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SUBDIVISION OF THE "CROMERIAN" IN THE NETHERLANDS; POLLEN-ANALYSIS, PALAEOMAGNETISM AND SEDIMENTARY PETROLOGY

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ABSTRACT

A subdivision of the lower part of the Middle Pleistocene ("Cromerian") of The Netherlands is proposed. At least 3 interglacials are now recognized. The Matuyama-Brunhes boundary (0.7 M.y.) has been located within this sequence.

1. INTRODUCTION

The lower pre-Elsterian part of the Middle Pleistocene in The Netherlands has so far yielded only scattered palaeoclimatic (especially palynological) evidence. This is mainly caused by the fact, that the fluviatile sediments (belonging to the Sterksel Formation and the lower part of the Urk Formation, table I) predominantly consist of coarse sand and gravel. Clay beds which are suitable for pollenanalytic investigations are scarce and usually not sampled in much detail in the borings available.

Since Zagwijn and Zonneveld (1956) found in a clay lense from the Sterksel Formation at Westerhoven evidence for an interglacial, which was at that time correlated with the Cromerian of East Anglia, and other scattered evidence from this formation also pointed to interglacial conditions, the whole of the pre-Elsterian part of the Middle Pleistocene in this country has been regarded to belong to one interglacial, the "Cromerian" (Zagwijn, 1960). However, more detailed investigations in East Anglia have shown that there are at least two complete interglacial climatic cycles present in the so-called Cromer Forest Bed Series (West and Wilson, 1966), of which the upper one is now called *Cromerian,* the lower one *Pastonian.* The new pollendiagrams from this area have shown that it is not possible to correlate purely on the basis of pollenanalytical data the interglacial found at Westerhoven with either of the interglacials found in East Anglia. Therefore, pending new investigations, the term "Cromerian" was placed between inverted comma's (Zagwijn, 1963) to indicate that this timespan might have witnessed a more complex climatic history than was thought of before. However, it is certain that in both

TABLE I

U. Pleistocene		Kreftenheye Formation
M. Pleistocene	Saalian	Urk Formation
	Holsteinian	
	Elsterian	
	"Cromerian Complex"	Sterksel Formation
L. Pleistocene	Menapian	
	Waalian	Kedichem Formation
	Eburonian	
	Tiglian	Tegelen Formation
	Praetiglian	

Subdivision of the Pleistocene of The Netherlands (according to van der Heide and Zagwijn, 1967).

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areas the sediments involved are older than the Holsteinian (= Hoxnian) Interglacial Stage, and are separated from it by a stage of severe cold, generally called the Elsterian.

Among the scattered pollen-analytic evidence obtained from the Sterksel Formation in The Netherlands, a highly characteristic pollen-assemblage was frequently met with, containing, besides common interglacial types (among which *Carpinus* is dominating) pollen of the Tertiary relic *Eucommia* in noteworthy frequencies (up to 10-15%) (Polak et al., 1962, Zagwijn, 1963). Other Tertiary relics (*Pterocarya, Tsuga, Carya*) which are present in the interglacials of the Lower Pleistocene are missing, however.

Theoretically, this phase can be placed in the second half of an interglacial, and as at Westerhoven the first half of an interglacial is present, they might belong to the same stage. However, the pollen diagrams from Ølgod and Harreskov in Denmark (Andersen, 1965), both showing a full interglacial cycle, have in their lower part a strong resemblance with the interglacial of Westerhoven, though in their upper part they show no trace of both *Carpinus* and *Eucommia.* Moreover, Grüger (1968) recently obtained an interglacial pollen diagram from the site Osterholz in Northern Germany, showing in its later half the same *Carpinus-Eucommia* assemblage which is so well-known from some levels of the Sterksel Formation in The Netherlands. This author came to the conclusion that in the so-called "Cromerian" of continental Western Europe at least two interglacials are represented. In view of these data more detailed investigations of the "Cromerian" sediments of The Netherlands seemed necessary. It was clear that only carefully sampled and cored borings would provide the necessary evidence.

Our first working hypothesis was that in the Sterksel Formation at least two different interglacials should be present: a lower one (of the Osterholz-type) with the Tertiary relic *Eucommia* and an upper one (of the Westerhoven-Harreskov-type) without that. Moreover, these interglacials are not necessarily the equivalents of the Cromerian and Pastonian interglacials of the East Anglian type-area. Formerly it was found that the uppermost part of the Sterksel Formation (the Weert heavy-mineral Zone – Zonneveld, 1947) yields evidence for cold, periglacial climatic conditions. At that time, this part of the Sterksel Formation was provisionally placed at the base of the Elsterian (Zagwijn, 1963). Furthermore it should be recalled that the Sterksel Formation, though its provenance is the river Rhine, almost completely lacks the mineral augite.

Since then, also pollenanalytical evidence for interglacial conditions has been found from the basal part of the next younger formation, the Urk Formation. This Urk Formation is characterized by the presence of augite in noteworthy quantities which came from the Eifel district of Germany. On the basis of K/Ar datings the strong increase of augite of the Rhine sediments (= base of Urk Formation) can be dated around 400,000 years ago (Evernden et al., 1957; Frechen and Lippolt, 1965).

Our second hypothesis was that in the basal part of the Urk Formation at least one other interglacial of the "Cromerian" complex occurs, which must be of pre-Holsteinian age.

The main purpose of the present paper is to discuss the results obtained by testing our first hypothesis. Sediments of the Sterksel Formation were used for this. In passing we will deal with the results of our investigations, though not yet completed, on the basal part of the Urk Formation.

2. SEDIMENTPETROLOGICAL AND PALYNOLOGICAL RESULTS FROM BORINGS FROM THE STERKSEL FORMATION

a. Waardenburg (fig. 2)

Introduction

This boring was cored as near as possible to the location of a former bailer boring which had yielded promising evidence for the presence of clay lenses as wanted for during our investigations. In fact the area is that of a pumping station for drinking-water supply and a fair number of borings had been made here. Only at this very locality the presence of a number of superimposed clay and peat lenses in the Sterksel Formation could be demonstrated. This again underlines that in this predominantly coarse-grained formation clay beds only occur as lenses (clay plugs in former riverbeds).

