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Cryoturbation Types in Eolian Würm Late Glacial Sediments in Flanders, Belgium

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Summary: An eolian coversand-belt of 80 km length was formed in the northern part of the Flemish Valley during the Würm Late Glacial period. A series of different cryoturbation types can be examined in the sedimentary structures of these sands. A schematic environmental model is outlined in order to explain these cast structures within a paleogeomorphological context.

Zusammenfassung: Im nördlichen Teil des Flämischen Tales erstreckt sich auf einer Länge von 80 km eine äolische Decksandzone, die im Würmspätglazial gebildet wurde. Die sedimentären Strukturen dieser Sande lassen eine Abfolge verschiedener Kryoturbationstypen erkennen. Anhand eines Modells werden diese Strukturen im Rahmen ihrer paläogeomorphologischen Milieubedingungen erklärt.

INTRODUCTION

The northern part of the Flemish Valley (TAVERNIER & DE MOOR, 1974) is characterized by the presence of an east-west running coversand-ridge of about 80 kilometres length extending from Stekene, through Zelzate, Eeklo and Maldegem towards Brugge, Roksem and Gistel (DE MOOR & HEYSE, 1978) (Fig. 1).

This coversand-ridge has a microrelief of small ridges and dunes, only a few metres high, separated by irregular microdepressions (HEYSE & DE MOOR, 1979). In flat areas this coversand-ridge dominates the adjacent lower lying areas. In hilly regions however, it forms a relatively low-lying rim near the basal concavity of the hill slope. Genetically, it is formed by deflation of locally outcropping sandy Pleistocene substrata, followed by eolian transport and re-deposition. C14 and palynological analyses of intervening peaty layers indicates the ridge formed during the Late Würm between 13,000 and 10,000 years BP. (HEYSE, 1975; VERBRUGGEN, 1970; VAN HOORNE & VERBRUGGEN, 1975; VERBRUGGEN & VAN DONGEN, 1977; HEYSE & DE MOOR, 1979; KOLSTRUP & HEYSE, 1980).

In this paper, different cryoturbation types, observed in these sediments in a detailed study of 27 exposures during the period 1969—1979, are described. The interaction between the paleo-micromorphological conditions and the climatic environment is analysed. The possible presence of permafrost during the Late Würm in northern Belgium is also discussed.

GEOMORPHOLOGICAL TYPE SECTIONS

There are two types of coversand-ridges: namely a valley-position (Fig. 2a) and a hillslope-position (Fig. 2b).

The east-west oriented coversand-ridge crosses several valleys which drain naturally south-north. Southwards, the coversand-rim depressions, which receive drainage, are overgrown by swampy plants and are infilled by marl and peat. Northwards, the coversand-belt, an extremely flat deflation surface with small local coversand-ridges, has been fashioned. This geomorphological type occurs in the Waardamme Valley, the Ede Valley and the Flemish Valley.

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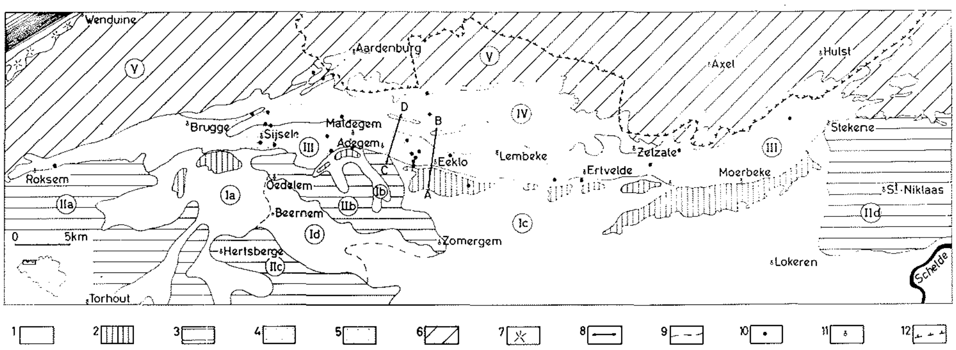

