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DEVELOPMENT OF DUNKIRK III DEPOSITS NEAR ALKMAAR, THE NETHERLANDS[1]

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ABSTRACT

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Dunkirk III sediments (*pik* clay, *rekere* clay, and *del* soils) in the province of Noord-Holland lie on top of tidal-flat deposits (Calais IV and Dunkirk O) and/or Holland peat with a time stratigraphic hiatus in between. Deposition during the Dunkirk III transgression probably took place in various phases under changing environmental conditions with varying sedimentation rates between AD 1050 and 1250. This conclusion is based on geological and historical data.

The initial sedimentation phase is represented by a thin layer of clay rich in organic matter, deposited under slightly brackish conditions. In the following phase of virtual non-deposition, sediment accumulated under almost freshwater conditions. Soil micromorphological, pollenanalytical, and malacological data confirm soil formation during the initial sedimentation phase while agriculture continued.

Between AD 1150 and 1250 the bulk of the Dunkirk III sediments were deposited under brackish conditions. The interrelationships between *pik* clay, *rekere* clay, and *del* soils are discussed.

INTRODUCTION

In the vicinity of Alkmaar (Fig. 1) relatively thin (0.2-1 m) clayey deposits (Dunkirk III) were studied. They are underlain by Holland peat or older sediments that belong to a complex of lagoonal, tidal-flat, and coastal-barrier deposits (BEETS ET AL., 1981; DE MULDER & BOSCH, 1982). These superficial deposits, that were mapped by DE ROO (1953) and DU BURCK (1957), are called *pik* and *rekere* clays and *del* soils. They occur in large parts of the province of Noord-Holland. The clays were deposited far inland in an area protected from the North Sea by a broad zone of coastal dunes with no major inlets except the former tidal inlet de Zijpe in the northwest (WESTENBERG, 1961; SCHOORL, 1973).

The varying environmental conditions in the backswamps, both before and during the sedimentation of the clays, are described. Furthermore, the interrelationship between the *pik* and *rekere* clays and the *del* soils shown on the soil maps mentioned are discussed.

Finally, the dating of the various sediments is discussed. PONS & WIGGERS (1960) assumed that these sediments were formed during the Late Roman-Merovingian transgression period (Dunkirk II, see Table I, in BERENDSEN & ZAGWIJN, 1984, this issue, p. 228). However, recent archaeological and historical data (SCHERMER, 1968, 1969, 1971, 1973; SCHOORL, 1973) and new information on the Holocene geology of this coastal area (JELGERSMA ET AL., 1970; ZAGWIJN, 1971; DE MULDER & BOSCH, 1982) point to a medieval age of these sediments.

METHODS

The field survey was based on manual borings (Edelman auger and gouge) and observations in pits. The sediments were described macroscopically. Samples and slides were prepared for pollen analyses according to the standard

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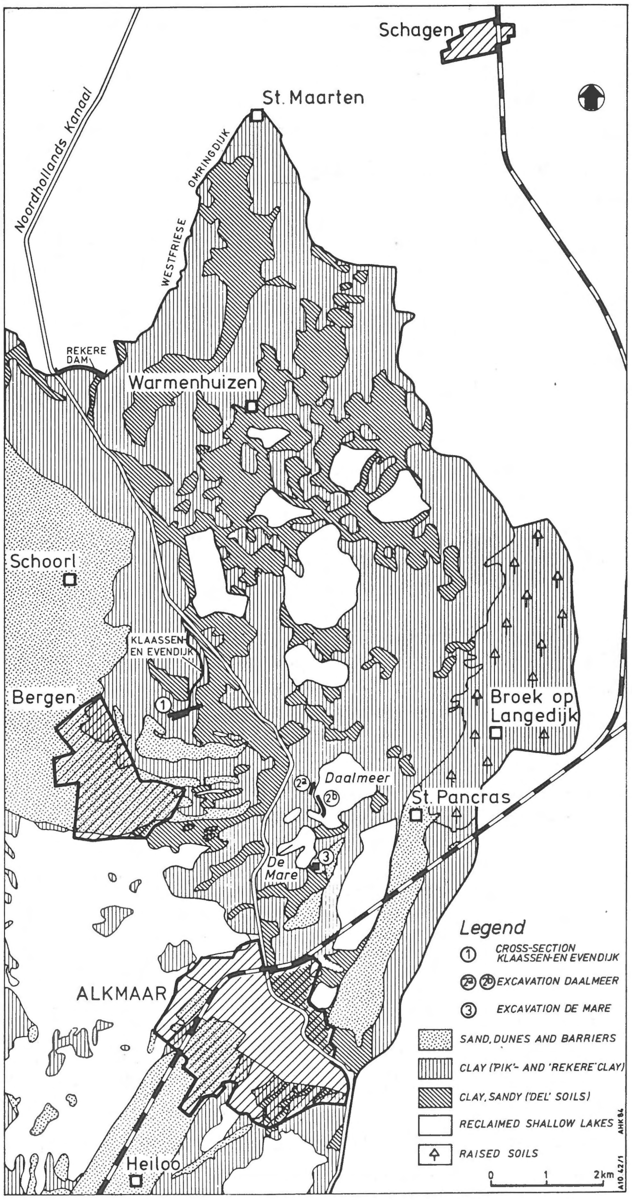

