VU Research Portal

Periodic ice-wedge formation and Weichselian cold-climate floodplain sedimentation in the Netherlands

Vandenberghe, Jef; Kasse, C.

published in
Proceedings 6th International Conference on Permafrost
1993

document version
Publisher's PDF, also known as Version of record

Link to publication in VU Research Portal

citation for published version (APA)
Vandenberghe, J., & Kasse, C. (1993). Periodic ice-wedge formation and Weichselian cold-climate floodplain sedimentation in the Netherlands. In *Proceedings 6th International Conference on Permafrost* (Vol. 1, pp. 643-647).

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:
vuresearchportal.ub@vu.nl

Download date: 03. Mar. 2023

PROCEEDINGS OF
THE SIXTH INTERNATIONAL CONFERENCE
ON PERMAFROST / BEIJING / 5–9 JULY 1993

PERMAFROST

VOLUME 1

OFFPRINT

PERIODIC ICE-WEDGE FORMATION AND WEICHSELIAN COLD-CLIMATE FLOODPLAIN SEDIMENTATION IN THE NETHERLANDS

J. Vandenberghe & C. Kasse

Institute of Earth Sciences, Vrije Universiteit,
De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands.

A radiocarbon-dated, seven metres thick, Weichselian Pleniglacial fluvial sediment sequence indicates seven periods when permafrost aggraded and degraded. The previous existence of permafrost is testified by the presence of ice-wedge casts, while the corresponding permafrost degradation is manifested by cryoturbations. The sedimentary sequence is characterized by cycles of overbank deposition (sand and silt) followed by periods of land surface stability (organic sediment). During the latter phases permafrost aggraded on the floodplain. Floodplain submersion, however, resulted in degradation of the (top of the) permafrost and subsequent formation of cryoturbations. The periods of inundation lasted several hundreds to thousends of years. After withdrawal of water from the floodplain, permafrost re-established and new ice wedge polygons developed, often above the old wedges and penetrating the previously cryoturbated zone. The latter are a special kind of syngenetic ice wedges because their upward growth was interrupted by cyclic fluvial flooding, resulting in the downward thawing of the ice wedges and cryoturbation.

INTRODUCTION

Ice wedges have been subdivided classically into two main categories: epigenetic and syngenetic ice wedges (e.g. French 1976; Harry 1988; French & Gozdzik 1988; Mackay 1990). For the epigenetic type the surface level is supposed to remain constant during the complete development of the wedge. Epigenetic ice-wedge casts have been recorded by far as the most numerous ice-wedge casts (Harry & Gozdzik 1988).

The development of syngenetic wedges, conversely, takes place during slow but generally continuous deposition at the surface. In the case of slow sedimentation rates the growth of the ice veins keep pace with the sediment aggradation and the wedges grow progressively in vertical direction. In some cases, the rate of deposition on top of the wedges is discontinuous resulting in thickness variations of the ice wedge and a more or less developed wedge-in-wedge structure originates (Dostovalov & Popov 1963; French & Gozdzik 1988; Vandenberghe & Van Huissteden 1988). Generally, the syngenetic ice wedges are not disturbed by the sedimentation process. In this paper, another type of syngenetic ice wedge formation is described which is characterized not only by the temporary interruption of wedge growth but also by partial melting which is caused by flooding.

The ice-wedge casts which were studied were formed in fine-grained, fluvial and aeolian sediments dating from the last glacial. The deposits were exposed in two tunnel contruction pits besides the Prinses Margriet Canal near Grouw in the northern Netherlands (53°04′45′′N, 5°49′54′′E; Figure 1).

