

THE PALAEOENVIRONMENT OF THE KEMPENLAND CLAY DEPOSITS (LOWER QUATERNARY, N. BELGIUM)¹

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ABSTRACT

Geys, J. F. (1978). The palaeoenvironment of the Kempenland clay deposits (Lower Quaternary, N. Belgium). *Geol. Mijnbouw*, 57, p. 33-43.

Grain-size analyses show that the Kempenland deposits (Lower Quaternary, N. Belgium) were deposited in an environment of rather quiet water with a low flow energy and no tidal influence. Electron microscopical investigations indicate that the water contained few salts. The sedimentary structures are the result of an unidirectional current towards the northwest, in a river with a mainly meandering character. No evidence could be found for a marine, littoral or perimarine genesis. Most probably the Kempenland deposits can be placed within the Kedichem and Tegelen Formations of Dutch authors.

RESUMÉ

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La composition granulométrique montre que la formation de la Campine (Quaternaire inférieur, Belgique septentrionale) a été déposée dans un milieu aquatique relativement calme. L'influence des marées ne s'y manifestait peu ou pas. L'examen des grains de quartz au microscope électronique indique que l'eau contenait peu de sels. Les structures sédimentaires sont causées par un courant unidirectionnel vers le nordouest dans une rivière à méandres. Des arguments pour une genèse marine, littorale ou périmarine n'ont pas été trouvés. Il est très probable que la formation de la Campine peut être placée dans les Formations de Kedichem et de Tegelen des auteurs Néerlandais.

INTRODUCTION

For more than a century clay beds have been known to be present in the northern Kempenland (province of Antwerp, N. Belgium). In the early literature many different names were used to designate these Lower Quaternary clays and the sandy layers which are often associated with them: Kempenland clay, Rijkevorsel clay, Merksplas clay, etc.

Up to the present neither the age nor the nature of the

palaeoenvironment, in which these deposits came into being, have been accurately known. It was generally accepted that they originated somewhere in the Lower Quaternary. PAEPE & VANHOORNE (1970) distinguished three separate members within the Kempenland deposits, dated respectively as Tiglian, Eburonian and Waalian.

The palaeoenvironment of the Kempenland deposits has always been the object of controversy among researchers. TAVERNIER (1954) considers this formation to be a fluvial deposit in a meandering river. Some other authors, such as HUYGHEBAERT (1961), DRICOT (1961), DE PLOEY (1961) and VAN OOSTEN (1967) maintain that the Kempenland deposits have been deposited in brackish or in salt water, possibly in an estuary or on tidal flats. The Kedichem and Tegelen Formations, which can be considered as the continuation of the Kempenland deposits in The Netherlands are almost unanimously regarded as fluvial deposits by Dutch authors, such

¹ Manuscript received: 1977-05-16.

Revised manuscript received and accepted: 1977-11-11.

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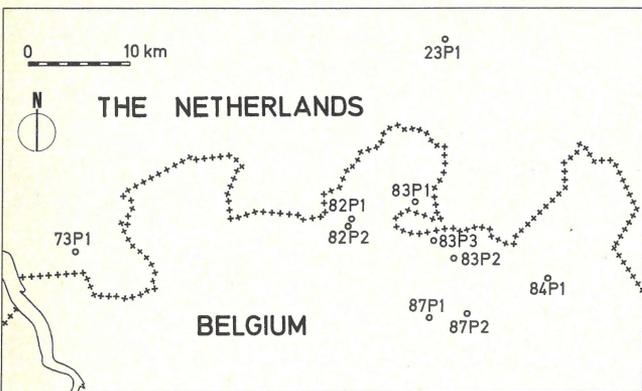


Fig. 1
Geographical location of the sampled exposures.

AS NELSON & VAN DER HAMMEN (1953), VAN DORSSER (1956), ZONNEVELD (1958), VAN DER HEIDE & ZAGWIJN (1967), VERBRAECK & BISSCHOPS (1971), ZAGWIJN (1974), etc.

The lack of fossils in the Kempenland deposits is an obstacle in the determination of the palaeoecological conditions at the time of the sedimentation. In a claypit near Breda (The Netherlands) a molluscan fauna, consisting of terrestrial and fresh-water species (SPAINK, 1968), indicates a fluvial or lacustrine environment. On the other hand the presence of large numbers of Chenopodiacean pollen in the Kempenland deposits seems to point to a salt- or brackish-water deposit (DRICOT, 1961). It should be noted, however, that other investigators in palaeobotany (GREGUSS & VANHOORNE, 1961; HACQUAERT, 1963; PAEPE & VANHOORNE, 1970; ZAGWIJN in VERBRAECK & BISSCHOPS, 1971) do not confirm Dricot's statement.

In this paper an attempt is made to determine the palaeoenvironment of the Kempenland deposits on the basis of a sedimentological investigation. To this end approximately 180 samples from the Lower Quaternary sediments were taken from 10 different exposures. Besides the grain-size distribution attention was paid to the morphoscopy and the surface textures of quartz sand grains and to the sedimentary structures.

DESCRIPTION OF THE EXPOSURES

The location of the exposures, indicated by their archive numbers, is given in Fig. 1. All other material, backing up the statements in this paper, can be found in GEYS (1975). Descriptions in extenso of the profiles, laboratory analyses, etc. are deposited in the archives of the laboratory for Mineralogy, Geology and Physical Geography of the State University of Antwerp (R.U.C.A., see authors' address).

GRANULOMETRY

Description

The granulometry of the coarse fraction was determined by dry sieving. The fine fraction was analysed by a hydrophotometer (cf. JORDAN et al., 1970).

Some parameters were computed, of which the means and the extremes have been compiled (Table I).