Fig. 1.
Simplified geological map of the area near Alkmaar, showing the investigated sections (after De Roo, 1953 and Du Burck, 1957).

methods used in the laboratory of the Department of Paleobotany Cenozoic of the Geological Survey. In general a pollen sum of 200 tree pollen (ΣAP) was used. Physical and chemical soil analyses were performed according to the standard methods of the Laboratory of Physical Geography and Soil Science of the University of Amsterdam. For soil micromorphological purposes, large thin sections (8 × 5 cm, 20 μm thick) of the undisturbed soil samples were prepared in the same laboratory according to the method described by JONGERIUS & HEINTZBERGER (1975). For the description and interpretation of the thin section according to BOLT & MÜCHER (1984), use is made here of BREWER'S (1976) terminology. Molluscs were determined in the Department of Macropaleontology Cenozoic of the Geological Survey.

FIELD DATA

Three sections (for location, see Fig. 1) were selected to illustrate the stratigraphical and lithological positions of the sediments.

Cross-section 1: Klaassen- en Evendijk (Fig. 2).

The Holland Peat (unit 2 in Fig. 2) is underlain by a heavy clay (unit 1) with rootlets of reed, which is interpreted as a marine lagoonal deposit of the Calais IV or Dunkirk O transgression phases (DE MULDER & BOSCH, 1982), The intercalated coarse sands (1a) are part of a barrier complex. The Holland Peat (*Phragmites*) is strongly oxidized and/or eroded at the top of the layer. Locally vertical contacts in the peat and lumps of peat in the younger deposit on the west side of the crosssection, indicate early-medieval peat digging (SCHERMER, 1974; KASSE, 1983).

The peat is overlain by a 10-50 cm *thick* layer of heavy brownish-green clay (unit 3 in Fig. 2). The base of this sticky clay – *pik* clay on the soil map of DE ROO (1953) – is rich in organic matter. The clay grades both vertically and laterally into a sandier laminated clay (unit 6), which often contains many shell fragments predominantly of *Cardium and Hydrobia spp.* The sandy clay (6), called *rekere* clay, contains carbonate particles in the sandy laminae. The differences in carbonate content between the heavy and the sandy clay can be regarded as primary. The two dikes built on the sediments are mentioned in medieval documents (WESTENBERG, 1974) and thus provide an upper time limit for the end of the sedimentation.

Section 2, a and b: Daalmeer (Fig. 3).

The substratum (1 in Fig. 3) is formed by sandy deposits with a thin (ca. 20 cm) clayey top layer that contains many rootlets and shows strong gley phenomena. These sandy sediments are interpreted as tidal channels, and the clayey top layer may be regarded to represent tidal mud-flats.

At location A (section 2a) there is a small remnant of a gully. The gully is filled with a sandy gyttja (4) which contains freshwater molluscs and reworked sediment from the mud-flat deposits (1). Pottery and fragments of bones point to human activity in the vicinity of the gully before the thin (5-10 cm) peat layer (5) on top of the infilling was formed.

In section 2a, situated outside the Daalmeer, the substratum (1) is overlain by a thin (25 cm) layer of brownish-green heavy clay, the base of which is strongly laminated and rich in organic matter (3 in Fig. 3; see also Fig. 4). At many, often regularly spaced places, the basal part of this clay is disrupted by shallow ditches that are filled with humic clay and/or sandy gyttjas (4a). This heavy clay grades upward into a lighter-textured brown clay (6) which often contains lenticular sand laminae. On DU BURCK'S (1957) soil map the north side of section 2a is indicated as *rekere* clay on *pik* clay and the southern side as *rekere* clay.

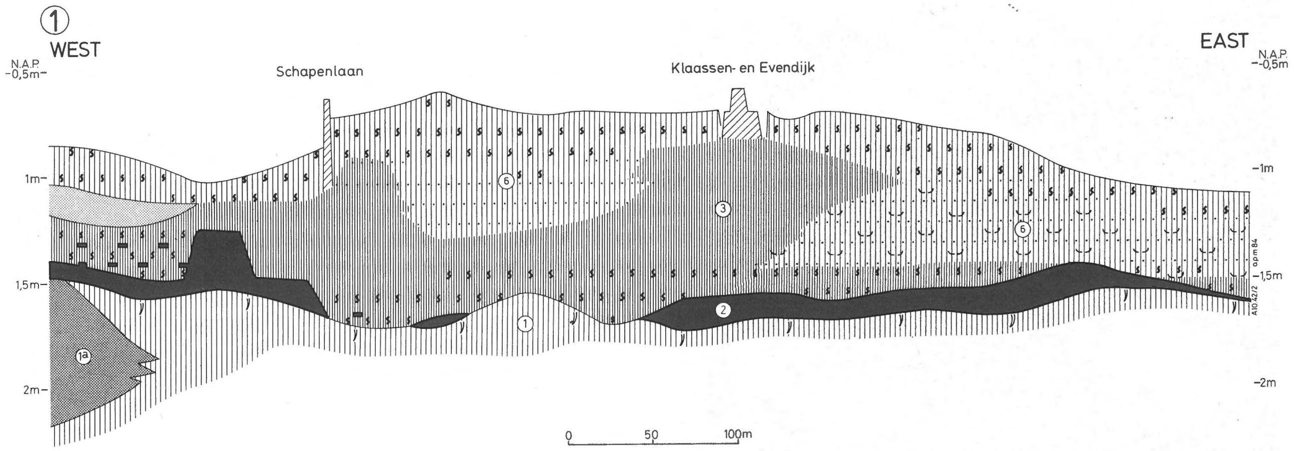

Fig. 2.
Cross-section 1:Klaassen- en Evendijk (after Kasse, 1983).

