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PERIGLACIAL PHENOMENA AND THE MEAN ANNUAL TEMPERATURE DURING THE LAST GLACIAL TIME IN THE NETHERLANDS

Abstract

This paper is an attempt to draw conclusions about the mean annual temperature during the last glacial time in the Netherlands. The data have been obtained by comparison of fossil periglacial phenomena and former environmental data with present-day features. Figure 10 shows the ultimate result together with curves derived from data of other disciplines.

INTRODUCTION

Although periglacial phenomena have for a long time attracted much interest, up until now it has only been possible to draw restricted conclusions about former temperature conditions. The last few years have seen an increased activity in the study of cold climates and recent cold climate processes, resulting in an important growth of knowledge of polar areas. On the other hand, from observations in good exposures and from other detailed geological studies, new data concerning periglacial features and circumstances during the Würmian are at our disposal from the Netherlands.

This paper is a summary of these phenomena especially with respect to the former mean annual temperature, derived from observations of present-day periglacial features. Numerous C^{14} datings made it possible to arrange the data in a chronological way and allow a comparison of the results with those obtained from other disciplines.

PERIGLACIAL PHENOMENA

(a) REMNANTS OF FROST MOUNDS

On the boulder clay plateau of the northern Netherlands hundreds of depressions occur. They are subdivided into shallow and deep ones (VEENENBOS, 1952). The deep depressions are characterized by a depth of more than 2 m and are surrounded by

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small ridges. These ramparts consist of loamy material with gravel and have heights of less than 1.5 m. The depressions are round to oval in form. They are associated with a corresponding hollow underlying boulder clay, which has a maximum diameter of 300 m (MAARLEVELD & VAN DEN TOORN, 1955). They are found either in the erosion valleys and their slopes or on the highest parts of the landscape. The floor of the depressions has a hollow form. Depths of more than 6 m are common. In only one

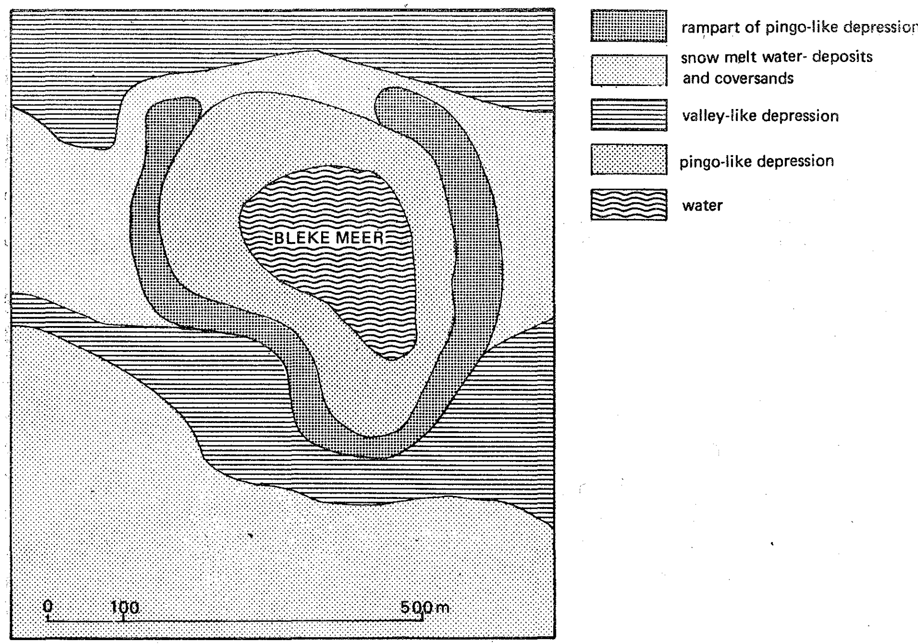


Fig. 1. Pingo-like depression near Uddel (Veluwe) according to data of C. J. M. KRAANEN and J. C. PAPE (1965)

case was such a depression filled with peat of Eem age found (WIGGERS, 1955; ANKER VAN SOMEREN, 1951). The material in all of the other depressions is younger than the Middle Pleniglacial (PLOEGER & GROENMAN VAN WATERINGE, 1964; TER WEE, 1966). The absence of Eemian peat in the depressions and the occurrence of a surrounding ridge consisting of non-aeolian material are the main arguments for a pingo origin. The ramparts should then be interpreted as pieces of pingo skin, that slid or were washed down during thaw (MAARLEVELD & VAN DEN TOORN, 1955). It seems probable, from the occurrence of disturbed layers, that a part of the ramparts was formed by pressure during the growth of the ice.

In the Central Netherlands there are also several round depressions but only a few have a rampart. Two of these are larger than those in the Northern Netherlands and furthermore have ramparts which are somewhat higher (Fig. 1). Their depth is more than 7 m. The subsoil of the depressions is covered by a layer of lake marl, dating from Older Dryas time (POLAK, 1953, 1963).

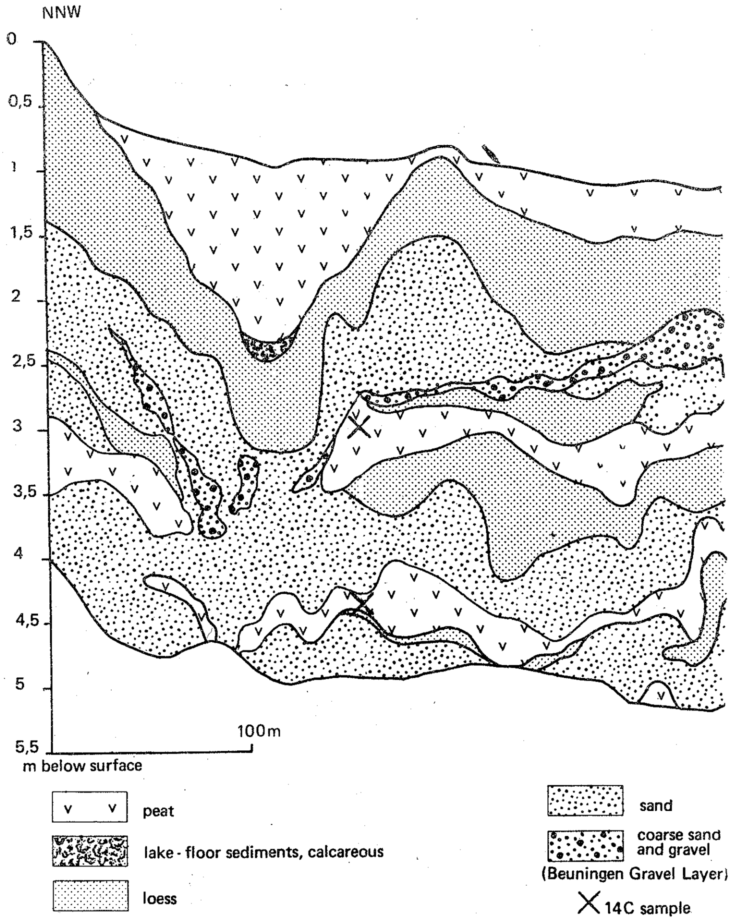


Fig. 2. Profile of the pingo-like depression near Bruuk (Nijmegen) according to data of J. F. BANNINK and J. C. PAPE (1968)

Another depression with a rampart in this part of the Netherlands (see fig. 2) gives more information about the time of its genesis. The lower peat layer has been dated by C^{14} and has an age of 37,040 $^{+1750}_{-1450}$ years (GRN 6200). The peat layer, at about 3 m below the surface, is only a little younger (34,660 $\pm$870 years, GRN 6199). The disturbed position of the peat layers indicates a growth of the frost mound after the peat formation. The same is true for the layers of loess and for the overlying gravel layer (Beuningen Gravel Bed). On the other hand the youngest loess is not disturbed. Moreover this layer of loess covers the depression and the rampart, which is lying on the Beuningen Gravel Bed. Consequently the depression came into existence after the formation of the Beuningen Gravel Bed and before the deposition of the youngest loess, also in the Upper Pleniglacial (see table I).

