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LOCATION, AGE AND ORIGIN OF PINGO REMNANTS IN THE DRENTSCHE AA VALLEY AREA (THE NETHERLANDS)[1]

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ABSTRACT

De Gans, W. 1982 Location, age and origin of pingo remnants in the Drentsche Aa valley area (The Netherlands) – Geol. Mijnbouw 61; 147-158.

Cross sections of five pingo remnants in the Drentsche Aa valley area reveal that the remnants are situated on the floors of small Pleniglacial tributary valleys. Lithological and palynological data from organic levels below some ramparts of these pingo remnants suggest growth of most of the pingos in a thaw lake environment. A hydrostatic (closed-system) origin of the pingos is suggested. Radiocarbon data from the organic levels and the lithostratigraphic position of the ramparts indicate that the pingos developed between 25,000 and 19,000 BP. Transformation of the pingos into pingo remnants was not isochronous, but occurred until the middle Late Glacial (Late Weichselian).

INTRODUCTION

Investigation of the Stokersdobbe pingo remnant, in the northwestern part of the Drente plateau, showed that this remnant is situated in a former tributary of the Boorne valley and that the rampart of this pingo remnant is located in places upon datable organic deposits in this valley. This situation allowed the maximum age of the rampart and the related pingo remnant to be established (PARIS ET AL., 1979). Investigation of some pingo remnants on the eastern part of the plateau has shown that these remnants are also located in former, now generally indiscernable, upstream parts of tributary valleys (DE GANS & SOHL, 1981). In this paper the results are given of an investigation into pingo remnants in the Aa valley area which was conducted to see whether the correlation of pingo remnants with former tributary valleys might be adopted as a general rule, and also to discover whether ramparts could be found upon datable organic levels, identical to the Stokersdobbe, to establish in detail the environment, period and mode of pingo growth and decay in this area.

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CONTEMPORARY PINGOS

Pingos are conical shaped ice-cored mounds whose distribution is confined to permafrost areas. They range in height from 3 - 70 metres and in diameter from 30 - 600 metres (MACKAY, 1962). MÜLLER (1959) distinguished two types of pingos: the open system or East Greenland type and closed system or Mackenzie pingos. Open system pingos are related to discontinuous permafrost conditions and are located on weak slopes and in valleys (HOLMES ET AL., 1968). They receive the water to grow their ice-cores from artesian pressure. Closed system pingos are related to continuous permafrost conditions and are located on flat areas in former lake environments. They receive the water to grow their ice-cores from pore-water expelled in advance of an aggrading lower permafrost surface (MACKAY, 1979). The literature on pingos has recently been reviewed by WASHBURN (1979) and FRENCH (1976). MACKAY (1979) proposed that pingos should be redefined into hydraulic system and hydrostatic system types, according to the source of the pressure gradient which supplies water to the growing ice-core.

Continuous growth of the pingo ice-core leads to mass wasting, permafrost creep, and rupture of the pingo skin. Subsequently the ice-core will melt and eventually a pingo remnant will be formed which consists of a pond surrounded by a rampart.

THE DRENTE PLATEAU AND THE AA VALLEY SEDIMENTS

The Drente plateau is located in the northern part of the Netherlands (Fig. 1). The Aa valley is situated at the eastern part of the plateau and is eroded into the Drente and Peelo Formation sediments (Table I). The Drente Formation consists of an impermeable till which is present on the water divides of the plateau. The thickness of this till is maximally 4 metres in the Aa area. The Peelo Formation underlies the Drente Formation and consists predominantly of fine sand and clay (ZAGWIJN & VAN STAALDUINEN, 1975; TER WEE, 1979).

The Weichselian and older fluvial deposits in the Aa valley are designated the Aa deposits (DE GANS, 1981a; DE GANS & CLEVERINGA, 1981). The oldest fluvial deposits comprise of sorted sand and gravel with mor-like organic levels which are dated as Eemian, Early Weichselian and Lower Pleniglacial respectively and are assigned to the lower Aa deposits (DE GANS & CLEVERINGA, 1981). The subsequent fluvial deposits consist of sorted sand and fine gravel. The humic loam layers in the top level of this sequence apparently originated in thaw lakes (DE GANS & CLEVERINGA, 1981). These deposits are regarded as the middle Aa deposits and are dated as Middle Pleniglacial.

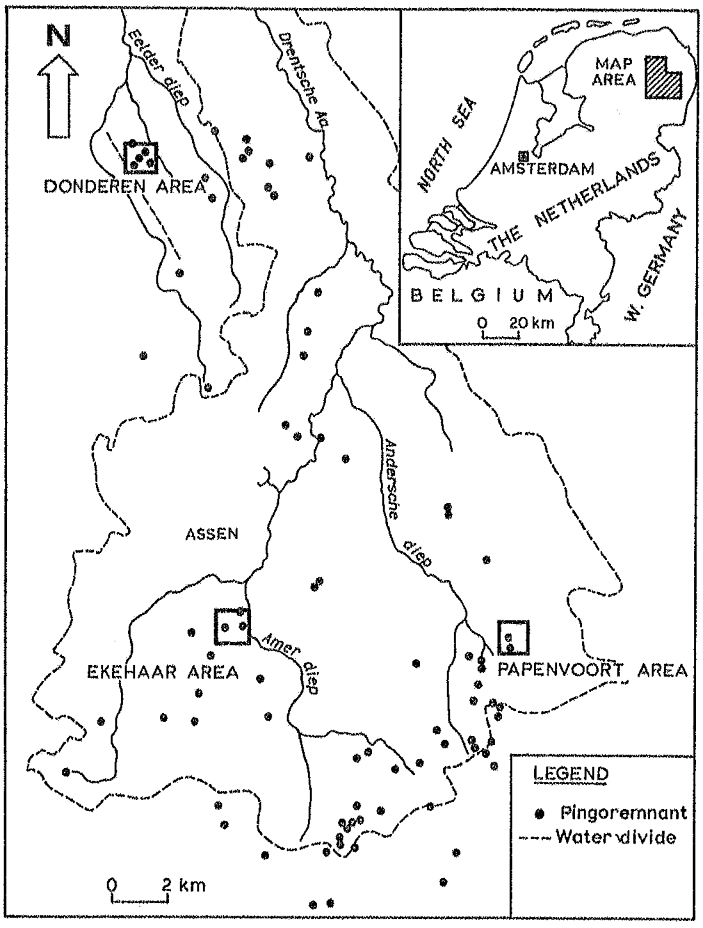

Fig. 1
The Drentsche Aa area and location of the pingo remnants and sample areas.

Table I
The tentative sequence of pingo growth and decay as related to the stratigraphy and lithology of the Middle Weichselian (Pleniglacial) and Late Weichselian (Late Glacial) Aa valley deposits.