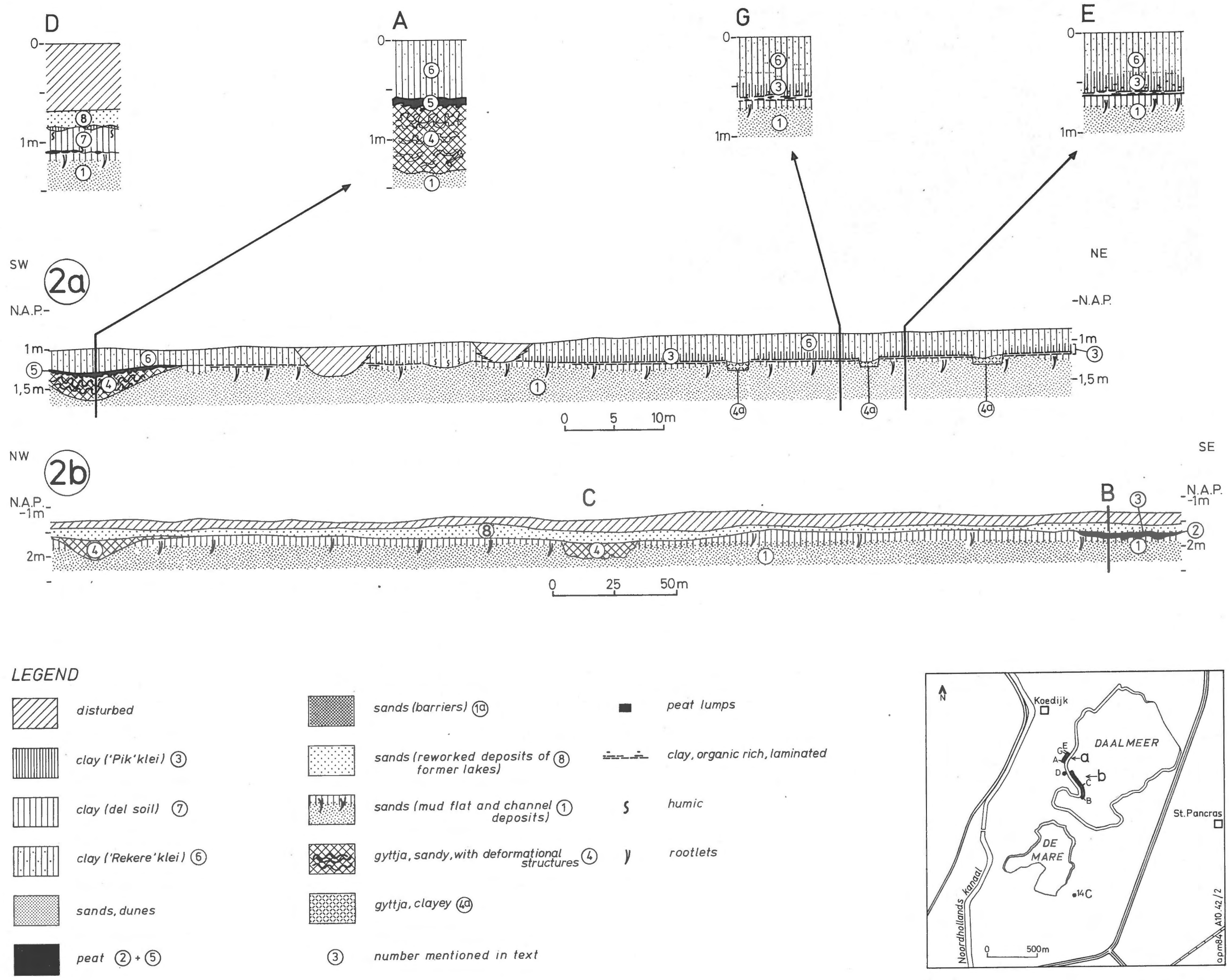

Fig. 3.
Section 2^{a+b}: Daalmeer.

