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Evidence of episodic permafrost conditions during the Weichselian Middle Pleniglacial in the Hengelo Basin (The Netherlands)

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Abstract

An ice-wedge cast level, dated between ca 41,000 and 36,600 years BP. has been found in Tubantian (Weichselian) deposits near Hengelo (Twente district, Eastern Netherlands). So far, well developed ice-wedge casts of Middle Pleniglacial age have not been recorded for the Netherlands. It is argued that mean annual temperatures were near the upper limit to permit ice-wedge development. In that case substrate and hydrological conditions are critical. Sedimentary structures overlying the ice-wedge cast level point to thaw lake development. Palaeoecological evidence shows that the sequence started in open (periodically running) water. Under a declining water budget a phase with terrestrial peat sedentation was initiated which, after a short interval, culminated in an increasingly dry environment as indicated by xerophilous taxa. The ice-wedge cast level is associated with taxa indicative of bare, disturbed grounds and with the break up of a continuous vegetation cover. Subsequently a phase with (temporary) running water, predominantly standing, shallow water and a return to running water are recognized. The top of the sequence shows a vegetation which can be compared with a chionophilous arctic dwarf shrub tundra. Vegetation development could be explained in terms of changing moisture conditions, while temperature changes are of minor importance.

Introduction

In a large highway construction pit (Hengelo A1 exposure, Fig. 1, located at N 52° 16′ 40″, E 6° 49′ 25″) on the northeastern fringe of the town of Hengelo, 8 m of Tubantian (Weichselian) basin fill sediments were exposed during the year 1986. The outcrop is situated in a glacial basin, shaped during the Saalian (Zagwijn, 1974). The sequence in the exposure correlates with the Twente Formation and covers most of the Pleniglacial.

The main subject of this study is the reconstruction of the periglacial, sedimentological and ecological conditions in a Middle Pleniglacial episode. These are compared with contemporaneous conditions in a wider context. Attention is focused on the lower part of the exposed sequence, which shows evidence of temporary permafrost conditions.

The sedimentary sequence in the Hengelo A1 exposure

In the Hengelo A1 exposure an alternating series of sand, silt and peat beds can be distinguished (Fig. 2). The base of the sequence consists of cross-bedded sands of fluvial origin, overlain by c. 1 m of

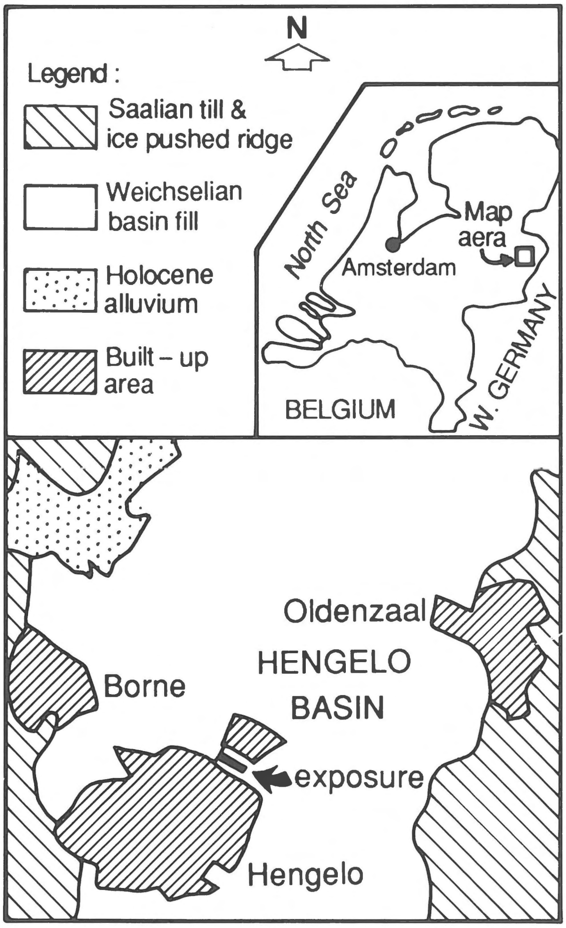


Fig. 1. Location of the study area.

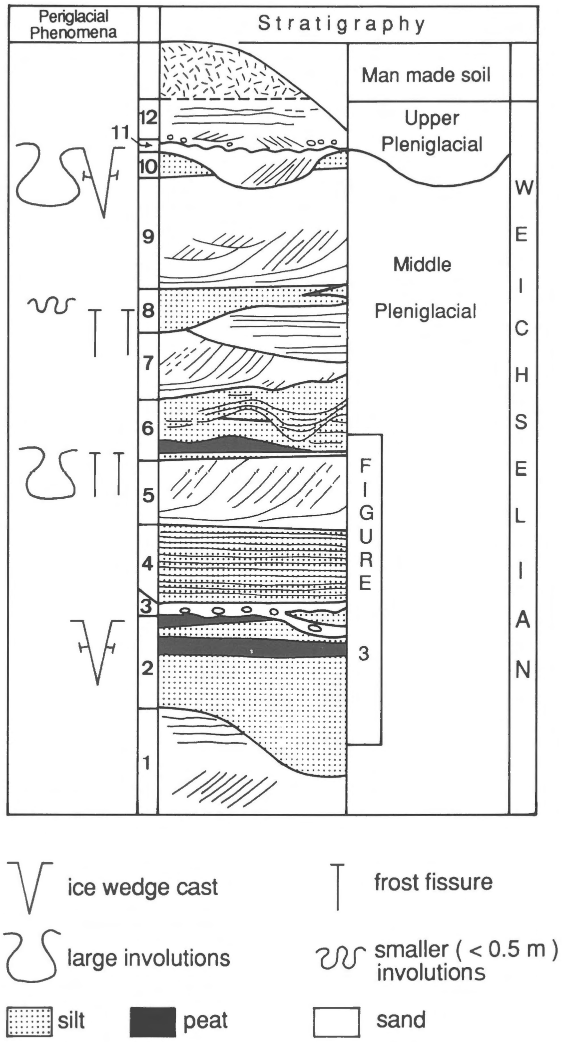


Fig. 2. Lithostratigraphy, periglacial phenomena and sedimentary structures of the Hengelo A1 exposure (after Van Huissteden & Vandenberghe, 1988).