CHRONOSTRATIGRAPHY			LITHOSTRATIGRAPHY		LITHOLOGY		TENTATIVE SEQUENCE OF EVENTS	
HOLOCENE			GRIENDTSVEEN Fm		PEAT AND GYTTJA		INFILLING OF PINGO REMNANTS	
WEICHSELIAN (TUBANTIAN)	LATE GLACIAL		TWENTE FORMATION		WELL-SORTED SAND (COVERSAND) PEBBLE BANDS	AND	DEEPER PART ICE CORE MELTS	
							DESERT PAVEMENT PB2	
	PLENIGLACIAL	UPPER	Aa DEPOSITS	UPPER	COARSE SAND	UNSORTED SAND WITH GRAVEL (SLOPE DEPOSITS)	DESTRUCTION OF PINGOS	
		MIDDLE		MIDDLE	SAND WITH HUMIC LOAM LAYERS		PINGO GROWTH	THAW LAKES
		LOWER		LOWER	SAND AND GRAVEL WITH MOR-LIKE LEVELS		VALLEY INCISION	
	EARLY GLACIAL							
EEMIAN								
SAALIAN			DRENTE FORMATION		TILL			
HOLSTEINIAN								
ELSTERIAN			PEELO FORMATION		SAND AND CLAY (POTKLEI)			

The upper Aa deposits consist of coarse fluvial or niveo-fluviatile sand. Generally a pebble band is located on top. This sequence is correlated with the Beuningen Gravel Bed as described by KOLSTRUP (1980), VAN DER HAMMEN & WYMSTRA (1971), and VAN DER HAMMEN ET AL. (1967) and is of Upper Pleniglacial age. Before or at the very beginning of the deposition of the Beuningen Gravel Bed the continuous permafrost disappeared from the Netherlands (KOLSTRUP, 1980). At the end of the Pleniglacial and during the Late Glacial or Late Weichselian, large parts of the Aa area were covered both by well-sorted sand and by unsorted sand with gravel which are interpreted as aeolian and slope deposits respectively and assigned to the Twente Formation.

In the upstream part of the valley system these deposits may completely cover the pre-existing relief of the Pleniglacial tributary valleys. Topographic depressions in the upper Pleniglacial landscape were filled with gyttja in the Late Glacial and with peat in the Holocene. These gyttja and peat deposits represent the Griendtsveen Formation (ZAGWIJN & VAN STAALDUINEN, 1975).

PINGO REMNANTS ON THE DRENTE PLATEAU

On the Drente plateau there are hundreds of topographic depressions filled with gyttja and peat, peat, or water. MAARLEVELD & VAN DEN TOORN (1955) were the first to conclude that some of these depressions were pingo remnants because of the occurrence of a surrounding rampart, their fairly uniform diameter, and their Weichselian age. The age was established because of the position of a rampart upon Pleniglacial sand and the occurrence of Late Glacial peat in these depressions which excluded a glacial or fluvioglacial Saalian origin. DE GANS (1976) added that some pingo remnants may also be characterised by deformation structures, due to updoming of strata during pingo growth; however, DE GANS & SOHL (1981) indicate that these structures may have originated independently of pingo growth as well. The minimum thickness of the organic fill of the pingo remnants investigated so far on the plateau is 2 metres. This datum is tentatively used as a rule of thumb to discriminate pingo remnants from aeolian depressions on the plateau (DE GANS & SOHL, 1981) and corresponds approximately with the depth of cryoturbation structures as found in Weichselian deposits in the Netherlands which may represent the active layer (MAARLEVELD, 1976). This correlation is explained by DE GANS & SOHL (1981) since the growth of an ice-core which forms a pingo must have taken place below the active layer to prevent the core from immediate melting. Thus, pingos with an overburden of over 2 metres were formed which ultimately gave rise to the development of pingo remnants with a depth of over 2 meters. However, as cryoturbation structures are scarce in contemporary permafrost areas, they were probably formed during the disappearance of the permafrost in the Netherlands (H.M. French, pers. comm., 1981). The maximum thickness found so far for the infilling material in a pingo remnant on the plateau amounts to 17 metres. This datum is tentatively correlated with the bottom of the ice-core in the pingo and consequently indicates the minimum depth of the permafrost during growth of this pingo (DE GANS & SOHL, 1981). It should be noted that the core of a pingo may consist of every possible gradation from pure ice to icy sediment. Consequently the relation between the depth of the ponds in pingo remnants and the bottoms of the ice-cores in pingos is an approximation only (MACKAY, 1978).

The basal organic infilling material in pingo remnants generally consists of gyttja and it is tentatively assumed that all gyttja deposits in these depressions have a Late Glacial age (DE GANS & SOHL, 1981). The position of the rampart of the Stokersdobbe pingo remnant on a radiocarbon dated peat layer indicates that the melting of this pingo occurred after 18.000 BP but before the Late Glacial (PARIS ET AL., 1979). PARIS ET AL. (1979), PLOEGER & GROENMAN-VAN WAATERINGE (1964), NOSSIN (1961), MAARLEVELD & VAN DEN TOORN (1955), and DE GANS & SOHL (1981) found that pingo remnants are located in tributary valleys of the major valley systems on the plateau. In the Aa area this correlation was not yet clear as the Weichselian tributary valleys are to a large extent covered by aeolian and slope deposits which obliterated the pre-existing relief.

INVESTIGATION OF THE AA VALLEY PINGO REMNANTS

To gain insight into the number and distribution of pingo remnants in the Aa area all topographic depressions were investigated to ascertain the depth of the infilling organic material. All depressions with an infilling of over 2 metres were tentatively regarded as pingo remnants and they comprise 40% of the topographic depressions in this area. Their distribution (Fig. 1) shows that most of them are located near the southern water divide or upon the east-facing slopes of the asymmetric valleys in the northern part of the area. Three sample areas were selected for detailed investigation of the pingo remnants. In order to investigate whether the distribution of these remnants can be correlated with a former drainage pattern, for each sample area (Fig. 1) cross sections were constructed from data obtained by means of hand-drilling equipment. Palynological and radiocarbon data of organic layers below the ramparts of the pingo remnants were used to establish their age and environment of growth. Some grain size and heavy mineral analyses were performed to support the discrimination made between the rampart material and the under- and over-lying sediments during the field investigation.

