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A PRELIMINARY REPORT ON THE STRATIGRAPHICAL POSITION OF THE MATUYAMA-BRUNHES GEOMAGNETIC FIELD REVERSAL IN THE QUATERNARY SEDIMENTS OF THE NETHERLANDS

H.M. van MONTFRANS and J. HOSPERS[1])

ABSTRACT

Continental sediments of Quaternary age from the Netherlands have been investigated palaeomagnetically. The evidence available at present concerning the stratigraphical position of the Matuyama-Brunhes geomagnetic field reversal (0.70 m.y. ago) places this boundary in or directly above the "Cromerian" interglacial stage. It is known that in the Netherlands the "Cromerian" interglacial stage was preceded by and followed by three glacial stages.

INTRODUCTION

It is now generally accepted that the earth's main geomagnetic field has changed polarity periodically, the last reversal having taken place about 0.70 m.y. ago. It is therefore natural to look for palaeomagnetic evidence for this reversal in Quaternary rocks. Extensive investigations of Quaternary igneous rocks have already been carried out. The geomagnetic reversal time-scale that could thus be established has proven to be useful for geological correlation purposes, and so now the attention tends to focus on sediments. Much work on continuous deep-sea deposits has been done, but only a few studies of other Quaternary sediments have been published so far.

Rutten and Veldkamp (1964) have reported palaeomagnetic investigations in the well-known Tiglian clays in the Netherlands. They found both normal and reversed remanent magnetizations, but got the impression that the clays above and those below the reversal showed systematic mineralogic differences. Accordingly, they were doubtful about the significance of the apparent reversal encountered.

Noltimier (1967) obtained some evidence of a geomagnetic field reversal in the marine clay of Easton Bavents in East Anglia. He stated that the age of this clay was "Upper Lower Pleistocene (Cromerian)".

Extensive palaeomagnetic investigations in Quaternary and older sediments of Western Turkmenia, U.S.S.R., have been reported by Khramov (1960). Pleistocene sediments were found to be normally magnetized; below them there was a zone of reversed magnetization followed again by a zone of normal magnetization. The correlation of this sequence with the Pliocene and the Pleistocene of Western Europe is not known well.

THE GEOMAGNETIC TIME-SCALE

Reversals of the geomagnetic field had already been suggested before World War II by M. Matuyama and by P.L. Mercanton on the basis of their palaeomagnetic investigations of basalts. Interest in this subject revived when, in the 1950's, Roche (1953) working in France and Hospers (1953,1954) working in Iceland, independently demonstrated that there was much palaeomagnetic evidence in favour of the idea that the main geomagnetic field had repeatedly reversed its polarity. Their basic evidence was that palaeomagnetic studies of suitable rocks indicated the presence in the rocks of a sequence of alternating normal and reversed zones of

[1]) Division of Geophysics, Geological Institute, University of Amsterdam, The Netherlands.

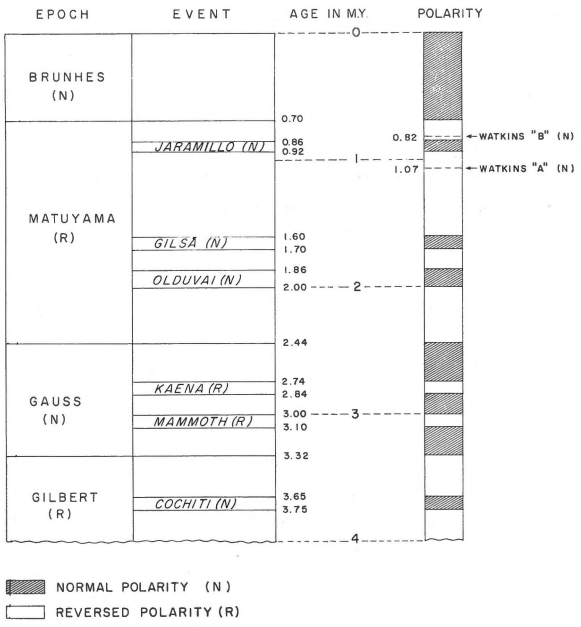


Fig. 1
Geomagnetic reversal time-scale after Cox (1968), Cox and Dalrymple (1967) and Cox, Doell and Dalrymple (1968). Also shown are two events of short duration (Watkins, 1968).

possible time-stratigraphic significance.