strongly calcareous clayey silt (units 1 and 2, Figs 2 & 3c). The basal part of this silt is of shallow lacustrine origin (pollenzone HGA-1, Fig. 4). A peat bed indicates a transition towards a terrestrial environment (pollenzone HGA-2a); above this peat, silt with peaty intercalations has been deposited (pollenzone HGA-2b). On top of unit 2 a polygonal network of ice-wedge casts has developed (Fig. 5). The silt layer and the ice-wedge casts have been truncated by a horizontal erosion surface, overlain by a 10 cm thick bed of coarse sand with many angular silt and peat lumps (unit 3). Unit 3 in turn is overlain by evenly laminated silt (unit 4, pollenzone HGA-4 and 4), deposited in a lacustrine environment. The remainder of the Middle Pleniglacial sequence (units 5–10) consists of an alternation of sandy crevasse splay deposits and lacustrine silts with intercalated peat beds (Van Huissteden, in prep.). The crevasse splay deposits consist of medium to coarse sand with remarkably straight, high-angle foresets. The foresets show delta-like features with toesets, attributed to distal sedimentation in shallow lakes. The top of the crevasse splay foresets is usually strongly disturbed by involutions and frost fissures (Fig. 3a), indicating subaerial exposure. The Upper Pleniglacial deposits (units 11 and 12) are represented by wide and shallow channels filled with sand and overlain by

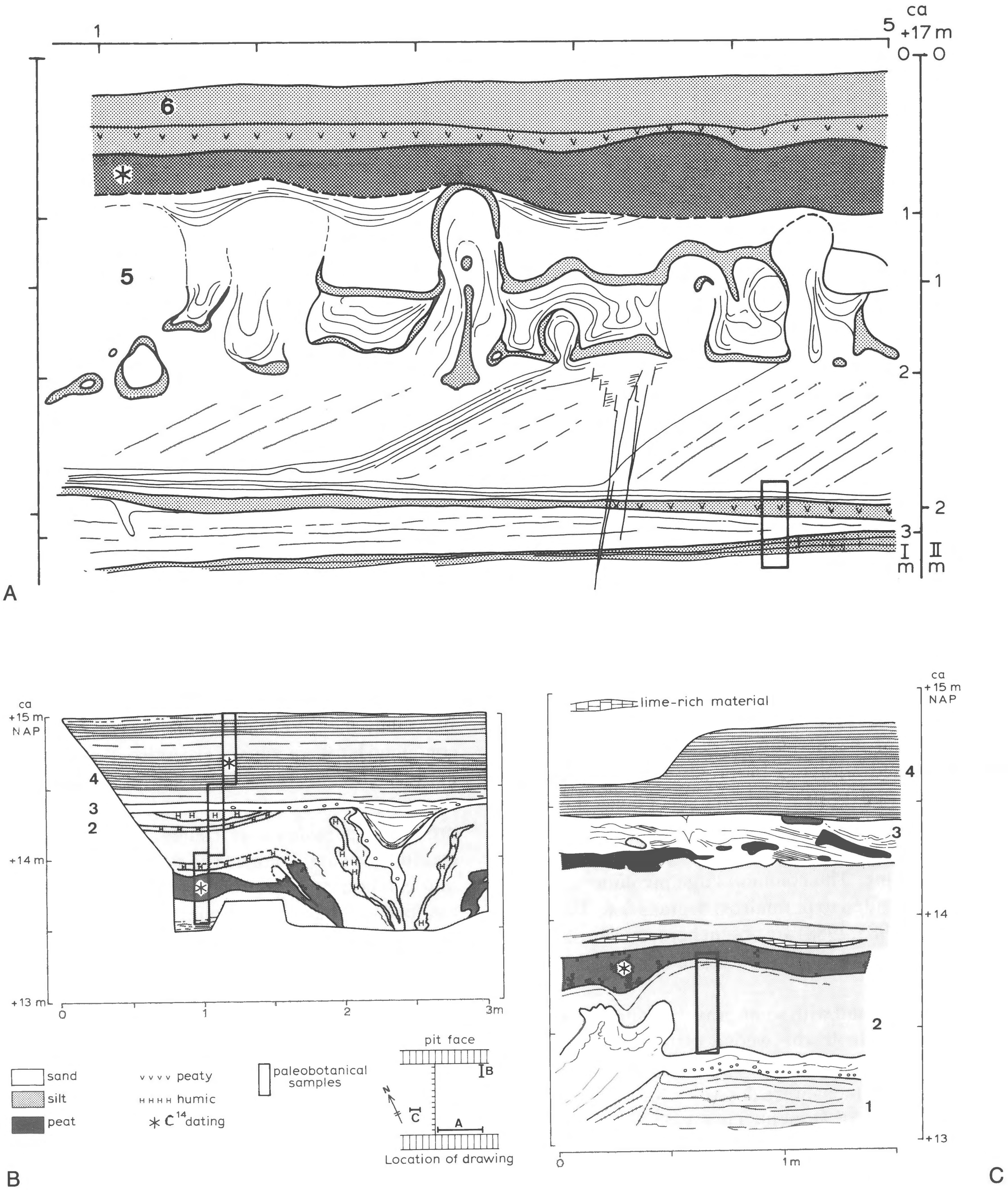
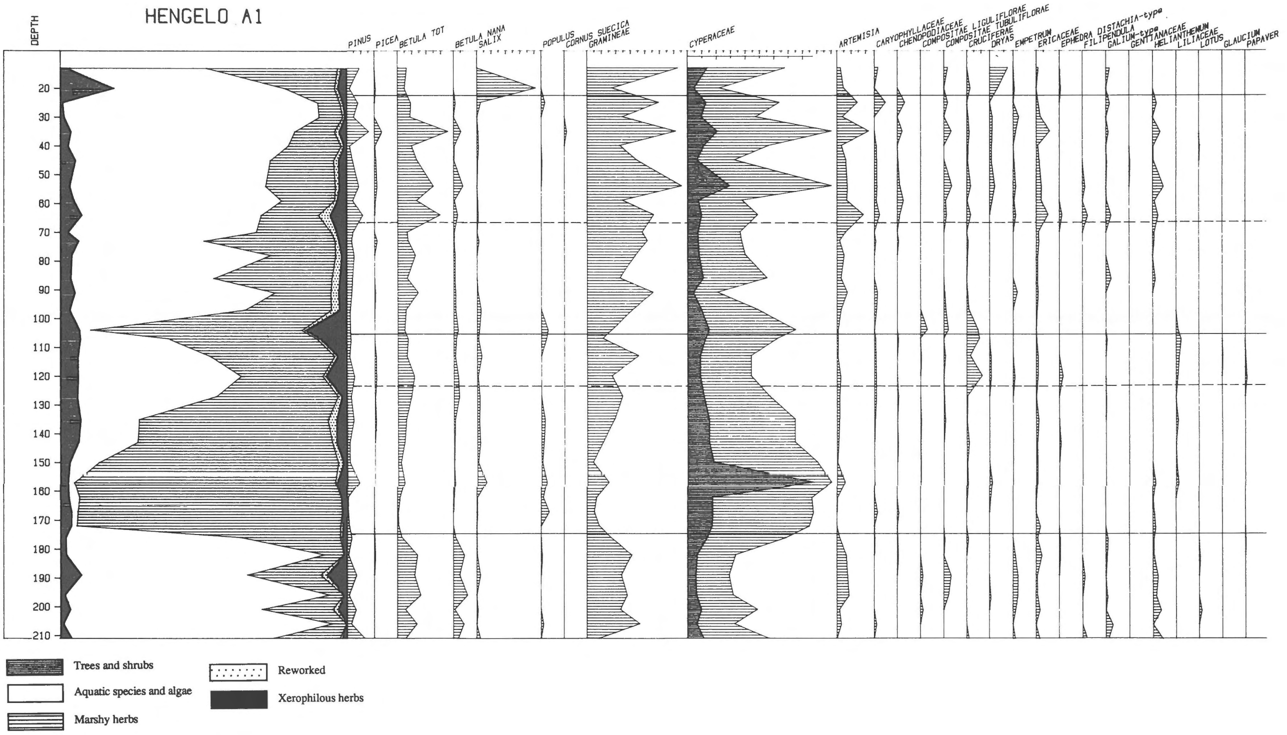