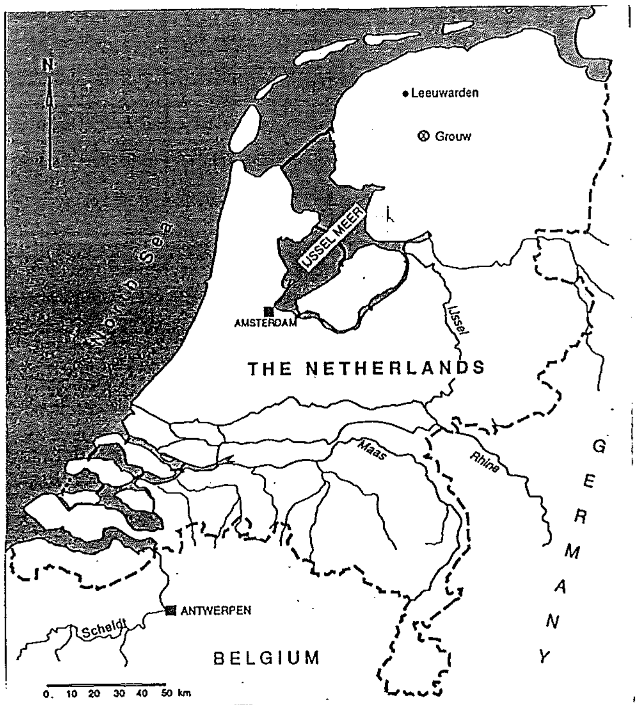

Figure 1 Location map of study area.

Geological setting

A condensed geological section is presented in fig. 2. The basal part is formed by a greenish till consisting of sandy clay with dispersed pebbles and cobbles and dating from the end of the penultimate glacial (Saalian). Its top is weathered by soil formation and covered by peat and sandy or clayey peat from the Eemian and Early Weichselian. During the subsequent Weichselian Pleniglacial fluvial deposition occurred in the headwater of a local small river catchment. This catchment draines the