Fig. 1: Outline of the Würm late glacial coversand-belt near Maldegem-Stekene. I = valleys (Late Pleistocene/Würm): Ia = Waardamme valley, Ib = Ede valley, Ic = Flemish valley, Id = saddle-shaped valley; II = hills (Middle-Late Pleistocene): IIa = hills of Torhout, IIb = hills of Oedelem-Zomergem-Adegem, IIc = hills of Hertsberge, IId = hills of „Land van Waas'' cuesta; III = coversand-ridge (Würm Late Glacial); IV = deflation surface; V = polders (Holocene Dunkirk). 1 = flat relief (fluvioperiglacial), 2 = swampy depression, 3 = hilly relief, 4 = eolian coversand-ridge, 5 = flat eolian deflation surface, 6 = marine clay, 7 = coastal dune, 8 = type sections, 9 = approximate valley boundary, 10 = excavation, 11 = village center, 12 = state boundary.

Abb. 1: Die Verbreitung der würmspätglazialen Decksandzone zwischen Maldegem und Stekene. I = Täler (Jungpleistozän/Würm): Ia = Waardamme-Tal, Ib = Ede-Tal, Ic = Flämisches Tal, Id = sattelförmiges Tal von Beernem; II = Höhenzone (Mittel- bis Jungpleistozän): IIa = Höhen von Torhout, IIb = Höhen von Oedelem-Zomergem-Adegem, IIc = Höhen von Hertsberge, IId = Höhen der „Land van Waas''-Stufe; III = Decksandrücken (Würmspätglazial); IV = Deflationsfläche (Würmspätglazial), V = Polder (Holozänes Dünkirchen). 1 = Flachrelief (periglaziärfluvial), 2 = sumpfige Niederungen, 3 = hügeliges Relief, 4 = äolischer Decksandrücken, 5 = ebene Deflationsfläche, 6 = mariner Ton, 7 = Küstendünen, 8 = typische Querprofile, 9 = ungefährer Talrand, 10 = Aufschluß, 11 = Dorf, 12 = Staatsgrenze.

Due to their hillslope-position (Fig. 2b) coversands thin out towards the hillslopes and form relatively low laying sandbelts which receive drainage water directly as run-off. Locally, wind-blown material occurs upon the hills. This is common for the northern hilly region of Torhout, the hills of Oedelem-Zomergem-Adegem and the cuesta landscape of Land van Waas (St.-Niklaas).

Sediments of the type sections:

(1) Tertiary substratum: Heavy plastic clay, glauconitic clay and sometimes glauconitic sands of Eocene or Oligocene age. This substratum has been strongly indented by Pleistocene fluviatile and fluvio-periglacial erosion, resulting in a relief of valleys up to 25 m deep and hilly interfluves of about + 30 m.

(2) Fluvio-periglacial Würm sediments: fine grey sands with scarce gravel elements, loamlayers, sand-loam or peaty loam with marl intercalations. Compact peat layers interdigitate with sandy and loamy layers. The Pleistocene valley systems are partly infilled and flattened with these sediments. Near the dipping Tertiary substratum fine laminated slope deposits occur.

(3) Eolian Würm Lateglacial gravel: silex pebbles, broken silex elements, greenish sandstone, calcareous sandstone and white quartz pebbles in a coarse sand, forming a horizontal stoneline. Some gravel elements are clearly polished by eolian action. This gravel layer is well developed north of the coversand-ridge.

(4) Eolian Würm Lateglacial coversand: fine well sorted and laminated sand with thin undulating peat lenses (up to 5 cm thick) on different levels. In some depressions sandloam laminae, loam lenses, thick peat (up to 30 cm) and marl layers occur. The topzone of the coversands is strongly podzolised.

(5) Swampy Würm Lateglacial sediments: dark brown peat and wood fragments, alternated with loam-layers, sandloam laminae and marl intercalations. Lenses with non-marine mollusca are locally abundant. These swampy sediments are a few metres thick and outcrop in the depression belt southwards of the coversand-ridge and interdigitate with the sandy ridge sediments.

(6) Eolian Holocene blownsand: fine well sorted and laminated sand with rare humus laminae and plant debris. These dune sands overlie a well developed podzol and are only developed upon the coversand-ridge.