The Donderen area

This sample area is situated on the east-facing slope (<½°) of the Eelder Diep valley which was formerly part of the Aa valley drainage system (DE GANS, 1980). In the Donderen area (Fig. 2) three topographic depressions were investigated. A

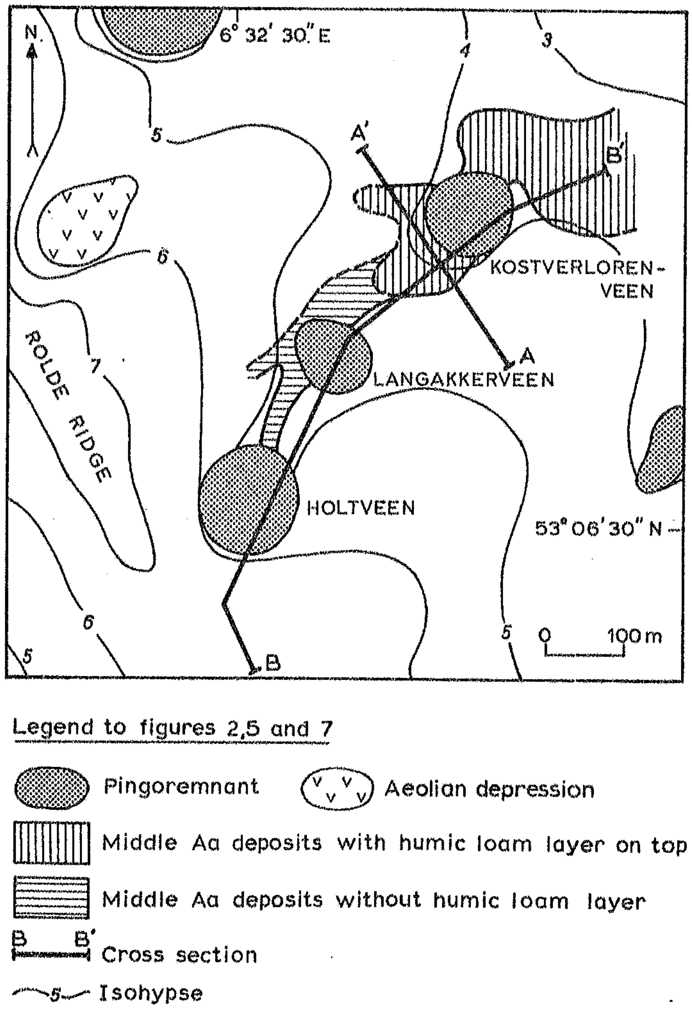

Fig. 2
The Donderen area (location Fig. 1).

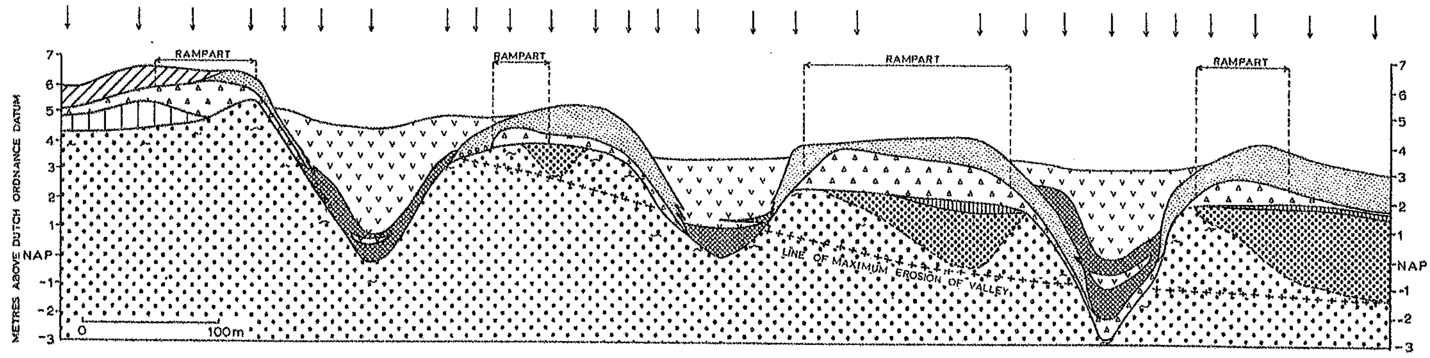

Fig. 3
Cross Section 1 – Donderen BB′ (location Fig. 2; legend Fig. 4).

lengthwise section through these depressions (Fig. 3) shows that they are located like paternoster lakes in a former tributary valley. The fluvial valley sediments are composed of sorted sand and gravel capped by a level of laminated humic loam with peaty intercalations and a maximum thickness of 1 metre (Fig. 4). On the basis of their lithology and position these fluvial deposits are considered to represent the middle Aa deposits (DE GANS & CLEVERINGA, 1981). The thickness and lateral extension of these deposits indicate that the former valley was eroded a few metres into the Peelo Formation and had a maximum width of 200 metres (Fig. 2). The middle Aa deposits are overlain by unsorted sand and gravel which is interpreted as a slope deposit. Its thickness varies between 0.2 - 1.5 metres (Fig. 4). The maximum thickness of the slope deposits is found near or between the depressions. Because of the morphological and lithological characteristics of this deposit it is interpreted as a rampart. These ramparts are located locally upon the organic level of the middle Aa deposits which has a radiocarbon datum of 43,000 ± 1300/1100 BP (GrN 8951) for the insoluble fraction, while the extract gives 31,610 ± 330 BP (GrN 10182) (Fig. 4). The three topographic depressions have a diameter of between 100 and 150 metres. The thickness of the infilling gyttja and peat varies between 3.5 - 6.0 metres, while the thickness of the gyttja increases in each succeeding depression downslope. In all three depressions the gyttja is intercalated with a thin peat layer composed of Hypnaceae. The Donderen area is overlain by a deposit of well-sorted sand (150 - 210 μm) which is interpreted as an aeolian deposit, and covers most of the former relief. Some aeolian sand is located on the slopes in the depressions but it is also found dispersed in the gyttja and lower part of the peat.

The Papenvoort area

This sample area is located near the Andersche Diep valley (Fig. 5) and has a very slight slope (<½°) towards the west. A detailed cross section of the northernmost depression (Fig. 6) shows that it is located in a former valley filled with fluvial sediments which have a laminated humic loam layer on top. Because of their lithology and position these fluvial sediments are assigned to the middle Aa deposits. As in the Donderen area the thickness and extension of these fluvial deposits (Figs. 5 and 6) indicates that the valley was eroded a few metres into the underlying Peelo Formation and had a width of about 100 metres. The depression is filled with sand and gravel, gyttja and peat successively. The organic infilling material has a thickness of about 6 metres. The depression has a diameter of 100 metres and is surrounded by a deposit of unsorted sand with gravel which is interpreted as a slope deposit. As this deposit has its maximum elevation near the depression it is here interpreted as a rampart (Fig. 6). This rampart overlies the humic top layer of the middle Aa deposits which has a radiocarbon date for the insoluble

