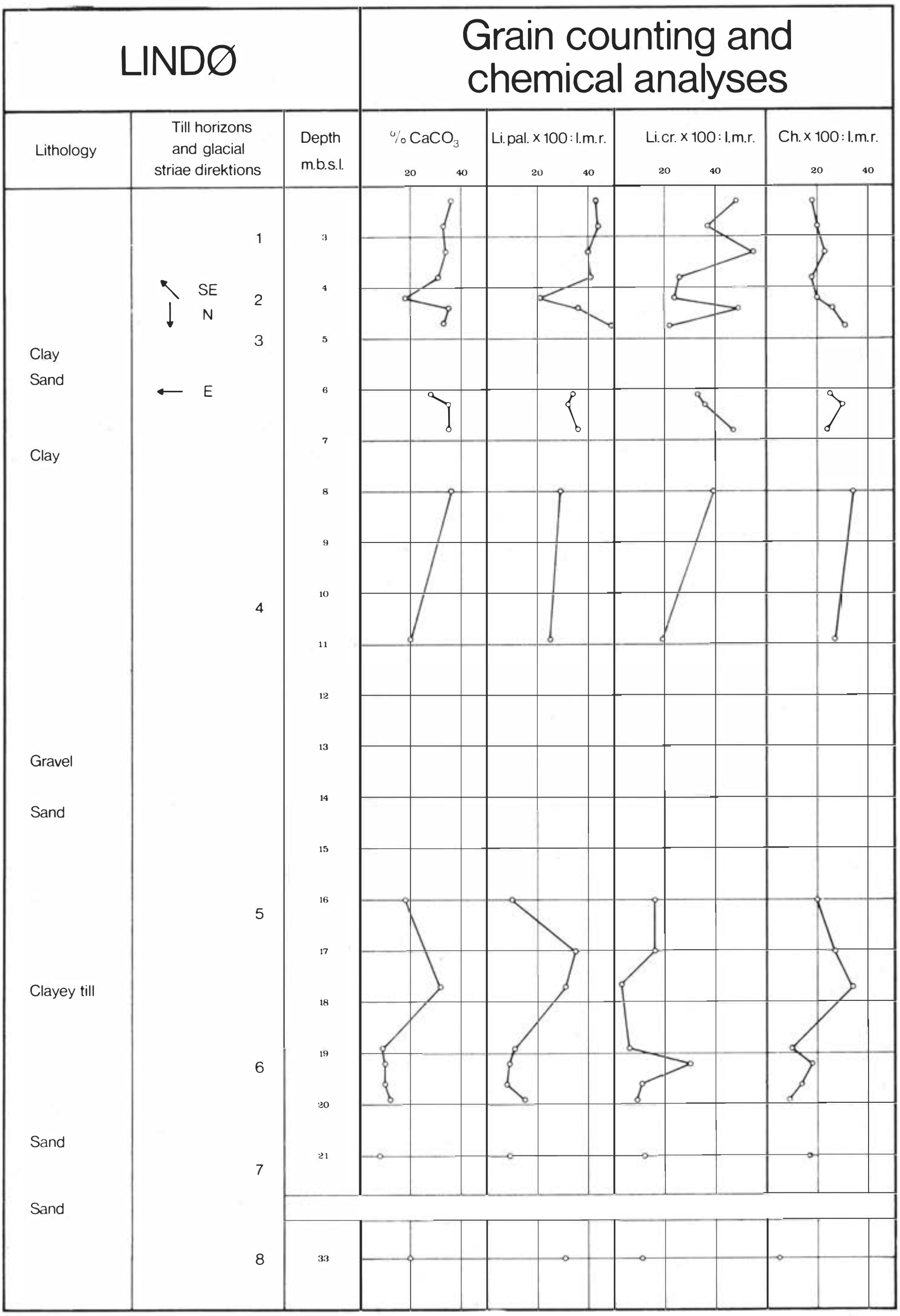
LINDØ
Grain counting and chemical analyses
Lithology
Till horizons and glacial striae direktions
Depth m.b.s.l.
% $CaCO_3$
Li.pal. x 100 : l.m.r.
Li.cr. x 100 : l.m.r.
Ch. x 100 : l.m.r.
20
40
Clay
Sand
Clay
Gravel
Sand
Clayey till
Sand
Sand
SE
N
E
1
2
3
4
5
6
7
8
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
33

Fig. 6.