WEDGE STRUCTURES

Frost crack pattern with desert pavement (Fig. 3, type 1)

The crack pattern of wedges is up to 0.3 m to 0.5 m deep and a few centimetres wide. The interdistances vary from a few centimetres up to 0.5 m. The cracks are infilled with homogeneous fine sand and the adjacent coversand laminations are undisturbed. The crack pattern is developed from an erosional base to the coversand and is associated with a stone layer. Some wedges, with downward laminated bending, belong to an older system. The pebble line, of silex, quartz and sandstone elements with an average diameter of 0.5 cm, covers the erosion surface and some elements are polished by eolian action. Locally, the frost crack pattern, as well as the gravel layer, are split up and envelop fine laminated coversand. This frost crack pattern is well developed in the flat zone north of the coversand-ridge of Maldegem-Stekene, under a thin sand veneer. On the coversand-ridge itself, the frost cracks and gravel elements are scarce.

The crack pattern probably developed under dry and cold polar desert conditions, the result of deflation processes by dominant northern winds. By selective deflation a desert pavement was formed in flat sandy areas while, simultaneously, fine sand was transported as asymmetrical sand dunes filling up the open crack pattern (frost crack according to DYLIK & MAARLEVELD, 1967). Different frost crack patterns from various seasons, are not always easy to distinguish from each other. The small cracks may represent either a juvenile pattern formed by relatively small temperature differences or the ends of deeply developed eroded cracks.

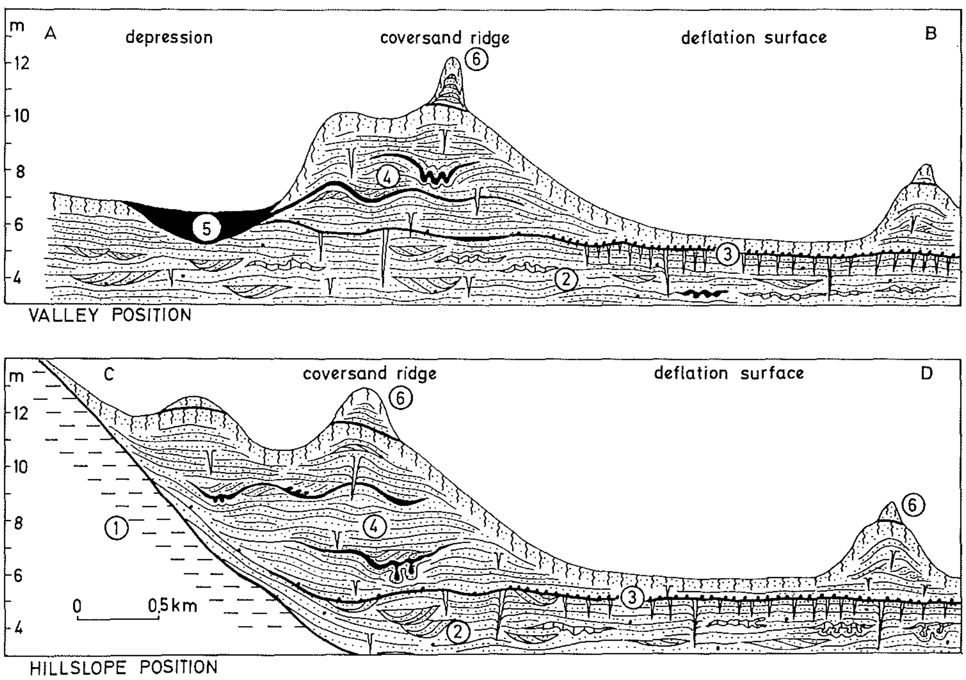

Fig. 2: Schematic type sections of coversand-ridges in Flanders. Above: valley-position, below: hillslope-position. 1 = Tertiary marine clay, 2 = Würm fluvioperiglacial sand, 3 = Würm late glacial deflation gravel, 4 = Würm late glacial coversand with peat lenses, 5 = Würm late glacial peat and marl, 6 = Holocene dune sand.

Abb. 2: Schematische Querprofile von Decksandrücken in Flandern. Oben: Tallage, unten: Hanglage. 1 = tertiärer mariner Ton, 2 = würmzeitliche periglaziärfluviale Sande, 3 = würmspätglaziale Steinsohle, 4 = würmspätglazialer Decksand mit Torflinsen, 5 = würmspätglazialer Torf und Mergel, 6 = holozäner Dünensand.