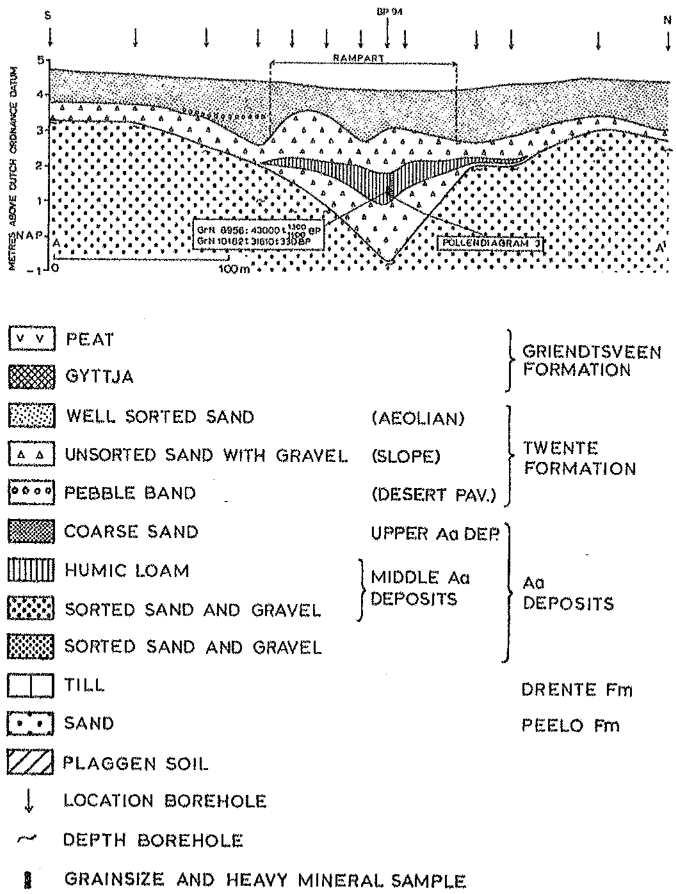

Fig. 4
Cross Section 2 – Donderen AA′ (location Fig. 2).

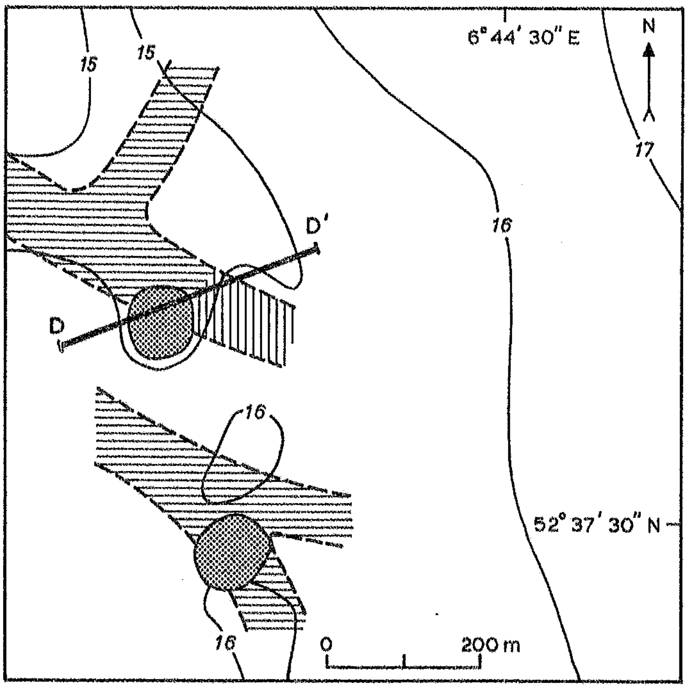

Fig. 5
The Papenvoort area (location Fig. 1; legend Fig. 2).

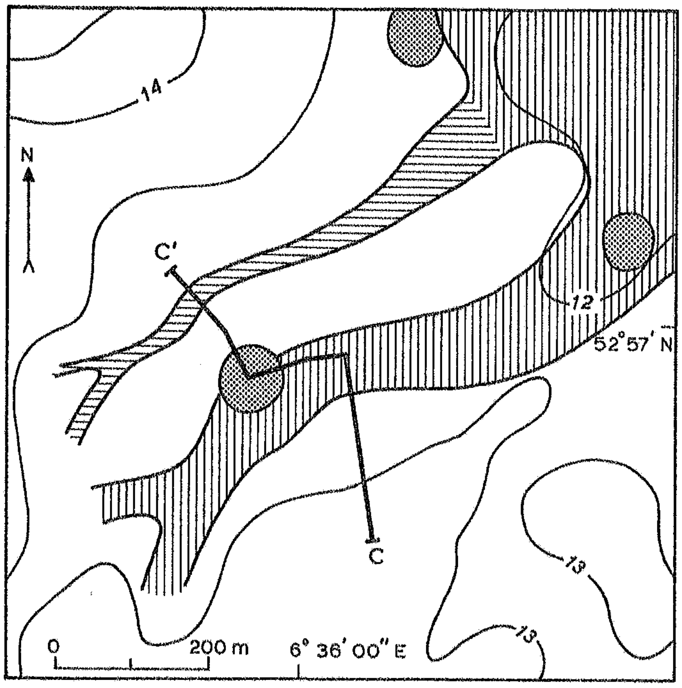

Fig. 7
The Ekehaar area (location Fig. 1; legend Fig. 2).

fraction of 37,250 ± 750 BP (GrN 8942) while the extract gives 29,140 ± 250 BP (GrN 10328). Aeolian sand covers most of the Papenvoort area and is to some extent found also in the depression.

The Ekehaar area

The depression investigated in this third sample area is located in a former tributary of the Amer Diep valley which has a subhorizontal relief (Fig. 7). A cross section (Fig. 8) shows the position of this depression with respect to the valley sediments. The middle Aa deposits have a thickness of about 2 metres and a laminated humic loam layer with peat and sand intercalations on top. This layer is split into two separate layers at the southern part of the valley. A slope deposit comprising of sand, gravel and loam fragments is located around the depression and interpreted as a rampart because of its morphology, lithology and position. The rampart locally overlies the humic top layer of the middle Aa deposits. Two radiocarbon assays of the insoluble fraction of the bottom and

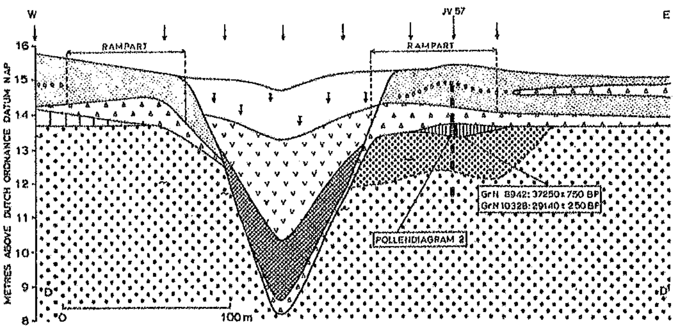

Fig. 6
Cross Section 3 – Papenvoort DD′ (location Fig. 5; legend Fig. 4).

top of this layer give: 42,250 ± 800 BP (GrN 8948) and 34,640 ± 460 BP (GrN 8950) while the two extract analyses give 34,480 ± 440 BP (GrN 10180) and 25,710 ± 170 BP (GrN 10181) respectively.

