An evaluation of the Cromerian complex period of The Netherlands

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Abstract

The Cromerian complex of The Netherlands is evaluated, based on available literature, published over the past forty years. Contrary to popular believe, the Cromerian complex of The Netherlands is not known in sufficient detail to allow a reliable reconstruction of the climatic development over this period. This is mainly due to the short sequences of sediments, as well as a lack of firmly established correlations and absolute dating. The original assumption that the Cromerian complex is a period with four interglacial and three glacial cycles is not reflected in the oxygen isotope stages. However, the boundaries of the Cromerian complex have been established correctly; Cromerian I can be correlated with OIS 21 and a final interglacial can be correlated with OIS 11.

Contents

1. Introduction

The Cromerian complex of The Netherlands has been subject to detailed research over the past 40 years (Zagwijn, 1963, 1985, 1996, 1998; Zagwijn *et al*., 1971). This resulted in a detailed biostratigraphy of this period, predominantly based on palynological research, reinforced through lithogical, petrological and palaeomagnetic investigations (Zagwijn *et al*., 1971; Montfrans, 1971) and in a reconstruction of the climatic development of the Cromerian complex, consisting of 4 interglacials and three glacial periods (Zagwijn, 1975, 1985, 1996, 1998).

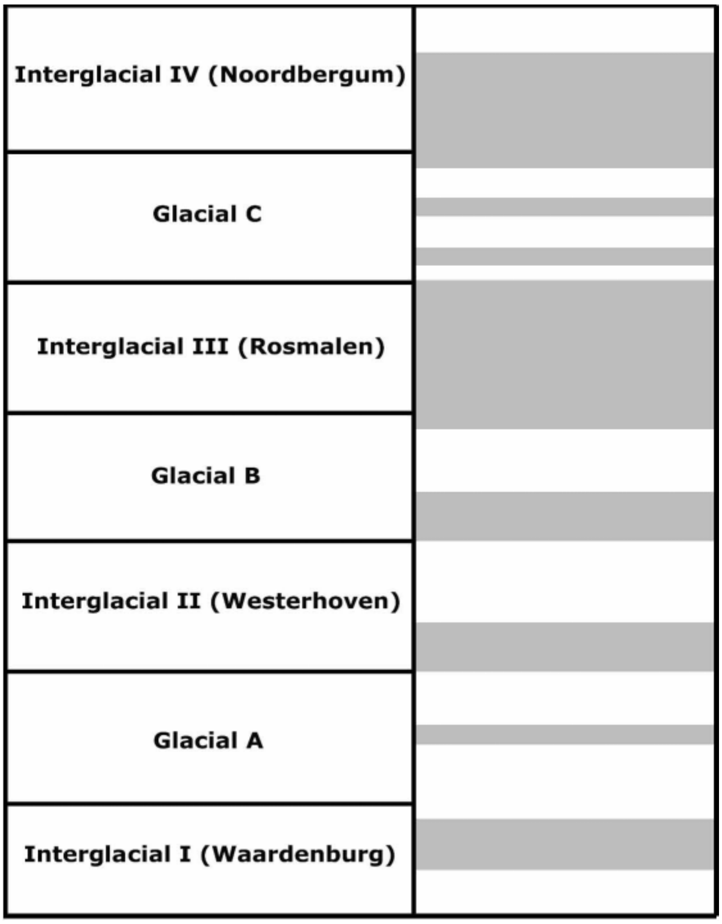

Figure 1. Availability of pollen samples during the Cromerian complex. Reworked after Zagwijn (1985).

The Cromerian complex *sensu* Zagwijn is a biostratigraphical sequence; based on palynological research (Zagwijn, 1963, 1985, 1996; Zagwijn *et al*., 1971; Zagwijn & Zonneveld, 1956), augmented with palaeomagnetic and sedimentary petrology data. The adequacy of the palynologic record of the Cromerian complex, as presented by Zagwijn (1985) is represented in figure 1.As a result it was considered possible to reconstruct the general climatic development during the Cromerian period with enough certainty and detail (figure 2). Zagwijn (1996) also attempted a correlation of the Cromerian complex with the oxygen isotope stages (figure 3).