Interpretation

The indices of Doeglas – Following a procedure proposed by DOEGLAS (1968), each sample of sediment is given an index, consisting of three or five digits. Most indices cannot be clearly interpreted, and some are not even mentioned among Doeglas' standard indices.

The Sk- σ -plot – Of the different graphical methods proposed by FRIEDMAN (1967), to distinguish between beach and river sands, the Sk- σ -plot is most commonly used. On the diagram (Fig. 2) for samples from the Lower Pleistocene, 61 out of 75 have fluvial characteristics. None of the points in the littoral zone is situated far from the dividing line. The Sk- σ -plot seems to point towards a fluvial origin for the Lower Quaternary sandy deposits.

Skewness and the Sk- K_g -plot – According to FRIEDMAN (1961) two different fields can be separated in a Sk- K_g -plot. While no significant difference in kurtosis between the two kinds of sediments can be seen, the skewness seems to be positive in most of the fluvial, and negative in most of the littoral sands.

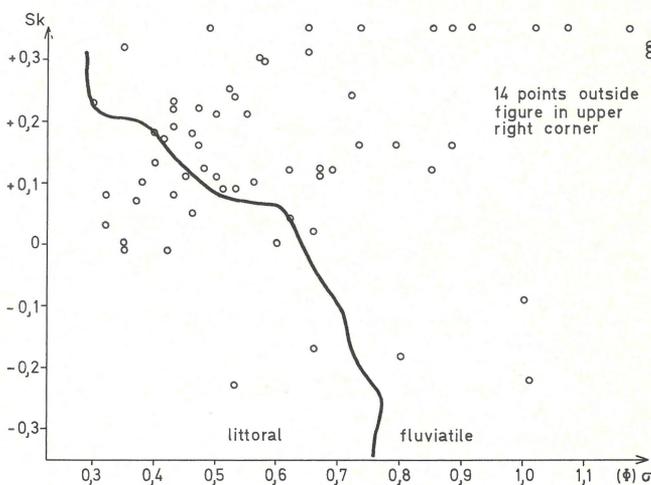


Fig. 2
Sk- σ -plot for sandy samples from the Lower Pleistocene.

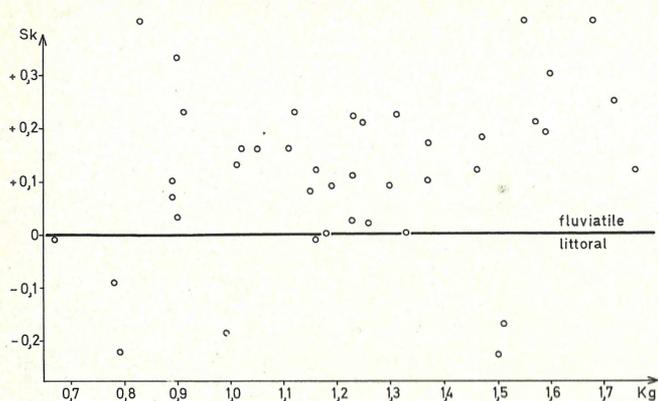


Fig. 3
Sk- K_g -plot for sandy samples from the Lower Pleistocene.

Negative skewness is expected to be dominant in sediments deposited by the winnowing action of surf and tides, while sediments deposited in a more quiet palaeoenvironment, such as a lake or a slowly flowing river, show a positive skewness in most cases (DUANE, 1967).

In the Sk- K_g -plot for the samples from the Lower Quaternary (Fig. 3), the distribution of the points fits fairly well with the pattern of the river sands in Friedman's figure. From figures 2 and 3 it becomes obvious that 67, out of 76 sandy samples are positively skewed. This seems to indicate that the investigated sediments can be considered as a 'chaff' deposit.

σ_1 - M_z -plot – Plotting the Mean M_z versus the inclusive graphic standard deviation σ_1 was seen to be irrelevant.

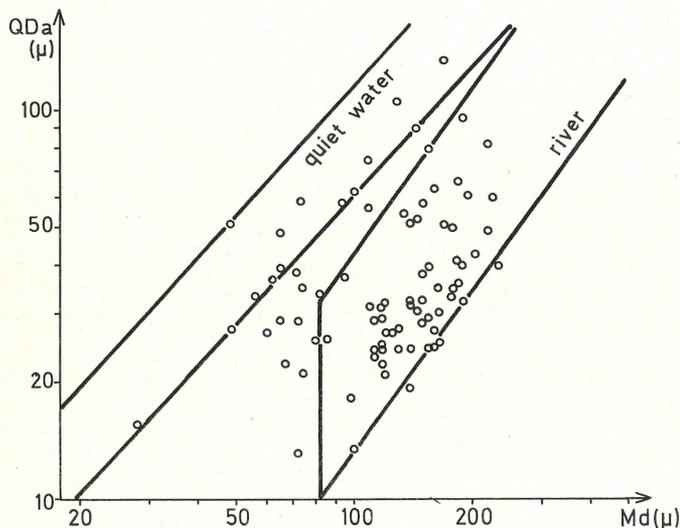


Fig. 4
QDa-Md-plot for lower Quaternary samples.

