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PERIGLACIAL DEPOSITS AND SEDIMENTARY STRUCTURES IN THE UPPER PLEISTOCENE INFILLING OF THE FLEMISH VALLEY (N.W. BELGIUM)

Abstract

The Flemish Valley forms the main upper Pleistocene outlet of the Scheldt river in Northern-Belgium (51°N lat. 3° E long.). It consists of a very wide thalweg pattern, deeply cut into a sandy-clayey Tertiary substratum and filled up by Saalian fluvioperiglacial deposits, by Eemian marine and fluviatile sediments and mainly by Vistulian deposits of dominantly fluvioperiglacial nature, covered by a rather thin sheet of Tardiglacial eolian sediments, which dammed and deviated the northwards directed upper Pleistocene drainage. The paper presents an outline of the evolution of the Flemish Valley and describes four outcrops in eo-Vistulian, meso-Vistulian, fini-Vistulian and Tardiglacial infillings of the Valley, especially focusing on fossil periglacial structures, their nature and their paleoclimatic meaning in a stratigraphical and paleomorphological framework.

Résumé

La Vallée Flamande constitue l'exutoire néopleistocène principal de l'Escaut (51° N lat., 3° E long). Elle est formée d'un système de thalwegs profondément incisés dans un substrat tertiaire sablo-argileux et remblayé par des dépôts fluvio-périglaciaires Saaliens, marins et fluviatiles Eemiens et en majeure partie par des formations essentiellement fluviopériglaciaires d'âge Vistulien, recouvertes d'une faible couche de sables éoliens tardiglaciaires, ayant barré et dévié l'écoulement. L'auteur décrit brièvement l'évolution de la Vallée Flamande et présente quatre coupes dans des dépôts éo-Vistuliens, meso-Vistuliens, fini-Vistuliens et tardiglaciaires appartenant au colmatage de la vallée, tout en soulignant la nature et la signification paléo-climatique des structures périglaciaires fossiles dans leur contexte stratigraphique et paléo-morphologique.

EVOLUTION OF THE FLEMISH VALLEY

Valleys of fluviatile origin, dissected river terraces and southeast-northwest running cuestas carved by watergaps form the morphological backbone of northwestern Belgium (mean latitude: 51° N.lat.). They all are related to a network of consequent and subsequent river valleys which originated upon the Plio-Pleistocene emersion surface and scoured the north dipping Tertiary and early Quaternary marine sand and clay strata of the emerged Southern North Sea Basin. The higher terrace levels are mainly interfluvial ones. Valley side terraces are rather slightly developed. This is partly due to the erodability of the substratum which, with a few exceptions where the thalwegs reach the Paleozoic substratum, is higher than that of the gravelly terrace deposits. It is presumably also bound to an intensification of the vertical

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erosion and an increase of the frequency of the climatico-eustatic cyclicity, as there is no evidence for a tectonic differentiation and no general relationship to a changing lithostructure. Some of the more recent terrace levels lie partly buried within the main upper Pleistocene valley bottom infillings due to rise of the aggradation level (R. TAVERNIER and G. DE MOOR, 1974).

The overall hypsography falls slowly from about 170 m (a.s.l.) in the south to less than 5 m in the northwest. The main valley bottom axes are the consequently running Scheldt and Lys valleys south of Ghent, continuing farther northwestwards in the Flemish Valley (R. TAVERNIER, 1946; G. DE MOOR, 1963). North of Ghent its width exceeds 50 km and there it is joined by a major subsequent tributary valley bottom, departing from the east. The elevation in that main valley bottom system seldom arises above 20 m (a.s.l.) and in the Flemish Valley itself lies below 10 m (a.s.l.). It very slightly slopes down in a northwestern direction.

This main valley bottom complex forms a Vistulian sandy fluvioperiglacial aggradation surface. It is covered by a Tardiglacial coversand blanket, thinning out southwards and passing into deposits of a loessic origin, particularly on the west side of the consequent valleys. In the Flemish Valley itself, the coversand is shaped into low transverse coversand ridges. That blanketed fluvioperiglacial aggradation surface has been incised by much smaller Tardiglacial and eo-Holocene river valley cuttings. These are partly filled up with peaty-clayey alluvia and they put the fluvioperiglacial aggradation into a terrace position. To the northwest, where that surface dips below the 5 m level, it has been covered by reclaimed, mainly Subatlantic tidal flat deposits.

