GEOLOGICAL INVESTIGATIONS ON BOULDER-CLAY OF E. GRONINGEN

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CHAPTER I

INTRODUCTION

1. GEOGRAPHY

An investigation of boulder-clay was made in the region of Winschoten. It is situated in the eastern part of the province of Groningen at the German border. The samples were collected from outcrops and borings (marked + in fig. 1). Analyses were made of unweathered boulder-clay samples only, so that the results would be more reliable.

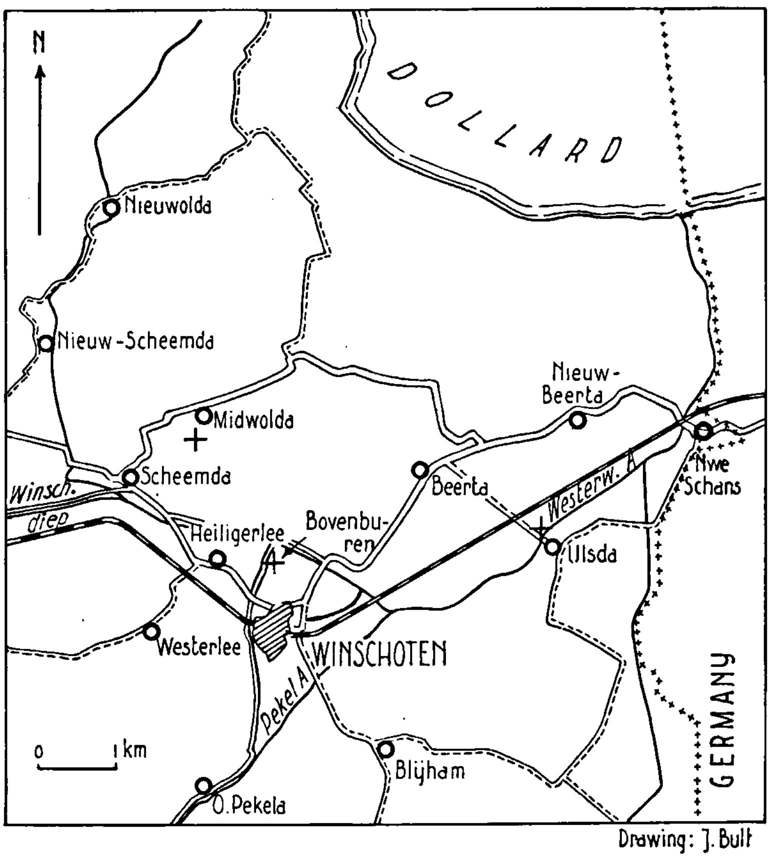

Fig. 1. Indexmap of the Winschoter area (E. Groningen) + locality of the samples

2. STRATIGRAPHY

The boulder-clay in this region is part of the rather fragmentary boulder-clay covering the northern provincies of the Netherlands, which was considered to be a ground moraine by Brouwer (1950). It was deposited by the continental ice during the last glacial but one (Saalien or Riss). On top of this boulder-clay an almost continuous layer of yellowish white "cover sand" occurs, deposited during the Late Pleistocene. This niveo-eolian sediment may in turn be covered by Holocene sediments. Nearly everywhere in this region a complex of preglacial deposits is found beneath the boulder clay. They consist of fine sands and humic clays deposited before the approaching glacial front and often disturbed by the push of the continental ice. Their origin is partly fluvio-glacial. To some extent the humic bluish-black clay, locally called "potklei" (pottery clay) which is found in this region, also belongs to it.

3. PURPOSE OF INVESTIGATION

During investigations in the field it was found that a closer examination of the boulder-clay at the laboratory might be advisable in order to solve all problems concerning its origin and composition.

The theory that the boulder-clay in this region is the normal type (de Ridder & Wiggers 1956) will be put to the test by the results of the authors' investigations. Observations in the field were made by P. van Gijzel (Chapter II). The same author examined the pollen and spores (Chapter III) as well as granulometric composition and heavy mineral content (Chapter IV) of all clay and boulder-clay samples. The erratics in the boulder-clay from Bovenburen were closely examined by C. J. Overweel (Chapter V). H. J. Veenstra analysed the microfossil and light mineral content (Chapter VI).

Several studies were already made of the boulder-clay in this region, e. g. by van Calkar, Bonnema and Martin (cf. de Waard 1947).

CHAPTER II

FIELD OBSERVATIONS

1. EXPOSURE AT BOVENBUREN

Near Winschoten along the new road connecting Oude Pekela and the highway from Groningen to Nieuwe Schans at some 500 metres south of the Klooster bridge across the Nieuwe Winschoterdiep there is an evenly curved drumlin. When this part of the road was being built the present author measured a profile in the eastern bank of the ditch (outlined in fig. 2) intersecting the core of this drumlin. Edelman & Maarleveld (1958) already stated that drumlins occur in this region. Just like the other drumlins at this locality the one at Bovenburen has a long axis pointing NE—SW.

It is striking how the curving in the underground is reflected in the present topography. In a gradually higher complex of bluish black humic clay (the so-called "potklei") with fine white and grey sands, a weathered brownish yellow layer of boulder-clay wedges southward. The boundary of the layer is irregular, due to cryoturbation. As a result lenses of boulder-clay occur in the clay. The reserve also occurs. The whole is covered by a thin layer of rather fine yellowish white eolean sand, the much younger so-called "old cover sand".

The boulder-clay itself is hardly ice-pushed contrasting with the underlying clay and sands. Faber (1947) already made mention of ice-pushed "potklei" beneath an undisturbed layer of boulder clay at Kloosterholt near Winschoten.

The "potklei" is strongly weathered above the ground water level, but not below. Due to chemical weathering the clay looks gummy. Among American pedologists this weathering is well known as "gumbo til". On account of the considerable time needed for their formation these tils are locked upon as Pleistocene soil weathering. Those found in the "potklei" in Drenthe were described in detail by van Heuveln (1959). In the profile (fig. 2) at the left only the unweathered grey boulder-clay occurs. Here samples B 1 and B 2 were collected. Field observations revealed a high sedimentary erratic content, which was confirmed by megascopic and microscopic examination (Chapter V). For the rest (colour, lime content) there is much resemblance megascopically with the grey boulder-clay type common in the northern provinces. De Waard described it for the N.O. Polder (1947). Granulometrically it is in accordance with the normal boulder-clay type of de Ridder & Wiggers (1956). At Bovenburen the boulder-clay had the greatest thickness observed in this region: in the profile at the left a maximum of 3 metres was found.

The microfossil content also confirms resemblance to the normal type (Chapter VI).

2. BOULDER-CLAY AT MIDWOLDA

Here, too, boulder-clay occurs at the core of a drumlin. Sample M 53 is from a boring along the Burglaan (road from Midwolda to Scheemda)

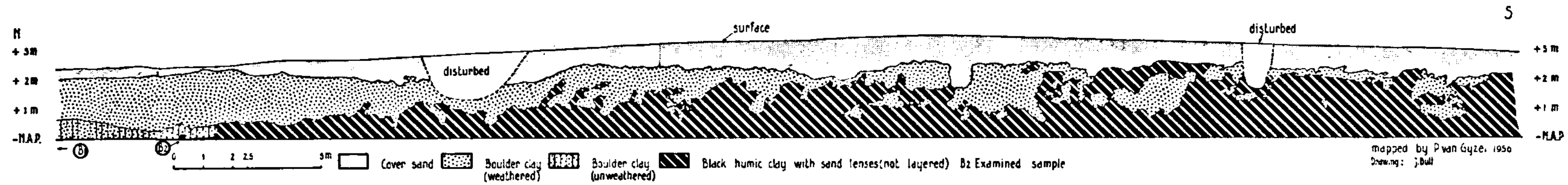

Fig. 2. Exposure of Bovenburen near Winschoten

at 500 metres south of Midwolda. This grey boulder-clay also lies between "cover sand" and "potklei". Only here and there it is unweathered. Usually just a layer of boulders is left. In the borings it appeared to be rich in clay, downward it was even found to pass into clay. Granulometric and palynologic examinations showed that clay material ("potklei") had entered the boulder-clay. Presumably considerable intermingling was caused by the ice.

3. APPINGEDAM

Sample A 51 was taken from an undisturbed layer of grey boulder-clay (180 centimetres thick) underneath younger holocene deposits and "cover sands" (720 centimetres thick), and on top of black humic clay ("potklei": sample A 53). It was collected in a temporary building pit for a military object and was not weathered at all.

4. ULSDA

At this locality boulder-clay is practically absent at the core of the drumlin. This is too much weathered for further examination. Here, too, the upper 100—150 cms of the underlying clay have been weathered into a "gumbo til", often containing flints. Examination of microfossils showed that this weathered clay cannot be a boulder-clay although megascopically there seems to be some resemblance. Sample U 4 (unweathered clay) from this locality was examined on pollen- and spores-content.

CHAPTER III

PALYNOLOGY

1. INTRODUCTION

Iversen (1936) made a detailed palynological investigation of boulder-clay in order to solve the problem of pollution of sediments by pollen material of older age (the so-called secondary pollen). He examined the boulder-clay from Egebjerg, Fyn (Denmark), which appeared to be rich in pollen, especially from thermophilous trees. A great part occurred as pollution in Late-Glacial sediments lying on top of the boulder-clay. Consequently palynological dating was very difficult. By subtracting the quantitative composition of the pollen in the boulder-clay from that in the younger sediments Iversen could make a quantative determination of the pollution. The remaining pollen spectra corresponded to the autochthonous vegetation so that dating was possible.

The phenomenon of secondary pollen also occurs in Pleistocene deposits near Winschoten and elsewhere in the northern provinces (Brouwer 1948). The characteristic bluish black humic clay ("potklei") underneath the boulder-clay has been polluted with older pollen material. However, according to Brouwer the boulder-clay itself contained a small amount of pollen: not exceeding 1 grain per 185 square millimetres per slide. Iversen's method of using the pollen content of the boulder-clay to measure the pollution of the clay failed here. On the other hand the age determination of the boulder-clay itself becomes very difficult if the immediately underlying sediments cannot be dated.

On geological grounds Brouwer held that the northern part of the Netherlands was covered by ice during the second stadial of the Riss glacial. In the first stadial a gully system was formed which may be more than 100 metres deep (e.g., near Winschoten). Brouwer placed the formation of the "potklei" filling this gully-system in the intermediate warmer interglacial. At any rate it seemed certain that these deposits were younger than the so-called "marine intercalation in the High Terrace", which is considered to be the marine Holsteinian after the new pleistocene terminology of van der Vlerk (1957). The "potklei" looks like the so-called "Lauenburger Ton", which is very extensive in NW-Germany. That black humic clay is considered to be a guide-horizon for that region. It has a Late-Elster age and lies near Hamburg beneath the marine Holsteinien (Wolstedt, 1950).

So it is clear that the "potklei" cannot be correlated with the "Lauenburger Ton" and must be younger.