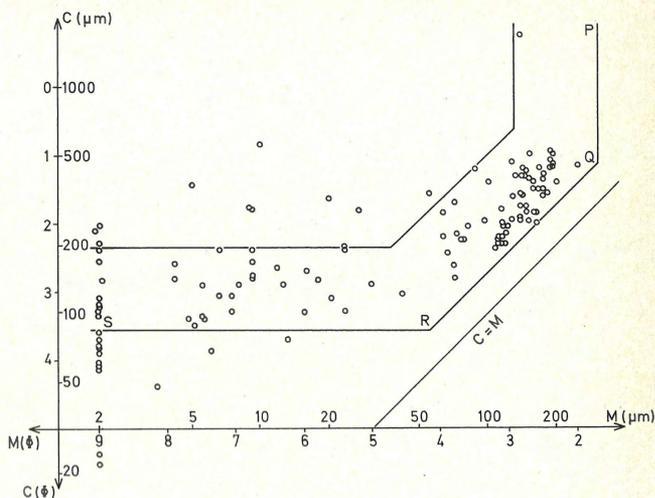


Fig. 5
CM-pattern for Lower Quaternary samples.

QDa-Md-plot – On the QDa-Md-plot, constructed according to the directives of BULLER & MCMANUS (1972), for the samples from the Lower Quaternary, the cloud of dots is a little diffuse and its trend line is difficult to trace. Its position vaguely indicates a fluvatile and/or a lacustrine palaeoenvironment. No affinity with a littoral origin can be shown (Fig. 4).

CM-pattern – Fig. 5 shows the CM-pattern (PASSEGA, 1957, 1964; R. PASSEGA & BYRAMJEE, 1969) for the Kempenland deposits. The pattern shows two main segments and points to an environment with traction currents. Sandy samples account for the dots in segment RQ, while segment SR is mainly made up of more fine grained samples. Clayey samples are grouped in segment T. From this evidence it may be stated that the material of the Kempenland deposits was transported almost exclusively in uniform, graded and pelagic suspensions. Segments QP, PO and ON are missing. Hence, rolling transport can have been of no importance.

Cumulative curves and truncation points – Cumulative curves on probability paper were drawn and interpreted as proposed by VISHER (1965, 1969). These curves, for samples from the Lower Quaternary, could be classified into four types:

- type I: consists of a saltation population alone, indicated by a straight line; no truncation points;
- type II: the most complete graph, with three populations, a suspension a saltation and a rolling population; two truncation points;
- type III: shows two mixed populations; the curve is concave to the lower side, but truncation points are not present;
- type IV: a saltation and a suspension population with one truncation point.

Profile	23 P 1	73 P 1		82 P 1		82 P 2	84 P 1			87 P 1				
layers	d-e	f-g	h-l	g-j (2)	g-j (1) (3)	e-g	m-n	o-p (1)	q	j-l	m-n (4)	o-r (1)	s-t	
% sand	mean	13,77	15,81	93,08	29,57	77,96	96,36	15,80	84,24	4,83	4,25	65,16	76,20	7,91
	max	35,94	24,89	99,60	48,15	83,09	98,27	23,85	91,93	8,29	15,53	92,82	86,81	21,75
	min	4,63	5,47	79,21	9,69	73,87	92,69	7,14	76,98	0,80	1,38	23,74	57,07	0,25
% silt	mean	39,59	30,49	—	41,36	13,65	—	37,69	—	59,08	32,95	—	—	44,10
	max	53,69	39,09	—	48,21	15,75	—	47,04	—	67,94	37,85	—	—	63,67
	min	29,27	21,91	—	34,92	10,47	—	26,46	—	50,95	26,49	—	—	31,92
% clay	mean	46,63	53,70	—	29,07	8,39	—	46,51	—	36,09	62,80	—	—	47,99
	max	55,95	72,62	—	42,10	11,35	—	66,40	—	48,25	71,84	—	—	67,83
	min	34,79	36,02	—	16,93	6,44	—	36,55	—	26,67	50,17	—	—	14,58
Md	mean	—	—	2,84 Φ = 138 μ	5,86 Φ = 17 μ	3,71 Φ = 76 μ	2,70 Φ = 154 μ	—	2,66 Φ = 158 μ	—	—	3,80 Φ = 72 μ	3,65 Φ = 78 μ	—
	max	—	—	3,20 Φ = 108 μ	7,50 Φ = 5,5 μ	3,80 Φ = 72 μ	2,95 Φ = 129 μ	—	2,80 Φ = 144 μ	—	—	7,65 Φ = 5 μ	4,15 Φ = 56 μ	—
	min	—	—	2,30 Φ = 203 μ	4,55 Φ = 43 μ	3,55 Φ = 85 μ	2,45 Φ = 183 μ	—	2,50 Φ = 177 μ	—	—	2,15 Φ = 225 μ	3,30 Φ = 101 μ	—
M _z	mean	—	—	2,94 Φ	—	4,18 Φ	2,72 Φ	—	3,16 Φ	—	—	—	3,17 Φ	—
	max	—	—	4,38 Φ	—	4,60 Φ	2,97 Φ	—	3,95 Φ	—	—	—	4,55 Φ	—
	min	—	—	2,28 Φ	—	3,67 Φ	2,43 Φ	—	2,55 Φ	—	—	—	3,25 Φ	—
σ_i	mean	—	—	0,58 Φ	—	1,20 Φ	0,43 Φ	—	1,33 Φ	—	—	—	2,30 Φ	—
	max	—	—	2,12 Φ	—	1,75 Φ	0,56 Φ	—	2,12 Φ	—	—	—	4,75 Φ	—
	min	—	—	0,30 Φ	—	0,72 Φ	0,32 Φ	—	0,62 Φ	—	—	—	1,07 Φ	—
Sk _i	mean	—	—	+ 0,19	—	+ 0,55	+ 0,09	—	+ 0,41	—	—	—	0,00	—
	max	—	—	+ 0,83	—	+ 0,68	+ 0,19	—	+ 0,81	—	—	—	+ 0,32	—
	min	—	—	- 0,23	—	+ 0,24	- 0,01	—	+ 0,12	—	—	—	- 0,25	—
K _g	mean	—	—	1,16	—	—	1,31	—	—	—	—	—	—	—
	max	—	—	1,72	—	—	1,59	—	—	—	—	—	—	—
	min	—	—	0,67	—	—	1,15	—	—	—	—	—	—	—

Table I
Granulometry.