Isolated frost cracks (Fig. 3, type 2)
Isolated cracks are of different depth (0.3 to 1 m) and a thickness between 0.5 cm and 2 or 3 cm practically without lateral laminated bending and infilled with homogeneous coversand. The toplevel is sometimes associated with coarser sand. The interdistances between the cracks are irregular (0 to 2 m) so that a real crack pattern is lacking. This type of cracks is preserved on different levels in the coversand, especially in paleogeomorphological ridge situations.

These frost cracks developed under dry and cold conditions in coversands and then were immediately filled and buried by younger sand, preventing further erosion. The depth of these cracks is directly related to the extreme seasonal winter temperatures.

Isolated frost wedges (Fig. 3, type 3)
Wedges may vary in depth between 0.5 and 1.5 m, and from a few millimetres to 3 cm in width, without regular pattern. A downward bending of the side laminae by a few centimetres is characteristic. Some wedges show a narrow funnel-like head widening. Occasionally broken wedges with partial side displacement occur. The toplevels are mostly situated in sandy ridge-sediments.

During their activity these wedges were probably infilled by snow followed by meltwater during the next warm period. This resulted in the downward displacement of the side laminae. However, the sideplanes of the wedges may have been covered by sublimation ice crystals and the melting of these would have caused the same effect on the side laminae (DYLIK & MAARLEVELD, 1967). The broken frost wedges would have been displaced by microtectonic pressure or simply by superficial mass movement and solifluction.

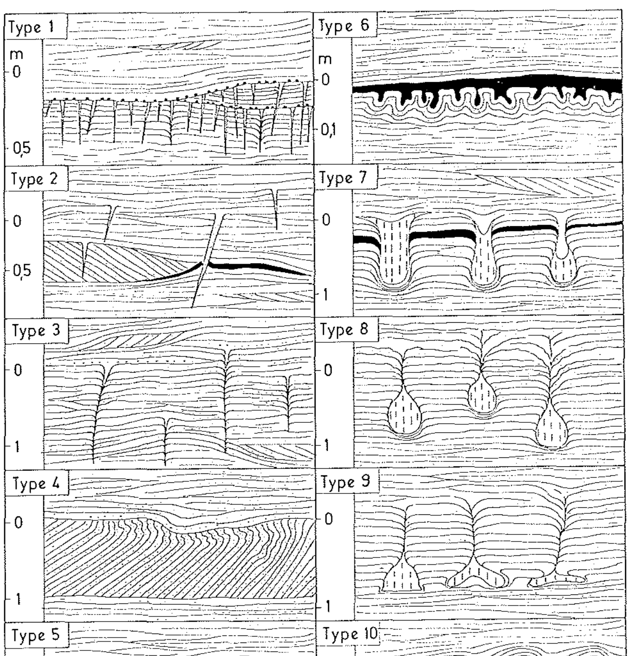

Fig. 3: Disturbance types in Würm late glacial eolian coversands.

Abb. 3: Perstruktionstypen in würmspätglazialen äolischen Decksanden.

FLUIDAL STRUCTURES

Laminated bending (Fig. 3, type 4)
The primary diagonal steeply dipping sand laminae in some coversand sets are disturbed undirectional at their topzone by regular fluidal turbations of a few centimetres in magnitude. These disturbances occur in thick coversand sets which have levelled and infilled old shallow depressions. Beneath these sets are impermeable compact peat layers or loam lenses. Sometimes, the laminae in the sets themselves are bended.

These disturbances are explained as load structures which occurred under supersaturated conditions. The relatively impermeable peat layer caused a temporary groundwater level, either during the warmer summer periods or the warmer phases of the Würm Late Glacial. The presence of waterplants and freshwater shells support a swampy phase and even open water in the largest depressions. By windworking, wave action and surface wash the thin oversaturated sand laminae can be moved over a few centimetres. At the same time some transport of sand is not excluded. Local permafrost would have the same effect on the groundwater level.

Chaotic bending and involutions (Fig. 3, type 5)
These disturbances are related to heterogeneous layers such as peat, loam and sandloam in a coversand matrix. The irregular involutions and disturbances occur in various directions and are 10 to 20 cm in dimension. They are accentuated by the parallel bending of the adjacent laminae. The layers can be discontinuous and broken by the disturbances. These chaotic disturbances are especially well preserved in infilled microdepressions and in the coversand-ridge. The more or less fluidal pattern suggests a viscous supersaturated environment under pressure. The absence of an impermeable substratum supposes the necessity of local permafrost and an active layer.