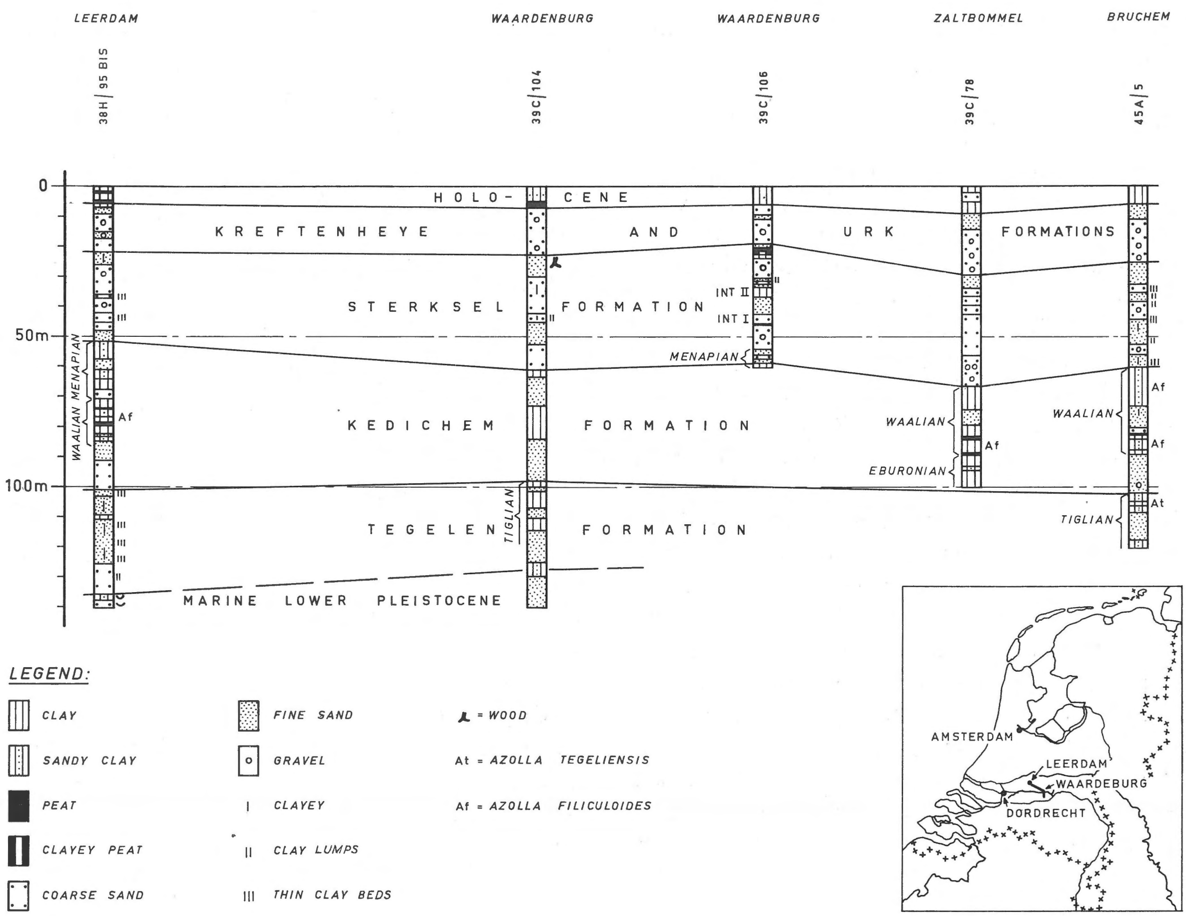


Fig. 1
Section Bruchem-Waardenburg-Leerdam, showing the superposition of the formations discussed in the text. Situation map of this section and of boring Dordrecht.

Sedimentary petrology

1. Heavy minerals

In the heavy-mineral diagram five zones have been recognized: *M-Zone, Sterksel Zone, Woensel Zone, Weert Zone* and *Augite Zone.*

The M-Zone, found in the clay bed at 58.75-60.05 m, is characterized by metamorphic minerals, tourmaline and other minerals, like zircone and rutile, which are predominant. The assemblage recalls the "M-association" (Crommelin, 1953). As the sediment is very fine-grained, the amount of zircone and rutile is higher than in the normal M-assemblage.

The Sterksel Zone (38.20-58.75 m) predominantly shows garnet, epidote, saussurite, alterite and hornblende and consists of coarse sand with gravel, a single intercalated bed of gyttja, and fine sand at the top.

The Woensel Zone (27.50-38.20 m) is characterized by garnet, epidote, saussurite, alterite and less hornblende than in the preceding zone. In its lower part a clay bed and fine sand are found, the upper part has coarse sand with gravel.

The Weert Zone (18.70-27.40 m) has a very high amount of saussurite and alterite. Not only the percentages of hornblende are low, but especially also those of garnet. The percentage of stable minerals (tourmaline, zircone, rutile and staurolite and other, metamorphic, minerals) is higher than in the Sterksel and Woensel Zones. The deposits consist of coarse, gravelly sand, capped by clay and peat, and fine sand at the very top.

In the Augite Zone (6-18.70 m) the combination of alterite and augite and some other volcanic minerals is typical. This Zone has mainly coarse sand rich in gravel.

2. Discussion

Two main changes can be observed in the heavy-mineral diagram. The first is at about 59 m, at the boundary of M-Zone and Sterksel Zone. The clay with M-Zone belongs to the Lower-Pleistocene Kedichem Formation (see fig. 1; cf. Doppert and Zonneveld, 1955; Zonneveld, 1958). In this area this mineral assemblage is restricted to the fine-grained uppermost part of this formation (zone C according to Jelgersma and Zandstra, 1970, p. 24). Its provenance is by a predecessor of the present river Meuse.

The part 19-59 m with alterite and saussurite is typical for the Sterksel Formation (S-association, Crommelin, 1953; Doppert and Zonneveld, 1955; Zonneveld, 1958). So for the first time a boring has shown the presence of the Sterksel, Woensel and Weert Zones outside the area from which they have been originally described (Zonneveld, 1947). The provenance is the river Rhine.

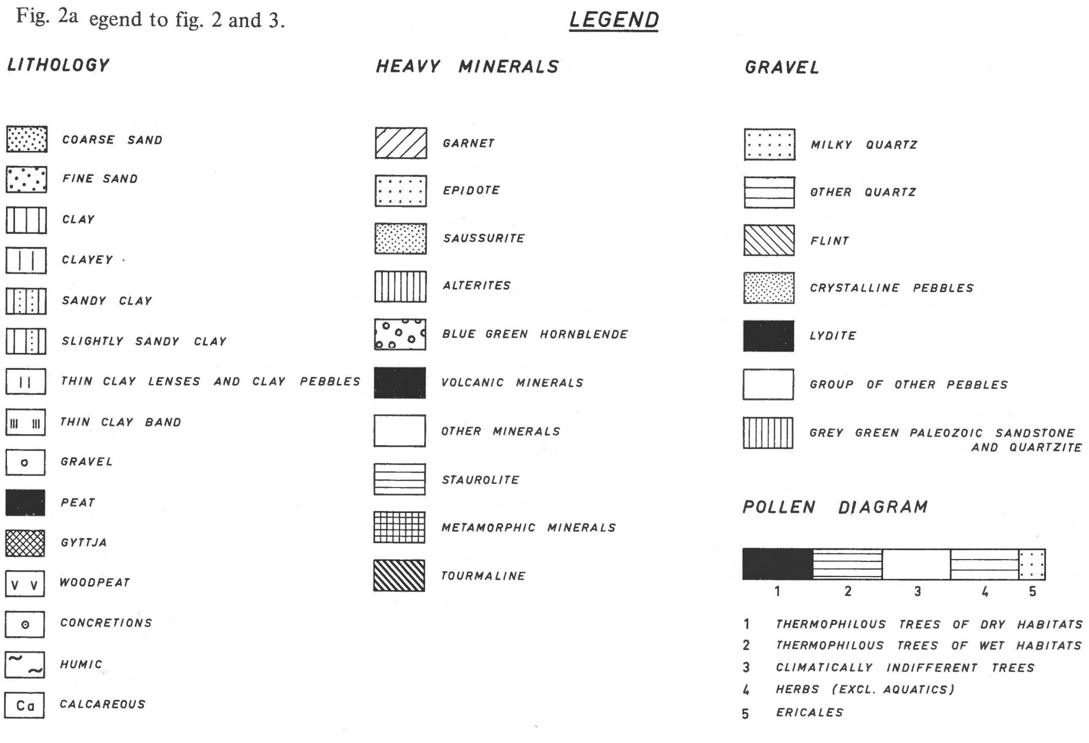
The second major change is at about 19 m, above which level volcanic minerals (especially augite) occur in high values (up to 40%). The provenance is the Eifel region, where since about 400,000 years ago augite was produced in such quantities, that it appeared in the contemporaneous Rhine sediments. The age of the Augite Zone (AS-association, Crommelin, 1953) is upper part of the Middle Pleistocene (Urk Formation) and Upper Pleistocene (Kreftenheye Formation). In the present area both formations occur on top of each other, though their exact delimitation is sometimes difficult (Jelgersma and Zandstra, 1970). In the present boring the boundary is placed at 16 m above a small augite top and a change in gravel content.