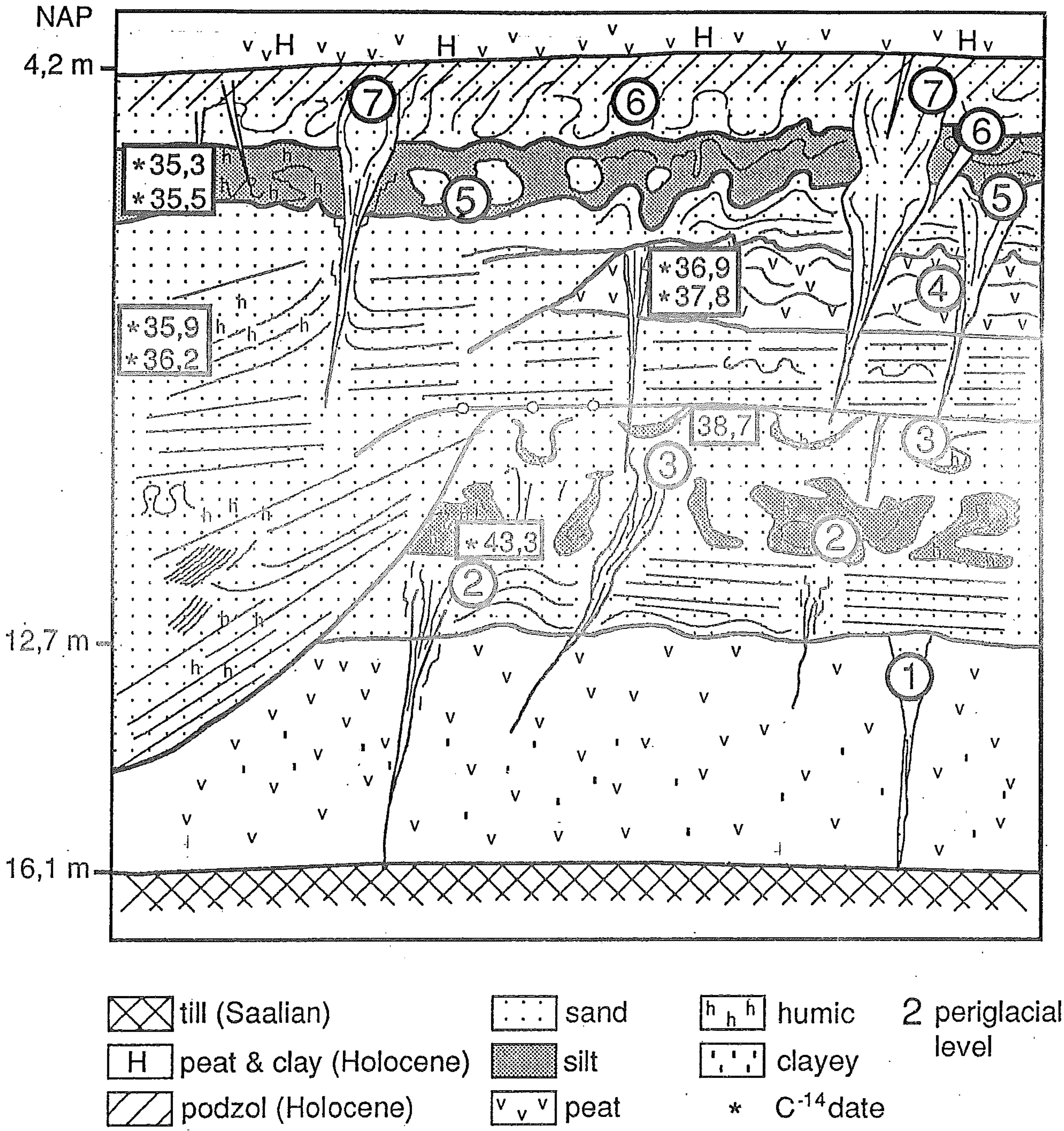

Figure 2 Simplified section of the Late Pleistocene sequence at Grouw.

higher Saalian till regions, approximately 20 to 40km south and east of the exposure. The sediments consist predominantly of fine sands alternating with (humic) silts and peat. They contain numerous levels of ice-wedge casts, each associated with cryoturbations. The presence of peaty layers enables accurate datation. The residue components and the humic extract of each organic sample have been dated in order to determine the effect of eventual humus infiltration. Only the residue dates are presented in Figure 2. The Pleistocene sediments and their morphology are covered by about 3.5 m of clay and peat which formed in the Holocene coastal plain.

Cyclic periglacial river activity during the Weichselian Pleniglacial

Two main sedimentary facies are distinguished. The first occurs in channels which incised the older Pleniglacial fluvial deposits, Eemian peat and locally the Saalian till (Figure 2, left part). This facies is characterized by a stacked sequence of channel sediments which reveal a general fining-upward of about 7 m. Fine to medium sand with large-scale crossbedded sets are common at the base. Higher in the sequence, the sands are fine-grained and intercalated with many humic silt beds. Horizontal and low-angle channel fill cross-bedding are dominant. Individual sand and silt beds reveal small-scale current ripple cross-lamination and climbing ripple lamination. A rhythmic alternation of fine sand grading into sandy silt with reworked organic material is regularly found. Locally the sands show a patchy outlook and are apparently homogenized by fluidization. Isolated small-amplitude (dm-scale) cryoturbations and frost cracks are found occasionally in the channel facies. All these characteristics point to channel deposition with large and repetitive (seasonal?) discharge fluctuations in a periglacial environment.

The second facies occurs outside the channels as a complex of extended sheets, each having a thickness of a few dm to 1.5 m. Five superposed sheets are recognized in the Grouw exposures. The topmost two units also extend over the channel facies. The individual sheets consist of a fining-upward sequence of fine sands grading into sandy silts, humic silts and sometimes (clayey) peat (Figure 2, right part). These sheets are interpreted as overbank deposits. Generally, they are not erosive, in contrast to the channel deposits. Lateral transitions from channel to overbank facies are preserved occasionally, but often they are eroded. It follows that it is not always possible to connect individual overbank units to the corresponding channel unit. The overbank deposits are characterized by cryoturbations and ice-wedge casts.

The fluvial dynamics can be conceived as a repetitive system of channel flow accompanied by flooding. The exposures did not permit identification of pointbar deposits and it was impossible to find out if the river was one- or multi-channeled. However, as channel infilling was rather fast, as indicated by the sedimentary structures, and because erosion was lateral only, the river was probably a quick lateral migrating type.

According to the general lithostratigraphy of the region (Vandenberghe 1985; Vandenberghe & Van Huissteden 1988) and radiocarbon analyses, the fluvial sediments date from the Weichselian Pleniglacial.

Cyclic development of periglacial structures during the Weichselian Pleniglacial

As shown above, a number of fluvial cycles is distinguished in the overbank series. Each of them is associated with a level of periglacial deformations, i.e. ice-wedge casts and cryoturbations. The latter levels are successively described below (see Figures 2 and 3).

