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An outline of the Quaternary stratigraphy of the Netherlands

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Abstract

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A review is presented of the chronostratigraphy and lithostratigraphy of the Quaternary of The Netherlands. The influence of glaciations is discussed and correlations indicated with the terrace systems of the river Rhine.

1. Chronostratigraphy

Until about 1950 the stratigraphic terminology introduced by Penck & Brückner (1909) was generally used by Dutch geologists for the subdivision of the Quaternary of The Netherlands. Van der Vlerk & Florschütz (1950, 1953) introduced a system of subdivision according to local ages given names ending in -ian that is essentially based on paleontological data (Fig. 1). Although it was not readily accepted by all geologists initially (see discussion in Florschütz 1950), this system was soon adopted by several workers, in particular those of the Geological Survey of The Netherlands (Pannekoek 1956).

Especially pollen-analytical work on Early Pleistocene deposits (Zagwijn 1957) revealed the existence of several more cold and warm phases than had hitherto been known. During a symposium held in Amersfoort on March 20th and 21st, 1957, many new data were presented and at the end of this meeting Van der Vlerk (1957) presented a subdivision of the Pleistocene that was meant to apply to the whole of the NW. European region rather than solely to the local conditions of The Netherlands (Fig. 1). The principle of using paleontological data (i.e., biostratigraphical data) as a basis for time-stratigraphic subdivision was explicitly applied. At that symposium, in discussions on Quaternary stratigraphic subdivision, the principles put forward by Hedberg for older deposits were used for the first time, particularly the distinction between lithostratigraphy and chronostratigraphy (Zagwijn 1957). A year later, this approach was applied by Zonneveld when he described the Quaternary deposits of The Netherlands from a lithostratigraphic point of view (Zonneveld 1958). The chronostratigraphic subdivision proposed in 1957 was maintained, with only minor changes in nomenclature (Van der Heide & Zagwijn 1967), until recently. Initially, there was a tendency to assign a stage name to each glacial and interglacial, but starting in 1971, it became clear that this would lead to an ever-increasing number of formal stage names and would also increasingly complicate the definition of the boundaries between these chro-

1950-1953	1957	1963-1967	1971	1983
Tubantian	Weichselian	Weichselian	Weichselian	Weichselian
Eemian	Eemian	Eemian	Eemian	Eemian
Drenthian	Saalian	Saalian	Saalian	Saalian
Needian	Hoxnian (Holst.)	Holsteinian	Holsteinian	Holsteinian
Taxandrian	Elsterian	Elsterian	Elsterian	Elsterian
	Cromerian	"Cromerian"	"Cromerian* complex"	"Cromerian"**
				Bavelian***
	Menapian	Menapian	Menapian	Menapian
	Waalian	Waalian	Waalian	Waalian
	Eburonian	Eburonian	Eburonian	Eburonian
Tiglian	Tiglian	Tiglian	Tiglian	Tiglian
Praetiglian				
	Pretiglian	Praetiglian	Praetiglian	Praetiglian

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*AT LEAST THREE INTERGLACIALS AND TWO GLACIALS
**AT LEAST FOUR INTERGLACIALS AND THREE GLACIALS
***TWO INTERGLACIALS AND TWO GLACIALS

Fig. 1. Chronostratigraphic subdivisions of the Pleistocene of The Netherlands applied since 1950.

nostratigraphic units. Originally, the Cromerian was thought to be one interglacial, comparable to the Cromerian stage recognized in East Anglia. Later, it became clear (Zagwijn et al. 1971) that in the interval between the Menapian cold stage and the Elsterian, the climate had oscillated many times between cold and warm temperate conditions. Furthermore, the paleomagnetic datings which became available at that time (Van Montfrans 1971) permitted two main conclusions: first, that the duration of the Quaternary as defined in The Netherlands was much longer than had been thought, namely about 2.3 million years, and second, that the approximate duration of the 'Cromerian' of The Netherlands was at least 400 000 to 500 000 years.