Recently the problem of the "potklei" was brought forward again by Florschütz (in van Heuveln, 1959). He stated that the pollen diagram of the upper three metres of this clay at Roden looks strikingly Reuverian. But on geological grounds such a Tertiary age seems very unlikely. Once more palynological dating failed due to pollution. Hence it is clear that palynological age determination of boulder-clay is closely connected with that of underlying sediments. Therefore a more detailed discussion of this connection will be given below.

2. PALYNOLOGICAL ANALYSIS

The boulder-clay samples B 2 (Bovenburen) and A 51 (Appingedam) contain a small amount of pollen. This pollen is corroded to a considerable extent. Sample M 53 (Midwolda), however, is far richer in pollen. Sample M 54 taken from the same boring but 10 centimetres further down (at 160 centrimetres below the surface) is almost as rich in pollen as the "potklei" (samples U 4 and B 29). The density of the arboreal pollen in slides B 2, A 51, M 53, M 54 and U 4 is one grain per 146, 128, 17.6, 1.76 and 0.21 square milimetres respectively. The density of total pollen in the same slides (non-arboreal pollen included) is one grain per 21.5, 44.7, 11.9, 1.43 and 0.18 mm^2.

However, the qualitative composition of the pollen in the boulder-clay is almost identical to that in the "potklei" (plates I, II, III). Probably a considerable part of the boulder-clay pollen came from sediments encountered by the ice on its way to this region. Hereto belong the strongly humic "potklei" found in the border district with Germany and similar clays in N.W. Germany, which lie right underneath the boulder-clay. These are very extensive (Wildvang 1938).

The pollen content of "potklei" samples B 29 (Bovenburen), A 52 (Appingedam) and U 4 (Ulsda) appears to include a high percentage (25 and over) of elements characteristic for the Young Tertiary and Old Pleistocene. Some of them are given in Plate II and III. Their occurrence in the south of the Netherlands has been fully described by van der Vlerk & Florschütz (1950, 1953) and Zagwijn (1957). They are a. o. ***Pinus haploxylon*-*type*, *Carya*, *Pterocarya*, *Tsuga*, *Liquidambar*, *Nyssa*, *Sciadopitys*, *Sequoia-type*** and ***Taxodium-type***, etc. ***Fagus*** may be included, too. They also occur frequently in the boulder clay (Plate I, II). Moreover, considerable percentages of pollen and spores (up to 25 % and more) occurring in the "potklei" are characteristic for the Miocene-Oligocene but scarce or absent in the Pliocene. For some of them see Plate I, II, III. They are a. o. ***Pollenites megaexactus*** *brühlensis, Poll. exactus exactus, Poll. henrici, Poll. liblarensis, Poll. microhenrici, Poll. villensis, Tricolporites edmundi, Tricolpopollenites pseudocingulum, Poll. vestibulum,* etc. (cf. Erdtmann 1954, Doktorowicz-Hrebnicka 1956, Leschik 1951, Potonié 1951, Szafer 1954, Thomson & Pflug 1953). They also occur in the boulder-clay. (Plate I, II.)

So on purely palynological grounds these "potklei" samples would be assigned a Miocene age or older. But this is in contradiction with the geological position of the clay. For instance at Scheemda coarse sands occur underneath a thick layer of "potklei" at a depth of 50 metres. According to a sediment-petrologic investigation by Edelman (1933) they belong to the Middle Pleistocene B-Scheemda province. At other localities, too, we could ascertain that the clay filling the gully system is younger than the Hoxnian, the interglacial preceding the Saale glaciation. Since in the underground of Groningen and Friesland the Young Tertiary occurs at a great depth (from over 100 to 200 metres) it seems unlikely that the upper part of the clay we examined should be ice-pushed Tertiary.

Therefore the palynological dating of the clay is presumably wrong (cf. van Heuveln 1959). This must be due to pollution of the sediment with much older — Miocene and older — pollen. The amount of secondary pollen in the "potklei" samples we examined was 50—75 %. Probably this secondary pollen belongs to Tertiary lignite and clays in NW-Germany carried off by river water after erosion, simultaneously with the clay particles, and deposited in gullies in the north of the Netherlands. This seems likely since at the time of glaciation the advancing ice formed a barrier in the lower courses of the pleistocene German rivers Elbe, Weser and Ems. Consequently they were forced to find a way westward. These "Urstromtäler" (peripheral glacial valleys) are wellknown in the related part of Germany (cf. Wolstedt 1950). In the region of Niedersachsen Tertiary clays and lignite often occur at or just below the surface.

These rivers will have strongly eroded the Tertiary sediments when they changed their courses. Lowering of the erosion bases of the rivers in glacial times due to lowering of the sea level may have played a part. Deeper Tertiary sediments such as lignite, which were extremely rich in pollen, became therefore a prey to erosion. This fact combined with the hypothesis that vegetation was poor in the region before the ice ridge might account for the domination of polluting pollen in the sediment deposited in this way. Our observations at several localities in the region of Winschoten seemed to confirm this.

Lenses with eolian sands which even have a loess quality frequently occur in the upper part of the clay (sample U 30, fig. 3). This would corroborate the view that at any rate the upper part of the clay is to be considered proglacial.

Separation of the secondary pollen from the autochthonous pollen present great problems. Since the polluting sediments occur underneath the boulder-clay instead of on top of it Iversen's method cannot be used. The characteristic Miocene-Oligocene and other Tertiary pollen gives no trouble. But great difficulties are presented by: *Pinus silvestris-type, Picea, Abies, Alnus, Betula, Carpinus, Corylus, Myrica,* etc., which occur in the Miocene or even earlier and continue all during the Quaternary. As yet it is impossible to distinguish between autochthonous and secondary pollen among this group by traditional methods. This investigation is still in progress.

On account of the aforesaid scarcity of pollen in the boulder-clay pollution of the upper part of the "potklei" by the boulder-clay seems unlikely though not quite impossible.

Until the quantitative composition of secondary pollen in proglacial sediments has been accurately determined no reliable dating can be done. However, we know only few cases of nonpolluted layers of peat occurring in these sediments in the Netherlands. Therefore no satisfactory sub-division of the Saale-glaciation by means of palynology can be given as yet.

CHAPTER IV

SEDIMENTOLOGY

For our correlations sedimentology has a disadvantage: several uncertain factors lower the value of the investigation. For instance the heavy mineral content of grey boulder-clay samples taken elsewhere in the provinces of Groningen and Friesland hardly differs from that of the underlying coarse sediments. Therefore it is not characteristic. Comparison may become unreliable owing to grain size variations and errors made in preparing and counting (granular variations) (Doeglas 1952). The results of this method of investigation are far less reliable than those of investigation of microfossils such as bryozoa. To a certain extent this is stated as well of pollen analysis.

1. GRANULOMETRY

The composition of the granulometrically examined samples is represented in sommation curves (fig. 3). The boulder-clay samples B 2 (Bovenburen) and A 51 (Appingedam) have a grain size distribution and sorting characteristic for the "normal" type of boulder-clay as appears from a comparison with the curves given by de Ridder & Wiggers (1956). This result is confirmed by micro-paleontological examination and analysis of erratics.

Due to its fairly high silt percentage (25 %) and grain-size distribution the Midwolda boulder-clay (M 53) has a slightly different composition, possibly caused by clay from the underground which entered the boulder-clay (local moraine). Moreover striking similarity is noted with the composition of the Markelo boulder-clay analysed by de Ridder & Wiggers.

The "potklei" samples B 29 (Bovenburen) and U 14 (Ulsda) resemble each other splendidly by their high lutum percentage (65—80 %). They have the same sommation curve as the one given by the de Ridder & Wiggers for the "potklei" from Winschoten.

The proglacial sand from Ulsda (U 30) has the same appearance and composition as part of the sands occurring in the "potklei" from Bovenburen. It has a high percentage of grains sized between 32 and 50 mμ and its sorting is very good. The grains have a frosted surface and are angular. Presumably it is a loess. Owing to the fact that the sand was ice-pushed its lutum percentage may have become more than average as clay particles entered it. Megascopically the sand is especially characterized by the frequent occurrence of biotite and muscovite flakes. An eolian origin might also account for the great discrepancies in the thickness of layers at Ulsda.

2. SEDIMENT PETROLOGY

Boulder-clay samples B 2, A 51 and M 53 show great resemblance as to their heavy mineral content (c.f. Table I). Epidote, hornblende and garnet dominate; but metamorphic minerals occur in smaller quantities. The

TABLE I

Sediment-petrological analyses

Location		Sample			garnet									sillimanite						alterite		hornblende						
			tourmaline	zircone	colourless + pink	red-yellowbrown	Meuse	rutile	anatase	brookite	staurolite	disthen	andalusite	grain	fibrolite-	topaz	chloritoide	epidote	saussurite s.s.	s. l.	green-	Vosges	alkali	brown	green	bas.	augite	hypersthene
APPINGEDAM	boulder-clay	A 51	5	12	20	—	—	7	—	—	2	21	—	—	1	—	—	29	—	—	—	—	—	—	23	—	—	—
BOVENBUREN																												
	boulder-clay	B 2	2	11	22	—	—	10	—	—	2	3	1	—	1	—	—	29	—	—	1	—	—	2	16	—	—	—
	“potklei”	B 29	3	19	13	—	—	7	3	—	4	10	—	—	—	—	—	31	—	—	—	—	—	—	10	—	—	—
MIDWOLDA	boulder-clay	M 53	2	18	13	1	—	5	3	1	2	5	—	—	—	—	—	34	—	—	—	—	—	—	16	—	—	—
ULSDA	“potklei”	U 14	—	7	15	—	—	4	1	—	2	8	—	—	—	—	—	42	—	—	—	—	—	—	21	—	—	—
	progl. sand	U 30	1	12	16	—	—	7	3	—	3	8	—	—	—	—	—	42	—	—	—	—	—	—	8	—	—	—

Olivine and titanite are not present

Midwolda boulder-clay (M53) has a somewhat dissimilar composition as regards heavy mineral content as well.

Since the red boulder-clay is characterized by an amphibole association (De Waard 1947) the boulder-clay of this region cannot be considered to belong to the red type. Due to grain size variations this investigation can hardly be compared to the results of analyses of erratics.