At the eastern side of the depression the middle Aa deposits are overlain by coarse sand which is assigned to the upper Aa deposits. It has a desert pavement on top which is correlated with pebble band PB2 as described by DE GANS & CLEVERINGA (1981). Because of its lithology and stratigraphic position this sequence of coarse sand with a pebble band on top is correlated with the Beunigen Gravel Bed as described amongst others by KOLSTRUP (1980). The depression is filled with sand and gravel, gyttja and peat in sequence. The actual thickness of the organic infilling material is about 4 metres, which, however, is 1 metre more than the original depth of the depression which is estimated to have been 3 metres. The same applies to the diameter of the depression which is now about 200 metres, but amounts to 100 metres if measured between the basal part of the rampart. Well-sorted aeolian sand obliterates the former relief and is deposited in the gyttja and also in the basal part of the peat in the depression. The abnormal position of the basal face of the till and the Aa deposits near the depression is tentatively interpreted as a deformation structure.

GRAIN-SIZE AND HEAVY MINERAL ANALYSES

From core BP 10 (Fig. 8) and JV 57 (Fig. 6) grain-size and heavy mineral analyses were made to discriminate between the rampart material and the over- and under-lying sediments.

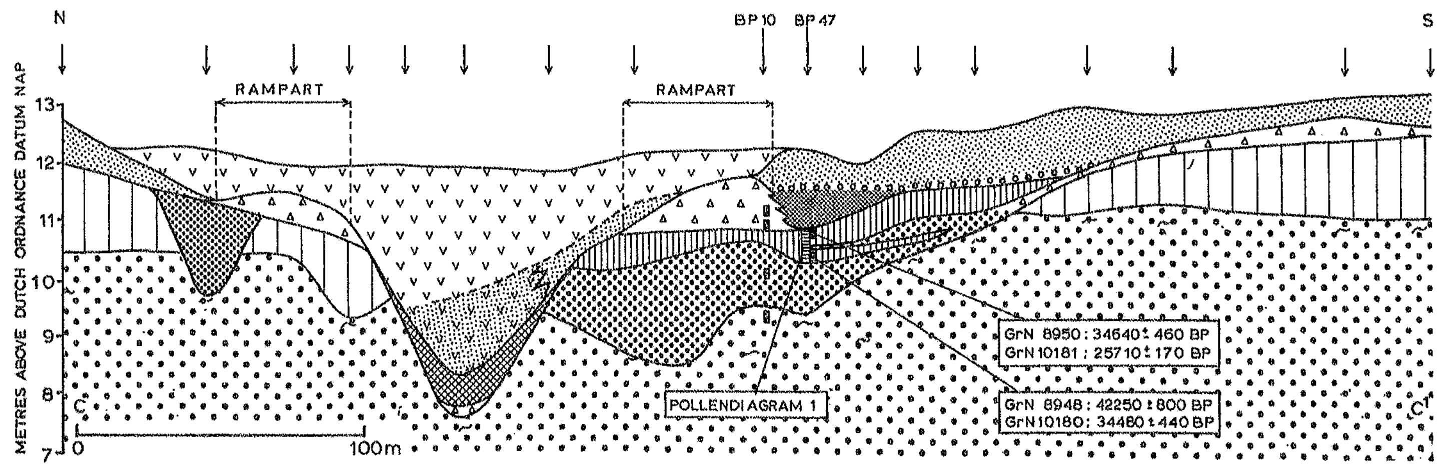

Fig. 8
Cross Section 4 – Ekehaar CC′ (location Fig. 7; legend Fig. 4).

The grain-size analyses (Figs. 9 and 10) indicate that the rampart material has a higher loam content and is less well sorted than the over- and under-lying sediments. The loam content of the rampart may be derived from aeolian sedimentation during growth of the pingo as well as from the loam layers of the middle Aa deposits which are redeposited in the ramparts.

The heavy mineral analyses of the fraction 105-210 μm (Fig. 11) in both cores show an increasing garnet and a decreasing hornblende percentage. Although the percentage of alterites seems highest in the rampart the differences between the heavy mineral percentages of the rampart and the over- and under-lying sediments are in fact not significant.

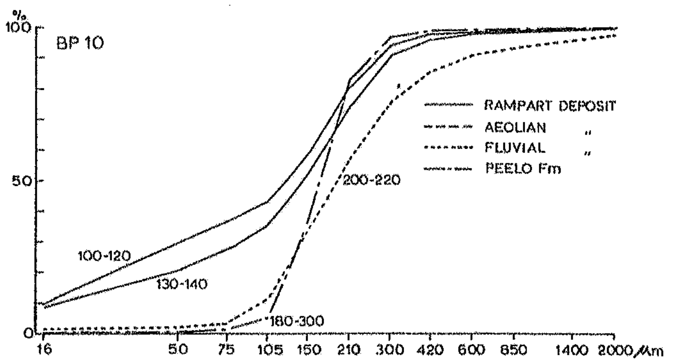

Fig. 9
Granulometric cumulative frequency curves of samples from core BP 10 (Fig. 8).

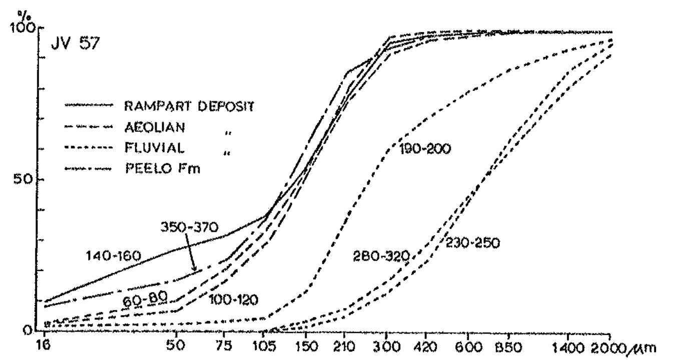

Fig. 10
Granulometric cumulative frequency curves of samples from core JV 57 (Fig. 6).

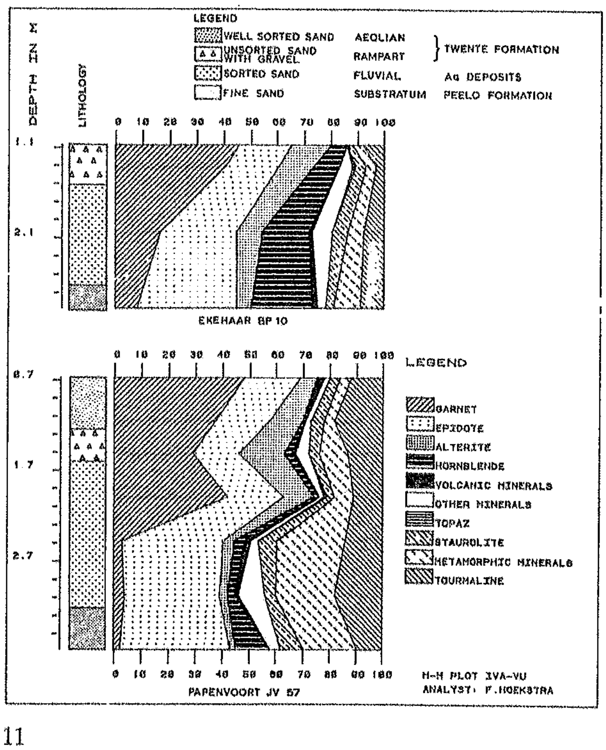

Fig. 11
Heavy mineral analyses from cores BP 10 and JV 57 (fraction 105-210 μm).