Fig. 3. Detailed sections of the lower sedimentary sequences: a) Units 4, 5 and 6; cryoturbations at the top of unit 5; b) Units 2, 3 and 4; top of ice-wedge cast in unit 2; c) Units 1 to 4; large peat and silt lumps in unit 3.



gravel strings and silty eolian sands. The gravel strings truncate a second ice wedge level and large involutions.

The sequence of units 2–4 (Figs 3b & c) shows details of the permafrost degradation processes, associated with the lower ice-wedge cast level. Apart from the peat beds, the silt of unit 2 shows no visible sedimentary structures. These may have been obliterated by either pedogenesis or ground-ice melting. The common large involutions which are attributed to permafrost degradation (Vandenberghe 1983, 1988) are absent here, which indicates a modification of the process in this particular situation.

Coarse sand with some gravel is found at considerable depth in the wedge casts, resulting from gully development above most of the ice wedges. Such phenomena were described for actual permafrost areas by Hopkins (1949). Subsequently the current velocity in the gullies has been strongly reduced, as is testified by the occurrence of laminated silty sand. The latter deposit, although slightly disturbed, is not deeply involuted in the wedge. Consequently, most of the wedge ice had disappeared at that time. These fine sediments are deposited in standing water that developed upon thawing and subsequent subsidence of the subsoil. Especially the silt of unit 2 potentially could have contained large amounts of excess ice. Black (1969) cites ice contents between 75 and 91% for clayey silt and peat. The minimum value already would produce a subsidence of roughly 0.8 m after ice melting from unit 2 alone. The standing water body thus can best be interpreted as a thaw lake, which has been initiated by ground subsidence upon thawing of excess ground ice. The erosion surface between units 2 and 3 is an abrasion plane formed by wave and current action while unit 3 represents the near shore deposits (Hopkins & Kidd 1988). The angular intraclasts of unit 3 are fragments produced by the caving in of the lake banks (Tedrow 1969). The evenly laminated silts (unit 4) are deposited below the wave base in the central part of the lake. According to the palaeoecological record of this unit (see below) the lake was affected by running water, at least periodically. Apparently, at that time the lake became incorporated in the fluvial sedimentation system. Afterwards, fluvial ac-