Initially, three interglacials were recognized within the 'Cromerian Complex', mainly on the basis of data from the southern part of The Netherlands. Later it was concluded that the uppermost of these intervals to which previously and erroneously, a Holsteinian age (De Ridder & Zagwijn 1962), had been assigned differed palynologically from the pre-Elsterian interglacial found at Noordbergum in the northern part of the country (Zagwijn 1974, pp. 380-382; 1975). On these grounds the existence of at least four interglacials within the 'Cromerian Complex' was assumed, of which only the latest, the interglacial of Noordbergum, could be correlated with the typical Cromerian of East Anglia as defined by West (1980). For more specific details, reference is made to Ruegg & Zandstra (1977, pp 77-80). More recently, palynological data have revealed that the climatic evolution after the Menapian glacial was even more complex than had been thought. In the later part of the Early Pleistocene, after the Menapian cold stage and before interglacial I of the 'Cromerian', evidence was found of two additional warm-temperate stages, each showing a complete interglacial cycle. These are called the Bavel and Leerdam interglacials (Zagwijn & Doppert 1978). Both of these interglacials are characterized palynologically by assemblages with *Pterocarya, Carya, Tsuga,* and *Eucommia,* which are also characteristic for the two older Early Pleistocene interglacial complexes, the Tiglian and the Waalian. Between the Bavel and the Leerdam interglacials and also between the latter and interglacial I of the 'Cromerian', signs of cold climatic conditions during the Linge and Dorst Glacials have been found. The time of deposition between the beginning of the Bavel interglacial and the beginning of the first interglacial of the 'Cromerian' is here assigned to a new stage, the Bavelian (Fig. 1). A detailed discussion of the Bavelian deposits will appear separately (Zagwijn & de Jong, 1984).

Within the Saalian glacial stage a temperate phase has been found which for the time being is considered as an interstadial (the Hoogeveen interstadial), but could also be classified as an interglacial, though probably as one of short duration (Zagwijn 1973). This indicates that the Saalian too is a complex stage, and probably other stages will later prove to be complex as well.

Fig. 2 gives a review of the climatic evolution during the Quaternary in The Netherlands according to present knowledge. The time scale is based on: a- radiocarbon datings (up to 50 000 years BP); b- the first influx of augite in fluvial Rhine sediments (this is connected with lava-flows in the Eifel area about 400 000 years old) during Glacial C of the 'Cromerian' and c- paleomagnetic data (mainly for the interval older than 700 000 years). The mean temperatures during July were estimated from pollen-analytical data and data on cryoturbatic structures, such as frost wedge casts, under the following assumptions:

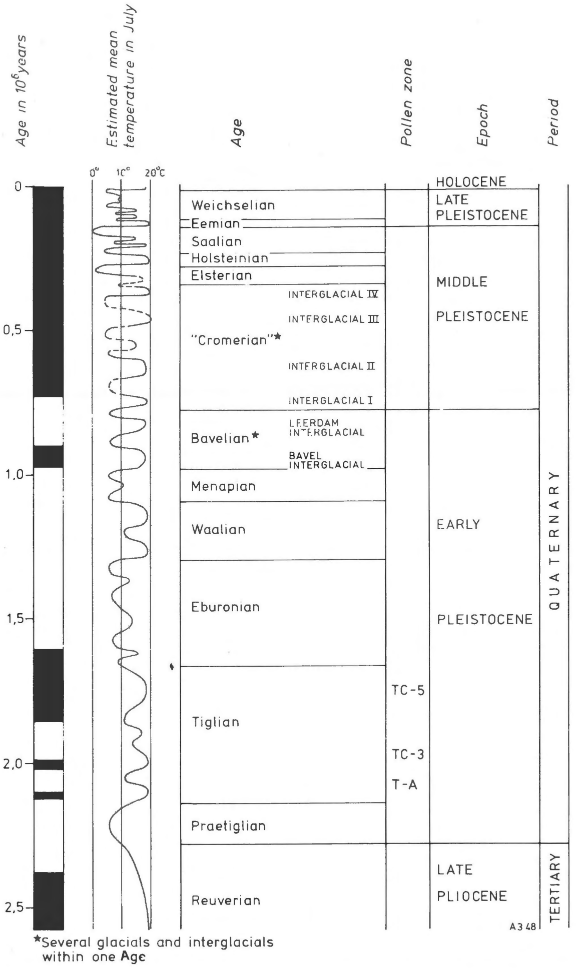

Fig. 2. Climate curve for the Quaternary in The Netherlands.

a. Polar desert conditions indicate a temperature lower than 5°C.
b. The tree-line corresponded (as today) with the 10°C isotherm during the warmest month.
c. Some species occurring during relatively warm phases can be used for temperature estimates, such as *Typha latifolia* (minimum 14°C), Ilex, Hedera (minimum 15°C), and Buxus (minimum 17°C).
d. Phases with forests of the present Central European broad-leaved type had summer temperatures like those prevailing at present or somewhat higher (minimum 17-18°C).