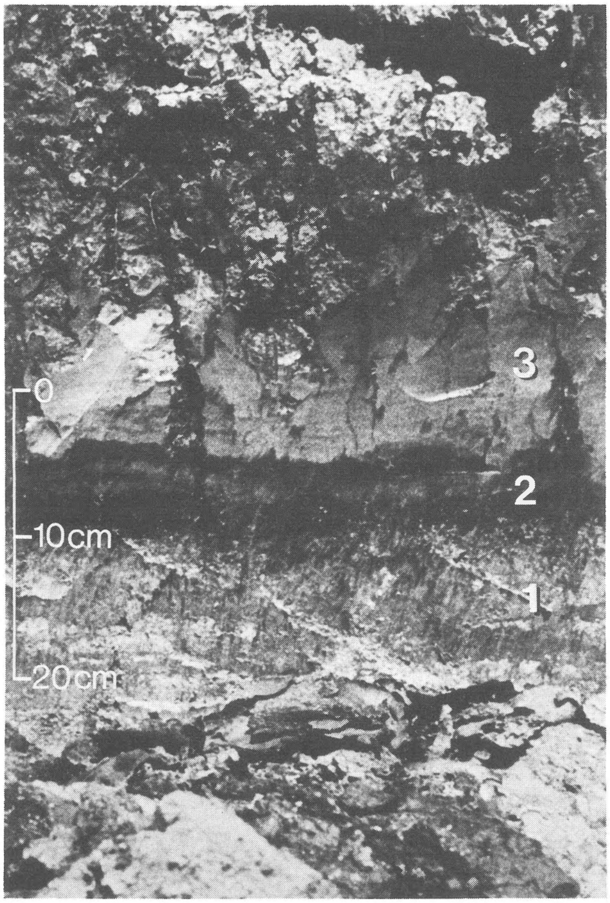

Fig. 4.
The profile at location G (Daalmeer);
1) mud-flat, 2) laminated clay rich in organic matter, 3) *pik* clay.

At location D, which is a very small pit situated just south of section 2a, there is a humic dark-gray heavy clay (7) with reworked peat fragments on top of the sandy substratum (1). The top part of this clay is slightly peaty and is overlain by a layer of yellowish-brown fine sand (8). These soils have been mapped as *del* soils (DU BURCK, 1957).

In section 2b (Fig. 3) the younger clayey sediments described above (3, 6 and 7) are absent except at location B, where a thin clay layer is present on top of a remnant of the Holland Peat. This section is situated within a reclaimed lake (Daalmeer). In the ditch at location C a fragment of pottery was found. The whole is overlain by a sheet-like layer (8) of fine to medium grained sand which contains many fine fragments of marine shells and echinid spicules.

Section 3: De Mare (Fig. 5)

This section shows the same lithological units as those distinguished in the Daalmeer sections described above. The layer rich in organic matter (3) is, however, more diffuse and mottled than in those sections. This basal part passes into a sticky, very heavy clay (6) (*pik* clay) with locally at the base clusters of molluscs, which accumulated in small depressions

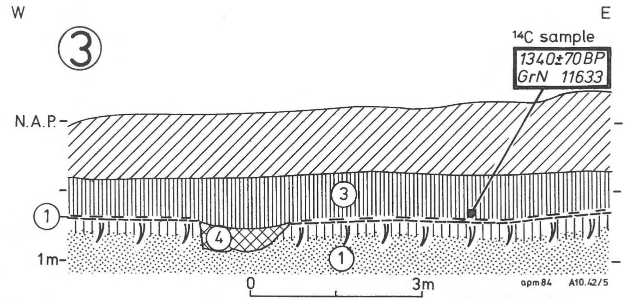

Fig. 5.
Section 3: De Mare.

in the substratum. The composition of the fauna is given in Table I. The shells of the bivalved *Cardium glaucum* were sampled for radiocarbon dating.

LABORATORY ANALYSES

Soil micromorphological data and physical and chemical analyses.

In areas of deposition, periods of sedimentation alternate with periods of non-deposition, according to the K-cycle defined by BUTLER (1959), i.e., an alternation of so-called unstable and stable periods. The stable periods represent hiatuses in the sedimentary history and are usually dominated by soil formation. These soils therefore give information about the periods of non-deposition and, in combination with data from sedimentological investigations, provide a complete picture of past events. This has been shown by, among others, MÜCHER & MOROZOVA (1983).

To obtain more information about the assumed hiatus between the mud flats (Calais IV/Dunkirk 0) and the younger Dunkirk III deposits, a micromorphological study was carried out combined with physical and chemical analyses of a profile in the Daalmeer section 2a, location G (Fig. 3). The analytical data are summarized in Table II.

The fine sandy sediments of the substratum (1 in Fig. 3) contain many fragments of shells, foraminifera, and echinid spicules. Most of the grains are quartz, but a few colourless micas, biotites, feldspars, glauconites, and carbonates are also present. Locally, some pyrite occurs. The abundance of aggregates indicates mechanical disruption of the original

Table I
Faunal composition of two shell samples in De Mare section.

H.M.C. 2		H.M.C. 3	
Bythynia tentaculata	0.2%	Hydrobia neglecta	56.5%
Hydrobia neglecta	8.5	Hydrobia ulvae	0.2
Hydrobia ventrosa	70.0	Hydrobia ventrosa	13.7
Littorina saxatilis tenebrosa	8.5	Littorina saxatilis tenebrosa	6.2
Retusa obtusa	1.5	Retusa obtusa	1.0
Abra tenuis	2.2	Abra tenuis	14.9
Cardium glaucum	9.4	Cardium glaucum	7.3
Macoma balthica	0.2	Mytilus edulis	0.2

lamination, which is consistent with the mud-flat origin. Remnants of the original laminations show that the clay particles lie parallel to the sedimentary laminations (unistrial plasmic fabric), which suggests deposition in shallow water under conditions of laminar flow.