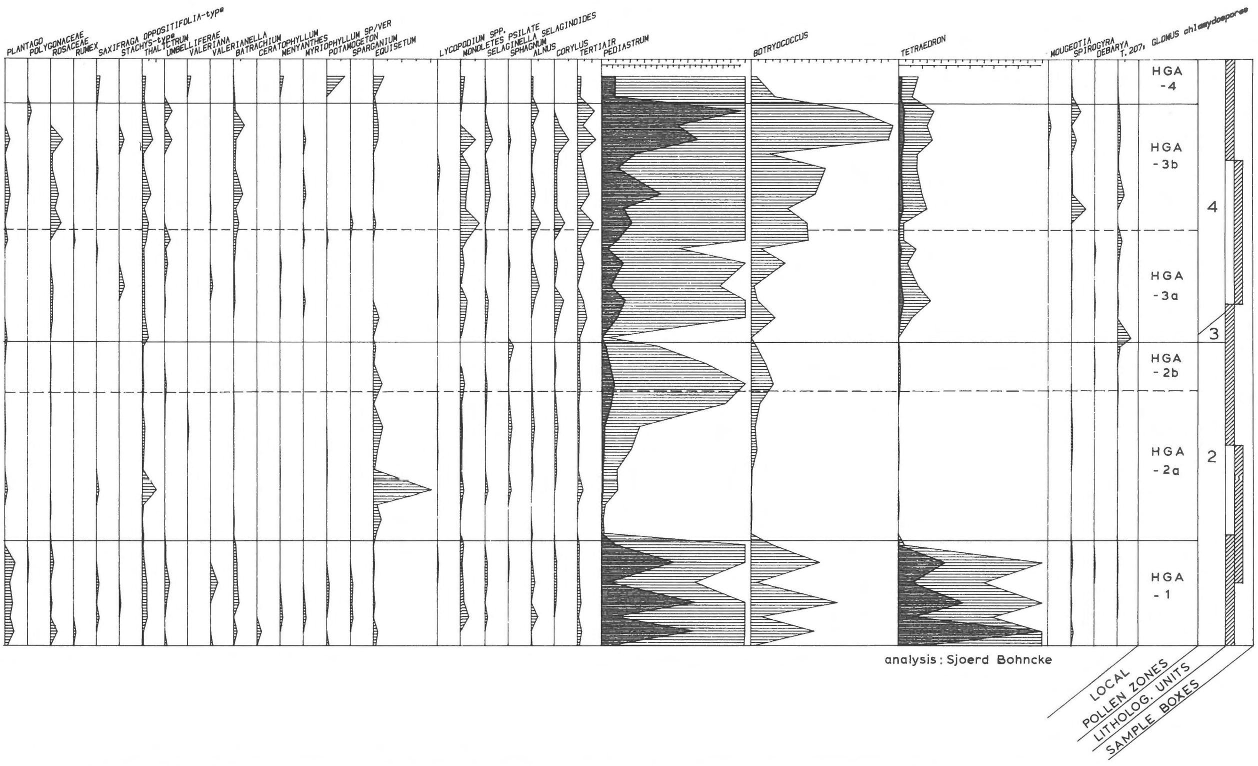


Fig. 4. Percentage diagram. The amounts of pollen, spores and algae are expressed as percentages of $\sum$-pollen.

tivity is clearly indicated by the deposition of the crevasse splay deposits (unit 5). A very similar evolution of environments has been described by Wallace (1948) and Walker (1978) for actual periglacial areas.

Stratigraphical evaluation of the sequence

The gravel strings between units 11 and 12 at the top of the exposure can be correlated with the Beuningen gravel bed in the nearby Dinkel valley (Van der Hammen et al. 1967, Van der Hammen 1971). The ice-wedge casts and large involutions immediately below it correlate with the Upper Pleniglacial permafrost period which is widely recognized in western Europe (e.g., Kolstrup 1980).

The remainder of the sequence is of Middle Pleniglacial age. Radiocarbon datings on organic levels in the sequence are listed in Table 1.

The residue datings on unit 2 result in a mean age of c. 40,200 years. One of these datings is confirmed by an extract dating. Consequently, the ice-wedge casts which have been developed in unit 2 are of Middle Pleniglacial age. Unfortunately, the datings on overlying units 10 and 8 apparently have suffered from contamination, as the extract dating on unit 8 indicates. The real ages therefore must be somewhat older.

The same applies for the datings on units 6 and 4, which are unexpectedly young. Datings on comparable stratigraphic levels in the exposures described by Zagwijn (1974) yield ages ranging between 36,000 and 39,000 BP. Moreover, from a sedimentological point of view it is not very likely that units 4 to 8 all give approximately the same age. Deposition of silts (unit 6) should have resulted at least in a detectable age difference. Therefore, it is concluded that the datings of unit 6 and 4 also suffered from contamination with younger carbon.

Another indication of the age of the erosion level between units 2 and 3 can be obtained by correlation with the nearby Rientjes brickyard clay-pit

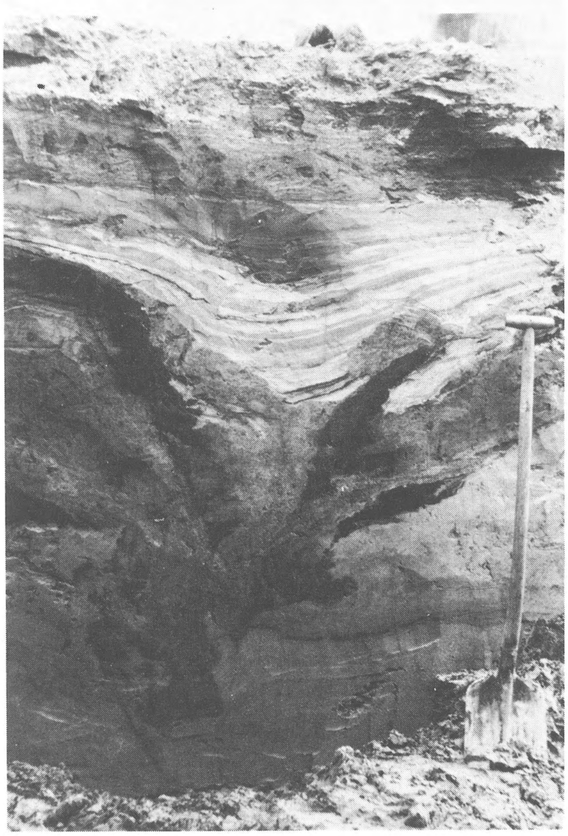


Fig. 5. Ice-wedge cast in unit 2.