Recently, a number of authors have made some reservations to the adequacy of the biostratigraphy of The Netherlands (Ehlers, 1996; Turner, 1996; Zagwijn, 1996). Zagwijn (1996: 146) voices some constraints with respect to the completeness of the biostratigraphy of the Cromerian complex: "[…] the nature of most interglacial sediments filling the tectonic basin of the Netherlands, and showing a fluviatile and sometimes estuarine facies, results in a rather fragmentary record of the interglacial vegetational successions involved." Turner (1996: 300) reinforces this statement, casting serious doubts on the adequacy of the Dutch biostratigraphy: "It has not always been fully realised […] how fragmented the sequences in […] the Netherlands […] actually are. This fragmentation results from the fact that […] sequences were largely the result of accumulation in shallow river beds. Further difficulties arise, because most of the sections on which the sequence is based have been observed in boreholes or temporary sections which are not really accessible for extended study." Based on these observations, Turner (1996: 313) concludes that: "The early Middle Pleistocene

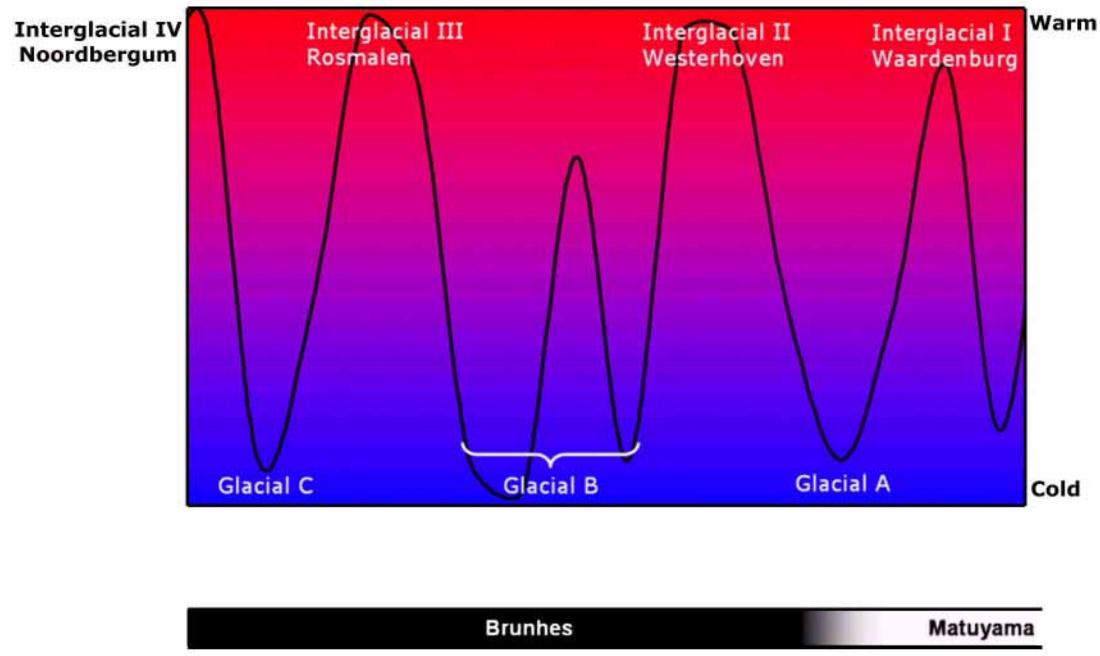

Figure 2. Climatic sequence during the Cromerian period. Reworked after Zagwijn (1985).