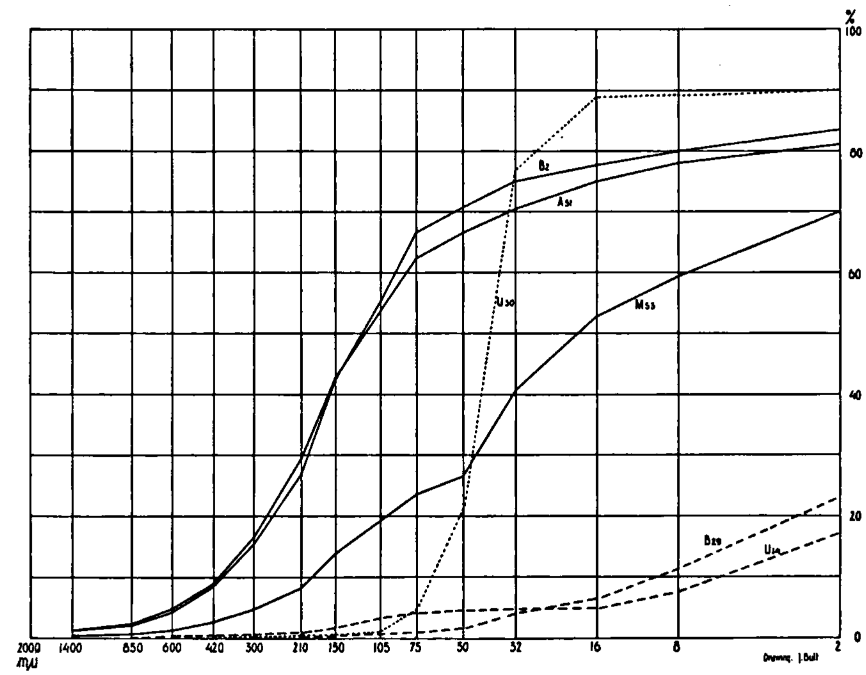

Fig. 3. Grain size diagram of investigated sediments
——— boulder-clay
.... proglacial sands
- - - - "potklei"

The "potklei" samples from Ulsda (U 14) and Bovenburen (B 29) differ considerably although this clay has been the same heavy mineral content in nearly all localities in the north of the Netherlands. Everywhere diagrams of the heavy fractions of thick layers of this clay are monotonously uniform (e. g. at Grijpskerk). Epidote and hornblende dominate; garnet and metamorphe minerals occur in small quantities (Bohmers 1937). The very fine proglacial sand (U 30) is characterized by an epidote-garnet association with metamorphic admixture.

CHAPTER V

CONTENTS

ASSOCIATION OF ERRATICS

1. COUNTINGS

I. Procedure

In connection with the present investigation of till a sample of 2600 cubic centimetres was taken at Bovenburen in October 1957. Half the sample was washed out and the erratics in the 6 mm to 5 cm fraction were counted. Thin sections were made of rocks in the 1½ to 5 cm fraction. They will be described in detail after the general discussion of the countings at Bovenburen.

The boulder-clay is greyish green. This colour as well as the high flint content would suggest a "normal till". However the crystalline and sedimentary components in the total number of erratics showed deviations from the countings by D. de Waard in the N.O. Polder. Therefore Bovenburen was visited in the summer of 1958. In the field, too, the great number of quartz bearing sedimentary rocks was striking. Crystalline rocks were not so frequent as in other boulder-clay outcrops in the Netherlands. The number of rocks larger than 5 cm was notably small. A second sample was taken at a 100 metres' distance from the first. Its size was 1700 cubic centimetres. The sample was also washed out and the erratics occurring in the 6 mm to 5 cm fraction were counted.

Countings were made according to the method of V. Madsen (1897) and performed in a way that the results are comparable to those of countings by D. de Waard in the N.O. Polder (1947). De Waard used a sieve which could contain about 7½ kilogramme of wet boulder-clay. Since his samples were of equal size he assumed that the absolute numbers of erratics occurring in the 6 mm to 5 cm fraction would reflect the association of erratics per till unit so that a conversion of the results into percentages was not necessary here.

We think the following objections could be made:

1. The results of countings of till samples taken in a different way or in other surroundings than those of the newly drained N.O. Polder can hardly be compared to de Waard's results.
2. As too little is known of the factors influencing the ratio of erratics during and after deposition of a till layer by glacial transport, we cannot maintain the thesis that absolute numbers of stones in samples of equal size give a statistically correct idea of their assemblages. For instance differential compaction and periglacial phenomena may in places disturb an originally equally distributed coarse fraction of a till layer.

Therefore we did not compare the absolute numbers per till unit, but the ratio of the various assemblages of stones in the total number of erratics occurring in a given sample.

The lower part of figure 69 in De Waard's publication (1947), showing the numbers of stones in the fraction of 6 mm to 5 cm, found in the "normal boulder-clay" from the N.O. Polder, is given below (table II A). In table II B the results of table II A have been converted into percentages.

TABLE II

	nrs.	crystalline	siliceous limestone	siliceous dolomite	limestone	flint	lignite	claystone	sandstone-quartzite	quartz	total number	flint-coefficient F/K
A. erratics in numbers	A 4	20	20	1	3	16	1	—	8	1	70	0.80
	A 9	22	17	—	4	17	—	—	12	5	77	0.77
	A 8	31	1	—	—	14	—	1	15	1	63	0.45
	A 12	33	—	—	—	9	—	—	18	2	62	0.27
	A 13	28	—	—	—	20	—	2	15	2	67	0.71
	A 10	25	—	—	—	9	—	—	13	2	49	0.36
	A 11	36	—	—	—	15	—	1	17	—	69	0.42
	A 1	27	—	—	—	9	—	—	6	3	45	0.33
B. erratics in percentages	A 4	28.6	28.6	1.4	4.3	22.9	1.4	—	11.4	1.4	100	0.80
	A 9	28.6	22.1	—	5.1	22.1	—	—	15.6	6.5	100	0.77
	A 8	49.2	1.6	—	—	22.2	—	1.6	23.8	1.6	100	0.45
	A 12	53.3	—	—	—	14.5	—	—	29.0	3.2	100	0.27
	A 13	41.8	—	—	—	29.8	—	3.0	22.4	3.0	100	0.71
	A 10	51.0	—	—	—	18.4	—	—	26.5	4.1	100	0.36
	A 11	52.2	—	—	—	21.7	—	1.5	24.6	—	100	0.42
	A 1	60.0	—	—	—	20.0	—	—	13.3	6.7	100	0.33

Countings of samples of the "normal till" taken by D. de Waard in de N.O. Polder. A. The total number of stones arranged into nine groups, after de Waard (1947). B. The total numbers converted into percentages.

The variations given in table II A as compared to those in table II B show a great disparity. Thus the variation of flint increased (table I A: 8, table I B: 15.3 %), that of crystalline stones has greatly increased (table II A: 16, table II B: 31.4 %), that of sandstone-quartzites has increased to a lesser degree (table I A: 12 table I B: 17.6 %). These disparities illustrate the postulate that caution must be used in comparing absolute numbers of stones in till samples of epual size.

II. Countings of the samples from Bovenburen

Results of countings of the 6 mm to 5 cm fractions in both samples are given in table III:

TABLE III

	sample I		sample II	
	number	percentage	number	percentage
crystalline	18	27.7	12	20.7
flint	19	29.9	15	25.9
sandstone and quartzites	28	43.1	24	41.4
limestone	—	—	7	12.0
	65	100.0	58	100.0

Results of the countings of the two samples from Bovenburen

This is a subdivision into four groups only as compared to one into nine groups by de Waard (1947). For this quantative investigation the three kinds of limestones are joined in one group. Quartz grains were encountered, too, but they were smaller than 6 mm. Limestone concretions, clay stones or lignite did not occur.

For a satisfying comparison with countings in the N.O. Polder the results of table II A were arranged as in table III. The various groups of limestones were brought together under one column; limestone concretions, clayey sediments and lignite were omitted as groups and in the totals.

The in this fashion computed percentages of the countings by D. de Waard in the N.O. polder are given in table IV.

TABLE IV

No.	crystalline	limestone	flint	sandstone and quartzite
A 4	29.4	35.3	23.5	11.8
A 9	30.5	29.2	23.6	16.7
A 8	50.8	1.6	23.0	24.6
A 12	55.0	—	15.0	30.0
A 13	44.4	—	31.8	23.8
A 10	53.2	—	19.1	27.7
A 11	52.9	—	22.1	25.0
A 1	64.3	—	21.4	14.3

Percentages of the countings from the N.O. Polder. The erratics have been grouped in the same way as in table III

Figure 4 is a diagram of table III and IV. The variations of the several components have been hatched. The results of countings of samples from Bovenburen are given by way of vertical lines.

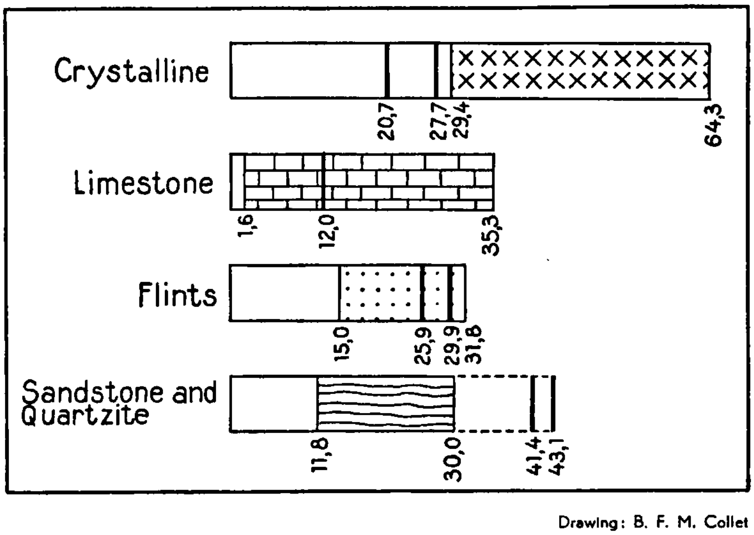

Fig. 4. The results of the countings at Bovenburen (heavy vertical lines) compared with the variations of percentages from the countings of D. de Waard in de N. O. Polder (hatchings)

Out of figure 4 it becomes evident that the flint percentages are within the variation of those of samples taken in the N.O. Polder, but the crystalline and sedimentary percentages from Bovenburen deviate in such a way that the percentage of crystalline stones is smaller and that of sandstones and quartzites is greater.

The flint coefficient also suggests a disparity between rock assemblages from the greyish green till at Bovenburen and those from the normal boulder-clay in the N.O. Polder. The flint coefficients in the N.O. Polder vary from 0.27 to 0.80, whereas the flint coefficient of the samples from Bovenburen amounts to 1.06 and 1.25.

Summarizing we may state that the results of these countings confirm the views of Bonnema and van Calker, who pointed out that the erratics occuring in the boulder-clay near Kloosterholt were of western Baltic origin (Bonnema, 1898, van Calker, 1898). However, the statistical differences between the different kinds of rock fragments in the boulder-clay from Bovenburen and from the N.O. Polder suggest that the normal grey till in the region we investigated is characterized by a local assemblage of erractics.