83 P 1			83 P 2	83 P 3	84 P 1		87 P 1	87 P 2				
h	i	j-l	e-g	f	g-lf (1)	i-l	u-x	j-m (1)	n-r	s-w	x	y-d'
6,18	96,16	23,82	93,70	96,57	68,18	94,84	36,17	85,20	11,71	60,99	3,46	45,16
7,45	96,45	41,88	94,87	98,48	72,62	99,20	56,71	98,48	31,19	84,92	4,14	77,14
4,25	95,87	7,94	91,57	93,01	63,74	88,53	23,91	63,81	1,78	35,48	1,40	9,94
43,16	—	41,90	—	—	19,37	—	27,27	—	30,85	15,23	35,61	19,08
47,98	—	50,01	—	—	23,42	—	36,78	—	36,34	31,03	37,84	33,80
39,17	—	38,30	—	—	15,32	—	20,06	—	15,62	5,89	34,51	9,63
50,66	—	34,28	—	—	12,45	—	36,55	—	57,44	23,78	60,94	35,76
53,97	—	53,76	—	—	12,84	—	43,82	—	82,49	46,18	64,31	56,26
44,57	—	17,59	—	—	12,06	—	23,23	—	36,71	9,19	58,03	13,23
—	2,32 Φ = 200 μ	—	2,79 Φ = 145 μ	2,56 Φ = 170 μ	3,92 Φ = 66 μ	3,04 Φ = 122 μ	6,18 Φ = 14 μ	3,10 Φ = 117 μ	—	4,20 Φ = 54 μ	—	5,44 Φ = 21 μ
—	2,35 Φ = 196 μ	—	3,10 Φ = 117 μ	2,80 Φ = 144 μ	3,95 Φ = 65 μ	3,60 Φ = 82 μ	7,25 Φ = 7 μ	4,05 Φ = 60 μ	—	7,25 Φ = 7 μ	—	10,50 Φ = 0,7 μ
—	2,30 Φ = 203 μ	—	2,45 Φ = 183 μ	2,35 Φ = 196 μ	3,90 Φ = 67 μ	2,40 Φ = 189 μ	3,95 Φ = 65 μ	2,10 Φ = 233 μ	—	2,45 Φ = 183 μ	—	2,25 Φ = 210 μ
—	2,42 Φ	—	2,85 Φ	2,61 Φ	4,61 Φ	3,06 Φ	—	3,48 Φ	—	—	—	—
—	2,48 Φ	—	3,12 Φ	2,83 Φ	4,70 Φ	3,50 Φ	—	5,26 Φ	—	—	—	—
—	2,37 Φ	—	2,65 Φ	2,42 Φ	4,53 Φ	2,45 Φ	—	2,15 Φ	—	—	—	—
—	0,49 Φ	—	0,72 Φ	0,76 Φ	1,48 Φ	0,51 Φ	—	1,20 Φ	—	—	—	—
—	0,50 Φ	—	0,85 Φ	0,88 Φ	1,62 Φ	0,65 Φ	—	2,72 Φ	—	—	—	—
—	0,48 Φ	—	0,67 Φ	0,66 Φ	1,35 Φ	0,37 Φ	—	0,37 Φ	—	—	—	—
—	+ 0,33	—	+ 0,18	+ 0,12	+ 0,70	+ 0,06	—	+ 0,31	—	—	—	—
—	+ 0,45	—	+ 0,41	+ 0,16	+ 0,70	+ 0,31	—	+ 0,67	—	—	—	—
—	+ 0,21	—	+ 0,11	+ 0,02	+ 0,69	- 0,25	—	- 0,12	—	—	—	—
—	1,46	—	1,51	1,11	—	1,32	—	—	—	—	—	—
—	1,68	—	1,76	1,26	—	1,51	—	—	—	—	—	—
—	1,25	—	1,28	1,02	—	1,19	—	—	—	—	—	—

- (1) Graphic values σ_g and Sk_g are given instead of inclusive values σ_i and Sk_i .
- (2) Clayey samples from layers g-j of profile 82 P 1.
- (3) Sandy samples from layers g-j of profile 82 P 1.
- (4) These layers consist of an irregular succession of laminae medium sand and clay, in variable amounts. The clay is identical to that from layers j-l. The sand has a medium grain size (mean about 2.15 Φ = 225 μ), is moderately well sorted (σ_g = 0.55 Φ) and shows a positive skewness (Sk_g = + 0.20).

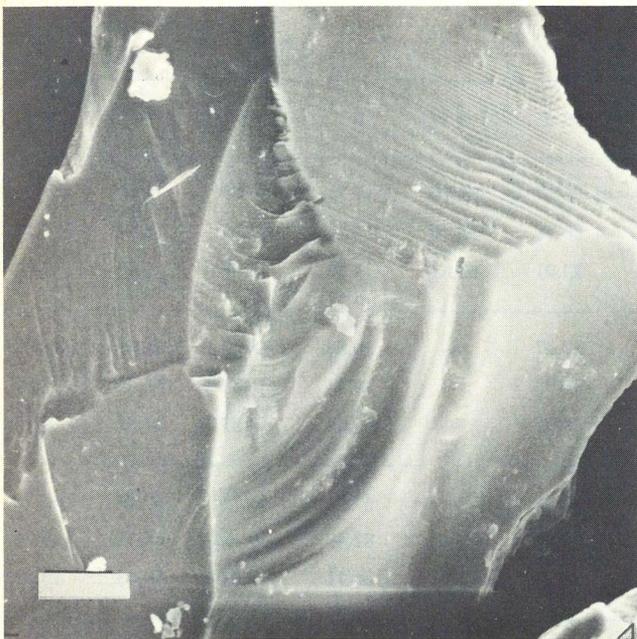


Fig. 6
Scanning electron micrograph of a quartz sand grain from the Lower Quaternary, showing imbricate and conchoidal fracture planes. Dash = 10 μm .