Upward involutions (Fig. 3, type 10)
A series of regular upward trending or vertical lobes of peat or peaty sand occur in a matrix of well sorted sand. The foldings are about 20 cm high and affect only the topzone of a laminated peat layer, the base of which is composed of compact sphagnum debris. The peat is restricted to a microdepression in the coversand-ridge. The compact nature of the sphagnum has undoubtedly acted as a temporarily impermeable layer, probably under frozen conditions. By local thawing of the overlying coversand and peat toplayer, an active layer was created. Lateral groundpressures in the active layer resulted in solifluction and sliding on the slope of the microdepressions so that blanket-like folding occurred. Thus, the frozen ground beneath the lowest part of the peat layer acted as a shear plane.

Downward micro-involutions (Fig. 3, type 6)
Small downward tongue-like involutions about 5 cm deep and 1 to 2 cm in breadth occur in humic peaty layers in well sorted coversand. The top level of the humic layer is nearly horizontal. The coversand laminae show a parallel bending with the micro-involutions, which are preserved in small depression-like forms in the coversand-ridge.

A frozen substrate with seasonal freezing and thawing of the surface layers is probably needed to explain the tongue-like involutions.

Droptails (Fig. 3, type 7)
Big downward trending tongue-like involutions (0.5 m to 1 m in depth and 10 to 15 cm in width) of loam, marl peaty clay or peat occur in a matrix of well sorted coversand. Exceptionally, the tongues reach a depth of 1.2 m and a breadth of 0.3 m. Developed lobes are mostly crescent shaped and the sideminae are interrupted and bent down. Near the lobebottom the sand laminae are elongated. Some disturbances are isolated while others are grouped with interdistances varying between 2 and 5 m. The droptail structures are related to heterogeneous sediments in depressions or to basal slope sediments adjoining valley bottoms. They can pierce older peat layers. Isolated tongues of humic clayey peat occur in ridge sedi-

ments. The original upper surface of some disturbances is situated in the soil profile and seems to correspond directly with the surface of actual microdepressions.

Droptails only develop in supersaturated conditions. The structures give a minimum thickness of the seasonally thawed zone. An impermeable layer of frozen ground beneath must exist. The refreezing of the thawed layer results in an increase in cryostatic pressure which activates the mechanism.

Dropstructures and spherical structures (Fig. 3, type 8)
Drop- and spherical structures of heavy loam, marl and clayey peat occur in well sorted coversand. The drop diameters usually vary between 5 and 20 cm and exceptionally to 30 cm. The smaller ones are common in peat, while the larger ones occur in loam and marl. Most dropstructures have a vertical tail of 10 cm passing gradually into a linear trail, seen as a downward bending of laminations. With depth, the elongated sandy laminations pass around the spherical structure. The trailsign is 0.5 to 1 m in length.

The dropstructures are developed in similar situations to droptails but represent a further evolution phase. The heterogeneous material retakes the spherical form and the central trail symbolizes the sinking direction. After the drops have passed through the adjacent sediments flow together again.

Clock structures and "boomerang" structures (Fig. 3, type 9)
Clock forms of heavy loam, marl and clayey peat occur in a coversand matrix with a well developed horizontal base level and with a trailmark. Variations occur as "boomerang" structures with downward lobes. The individual types (30 to 40 cm wide) are situated at 0.3 or 0.5 m from each other. The sandy coversand laminae are disturbed at the same way as for types 7 and 8 with the exception for the completely undisturbed base laminae. These disturbance types occur in analogous paleogeomorphological circumstances to types 7 and 8.

The clock structures are related to permafrost and a refreezing seasonally thawed layer, as with drop-and spherical structures, but they represent a still further evolution phase. The vertical downward movement was stopped suddenly by the impermeable frozen layer, which acted as an obstruction for the viscous loam ball. The flow structures for the "boomerang" structures during the end phase are not so regular. In any case, the top of the previously frozen soil layer is easy to reconstruct.