Fig. 3 gives a summary of the climato-stratigraphic data, and indicates also the regions for which pertinent pollen-analytical information is available. It is noticeable that the lower part of the stratigraphic column (up to glacial C of the 'Cromerian') is based on information from the southern part of The Netherlands, particularly the Central Graben area, and the upper part mainly on information from the northern part of the country, which was glaciated during the Saalian. The infor-

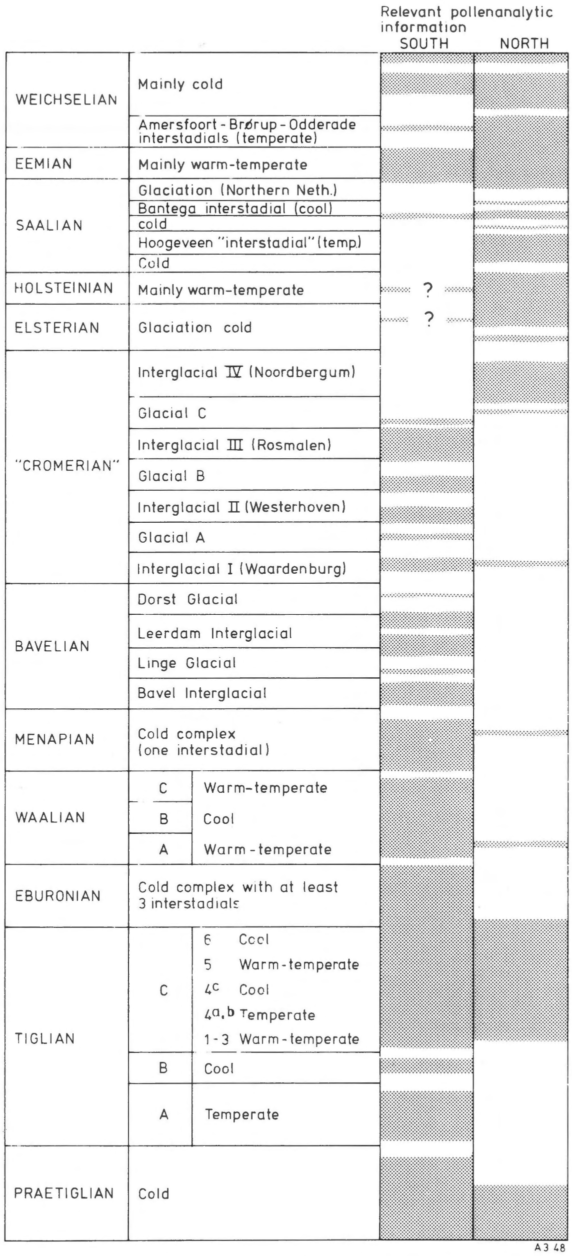

Fig. 3. Stratigraphic and climatic subdivisions of the Pleistocene in The Netherlands and provenance of relevant pollen-analytic information.

mation for both regions is rather detailed, but because the two series of records do not overlap it is not known whether much information is missing for the interval between the top of the lower and the base of the upper series, i.e., for a time about 400 000 years ago (base of Urk Formation). Comparison of the climate curve in Fig. 2 with oxygen isotope curves based on fauna from deep-sea sediments reveals some striking similarities in the number of fluctuations, but more dating checks would be needed to demonstrate an exact match. In particular, more precise dates for the Holsteinian and for interglacial II of the 'Cromerian' are needed for a more detailed comparison of the two records. The paleoclimatic record for the Bavelian and early part of the 'Cromerian', which was calibrated by paleomagnetic dating, corresponds closely with the deep-sea record.

2. Lithostratigraphy

In The Netherlands, many formations were established and described some years ago (Doppert et al. 1975). Criteria for classification were in the first place lithological, but use was also made of lithogenetic features such as predominant facies and the type of sediment, i.e. marine; fluviatile in the sense of deposition by major river systems; local deposition by eolian action, solifluction and other periglacial phenomena, in brooks and organic deposits in peatbogs and lakes; and deposits with glaciations. An important tool for lithostratigraphic classification, particularly with respect to possibilities for correlation, is sedimentary petrography, which was established as a method for this region by Edelman (1933).