Table 2. Grain-counting table. Odense.

m.a.s.l.	Ch.	Li.Cr.	Li.Pal.	I.m.r.	S.a.	Sh.	Var.	Total
Odense: Boring No. 3								
11.0	31	30	52	165	28	6	0	312
10.0	44	33	50	131	25	7	0	290
9.5	35	37	53	179	22	4	0	330
9.0	62	43	46	156	21	2	0	330
8.5	71	39	63	185	52	18	0	428
8.0	28	35	24	115	19	6	0	227
7.5	20	34	75	187	35	19	4	374
7.0	27	22	56	129	29	5	0	268
6.5	39	19	58	113	63	16	0	308
6.0	23	9	55	112	29	12	1	241
Odense: Boring No. 6								
10.8	47	27	68	160	51	23	3	379
10.3	60	63	76	228	46	28	0	501
9.8	33	19	57	141	30	11	0	291
9.3	45	45	54	139	32	11	0	326
8.8	33	40	53	131	21	7	0	285
8.3	46	49	49	146	27	10	0	327
7.8	43	30	61	130	36	4	0	304
7.3	28	17	72	152	29	4	0	302
6.8	21	21	66	124	30	8	0	270
6.3	18	15	48	107	19	5	0	212
5.8	25	20	65	151	50	2	2	315

Odense

For the third investigation, samples were studied from six borings carried out by the Danish State Railways as a pilot study for the construction of a container terminal on Odense freight station. The borings are placed at intervals of 30 m. During the drilling, vane tests were carried out which showed an increase in undrained compression at about the same depth (7.5 m above sea-level) in all the borings (see diagrams, Fig. 7). The sample descriptions showed that the increase in strength was accompanied by a colour change. The compact, lower part of the profile was brownish, while the upper part had the typical grey colour of ordinary boulder clay. All the samples from this locality consisted of boulder clay and the investigations in the laboratory showed that the brown material generally had a larger content of silt and a smaller content of sand than the grey material, whereas the clay content was practically the same (see diagrams, Fig. 8). In borings Nos. 6, 7 and 10, these tendencies are the most pronounced. The three samples (boring No. 3, 9.5 m above sea-level, boring No. 14, 8.5 m above sea-level and boring No. 11 (6.5 m above sea-level) which deviate from the norm represent brown smears in the grey boulder clay and grey lumps in the brown one. These variations show even more distinctly in the curves for median grain size (see diagrams, Fig. 9). The $CaCO_3$ content cannot be used for dividing the section into the two boulder-clay layers, since it is almost the same for all depths in the six borings (see diagrams, Fig. 10). On the contrary, the quotients for limestones in the grain-counting are very useful (see diagrams, Fig. 11). The content of Palaeozoic limestone is a little higher and that of the Cretaceous limestone a little lower in the brown boulder clay, and since the increase and decrease are about equal, a constant $CaCO_3$ content follows. The variation in the limestone content cannot have been caused by weathering and it must be concluded that it shows that the grey and the brown boulder clays are of different origins. The brown colour may be a consequence of the larger content of Palaeozoic limestone.

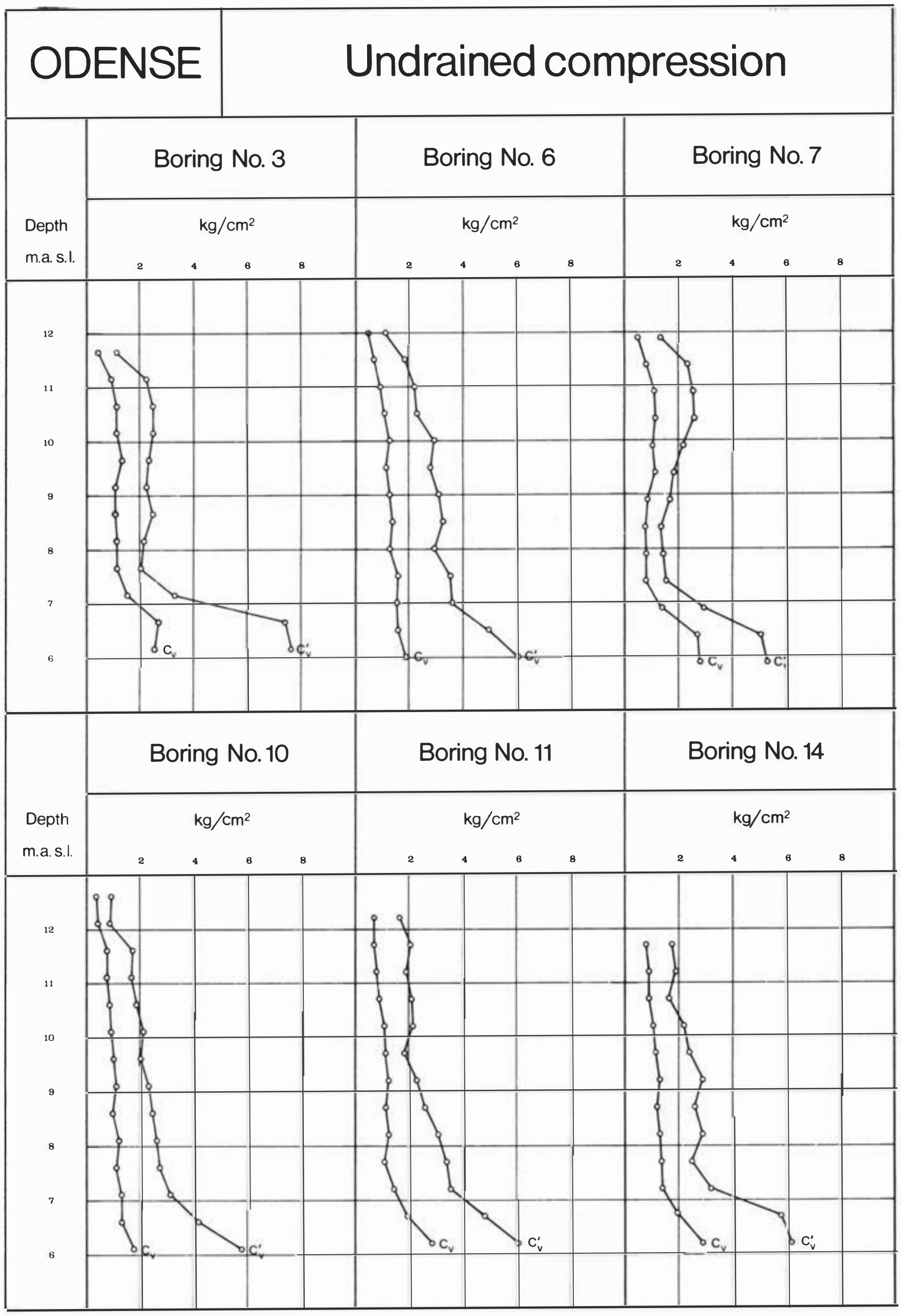
ODENSE
Undrained compression
Boring No. 3
Boring No. 6
Boring No. 7
Depth
m.a.s.l.
kg/cm²
2
4
6
8
12
11
10
9
8
7
6
Cv
C'v
Boring No. 10
Boring No. 11
Boring No. 14