(Zagwijn 1974, Vermey & Heukeshoven 1974, Van Huissteden, in prep.). In the latter exposure, a peat underlying an erosion level similar to the one corresponding with unit 3 has been dated at 43,030 + 1680 − 1390 BP. (GrN 6925), while overlying gully fill sediments yield an age of 37,500 ± 650 BP. (GrN 1763, Zagwijn 1974). In the Hengelo K.N.Z. pit, described by Zagwijn (1974), strongly involuted clay and peat, dated at 38,350 ± 550 BP. (GrN 4828) is overlain by undisturbed horizontally bedded gyttja dated at 36,600 ± 600 BP. (GrN 2685, dating on *Batrachium* seeds). The involuted peat and clay is correlated with unit 2 in the Hengelo A1 exposure. Therefore the erosion features overlying the involutions and ice-wedge casts are at least older than 36,600 BP.

Periglacial phenomena and climatic conditions

Horizontal examination of the level with ice-wedge casts showed a polygon network with a diameter of c. 20 m. The wedges penetrate from the top of unit 2 downwards and reach to a depth of at least 2 m, and have a width of c. 1 m at their top. The infilling of the casts mainly consists of the surrounding silt and peat, which has slumped and flowed into the void left by the wedge ice (Figs 3b & 5). The horizontal erosion surface (see above) may have removed the top of unit 2 although the structure of the wedge casts suggests that no more than a few dm has been displaced. According to observations in present-day periglacial environments (e.g. Péwé 1966) the occurrence of ice-wedge polygons points to the existence of a continuous permafrost at the time of their formation. Radiocarbon datings (see Table 1) and lithostratigraphical correlation date the phase with ice-wedge casts to the period between c. 40,200 and 36,600 BP. Well developed ice-wedge casts in The Netherlands of Middle Pleniglacial age have not been described previously. In the Haine Basin (Belgium) Haesaerts (1984) and Haesaerts & Van Vliet-Lanoe (1981) mention isolated Middle Pleniglacial ice-wedge casts. It has been demonstrated previously that the large cryoturbations which have been described by Zagwijn (1974) and dated at c. 36,600–38,350 BP. originate from the melting of an underlying permafrost (Vandenberghe & Van de Broek 1982, Vandenberghe 1983). The same kind of cryoturbations have been found in an identical stratigraphical position in the brickyard exposure at Rientjes (see above). Other periglacial features in the Middle Pleniglacial sequences in Belgium and the Netherlands are limited to small-scaled cryoturbations and frost fissures (e.g., Van der Hammen et al. 1967, Zagwijn 1974, Van der Meer et al. 1984, Vandenberghe 1985, Vandenberghe & Krook 1985, Vandenberghe 1988).

The permafrost indications in both the Hengelo region and the Haine Basin have in common that they are formed in a silty substrate. Most other Middle Pleniglacial sites that have been studied in Belgium and The Netherlands show a sandy sequence. Fine-grained sediments have proven to be much more sensitive to ice lensing and wedge development than coarse-grained sediments (Taber 1930, Mackay 1971). As is the case in actual periglacial areas, lithology must have played an important role in permafrost distribution in the past. Romanovski (1985) has shown that the depth of the seasonally thawed layer is larger in a substrate consisting of sands or gravels, than in silts since the former substrate is generally 'warmer'. Therefore ice wedges in fine-grained substrate may form already when the mean annual temperature is c. − 4.7° C (Péwé et al. 1969), while in sands c. − 8° C is the upper limit (Péwé 1966, Washburn 1980, Romanovski 1985). Since the surficial distribution of lithologies is related to their geomorphological position, it is in fact the latter position which is significant for the development of ice wedges (Vandenberghe 1985). From these points of view it may be explained that within one region permafrost existed at some places, while it was absent at others (Pissart 1987). The absence of ice-wedge casts in sandy substrates around 38,000 BP. may be an indication that climatic conditions were marginal for the formation of ice-wedge casts in The Netherlands and Belgium, and that the mean annual temperature probably was around − 4.7° C. In contrast to the relatively mild Middle Pleniglacial, the Upper and Lower Pleniglacial suffered from a much more severe climate, with overall occurrences of permafrost (ice-wedge casts and large flat-bottomed cryoturbations in sands and gravels). Mean annual temperatures of less than − 8° C may be derived for these periods.

The palaeobotanical record

Units 2, 3 and 4 from the Hengelo construction pit have been subjected to pollen and macroremain analyses. The pollen samples have been treated by standard methods according to Faegri & Iversen (1975). A specified number of Lycopodium spores was added to determine the pollen concentrations (Stockmarr 1971). For the macroremain analysis 10 cc of sediment was boiled in KOH (5%) and subsequently rinsed with tapwater on a 130 μm sieve. All distinguishable elements have been analysed.