2. DETAILED DESCRIPTION OF THE ERRATICS

I. Crystalline rocks

Crystalline rocks may be subdivided into two main groups namely:

A. pyroclastic sediments
B. igneous rocks

A. *Pyroclastic sediments*

a. Laminated tuffaceous sandstone

This group is represented by three specimens, all of which are laminated. Megascopically their composition proves to be more complicated than that of the arenites which will be discussed later in this article. Parallel films, made up by mica's and a microscopically fine, dark material are evenly distributed in an almost aphanic matrix. They have a rough surface and a pale yellowish grey colour in common (5 Y 7/2).[1]) It should be noted that specimen st. 88202[2]) only shows this colour at the weathered surface. The core has pale red (10 R 6/2) stripes and spots alternating with medium grey (N 5) stripes and spots. St. 88193 has a somewhat equidimensional shape and its size is 5 × 5 × 4 cm. St. 88202 is an almost perfectly quadrangular prism (2 × 2½ × 3 cm). St. 88210 is flattened (2 × 3 × 1½ cm).

Microscopically st. 88193 and st. 88210 are almost identical. Seriate quartz grains, cemented with quartz, make up a matrix in which feldspar grains, biotite and muscovite grains are embedded.

The grain size of the quartz (st. 88210) varies from 0.05 to 0.2 mm. The modal average is at 0.1 mm. The feldspar grains represented by orthoclase and microcline, as well as the muscovite and biotite flakes show the same grain size variation as the particles of the matrix.

The grain size of microcline, oligoclase and biotite in sample st. 88193 is also in the size range of the quartz particles (0.1—0.2 mm) occurring in the matrix. However, the fragments of orthoclase and the irregular quartz grains are considerably larger than the average grain of the matrix. Their sizes range from 0.4—1.5 mm and 0.4—0.6 mm respectively. Therefore the texture of st. 88193 has a porphyritic appearance.

Sample st. 88202 stands out in spite of some similarity: megascopically by the colour and the texture of the core, but microscopically as well. The matrix has a much finer grain. The specimen consists of three different components which closely resemble each other in composition and texture. Pseudo-porphyritic texture occurs in the three components and one of them has a pronounced layered texture as well. The larger microcline and quartz fragments are 0.4—3 mm in size. Because of the three homologous components the structure of the specimen resembles that of agglomerates.

According to the textural and structural classification of pyroclastic arenites by C. W. Correns and V. Leinz (Pettijohn, 1948) the group under discussion must have been deposited in lacustrine surroundings.

b. Porphyritic Tuffaceous Sandstone

Megascopically the two specimens of this group have an unlayered, porphyritic texture in common. Both are red. St. 88190 is pale reddish brown (10 R 5/4) and st. 88212 is "pale red" 5 R 6/2); in other respects there is little similarity megascopically.

St. 88190 is a trilateral prism. Altitude and base of the trilateral basal plane are 2½ and 1½ cm respectively, altitude of the prism is 3 cm. This compact specimen has a smooth surface. Solarity 1 to 2 mm long feldspar

[1]) Colours after Rock color chart of the Geological Society of America (1951).

[2]) Specimen number in the register of the Rijksmuseum van Geologie en Mineralogie, Leiden.

crystals are scattered in the aphanic matrix. Their colour is somewhat lighter.

St. 88212 has an oval shape ($3\frac{1}{2} \times 3 \times 2$ cm) and is also compact. Its surface, however, is rough with lighter feldspar prisms. At the cut surface the rock resembles an agglomerate.

Microscopically the two components differ. In st. 88190 a silt-like ground mass is found. The size of the quartz grains ranges from 0.01—0.15 mm, the modal average is between 0.01 and 0.025 mm. The quartz grains are well rounded. 57 % of the quartz content is clear, 42 % being covered with heamatite dust. The feldspar fragments are much larger. Their size ranges from 0.2—2.5 mm. The feldspars are represented by microcline (non-perthitic) and basic oligoclase (anorthite percentage 20—28). St. 88190 is still very similar to a tuffaceous siltstone, whereas st. 88212 resembles an actual tuff due to its microtexture.

The ground mass is practically microcrystalline suggesting devitrificated volcanic glass. The larger crystal fragments (0.4—1.5 mm) have been altered. Orthoclase and acid plagioclase have been altered into a mixture of kaolinite, sericite and prehnite. Sanidine also occurs, and here and there a larger quartz grain is to be seen. According to the classification by Correns and Leinz the unlayered porphyritic pyroclastic arenites are to be considered as terrestrial deposits.

B. Igneous Rocks

Four igneous rocks in the fraction of $1\frac{1}{2}$—5 cm were found. Beyond this fraction one larger specimen, of $15 \times 11 \times 8$ cm, has been encountered, wich will be discussed here, too. Of these five igneous rocks three are granitic, two basic.

a. Granitic Igneous Rocks

Two of the three specimens are granites. One is a biotite-aplite granite (st. 88205), the other a biotite-alkali-aplite granite (st. 88196). The third specimen is an alkali-rhyolite (st. 88211). (The nomenclature of P. Niggli (1931, 1933) is employed here.) They have a brown hue in common. St. 88205 is light brown (5 YR 6/4), st. 88196 is pale yellowish brown (10 YR 6/4) and st. 88211 is light brownish grey (5 YR 6/1). The two granites have rough surfaces. The biotite-aplite granite is roughest. The rhyolite has a chalky surface.

Microscopically the biotite-aplite granite has a normal hypidiomorphic texture. The grain size ranges from 0.1—2.0 mm. Microcline and quartz have the largest grain size. The anorthite percentage of the plagioclase is 28. 5 Volume % of biotite occurs as a dark mineral, 63 out of 66 % of alkali feldspar is microcline. Quartz takes up 22 volume % of the rock and plagioclase takes up 7 %. About 1 % of the plagioclase is myrmekitic.

The biotite-alkali-aplite granite has a somewhat smaller grain size, ranging from 0.1—1.5 mm. As the name implies it is poor in dark constituents. The volume % of the biotite is only 0.6, quartz takes up 33.4 volume %. The quartz grains have an undulatory extinction. In one part of the thin slide a rough mortar texture is to be seen. The feldspar content mainly consists of perthite microcline (61 volume %); only 3 % of acid plagioclase occurs, the anorthite percentage is 14.

The alkali-rhyolite is permeated with limonite, in contrast with the discussed granites which are microscopically pure. The spherolitic ground mass contains some 0.25 mm long quartz phenocrysts and occasionally some, 0.7 mm long, sanidine phenocrysts. A few 0.01 mm magnetic grains and one epidote grain were observed.

b. Basic Igneous Rocks

Representatives of this group are a biotite bearing hornblende diorite (st. 88191) and an augite-anorthosite porphyrite (st. 88197). Both have a greenish colour. The anorthosite is greyish olive (10 Y 4/2). The diorite is dark greenish grey (5 GY 4/1). The diorite has the shape of a rough rectangular prism (4 × 3 × 2 mm); the anorthosite is wedge shaped (15 × 11 × 8 cm). The two samples have a rough surface, the diorite being somewhat rougher than the anorthosite. The anorthosite shows fine glacial striae (plate IV).

Microscopically the hornblende forms a network in the diorite; in the meshes andesite occurs. The anorthite percentage of the plagioclase is 35. Hornblende takes up 55 volume %, andesite 42 volume %; some biotite, sphene and ore occur as well. The grain size of the hornblende and the andesine varies from 0.1—0.9 mm. The pleochroism of the amphibole is X = pale ochre, Y= grass green en Z = bluish green.

The microscopical texture of the augite anorthosite porphyrite is somewhat fluidal. 0.4 mm long plagioclase crystals are more or less parallel. Plagioclase, chlorite and sericite occur intersertally. 61 % of the total volume is taken up by labradorite phenocrysts and 31 % by the finely grained ground mass; besides 8 volume % of augite occurs. The grain size of the augite varies from 0.4—1 mm; the modal average is at 6.5 mm. The augite is found in the interstices between the lath-shaped plagioclase crystals.

II. Flints

15 Flints occur in the 1½—5 cm fraction (st. 88195, st. 88204 and st. 88214). Seven out of them are somewhat equidimensional, eight are flat and rather angular. The surface may be more or less rounded, sometimes having small cavities. It is either fine or coarse grained and calcareous.

Nine specimens, coloured "olive-grey" (5 Y 2/1) or "moderate yellowish brown" (10 YR 5/4) which may pass into "dark yellowish orange" (10 YR 6/6), seem to belong to one group, since a large flint, 18 × 10 × 4 cm, taken from the same sample, showed the same colour variations as the nine specimens in combination.

The shade "dark yellowish orange" (10 YR 6/6) in the large specimen is that of the tarnish. By further investigation of the smaller specimens the attention was drawn to the fact that orange is a colour especially occurring in specimens which are rich in fossils. The calcareous material of the fossils seems to accelerate the erosion at the surface indicated by the orange colour. Megascopically an "olive black" (5 Y 2/1) specimen was found to contain no fossils; the almost black flint is also very poor in fossils. Therefore the so-called black flint might be a fossil-poor member of this group.

Beside the ten aforesaid specimens four flints occur which probably belong to three different groups. Three of them have the same "pale yellowish brown" (10 YR 6/2) colour. Two specimens are nearly identical as regards habit, fine-grained surface and cavities covered with calcareous film. Further investigation will be needed to ascertain whether they belong to a separate group.

A splinter, "dark yellowish orange" (10 YR 6/6) on one side, "greyish orange" (10 YR 7/4) on the other, seems so different from the other yellow specimens that for the time being it has been set apart.

Mention should also be made of a "moderate reddish brown" shell-like splinter which resembles the first large olive-brown-orange group in habit, and probably belongs to it.

III. Sandstones and quartzites

In the fraction of 5—1½ cm 12 arenites were found. Moreover one large specimen of 12 × 6 × 6 cm occurred in the till sample. The arenites may be subdivided into seven groups.

A. *Orthoquartzites*

Megascopically the stones in this group are very similar. The surface is smooth and rounded. They may be said to be streamlined. The colour ranges from "very pale orange" (10 YR 8/2), "pale yellowish brown" (10 YR 6/2), "pale brown" (5 YR 5/2) to "greyish brown" (5 YR 3/2). The "pale yellowish brown" dominates.

Two specimens, st. 88188 and st. 88194, are somewhat cylindrical; they are 5 cm long having a diameter of 3½ and 2 cm respectively. The third specimen is flattened. Its diameter is 2½ cm, its height ½ cm.

Microscopically the three specimens were found to be similar as regards their high quartz contents (95—99 %), quartz cement and dense packing. Especially st. 88188 and st. 88207 are very similar. The size of the quartz grains in the two samples ranges from 0.05—0.4 mm, the modal average in both specimens is 0.2 mm. The outline of the original grains of sand could not be seen. The grains have an angular form.

St. 88149 has a slightly coarser grain (the grain size ranges from 0.05—1.0 mm). The primary, well rounded, seriate grains are still covered by the original hematite film. The specimen is found to be laminated, both megascopically and microscopically.

B. *Glauconite bearing orthoquartzites*

Two specimens were encountered in the boulder-clay sample. The larger one is clearly laminated. It is a two cm thick prism with a trapezium-shaped base. The altitude of the trapezium is 5½ cm, its base is also 5½ cm, the parallel side is 2½ cm. The smaller specimen is a prism, which measures 2 × 1½ × 1½ cm. In contrast to the trapezium-shaped specimen lamination is not visible here. The two specimens have a high quartz content (90 to 95 % in common. They are placed together into one group because of the occurrence of glauconite.