The lowest level of periglacial activity (1) consists only of ice-wedge casts; they have developed on top of fine fluvial sands. As the wedges were filled by this sand, the ice wedges postdated the fluvial deposition. These sands and the ice-wedge casts are both younger than Eemian (the age of the underlying peat). On the other hand, they are overlain by a widespread erosional pebble horizon, which dates from the end of the Early Pleniglacial (Vandenberghe 1985) and by a humic layer radiocarbon dated at 43.3 ka. Thus, it is concluded that the ice wedges as well as the fluvial sands which form the fill of these wedges date from the Early Pleniglacial (72-61 ka). This period represents the first cold phase of the last glacial in Europe with continuous permafrost.

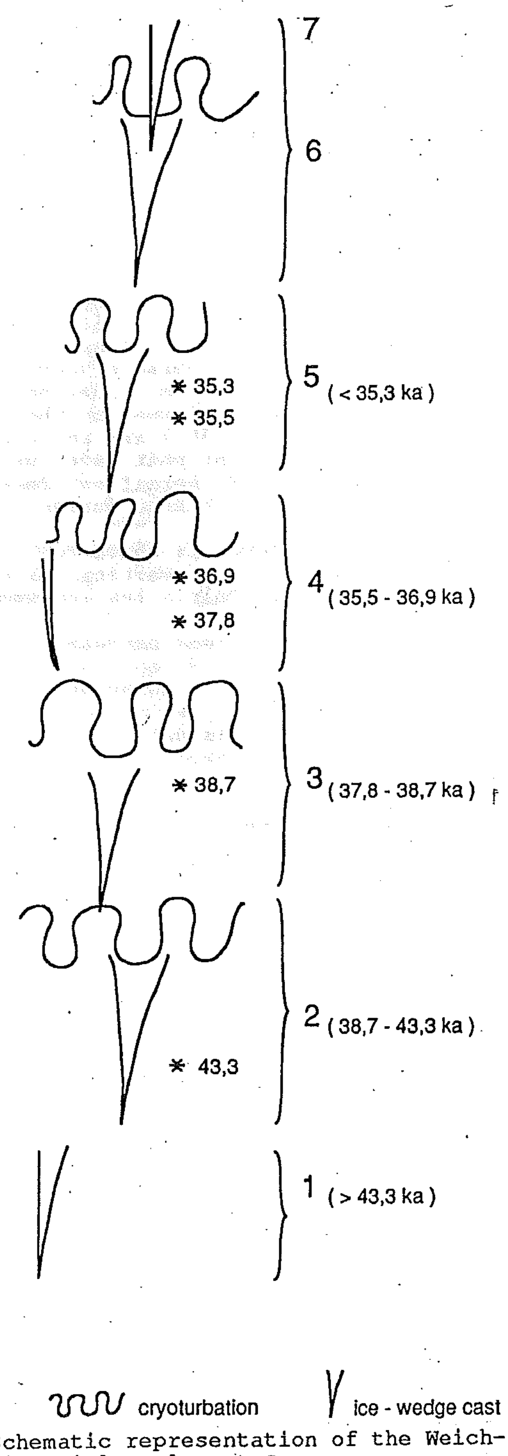

Figure 3 Schematic representation of the Weichselian periglacial cycles at Grouw.

The second level consists of numerous casts of different size overlain by a zone of cryoturbation, 80 to 110cm in amplitude. Some of the casts are fully developed while others seem to have been interrupted in a young stage. As demonstrated earlier (Vandenberghe 1983), the ice-wedge casts and cryoturbations formed in a single time span during permafrost degradation; remnants of the ice wedges continued to exist below the permafrost table while the involutions formed in the deepening active layer. This means that the involuted organic silt, although it overlies the ice-wedge casts, is at least as old as, or older, than the ice- The organic layer is dated at c. 43.3 ka while another overlying organic silt, which is not affected by the cryoturbation, is dated at c. 38.7 ka. It follows that permafrost established and (partially) disappeared between these two dates.