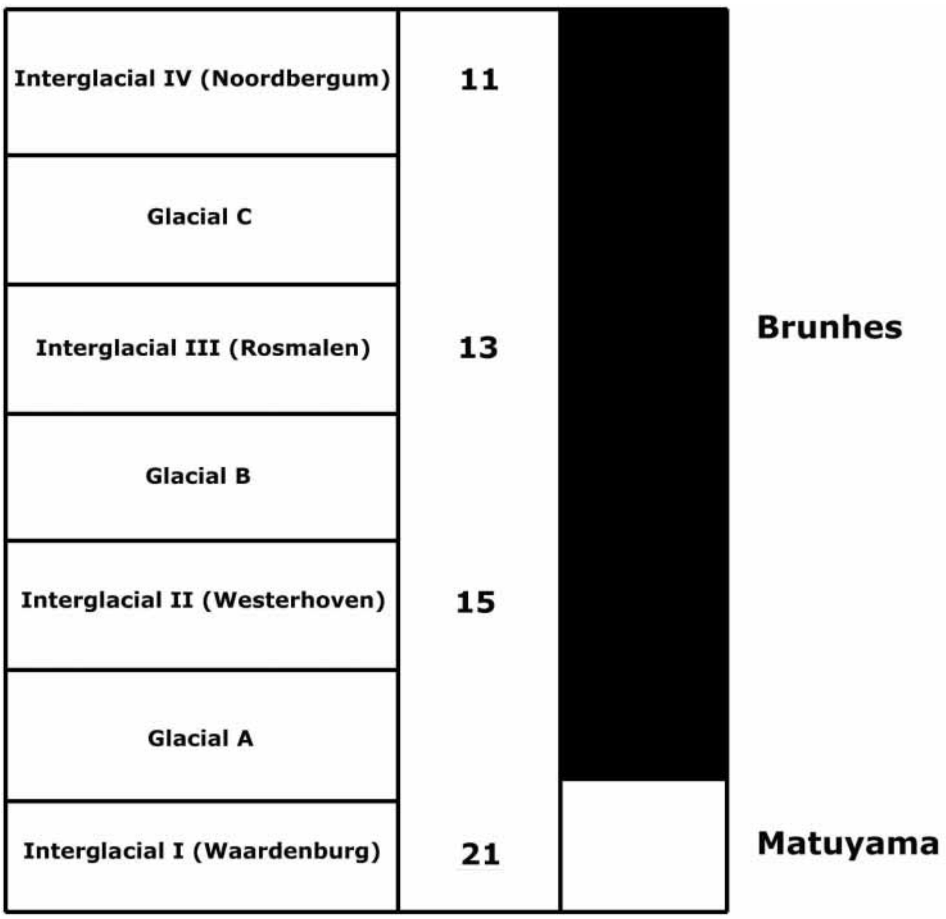

Figure 3. Correlation of Cromerian complex with oxygen isotope stages and paleomagnetization. Reworked after Zagwijn (1996).

sequences of the classic ‘stratotype’ areas of the Netherlands and eastern England are extremely fragmentary. Although still open to amplification and reinterpretation, they are unlikely to provide an adequate stratotype for this period in the long run.” These reservations warrant a closer look at the early Middle Pleistocene period of The Netherlands.

This paper presents the result of an evaluation of the Cromerian complex period, based on evidence published by various authors over the last forty years. In table 1, the different core segments that contributed to our current knowledge of the Cromerian complex, are summarized; a discussion of the various phases of the Cromerian complex are presented.

Phase	Location	Length	**Nr. samples**	**Mag**.
Interglacial I	Waardenburg 39C/106	1 m	5	Reversed
	Waardenburg 39C/106	50 cm	4	No data
	Dordrecht 38c/384 bis	10 m	± 30	Reversed
Glacial A	Waardenburg 39C/106	± 5 cm	1	No data
	Dordrecht 38c/384 bis	± 1m	8	No data
Interglacial II	Waardenburg 39C/106	4 m	14	Normal
	Westerhoven	3.5 m	22	No data
Glacial B	Waardenburg 39C/106	3 m	4	No data
	Waardenburg 39C/106	4.5 m		Normal
Interglacial III	Rosmalen	5 cm	1	No data
	Rosmalen	1.4 m	30	No data
	Rosmalen	50 cm	11	No data
	Het Zwinkel	3 m	21	No data
Interglacial C	No data	No data	No data	No data
Interglacial IV	Noordbergum	1 m	3	No data
	Noordbergum	3m	5	No data
	Wolvega	1.5 m	8	No data
	Roswinkel	70 cm	9	No data

Table 1. Overview of core segments that contributes to the knowledge of the Cromerian complex.

2. Interglacial I/Cromerian I

Proof of this interglacial was found in a sequence between 43 and 46 meters in Waardenburg (39C/106) and in a sequence between 37 and 47 meters in Dordrecht (Zagwijn *et al.,* 1971). The pollen spectra of Waardenburg have been published in detail only recently (Zagwijn, 1996). The pollen spectra of Dordrecht have not been published yet.

2.1. Waardenburg 39C/106

At Waardenburg, Interglacial I is found in the Sterksel mineral zone within the Formation of Sterksel (Zagwijn *et al.,* 1971). The heavy mineral assemblage predominantly shows garnet, epidote, saussurite, alterite and hornblende.

The pollen analysis of Waardenburg is coarse; of a core-length of 3 m, a middle portion of 1.5 m in length has not been analysed and the lower section also leaves a gap of approximately 75 cm without pollen samples. The two sections of Waardenburg also show a clearly different pollen spectrum with markedly different presences of *Eucommia*, *Pinus*, *Betula*, *Vitis*, *Quercus* and *Alnus*. Consequently, it is considered highly tentative to assume a single interglacial cycle based on this scanty evidence. However, Zagwijn *et al*. (1971) considered the data conclusive to postulate Interglacial I. In addition, they assume the base of Glacial A at the upper limit of the core section at Waardenburg. The fact that a gap of 3 m exists between the upper border of Interglacial I and the lower border of Glacial A also seems no obstacle to them to postulate this relationship. The coarse nature of the data once again seems to conflict with their assumptions.