Megascopically a more or less greenish hue is seen in both specimens. St. 88189 has a "greenish grey" (5 GY 6/1) and St. 88200 a "light olive grey" (5 Y 6/1) color. The sample with the darker hue of green contains more scattered grains of glauconite, in spite of the low volume percentage of this mineral.

Microscopically the two specimens are found to be fairly pure quartz arenites. No original grains are visible; they are angular and have grown together. The larger sample has finer grains, and two different grainsizes, characterized by the modal averages of 0.2 and 0.4 mm, occur apart in alternating layers. The smaller sample (st. 88200) is less sorted. The grains are seriate with a grain size range from 0.1—0.7 mm and a modal average at 0.2 mm.

C. Arenites between quartz wacke and orthoquartzite

As compared with the arenites dealt with so far, the two representatives of this group have a more equidimensional shape. The larger specimen (st. 88198) does not really belong to the fraction of 5—1½ cm. It measures 10 × 6½ × 6 cm. The smaller sample (st. 88213) is 5 × 5 × 4½ cm.

Megascopically the two rocks are pale reddish violet with a yellowish brown alteration surface. According to the colour chart st. 88198 is "pale red" (10 R 6/2). The smaller rock has the same colour but shows a little more yellowish brown in its thin alteration crust. The two specimens have a rough surface. With a magnifying glass the several quartz grains, left over after corrosion, can clearly be distinguished. Scattered dull pinkish-white grains are also visible megascopically. Microscopic examination showed them to be feldspars, especially microcline.

Microscopically the two specimens are very similar. They contain 83—84 % of quartz. The subrounded grains are sometimes cemented by secondary quartz, but they are mainly connected by micro-crystalline aggregates. By the latter property they are related to the quartz wackes. They are very similar to Pettijohn's second-cycle-orthoquartzites (Pettijohn 1948). The grain size of the smaller rock (st. 88213) ranges from 0.005—0.5 mm, for the larger rock (st. 88189) it was found to be 0.1—0.6 mm. The modal average is at 0.3 and 0.2 mm respectively. Both specimens are slightly porous.

D. Quartz wacke

According to its megascopical and microscopical properties st. 88199 may be considered to belong to the group of arenites in between quartz wackes and orthoquartzites. According to Turner's petrographic classification (1954) this sample belongs to the quartz wackes since a great part of the matrix consists of micro-crystalline aggregates. Sericite and chlorite form a great part of the matrix. The grain size is slightly larger, ranging from 0.1—1.0 mm, the modal average is at 0.4 mm. Except for the micro-crystalline matrix and the somewhat larger grain size the specimen strongly resembles st. 88198 and st. 88213 microscopically.

Megascopically, too, there is great resemblance. The pale red hue is slightly more purplish. According to the colour chart it is "pale red" (5 R 6/2). The alteration of the crust is also yellowish brown. The rough surface with the sorted grains is identical. The more or less droplike sample is 3 × 2 × 1½ cm in size.

E. Porous quartz arenites

Megascopically this group is distinguished from the orthoquartzites by its much rougher surface and its paler colour. The colour of st. 88203 is "very pale orange" (10 YR 8/2), that of st. 88208 is "greyish orange" (10 YR 7/4). St. 88203 is prismatic (4 × 2½ × 2½ cm) whereas st. 88208 is shaped like a right-angled triangle, its cathetes being $2\frac{1}{2}$ and 2 cm respectively. It is 1 cm thick.

The rough surface noted during megascopical examination is caused by the relatively high volume percentage of microscopic pores (9 and 12 volume % for st. 88208 and st. 88203 respectively). Both are pure quartz arenites. The original grains, which are still visible here and there, have been cemented with secondary quartz.

The grain size of st. 88203 ranges from 0.1—0.9 mm. The modal average is at 0.2 mm. A few feldspar grains and some muscovite scales occur.

St. 88208 is a very pure, unsorted and much coarser grained quartzite. The grain size, ranging from 0.2—2.2 mm is seriate.

F. Siltstone

Megascopically this rock (st. 88201) seems very dense. It is pale yellowish orange: "greyish orange" (10 YR 7/4). The seemingly smooth surface is rather rough to the touch. The shape is somewhat prismatic ($3\frac{1}{2} \times 2 \times 2$ cm).

Microscopic investigation shows the sample to be very finely grained (grain size 0.01 mm) and well sorted. The volume percentage of the pores is 15. This accounts for the slightly rough surface. Sericite is abundant, namely 17 %. According to Pettijohn this is a property of siltstone (Pettijohn 1948).

G. Feldspathic arenite

Only one representative of this group was found in the boulder-clay from Bovenburen (st. 88192). It is six-sided prismatic. The irregular hexagon fits in a circle with a 4 cm diameter. The altitude of the prism is $2\frac{1}{2}$ cm. The dominating colour is "yellowish grey" (5 Y 7/2). In the yellowish grey matrix numerous white 1 mm large spots occur. At the cut surface dull white pits form a layered texture. The specimen has a rather rough surface.

Microscopic investigation shows we have to do with a feldspathic arenite. Its modal composition is 82 % of quartz and 18 % of feldspar grains. Its cement is quartz. No original grains of sand are to be seen. The quartz occurs in grain sizes of 0.1—0.3 mm and 0.9—0.6 mm. The smaller grain size fraction is most rounded. The grain size of the feldspars ranges from 0.1—0.5 mm. The modal average is at 0.2 mm. So the grain size of the feldspars agrees with the smaller quartz fraction. The feldspar grains are composed of orthoclase, microcline, micropegmatite and oligoclase.

CHAPTER VI

MICROFOSSILS AND LIGHT MINERALS

From Mr van Gijzel the present author received some soil-samples taken with an auger in the neighbourhood of Winschoten. These samples were examined in the course of a large scale investigation of the boulder-clays of western Europe.

It appeared that three of the received samples — B 36 (nr. 37), U 3 (nr. 38), B 27 (nr. 39) — consisted of clay (potklei), whereas the other three consisted of genuine boulder-clay — A 51 (nr. 40), B 2 (nr. 43), M 53 (nr. 44) —.

The clay-samples had a lime-content of about 4 %; after washing the residuum consisted of a fine, nearly pure, quartz-sand. No crystalline fragments or flint were found, only some hollow cylindrical concretions probably formed around rootlets. Sample B 27 contained a lot of wood-particles.

The unweathered boulder-clay samples were characterized by a lime-content of about 13 %.

It may be briefly stated that there are at least two distinct types of boulder-clay in the Netherlands; the normal or grey boulder-clay and a red boulder-clay which occurs in floes in the normal boulder-clay (De Waard 1947). In the described area this red boulder-clay was unknown.

The method of investigation was the following:
150 gr of the sample was washed and sieved on 0.42 and 0.85 sieves. The obtained three fractions were studied under a binocular microscope. The minerals of two fractions were examined; quartz Qz, white feldspar Fw, red feldspar Fr, crystalline fragments Cr, limestone Ls, flint Fl and a sandstone group Sa were distinguished (Dreimanis 1939).

Also 100 clear quartz grains were examined on roundness and dullness of the rounded and sub-angular grains. In this investigation three groups were used: R - rounded, SA - sub-angular and A - angular (cf. Russell & Taylor 1937; Krumbein 1941).

The normal boulder-clay has a quartz-content of about 40 % in the fraction > 0.85 mm; red boulder-clay has a quartz-content of 20 % in the corresponding light fraction.

The roundness of the > 0.85 mm light fraction in a normal Dutch boulder-clay is about 20 R - 60 SA - 20 A; about 40 % of the rounded grains possesses a frosted surface and of the subangular grains about 20 % (Table VI).

In the red boulder-clay the roundness is about 15 R - 35 SA - 50 A and 60 % of the rounded grains and 30 % of the subangular grains are frosted.

Fiedler (1936) discovered in Mecklenburg that in younger boulder-clays the number of rounded grains was greater than in the older boulder-clay deposits.

De Waard (1947) already stated that the light fraction of the red boulder-clay possessed more crushed mineral-fragments and therefore was more angular than the light fraction of the grey boulder-clay. This is one of his arguments to place the original deposits of the red boulder-clay in the Elster ice-age.

The amount of the crushing of the grains in the ice-cap may account for the difference in roundness. It seems fairly certain that the grains were already rounded before they entered the glacier.

The frosted surface (Cailleux 1942) may be caused by eolian working or chemical reactions. In the case of boulder-clays it seems probable that eolian actions caused the frosted surface of the grains before the material was caught up in the ice. Chemical reactions in the deposited moraine are improbable because, although there is a great difference in the lime-content of weathered and unweathered (situated under groundwater level) boulder-clay, there is no difference in the percentage of frosted quartz grains.

In the grey unweathered boulder-clay a microfaunal assemblage was found (v. Voorthuysen & Lagaay 1950), consisting of white bryozoa and microforaminifera, derived from Upper Cretaceous layers, whereas in the red boulder-clay an assemblage consisting of brown bryozoa, ostracoda and crinoid stem-fragments of Silurian age was found (Plate V; 1, 2). In weathered boulder-clay generally no calcareous microfossils are found.

The foraminifera were found in the fraction $<$ 0.42 mm, the bryozoa mostly in the 0.42—0.85 mm fraction.

It is evident that the fine material of the grey boulder-clay must be derived from an area with Danian and Upper Senonian outcrops, according to the fossils (Table V). We don't need to consider areas where the Cretaceous layers are covered by Tertiary deposits.

So it is most probable that the source of the examined material was formed by the Upper Cretaceous of Denmark and Schonen (southern Sweden). Moreover only yellow-brown flint-fragments were encountered. This corresponds with the fact that in Denmark the flint from the Danian has a grey or yellow-brown colour, whereas the flint from the Upper Senonian has a black colour. This was already observed by Madsen (1928).

Analogous associations of microfossils are found in Danish boulder-clays (Plate V; 3); these fossils are of Upper Cretaceous (mostly Danian) origin as observations in adjoining Cretaceous outcrops prove.

We think that the bryozoa were mostly derived from soft bryozoan limestones (e. g. Danian C). Blocks of these limestones were picked up by the ice and crushed. One may wonder why all these delicate microfossils were not pulverized; apparently the fine clay-matrix protected the enclosed microfossils against the pressure in the ice-cap.

As the somewhat weathered surface of Weichselian boulder-clay cliffs near Kiel (W. Germany) proves, the bryozoa are scattered throughout the matrix.

One might suppose that the bryozoa in the boulder-clay came from weathered flint blocks. This is not the case, for such bryozoa are silicified. These, however, are seldom encountered in our samples.

Another possible source are the cavities in flint blocks, filled with Cretaceous material. As this peculiar sort of flint is seldom found in the Netherlands, this source is not important either.

So we may conclude that the fine material of the examined grey boulder-clay was derived from the area mentioned above, which implies a north-eastern ice-current in the Netherlands during the Saalian.