3. Gravel content

The gravel available was quantitatively examined according to the method of Maarleveld (1956), with some modifications (Zandstra, 1959) and the recognition of additional types. 300 particles ranging between 3 and 5 mm per sample were classified within 30 groups. The percentages are presented graphically (fig. 2, 3).

Only small differences in the composition of the Rhine gravel in the Sterksel, Urk and Kreftenheye Formations are present. Flint, crystalline pebbles and lydite comprise less than 10% of the total. Milky quartz, other quartz, palaeozoic sandstone and

Fig. 2a egend to fig. 2 and 3.



quartzite, as well as the group of other pebbles predominate (RM-association, Z a n d s t r a, 1959).

Closer observation shows, that in the Sterksel Formation, in the part pollen-analytically attributed to Interglacial I, the total quartz percentages are higher than in the glacial sequences of the Menapian and Glacial B. The gravel content of the Urk Formation differs in a similar way from that in the Kreftenheye Formation, the quartz values being higher in the former than in the latter.

The following table II, giving mean values of quartz versus all remaining components per unit, summarizes the results:

TABLE II

	% quartz	% remaining components
Kreftenheye Formation	64	36
Urk Formation	75	25
Sterksel Formation:		
Glacial B	59	41
Interglacial I	73	27
Menapian	65	35

Perhaps climatically controlled differences in the chemical weathering during transport and even after sedimentation, may account for the differences observed. If this is true the Urk Formation in this site could date from an interglacial (Holsteinian) whereas the Kreftenheye Formation dates from a glacial stage. This conforms the general accepted dating for this area (Weichselian Glacial Stage).

P o l l e n - a n a l y s i s

Some remarks on the presentation of the pollen data may preceed the discussion of the results. Both in this boring and in boring Dordrecht the pollen sum was 400, spores of *Dryopteris* and *Osmunda,* as well as pollen of aquatics are kept outside the sum. As the presentation of all the curves would require too much space, only the main diagram (based on a pollen sum according to Z a g w i j n, 1963) is given and in addition to this the curve of *Eucommia*. In a later monograph, to be published in Mededelingen Rijks Geologische Dienst, Nieuwe Serie, the complete data will be given.

The top part of the Kedichem Formation (58.75-60.05 m) yielded a pollen diagram which is dominated by herbaceous pollen, whereas thermophilous elements are scarce. This assemblage indicates glacial conditions, and from the stratigraphic position it is fully clear that this Glacial is the M e n a p i a n.

To illustrate this in more detail the section fig. 1 can be consulted. In boring Zaltbommel (the stratotype of the Waalian Interglacial) this Interglacial is found unconformally overlain by the Sterksel Formation (Z a g w i j n, 1960), in boring Leerdam (38H/95 bis) which was recently completely cored in order to make a special study of the detailed succession within the Waalian, the Menapian was found overlying the Waalian in the top beds of the Kedichem Formation, a similar position as in boring Waardenburg.

The basal part of the Sterksel Formation (about 54-58.75 m) has yielded some spectra of the same type as that from the underlying Kedichem Formation. As we had only bailer samples from this part of the boring it could not be decided with certainty whether these spectra came from thin clay bands in situ, or possibly from clay pebbles reworked from the Kedichem Formation. However, in comparison with conditions in other sandy parts of this boring, that often yield thin autochtonous clay bands in cores, it seems likely that the spectra are not from reworked clay pebbles. They indicate that the basal part of the Sterksel Formation still dates from the M e n a p i a n G l a c i a l.

From 43-46 m the character of the pollen assemblage is clearly interglacial (Interglacial I). Both the gyttja (45.70-45.90 m) as well as clay bands on top of it are characterized by a warm temperate assemblage containing *Alnus, Quercus* and *Carpinus* (up to 6%) and up to 4% of *Eucommia.* This part of the boring is equivalent to part of the "*Eucommia*-zone" discussed in the introduction. Furthermore *Celtis* (= *Coriaria*, sensu Z a g w i j n, 1963) has been found. At 42.90 m a rise in herbaceous pollen can be observed, whereas the thermophilous trees have diminished. Here the base of a next glacial stage can be assumed. Also the spectrum at 38.90 m (with *Juniperus* 10%, *Artemsia* 3%, *Betula* 17%, *Pinus* 20%, herbs 40%, little thermophilous trees) indicates subarctic conditions and ranges within a glacial stage (Glacial A).

The clay bed 33.16-36.60 m again yielded a pollen diagram of clearly interglacial character (Interglacial II). Mixed oak forest elements, especially *Quercus* (up to 60%) and *Ulmus* (up to 30%) are dominant. Other elements present are *Taxus, Corylus; Eucommia* is absent and *Carpinus* is only present in some samples (less than 0.5%). The pollen assemblage is very similar to the *Ulmus*-zone of the Interglacial of Westerhoven, and we think they are more or less synchronous. Again only a fragment of the whole interglacial sequence is found (about the middle part) and further data are necessary to reconstruct the whole succession.

Finally, the uppermost part of the Sterksel Formation dates from a glacial stage (Glacial B). Especially from 31-32 m herbaceous pollen has high percentages in the pollen diagram, and this is also the case at the top of the clay and gyttja beds at about 20.50 m. Thermophilous trees are scarce, as is also the case in the intervening range, where, however, the amount of herbaceous pollen is low, and among the tree pollen *Betula* and *Pinus* are dominating. This part of the section has interstadial character.

b. *Dordrecht* (fig. 3)

Introduction

This boring was cored near a former bailer boring from which some samples studied had revealed the presence of a thick upper clay bed with a typical "*Carpinus-Eucommia*-zone" (Sterksel Formation), covering lower clay and peat beds of Waalian age. The upper clay bed forms part of a more extensive one found in the area of Dordrecht, usually separated from the underlying Waalian clay (Kedichem Formation) by 5 to 10 metres of coarse sand.

The clay horizon seems to represent a marginal facies of the Sterksel Formation as it is found at the westernmost boundary of the occurrence of this formation. The new boring hit a gully filled with the upper clay; the normally intervening sand appeared to be reduced to a thin gravel bed at the very base of the gully filling (at 47.17 m). Directly below follows peaty clay of the Kedichem Formation.

The situation of the boring within the Sterksel Formation is rather exceptional, as clay beds of this thickness (about 20 m) are extremely scarce in this formation.

Sedimentary petrology

1. Heavy minerals

In the heavy-mineral diagram five zones have been recognized: *A, B, C, D* and *Augite-Zone.*

Zone A (50.60-60.05 m) has mainly garnet, epidote and hornblende, the mean percentage of stable minerals is 13%. The sediments are fine sand, merging upward into clay with some peat.

Zone B (47.17-50.60 m) has the same character, but the percentages of stable minerals are higher (about 33%). Lithology: clay and some peat at the top.

Zone C (36.40-47.17 m) has about 50% epidote, and garnet, hornblende and a mean of 17% stable minerals. The base coincides with the unconformity at 47.17 m.

Zone D (27.20-36.40 m) has besides of epidote no less than an average of as much as 70% of stable minerals (especially zircone, rutile, anatase) resembling the M-association (Crommelin, 1953). The deposits are clay and gyttja and some metres of fine sand with clay bands at the top.

The Augite Zone (14-27.20 m) consists of coarse sand rich in gravel.