After deposition there was a relatively stable period in which soil formation occurred, as shown by features of the uppermost part of the mud-flat deposits. Such features are biological channels (cylindrical voids formed by rootlets and burrowing animals), pedotubules (filled channels), and excrement, all pointing to increased biological activity. Many of the pedotubules in this part of the profile are filled with soil material from another soil horizon (the overlying laminated clay). According to the type of filling, one can distinguish: light greyish sand, dark-brown clay, and/or black organic matter, or combinations of these components.

In the biological channels and some other pores, there are cutans of mineral material (clay to sand) covered by coatings of organic material that are known as organans. They indicate that under certain pedological conditions amorphic organic matter could be formed and eventually transported and illuviated into a lower level as cutans (organans) or as distinct layers (dopplerite). In the pedotubules the opposite was also observed.

In the lower part, hydromorphic features indicate alternating wet and dry conditions. These features include: iron segregation, formation of ferric nodules and manganiferous neocutans around voids, oxidation of pyrite, and at the top of the sandy sediments, a small degree of decalcification (Table II).

Only during the very beginning of the sedimentation of the *pik* clay (3 in Fig. 3), soil formation was able to keep pace with the rate of deposition. This is indicated by the presence of pedotubules filled with material from the same horizon (brown ortho-isotubules) and dark organic faecal pellets. This relatively thin zone (only a few centimetres thick) passes rather quickly into a dense clay-rich sediment (3) with a strong unistrial plasmic fabric. The origin of the organic material can be explained in two ways: as a sedimentary relic or as a pedological phenomenon. The second possibility is supported by the following observations. Illuviated organans and faecal pellets were found under the laminated basal part of the *pik* clay, and about 45% of the organic matter (sampled by hand) consists of amorphous material (see Table II). The low Mn content shows that the role of manganese in the formation of the black organic material was negligible (Table II). The results of the analyses suggest that a peat layer was formerly present on top of the mud-flats, which led to the formation of the amorphous organic material, i.e., dopplerite, deeper in the profile. The presence of faecal pellets and the absence of other organic matter show that biological activity produced the pellets. This favours the presence of a layer rich in organic matter in the past. The low C/N ratio of the total profile (Table II) corresponds with the C/N ratios of weak acid to weak alkalic found in peaty clay soils with a high

Tabel II
Grain-size distribution and results of chemical analysis, profile G, Daalmeer section 2a.

Soil horizon	Sample depth cm - surface	pH-H_2O	pH - $CaCl_2$	% C	% dispers C	% CO_2	EC_{25} µs/cm (electric conduct. at 25°C.)	% N	C/N	C.E.C.me./100 g. (cation exchange capacity pH 8.2)	% Mn
Ap	10-15	7.15	6.68	2.58			423	0.23	11.3	22.4	
C1	30-35	7.31	6.59	1.42			240	0.13	10.6	27.4	
C2	50-55	7.23	6.71	1.56		0	261	0.14	11.2	36.9	
org.matt	ca.64			11.99	5.43						0.045
D1	62-65	7.40	6.90	4.74		0	414	0.32	14.6	39.8	
D2g	70-75	7.61	7.13	1.09		0.98	309	0.09	12.5	13.3	
D3g	80-88	7.77	7.29	0.76		4.96	283	0.13	6.0	8.2	

Soil horizon	< 2 µm	2 - 4	4 - 8	8 - 16	16 - 32	32 - 50	50 - 75	75 - 105	105 - 150	150 - 212	212 - 300	300 - 425	425 - 600	600 - 850	850 - 1190	1190 - 2000 µm
Ap	30.12	3.96	4.52	8.23	9.72	7.37	1.39	4.64	7.91	19.46	1.91	0.43	0.12	0.06	0.07	0.04
C1	44.79	5.44	6.51	11.68	13.94	8.86	0.70	1.72	2.08	4.01	0.06	0.04	0.01	0.01	0.01	0.01
C2	58.44	6.88	9.30	12.44	6.85	1.61	0.41	1.21	1.57	0.73	0.19	0.11	0.08	0.09	0.04	0.03
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D1	45.24	5.44	7.60	7.03	5.63	5.14	1.19	7.76	7.00	7.45	0.25	0.09	0.05	0.04	0.01	0.02
D2g	17.49	3.14	1.48	4.78	6.39	13.80	5.28	11.26	11.55	24.03	0.38	0.09	0.06	0.04	0.02	0.01
D3g	11.72	1.09	2.45	3.33	4.59	10.99	2.58	17.07	21.79	22.62	1.40	0.10	0.08	0.05	0.02	0.01

degree of humification. It is unlikely that the illuviated organic matter (organans) and the organic faecal pellets were related to soil formation, e.g. podzolization. In this respect the parent material (the mud-flats), from the pedogenetical point of view, is too rich in exchangeable cations and too young to have led to the development of this type of soil.

In the next unstable phase this soil profile became truncated down to the black organic material, and clay was again deposited. Only at the beginning was this clay mixed with organic material. The clay and sandy clay (3 and 6, respectively, in Fig. 3) is characterized by an upward increase in the number of lenticular laminae that are composed of fine sand and silt and show an unistrial plasmic fabric. The silt fraction contains many diatoms and fragments of diatoms.