At Waardenburg 3 palaeomagnetic results were available in the lower section between 45 and 46 m, all of which showed reversed magnetization indicating a pre-Brunhes age. No palaeomagnetic evidence was presented of the upper section.

2.2. Dordrecht 38C/384 bis

At Dordrecht, Interglacial I is found in heavy mineral zone C within the Formation of Sterksel. This zone is characterised by very low percentages of saussurite and alterite and very high percentage of epidote. This is attributed by Zagwijn *et al.* (1971) to differences in grain size. However, apart from mentioned differences also the percentage in hornblende and other minerals differ considerably (*ibidem*, figure 2 and 3). The heavy mineral assemblage of Dordrecht and Waardenburg is inadequate to serve as a means for time correlation between the two sites during Interglacial I.

The pollen analysis of Dordrecht is based on a large number of pollen samples at regular intervals. Detailed pollen spectra of this site have not been published. According to Zagwijn *et al.* (1971), the pollen assemblage shows high frequencies of *Quercus*, *Ulmus* and *Carpinus*. Tertiary relics like *Eucommia* are commonly present.

In Dordrecht Zagwijn *et al*. (1971) also recognize the onset of Glacial A at the uppermost border of the pollen spectrum of Interglacial I. In this case there is a gap of 6 m between the upper border of Interglacial I and lower border of Glacial A. As with Waardenburg, this conclusion seems to be highly tentative and should be discarded. At Dordrecht a large number of palaeomagnetic measurement showed all reversed magnetization over the whole of the interglacial period.

2.3. Discussion

Based on the published evidence on Interglacial I, it is concluded that only Dordrecht provides conclusive proof of a single interglacial. Since no specific absolute dating is possible, the only conclusion that can be made is that the interglacial is of pre-Brunhes age, since the interglacial yielded reversed magnetic results. The presence of a single interglacial in Waardenburg is not convincingly established. The relationship between the pollen spectra at Waardenburg and at Dordrecht is not convincingly established and should be discarded.

3. Glacial A

This glacial is represented by two short sequences at Waardenburg (39C/106) and Dordrecht.

3.1. Waardenburg 39C/106

At Waardenburg, Glacial A is found in the same mineral zone as Interglacial I, the Sterksel Mineral Zone within the Formation of Sterksel. The pollen analysis at Waardenburg is based on only one sample; no detailed pollen spectrum has been published. According to Zagwijn *et al*. (1971) subarctic conditions were visible from the pollen spectrum (40% herbs, 10% *Juniperus*, 20% *Pinus*, 17% *Betula*, 3% *Artemisia* and few thermophilous trees). No palaeomagnetic data are available from this section.

3.2. Dordrecht 38C/384 bis

At Dordrecht, Glacial A is found in mineral zone D within the Formation of Sterksel. The mineral assemblage is completely different from the Sterksel Mineral zone at Waardenburg, this time explained by a difference in the contribution of rivers (Zagwijn *et al.,* 1971).

Mineral Zone D is ‘dated’ using pollen analysis (ibidem), linking this zone to the upper part of the Sterksel Mineral Zone at Waardenburg, were the single pollen spectrum attributed to Glacial A is located. The pollen analysis of Dordrecht is based on approximately 8 pollen samples. Detailed pollen spectra have not been published. Zagwijn *et al*. (1971) only present a very limited description in which they mention high herbaceous frequencies and lacking thermophilous elements.

The fact that this glacial is only established in Dordrecht, together with the absence of palaeomagnetic evidence and the large hiatus between the supposed end of Cromerian I in the Dordrecht core make it impossible to objectively confirm its proposed position as the immediate successor of Cromerian I.

3.3. Discussion

The evidence of Glacial A is very limited indeed. However, the number of pollen spectra of Dordrecht indicating cold conditions seems to point to the existence of a glacial period. The relationship between Waardenburg en Dordrecht is extremely tentative and should be discarded. Without clear and unambiguous correlations there is no firm evidence of a time correlation between the two localities for the observed cold period.