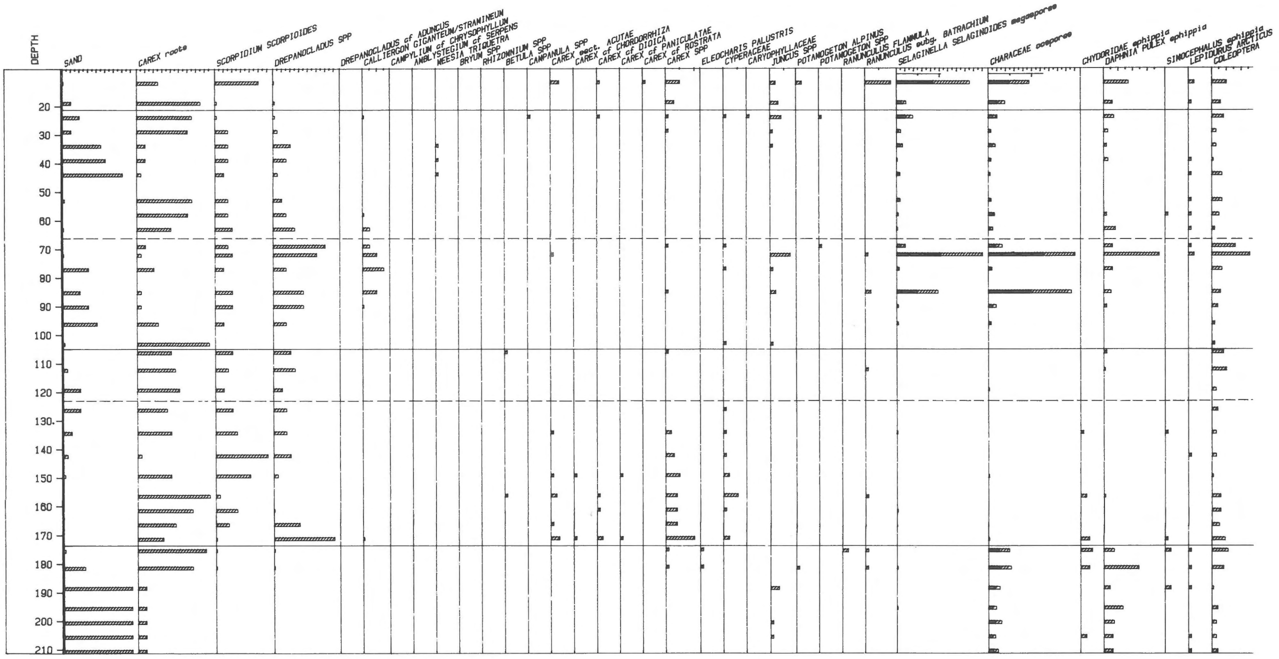
The pollendiagram (Fig. 4) has been subdivided into six zones and subzones, based on changes in the percentages of the principal taxa and concomitant major changes in the macroremain assemblage (Fig. 6). Particular attention has been paid to taxa whose fluctuations could be interpreted in terms of environmental changes (predominantly moisture) in the vicinity of the site. An obvious development within the amount of trees and shrubs, related to regional changes, seemed to be absent. The overall conditions throughout the profile were base rich and calciphilous taxa such as Characeae, Ostracoda and *Corynocera ambigua*, were abundantly present.

Zone HGA-1 (211 – 174 cm)

This zone is characterized by a high algae content (*Pediastrum, Botryococcus, Tetraedron*) and by the presence of aquatic species (*Batrachium* pollen + fruits, *Potamogeton alpinus* pollen + fruits, *Menyanthes trifoliata, Myriophyllum spic./vert., Ceratophyllum*). Sand forms the bulk of the macro-

Table 1. Radiocarbon datings from the Hengelo A1 sequence

Unit	Material	Residue dating	Extract dating	Laboratory nr.
10	silt	28,670 ± 110	27,780 ± 230	GrN 13428/13429
8	peat	32,860 ± 270	27,350 ± 210	GrN 13424/13425
6	peat	32,490 ± 160		GrN 13426
	peat	31,250 + 600		GrN 15124
4	silt	33,100 + 600		GrN 15123
2	peat	41,110 ± 480	39,200 + 1800 − 1500	GrN 13427/14221
	peat	39,640 ± 370		GrN 14215



remains but its relative contribution rapidly diminishes towards the top of the zone. Throughout the zone oospores of Characeae occur, permitting the conclusion that, at least during the growing season, clear and probably standing water was present. The large amounts of Crustaceae (*Daphnia pulex, Lepidurus arcticus* and Ostracoda) also indicate the availability of open water. The recording of the chironomid *Rheocricotopus* points to (temporary) running water. Towards the top of the zone, a process of growing in with vegetation is initiated. Especially *Eleocharis palustris, Carex* spp. and mosses, capable of colonizing shallow open water, take part herein.

Zone HGA-2 (174 – 105 cm)

The nearby absence of obligate aquatics, present in the preceding zone, and the occurrence in relatively low values of xerophilous species (*Ephedra, Artemisia*) and species with a preference for dry habitats (*Populus,* Liliaceae (*Convallaria* type sensu Moore & Webb 1978) makes this zone unique within this pollen record. Moreover, pollen density within zone HGA-2 reaches maximum values (see Fig. 7). Since these higher values are recorded for all taxa, a slow accumulation rate for this zone is concluded. Two subzones have been created, based on the relative frequencies of Cyperaceae, Cruciferae, *Populus* and algae.

Subzone HGA-2A (174 – 124 cm). Most prominent in this zone are the relatively high values of Cyperaceae, which gradually decline towards the top of the zone. Its predominant local occurrence is confirmed by the presence of *Carex* roots and achenes of *Carex* sectie *Acutae, C. chordorrhiza, C. dioica* and *C. rostrata*. The curve of *Equisetum* spores reaches its maximum in this zone. A terrestrial marsh vegetation replaces the aquatics of the preceding zone. Mosses thrive abundantly in this vegetation type (in the initial phase *Drepanocladus* and *Calliergon*, succeeded by *Scorpidium scorpioides*).