ENVIRONMENTAL MODEL

The different disturbance types can be grouped on their morphological and paleomorphological position:
(1) The crack structures (Fig. 3, type 1) are associated with sandy flat zones and a thin coversand layer (deflation area).
(2) The wedge structures (Fig. 3, type 2, type 3) are preserved in the dry sandy ridges of the large coversand-belt Maldegem-Stekene and also in the smaller coversand-ridges developed upon the deflation surface.
(3) The fluidal structures (Fig. 3, types 4, 5, 6, 7, 8, 9 and 10) are associated with heterogeneous sediments in actual or previous depressions in the coversand area Maldegem-Stekene. Some disturbance types (types 7, 8, 9) represent successive evolution phases of one process.

By reconstructing a global genetic scheme, the morphological factor was a dominant influence in an active eolian landscape during the Würm Late Glacial climate. The following evolution phases can be distinguished:

Phase 1: Coversand morphology of ridges and depressions with freezing of the soil during the winter periods.

Phase 2: Preferential frost crack development (types 2, 3) on flat surfaces and on the highest snowfree ridges, as a consequence of strong windworking and extra low winter temperatures. The depressions are protected by snowcover.

Phase 3: Infilling of the open cracks with driftsand (type 2) or snow (type 3). During this phase superficial eolian erosion of the cracks is possible.

Phase 4: During a warmer season or period, snow melts in the depressions and colluvium, loam or peat forms. Melting of the frozen bottom develops an unfrozen layer. In an analogous way, the cryoturbation types 2 and 3 developed in flat areas.

Phase 5: After maximal thaw solifluction occurs on the slopes and the depressions are infilled. Frost wedges are either deformed on smooth slopes or are displaced at the contact between the permafrost and the active layer. Initial disturbances (type 5), and involutions (type 10) originate in the colluvial and peaty sediments under pressure.

Phase 6: Refreezing from the surface as well as from the top of permafrost induces an active layer under pressure and results in the further development of some fluidal disturbances (types 5, 6, 10).

Phase 7: The ridge environment is more suited to the quick aggradation of permafrost; in the depressions unfrozen ground persists as the result of locally thicker depth of seasonal thaw, the possible lower freezing rate of the peaty and loamy sediments, and the supplementary protection of snowcover. The fluidal disturbances such as types 7, 8 and 9 develop. In this phase it is probable that surface freezing is unequal from one spot to another and depends on morphological factors.

Phase 8: The disturbances in the sediments in the depressions are fossilized by the permafrost.

Phase 9: Further accumulation by coversands results in a complete levelling of the depression, and the formation of a different eolian microrelief. It permits an aggradation of permafrost. The relative deeply buried disturbance types are not disturbed anymore by the next thaw-freeze cycle.

CONCLUSION

The disturbance types of Fig. 3 are syngenetic for the large coversand-ridge sediments and have undoubtedly a paleoclimatological meaning for the Würm Late Glacial period in North Belgium. The absence of ice-wedges lets one assume that the average annual temperature was higher than —6 ° C (PÉWÉ, 1966). The presence of frost cracks and frost wedges are the only indicators for extreme cold winter temperatures. These seasonal phenomena can already develop from —15 ° C (DYLIK & MAARLEVELD, 1967). The thickness of an active layer in homogeneous sandy sediments in flat areas is a parameter for the summer temperatures. Seasonal solifluction processes have nevertheless involved differences in the active layer. On slopes the thickness of the previous active layer of about 0.4 m is evident; in depressions the maximum thickness reaches about 1.2 m.

Field evidence of frozen ground which survived the warmer summer seasons is numerous and supports at least the assumption of discontinuous permafrost during the Würm Late Glacial period. However, it is not clear if this permafrost was only present for the cold phases of the Würm Late Glacial (Oldest Dryas, Old Dryas and Young Dryas) or also could have persisted during the warmer periods of the Bölling and the Alleröd.

The problem of permanent permafrost, discontinuous permafrost, aggrading or degrading permafrost