Fig. 7.

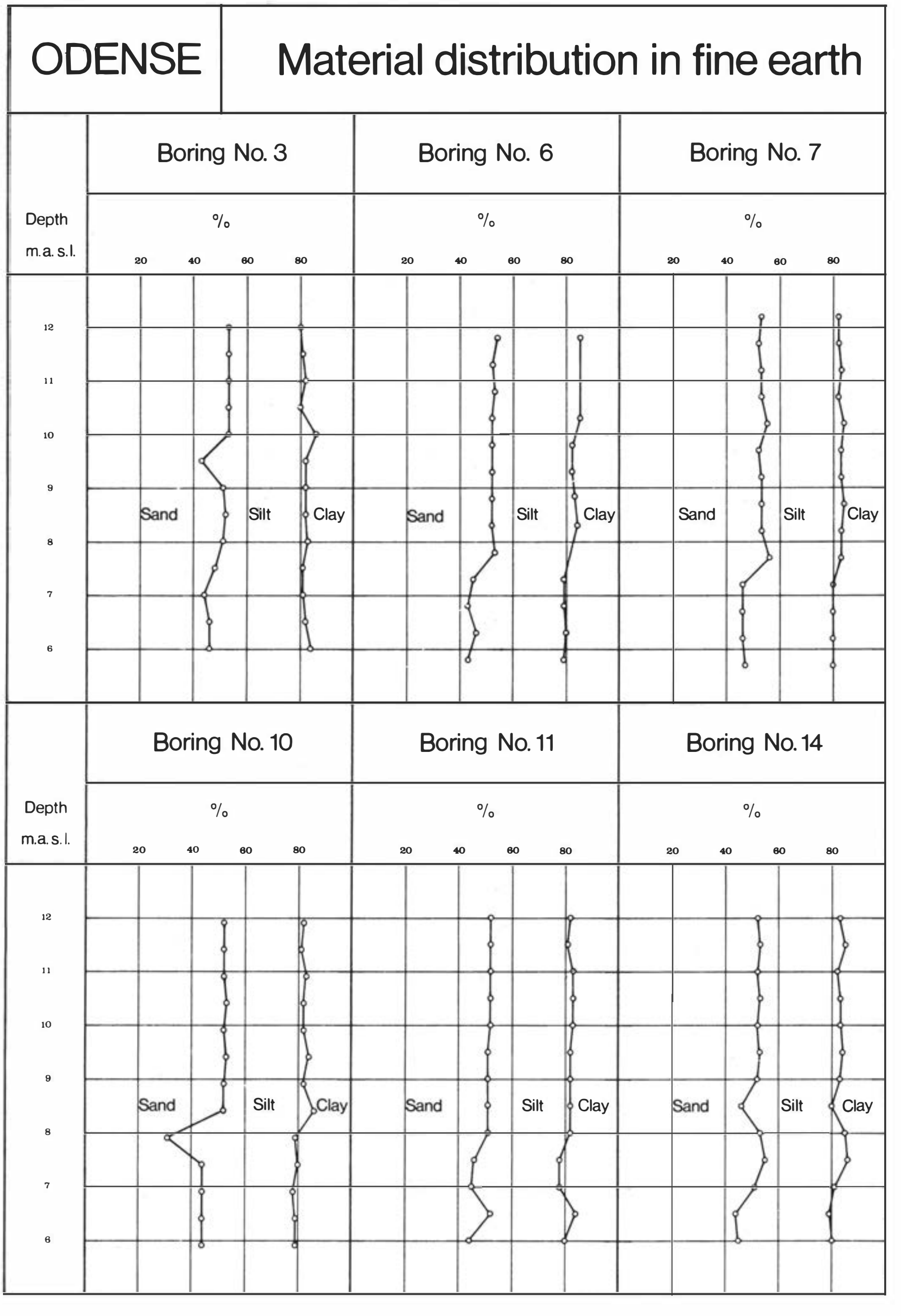
ODENSE
Material distribution in fine earth
Boring No. 3
Boring No. 6
Boring No. 7
Depth
m.a.s.l.
%
20
40
60
80
12
11
10
9
8
7
6
Sand
Silt
Clay
Boring No. 10
Boring No. 11
Boring No. 14

Fig. 8.