If the explanation of the depressions as pingo remnants is correct, the mean annual temperature during the time of their formation was no more than $-2°$C (BROWN &

Table I

Stratigraphy of the last glacial time

Lithostratigraphical units	Chronostratigraphical units			
			Holocene	
Younger Coversand II	Late Dryas Stadial		Late Glacial	Würmian (Weichselian)
Usselo Bed or Soil	Allerød Interstadial			
Younger Coversand I	Earlier Dryas Stadial			
Lower Loamy Bed	Bølling Interstadial s.l.			
Older Coversand II		Upper	Pleniglacial	
Beuningen Complex				
Older Coversand I				
sands		Middle		
peat bed or loamy bed	Denekamp Interstadial			
sands				
peat bed or loamy bed	Hengelo Interstadial			
sands				
peat bed or loamy bed (complex)	Moershoofd Interstadial			
loamy coversand		Lower		
sand-gravel and coversand beds				
loamy coversand				
loam, peat and sand beds	Odderade Interstadial		Early Glacial	
	Børup Interstadial			
	Amersfoort Interstadial			

PÉWÉ, 1973). This must have been during the Upper Pleniglacial. Taking into consideration the size of the depressions, it is doubtful whether conclusions about the duration of growth can be drawn. According to J. ROSS MACKAY (1973) pingos tend to grow higher rather than both higher and wider. The size and shape of a residual pond exercises a strong control upon size and shape of the pingo which grows within it.

There is a great difference in height between the ramparts in Wales, Belgium and the Netherlands. The highest ramparts in Wales are 7 m (WATSON, 1974). The highest ramparts in Belgium (at an altitude of about 600 m) are about 5 m (PISSART, 1974) and in the Netherlands they are not higher than 1.5 m. Whether or not these differences can be explained by climatic conditions is unresolved.

(b) FROST FISSURES

Frost cracks or sag fissures are characterized by a fairly uniform width of less than 10 cm and by a polygonal pattern. The material filling the fissures mostly shows a vertical lamination with a downwarping of the adjacent layers. In a few cases, very small faults have been formed along which sandy material subsided. This type of fissure belongs to the first type in ROMANOVSKY's classification (1973), the so-called fissures with secondary seasonal infilling. They occur in both the seasonally frozen soil and in the active layer. Frost fissures are described as forms which decrease rapidly downwards in width and have a primary polygonal pattern, with diameters mostly exceeding 7 m (DYLIK & MAARLEVELD, 1967). Frost cracks and frost fissures are transitional. Nevertheless most frost fissures in the Netherlands posses a vertical lamination. They belong also to the first type of ROMANOVSKY and are formed without permafrost. Fossil frost fissures occurring in permafrost — the pseudomorphoses left by fissure ice — are rather seldom. Up until now they have been only found in two horizons. The oldest horizon with this type of fissures is older than the Moershoofd Interstadial (see table I) and younger than the Early Glacial time. The age of this zone has been assessed by WYMSTRA & VAN DER HAMMEN (1974) as ca. 70,000 years. The youngest horizon with fossil ice fissures formed in permafrost is younger than the Denekamp Interstadial and older than the Bølling time. It is of about the same age as the Beuningen Complex. The maximum width of the fissures is ca. 40 cm and they are more than 2 m deep. They are characterized by the downbending of the sedimentary layers at their place of contact with the fissure, by distinctly developed faults, and by a typically disordered arrangement of the infilling material. Figure 3 is an example of a fossil ice fissure in the Beuningen Gravel Bed. After the greatest part of the fissure ice had melted, the ensuing depression became filled with coarse sand. The deposit is younger than the layer in which the frost fissures were formed (Beuningen Gravel Bed I) and therefore belongs to the Beuningen Gravel Bed II. According to BROWN & PÉWÉ (1974) in Alaska, the ice wedges are typical of areas having a winter ground surface temperature of less than −15° C and an annual temperature of −6° C or less. It is important, in relation to the erosion by snow meltwater, that they are also typical of zones with continuous permafrost. GOŹDZIK (1973) also maintains