2. Discussion

Mineral zone A is found in beds of Waalian age (see below), Zone B likewise dates from this Interglacial. Therefore they belong to the Kedichem Formation. The M-zone found at the top of the Kedichem Formation in boring Waardenburg in beds of Menapian age, is apparently missing here, indicating the presence of a substantial hiatus at 47.17 m.

Mineral zone C, dated within Interglacial I, has the same age according to pollen analysis (see below) as the middle part of the Sterksel Zone at Waardenburg. The heavy-mineral assemblage is different, however, as the percentages of saussurite and alterite are very low and that of epidote is very high in the Dordrecht Zone C.

It is possible, however, that the difference is mainly caused by differences in lithology: Zone C has sandy clay resulting in mostly heavy minerals of grain size 50-110 micron; at Waardenburg the Sterksel Zone has (as is normally the case) coarse sand and the mineral particles counted are mainly 110-500 micron. It is known that in the size fractions smaller than 110 micron the amount of alterite decreases, whereas that of epidote strongly increases (van Andel, 1950).

Zone D dates, according to pollen analysis, from Glacial A, corresponding in age with the upper part of the Sterksel Zone at Waardenburg. Mineralogically, however, there is no resemblance between the two. Provenance of the river Rhine can be excluded and

g. 2
hart of boring Waardenburg, showing lithology, heavy mineral and gravel diagrams, pollen diagram (legend fig. 2a) and terpretation of the palaeomagnetic data. Black is normal polarity of the geomagnetic field, white reversed polarity.

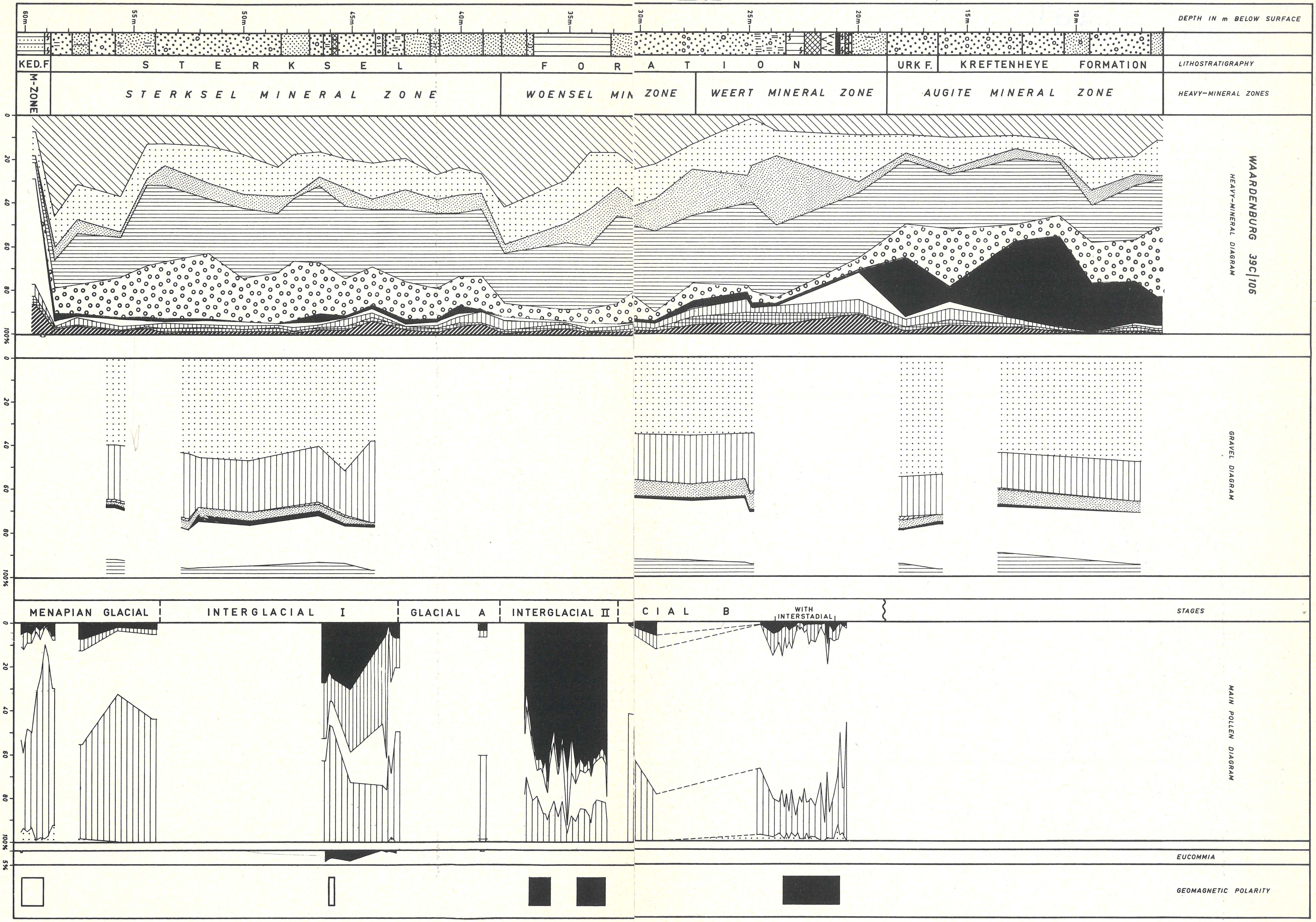
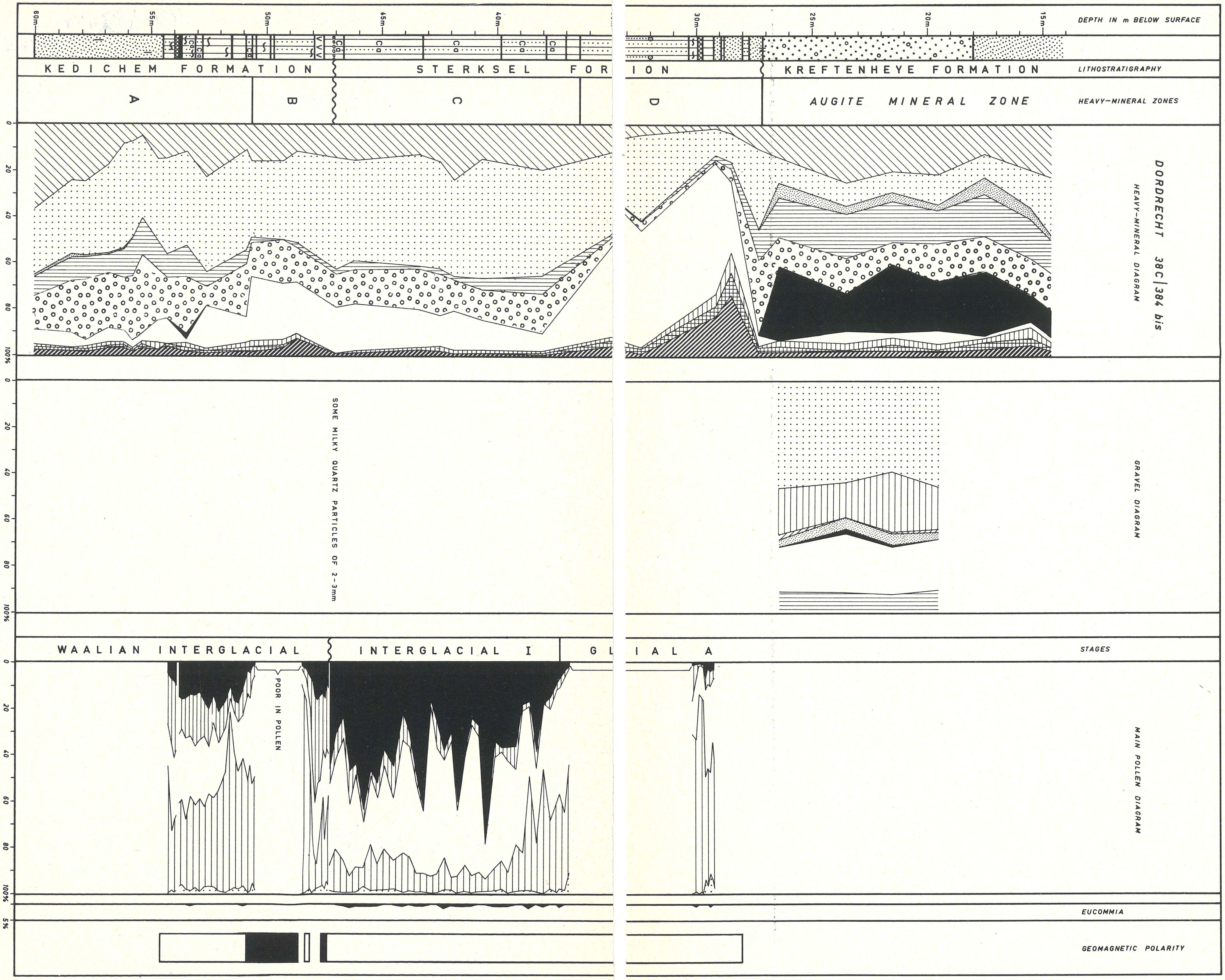