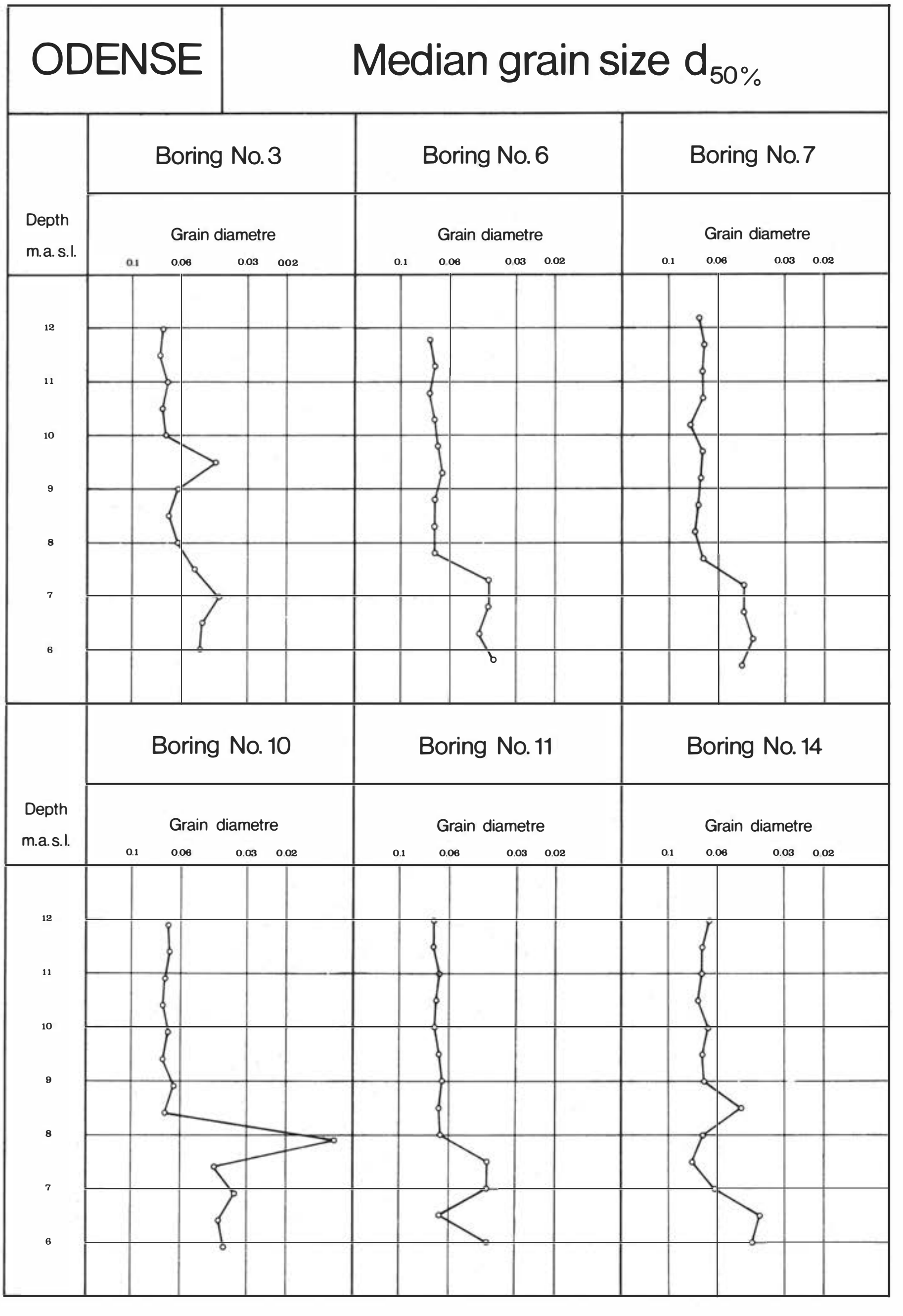
ODENSE
Median grain size $d_{50\%}$
Boring No. 3
Boring No. 6
Boring No. 7
Boring No. 10
Boring No. 11
Boring No. 14
Depth m.a.s.l.
Grain diametre
0.1 0.06 0.03 0.02
12
11
10
9
8
7
6

Fig. 9.