Some type III distributions were plotted, according to the method of DOUGLAS (1950). In that way, two populations could be discerned, separated by a truncation point: a large suspension population and a saltation population of much less importance.

Visher's curves of the Lower Quaternary sediments most frequently belong to types III and IV (GEYS, 1975). Type III curves are characteristic for fine-grained, very clayey sediments, while clay with sandy lenses or predominantly sandy material generally give rise to type IV curves. In most cases only a saltation and suspension population seem to be present. Nevertheless, the relative share of each population can vary considerably, from 0,5% to 97% saltation. The truncation point can vary in grain size from 1 Φ (500 μm) to 6 Φ (15,5 μm), but in most cases it is situated between 3,5 Φ (88 μm) and 4,5 Φ (44 μm).

Some rare type I curves do occur. Most probably they can be considered as actual type IV curves, with a very inconsiderable suspension population, which was not analysed separately. Hence no data are available on the fine tails of these grain-size distribution graphs.

Type II curves, indicating the presence of a rolling population, occur almost exclusively in layers with a partial residuary character, which are dissected by overlying strata. Even in those cases, the rolling population never shares for more than 2,5% and it rarely even exceeds 1% in the total weight of the sample: it remains unimportant.

It can be mentioned that the suspension population and the

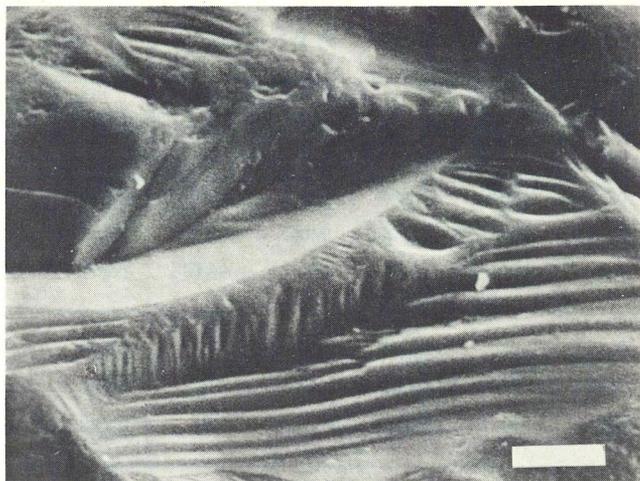


Fig. 7
Scanning electron micrograph of a quartz sand grain from the Lower Quaternary, showing semiparallel and arc-shaped steps. Dash = 5 μm .

saltation population, in the sense of VISHER (1965), may be considered as synonymous with the uniform and the graded suspension respectively, in the sense of PASSEGA (1964).

MORPHOLOGY OF THE QUARTZ GRAINS

Morphoscopy

Roundness P , sphericity ψ and the percentage of frosted grains were determined in a subjective way, observing 100 grains from the grain-size fraction 74-105 μm of each sample by means of a binocular microscope, and comparing their outlines with the standard chart of KRUMBEIN & SLOSS (1951).

According to MACCARTHY (1935) the difference in roundness between aeolian and aquatic sands is related to grain size. The 74-105 μm fraction was selected since it shows a fair contrast and since it is present in all samples. The following values were obtained for the morphological parameters in the Lower Quaternary:

% frosted grains: 40% to 82%;
mean P = 0,118 to 0,306;
mean ψ = 0,644 to 0,770.

In the same profile, the parameters hardly show a contrast, except on the boundary between Lower and Upper Quaternary. The Upper Quaternary coversands and dune sands are always better rounded than the Lower Quaternary sands which they overlay. Moreover they often contain more frosted grains. Similar differences in shape between aeolian and non-aeolian sands were previously ascertained by MACCARTHY (1935), BEAL & SHEPARD (1956) and CAILLEUX & TRICART (1963).

The extreme roundness and the relatively large percentage



Fig. 8
Scanning electron micrograph of a quartz sand grain from the Lower Quaternary, showing sickle-shaped collision traces. Dash = 20 μm .

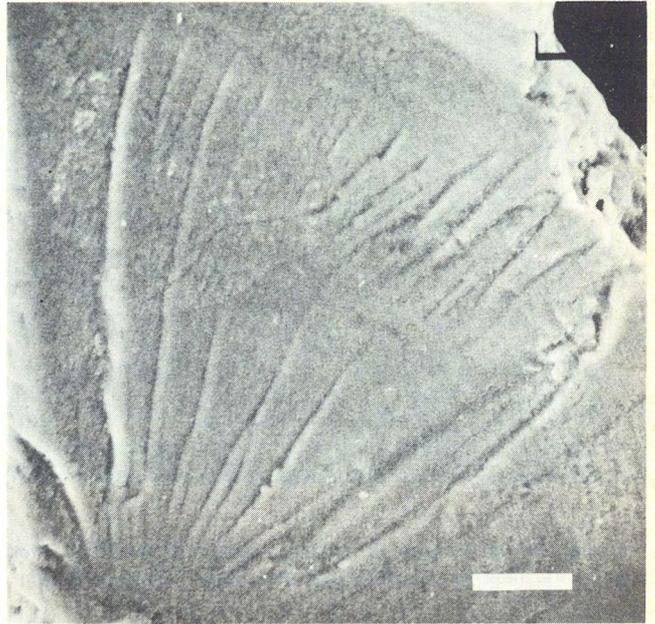


Fig. 9
Scanning electron micrograph of a quartz sand grain from the Lower Quaternary, showing a pattern of convergent striae. Dash = 10 μm .

of frosted grains in layer j of profile 84 P 1 (mean $P = 0,256$; % frosted grains 66%, whereas those mean parameters are respectively 0,203 and 53% in the remaining part of the Lower Quaternary in that profile) indicate a dominant aeolian influence.