4. Interglacial II/Cromerian II

4.1. Waardenburg 39C/106

At Waardenburg proof of this interglacial is found between 33.2 and 36.6 m; it is located in the Woensel Mineral zone of the Formation of Sterksel. The Woensel Mineral zone is characterized by garnet, epidote, saussurite, alterite and less hornblende than in the Sterksel Mineral zone.

The pollen analysis is based on 13 samples. Detailed pollen spectra have been published by Zagwijn (1996). Mixed oak forest elements, especially *Quercus* (up to 60%) an *Ulmus* (up to 30%) are dominant, *Eucommia* is absent. Zagwijn *et al.* (1971) assumes this indicates the middle part of a full interglacial cycle.

Four out of the five palaeomagnetic measurements taken show normal magnetization. This probably indicate Brunhes age.

4.2. Westerhoven

At Westerhoven, an interglacial is found between 0 and 2 m of which detailed pollen spectra have been published (Zagwijn, 1996). Zagwijn *et al*. (1971) suggest that the interglacial of Westerhoven is more or less synchronous with Interglacial II of Waardenburg but evidence to substantiate this suggestion has never been published.

4.3. Discussion

At Waardenburg substantial evidence was found of an warm/temperate flora during a period of normal magnetization. Since this segment overlies an earlier (Interglacial I) warm temperate zone with reversed magnetization it is clear that during the (unknown) time span at least two temperate climate periods occurred. Though tentative, it seems relatively safe to assume a post Jaramillo age for the first interglacial period at Waardenburg.

5. Glacial B

Proof of this glacial is found at one location, Waardenburg 39C/106.

5.1. Waardenburg 39C/106

Proof of this glacial was found in two segments. The first segment, between 29 m and 32 m, is located in the Woensel Mineral Zone. The second segment, between 21 and 25 m is located in the Weert Mineral Zone, also part of the Sterksel Formation. The Weert Mineral Zone is characterized by a very high amount of saussurite and alterite with very low percentages of hornblende and garnet.

The pollen analysis is based on four samples of the first segment and on approximately 24 samples in the upper segment. No detailed pollen spectra have been published. According to Zagwijn *et al.* (1971) the lower segment represents a glacial period (Glacial B) whereas the upper segment represents an interstadial period within the same glacial.

5.2. Discussion

The assumption of Zagwijn *et al.* (1971) of a glacial period up until the interstadial seems to be tentative. A gap of more than 4 m between the pollen samples seems to be large enough to refrain from such a suggestion and to postulate the existence of a single glacial based on only 4 pollen samples that were widely spaced seems also dubious.

6. Interglacial III/Cromerian III

At Rosmalen a Holsteinian succession (Ridder & Zagwijn, 1962) is later attributed to Cromerian complex period and positioned as Interglacial III (Zagwijn, 1996). The position as a third interglacial is based on the mineral assemblage, called Rosmalen Zone, later in age than the top of the Sterksel Mineral Zone in this area (*ibidem*).

The Rosmalen core consists of three segments: a top segment of less then 10 cm with one pollen sample; a middle segment of 1.6 meter (21.0 m – 22.6 m) with 28 pollen samples and a bottom segment of 60 cm (24.0 m – 24.6 m) with 11 pollen samples.

A second succession, attributed to Cromerian III, was found at Het Zwinkel. A single segment, 2.4 m in length (27.8 m – 30.2 m) yielded 22 pollen samples. While this segment is placed in Interglacial III, it shows a high percentage of herbs and a low percentage of thermophilous trees, with the exception of a segment between 28.3 – 28.8 m.

6.1. Discussion

First of all, the pollen spectra of the three segments in the Rosmalen sequence appear to be considerably different, with the exception of a high percentage of *Pinus* in all three segments. However, the middle segment show high percentages (on average over 40%) of thermophilous trees, while bottom and top segments show low percentages (under 20%). *Alnus* is abundant in the middle segment, but is nearly absent in the top and bottom segments. Once again, a gap of nearly 1.5 m between the bottom and middle segment seems large enough to refrain from making a connection between these two segments. This view is reinforced by the markedly different pollen assemblages.

The pollen spectra of Rosmalen and Het Zwinkel are also markedly different. On the basis of the pollen spectra, it is unclear why both sequences are correlated and placed into one interglacial. It is suggested that the lithology and mineral assemblage overlay the Sterksel Mineral Zone, thus allowing a more recent dating for this period.

7. Glacial C

While Glacial C is mentioned by Zagwijn (1985) and pollen sequences are apparently present (see figure 2), no palynological evidence of this glacial was ever published; since no published evidence of Glacial C is available, it should be omitted from the Cromerian complex.