The nearby absence of sand in the samples might permit the conclusion that fluvial activity was greatly reduced. The recording of *Populus*, which has a preference for dry habitats with a fluctuating ground water level and which occurs in areas with very little precipitation (e.g. the 'Wald-Steppe'

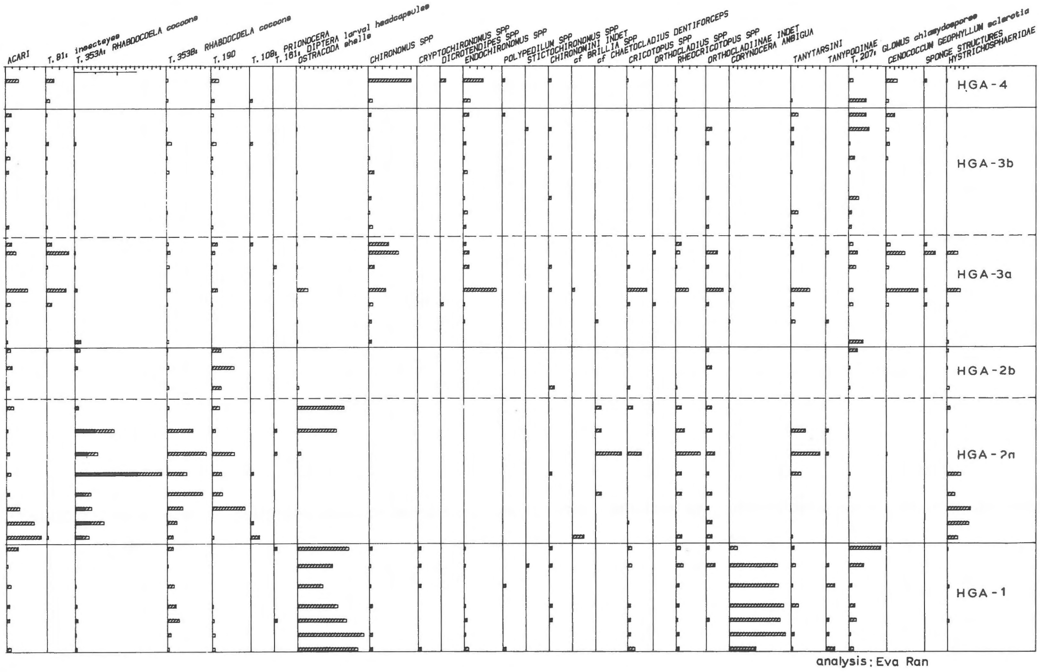


Fig. 6. Macroremain diagram.

Zone with a yearly precipitation of 300–325 mm, Walter 1974, Bohncke et al. 1988), points to relative lowering of the ground water table. Moreover, locally some running water was present, at least temporary, as indicated by the continuous record of *Rheocricotopus*.

In the upper part of the zone the amounts of algae gradually increase, especially *Pediastrum* becomes abundant. Also chironomids become more frequent and Ostracoda reappear, thus indicating the return to open water. This could be caused by increased periodically flooding of the site by the adjacent river system.

Subzone HGA-2b (124 – 105 cm). In the beginning of this zone shallow pools, in which the algae and chronomids thrived, were present. Throughout the zone these small bodies of water dried up, dry habitats spread at the expense of wet habitats. Open ground indicators (Cruciferae, Caryophyllaceae and Compositae) argue for the break up of a continuous vegetation cover (Lowe & Walker 1977, Pennington 1977). Especially Cruciferae were very prominent, clusters of pollen point to their local occurrence. They indicate the presence of bare and disturbed grounds, which were probably induced by the development of permafrost and frostwedges. Evidence of these are present in the profiles of the Hengelo pit (Fig. 3b). The break up of the continuous vegetation cover can be correlated with an increase in frost disturbance, during freeze-thaw cycles, of ground not protected by a snowcover (Pennington 1977). Conditions were dry as well as cold. The presence of *Glaucium* and *Papaver*, both confined to this zone, are in agreement with the type of environment described above.

Zone HGA-3 (105 – 22 cm)

Lithologically the boundary between zones 2 and 3 is interpreted as an erosive one. It may well be that part of the palaeobotanical record is missing due to surficial erosion. Subsequently resedimentation of older material is a real danger and requires careful interpretations. The return of aquatic taxa and the infrequent occurrence of xerophilous taxa is obvious. A subdivision is postulated based on a more prominent fluviatile influenced lower part and a more semiterrestrial upper part.