Fig. 3
Chart of boring Dordrecht, showing lithology, heavy-mineral and gravel diagrams, pollen diagrar nd fig. 2a and interpretation of the palaeomagnetic data. Black is normal polarity of the geomagnetic field, white revers ity.



we have to look for a precursor of the river Meuse or some other former river between Meuse and Scheldt to account for this assemblage. Influence of the river Scheldt cannot be excluded (Zandstra, 1969), whereas also a relation with the Budel (Meuse) Zone of the Sterksel Formation of the SE Netherlands (Zonneveld, 1947) can be suggested.

Mineralogically the Augite Zone shows little variation and we suppose that it completely belongs to the Kreftenheye Formation, on the basis of its lithology and the gravel content.

3. Gravel content

Only material from the Augite Zone was available for gravel analysis. The mean quartz percentage (64%) is exactly the same as that found at Waardenburg in the Kreftenheye Formation. The presence of an angular fragment of baltic granite (at 24 m) indicates reworking of Saalian material. Therefore a pre-Saalian age can be excluded. At the same depth particles of pumice occur, which in the river area of the Central Netherlands are known only from the Kreftenheye Formation (Crommelin, 1963).

Pollen-analysis

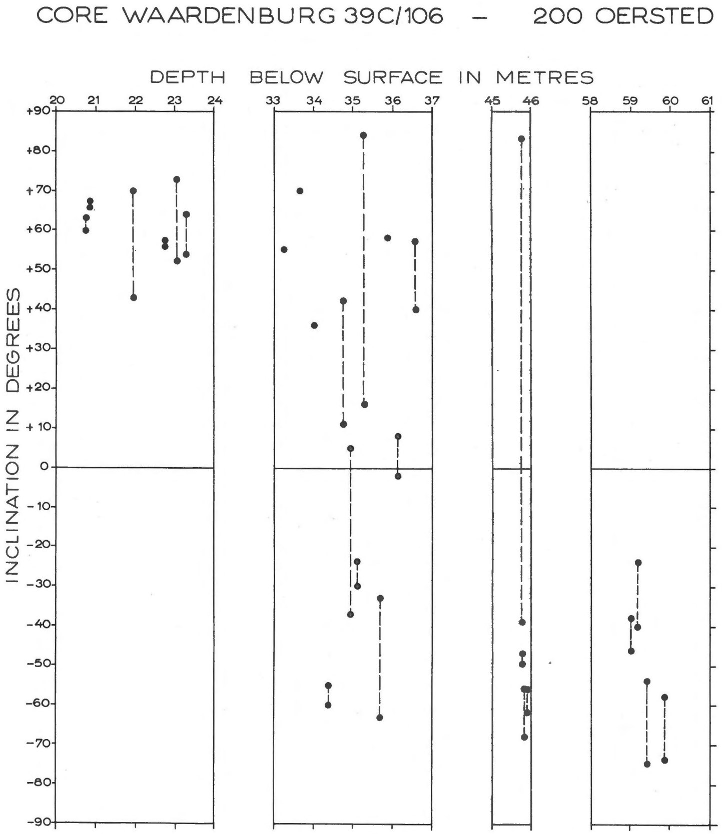
As to the presentation of data we refer to boring Waardenburg. The peat and clay beds from 47.17-54.50 m have yielded an interglacial pollen assemblage indicating their Waalian age (presence of *Tsuga, Pterocarya, Carya, Eucommia; Azolla filiculoides*). A similar threefold subdivision of a lower temperate (A), a middle cool (B) and an upper temperate zone (C) can be observed, as was found before in other Waalian sections (Zagwijn, 1960, 1963). Their ranges are: Waalian A: 51-54.50 m, Waalian B: 48-51 m, Waalian C (incomplete): 47.17-48 m.

The clay bed 29.30-47.17 m essentially shows two different pollen assemblages. A lower one (37-47.17 m) which is clearly of interglacial character, and an upper one, which is, as far as the partly barren sediments permit to conclude, of clearly cold, glacial character (high herbaceous frequencies, thermophilous elements lacking). In fact, however, there is a transition between the two as the upper part of the interglacial section shows a decrease in thermophilous trees, a strong increase of *Pinus*, and some increase of herbs. Therefore we think that this part of the section does not show any substantial gaps and that the interglacial sequence (which only shows the upper half of the interglacial cycle) is conformably overlain by sediments of the next glacial.

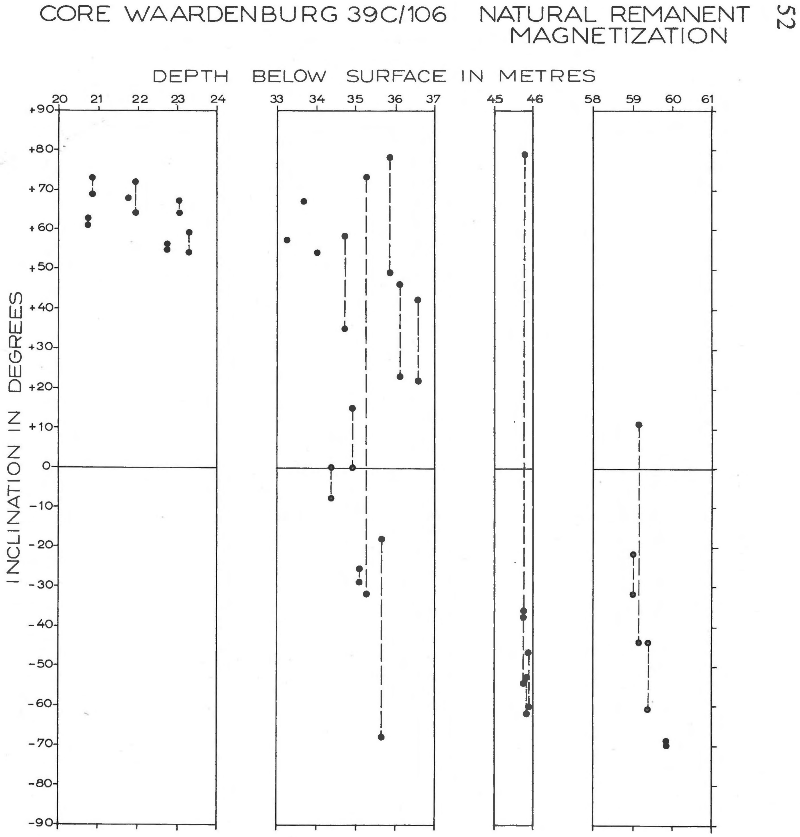
The interglacial pollen assemblage shows high frequencies of *Quercus, Ulmus* and *Carpinus* (up to 20%). Of the Tertiary relics only *Eucommia, Celtis* and *Parthenocissus* are commonly present. In some spectra scattered pollengrains of other "Tertiary types" (such as *Tsuga, Pterocarya*) were met with, but in these cases they were always associated with such pollentypes as *Sciadopitys, Nyssa, Taxodium,* which do not reach higher than the Pliocene. Therefore, in these cases, reworking is the most likely explanation. The interglacial assemblage found from 37-47.17 m as a whole, however, is evidently that of the "*Carpinus-Eucommia*-Zone" mentioned several times before, found in boring Waardenburg in the lower part of the Sterksel Formation (Sterksel Zone) and called Interglacial I.