The heavy-mineral and gravel contents have from the first proved to be very useful criteria for the recognition of major lithostratigraphic units. Later experience has shown that these units can be recognized in the field by secondary macroscopic features too (colour, relative amounts of certain pebble types, presence of reworked glauconite, etc.), and in some cases also by geophysical techniques, in particular those providing gamma-ray and electric well-log characteristics. In the following only some important formations are dealt with. Detailed documentation on stratotype, general character, occurrence, age, and relation to older descriptions in the literature can be found in Doppert et al. (1975).

The Quaternary formations of The Netherlands, except those of local origin, can be grouped as shown in Fig. 4. Three major modes of origin may help to assign them to the following groups: marine, fluviatile (main rivers), and glacigenic s.l. The lowermost Pleistocene marine beds (Maassluis Formation) are composed of rather coarse sand alternating with clayey beds overlying a clay sequence which is considered to represent the top of the Oosterhout Formation. Other marine beds are found much higher in the stratigraphic sequence, and these are related to interglacial eustatic sea level rises. Four interglacial marine tongues of this kind have been recognized: two of Middle Pleistocene age (one of them 'Cromerian' interglacial IV, the other Holsteinian), one of Late Pleistocene age (Eemian), and one of Holocene age. Fluviatile sedimentation was dominant during most of the Quaternary. Some of the sediments were supplied by the river Rhine. This river contributed volcanic minerals from the Eifel (in particular augite) to the Urk and Kreftenheye

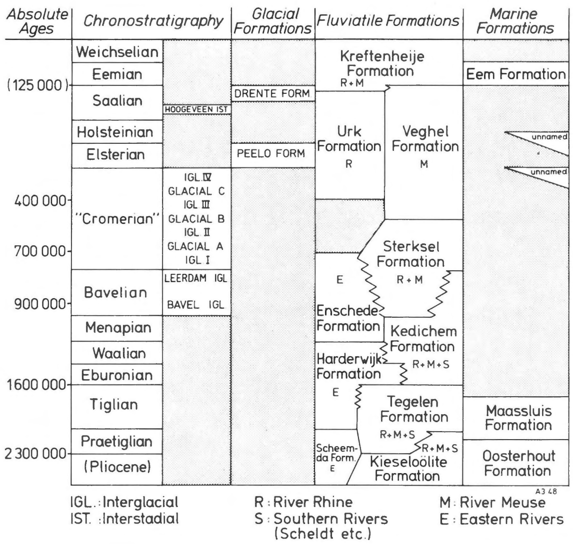

Fig. 4. Chronostratigraphy and lithostratigraphy of the Pleistocene in The Netherlands.

Formations. Consequently, these formations are considered to be younger than about 400 000 years (Frechen & Lippolt 1965).

The river Meuse was important for sedimentation in the southern part of The Netherlands, as were smaller southern rivers, for instance the Scheldt, throughout the Pleistocene. Up to the beginning of the Middle Pleistocene, rivers from the east and northeast, including predecessors of the present Elbe and Weser in northern Germany but also a system of large rivers draining the Baltic region, deposited large amounts of sediments incorporated into two formations, the Harderwijk Formation and the Enschede Formation.

3. Glacigenic influence of Scandinavian ice-sheets in the lithostratigraphic sequence of The Netherlands

Variably clear indications of the presence of Scandinavian ice-sheets have been found at four stratigraphic levels (fig. 5):

a. The Hattem beds (Hattem Complex, Lüttig & Maarleveld 1961, 1962; Hattemlagen, Zandstra 1971): These beds comprise some layers of coarse gravel and boulders intercalated in the lower part of the Enschede Formation. Some of the boulders are unweathered and of eastern origin, others are strongly weathered and of Scandinavian origin. The latter must have arrived at the sedimentation site in an weathered condition and must therefore have travelled by ice-flow transport. The age of the Hattem beds is assumed to be Menapian. They are considered to testify to the existence of a Scandinavian ice-sheet that did not reach The Netherlands during that interval.

b. The mixed zone at the base of the Urk Formation in the northern part of The Netherlands: Generally speaking, the Urk Formation is composed of sediments of the Rhine containing augite and hence dating from after about 400 000 years ago. In most of the northern part of The Netherlands the base of the Urk Formation shows sands consisting of a mixture of Rhine sediment and material of eastern provenance (Weerdinge Beds).