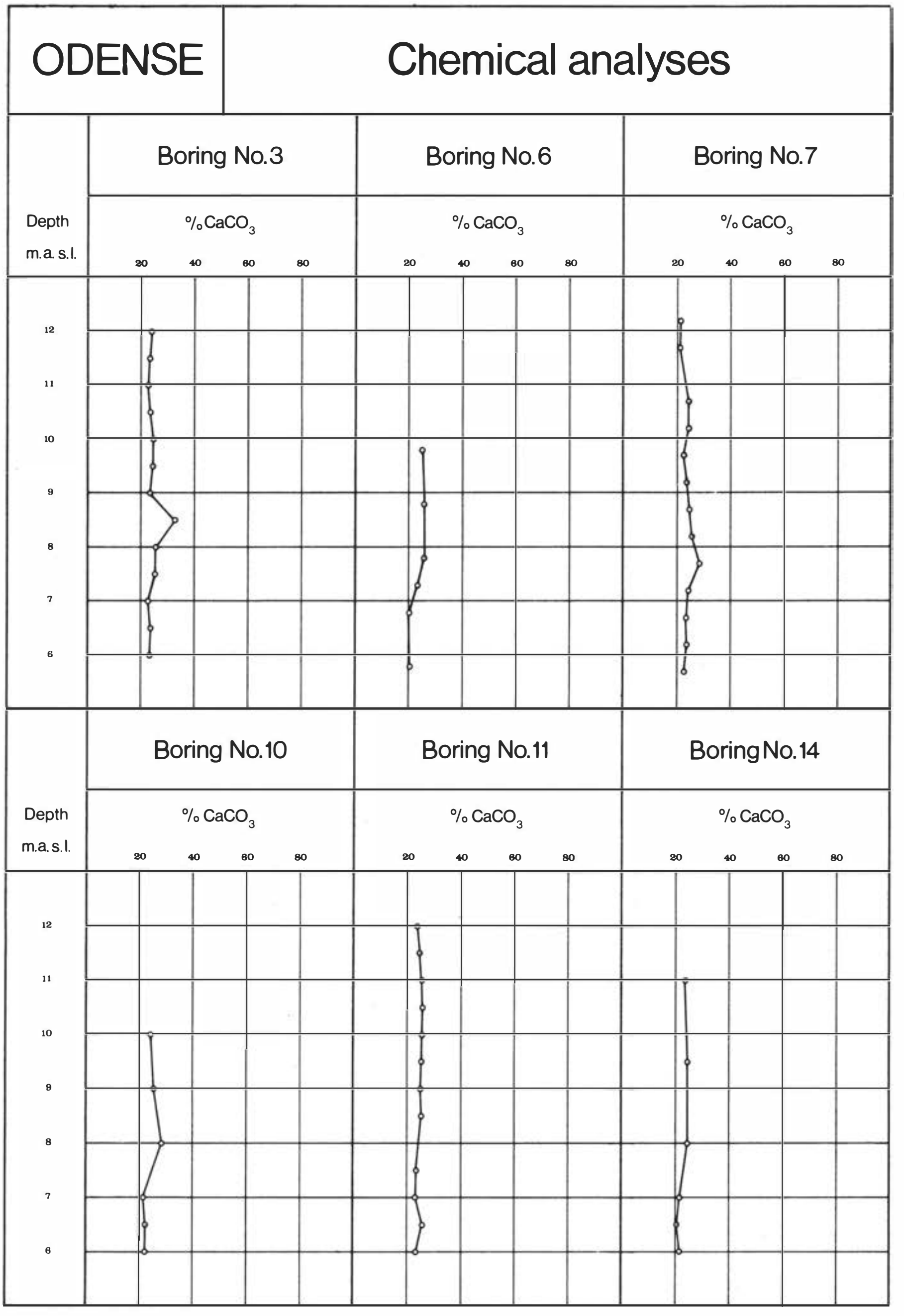
ODENSE
Chemical analyses
Boring No.3
Boring No.6
Boring No.7
Boring No.10
Boring No.11
Boring No.14
Depth
m.a.s.l.
% $CaCO_3$
20
40
60
80
12
11
10
9
8
7
6

Fig. 10.