PALYNOLOGICAL ANALYSES

Method

To establish the palaeoenvironment of the humic loam layers upon which the ramparts of the pingo remnants are situated and to correlate these levels with those described by DE GANS & CLEVERINGA (1981) from the middle Aa deposits, cores were collected from these humic loam layers with an auger (∅ 50 mm). All pollen samples were treated with KOH and subsequently subjected to bromoform separation. Pollen slides were prepared from each centimetre of core JV 57 (Fig.

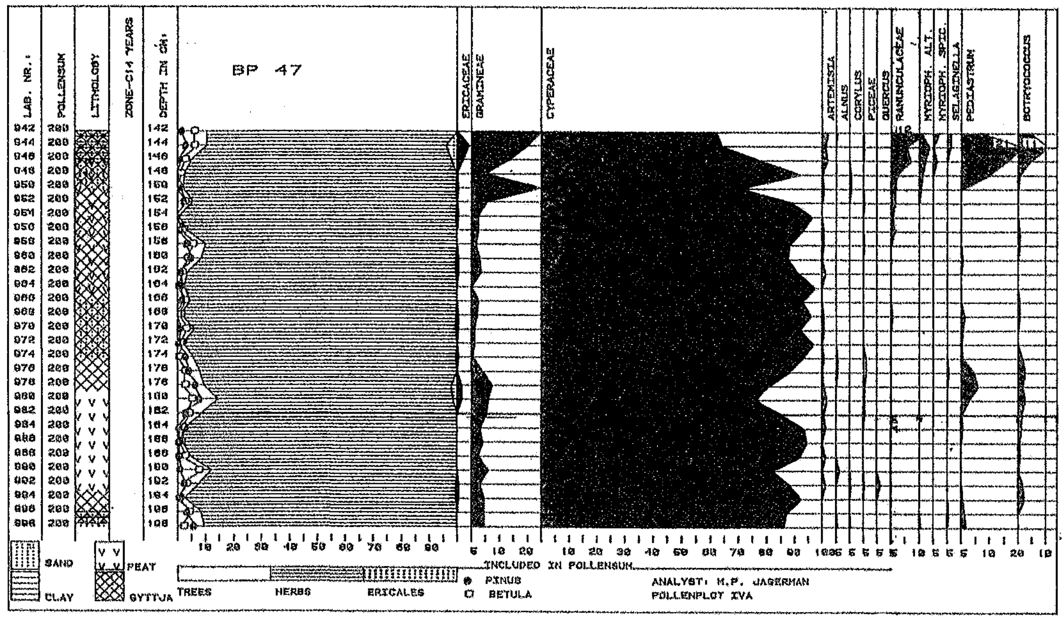

Fig. 12
Pollen diagram 1.

6) and from every second centimetre of cores BP 94 (Fig. 4) and BP 47 (Fig. 8). In the pollen diagrams the percentages are calculated on the basis of the sum of the AP (arboreal pollen) and 'dry' NAP (non arboreal pollen). A pollen sum of 300 AP + NAP has been used with the exception of diagram 1 (Fig. 12) where a sum of 200 was used.

The pollen diagrams

The pollen diagrams 1, 2 and 3 which are derived from humic loam layers in cores BP 47, JV 57 and BP 94 are represented in figures 12, 13 and 14 respectively.

Pollen diagram 1 (Fig. 12) in its lower part is characterised by percentages of arboreal pollen up to 15% and by continuous curves of *Pinus* and *Betula*. The percentages of the non-arboreal pollen are high, Cyperaceae reaching 90%. The *Artemisia* curve is discontinuous and below 2%. The upper part of this diagram is characterised by a rise of aquatics such as *Myriophyllum* and Ranunculaceae and by an increase of Gramineae and the algae *Botryococcus* and *Pediastrum*.

In its lowest part pollen diagram 2 (Fig. 13) shows high percentages of Cyperaceae (up to 92%) and low percentages of *Pinus* and *Betula* (below 3%). In the upper part of the diagram *Artemisia* has a continuous curve (up to 2%), the Gramineae have a slightly higher percentage while the algae *Botryococcus* and *Pediastrum* show a distinct increase.

In contrast to diagrams 1 and 2 pollen diagram 3 (Fig. 14) shows in its lower part high percentages of the aquatics, especially *Myriophyllum* (max. 32%), Ranunculaceae (max. 9%) and the algae *Botryococcus* and *Pediastrum*. Cyperaceae has a percentage varying between 65 and 80% while the Gramineae percentage varies between 5 and 20%. This part of the core has also been analysed for macro remains, and revealed the occurrence of seeds of *Batrachium*, *Potamoge-*

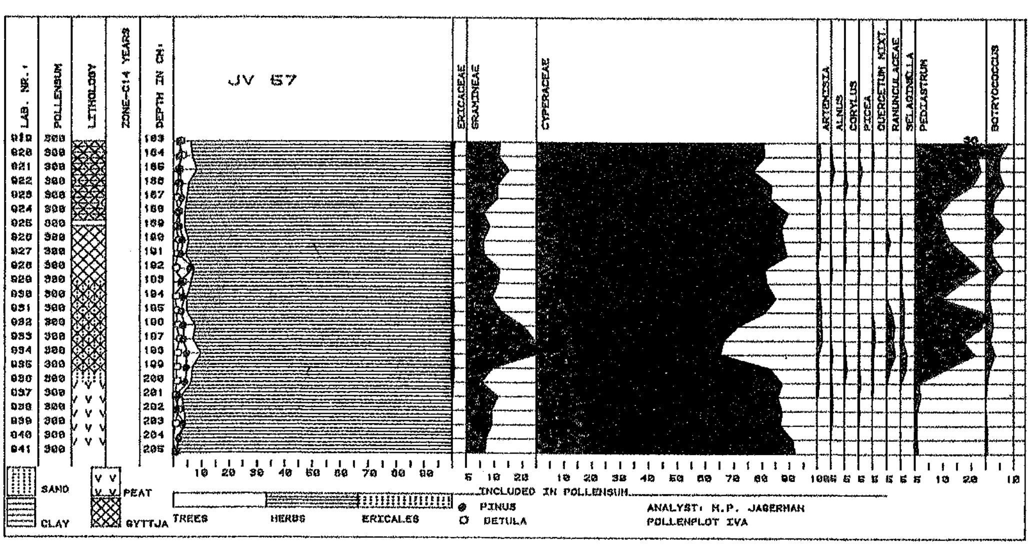

Fig. 13
Pollen diagram 2.

the data of the insoluble fraction. If this holds true the humic loam layers from which pollen diagram types LT1 and LT2 were derived were formed between 34,480 and 25,710 radiocarbon years BP.