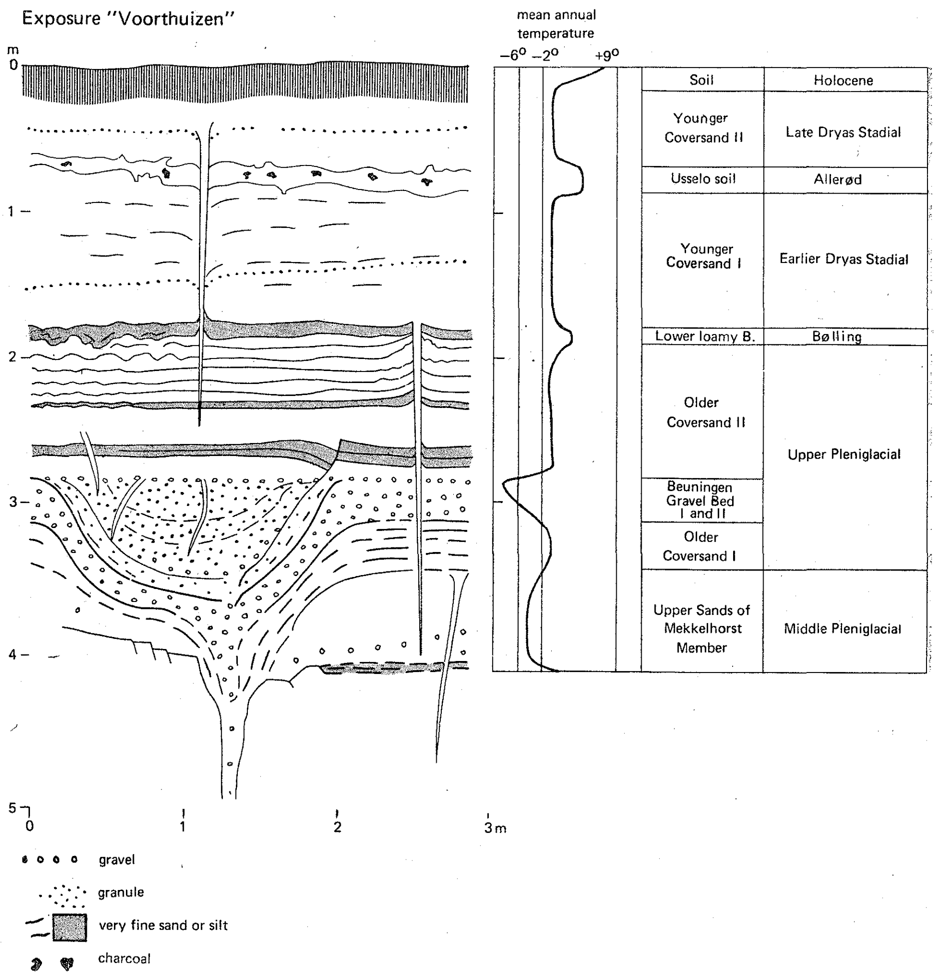


Fig. 3. Diagrammatic section of a part of a sandpit near Voorthuizen

that for Poland the mean annual temperature during the formation of permafrost was lower than −6° C (see also ROMANOVSKY, 1973, pp. 270-1). The section of a sand pit near Voorthuizen (Province of Gelderland) also shows frost cracks in the deposit underlying the Older Coversand I. The same figure also shows the sandy deposit between the Hengelo and the Denekamp Interstadial (ZAGWIJN, 1974). In the deposit between the Moershoofd and the Hengelo Interstadial rather well developed frost fissures occur (ZAGWIJN, 1961). The best investigated ones occur in deposit younger than the Allerød and are also most probably of Late Dryas age. The map (see fig.4) showing the occurrence of these features in Western Europe has been compiled from various sources. The data from the Netherlands and Sweden were collected by VAN DER TAK-SCHNEIDER (1968), (see also SVENSSON, 1974), from Scotland by GALLOWAY (1961), from Norway by MANGERUD & SKREDEN (1972), from Finland by DONNER,

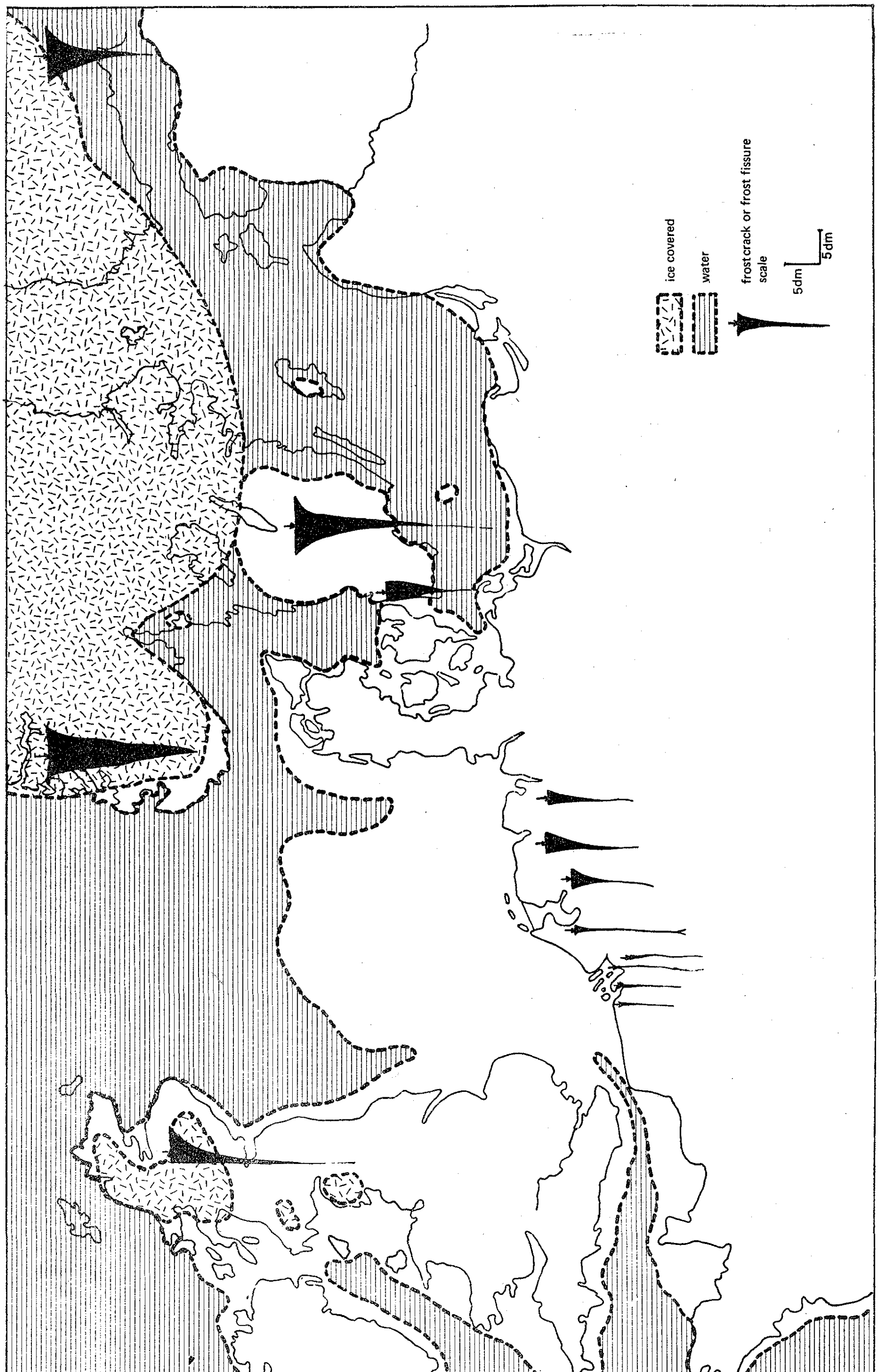


Fig. 4. Frost cracks and frost fissures of Late Dryas age compiled from various sources