8. Interglacial IV/Cromerian IV

This interglacial is located in the lower part of the Formation of Urk (Zagwijn, 1996). The Formation of Urk is characterized by a relatively high percentage of augite, attributed to volcanic activity in the Eiffel area. Zagwijn (1996) refers to Van den Boogaard & Schmincke (1990) who dated this event around 380 ka – 430 ka.

The Cromerian IV interglacial has been found in the Northern part of The Netherlands. While no full interglacial cycle has been recovered, Zagwijn (1996) states that the main succession is shown relatively completely at Noordbergum and Roswinkel. This observation seems rather questionable, since the Noordbergum sequence is extremely fragmented (8 pollen samples over a borehole segment of more than 10 m; furthermore, a gap of more than 6 m without pollen samples is ignored) and the Roswinkel sequence is based on a borehole segment of only 50 cm in length.

8.1. Discussion

The reason for recognizing a fourth interglacial period in the Cromerian complex is based on apparent palynological differences between Cromerian IV and Cromerian III (Zagwijn, 1996). However, the evidence of Noordbergum and Roswinkel, as presented by Zagwijn (*ibidem*), is very limited indeed and should be used with the utmost constraint.

Since Cromerian IV is only recognized in the northern part of The Netherlands it cannot be ruled out that regional differences account for a different pollen spectrum. Since the position of Cromerian III has not been established with an objective dating point it is also possible that these two interglacial periods are in fact one and the same interglacial. However, this does eliminate the fact that interglacial conditions were found after the augite event, which is believed to be due to Eiffel volcanism, allowing dating of an interglacial period of the early Middle Pleistocene.

9. Final discussion and conclusions

While the Cromerian complex is thought to be relatively well-known, a detailed analysis of the published evidence clearly points to the contrary. The limited number of sequences, often of short length, the small number of pollen samples, the absence of absolute dating possibilities and the limited amount of palaeomagnetic data all combine to impede the ability to recreate the Cromerian complex to any level of certainty and accuracy.

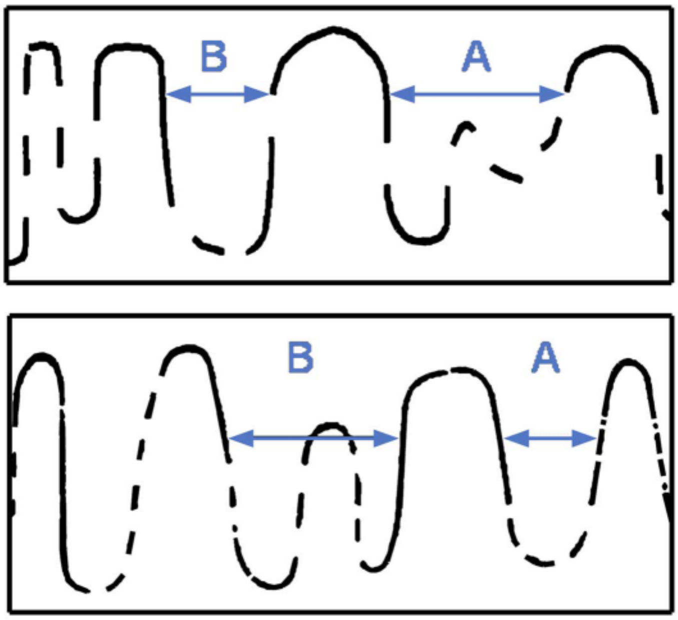

Figure 4. Climatic curves of the Cromerian complex. Reworked after Zagwijn (1985, 1998).

However, there is perhaps more clarity at the onset and probably the close of the Cromerian complex period. The first interglacial (Cromerian I) found in the Formation of Sterksel shows reversed magnetization, indicating a pre-Brunhes age. This interglacial is likely followed by a complex of climatic oscillations, not properly recorded in the continental record of The Netherlands. The last interglacial of the Matuyama reversed epoch can be related with enough confidence to OIS 21; approximately 850 ka. Therefore, if we assume that the first interglacial of the Cromerian complex is indeed the last interglacial in the Matuyama epoch, the lower boundary of the Cromerian complex is clearly established. Furthermore, the interglacial found in the Formation of Urk (Noordbergum, Roswinkel) can be seen as the upper boundary of the Cromerian complex. Once again, a relatively good dating point can be established due to the volcanic activity of the Eiffel region. An age between 380 ka and 430 ka points to a correlation with OIS stage11.