In the hilly regions, surrounding the Flemish Valley and its tributaries, morphological obliteration by periglacial processes is as well important. Moreover, the erosional surface of the substratum of Tertiary strata and Quaternary terraces has been slightly reshaped by loessic deposits.

In the Flemish Valley and its main branches the Quaternary cover reaches a thickness of 15 to 30 m (G. DE MOOR, 1963). Hence the elevation of the buried erosional surface of the Tertiary substratum there varies between −5 and −20 m a.s.l. (Fig. 1). That surface is a polygenetic and polychronic thalweg complex, scoured by successive phases of deep channel incision, valley widening, channel shifting and valley infilling. The resulting main thalweg scars are directed to the northwest. The most striking fact of the hydromorphological evolution is that, north of Ghent, the northwestern drainage direction has been diverted into an easterly directed Holocene one, mainly by Tardiglacial eolian damming and due to the formerly burying of an easterly situated saddle-shaped watergap by the fluvioperiglacial surface (G. DE MOOR, 1963).

The geologic nature of the thalweg infillings allows a reconstruction of the evolution of the Flemish Valley (G. DE MOOR and I. HEYSE, 1974; R. TAVERNIER and G. DE MOOR, 1974).

During the Elster glacial period consequent river valley bottoms and gravel deposits, more or less related to parallel running courses of pre-Scheldt and pre-Lys rivers, stretched out as well north as south of Ghent at an elevation of about +25/+30 m. There are also indications (V. DE GROOTE, 1977) that under still cold pre-Holstein