The third level shows many similarities with the second. It consists of ice-wedge casts with overlying cryoturbations (amplitude 50 - 100 cm). Dating of this phase of permafrost aggradation is possible by considering the age of the organic layer deformed by the cryoturbations of this phase (38.7 ka) and the age of the base of an overlying peat layer which is not deformed (37.8 ka). Permafrost re-established and degraded at this site during this 900 years period.

The fourth level is characterized by involutions, about 70 cm in vertical extent, on top of a peat layer. Only a few ice-wedge casts have been found.
Although somewhat less expressed, these periglacial features point again to the development of permafrost and its subsequent degradation. The top of the peat, which formed before the ice-wedge growth, is dated at c. 36.9 ka while the next youngest organic layer, formed with certainty after the degradation of that permafrost, is 35.5 ka old.

Fully developed ice-wedge casts and associated well-expressed cryoturbations (amplitude 100 cm) characterize the fifth level. This level postdates a deformed organic layer the top of which is dated at c. 35.3 ka. Thus, the development and degradation of permafrost is slightly younger than this date.

The sixth phase mainly consists of extensive cryoturbations (c. 70 cm amplitude) which are developed in the uppermost fluvial sands. Only a few ice-wedge casts have been observed. Unfortunately, levels 6 and 7 cannot be dated absolutely, because of the absence of organic matter.

The uppermost level (7) is composed only of large ice-wedge casts. The overlying (cryoturbated) sediments have been removed by erosion (possibly deflation) during the Weichselian Late Pleniglacial or Late Glacial. The Holocene podzol was formed in this eroded Weichselian surface (see fig. 2). The wedge casts of level 7 form together with the casts from the underlying levels classical examples of syngenetic ice-wedge casts: they form a wedge-in-wedge structure (Vandenberghe & Van Huissteden 1988; Mackay 1990). The wedges of level 7 may have been formed shortly after the older levels, this means shortly after 35 ka. Otherwise, it is also possible that the last two periglacial levels developed during the last glacial maximum around 23-17 ka.

Relation between sedimentary environment and permafrost development/degradation

The overbank facies reveals a sedimentary and a periglacial cyclicity. The sedimentary cycles consist of fining-upward sequences from fine or medium sands into (humic) silts or (clayey) peat. These sedimentary cycles are stacked upon each other without interruption or they are separated by concordant erosion levels. According to the regular sedimentation sequence it seems that the eroded volumes were very small (except for the lower- and uppermost levels).

The periglacial levels normally consist of ice-wedge casts associated with overlying cryoturbations. It is striking that the periglacial levels correspond with the sedimentary cycles and both systems run perfectly parallel. The topographic surface at the time of permafrost development probably coincides with the top of the fining-upward sequence. However, the upper surfaces of the cryoturbated zones do not necessarily correlate with the top of the fining-upward series. Instead, they generally occur in the lower sandy part of the overlying sediment cycle. The cryoturbated zones mostly consist of an intermingling of silt/peat (top of the lower fining-upward sequence) and sand (base of the overlying fining-upward sequence). This indicates that permafrost degradation occurred during flooding at the beginning of a new overbank sedimentation cycle. The bottom of the cryoturbations marks the minimum depth of permafrost degradation.

Model of permafrost development on a periglacial floodplain

A model of periglacial river activity and permafrost development is proposed.

The fluvial system is subdivided into channel and adjacent overbank environments. The overbank environment is characterized by cyclic deposition. Flooding of the river plain (deposition of sand by running water) is followed by a period of decreasing flow and standing water conditions (deposition of sandy to clayey silts) and finally transformation of the ponds into marshes (organic silts, peat).

During the latter phase of stable conditions permafrost becomes established and ice wedges form. This development continues until the next invasion of the floodplain. At that point sands are deposited while permafrost thaws as a consequence of the water on the floodplain. Then wedge ice melts, as well as the top of the ice-rich permafrost, resulting in the transformation of ice-wedges to ice-wedge casts and the formation of cryoturbations in the top sediments. The sedimentation cycle continues by deposition of fines in the backswamps while permafrost (at least) partially disappears depending on its thickness and the duration of flooding.

This twofold cycle has been recognized at least seven times. The frequent presence of organic backswamp deposits allows detailed dating of the events. This holds especially for the cycles 2, 3 and 4 which are bracketed accurately between radiocarbon dates. It is striking that the periglacial cycles 3 and 4 and their parallel sedimentary cycles were established in a short time: in less than about 0.9 ka and 1.4 ka respectively.