The ramparts of the pingo remnants have a maximum thickness of 1,4 metres (Fig. 4) and are partly located upon these thaw lake deposits. The material composition of the ramparts depends on the lithology of the sediments in which the ice-cores were formed, but generally comprises unsorted sand with some gravel. The grainsize analyses support the interpretation that ramparts are present below the aeolian sand cover, but the heavy mineral composition is not indicative for the discrimination of the ramparts between the over- and under-lying sediments. As the size and elevation of the ramparts is smaller than might be expected from the volume of the depressions, erosion of the ramparts must have taken place (DE GANS, 1976).

The position of the eastern part of the rampart of the Ekehaar pingo remnant (Fig. 8) with respect to the Aa deposits indicates that the formation of the rampart is probably isochronous with the deposition of upper Aa deposits, but antedates the deposition of pebble band PB2. This indicates that the melting of this pingo is more or less synchronous with the deposition of the Beuningen Gravel Bed. The Beuningen Gravel Bed is dated by KOLSTRUP (1980) between 19,000 and 14,000 BP which means that the melting of the Ekehaar pingo occurred in the same period. This is supported by PARIS ET AL. (1979) who dated the melting of the Stokersdobbe pingo between 18,000 and 13,000 BP.

The growth of the pingos in the Aa area took place between 25,000 BP (the youngest radiocarbon date below a rampart in the Aa area) and 19,000 BP (beginning deposition of the Beuningen Gravel Bed). This period corresponds in outline with the time interval during which a continuous permafrost may have been present in the Netherlands (KOLSTROP, 1980), and the phases of maximum Weichselian cold climate (MAARLEVELD, 1976; COOPE, 1977; ZAGWIJN, 1975) and maximum expansion of Weichselian ice sheets (WOLDSTEDT & DUPHORN, 1974). The involved space of time is in agreement also with the maximum age of recent pingos investigated so far (WASHBURN, 1979). The earliest organic infilling in the pingo remnants is not isochronous but variously dated to the Upper Pleniglacial (CLEVERINGA ET AL., 1977), Bølling (TER WEE, 1966; CLEVERINGA & DE GANS, 1978; PARIS ET AL., 1979) or Early Dryas (CASPARI & VAN ZEIST, 1960; PLOEGER & GROENMAN-VAN WAATERINGE, 1964, and DE GANS & CLEVERINGA, 1981). This may be a result of the retarded melting of the complete ice-cores, depending on the thickness of the ice-cores themselves and the overburden. This may also explain why in some remnants the gyttja has an intercalated peat layer, whereas it is absent in others. A related phenomenon is the presence or absence of Late Glacial aeolian sand in the pingo remnants. DE GANS (1981 b) explained its absence by having the aeolian sands trapped in the vegetation on the ramparts of the pingo remnants. MAARLEVELD & VAN DEN TOORN (1955) in contrast suggested that the pingos were still active during deposition of most of this sand. In this paper it is suggested that the retarded melting of some pingos may explain this phenomenon.

Generally the pingos which were formed on the Drente plateau are explained as open system pingos (DE GANS, 1976). The low relief values in the areas where they originated, the location of most of them in a thaw lake environment, the supposed presence of a continuous permafrost, and the occurrence of a till on the water divides – which excludes the existence of source areas for groudwater necessary for open-system pingo growth – do not support an origin as hydraulic pingos. Thus it is suggested that the Aa valley pingos originated as hydrostatic (closed-system) types:

At the beginning of the Pleniglacial there was a valley incision in the Aa area (DE GANS, 1981a) that gave rise to a dense drainage pattern under discontinuous permafrost conditions (Fig. 15A). After this erosion phase the middle Aa deposits were formed. Diminished discharge and an increasing cold climate caused the permafrost to close under the valley floors and thaw lakes began to develop (Fig. 15B). The aggrading permafrost expulsed the pore water and thus hydrostatic pingos were formed on the floor of the valley system (Fig. 15C). During growth of the pingos mass wasting and permafrost creep of the pingo skin or overburden occurred covering thaw lake deposits with rampart material (Fig. 15D). From the upper Pleniglacial the pingos were transformed into pingo remnants due to climatic amelioration (Fig. 15E). The ramparts of the pingo remnants became gradually lowered due to mass wasting, fluvial erosion or deflation. During the Late Glacial aeolian sand was deposited covering most of the Pleniglacial relief and creating aeolian depressions (Fig. 15F).

CONCLUSIONS

The pingo remnants in the Aa valley area are characterised by a diameter of 150-200 metres, a thickness of the infilling organic material of over 2 metres, and a relatively small rampart. If the 2 metres thickness is used as a rule of thumb to discriminate the pingo remnants in the Aa area from aeolian depressions, about 40% of the topographic depressions may be regarded as pingo remnants. The ramparts surrounding the pingo remnants are composed of slope deposits and may be distinguished by their morphology and grain size composition. Heavy mineral analyses proved to have a limited value for this purpose. The investigated remnants are located in the upstream part of former, now quite often completely covered, tributary valleys. This may give rise to a paternoster lake-like distribution of the remnants. If the correlation of the remnants with former valleys is accepted as a general rule, the distribution of the pingo remnants indicates that in the Aa valley area the Middle Pleniglacial drainage pattern was more dense than the present one.