The examined bryozoa belong to the orders cyclostomata and cheilostomata, of which the latter forms the majority. In the Baltic Upper Senonian 350 species and in the Danian 117 species of the cheilostomata were known (Voigt 1930); it is certain that at least 79 species of this order occur in both stages (Voigt 1925). The number of the cyclostomata in the Upper Senonian can be estimated at 300 species (Voigt 1930) and in the Danian at about 100 species (Voigt 1924).

Finely we may remark that the samples A 51 (40) and B 2 (43) contained some brown bryozoa, ostracods and crinoid stem-fragments. This might indicate that there is an admixture of red boulder-clay.

TABLE V

MICROFOSSILS

APPINGEDAM sample A 51 (40),

situated 25 km to the north of WINSCHOTEN

white bryozoa: 10 fragments were identified, 84 fragments could not be determined. Moreover one microforaminifer, shell-fragments of lamellibranchiata, spines of echinids and a few brown bryozoa, crinoid stem-fragments and ostracoda were found.

	species	U. Senonian	Danian
cyclostomata	*Entalophora proboscidea* M. Edw.	+	+
	Entalophora cf. geminata v. Hag.	+	—
	Idmonella pseudo-disticha v. Hag. (2 ×)	+	+
	Idmonella subcompressa v. Hag.	+	+
cheilostomata	*Membranipora cf. monocera* Marss.	+	+
	Onychocella (?) chilostoma Marss.	+	—
	Vincularia canaliculata d'Orb.	+	—
	Aechmella microstoma Marss.	+	+
	Micropora subgranulata v. Hag.	+	+

+ = occurs in this stage — = unknown in this stage

BOVENBUREN near WINSCHOTEN sample B 2 (43)

white bryozoa: 37 fragments were identified, 126 fragments could not be determined. Moreover five microforaminifera, some brown bryozoa and crinoid stem-fragments were found.

	species	U. Senonian	Danian
cyclostomata	*Filisparsa fragilis* Marss.	+	—
	Entalophora proboscidea M. Edw. (15 ×)	+	+
	Entalophora proboscidea M. Edw. var. *rustica* v. Hag. (3 ×)	+	+
	Idmonella pseudo-disticha v. Hag. (3 ×)	+	+
	Idmonella dorsata v. Hag.	+	+
	Idmonella lichenoides Goldf.	+	—
cheilostomata	*Amphiblestrum elegans* v. Hag.	+	+
	Coscinopleura angusta angusta Berth.	—	+
	Microspora tenera Voigt	—	+
	Onychonella (?) chilostoma Marss.	+	—
	Onychonella cf. abscondita Marss.	+	—
	Onychonella cf. piriformis Goldf.	+	—
	Vincularia canalifera v. Hag.	+	+
	Pithodella cincta Marss.	+	+
	Quadricellaria excavata d'Orb.	+	+
	Columnotheca cribrosa Marss. (2 ×)	+	+
	cf. *Bactrellaria rugica* Marss.	+	—
	Porina cylindrica Voigt	+	+

MIDWOLDA sample M 53 (44)

white bryozoa: 17 fragments were identified, 56 fragments could not be determined. Moreover one microforaminifer and three shell-fragments of lamellibranchiata were found.

	species	U. Senonian	Danian
cyclostomata	*Idmonella pseudo-disticha* v. Hag.	+	+
	Idmonella laticosta Marss.	+	—
	Idmonella communis d'Orb.	+	+
	Entalophora proboscidea M. Edw. (4 ×)	+	+
cheilostomata	*Membranipora celsospinata* Voigt	+	—
	Vincularia cf. parisiensis d'Orb.	+	—
	Floridina gothica d'Orb.	+	+
	Micropora cf. erratica Voigt	—	+
	Aechmella microstoma Marss.	+	+
	Amphiblestrum elegans v. Hag.	+	+
	Quadricellaria excavata d'Orb. (2 ×)	+	+
	Lunulites faxensis Lev.	—	+
	Acropora foraminosa Voigt	+	—

TABLE VI

LIGHT MINERALS

APPINGEDAM sample 40

fraction	R	SA	A	frosted-R	frosted-SA	Qz	Fw	Fr	Cr	Ls	Fl	Sa
0.85 mm — 1.00 cm	12	77	11	5	18	36	1	3	24	18	—	18
0.42 — 0.85 mm	16	70	14	7	13	81	1	2	3	3	—	10
number of grains	$\underbrace{\quad}$ 100					$\underbrace{\quad}$ 100						

BOVENBUREN sample 43

fraction	R	SA	A	frosted-R	frosted-SA	Qz	Fw	Fr	Cr	Ls	Fl	Sa
0.85 mm — 1.00 cm	15	63	22	10	15	50	—	4	19	15	3	9
0.42 — 0.85 mm	18	55	27	7	15	86	1	2	2	5	—	4
number of grains	$\underbrace{\quad}$ 100					$\underbrace{\quad}$ 100						

MIDWOLDA sample 44

fraction	R	SA	A	frosted-R	frosted-SA	Qz	Fw	Fr	Cr	Ls	Fl	Sa
0.85 mm — 1.00 cm	16	66	18	7	9	46	4	2	22	9	1	16
0.42 — 0.85 mm	25	40	35	9	10	69	4	5	15	4	—	3
number of grains	$\underbrace{\quad}$ 100					$\underbrace{\quad}$ 100						

explanation:

R	rounded quartz grains
SA	sub-angular „ „
A	angular „ „
Qz	quartz
Fw	white feldspar
Fr	red „
Cr	crystalline fragments
Ls	limestone
Fl	flint
Sa	sandstone, quartzite a.s.o.

SUMMARY

In this article the results of a study on boulder-clay in the neighbourhood of Winschoten (N.E. Netherlands) are communicated (Chapter I).

The underlying sediments of the boulder-clay in this area consist of fine preglacial sands and black clay. In the nuclei of the many drumlins a strongly ice-pushed boulder-clay may be encountered (Chapter II).

Palynological analysis showed the pollen content of the boulder-clay to be very small. In a few samples more pollen was found (Plates I and II), but in these cases there appeared to be an admixture of black clay, obviously picked up by the land-ice. This black clay (the so-called potklei or pottery clay) is very humic and resembles the Lauenburg clay from Germany, but is younger.

Using pollen analysis only one would date this clay as Miocene or even older (Plates II and III). This is impossible however, for in borings in this area Pleistocene sediments underneath the potklei are encountered.

The solution of the problem is that we are dealing here with secondary pollen material, originating from the Miocene in N.W. Germany; this pollen was transported by rivers before the land-ice came (Chapter III).

Granulometric analysis proved the boulder-clay of Winschoten to be the normal Dutch type. As far as we know this boulder-clay was deposited during the Saale glacial (Chapter IV).

The erratics in two samples were carefully examined. To this purpose the erratics from 6 mm — 5 cm were counted (according to the Madsen-method 1897); the results were arranged in such way that a comparison with the countings from De Waard (1947) in the N.O. Polder could be made. Therefore the percentages of the various groups of erratics taken from the total content of erratics were compared with each other (Chapter V).

Fig. 4 shows the countings. It will be seen that the number of crystalline erratics in the boulder-clay from Bovenburen is considerably smaller, the sandstone and quartzite content far greater than that found in the boulder-clay from the N.O. Polder. In the field too, this was striking. We might speak of a local association of erratics in the grey boulder-clay at Bovenburen.

The analysis of the light fraction (Chapter VI) gave the following data: the composition of the samples, the roundness and dullness of the quartz grains correspond with the data from the normal grey boulder-clay (Table VI).

This agrees with the fact that the microfossils mentioned in this article were only found in grey boulder-clay. A small admixture of red boulder-clay is possible however, on account of an occasional find of some brown bryozoa and ostracoda characteristic for the red boulder-clay. Moreover the identification of the bryozoa indicated that fine components of the boulder-clay we examined originated from an area (Denmark and S. Sweden) with Danian and Upper Senonian outcrops (Table V).

ZUSAMMENFASSUNG

In diesem Artikel werden einige Untersuchungen am Geschiebelehm in der Nähe von Winschoten (N.O.-Niederlande) beschrieben (Abschnitt I).

Das Liegende des Geschiebelehms in diesem Gebiete besteht aus feinen präglazialen Sanden und schwarzem Ton. In den Kernen der vielen Drumlins findet man bisweilen stark gestauchten Geschiebelehm (Abschnitt II).

Palynologische Forschung ergab, dass die Pollenführung des Geschiebelehms nur sehr gering war. In einigen Proben wurde mehr Pollen gefunden (Plates I und II), doch es stellte sich heraus, dass es sich in diesen Fällen um Beimischung vom schwarzen Ton handelte, offenbar vom Landeis dem Untergrund entnommen. Dieser schwarze Ton (sogen. "Potklei") ist stark humös und ähnelt dem Lauenburger Ton, aber muss jünger sein.

Bloss auf Grund der Pollenzählungen würde man diesen Ton als Miozän datieren (Plates II und III). Das ist hier jedoch völlig ausgeschlossen, weil man in Tiefbohrungen in diesem Gebiet pleistozäne Ablagerungen unter dem Potklei gefunden hat. Die Lösung dieses Prolems ist, dass man mit sekundärem Pollenmaterial zu tun hat, das aus dem Miozän (und möglich aus älteren Ablagerungen) Nordwestdeutschlands herkommt und fluviatil transportiert ist, bevor das Landeis kam (Abschnitt III).

Die granulometrischen Beobachtungen ergaben, dass es sich bei Winschoten um normalen grauen Geschiebelehm handelte (Abschnitt IV). Sofern wir wissen hat sich dieser Geschiebelehm während der Saale-Eiszeit abgelagert.

Auch die Geschieben aus zwei Proben wurden eingehend untersucht. Zu diesem Zweck wurden die Geschieben von 6 mm bis 5 cm — der Methode V. Madsens (1897) gemäss — gezählt und die Ergebnisse in solcher Weise bearbeitet, dass man diese mit den Zählungen De Waards (1947) aus dem N.O. Polder vergleichen konnte. So wurden die Prozentsätze der verschiedenen Gesteinsgruppen aus der totalen Geschiebeführung miteinander verglichen (Abschnitt V).

Fig. 4 stellt die Zählungen dar und zeigt dabei, dass der Geschiebelehm Bovenburens viel weniger kristalline Geschieben, aber viel mehr Sandstein und Quarzit enthält als im N.O. Polder. Im Gelände war das schon auffallend. Vielleicht kann man also von einer lokalen Geschiebe-Assoziation im grauen Geschiebelehm von Bovenburen sprechen.

Die Leichtmineralanalyse (Abschnitt VI) erwies Folgendes:

Die Zusammensetzung der Proben, die Abrundung und Mattheit der Körner stimmen völlig überein mit den bekannten Daten aus dem normalen grauen Geschiebelehm (Table VI).