Electron microscopy

From each profile samples were selected to represent, as well as possible, the different sets of layers. Without any selection in size, some grains of each sample were examined, using a scanning electron microscope JEOL JSM-U3.

Characteristic textures are relatively rare on quartz grains from the Lower Quaternary in the Northern Kempenland. Most surface textures are fracture patterns: imbricate fracture blocks, conchoidal fracture planes, semi parallel and arc shaped steps, very high relief (Figs. 6 and 7). Less common are irregular small indentations and parallel striations. All those textures are thought to be characteristic of glacial environments (KRINSLEY & DONAHUE, 1968). Nevertheless these textures also occur frequently on quartz grains from other kinds of deposits (SETLOW & KARPOVICH, 1972; GEYS, 1973).

Many grains show collision traces as small, sickle-shaped indentations (Fig. 8), probably caused by subaquatic transport. A pattern of convergent striae, similar to those described by SOUTENDAM (1967) in the Loire river sands, could be observed on a few grains (Fig. 9).

Triangular and rectangular etching figures are very rare and most have a worn appearance (Fig. 10). Assuming that the Kempenland deposits are a salt water sediment, a frequent

occurrence of such etching figures could be expected. Indeed, earlier papers mention that etching not only occurs on grains from beach sands, but also on grains from other saltwater sediments, such as tidal-flat deposits (GEYS, 1973).

Hence, since unworn etching figures and marine surface textures are missing, the Kempenland deposits may be considered to have originated in a relatively fresh environment. These few grains bearing such textures, though worn, are very probably reworked from older marine sediments.

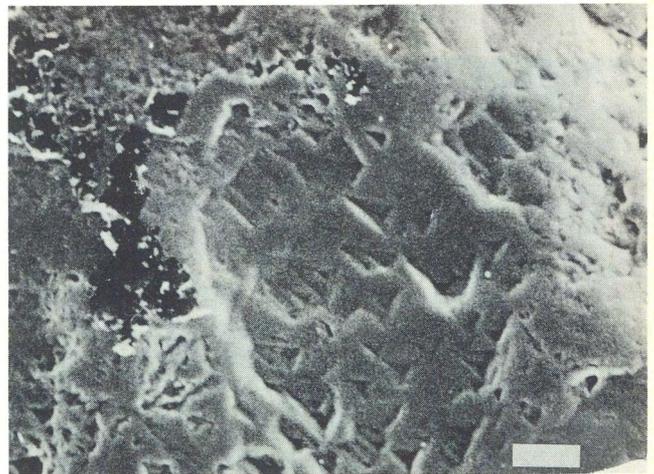


Fig. 10
Scanning electron micrograph of a quartz sand grain from the Lower Quaternary, showing slightly worn triangular etching figures. Dash = 10 μm .

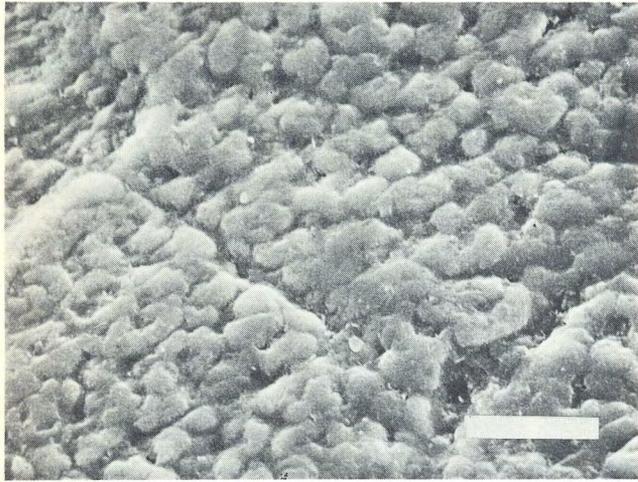


Fig. 11
Scanning electron micrograph of a quartz sand grain from the Lower Quaternary, showing typical 'orange peel texture'. Dash = 10 μm .

Yet it has to be stated that, hitherto, no characteristic fluvial or lacustrine surface textures have been found. No direct proof as such for a fluvial or lacustrine environment is available.

Investigations by the electron microscope have demonstrated aeolian influence in a bed of Lower Quaternary age. The same level was noticed above for the exceptional roundness of its grains: layer j in profile 84 P 1. Indeed the quartz grains from this level show aeolian textures such as meandering ridges, pitted surface and so called 'orange peel textures' (Fig. 11).



Fig. 12
Megaripples and large-scale fore-set cross-bedding in layers m-n of profile 87 P 1.