Further palaeomagnetic work on volcanic rocks, together with the application of K/Ar dating techniques has now yielded a well-defined and dated time-scale for geomagnetic reversals for at least the past 4 m.y.. Palaeomagnetic data from deep-sea sediment cores and the polarity data from investigations of sea floor spreading are also used in determining this time-scale, especially while extending it beyond the 4 m.y. already mentioned.

This time-scale is shown in Fig. 1 for the past 4 m.y.. It is based on data in Cox (1968), Cox and Dalrymple (1967) and Cox, Doell and Dalrymple (1968). The Olduvai normal event in the Matuyama reversed epoch has been found in several localities all over the world. It may, in fact, be a double event, but is shown as one in Fig. 1. The Jaramillo normal event is also well defined. K/Ar dates for these two events allow reliable estimates of their duration to be made. The reality of the other events is also accepted by many, as their existence is supported by evidence from sea floor spreading and deep-sea sediment cores. The uncertainties concerning the details of the time-scale need not be discussed, as they are not immediately relevant to the preliminary investigations reported here.

Also shown in Fig. 1 are the very short normal polarity events in the reversed Matuyama epoch for which Watkins (1968) has found evidence in deep-sea sediment cores. They have been designated as the events Watkins "A" (1.07 m.y.) and Watkins "B" (0.82 m.y.) in Fig. 1. These short events must still be confirmed, however.

It is quite well possible that additional events will be discovered in the future, but then probably of short duration. The Brunhes normal epoch is based upon 44 K/Ar ages of normally magnetized volcanic rocks (Cox, Doell and Dalrymple, 1968). Although these dates are reasonably well spread in time, it is possible that events with a duration of less than 0.05 m.y. may have remained undetected (Cox, 1968, p. 3259). This can also be said of the marine palaeomagnetic work done so far. Although, with one exception to be noted below, evidence of reversed events in the Brunhes normal epoch has not yet been found in marine deep-sea cores (cf. Glass et al., 1967; Phillips et al., 1968; Watkins, 1968), the resolving power of this method and of the studies of magnetic anomalies over oceanic ridges is not better than that of K/Ar dating, combined with palaeomagnetic work.

Two restrictions must be made explicitly in this context. The first is the exception noted above. It concerns the discovery of a short interval of reversed polarity in the upper part of the Brunhes normal polarity epoch, described from deep-sea cores by Smith and Foster (1969). These authors call it the "Blake event"; its boundaries are estimated to be 108,000 and 114,000 years old.

The second restriction concerns the evidence for a possible reversed event reported by Bonhommet and Babkine (1967) from palaeomagnetic investigations of volcanic rocks in France with an age of less than 40,000 years (Bonhommet, 1968).

These events, if confirmed, are so young, relatively speaking, that it would be impossible in our research to confuse them with the Matuyama-Brunhes boundary.

On the basis of the data shown in Fig. 1 and the above discussion, the present authors consider it a valid procedure to carry out a palaeomagnetic investigation of Quaternary sediments, work backwards in

HOLOCENE		
LATE AND MIDDLE PLEISTOCENE	WEICHSELIAN GLACIAL	Würm
	EEMIAN INTERGLACIAL	Riss-Würm
	SAALIAN GLACIAL	Riss
	HOLSTEINIAN INTERGLACIAL	Mindel-Riss
	ELSTERIAN GLACIAL	Mindel
	"CROMERIAN" INTERGLACIAL	Günz-Mindel?
EARLY PLEISTOCENE	MENAPIAN GLACIAL	Günz?
	WAALIAN INTERGLACIAL	
	EBURONIAN GLACIAL	Donau?
	TIGLIAN INTERGLACIAL	
	PRAETIGLIAN GLACIAL	
PLIOCENE	REUVERIAN	