Dies steht im Einklang mit den Mikrofossilien, die auch auf einen normalen Geschiebelehm deuten, obwohl eine geringe Beimischung mit rotem Geschiebemergel möglich ist auf Grund einiger brauner Bryozoen und Ostrakoden, die für den roten Geschiebemergel charakteristisch sind.

Ausserdem zeigt die Bestimmung der Bryozoenarten, aus welchem Gebiet das feine Material des untersuchten Geschiebelehms herkommt (Table V); zweifellos ist viel Material Dänemark, wo Danien und Ob. Senon nebeneinander anstehen, entnommen worden.

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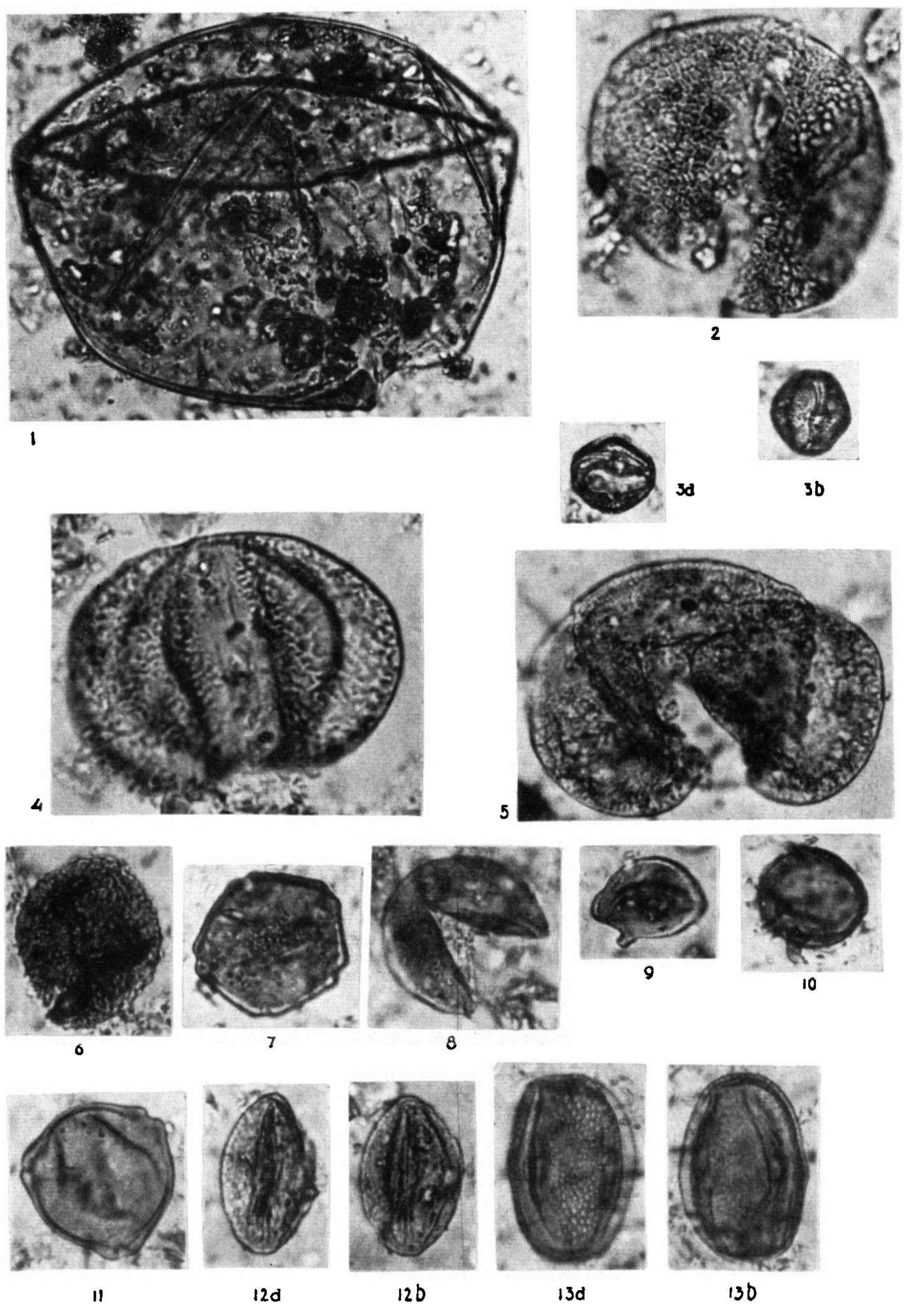
PLATE I. **Pollengrains from boulder-clay**

1.	*Larix-type*, 120 μ ; Bovenburen (B 2)
2.	*Pinus haploxylon* 70 μ ; Midwolda (M 53)
3a, b.	unknown grain 19 μ ; Midwolda (M 53)
4.	*Pinus haploxylon* 58 × 45 μ ; Bovenburen (B 2)
5.	*Pinus silvestris* 79 × 55 μ ; Midwolda (M 53)
6.	*Sciadopitys* 36,5 μ ; Bovenburen (B 2)
7.	*Pterocarya* 30,5 μ ; Appingedam (A 51)
8.	*Taxodium-type* 36 μ; Midwolda (M 53)
9.	*Sequoia-type* 25 μ ; Midwolda (M 53)
10.	*Sequoia-type* 27 μ; Appingedam (A 51)
11.	*Myricaceae* 32 μ; Bovenburen (B 2)
12a, b.	*Pollenites henrici* 34 × 20,5 μ ; Bovenburen (B 2)
13a, b.	unknown grain (*Stewartia ?*) ; 39,5 × 24,5 μ; Bovenburen (B 2)

(All grains photographed with object. 45 × and oculair 10 ×; P. v. Gijzel)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2
3a
3b
4
5
6
7
8
9
10
11
12a
12b
13a
13b

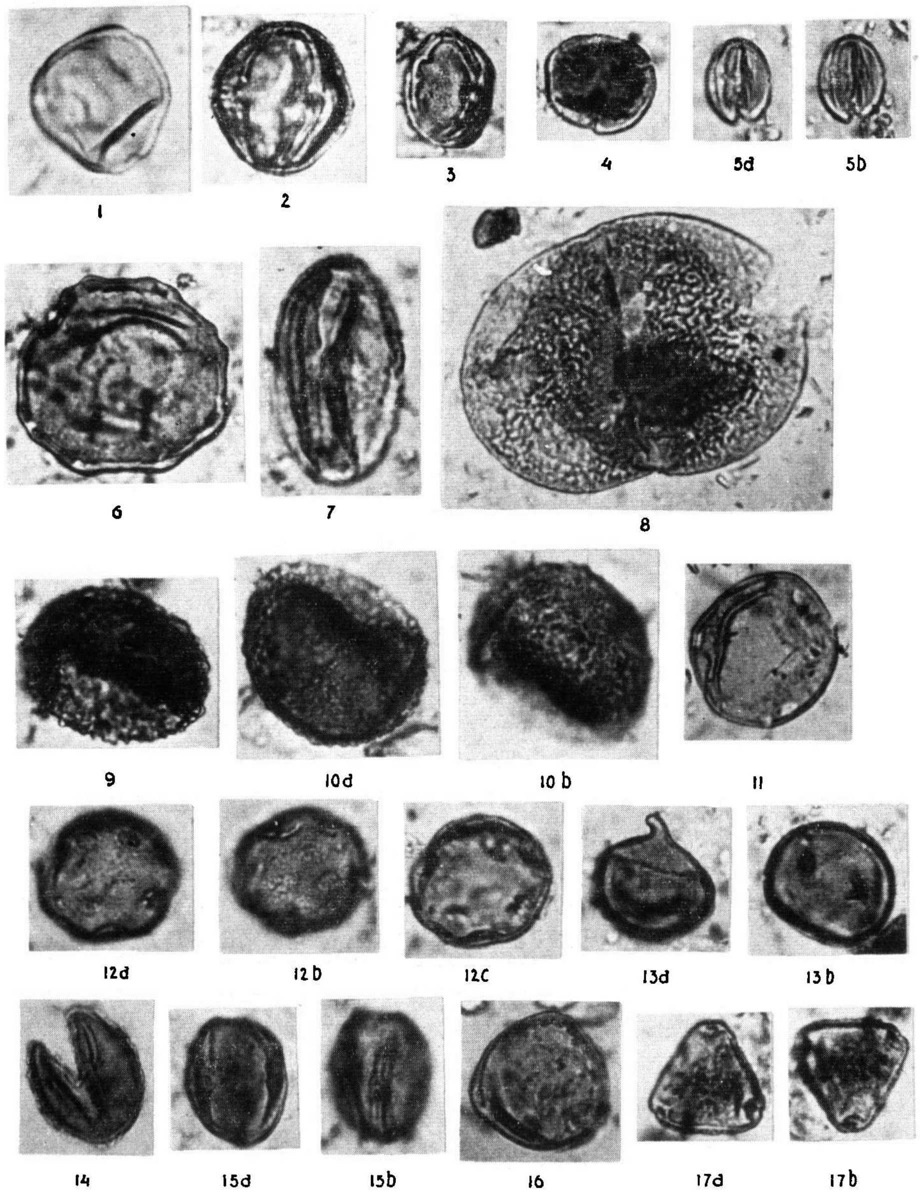
PLATE II. **Pollengrains from boulder-clay (continued)**

1.	*Engelhardtia* 27,8 μ; Appingedam (A 51)
2.	unknown grain 30,5 μ ; Midwolda (M 53)
3.	*Nyssa spec.* 26,5 μ; Bovenburen (B 2)
4.	*Pollenites megaexactus brühlensis* 20 μ; Bovenburen (B 2)
5a, b.	*Castanea* 21μ ; Appingedam (A 51)

Pollen and spores from "potklei"

6.	*Pterocarya* 37 μ ; Ulsda (U 4)
7.	*Pollenites microhenrici* 36 $\times$ 21 μ; Bovenburen (B 29); (1000 $\times$ oil-imm.)
8.	*Pinus haploxylon* 68 μ ; Ulsda (U 4)
9.	*Sciadopitys* 41 μ ; Bovenburen (B 29)
10a, b.	*Sciadopitys* 44 μ; Ulsda (U 4)
11.	*Carya* (small type) 33 μ; Ulsda (U 4)
12a, b, c.	*Liquidambar* 29 μ ; Bovenburen (B 29)
13a, b.	*Sequoia-type* 24,5 μ ; Ulsda (U 4)
14.	*Taxodium-type* 33μ ; Appingedam (A 52)
15a, b.	*Nyssa spec.* 27,5 $\times$ 21 μ ; Bovenburen (B 29)
16.	*Myricaceae* 28 μ ; Bovenburen (B 29)
17.	*Porocolpopollenites vestibulum* 24,5 μ ; Appingedam (A 52)