The Aa valley pingos were formed in the late Middle

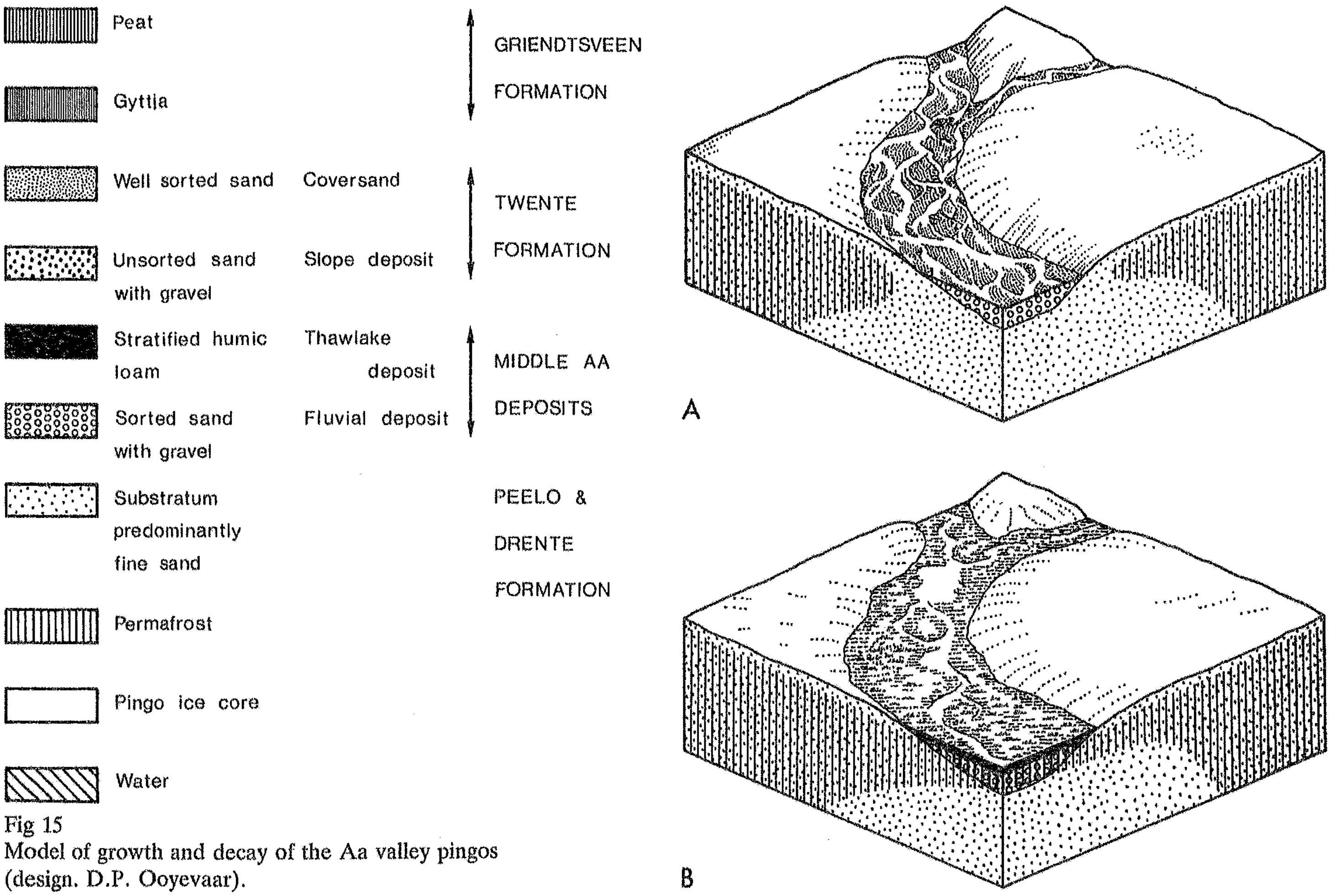

Fig 15
Model of growth and decay of the Aa valley pingos (design. D.P. Ooyevaar).

Pleniglacial as hydrostatic pingos under continuous permafrost conditions. The transformation into pingo remnants occurred in the Upper Pleniglacial before the formation of desert pavement PB2 which is correlated with the upper part of the Beuningen Gravel Bed. The infilling of the remnants with gyttja did not start before the ice-core was completely melted. This means that the earliest infilling is not necessarily synchronous but depended on the thickness and composition of the ice-core and the thickness of the overburden.

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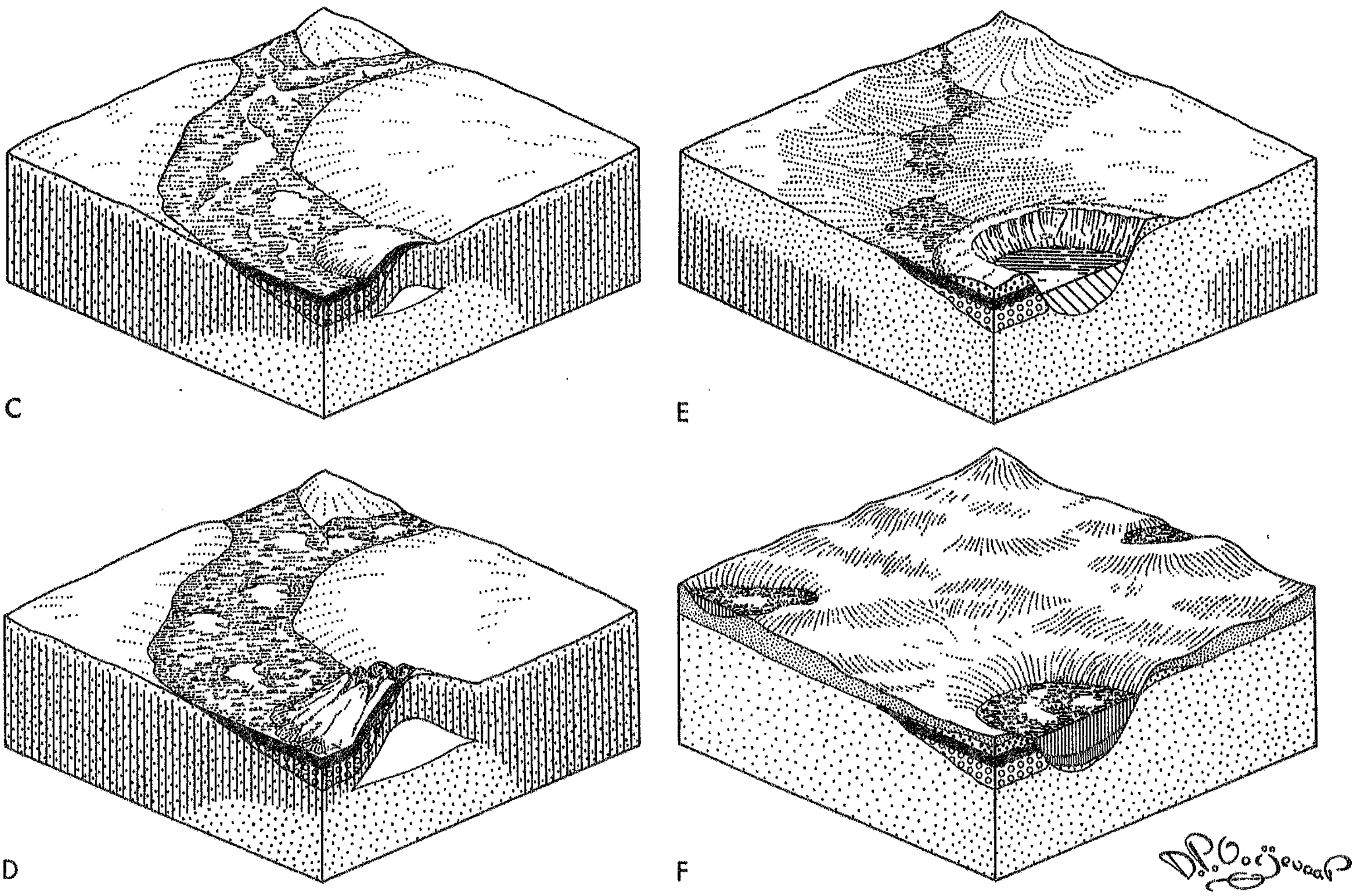

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