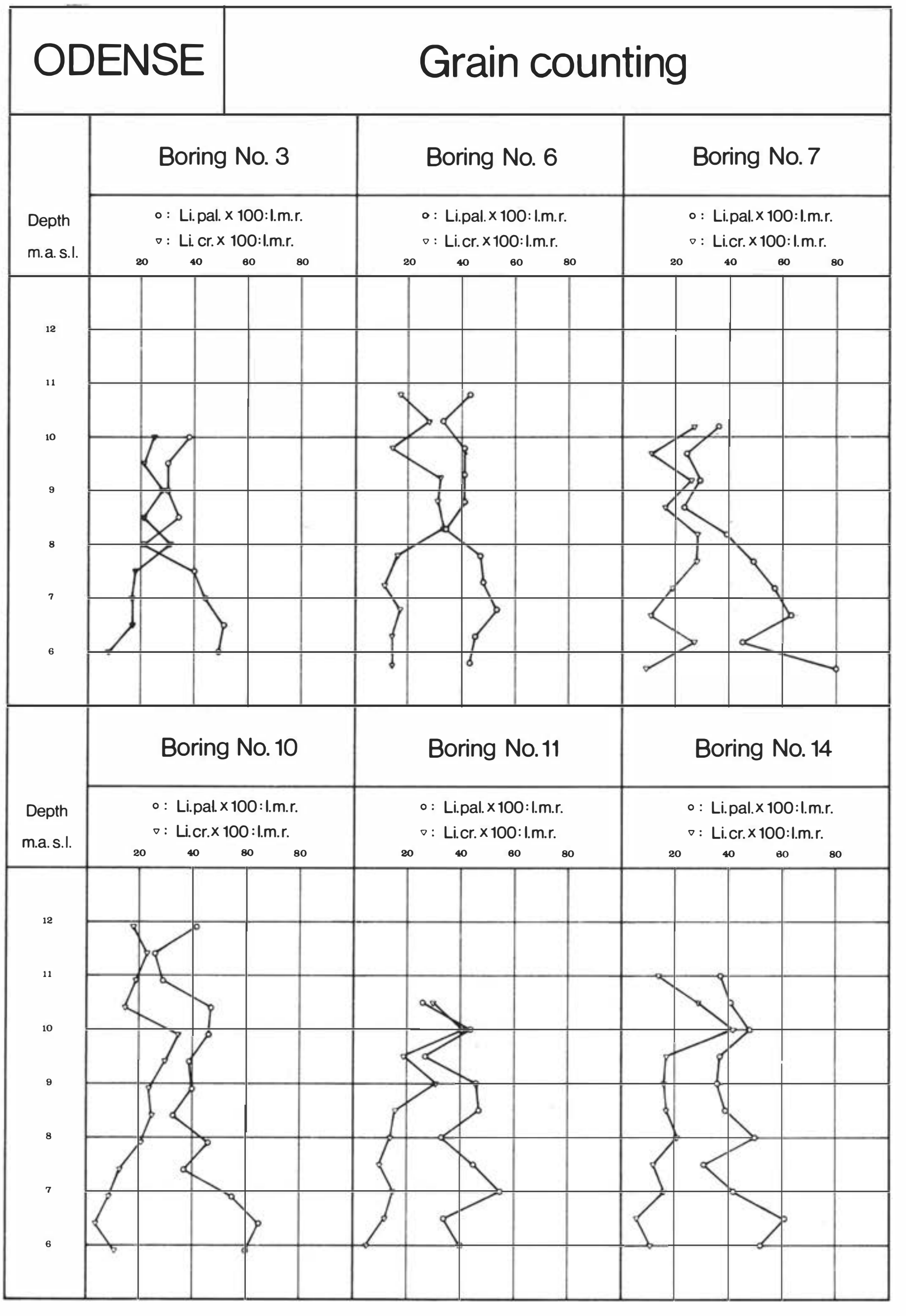
ODENSE
Grain counting
Depth
m.a.s.l.
Boring No. 3
Boring No. 6
Boring No. 7
o : Li.pal. x 100 : l.m.r.
▿ : Li.cr. x 100 : l.m.r.
20
40
60
80
12
11
10
9
8
7
6
Boring No. 10
Boring No. 11
Boring No. 14

Fig. 11.

Table 2. (continued)

m.a.s.l.	Ch.	Li.Cr.	Li.Pal.	I.m.r.	S.a.	Sh.	Var.	Total
Odense: Boring No. 7								
10.2	42	52	70	197	22	4	12	399
9.7	55	40	67	194	43	8	0	407
9.2	34	45	51	174	17	6	1	328
8.7	41	28	41	178	35	3	1	327
8.2	46	49	64	167	29	17	0	372
7.7	50	39	69	140	38	21	0	357
7.2	29	23	67	118	51	13	0	301
6.7	31	16	91	145	27	10	3	323
6.2	23	35	58	129	29	13	0	287
5.7	22	11	95	119	26	10	2	285
Odense: Boring No. 10								
11.9	61	30	69	166	23	3	2	354
11.4	30	43	49	189	30	4	0	345
10.9	49	37	58	198	38	13	1	394
10.4	25	26	82	173	39	1	0	346
9.9	46	53	70	153	28	4	0	354
9.4	64	60	79	201	48	18	3	473
8.9	42	30	50	124	49	16	0	311
8.4	41	49	65	197	36	16	1	405
7.9	10	9	20	43	10	0	1	93
7.4	25	12	36	97	31	4	0	205
6.9	12	9	54	99	21	2	2	199
6.4	27	4	90	139	43	11	0	314
5.9	11	11	57	95	29	5	0	208
Odense: Boring No. 11								
11.0	38	33	70	122	22	9	1	295
10.5	34	33	29	111	21	5	0	233
10.0	40	47	51	116	24	9	0	287
9.5	30	24	34	124	23	6	0	241
9.0	16	30	45	98	19	7	0	215
8.5	26	19	57	122	32	12	0	268
8.0	42	20	46	139	29	21	0	297
7.5	22	11	51	113	35	6	0	238
7.0	18	16	58	106	36	3	0	237
6.5	180	17	48	141	57	14	0	457
6.0	28	6	50	124	40	4	0	252
Odense: Boring No. 14								
11.0	22	12	32	86	27	12	0	191
10.5	47	38	53	130	22	8	0	298
10.0	51	52	59	124	17	3	0	306
9.5	36	23	45	126	27	21	0	278
9.0	43	34	78	219	34	9	0	418
8.5	29	22	51	131	27	5	0	265
8.0	40	24	57	114	31	9	1	276
7.5	41	20	51	166	35	14	0	327
7.0	17	19	51	121	34	9	0	251
6.5	27	6	63	104	42	10	0	252
6.0	28	13	62	119	23	5	1	251