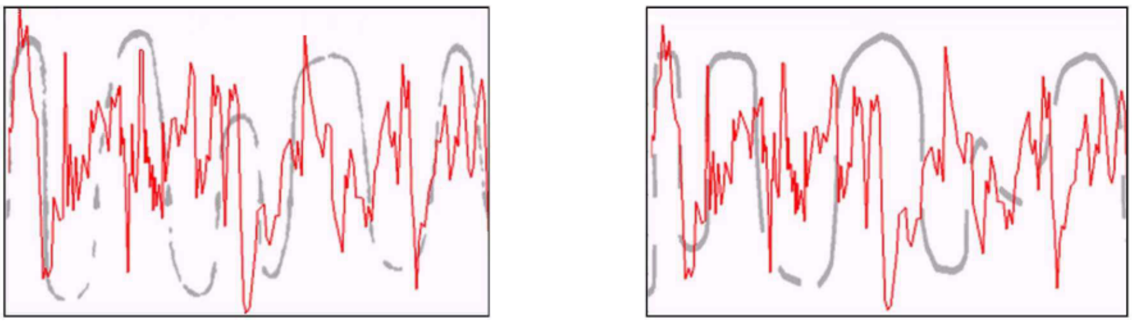

Figure 5. Oxygen isotope curve (Bassinot et al.*, 1994) superimposed on the climatic curve of the Cromerian complex. Reworked after Zagwijn (left, 1985; right, 1998).*

On the other hand, the climatic development between the beginning and the end of the Cromerian complex is by and large unknown. The only conclusion that can be drawn from the evidence published is that climatic oscillations have occurred. Duration, position and frequency of oscillations are unknown. The difficulty of position and duration of climatic oscillations is clearly presented in the changes of the climatic curve over time (Zagwijn, 1985, 1998), see also figure 4. When superimposing the climatic curves of Zagwijn (1985, 1998) with the oxygen isotope curve (Bassinot *et al*., 1994) it becomes clear that the climatic oscillations of the Cromerian complex are not known to any great extent (figure 5). While the first and last interglacials seem to fit well with the oxygen isotope curve, the intermediate climatic oscillations of Zagwijn cannot be correlated to any degree of confidence. By turning to the oxygen isotope stages, it is perhaps possible to postulate the climatic development of the Cromerian complex more accurately. According to Ehlers (1996: 5): “Deep-sea research has succeeded in establishing an almost complete Quaternary stratigraphy that records, at least in broad detail, the course of palaeoclimatical changes. Comparable long sequences in the continents are only provided by the long lake-deposit sequences. Time scale of deep-sea stratigraphy has been improved so that it must considered reliable for the last 1.5 million years. Thus the ocean sediments provide a Quaternary time scale to which the continental stratigraphies might eventually be fixed.”