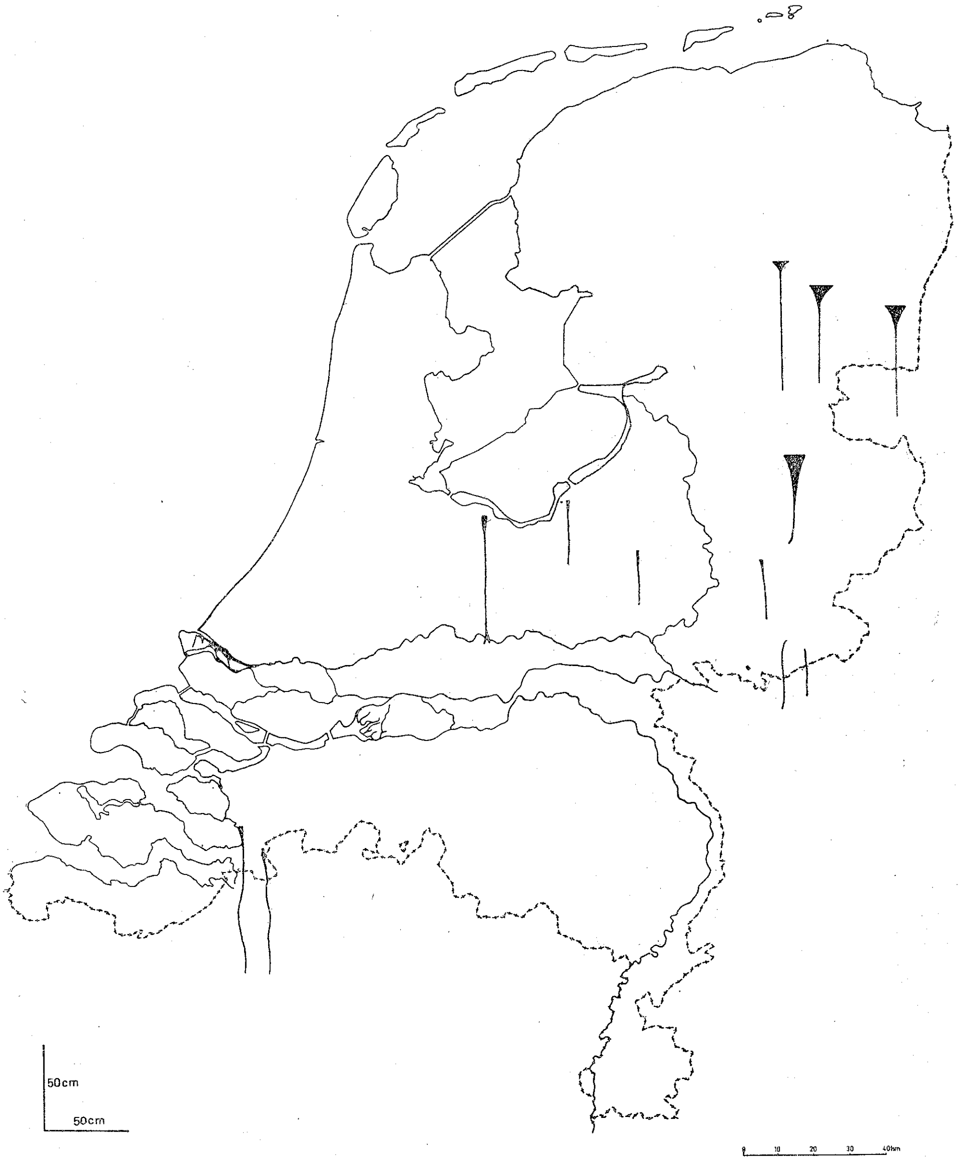


Fig. 5. Widest frost cracks and frost fissures of Late Dryas age in the Netherlands (V. VAN DER TAK-SCHNEIDER, 1970)

LAPPALAINEN & WEST (1968), and from Belgium by Dr. E. HEYSE (oral communication). According to GOŹDZIK (1973) frost fissures did not occur at this time in Poland. No data were available from Ireland, Wales, England or Denmark and there is only one observation from Germany Federal Republic. Nevertheless the distribution gives a good impression of the way in which the width of the fissures decreases southwards.

In the Netherlands (see fig. 5) these frost features have been observed in aeolian material (coversands), especially in the coversand ridges. They are found between 30—150 cm below the surface and are not always in the same horizons. The occurrence of the cracks in pure aeolian sands precludes formation by dehydrational contraction and an explanation by thermal contraction is therefore plausible. The existence of these features in sand ridges points to a formation at locations which had no or only a small amount of snow cover. The position of the cracks or small fissures near the surface and the vertical lamination of the infilling material clearly can be explained by their formation in a seasonal frost layer. South of the river Rhine the cracks of Late Dryas age are very infrequent while those of Older Dryas age are more common. This means that the Older Dryas time was a little colder than the Late Dryas time (see also GOŹDZIK, 1973). With one exception of 3 m in the middle part of the Netherlands, the depth of cracking was no more than 2 m, so that it may be assumed that the depth of seasonal frost penetration was at least of the same order of size. By means of the Stefan equation it is possible to determine approximately the minimum freezing index (see YONG & WARKENTIN, 1966). Given this equation: $x = 48k_fF/L$

where: x — depth of frost penetration,
k_f — thermal conductivity,
F — freezing-index mean surface temperature during freezing period,
L — 1.434 wy_d,
w — water-content in %, and
y — dry density,
with the following values:
$k_f = 0.9$, $w = 10\%$, $y_d = 100$ lb/ft^3 and $x = 2.5$ m.,

the freezing index is 2230.

This is value lying outside the limit of permafrost and existing today, for example, in Northern Scandinavia (see plate 6 in CORTE, 1969). The same picture has been found by many investigators. In Iceland and Northern Scandinavia frost cracks and small fissures are found in regions with a mean annual temperature of —1°C or 0°C FRIEDMAN *et al.*, 1971; SVENSSON, 1969; SEPPÄLÄ, 1966). COSTIN & WIMBUSH (1973) record the presence of this phenomenon even at a mean annual temperature of about 3°C in the Snowy Mountains, Australia. According to ROMANOVSKY (1973) mean annual temperature just below and also above 0°C, under conditions of very high temperature gradients in the subsurface horizont, may favour the formation of a network of shallow fissures. When occurring in the deposits of the middle part of the Netherlands a mean annual temperature of 0°C has been adopted for the narrow type of this frost crack phenomenon. In relation to the width of the transitional type to the fossil ice wedge formed in permafrost, values have been accepted of between 0°C and —6°C.

(c) CHAOTICAL DEFORMATIONS

At some places there are 2 zones with chaotical deformations of peat, clay, loam and sandy layers to a maximum depth of ca. 2 m. This phenomenon occurs especially in places where there is a great diversity of material, with strongly divergent grain size, which is at least partly, frost susceptible. This type of deformation is mainly found in the flat and low lying parts of the landscape. Most probably, the layer with this type of deformation represents the active layer and has been formed by differential frost penetration. EDELMAN, JESWIET & FLORSCHUTZ (1936) described these forms as a kind of cryoturbation. Figure 6 is an example of the two zones. The zone with the oldest deformation is older then the Moershoofd Interstadial (see table I), whereas the contorted peat layer has an Early Glacial age. These facts favour an age similar to