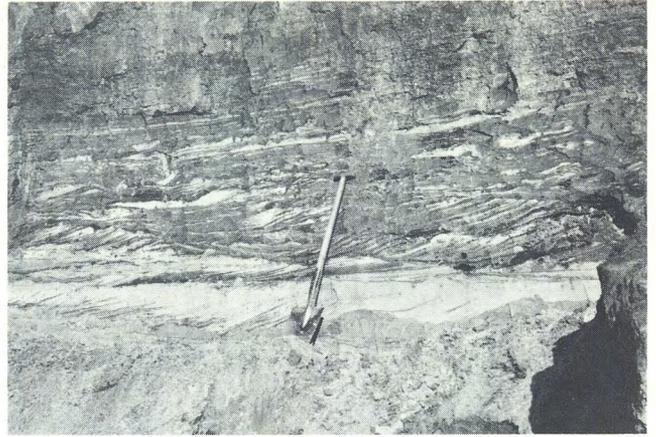


Fig. 13
Parallel laminae, ripple marks and trough-fill cross-bedding in layers o-r of profile 87 P 1.

SEDIMENTARY STRUCTURES

In two of the largest studied claypits, D.A.K.T. (87 P 1) and K.V.S. Het Blak (87 P 2), both located at Beerse, Lower Quaternary sandy layers were exposed. They showed very striking sedimentary structures. In both profiles a unit with macrostructures overlies a unit with microstructures.

Layers m-n in profile 87 P 1 form a rather monotonous set of macro-structures. Megaripples and large-scale foreset cross-stratifications with an alternation of coarse and fine-grained laminae can be seen over the full length of the exposure (Fig. 12). The same structures are observed in the nearby claypits of De Breyne and Nova, on freshly excavated walls, oriented

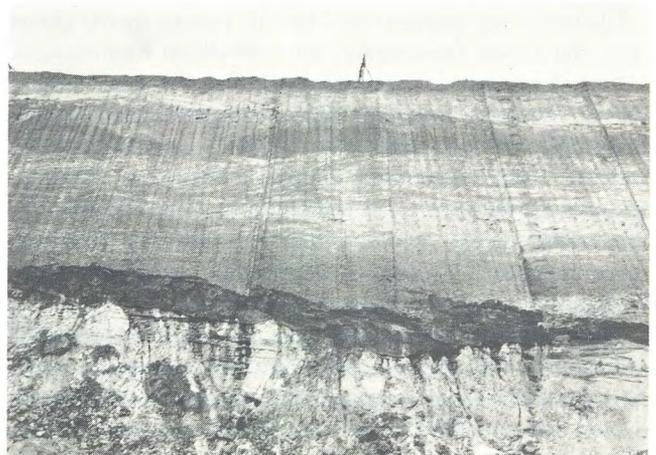


Fig. 14
Unit with macro-structures, overlying unit with micro-structures in profile 87 P 2.

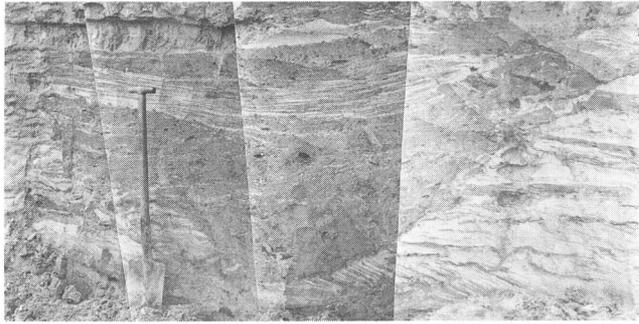


Fig. 15
Photomosaic, showing a larger gully in layers o-e' of profile 87 P 1. Parallel laminae, trough-fill cross-bedding and bioturbations can be seen.

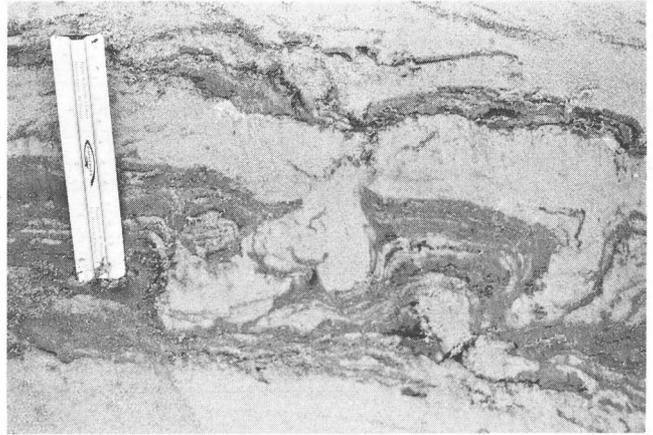


Fig. 16
Load-casts in layer o-e' of profile 87 P 2.

perpendicularly to the wall of D.A.K.T. (87 P 1). This fortunate coincidence provided the possibility of evaluating the palaeocurrent direction towards the the NW. MCGOWEN & GARNER (1970) described similar sedimentary structures in point bars of meandering rivers. In this particular case, the river must have been considerably large, as structures from the same microenvironment extend over more than 1 km². These macro-structures could also be the result of a constant succession of micro-avalanches in a braided river, as described by SMITH (1972).

The microstructures in layers o-r of the same profile are more complicated. Trough-fill cross-bedding is the dominant feature in the sandy parts of these layers, while additionally, ripple marks with different amplitudes occur (Fig. 13). Some of the sandy troughs contain lumps of peat. The more fine-grained parts of the same layers mainly form parallel laminae; they originated in quiet water. Bioturbations and load casts are common. The palaeocurrent was directed towards the NW. This whole complex of structures is rather similar to what has been observed in chute bars of meandering rivers, by MCGOWEN & GARNER (1970).

Herringbone or other structures indicating a tidal influence were not observed.

Macro-structures are found in layers s-w of profile 87 P 2. Here they consist of large scale trough-fill cross-bedding and megaripples (Fig. 14). According to MCGOWEN & GARNER (1970) such structures may be found in the scour pool of a meandering river. Observing the structures on two perpendicular walls, the palaeocurrent could be estimated as being directed towards the WNW.