Other localities

After the positive results gained in Rødby, Lindø and Odense, the same methods were applied to the samples in two of the studies in this bulletin (Petersen, 1973 and Binzer, 1973). The present report will not include the details of these investigations, but it should be mentioned that also here it was possible to observe lithological differences between the different boulder-clay layers.

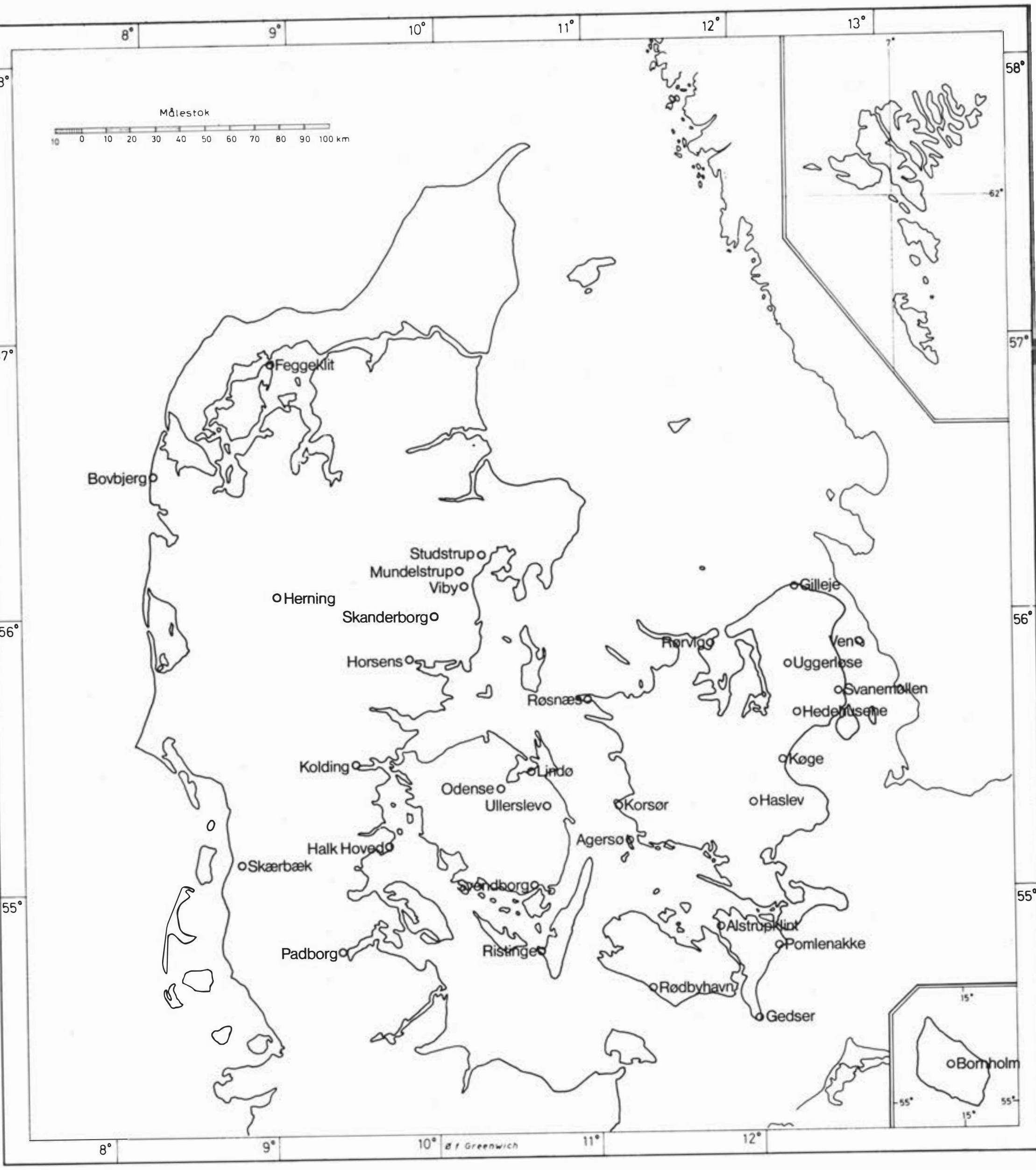

Fig. 12. Grain counting localities.