3. POLLEN-ANALYTICAL DATA FROM THE BASAL PART OF THE URK FORMATION

In the higher part of the Urk Formation clay and peat beds of definitely Holsteinian age can be found in the northern Netherlands (e.g. Bantega, Brouwer, 1948; Zagwijn, in prep.; Peelo, Zagwijn, in prep.). Below it Elsterian fluvioglacial clay (so-called "Potklei") of the Peelo Formation occurs in places. The basal part of the Urk Formation (consisting of coarse sand rich in augite and of coarse sand of the "mixed zone" (Zonneveld, 1958) sometimes yields clay bands, from which isolated pollen spectra of interglacial character have been obtained (Zagwijn, internal report Geol. Survey). These sediments are in part certainly older than the Elsterian fluvioglacial clay, which is on top. In our opinion this is also the case with Bergumerheide about 45-65 m (Brouwer, 1948), from which a more complete diagram was published, partly from marine beds, and formerly thought to be of Holsteinian age. In fact, however, the deposits are lying much deeper than the Holsteinian beds usually found in this area. Another case was a bailer boring in the southern part of the IJsselmeer (boring Oostvaardersdiep) outside the area of the Peelo Formation. Here from 86-104 m in the basal part of the augite-bearing Urk Formation a well developed, more or less complete, interglacial sequence was found (Zagwijn, internal. report Geol. Survey). At first it was thought


CORE WAARDENBURG 39C/106 – 200 OERSTED
DEPTH BELOW SURFACE IN METRES
INCLINATION IN DEGREES

4b


CORE WAARDENBURG 39C/106 NATURAL REMANENT MAGNETIZATION
DEPTH BELOW SURFACE IN METRES
INCLINATION IN DEGREES

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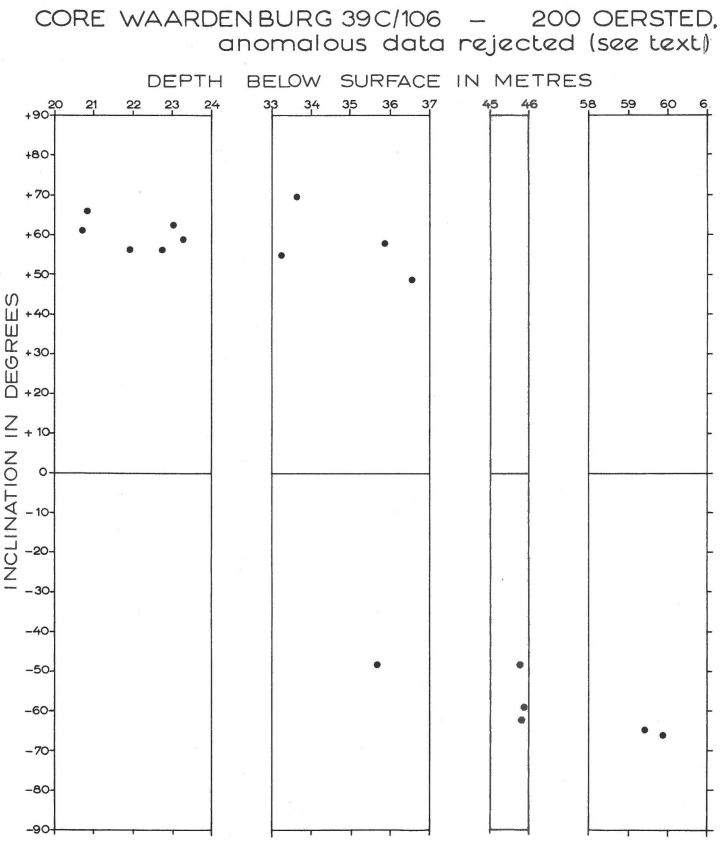


4c

Fig. 4
Palaeomagnetic results of core Waardenburg 39C/106.

that it was of Holsteinian age, but later it was found that in this area, too, the actual Holsteinian beds are situated much higher (at about 30 m, e.g. boring Hoorn).

However, as in this area much post-Holsteinian erosion took place, complete sections are scarce. As far as we can say now, this interglacial is similar to the Holsteinian in its vegetational sequence, except for *Ulmus* being more important in its lower part and *Abies* missing in its upper part. It is planned to study this problem further by making especially cored borings so as to be able to confirm the second hypothesis that a third interglacial (or perhaps even more) of pre-Elsterian Middle-Pleistocene age exists. Therefore, it is better to postpone the presentation of more pertinent data.

4. PALAEOMAGNETIC STUDIES

Introduction

The cores Waardenburg 39C/106 and Dordrecht 38C/184bis have been studied as a part of a palaeomagnetic investigation of Pleistocene sediments of the North Sea Basin. The first results of this investigation have been published by van Montfrans and Hospers (1969). The aim of this investigation is to correlate the stratigraphic succession of these sediments with the time-scale of geomagnetic reversals. Working from young to old, it is attempted to assign in this way absolute ages to a number of stratigraphic levels. The results of the palaeomagnetic investigation of the present two cores appear to be of great importance.

Palaeomagnetic investigations

The clayey parts of the cores have been sampled at intervals not exceeding 50 cm. The cores had not been oriented, but top and bottom were known for each core segment. Almost every time two specimens could be taken at a given depth. The relative orientation of these pairs of specimens was properly recorded. Specimen sizes ranged from 2.7 to 9.0 cm^3. An astatic magnetometer was used for measurements of the remanent magnetization, and all specimens have been subjected to partial demagnetization in an A.C. field of 200 oe. peak value.

About 10% of the Waardenburg specimens were too weakly magnetized to be measured. Of the Dordrecht core less than 10% of the specimens were too weakly magnetized. All other specimens were measured, except a number of the "second specimens" from Dordrecht between 36 and 47 metres below surface, where the results appeared to be particularly uniform.

The results are shown in figures 4 and 5. In these figures, the inclination of the magnetization has been plotted against depth. Reversed directions have a negative sign, normal directions have a positive sign. Depths are in metres below surface. Results from two specimens from the same depth have been connected with dashed vertical lines. On the whole the results are fairly clear-cut except those obtained after partial demagnetization in an A.C. field of 200 oe. peak value from the Waardenburg core between 33 and 37 metres, and those from the Dordrecht core between 27 and 34 metres. Therefore, two criteria for accepting or rejecting a result have been applied to all results obtained after partial demagnetization at 200 oe. These criteria are fairly logical but remain, to some extent, arbitrary.