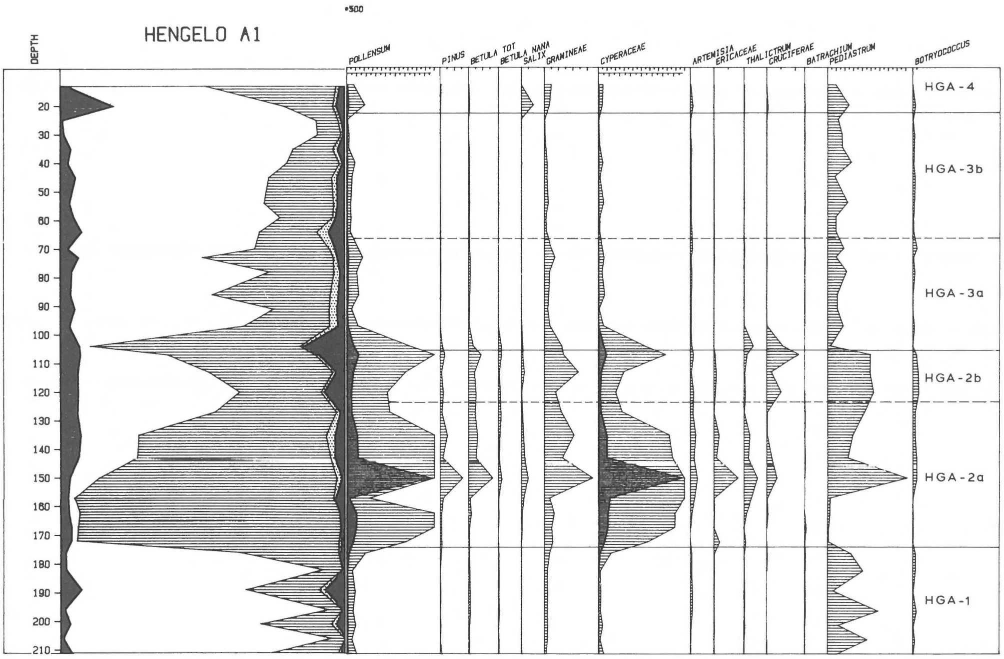


Fig. 7. Concentration diagram.

Subzone HGA-3a (105 – 66 cm). It is assumed that the basal layers of this zone bare the imprint of the underlying dry continental phase (Cruciferae, Compositae and excessive low algal values). Immediately after this phase the environment becomes moist again as aquatics (*Myriophyllum, Menyanthes, Batrachium* and *Potamogeton*) reestablish themselves together with an expansion of the algae (*Pediastrum, Botryococcus* and *Tetraedron*). The macroremain records of Characeae, Crustaceae and Chironomidae also point to the local presence of open water. This is in agreement with the sedimentological record, which shows the development of a thaw lake of a limited depth. However, the occurrence of the chironomid *Rheocricotopus* indicates (temporary) running water. The conclusion seems to be justified that the thaw lake was fed by an adjacent river system. The dominant mosses (*Scorpidium scorpioides, Drepanocladus* and *Calliergon giganteum/stramineum*) are capable of colonizing shallow water, while the others (*Meesia triquetra, Bryum*) can grow under very humid conditions, i.e. on the edges of pools and streams. On those humid places *Selaginella selaginoides* could thrive as well.

Subzone HGA-3b (66 – 22 cm). At the transition towards zone 3b dry conditions possibly are more prominent, as indicated by a rise in the percentages of *Artemisia* and the presence of *Ephedra*. Inundations decrease and shallow pools with standing water prevail. *Rheocricotopus* is virtually absent and instead, *Spirogyra* (a member of the Zygnemataceae) is more frequent, indicating the dominance of standing water over running water. *Helianthemum* becomes more frequent. Locally a marshy vegetation with Cyperaceae, *Dryas, Filipendula*, Ericaceae, Rosaceae (possibly *Potentilla palustris*), *Selaginella selaginoides*, Carophyllaceae, *Galium* (possibly *G. palustris*) and *Lotus* develops. In the shallow open water of the pools the algae (*Pediastrum, Botryococcus* and *Tetraedron*) thrive. One pollen grain of *Cornus suecica* is encountered in this zone. Its occurrence in combination with relatively high values of *Betula nana, Empetrum* and *Dryas*, makes a comparison with a (sub)arctic dwarfshrub tundra applicable.

Zone HGA-4 (22 – 12 cm)

Most characteristic for this zone is the sharp increase in the curves of *Salix* (*Salix herbacea*-type) and *Dryas*. The relative decline in *Artemisia* in concomitance with these high *Salix* values (clusters of pollen indicate local occurrence) may point to an increasing importance of a snow cover in this zone. Its melting during spring time causes a rise in fluvial discharge and results in flooding of the site. This trend is already indicated in the top most sample of the section, where *Potamogeton* cf. *alpinus* increases. In the macroremain assemblage this species is accompanied by *Batrachium* and increasing values of Characeae, Crustaceae and Chironomidae. The pollen sequence is overlain by fluvial sands, in which palaeobotanical analyses have not been performed.

Discussion and conclusions

The sequence in the construction pit at Hengelo shows for the first time in the Netherlands evidence of the occurrence of ice wedges in Middle Pleniglacial deposits. These ice wedges and the concomitant presence of permafrost indicates a yearly mean temperature of about – 2.5° C to – 6° C, at least for the period between 41,000 and 36,600 BP. The underlying and overlying deposits do not yield indications for major changes in temperature based on the palaeobotanical and palaeozoological assemblages. Neither does the thaw-lake development necessarily have to coincide with a climatic warming.

Moisture seems to be the major regulating factor for vegetation growth. In the palaeobotanical record no elements have been found, which were true coldstenotherms. The only cold indicating species is *Lepidurus arcticus* (Taylor & Coope 1985). This crustacean inhabits shallow water bodies, its occurrence thus is primarily limited to the presence of open water.

The pollen diagram resembles the pollen diagram from the Rientjes brickyard, which is derived from comparable stratigraphical levels (Vermeij & Heukeshoven 1974). The latter authors interpreted the changes in the vegetation as temperature fluctuations. A closer look however, shows that moisture was even more important, as the vegetation changes can be correlated with changes in water level. This same phenomenon has been found in the adjacent Tilligte basin (Ran, in prep). In this basin several organic layers showed the occurrence of a (sub)arctic tundra vegetation throughout the Middle Pleniglacial. This is more or less the same kind of vegetation as has been derived for the Hengelo sequence.

The development of ice-wedge structures seems to coincide with relatively dry conditions at the site and is favoured by a fine grained substrate. Besides changes in the fluvial regime the amount of precipitation and its distribution over the seasons may have contributed to the establishment of drier conditions.

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