(All grains, without photo 7, photographed as in plate I; photos: P. v. Gijzel)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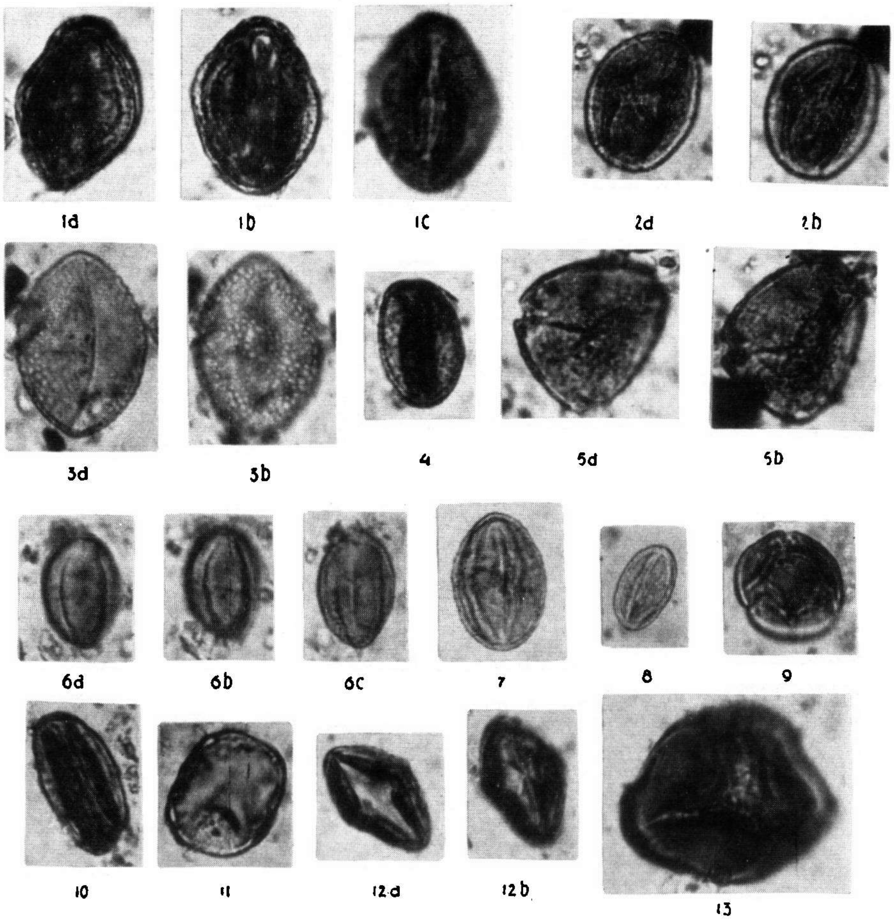


PLATE III. Pollen and spores from "potklei" (continued)

1a, b, c. *Tricolporites edmundi* 38,5 × 27 μ ; Ulsda (U 4)
2a, b. unknown grain 31 × 22,7 μ; Ulsda (U 4)
3a, b. *Palmae (c.f. Parrareolatus)* 38 × 27 μ ; Bovenburen (B 29)
4. *Pollenites microhenrici* 26 × 15 μ; Ulsda (U 4)
5a, b. *Symplocaceae* 32,5 μ ; Ulsda (U 4)
6a, b, c. c.f. *Rhus spec.* 23 × 16,5 μ ; Bovenburen (B 29)
7. *Pollenites microhenrici* 33 × 19,5 μ; Bovenburen (B 29)
8. *Pollenites villensis* 19,5 μ ; Bovenburen (B 29)
9. *Pollenites megaexactus brülensis* 24,5 μ ; Appingedam (A 52)
10. *Pollenites henrici* 32 μ ; Appingedam (A 52)
11. *Zelkova* or *Ulmus* 24 μ ; Ulsda (U 4)
12a, b. *Pollenites pseudocingulum* 28 μ ; Bovenburen (B 29)
13. *Concavisporites spec.* 43 μ ; Bovenburen (B 29)
(All grains photographed as in plate I; photos: P. v. Gijzel)

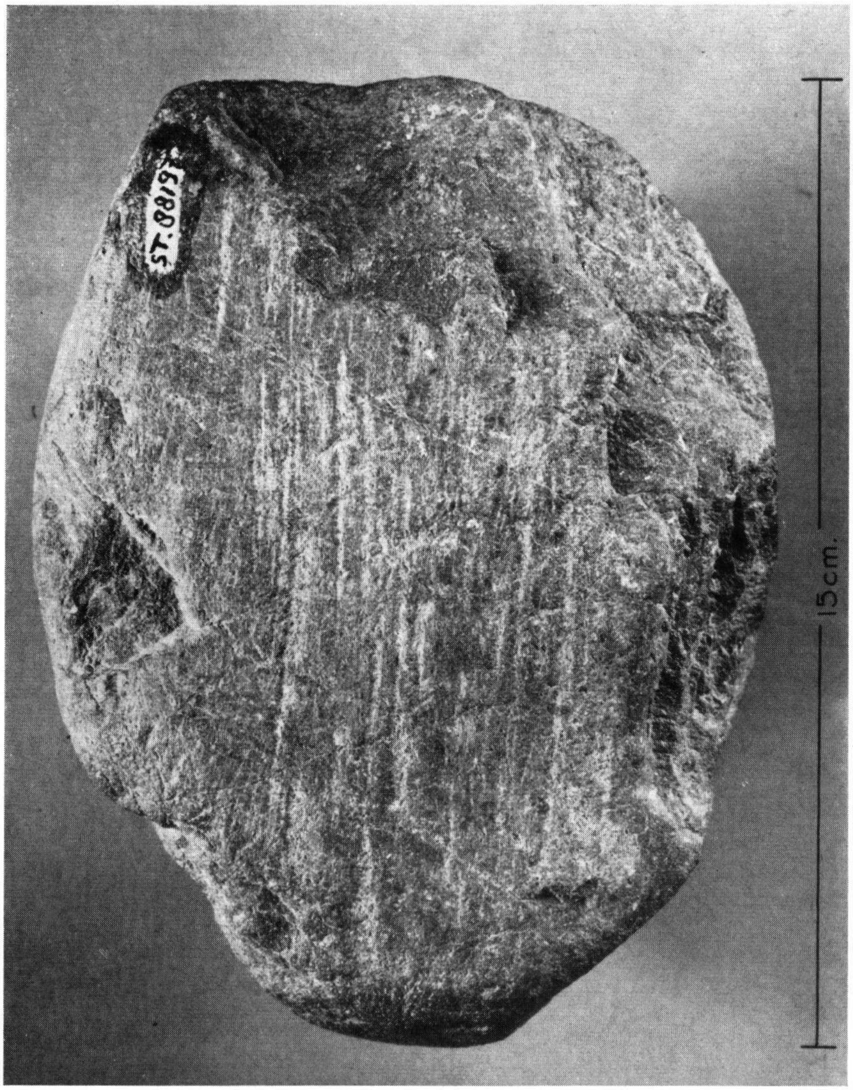
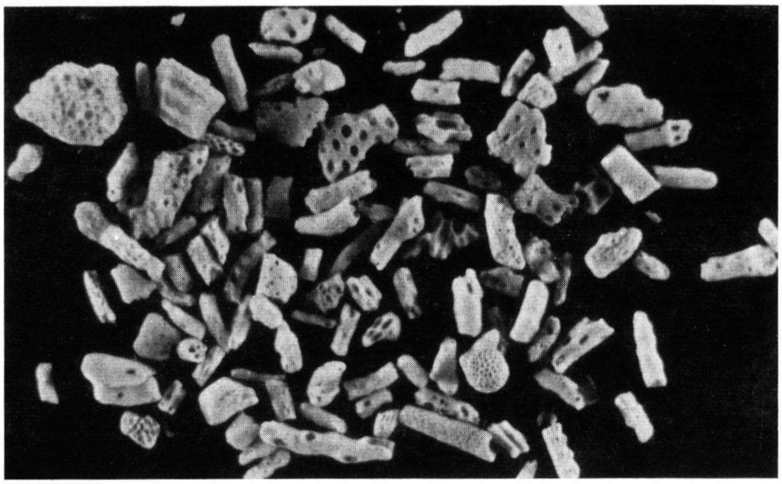


PLATE IV. Augite-anorthositeporphyrite with glacial striae
(photo: B. F. M. Collet)

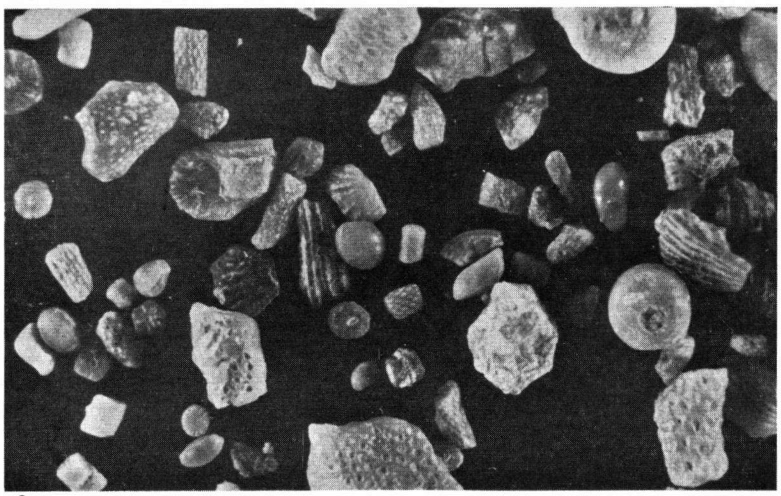
PLATE V

Microfaunal assemblages (magn. 5.5 x)

1. Grey boulder-clay (Saale). WINSCHOTEN sample 43 II
2. Red boulder-clay (Saale). GRONINGEN sample 32
3. Grey boulder-clay (Weichsel). RISTINGE KLINT sample 506 III (Langeland, DENMARK)



1.



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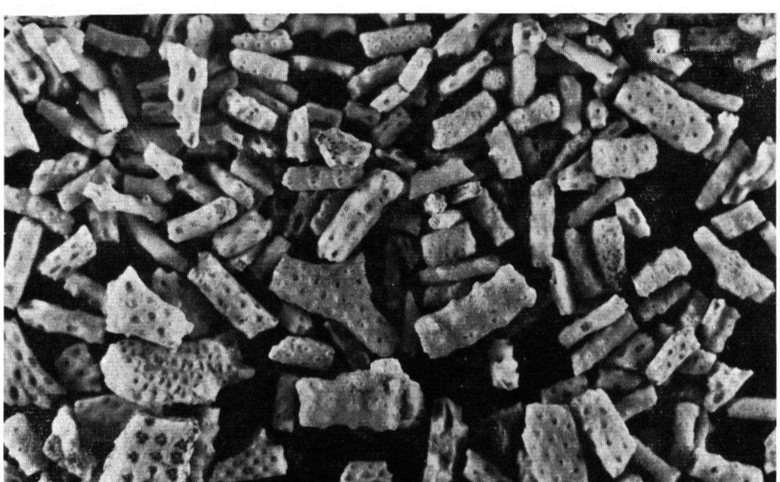

3.

(Photos by J Hoogendoorn)