1. A result was rejected when the angle between the directions of magnetization of two specimens from the same depth was more than of 40° (in principle, two specimens from the same depth might be expected to give the same direction, because the relative orientation was retained). The larger this angle is, the less the sediment can record and preserve the direction of the geomagnetic field at the time of deposition.
2. When the absolute value of the mean of the inclinations of two specimens from the same depth was less than 45°, the result was rejected. When only one specimen had been measured, that inclination was used. For various reasons (secular variation, inclination errors, secondary magnetizations) the direction of magnetization that is found may not coincide with the local direction of the field of an axial geocentric dipole, which has an inclination of 69° at the sampling sites.

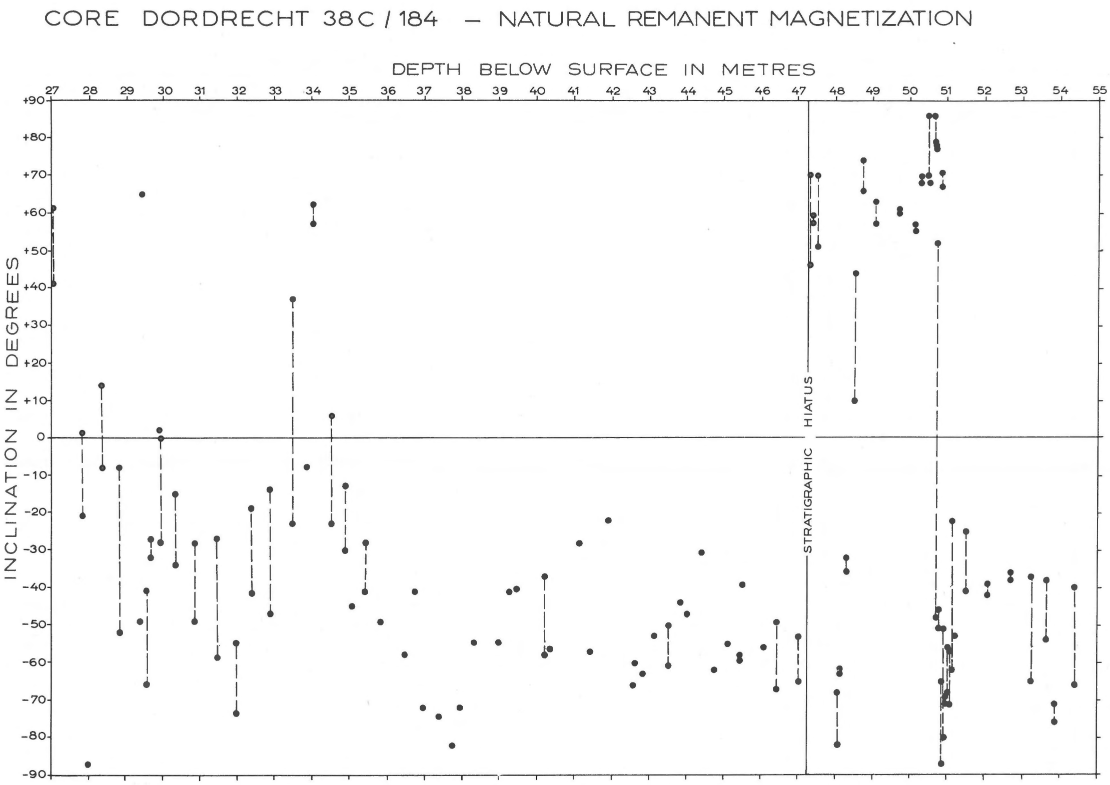
A number of results that were rejected by the second criterion had already been rejected by the first one. However, it is realized that possible real intermediate directions (for instance those occurring at the time of a geomagnetic reversal) may be erroneously rejected on the basis of the second criterion. The selected results, remaining after application of the two criteria are shown in fig. 4c and 5c.

Discussion of results

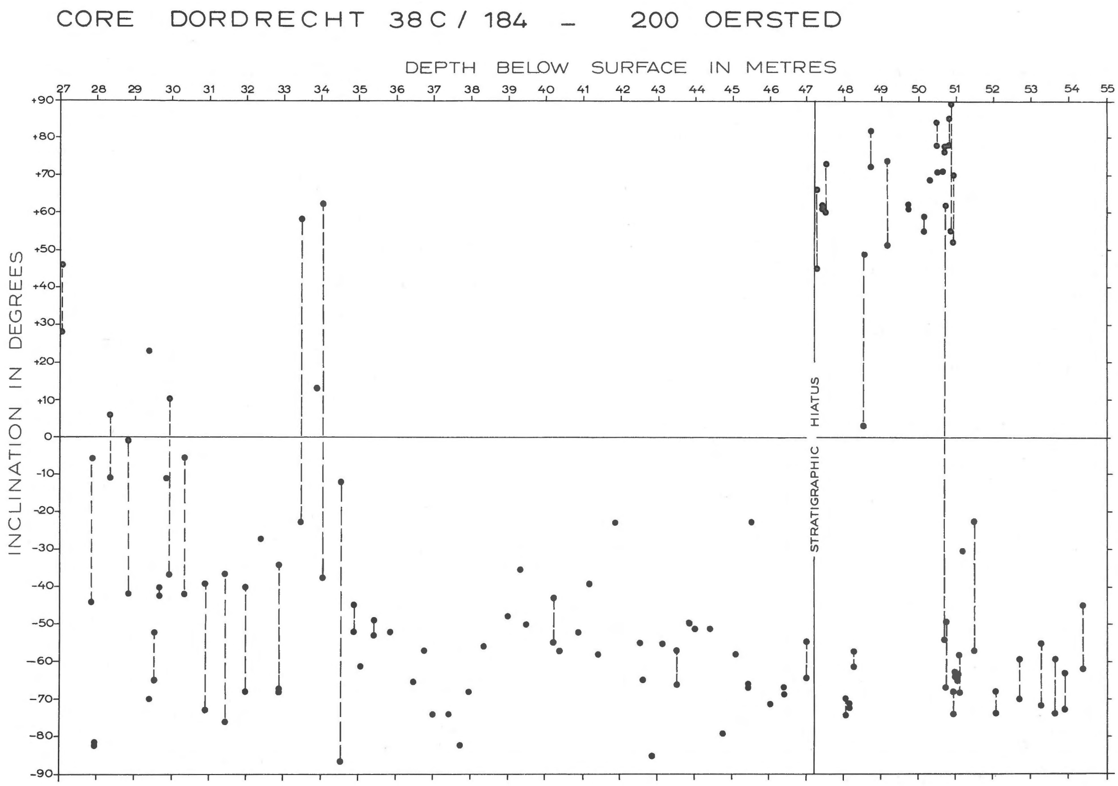
The result of the interpretation of these data in terms of polarity of the geomagnetic field is shown in the compilation figures 2 and 3. It is stressed here that this is only a working hypothesis. A specific polarity (normal or reversed) for a specific stratigraphic level may be considered reliable only after it has been found a few times.

The most important result of the present investigation is that reversed directions of magnetization have now been found twice in sediments of the same stratigraphic age near the base of the Middle Pleistocene (Interglacial I of the "Cromerian" complex). These are the data of Dordrecht between 28 and 47.17 metres, and of Waardenburg between 45.70 and 45.90 metres. Thus, these sediments can be considered to be older than 700,000 years (see fig. 6, after Cox, 1968).