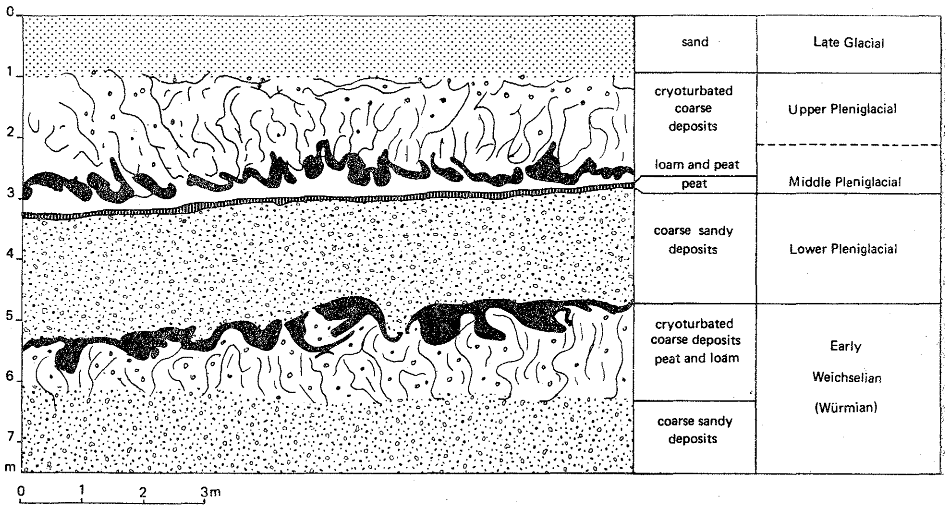


Fig. 6. Sandpit „Heideroos", near Eerbeek (Veluwe)

that of the oldest zone of the fossil frost fissures occurring in permafrost. The upper zone in the sandpit (fig. 6) is older than the Beuningen Gravel Bed II and younger than the Moershoofd Interstadial. Most probably the deformation took place at about the same time as the formation of the youngest fossil frost fissures formed in permafrost. If this is true these zones with deformations represent the then active layer; this points to a mean annual temperature less than —2° C.

(d) REGULAR DEFORMATIONS

The forms of this type are characterized by a regular pattern. The most typical member of this group has in vertical section a droplike form. In the Netherlands they are described by VAN GALEN (1943) and in Germany by STEUSLOFF (1952). The infilling material consists of peat, loam or clay and to a lesser extent of sand. A horizontal section shows a polygonal pattern with diameters of more than 10 cm. Uncovering the surface results in an arched top (FLORSCHÜTZ & VAN DER VLERK, 1938) and reveals a structure resembling close-fitted pillows (SCHMID, 1953; see also WASHBURN, 1969: fig. 84). In section the deformations resemble the cross section of non-sorted polygons shown by WASHBURN (1969: fig. 85 and 86). The maximum depth of these structures extends 2 m below the surface of the periglacial sediments, but they vary in length between 2 m and 15 cm. The form is related to deposits formed under severe circumstances and has never been recorded in Holocene deposits. For example WIGGERS (1955) investigated the walls of ditches with a depth of 1.4 m over a length of 1500 km in the Holocene deposits of the Noordoostpolder and never found the drop-like structure. Drop-like structures are found in the Middle Pleniglacial (for example in the deposit between peat layers of circa 50,000 years and 45,000

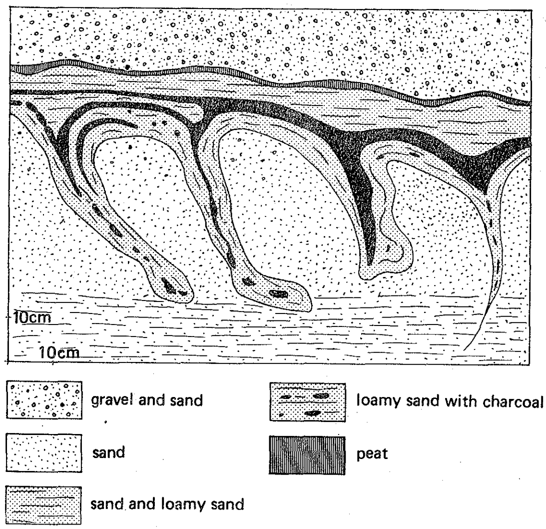


Fig. 7. Profile in sandpit „De Goudvink" near Uchelen (Veluwe)

years at Eerbeek, as well as in the Upper Pleniglacial deposits. They are rare in the Late Glacial sediments. An example from the Late Dryas time is shown figure 7. The charcoal found in the infilling has an age of 11,010 $\pm$ 120 years (GRN 907) and can thus be placed in the Allerød. The undisturbed peat layer was formed during the beginning of the Late Dryas time (VAN DER HAMMEN & MAARLEVELD, 1952).

According to WILLIAMS (1961) the development of patterned ground depends on the proximity of the mean annual temperature of ca. 0°C, and the mean annual air temperature of ca. + 3°C is suggested as marking the upper limit of its development.

ENVIRONMENTAL DATA

(e) MELTWATER RUN-OFF

The above mentioned data point to the existence of continuous permafrost during two periods in the Würm and to discontinuous permafrost at other times. It is of interest to trace the influence of these types of permafrost in relation to the rate of snow meltwater run-off. Continuous permafrost is especially typical of regions of low snowfall. In the region with so-called polar climates (TROLL, 1964) there are even areas such as Sandflugtdalen, East Greenland (HANSEN, 1970), the far northern islands of Canada, Northern Greenland and McMurdo Sound, Antarctica (WEYANT, 1966), where a scanty precipitation during the winter results in a nearly bare surface.

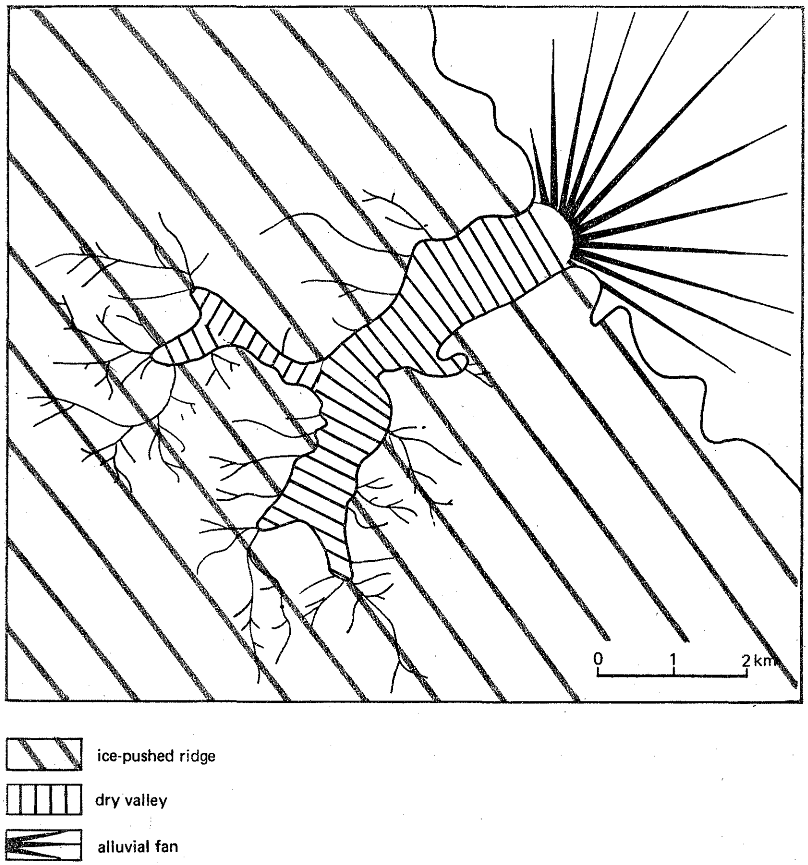
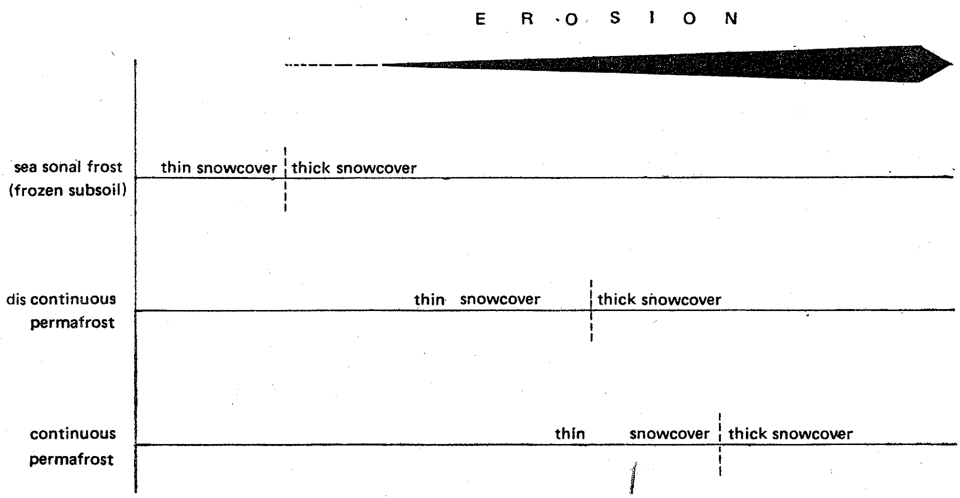