Fig. 2
Stratigraphical table for the Netherlands and its correlation with the glacial and interglacial stages known from the Alps (simplified after de Jong, 1963, p. 408). The "Cromerian" interglacial stage is the subject of more detailed pollen-analytical investigations at the Geological Survey of the Netherlands.

time from the Holocene, and subsequently locate the Matuyama-Brunhes boundary where the first reliable palaeomagnetic evidence of reversed magnetization is encountered. Necessary conditions are that the coverage in time is sufficiently dense, that the first indication of a reversal is found at at least two different localities at about the same stratigraphical level and that confusion with the Blake or younger events is impossible. This is, in fact, the procedure applied to the Quaternary sediments of the Netherlands.

THE QUATERNARY SEDIMENTS OF THE NETHERLANDS

The Netherlands are situated in that part of the European continent which is affected by the subsidence of the North Sea Basin. Consequently, an almost complete sequence of Quaternary sediments is present in the subsurface of the country. At a number of places, sediments of Pleistocene and of Pliocene age are accessible at the surface in natural and artificial exposures. In the western part of the country the Quaternary sedimentary sequence consists of marine and fluvial deposits; their maximum total thickness is of the order of 600 metres.

Fig. 2 shows the stratigraphy of the Quaternary sediments in the Netherlands. This figure has been simplified after one given by d e J o n g (1963), who has written an excellent review in English of the Quaternary of the Netherlands. Fig. 2 shows that the Pleistocene of the Netherlands comprises six glacial stages, separated by five interglacial stages. The three youngest glacial stages (Elsterian, Saalian and Weichselian) are usually correlated with the Alpine Mindel, Riss and Würm ice ages respectively, although this correlation can in fact only be proved in the case of the Weichselian and Würm. It must be stressed furthermore, that in the lower part of the Middle Pleistocene the number of interglacials may be greater than has been hitherto assumed. Especially the correlation of the so-called "Cromerian" of the Netherlands with the typical Cromerian of East Anglia is uncertain, the more so as in the latter area an additional interglacial has been found below the Cromerian. This interglacial has been called the Pastonian (W e s t and W i l s o n, 1966) and must, according to pollen analysis, belong to the Middle Pleistocene (compare with Fig. 2).

The Pliocene-Pleistocene boundary in the Netherlands has been established in marine as well as in continental environments. Palaeontological investigations (v a n V o o r t h u y s e n, 1950, 1962; L a g a a y, 1952) showed that changes in the marine fauna reflected a marked cooling.

Pollen-analytical studies of the continental deposits in the Netherlands are far advanced. Z a g w i j n (1960) established the Reuverian-Praetiglian boundary in a number of places in the southeastern part of the Netherlands on climatological criteria, thus determining a well-defined Pliocene-Pleistocene boundary. Probably the oldest glacial period in Europe has been recorded here.

These two methods of determining the Pliocene-Pleistocene boundary have been succesfully applied to core material from the southwestern part of the country, in which a clay horizon of marine origin, containing pollen, was present.

Furthermore, two mammal faunae which can both be correlated with the upper part of the Villafranchian from Italy, have long been known from the Netherlands. They are the Tiglian fauna from Tegelen and the "black bones" fauna from the River Schelde estuary. The age of the Tiglian fauna is upper Tiglian, whereas the "black bones" fauna is thought to be derived from the lowermost Pleistocene deposits known in the Netherlands (d e J o n g, 1963).

It thus appears that the Pliocene-Pleistocene boundary in the Netherlands can be clearly recog-

nized. However, the precise correlation with the Plaisancian/Astian-Calabrian section in Italy has not yet been established.

METHODS OF INVESTIGATION

Up till now, only continental sediments have been investigated. Among these, clays and loams appeared to give useful results. The samples were collected from pits that are being worked as well as from a number of cores made available by the State Geological Survey (Rijks Geologische Dienst) at Haarlem.

In the field, samples were taken by means of a $1\frac{1}{2}$ inch square brass pipe, driven horizontally into the clay. The orientation of the pipe was measured, and the samples were packed in airtight plastic bags. In the laboratory specimen cubes of 46 cm^3 were cut from these samples by means of a violin string, and these were immediately treated with a solution of perspex in methylene-chloride, or varnished with polyester resin. The latter method proved to be the best way to prevent the samples from drying.