Layers y-e' of profile 87 P 2 show micro-structures, similar to those in layers o-r of profile 87 P 1. Trough-fill cross-bedding is the dominant structure. Occasionally larger gullies occur (Fig. 15). They are filled with more fine-grained material showing parallel laminae, bioturbations and load casts (Fig. 16). These structures could have originated in the chutes

and in the chute bar of a meandering river. The palaeocurrent direction is W. No tidal structures such as herringbones were observed.

The results of the analysis of the sedimentary structures are summarized in Table II.

DISCUSSION AND CONCLUSIONS

The sedimentological investigation indicates a fluviolacustrine genesis of the Kempenland deposits. The river by which these sediments were deposited, and which we will call the 'Noorderkempen' River, followed a northwesterly direction. It had a mainly meandering and occasionally braiding character.

The granulometry shows that the influence of the tides was negligible. The electron microscopical investigation indicates that sedimentation took place in water poor in salts. Sedimentary structures show the presence of a unidirectional current towards the NW or the WNW.

With a reasonable degree of certainty one may assume that the flow energy of the Noorderkempen River was low. The material was mainly transported as a uniform, graded and pelagic suspension. At certain places and at certain times stagnant water occurred. In these lacustrine conditions most of the fine-grained fractions were deposited. Rolling transport rarely occurred. The capricious pattern of clayplates and sandstrips thus developed (GEYS, 1976a) bears some similarity with the pattern of clayey flood plain soils and sandy channel soils in the Holocene river clay area of the central Netherlands.

No sedimentological evidence for a cold climate oscillation, such as the 'Beersian' of DRICOT (1951) could be found. The cryoturbation-like structures in a clay-pit near Essen (GEYS & DELANNOY, 1972) must rather be interpreted as convolute laminations, which are not caused by cold conditions. Never-

Profile	layers		Sedimentary structures	Palaeocurrent direction	Palaeoenvironment
87 P 1	m-n	macro	Megaripples and alternation of fine and coarse-grained foreset-laminae	NW	Point bar of meandering river, or braided river
	o-r	micro	Trough-fill cross-stratification in coarse-grained parts; parallel laminae in fine-grained parts.	NW	Chute bar of meandering river
87 P 2	s-w	macro	Megaripples, large foreset-laminae and large trough-fill cross-stratification	WNW	Scour pool of meandering river
	y-e'	micro	Trough-fill cross-stratification in coarse-grained parts; gullies with fine-grained sediment, with parallel laminae.	W	Chute and chutebar of meandering river

Table II
Sedimentary structures.

theless, the existence of such a cold stage is probable, taking into account the findings of palynological investigations (HACQUAERT, 1963; PAEPE & VANHOORNE, 1970). We agree with the latter authors in correlating the top layers of the Kempenland deposits, which are normally polarised, with the Waalian Jamarillo event (VAN MONTFRANS, 1971) and identifying the cold stage with the Eburonian. It has to be noted however that the transitions from warm to cold climate and vice-versa, may not be linked to lithological changes as rigorously as they were by PAEPE & VANHOORNE (1970).

It is clear that the lowermost part of the Kempenland deposits has to be dated as Tiglian (PAEPE & VANHOORNE, 1970; VAN MONTFRANS, 1971). The WNW-direction of the Noorderkempen River is in good agreement with palaeogeographical map nr. 3 of ZAGWIJN (1974).

DE PLOEY (1961) recognized sandy units with heavy-mineral associations similar to those of the Tegelen and Kedichem Formations. The upper unit contains many metamorphous minerals, ubiquists, tourmaline and garnet. The sands interpreted by DE PLOEY (1961) as aeolian deposits and called the 'St. Lenaarts Formation' bear mineralogical similarity to the Kedichem Formation. An underlying unit called 'Wadzanden' by DE PLOEY (1961) has a heavy-mineral content resembling that of the Tegelen Formation, with relatively high amounts of garnet, epidote and hornblende. The heavy-mineral content of the Kedichem and Tegelen Formations have been described by VAN RUMMELEN (1972) and VAN DEN TOORN (1967).

The Kempenland deposits have an intermediate position between the Tegelen Clay and the Kedichem Formation (S. Limburg) in the east and some fluvial deposits, which are placed in the Tegelen and Kedichem Formations (ZAGWIJN, 1963; VAN RUMMELEN, 1972) in the west (Zeeland). The latter were previously described as 'Halsteren deposits' by VAN VOORTHUYZEN (1957). Moreover the Lower Quaternary fluvio-lacustrine deposits of the northern Kempenland extend northwards over a considerable area into Dutch territory. In the province of Noord-Brabant, they are again known as the Kedichem and Tegelen Formations (VERBRAECK & BISSCHOPS,

1971; BISSCHOPS, 1973). North of Breda these deposits are covered by younger sediments. The Kedichem and Tegelen Formations continue northwards, covered by younger Quaternary strata, until they interfinger with the Harderwijk Formation near Gorinchem (VERBRAECK, 1970).

All these data should fit very well into a pattern, assuming that the Kempenland deposits belong to the Kedichem and Tegelen Formations. It can be mentioned that the Brasschaat Sands, sedimentologically characterized by GEYS (1976b), can hardly be distinguished from a sandy facies of the Kempenland deposits.

Because of their lateral continuity, their common palaeoenvironmental characteristics and their similar age, the Kedichem and Tegelen Formations in Limburg, Noordbrabant and Zeeland, the Kempenland deposits and the Brasschaat sands can be considered as members of the same large fluvio-lacustrine complex.

Let us finally point out that the evidence presented in this paper supports the palaeogeographical reconstructions of ZAGWIJN (1974) rather than those of GULLENTOPS (1974).

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