Fig. 8. Alluvial fan and dry valleys near Eerbeek (Veluwe)

Furthermore an important part of the snow disappears by sublimation (WEYANT, 1966). A typical feature of these regions are sand wedges (PÉWÉ, 1974). The absence of this type of frost fissure in the Netherlands, however, points to a climate with more snow during the coldest parts of the Würm than the above mentioned areas have today. This is also born out by the chaotical and regular deformations. An estimation of the amount of precipitation is not possible and furthermore the quantity would not always have been the same during all parts of the Würm. Morever, snow melting would have only resulted in erosion if it flowed over material on a sufficiently steep slope. Favourable circumstances were provided by the ice-pushed

Table II

Kinds of valley erosion in ice-pushed ridges, frost and snow cover



ridges in the central part of the Netherlands. Many dry incised valleys are found here with immense alluvial fans in front of them (see fig. 8). The material of these fans lies on material of Eem age and the overlying sand is from the Late Glacial time, which means that erosion took place during the Würm. As the material of the ice-pushed ridges consists of coarse sandy deposits, the erosion was only possible by snow meltwater run-off over frozen subsoil. The strongest erosion was possible during times with continuous permafrost; relatively less erosion would have occurred during times of discontinuous permafrost and the least amount during winters rich in snow, with a seasonally frozen soil and a poor (heather) vegetation (see table II).

Considered regionally, there are two main layers with coarse components of Würm age. The oldest coarse layer belongs to the Lower Pleniglacial and the youngest one to the Upper Pleniglacial. The last mentioned layer is called the Beuningen Gravel Bed (VAN DER HAMMEN *et al.*, 1967; VAN DER HAMMEN, 1971; ZAGWIJN & PAEPE, 1968). The coarse layers conform with the upper part of the fossil ice wedges, formed in permafrost (see fig. 3). The deposits are as old as, or a little older than the formation of the ice fissures. Taking into account the erosive power needed for the deposition of the coarse material, probably at least a part of the coarse layer was deposited during the presence of continuous permafrost.

More sandy snow meltwater deposits are common in the stadials between the Moershoofd and the Hengelo Interstadials, between the Hengelo and the Denekamp Interstadials and in a period following the Denekamp Interstadial (VAN DER HAMMEN, 1971; ZAGWIJN, 1974). There are frost fissures, of a different size, of the secondary seasonal infilling type in these deposits. Taking into consideration the erosion (see table II) it probably points to the existence of discontinuous permafrost.

Snow meltwater deposits of local origin are known from the Late Dryas time, but it is not correct to draw the conclusion from those that a local permafrost existed. The presence of snow together with a seasonally frozen subsoil and a poor vegetation would have been sufficient to explain this erosion.

(f) AEOLIAN DEPOSITS

The infilling of the dry valleys with aeolian deposits means an absence of erosional activity. It is possible to explain this fact by the occurrence of very dry conditions. In the aeolian deposits there are only narrow frost cracks of the secondary seasonal infilling type. This is true of both the Older and Younger Coversands and applies to the youngest loess since in the Netherlands a transition occurs between the Older Coversands and loess deposits. Taking the occurrence of only this type of frost crack into consideration, the deposition of the loess without permafrost is not quite impossible. Of interest here, is the observation of RICHMOND (1962) in the La Sal Mountains (Utah), that maximum loess accumulation took place during the recessional stages of a glacial advance.

The Older Coversand I is older than the Beuningen Gravel Bed (see table I). According to VAN DER HAMMEN (1971) there are indications of fluviatile activity in the lowest part of this deposit. This gradual diminution of erosional activity is not in contradiction with the disappearance of permafrost near the surface. The Older Coversands II and the Youngest Loess together with the infilling material of the ice fissures overlie the Beuningen Gravel Bed. The collapse of the infilling material and the lowest part of the Older Coversands II (see fig. 3) points to a melting of the last remains of fissure-ice during the deposition of the Older Coversands II. Furthermore the great similarity of the Older Coversands I and II is in favour of a genesis during the similar climatic circumstances. Only narrow frost cracks are common in these deposits. In addition, these deposits are younger than the pingo remnants (BISSCHOPS, 1973; TER WEE, 1966) and the dry valleys (VINK, 1949). These facts point to a deposition without permafrost. The same is true for the Younger Coversands which also contain small frost cracks (see fig. 3). Although the distribution of ventifacts in the Netherlands is well known (SCHÖNHAGE, 1969), the time of their formation is still under investigation and it is not as yet possible to draw any conclusions.

(g) PEAT LAYERS

Peat layers are found both in alluvial fans and depressions. Peat layers of Early Glacial age are important in the Gueldern Valley (ZAGWIJN, 1961). They at least indicate a stagnation in the rate of erosion. They are also important in the Middle Pleniglacial and, especially, in the Moershoofd Interstadial. In the Hengelo Basin the peat of this age is in contact with the ice-pushed ridge (see ZAGWIJN, 1974). The same situation occurs near Amersfoort (ZAGWIJN, 1961). TEUNISSEN & TEUNISSEN-VAN OORSCHOT (1974) also found a peat layer of this age lying in a shallow valley of an alluvial fan near Nijmegen. KOLSTRUP (1975) found the same position of peat layers of ca. 45,000 years and ca. 50,000 years in an alluvial fan near Eerbeek.