The textural composition of the heavy clay (3) passes gradually into that of the more sandier clay (6), which can also be seen in Table II. This points to a steady increase of energetic conditions during deposition of these sediments. After deposition the recent and final soil formation started, which is characterized by the following pedological features: ripening accompanied by cracking and development of structure, reorientation of clay (plasma) through biological activity, illuviation of fine and coarse mineral material, and hydromorphic phenomena. The dispersion of the clay particles was induced by the high sodium concentration and led to the formation of illuviated argillaceous cutans (JONGERIUS, 1970; VEENENBOS & VAN SCHUYLENBORGH, 1952). This well-known pedological process in sodium-rich sediments is known in The Netherlands as *knip* formation. As a result of repeated swelling (due to wetting) and shrinking of the argillaceous material, almost all of the illuviated clay was subsequently incorporated into the matrix by mixing of the soil material. The low contemporary EC_{25} values in Table II show, however, that this *knip* formation cannot have been active any longer and therefore what occurred must be regarded as a fossil soil formation process. This process may have intensified the lithological differences between the heavy clay (*pik* clay) and the sandy clay (*rekere* clay).

The extent to which the individual sedimentological and pedological processes contributed to the formation of the sandy clay can no longer be determined.

Pollen analyses

In the Daalmeer sections (Figs. 1 and 3) four rather closely spaced profiles were examined with respect to their pollen content. The zonation of the pollen diagrams (Fig. 6) was based on the pollen-zonation system used by the Department of Paleobotany Cenozoic of the Geological Survey (ZAGWIJN, 1975; DE JONG, 1981).

In pollen spectra derived from the substratum (locations B, D, E) *Quercus, Corylus* and *Alnus* form the main tree pollen taxa. Herb values are low in the sandy clay of the mud-flat deposits, but *Gramineae* and *Cyperaceae* values are higher than 100% in the peat (location B). On the basis of low percentages of *Fagus* and the absence of *Carpinus*, the end of the clastic sedimentation and the beginning of peat growth can be dated in the second half of the Subboreal (pollen subzone IVb).

The pollen subzones applied, up from the Subboreal are: IVb (*Fagus* 1%; late Subboreal), Vb (*Fagus, Carpinus*; late Subatlantic), to be subdivided into Vb1 (low values of *Cerealia*) and Vb2 (increasing values of *Cerealia*, generally with *Secale*). The latter subzone can be divided into a subzone Vb2a with low percentages of *Secale* and a subzone Vb2b with unequivocal presence of *Secale*. The *Cerealia* include all pollen grains of the *Gramineae* type >40 μm.

The sandy gyttja with fragments of bones and pottery found at location A is characterized by an arboreal pollen assemblage in which *Quercus, Alnus* and *Corylus* dominate. The values of *Fagus* (5%) and the presence of *Carpinus* make a post-Roman dating obvious (subzone Vb2a). In the upper part of the gyttja a gradual increase of non-arboreal pollen indicates a local reed and sedge vegetation bordering the gully. This culminates in a gully filling consisting of reddish-brown homogeneous monocot peat dominated by fragments of *Phragmites. Gramineae, Cyperaceae,* and *Ranunculus* are the main herb pollen taxa here. The presence of *Pediastrum* and abundant pollen of *Lemna* may indicate that the material is not a real phragmites peat. Persistent frequencies of *Plantago lanceolata, Cereals* and *Secale, Rumex, Compositae liguliflorae*, and *Artemisia* (pollen zone Vb2b) indicate a strong influence of man. Dating of the peat growth at location A is based on the above-mentioned findings which probably point to the eleventh or twelfth century.

The pollen assemblage in the sandy clay (7) deposited after the peat growth at A indicates a lower but still intense influence of human activity.

At location E, after the first increase of *Chenopodiaceae*, the pollen frequencies of *Gramineae,* and *Cyperaceae* rise sharply to maxima of 215% and 165% AP, respectively. In the heavy but also sandy clay *Chenopodiaceae* increased again, reaching 285% AP. *Alnus* and *Corylus* are the main tree-pollen taxa. The dominance of *Corylus* in the upper part of the heavy but partly sandy clay gives grounds to subdivide pollen zone Vb2b ($\alpha + \beta$). Noteworthy are the high percentages of *Ericaceae, Sphagnum*, and *Dryopteris* together with *Chenopodiaceae* in the clay.

DISCUSSION

Environmental conditions during the Dunkirk III transgression phase.

In the western part of the study area (west of the Noord-Hollandskanaal) the Holland peat is more or less continuous, as is visible in the cross-section Klaassen- en Evendijk (Fig. 2). In other parts of the area some remnants of the original peat are found (Fig. 3, location B), and the *pik*/*rekere* clays are situated directly on the mud-flat deposits. From pollen-analytical data it is concluded that peat growth started in the second half of the Subboreal.

The transition between the older and younger sediments is marked by a layer, a few cm thick and rich in organic matter, the basal part of the *pik* clay. As discussed above the strongly decomposed illuviated organic matter (high percentage of amorphous carbon) seems to have originated from a now vanished peat layer.