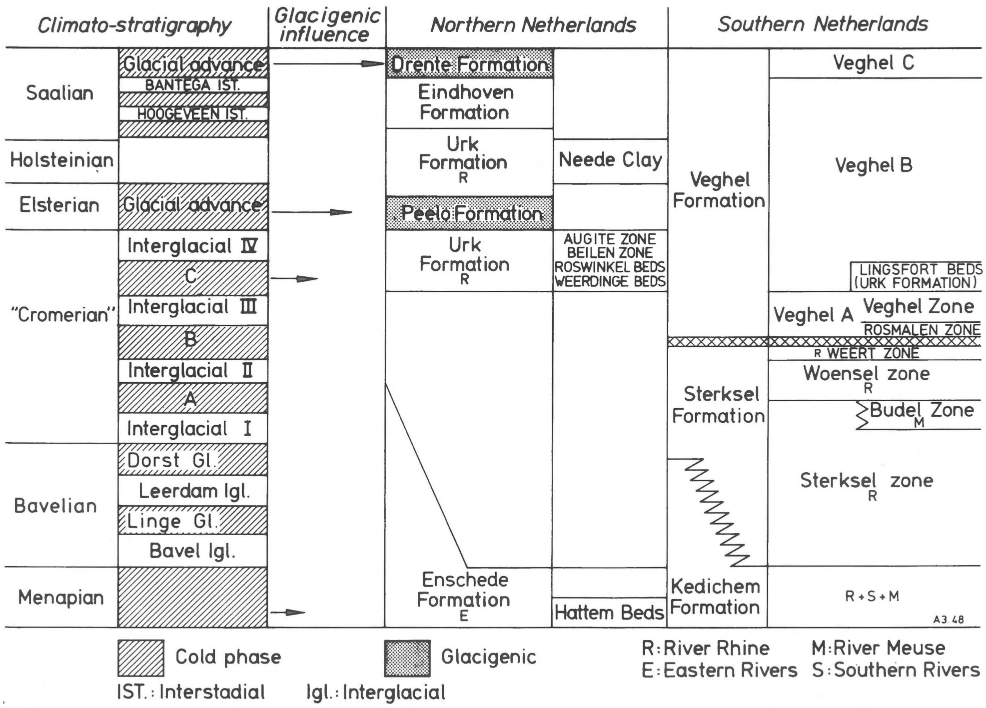

Fig. 5. Subdivision of the Urk, Veghel, and Sterksel Formations and presence of glacigenic influence and formations in The Netherlands.

In addition, interspersed boulders of Scandinavian origin and sedimentary structures indicating a fluvio-glacial influence led Ruegg & Zandstra (1977) to conclude that inland-ice had been present in the vicinity.

c. The Peelo Formation and the Elsterian inland-ice: In the northern part of The Netherlands a series of deposits of presumably glacial origin underlie deposits of Holsteinian age in several places. The former deposits have been assigned to the Peelo Formation. Part of this formation consists of clays of lacustro-glacial origin, called pottery clay. These clay beds are found in a system of narrow elongated basins or channels reaching a considerable thickness (several hundred metres) in some places. The filling may consist either entirely of sands or of sands overlain by pottery-clay.

Glacial till is extremely scarce in the Peelo Formation (Zandstra 1977). The 'pottery-clay' deposits of the Peelo Formation are the counterpart of the Lauenburger Ton of NW Germany, which is Elsterian in age. The Lauenburger Ton also has a typical pattern of channel-like basins (Kuster & Meyer 1979, Grube 1979).

d. Drente Formation (Saalian): Beds belonging to the Drente Formation are present in the northern half of The Netherlands. Tills, lacustro-glacial clays and fluvio-glacial sands occur in this formation. In the central part of the country the Drente Formation is associated with glacial tongue basins (Jelgersma & Breeuwer 1975) surrounded by ice-pushed ridges (Maarleveld 1953, 1981). The northernmost provinces show a ground-moraine landscape with local tongue basins and some ice-pushing (Ter Wee 1962, 1981). The Drente Formation is followed by Eemian deposits and overlies sediments of Holsteinian age. The position is known in even more detail for the northern part of the country, where deposits of Early Saalian age, including those of two temperate intervals (Hoogeveen and Bantega interstadials), underlie the tills of the Drente Formation (Zagwijn 1973). The Hoogeveen interstadial probably correlates with the *Wacken Warmzeit* of Eastern Germany (Erd 1970), which would indicate a Late Saalian date for the inland-ice covering of The Netherlands.