Until now only one younger peat layer in an alluvial fan has been found. The peat was only a few cms thick and was formed at the beginning of the Late Dryas time (VAN DER HAMMEN & MAARLEVELD, 1952). This peat layer is shown in fig. 7. The existence of peat layers in alluvial fans indicates a total absence or very restricted occurrence of snow meltwater erosion. Very dry conditions are contrary to the growth of peat and indicate a lack of ground-ice. Arguments for slightly better climatic conditions during the Moershoofd Interstadial can also be drawn from pollen-analytical data, and those are in agreement with data on insect faunas in deposits dating from approximately 43,000 years ago (COOPE, 1972). Taking into account the altitudes of the Holocene peat layers at the fringe of the ice-pushed ridge and the occurrence of peat layers on the same level in the alluvial fan near Eerbeek, the possibly important influence of seepage, in the absence of permafrost, has not been excluded.

MEAN ANNUAL TEMPERATURE

(h) LOWEST MEAN ANNUAL TEMPERATURE

The fossil ice fissures formed in permafrost as well as the occurrence of continuous permafrost provide information only about the maximum mean annual temperature. To determine the minimum value it is important to know the southern limit of the permafrost. The relevant data for the reconstruction of this limit are mostly related to the fossil frost fissures and frost cracks (see fig. 9), because these features can be identified with permafrost. As a matter of fact they are mostly approximately confined to a mean annual temperature of max. 0° C. Nevertheless, due to a lack of good data a mean annual temperature of −2° C has been taken. The frost cracks are used in fig. 9 and the southern limit thus shown is approximately the same as that mentioned by KAISER (1960), TRICART (1956) and TRICART & CAILLEUX (1967). According to these authors the southern limit of permafrost crossed the Vendée and also coincided with the recent mean annual temperature of about 12° C. If this is true there was in this part of France a maximum decrease of the mean annual temperature of −2 to +12° C = 14° C. Taking into consideration the distribution of the fossil ice wedges formed in permafrost (mean annual temperature −6° C or less) and found by WILLIAMS (1969), the position of the southern limit in England coincides with the recent mean annual temperature of 10° C. According to these data the lowering of the mean annual temperature could have been about −6 to +10° C = 16° C. According to data of MICHEL (1975) the fossil ice wedges formed in permafrost are rare in the neighbourhood of Paris. Consequently, in this part of France the southern limit also coincides with a recent mean annual temperature of 10° C, resulting in a maximum lowering of 16° C.

The influence of the inland ice on the climate was greater in England than in the middle part of France, but it was about the same in England as in the Netherlands.

The recent mean annual temperature of the Netherlands is ca. 9° C. Applying the results from England to the Netherlands, there was a minimum mean annual temperature of about −7° C.

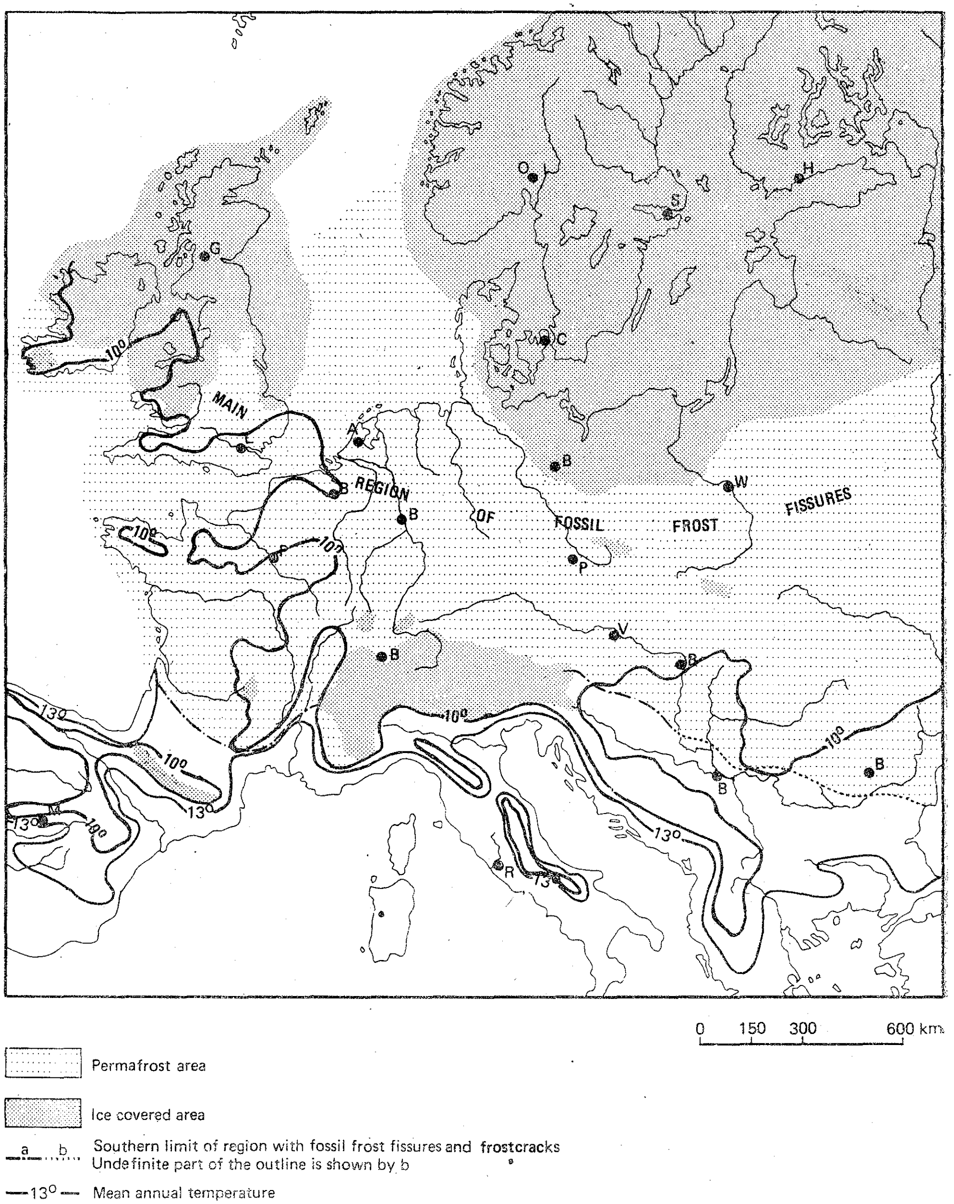


Fig. 9. Map of the area with permafrost during the Würm time, compiled from various sources.

It is also interesting to take into consideration data concerning the altitude of recent and fossil patterned ground from Würm time. According to TROLL (1944) and TRICART & CAILLEUX (1967), the lower limit for the formation of patterned ground in the Pyrenees is about 2600 m. Patterned ground from Würm age is found as far as Tarbes (altitude ca. 300 m), according to a map of TRICART (1956). If patterned ground does not occur at a lower altitude in this region, and taking into account a reduction of 0.65° C for every 100 m, it results at this point in a lowering of temperature of ca. 15° C. This is about the same as the value suggested by the southern limit of permafrost drawn in fig. 9.