From the pollen-analytical investigations it can be concluded that before the deposition of the *pik* clay started, cereals were cultivated and therefore dry conditions must

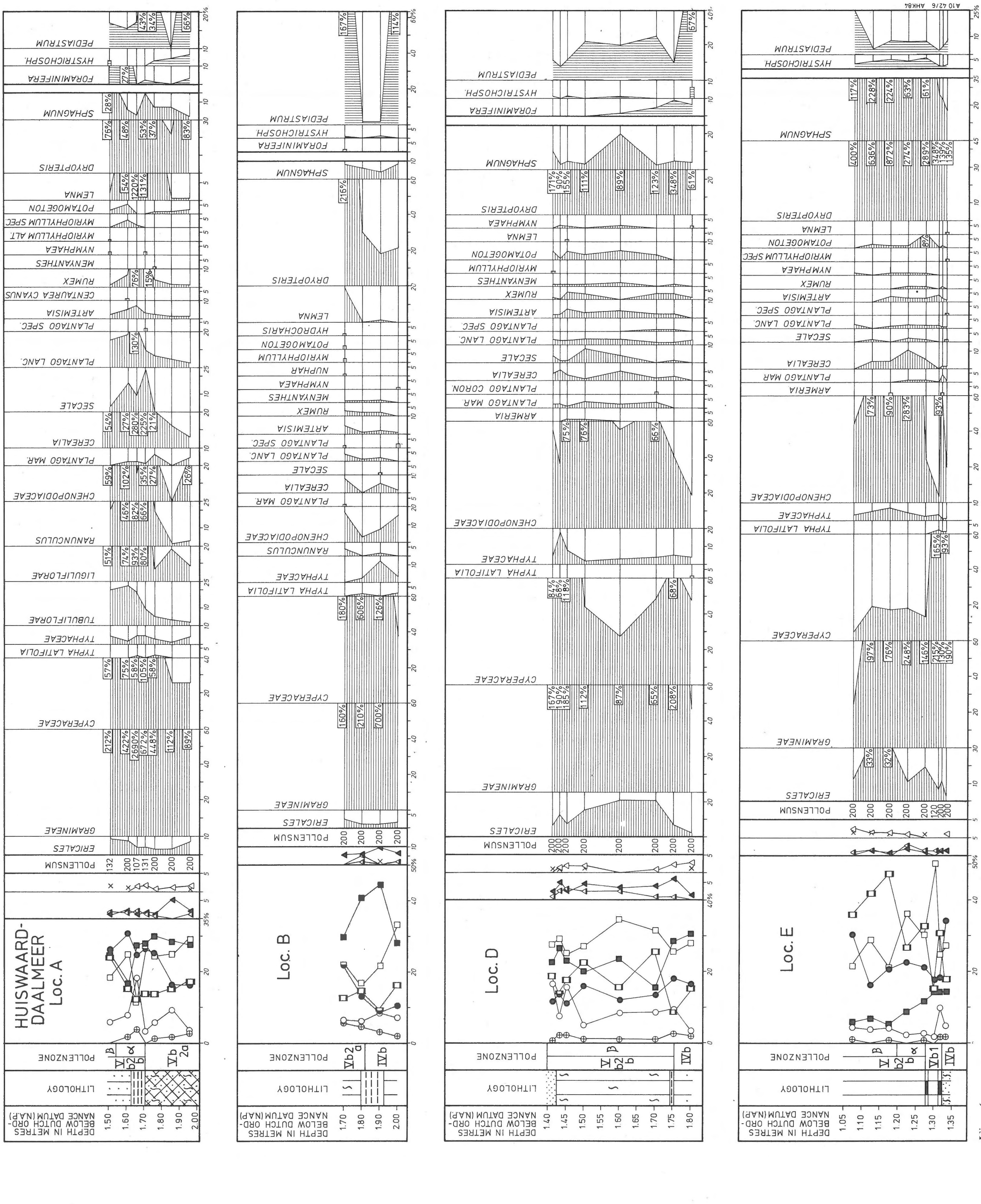

Fig. 6.
Pollendiagrams for locations A, B, D and E (Daalmeer).

have prevailed. During this period the peat layer decayed. The extent to which the Holland peat was exposed to decomposition in preceding periods cannot be concluded from our data.

Just prior to deposition of the *pik clay*, wet conditions prevailed locally. Under these conditions, clay, rich in organic matter, was deposited initially on top of the mud-flat deposits. During the sedimentation part of the organic matter was whirled up into suspension, to be deposited later together with the clay. The distribution of the organic matter in the clay may be diffuse or laminated, due to local water currents.

The molluscs at the base of the *pik* clay (section De Mare, Table I) indicate an environment with shallow water and little water movement. Probably together with the first clay sediments, spatefall, of *Cardium glaucum* was transported inland. This marine type of mollusc tolerates a slightly brackish (7-10% Cl^-) watery environment. However, in this environment the absence of Na+ means minimal conditions of life (MEYER, 1983).