Synthesis

Ice-wedge growth in the Weichselian periglacial floodplain was interrupted by flooding phases with partial melting of the permafrost.

Figure 4 Ice-wedge cast and associated cryoturbation from level 3 overlain by ice-wedge cast from level 4. The cryoturbated zone at the base of the photo belongs to periglacial level 2.

After an inundation event, when the floodplain fell dry, the buried remnants of the ice wedges were reactivitated. Ice-wedge casts from one level are found on top of wedge casts from an older level and partially penetrating into them (Figure 4). This mechanism of cyclic syngenetic ice-wedge
growth differs from classical syngenetic ice-wedge formation, described by French & Gozdzik 1988, which is characterized by more continuous deposition and simultaneous upward growth of the ice wedge (Figure 5). Cyclic syngenetic ice-wedge formation, as described here, is characterized by a more steplike development. This is caused by substantial sedimentation in between the different phases of ice-wedge development and by the partial melting of the wedge ice from a previous growth phase. In this way, cyclic syngenetic ice-wedge casts can be dis-tin-guished in the field.

References

Dostovalov, B.N. and A.L. Popov (1963) Polygonal systems of ice wedges and conditions of their development. In 'Proceedings International Conference on Permafrost', Lafayette, Indiana. Nat. Res. Council, Washington D.C., 102-105.

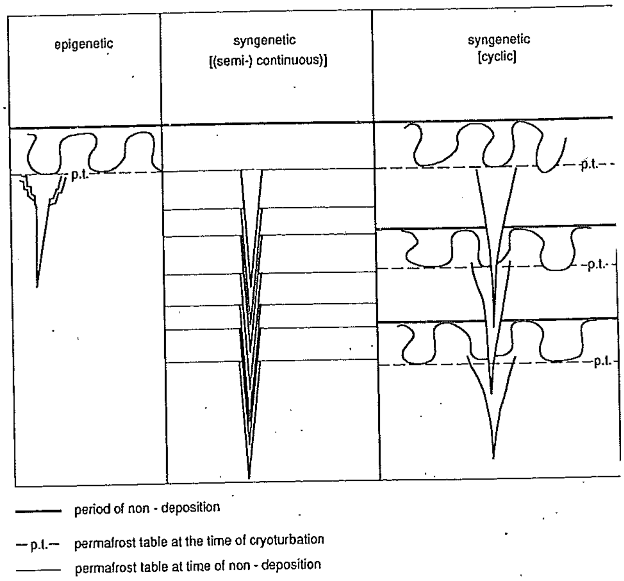

Figure 5 The main characteristics of cyclic syngenetic ice-wedge casts and cryoturbations compared with syngenetic and epigenetic forms.

French, H.M. (1976) The periglacial environment. Longman, London.

French, H.M. and J.S. Gozdzik (1988) Pleistocene epigenetic and syngenetic frost fissures, Belchatów, Poland. Can. J. Earth Sci. 25, 2017-2027.

Harry, D.G. (1988) Ground ice and permafrost. In Clark, M.J. (ed.) 'Advances in Periglacial Geomorphology', Wiley, Chichester, 113-149.

Harry, D.G. and J. Gozdzik (1988) Ice wedges: growth, thaw transformation, and paleoenvironmental significance. Journ. of Quatern. Science 3, 39-55.

Mackay, J.R. (1990) Some observations on the growth and deformation of epigenetic, syngenetic and anti-syngenetic ice wedges. Permafrost and Periglacial Processes 1, 15-29.

Vandenberghe, J. (1983) Ice-wedge casts and involutions as permafrost indicators and their stratigraphic position in the Weichselian. Proc. 4th Int. Conf. Permafrost I, Fairbanks, 1298-1302.

Vandenberghe, J. (1985) Paleoenvironment and stratigraphy during the Last Glacial in the Belgian-Dutch border region. Quaternary Research 24, 23-38.

Vandenberghe, J. and J. Van Huissteden (1988) Fluvio-aeolian interaction in a region of continuous permafrost. Proc. 5th Int. Conf. Permafrost, Trondheim, 876-881.