(i) THE CURVE

Summarizing the data obtained, the mean annual temperature suggested by the presence of various features is:

ice frost fissures in permafrost: max. −6° C
small seasonal frost cracks: about 0° C
other seasonal frost cracks between 0° C and −6° C
pingo remnants: max. −2° C
chaotic deformations: max. −2° C
regular deformations: max. 0° C
extensive coarse snow meltwater deposits: between −7° C and −5° C
extensive sandy snow meltwater deposits: between −5° C and −2° C
local sandy snow meltwater deposits: more than −2° C

By means of several C^{14} datings it is possible to arrange these data and those mentioned in (a) to (h) in a chronological way. The result is shown in fig. 10. Between ca. 28,000 years and ca. 13,000 years B. P. C^{14} data are missing. Therefore, it is not possible to assign the correct position to the minimum mean annual temperature and so on. However there are some possibilities. Possibility *a* (fig. 10) is obtained by using the data of WYMSTRA (1969) in relation to the cold time after 28,000 years and to the coldest time between 30,000 and 10,000 years. Possibility *b* has been compiled by using data of GEYH (1970 *in*: WOLDSTEDT & DUPHORN, 1974), MANIA & STECHEMESSER (1970) and ZUBAKOV (1975).

If we compare the curve from 50,000 to 30,000 years ago, the warmer time around 50,000 years B. P. is broadly the same as that found by DANSGAARD *et al.* (1971) and by MCINTYRE (1972), but the data about the amelioration of ca. 45,000 years ago do not apply in this case. The deterioration of ca. 42,000 years ago has been found by DANSGAARD *et al.* (1971), WYMSTRA (1969) and VAN DER HAMMEN *et al.* (1967) and the one of ca. 34,000 years ago by SANCETTA *et al.* (1973), WYMSTRA (1969), VAN DER HAMMEN *et al.* (1967) and with some restrictions by DANSGAARD *et al.* (1971) and HAESAERTS (1974). More resemblance is found around 30,000 years ago. Here all the curves show a distinct amelioration of the climate.

From 30,000 years ago to 10,000 years ago possibility *a* shows a colder part ca. 27,000 years ago. The same ascillation was not only found by WYMSTRA (1969) but also by DANSGAARD *et al.* (1971), SANCETTA *et al.* (1973) and HAESAERTS (1974, see also HAESAERTS & VAN VLIET, 1975). WYMSTRA's last cold time of ca. 13,000 years ago was mentioned by SANCETTA *et al.* (1973) and MCINTYRE *et al.* (1972).

Possibility *b* exhibits a little warmer time ca. 20,000 years ago. It corresponds to the climatic ameliorations mentioned by DANSGAARD *et al.* (1971), MCINTYRE *et al.* (1972) and HAESAERTS (1974). The coldest part of the curve round 17,000 years ago

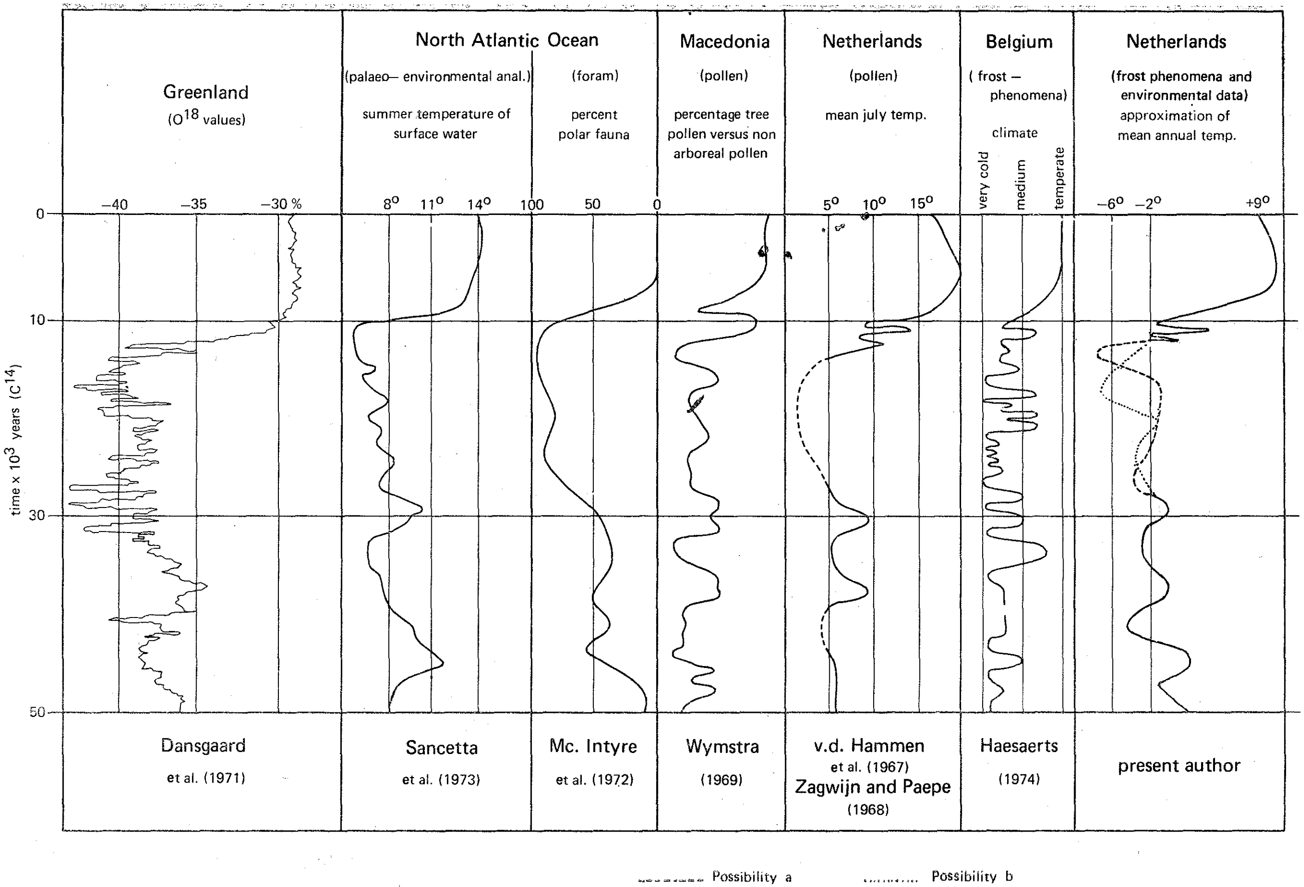


Fig. 10. Attempt of correlation of different climatic curves

was ascertained by DANSGAARD *et al.* (1971) and VAN DER HAMMEN *et al.* (1967) and corresponds to the retreat of polar waters from the western coast of Southern Europe. However, it is premature to draw conclusions from these comparisons and therefore further investigations are necessary to obtain more clarity.

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