Most of the cores available were old ones and hence quite dry. Cubes of various sizes were cut from them after impregnation with perspex. One core was recently taken at Dordrecht, and the material was still wet. This core was sampled with a knife and the samples were kept wet until they were measured. Of the specimen cubes from the cores, only top and bottom were known, so that from them only the direction of the vertical component of magnetization could be obtained.

The measuring instrument used is an astatic magnetometer, built after a design of the Royal Netherlands Meteorological Institute at de Bilt (A s, 1960), with a sensitivity of 6 x 10^{-7} gauss. cm^3 per mm. scale. Samples were always measured in 24 positions before and during progressive a.c. demagnetization in fields of up to 300 oersted (peak value).

DISCUSSION OF RESULTS

A truly continuous palaeomagnetic record of the Quaternary sediments of the Netherlands cannot be obtained. The continental deposits often have hiatuses and are lithologically not always suitable for palaeomagnetic work. This second fact also applies to the marine deposits from the Early Pleistocene of the Netherlands. The approach therefore has been to obtain as many palaeomagnetic spot-readings (means of groups of samples) as possible at well-established stratigraphical positions.

The present preliminary results, shown in Fig. 3, comprise all results obtained so far, beginning with the Weichselian glacial down to the top of the Tiglian interglacial stage. The table shows the sediments sampled at each locality (pit or bore hole), their stratigraphical position, and the nature (normal or reversed) of the direction of magnetization encountered. This report being provisional, the amount of detail given on localities, quantity and lithology of material available, exact relative stratigraphical position of samples at different localities, and results of magnetic measurements is restricted to a bare minimum. Fig. 3 nevertheless shows that the Matuyama-Brunhes geomagnetic polarity reversal (0.70 m.y. old) probably must be placed in or directly above the "Cromerian" interglacial stage.

Three remarks must be made:

1) The stratigraphical position of the Matuyama-Brunhes reversal must be established more precisely. This problem is closely connected with certain stratigraphical problems concerning the "Cromerian" mentioned before. Normally magnetized sediments of "Cromerian" age have been found in two localities (see Fig. 3). The stratigraphical relation of these sediments to those from Dordrecht has still to be established more firmly, and more results from deposits of so-called "Cromerian" age must be obtained. We expect that the Matuyama-Brunhes boundary will be found within the "Cromerian" interglacial stage. Otherwise marked differences would appear between the palaeomagnetic results and those obtained by means of other absolute dating methods (see next section).
2) The Pleistocene sediments of younger than "Cromerian" age must be further investigated for palaeomagnetic evidence for a possible reversal. If such evidence would be found, the Matuyama-Brunhes boundary might then have to be placed at this younger level. We do not expect this to happen, because the spot-readings obtained up to now are reaonably well spread over this part of the stratigraphical column, and also because of the reason mentioned last in remark no. 1.
3) The possibility that in the "Cromerian" we are dealing with a so far undetected reversed event in