4. The Quaternary Rhine sediments of The Netherlands in relation to the Lower Rhine area of Germany

Because the above-mentioned Rhine deposits must be the continuation of upstream deposits in the adjoining Lower Rhine District of Germany, several authors and in particular Zonneveld (1956), have sought correlations with that area. However, several details of such correlations still raise doubts, mainly because the Quaternary sediments of The Netherlands are in an area of subsidence providing rather complete sedimentary sequences, whereas the Lower Rhine District is characterized by a terrace morphology of Middle Pleistocene and younger sediments. This led to a set of sediment bodies separated by hiatuses of unknown extent. Moreover, biostratigraphic support for correlation is only found in some discrete levels.

In the Erft Basin, sediments of Pliocene and Early Pleistocene age (beds A to D) have been described by Boenigk et al. (1972) and Brunnacker (1975, 1978). According to palynological studies by Urban (1978, 1979), these sediments can be correlated biostratigraphically with deposits in The Netherlands, as indicated in Fig. 6.

The sediment bodies underlying the terraces described by Brunnacker (1975, 1978) can with some confidence be correlated with sediments in The Netherlands on the following basis:

a. Main Terrace 2 (HT 2), as defined by Brunnacker (1975, 1978) and Boenigk et al. (1972),

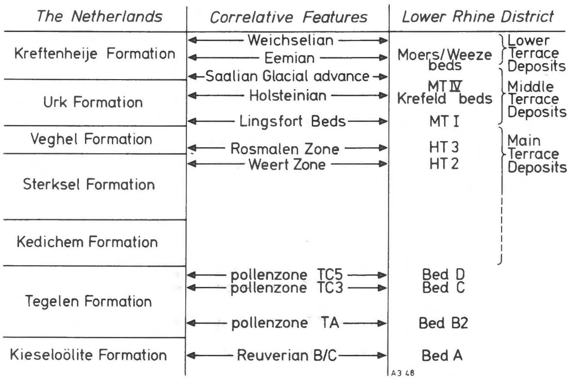

Fig. 6. Correlations between The Netherlands and the Lower Rhine District of Germany.

correlates with the uppermost part (Weert Zone) of the Sterksel Formation. This Zone dates from the Glacial B of the 'Cromerian'.

b. The Rosmalen Zone in the Central Graben area of the southern part of The Netherlands represents the youngest sediments influenced by the Rhine in this region. Later on, only sediments of the river Meuse were deposited. The former beds date from Glacial B and the overlying interglacial III of the 'Cromerian complex'. During the accumulation of the sediments of the Main Terrace body HT 3, the Rhine flowed for the last time west of the present divide between that river and the Meuse. This means that the Rosmalen zone can be correlated with the sediments of HT 3 (Boenigk 1984, pers. comm.).

c. The Lingsfort Beds in the southeastern part of The Netherlands (containing high percentages of brownish-green hornblende) belong to the Urk Formation and correlate with the oldest Middle Terrace sediment body (MT I) of the river Rhine. Therefore, they must be younger than the beds discussed above under b, and may date from Glacial C of the 'Cromerian complex'.

d. The Krefeld beds of Holsteinian age are intercalated within terrace body MT IV. These beds correlate with the Neede Clay of the central and northern parts of The Netherlands, which was pushed by the Saalian inland-ice. The uppermost beds of MT IV are generally considered to be contemporaneous with the Saalian glacial advance.

e. The type-section of the Kreftenheye Formation is in a well near the Dutch-German border in an area morphologically defined as Lower Terrace. The main part of the coarse-grained sediment body underlying this Lower Terrace level must be older than the Eemian, because peatbeds of this age have been found close to the surface at Weeze, slightly to the east of Kreftenheye (Von der Brelie et al. 1955). In The Netherlands these coarse sediments are considered to coincide with the maximum extent of the Saalian inland-ice (Zonneveld 1947, 1958, Van de Meene & Zagwijn 1978, Doppert et al. 1975), because they underlie the floor of an ice-marginal valley belonging morphologically to the Lower Terrace. This means that the maximum extent of the inland-ice is contemporaneous not only with the formation of the latest Middle Terrace deposits, but also with the earliest sediments underlying the Lower Terrace.

f. The remaining sediments underlying the Lower Terrace in the Lower Rhine District are of Weichselian age and correlate well with the main part of the sediments belonging to the Kreftenheye Formation. For more details, reference is made to the paper by Van de Meene & Zagwijn (1978).

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