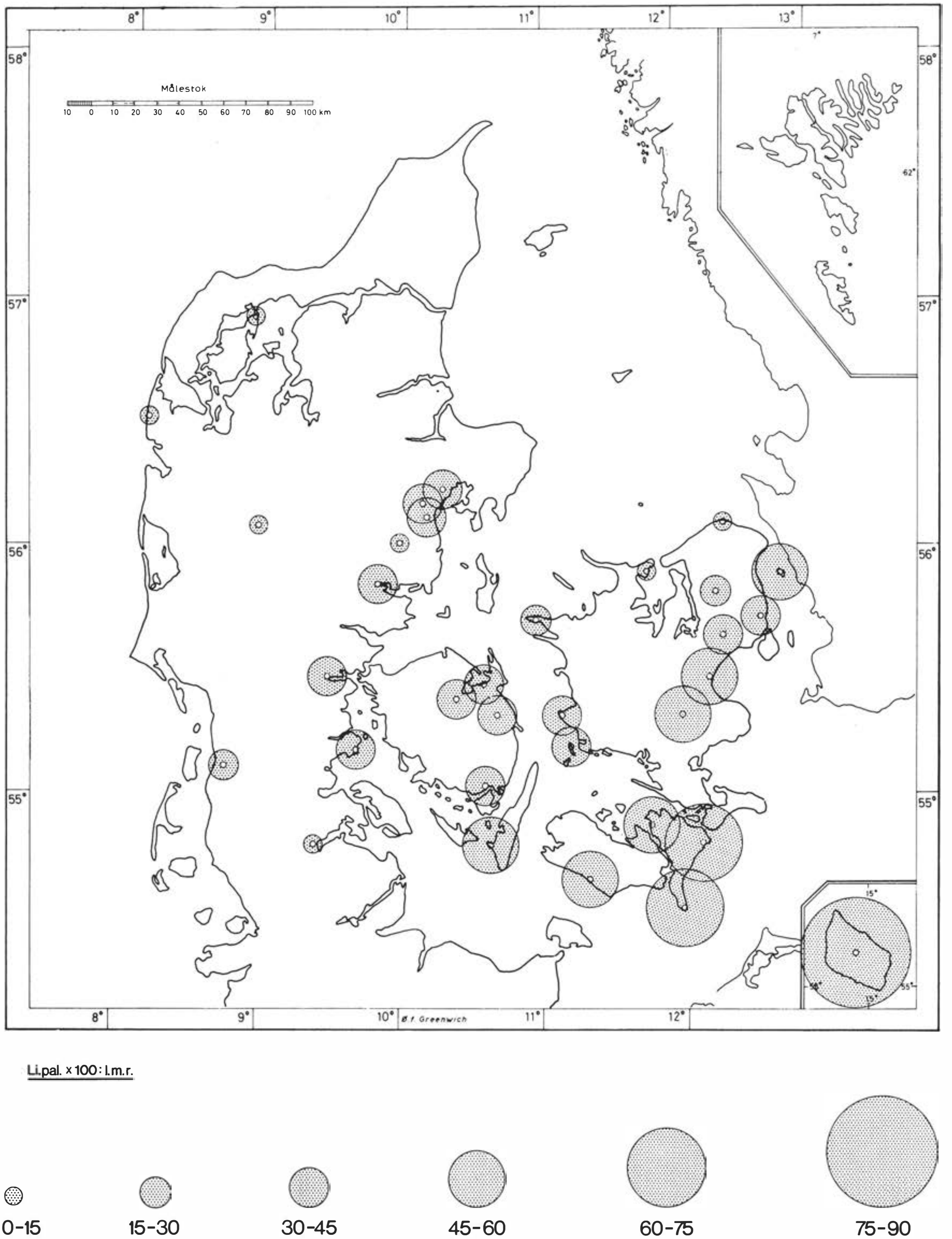

Fig. 13. Regional variation for Palaeozoic limestone in the uppermost boulder clay layer.

CONCLUSION

As a first result, this investigation shows that a boulder-clay unit usually has a surprisingly constant grain-size distribution. Hence the median grain size $d_{50\,\%}$, normally gives a quick idea of the build of a profile with several boulder-clay units. Likewise, by investigating the petrographic grain distribution in the fine-gravel and the coarse-sand fractions, an unquestionable uniformity within each unit is demonstrated. The use of more than one method of analysis ensures that the observed variations between the units are actually caused by differences in origin and are not only a result of weathering. A surprising fact which is revealed by the grain-counting is the large content of Palaeozoic limestone. Even as far as the central part of Jylland, these relatively soft rocks, transported from afar, are found in considerable amounts. Possibly their aptitude for being ground into a streamlined shape is a contributory cause of their preservation.

APPENDIX

From these studies, it appears that the quotient of Palaeozoic limestone (amount of Palaeozoic limestone multiplied by 100 and divided by the amount of igneous and metamorphic rocks) shows a great variation as between the localities analysed. It was found desirable to record any regularity in the regional variation. Therefore, as a preliminary investigation, grain-countings were carried out in the uppermost boulder-clay layer in about 35 localities (see map, Fig. 12). There seems to be a decrease from south-east to north-west and a sudden fall to about zero outside the line indicating the ice border in eastern Jylland (see map, Fig. 13). A similar low value of this quotient is found in the underlying boulder clay in several places in the eastern part of Denmark.

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