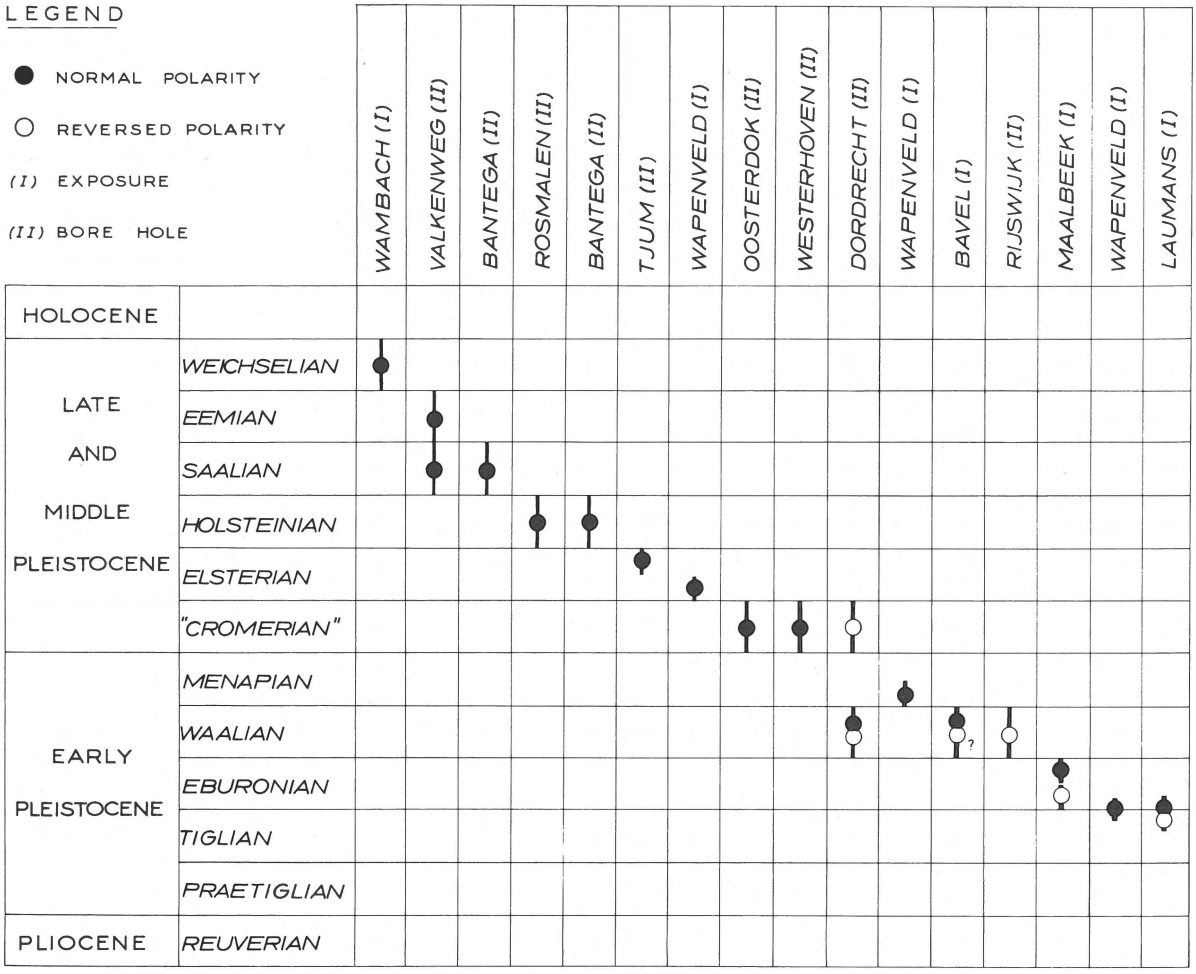


Fig. 3

Preliminary palaeomagnetic results. The locations of the sediments sampled have been plotted horizontally, the stratigraphical column vertically. The vertical bars above and below the polarity-symbols indicate the maximum limits of the stratigraphical range within which the samples can be placed. In Bavel possible evidence for a reversal has been found. However, this observation could not be confirmed because the sampling site was not accessible for a second visit.

the Brunhes normal epoch can not yet be excluded. The thickness of the clays of "Cromerian" age with reversed magnetization directions in the Dordrecht core is 18 metres. This value is, however, of little use in estimating the length of time represented by these clays, as we are dealing here with a continental deposition environment. The best way to exclude this possibility is to look for other material of "Cromerian" age showing reversed magnetization directions.

COMPARISON WITH OTHER ABSOLUTE AGE DETERMINATIONS

The "Cromerian" interglacial stage is tentatively assigned a minimum age of 0.70 m.y. on the basis of the palaeomagnetic data presented here. This may be compared with the following absolute age dating results, which were obtained by other workers by means of the fluorine method and by means of the K/Ar method applied to volcanic materials. It will be realized that the fluorine method is essentially a method for determining relative ages of mammal bones of younger than Pliocene age.