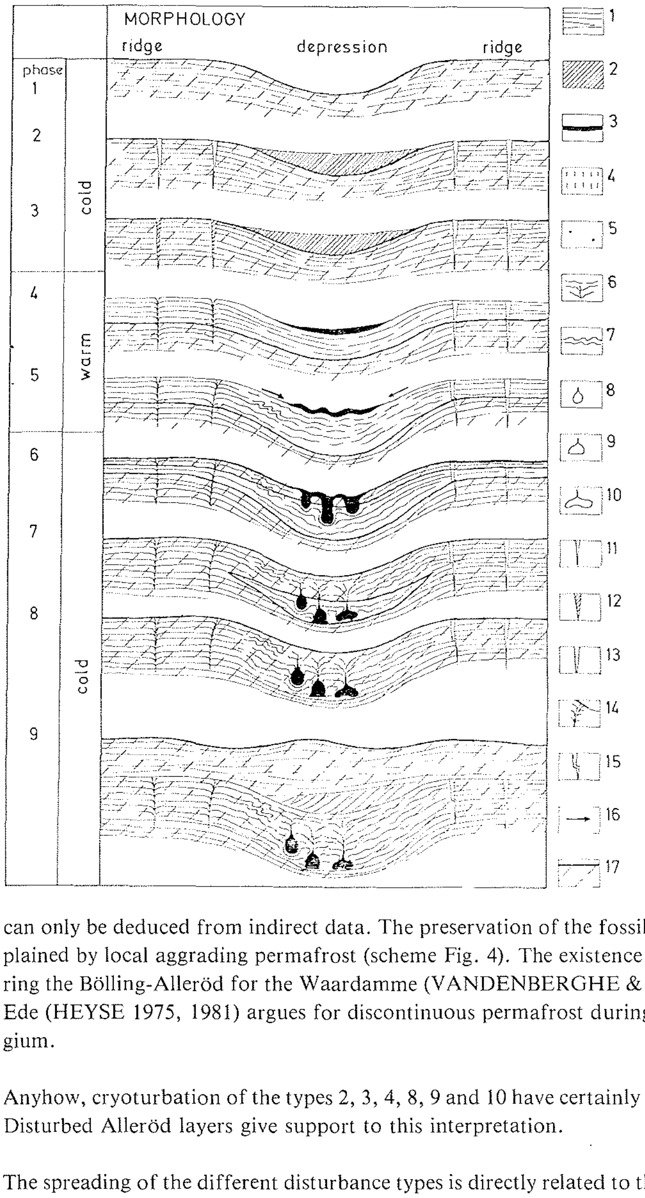

Fig. 4: Würm late glacial environmental model in coversand area, Flanders. 1 = sandy laminations, 2 = snow, 3 = peat, 4 = loam, 5 = gravel, 6 = disturbed lamination, 7 = micro-disturbations, 8 = droptails, 9 = clock disturbances, 10 = boomerang disturbations, 11 = frost crack, 12 = frost crack with snow, 13 = frost crack with sand, 14 = bended frost crack, 15 = disturbed frost crack, 16 = direction of solifluction, 17 = permafrost.

Abb. 4: Modell der würmspätglazialen Milieubedingungen im Decksandgebiet von Flandern. 1 = sandige Bänderung, 2 = Schnee, 3 = Torf, 4 = Lehm, 5 = Kies, 6 = gestörte Bänderung, 7 = Mikroperstruktionen, 8 = Tropfenböden, 9 = uhrförmige Tropfenböden, 10 = bumerangförmige Perstruktionen, 11 = Frostspalte, 12 = schneegefüllte Frostspalte, 13 = sandgefüllte Frostspalte, 14 = verbogene Frostspalte, 15 = versetzte Frostspalte, 16 = Richtung der Solifluktion, 17 = Dauerfrostboden.

can only be deduced from indirect data. The preservation of the fossil disturbance types can easily be explained by local aggrading permafrost (scheme Fig. 4). The existence, however, of fluviatile activity during the Bölling-Alleröd for the Waardamme (VANDENBERGHE & GULLENTOPS, 1974) and for the Ede (HEYSE 1975, 1981) argues for discontinuous permafrost during the warmer periods in North Belgium.

Anyhow, cryoturbation of the types 2, 3, 4, 8, 9 and 10 have certainly developed after the Alleröd period. Disturbed Alleröd layers give support to this interpretation.

The spreading of the different disturbance types is directly related to the types of sediments and to the paleogeomorphological position (flat, depression, ridge or slope). The paleohydrological conditions were directly related to the morphological site, the permeability of the sediments and the depth of the frozen subsoil and resulted in extreme dry conditions and extreme wet conditions upon the Würm Late Glacial coversand belt.

The evolution of the cryoturbation types (Fig. 4) can be related to seasonal frost-thaw cycles as well as to the colder and warmer phases of the Würm Late Glacial.

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