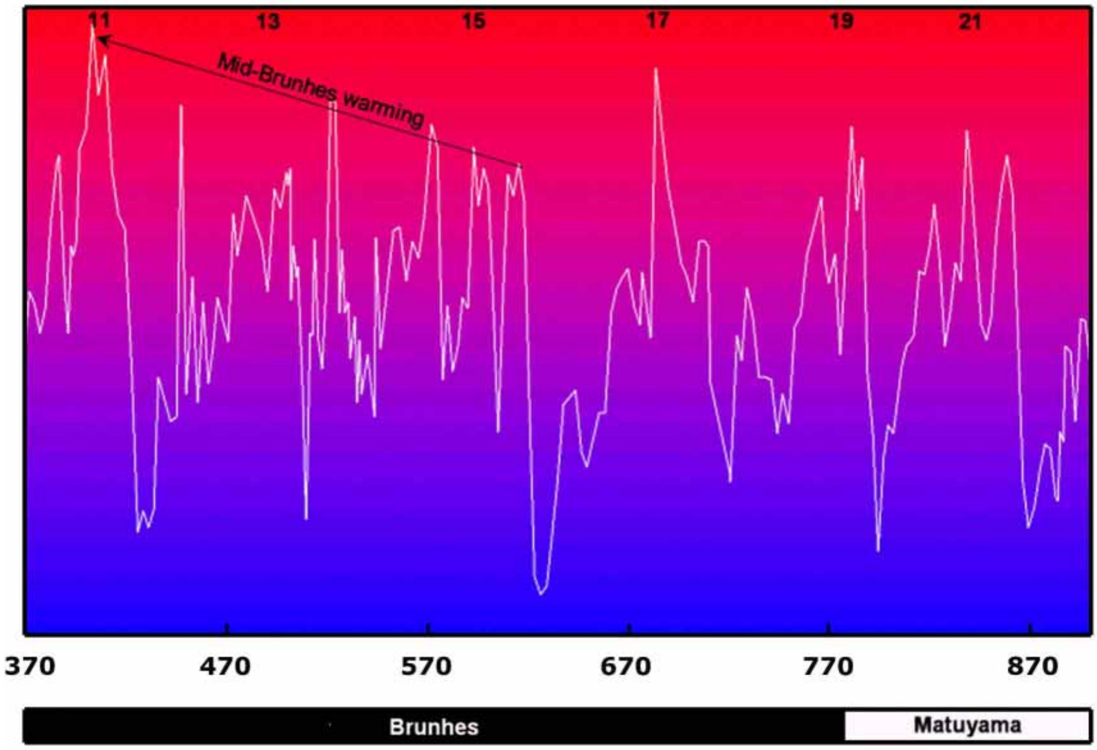

Figure 6. Oxygen isotope record of core MD900963. Reworked after Bassinot et al. *(1994).*

The oxygen isotope record is well-dated through both K/Ar and/or Ar/Ar dating as well as paelomagnetism. Deep sea sedimentation was continuous and is believed to have been of relatively even pace. As a result, the oxygen isotope record is extremely detailed, certainly compared to the continental record. Also, theoretical models seem to predict the curve of the climate surprisingly well (and in close relationship with the oxygen isotope curve), thus giving a theoretical framework for the palaeoclimate of the Pleistocene era.

A vast and global change took place around 0.9 Ma ago. Maasch (1988) found that the earth’s climatic system might have experienced a dramatic change, resulting in global cooling and an increase in ice mass. This mid-Pleistocene revolution (Berger *et al.*, 1994), has been correlated with isotope stage 22, the first large amplitude glaciation of the late Early Pleistocene, around 880 ka.

Before 0.9 Ma the 41 ka cycle of obliquity (tilt) dominated. The 100 ka periodicity of eccentricity rather suddenly dominated over the stronger precession and obliquity cycles after 0.9 Ma (Raymo *et al*. 1997). It is not clear if the first severe glaciation triggered the development of the 100 ka cycle or if it corresponded to a ‘threshold jump’ in a progressively evolving climate system in which the northern ice sheets had already initiated a new mode of oscillations (Bassinot *et al.,* 1997).

At present, it is still uncertain to which extend the oxygen isotope curve accurately reflects climatic developments on land. Although a clear relationship is established for the Late Pleistocene, this is not (yet) the case for the Early Pleistocene period. The Middle Pleistocene is relatively unknown, due to a lack of well-dated sediments from continental origin.

Over the time span of the classical Cromerian complex we can observe a division in an early phase (OIS 21 – OIS 16) with possibly two colder periods (OIS 20, OIS 16) and three warmer periods (OIS 21, 19 and 17).

OIS 18 seems of intermediate impact. The late phase (OIS 15 – OIS 11) is characterized by the mid/Brunhes warming (Berger *et al*., 1994), indicating an gradual warming of the climate over this period. A very short-lived ´cold´ stage (OIS 14) seems to be too limited to have had a pronounced impact on overall climate. OIS 12 is a more marked cold stage, possibly indicating a colder period on land too. This allows a relationship between the oxygen isotope stages and the climatic oscillations, as shown in table 2.

OIS	Climate	Cromerian
21	Warm	Interglacial I
20	Cold?	?
19	Warm	?
18	Intermediate?	?
17	Warm	?
16	Cold	?
15	Warm	?
14	Intermediate?	?
13	Warm	?
12	Cold	?
11	Warm	Noordbergum

Table 2. Possible climatic oscillations during the Cromerian complex.

The complete absence of absolute age points in combination with the fragmentary nature of the pollen sequences do not appear to yield reliable results with respect to the climatic development during the early Middle Pleistocene of The Netherlands. Contrary to the opinion of Zagwijn (1996), it is proposed that The Netherlands is not, and cannot be, a key area for determining the subdivision of the Middle Pleistocene. The sediments of this period do not provide sufficiently continuous pollen records or unambiguous dating.

The current naming convention for the Cromerian complex seems inadequate to sufficiently reflect the complex climatic oscillations during this period, since the oxygen isotope record clearly provides a better and more detailed basis. It is based on well-dated sediments and has global relevance, making it an absolute and objective yardstick, absent from the continental record in The Netherlands.

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