1) R i c h t e r (1958) used the fluorine method on fossil bones and found the following ages for material from Germany:
   Eemian interglacial : 0.06 m.y. and older.
   Holsteinian interglacial : 0.24 m.y..
   Cromerian interglacial : 0.64 m.y..
   Tiglian interglacial : 1.5 (± 0.3) m.y..
2) F r e c h e n and L i p p o l t (1965) used the K/Ar

method of radiometric dating on volcanic rocks from the Laacher See area in the Eifel. By correlating these rocks with the Rhine terraces, they found ages of 0.34 and 0.35 m.y. for the upper part of the "jüngere Hauptterrasse" and of 0.41 and 0.42 m.y. for the early part of the Günz ice age. Their result is in agreement with the 0.37 m.y. age, found by Evernden, Curtis and Kistler (1957) for the upper part of the "jüngere Hauptterasse". They also arrived at a maximum age of 0.57 m.y. for the lowest part of the "ältere Hauptterrasse".

It is probably fair to state that the absolute ages obtained by means of the fluorine method have been superseded by the K/Ar dates. This would remove strong internal discrepancies in the listed dates. Another important problem is the correlation of these absolute dating results with the stratigraphy of the Netherlands, which has been established mainly by means of pollen analysis. In this context it can be said, that the upper part of the "jüngere Hauptterrasse" (0.34 – 0.35 m.y. according to Frechen and Lippolt (1965)) can be correlated with the early part of the Elsterian glacial age. The stratigraphical position of the older dates, however, is not clear (W.H. Zagwijn, pers. comm.). Consequently, it is difficult to say whether our provisional result is in agreement with the absolute dates listed above. However, it can be stated that our result, if confirmed, would exclude a correlation of both the "ältere Hauptterrasse" and the "jüngere Hauptterrasse" (Frechen and Lippolt, 1965) with a stratigraphical level below the "Cromerian" in the Netherlands.

DURATION OF THE PLEISTOCENE EPOCH

We assume that the Pliocene-Pleistocene boundary in the Netherlands, which is based on climatological criteria, has been correctly located. We also assume that it more or less correlates with the Pliocene-Pleistocene boundary as established in the Calabrian type section in Italy.

If this is so, then the Pliocene-Pleistocene boundary in the Netherlands can be given an absolute age of approximately 2.0 m.y.. Glass et al (1967) made a micropalaeontological comparison between deep-sea sediment cores and the Calabrian type section, and carried out palaeomagnetic studies of these cores. They locate the Pliocene-Pleistocene boundary at the base of the Olduvai event, which is 2.0 m.y. old.

Similarly, Phillips et al (1968), using a geomagnetic reversal time-scale based on sea floor spreading and affecting a slightly different correlation, suggest an absolute age of 1.85 m.y. for the Pliocene-Pleistocene boundary. This agrees closely with Selli's (1965) independant estimate of 1.8 m.y. for the Pliocene-Pleistocene boundary.

From these results it may be concluded that if the Matuyama-Brunhes boundary may indeed be placed within the "Cromerian", the total duration in the Netherlands of the Late and Middle Pleistocene together is considerably less than that of the Early Pleistocene by itself. This supports a suggestion made by Zagwijn (1963, p. 174) to this effect. It also means that the first three glacial stages hitherto recognized in the Netherlands (Praetiglian, Eburonian and Menapian) nearly occupied twice as much time as the last three glacial stages (cf. Fig. 2).

FUTURE WORK

The present investigations are still being continued. Apart from further work towards defining the Matuyama-Brunhes reversal, work is also being done on the remaining older part of the Early Pleistocene and on the Pliocene. It is of great importance to obtain good coverage in time of the stratigraphical sequence involved, as well as to obtain as many data as possible from deposits of equal age in order to be able to deal with the various uncertainties inherent in this work.

It is hoped that these investigations can be extended succesfully down to the Pliocene-Pleistocene boundary. Fig. 3 shows that sediments of Menapian and Waalian ages have been found to possess normal magnetization directions. It is, of course, tempting to suggest that one is dealing here with the Jaramillo normal event in the Matuyama reversed epoch. However, the data available now are too few to be able to state this with any certainty.

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