From the micromorphological investigations it is concluded that soil formation and biological activity continued during the initial sedimentation phase. Pollen-analytical data on the sediments at the base of the *pik* clay also indicate a substantial influx of freshwater after an initially slightly brackish influence. Shallow ditches that intersect the basal parts of the *pik* clay, which was rich in organic matter, indicate both minimal sedimentation conditions and a watery environment, and also that during the initial sedimentation phase people tried to drain the area. The existence of dwelling mounds situated on a thin clay layer in the neighbourhood of Schagen (Fig. 1) (KLEINSMAN, 1981) seems to support our conclusions.

The results of the geological, micromorphological, and palynological investigations show that after the initial somewhat hesitant sedimentation phase, the bulk of the *pik* and *rekere* clays was deposited. The absence of pedological phenomena simultaneously with the sedimentation of these clays established either rapid sedimentation rates or unfavourable conditions for biological activity during the deposition of the *pik-rekere* clays. The heavy pik clay or *pik* layer was formed first. This layer gradually changed into the lighter-textured *rekere* clay. These two lithologically different units always pass into each other gradually and without a hiatus or erosional contact. This is seen in vertical sections but also in a lateral sense (see Fig. 2, Klaassen- en Evendijk section). Therefore, these two units can be explained to belong to one deposit. Sedimentation started in a quiet, watery environment with fresh-water influxes and was followed by a gradual increase in energetic conditions that is reflected by the lighter-textured upper part. During this second phase of sedimentation the area was not suitable for agriculture, and it seems likely that habitation diminished. The absence of the *pik* clay in the now reclaimed shallow lakes like the Daalmeer, discussed elsewhere (DE ROO, 1953; DU BURCK, 1957), is usually explained as the result of erosion of the *pik* clay due to new ingressions of the sea. In our opinion, it is likely that during the deposition of the *pik* clay, locally, and especially in the lower parts of the pre-Holland Peat landscape, peat cushions occurred above the sedimentation level of the *pik* clay. Their presence would have prevented sedimentation of the clay.

Continuing use of these peat areas for agriculture and/or digging of peat for fuel before or during the sedimentation of the *pik-rekere* clays, led to a lowering of the surface and formation of lakes. Enlargement of the lakes by wave action seems likely. The sheet-like sand body along the border of the Daalmeer (section 2b) is thought to have been formed during the lake phase. In some parts of the area, the wave action may have moved sediments and have contributed to the formation of the *del* soils.

A pottery fragment of what is called the *Kugeltopf mit Besenstrichmuster* was found in the shallow ditch at location C in Daalmeer section 2b (Fig. 3). It could be dated to belong in the late thirteenth to early fourteenth century and this supports the hypothesis concerning human activity in the Daalmeer.

Dating of the Dunkirk III deposits

From the archaeological finds of Pingsdorf pottery under the *pik* clay (SCHERMER, 1971; 1973), it can be concluded that sedimentation did not start before the first half of the eleventh century. Historical data lead to a similar conclusion: the area was inhabited and the land exploited before the eleventh century (DE COCK, 1965, SCHOORL, 1973; WESTENBERG, 1961, 1974; HALLEWAS, 1985, this issue).

The pollen-analytical data confirm deposition of the *pik* clay in the eleventh and twelfth centuries. The agriculture activity prior to the deposition of the *pik* clay, expressed by the curve for *Cerealia* together with that of *Secale,* is usually dated between AD 1100 and 1300. The finding of pollen of *Centaurea cyanus* in the sandy clay (6) at location A (Daalmeer) indicates that sedimentation started here in about 1300 (MIKKELSEN, 1952).

Radiocarbon dating of the onset of the *pik* clay sedimentation has not been very successful. The age obtained for the bivalved shells of *Cardium glaucum* in De Mare is in agreement with another date, namely 1355 ± 55 BP (GrN 6764), at Koedijk (this date is mentioned by DE MULDER & BOSCH, 1982). A radiocarbon date for bivalved shells of *Cardium* sp. at the base of the *pik* clay near Schagen (950 ± 150 BP (GrN 9120) seems in agreement with the archaeological, historical and palynological data.

The differences between the pollen-analytical and radiocarbon results with respect to the date of the beginning of the *pik* clay sedimentation may be due to solution of carbon from older sediments rich in calcareous material. Probably during the initial *pik* clay sedimentation, the already-mentioned continuous soil-forming processes may have been responsible for the solution of rests of shell fragments in the upper part of the mud-flat depostis.

The construction of dikes in this area provides information about the end of the sedimentation. The Klaassen- en Evendijk (Fig. 2), which is situated on top of the *pik* clay sediments, was already mentioned in AD 1235 (WESTENBERG, 1974), and the Schapenlaan or Hooydijk even earlier (end of the twelfth century). The completion of the Westfriese omringdijk in about AD 1250, and of the Rekere dam (Fig. 1) in 1285, put a definite end to the sedimentation.

CONCLUSIONS

The datings mentioned justify the conclusion that the sedimentation period of the *pik/rekere* clays was relatively short. The first part of the Dunkirk III transgression phase is characterized by a slightly brackish influence in a watery, predominantly freshwater environment (backswamp). It was followed by a rather quiet period with no appreciable sedimentation. The habitation of the area was maintained. Between AD 1150 and 1250, the bulk of the *pik/rekere* clays was deposited under more brackish conditions.

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