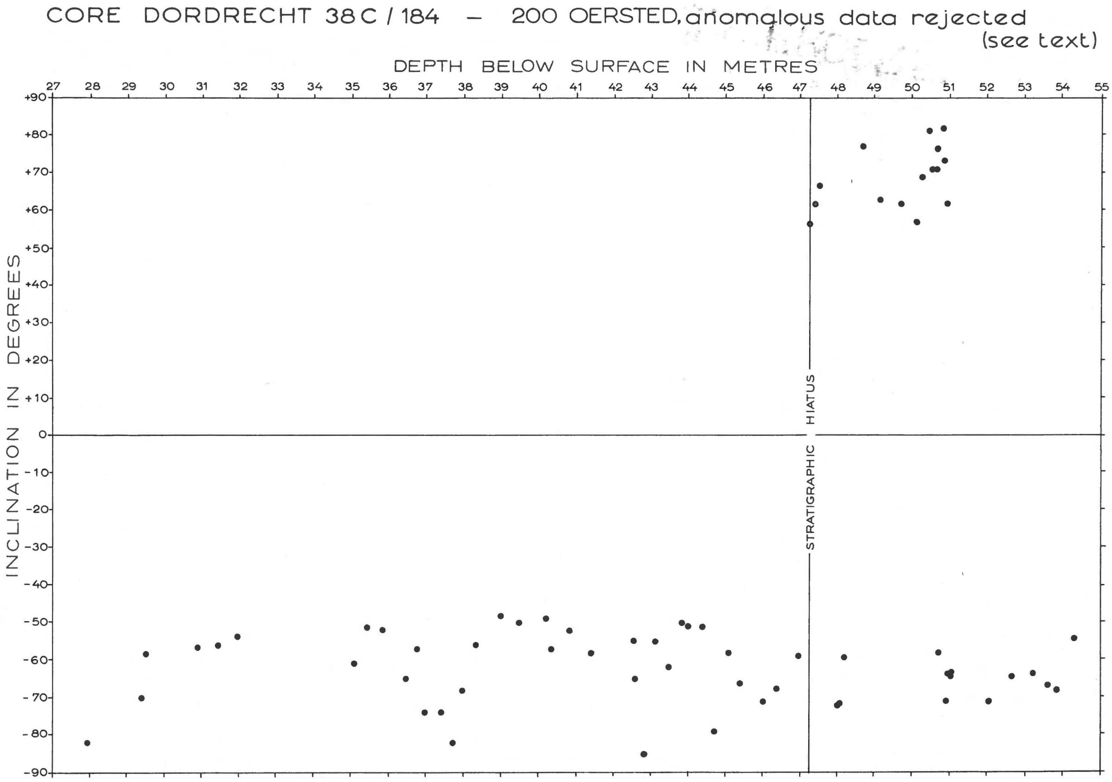
Reversed directions have also been found in sediments of Menapian age of the Waardenburg core, between 59 and 60 m (fig. 2). In the Dordrecht core the Menapian is missing (stratigraphic hiatus at 47.17 m in fig. 3), but reversed directions have been found elsewhere in this stage. Further below in the Dordrecht core, it is more hazardous to assume that the polarities as they were found are representative for the polarity of the geomagnetic field at the time of deposition of the sediment. In Dordrecht, the Waalian C has normally magnetized sediments on top of reversely magnetized ones (between 47.17 and 48.20 m). Also elsewhere, reversed directions were found in the lower part of the Waalian C. In the Waalian B, however, reversed directions have been


CORE DORDRECHT 38C / 184 — NATURAL REMANENT MAGNETIZATION
DEPTH BELOW SURFACE IN METRES
INCLINATION IN DEGREES
STRATIGRAPHIC HIATUS

5a


CORE DORDRECHT 38 C / 184 — 200 OERSTED
DEPTH BELOW SURFACE IN METRES
INCLINATION IN DEGREES
STRATIGRAPHIC HIATUS

5b



5c

Fig. 5
Palaeomagnetic results of core Dordrecht 38C/184 bis.

found elsewhere, unlike the situation in the Dordrecht core (between 48.50 and 50.80 m). The tentative explanation that we are dealing in the Dordrecht core with chemical alteration below 47.17 m is supported by:

- the considerable stratigraphic hiatus at 47.17 m;
- a possible anomalous polarity of Waalian B sediments;
- the coincidence of this anomalous polarity with a zone of stable minerals (see fig. 3).

In such a zone, chemical remagnetization would be a realistic possibility.

In the Waalian A (50.80 to 54.50 m), reversed directions of magnetization were found like elsewhere. When these data are compared with fig. 6, it is possible to conclude that the Jaramillo event (about 900,000 years old) should be placed high in the Waalian C, and perhaps in the lower part of the Menapian. More research is still needed here.

5. CONCLUSIONS

1. Within the Sterksel Formation the mineral Zones of Sterksel, Woensel and Weert have been recognized for the first time outside the area in which they have originally been described. The basal part of the Sterksel Zone as well as the underlying top part of the Kedichem Formation, date from the Menapian Glacial.
2. In the remaining part of the Sterksel Formation two separate interglacial stages are present (Interglacial I and II). Only fragments of them, however, have been found up till now. Of Interglacial I the second half is known, characterized by a *Carpinus-Eucommia* pollen zone. It is followed by a glacial stage (Glacial A). The first half of Interglacial II has been found at Westerhoven and another part at Waardenburg. It has an *Ulmus-Quercus* pollen zone at the latter locality. *Eucom-*

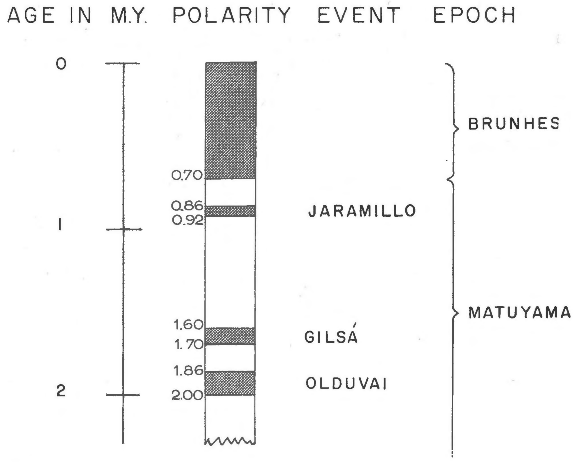


Fig. 6
Radiometrically dated time scale of geomagnetic reversals after C o x (1968). Black is normal, white is reversed polarity.

mia is not known from this interglacial. This interglacial is followed by Glacial B, which comprises a well-developed interstadial. No formal stratigraphic nomenclature has been adopted as yet.

3. Interglacial I and Glacial A have been found within the Sterksel heavy-mineral Zone, Interglacial II (both at Westerhoven as well as in boring Waardenburg) within the Woensel Zone, Glacial B within the upper part of the Woensel Zone, and in the Weert mineral Zone. A correlation has been found between climatic conditions and the quartz percentage of the gravel.
4. Within the next higher formation (Urk Formation) below the beds of Elsterian glacial age at least one more, hitherto unnamed, interglacial occurs.
5. The Matuyama-Brunhes boundary (about 700,000 years ago) is situated between Interglacial I and part of Interglacial II, most probably within Glacial A. It is possible that the Jaramillo event (about 900,000 years ago) should be placed in the upper part of the Waalian C.
6. On the basis of the pollen diagrams available Interglacial I can be correlated with the (completely known) interglacial of Osterholz (Germany – G r ü g e r, 1968). Interglacial II can be correlated with the likewise completely known interglacials of Ølgod and Harreskov (Denmark – A n d e r s e n, 1965). Neither Interglacial I nor II can be correlated with the Cromerian at its type site (D u i g a n, 1963; W e s t, 1969).

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