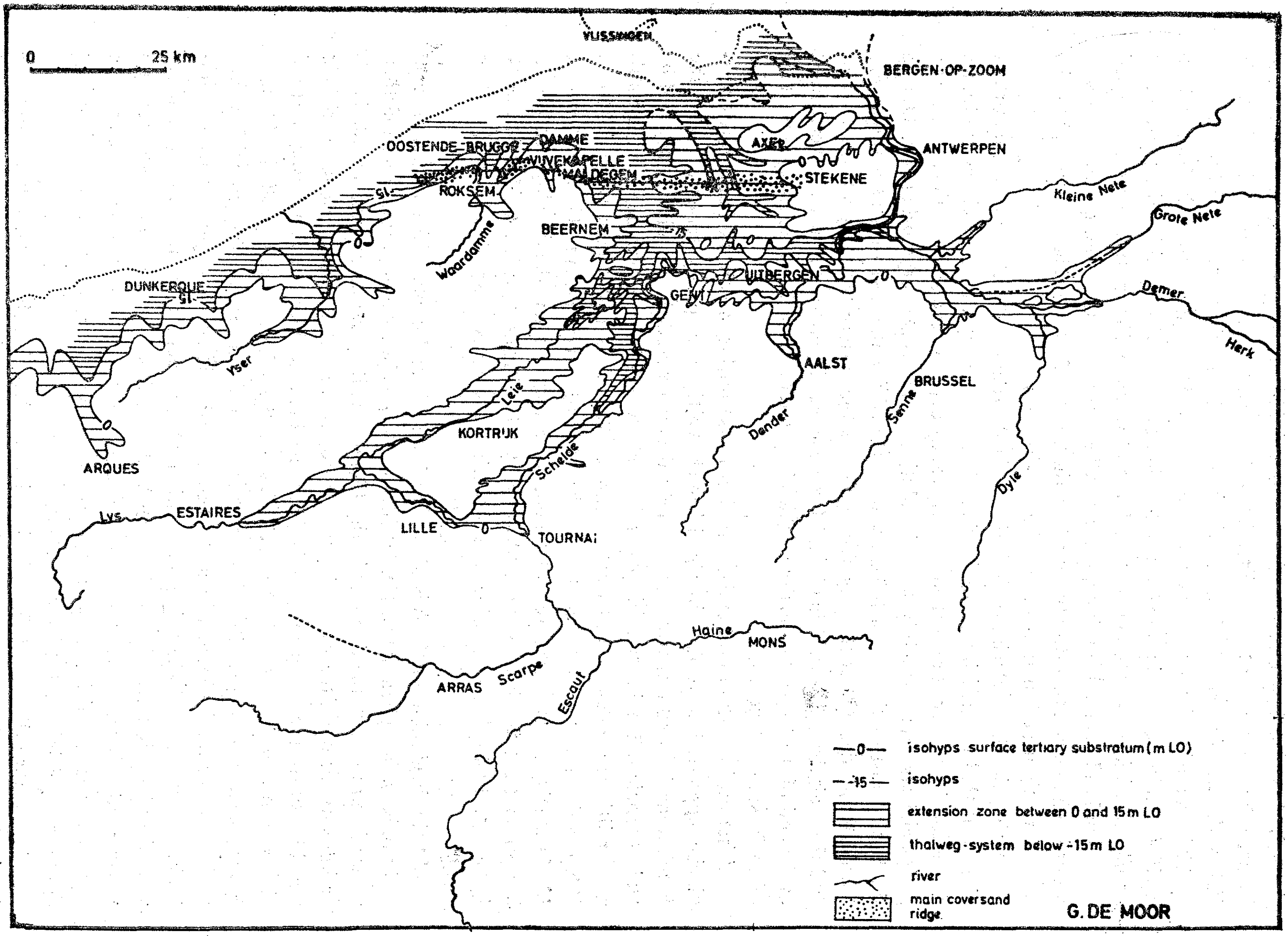

Fig. 1. Extension oı the Flemish Valley and its principal tributaries

conditions rather small southwards regressing thalwegs were scoured out, reached the neighbourhood of Ghent and knew thin infillings. They are presumed to have induced the development of the Flemish Valley and to have formed a paleo-Flemish-Valley thalweg system which near Ghent reached a level of about +10 m.

This scouring interferes with a renewed eo-Holstein thalweg incision which itself was followed up by fluviatile valley infilling, characterized by the presence of *Azolla filiculoides* (V. De Groote, 1977), and whose valley bottom surface reached a +15 m level near Ghent. Northwest of Ghent peaty-loamy infillings are known to occur in channels rather deeply cut below the 0 m (a.s.l.) level. They are thought to be related to tidal action in a perimarine environment.

During the Saale glacial period, the Flemish Valley knew at least two important phases of thalweg incision, each of them followed up by fluvioperiglacial infillings. These consist mainly of reworked Tertiary sandy deposits and show distinct syngenetic periglacial structures, mainly large involutions and regular cryoturbations. During the Saale most of the Flemish Valley was shaped for the first time as a wide, very flattened and deeply cut thalweg system. The large eastern tributary was carved out and the main branches of Scheldt and Lys were incised far southwards. Nevertheless, at the end of the Saale, the fluvioperiglacial aggradation surface reached again a level of at least −5/0 m a.s.l.

After an important eo-Eemian incision phase during which the Saale fluvioperiglacial aggradation surface in the Flemish Valley was partly scoured away, the Eemian marine and estuarine environment deeply entered the Flemish Valley and its main branches. Tidal action deeply and widely scoured the resting deposits. Estuarine conditions extended to at least 30 km south and east of Ghent (G. De Moor, 1963) and temporary interfered with the fluviatile environment (G. De Moor & M. Lootens, 1975). Northwest of Ghent the coastline knew the development of an important tidal flat belt (G. De Moor & W. De Breuck, 1973; G. De Moor & I. Heyse, 1978). These marine and estuarine sediments reached a level of +2 m (a.s.l.).

At the beginning of the Vistulian, sea level fell and climatic deterioration seem to have been fast phenomena (D. De Moor *et al.*, 1978). An important incision then scoured out most of the deposits in the Flemish Valley and its branches while back- and downwearing of the valley side by hill side processes started, particularly in frost sensible substratum. Northwest of Ghent the Eemian tidal flat belt however stood unremoved, and it protected the backlying smaller tributary valleys of the Flemish Valley, such as the depression of Beernem, west of Ghent. In the large Flemish Valley itself however the incision, which reached a −10/−15 m level, quite fastly was followed up by an early-Vistulian deposition phase. Departing from the mouths of second order tributaries in the Flemish Valley depression, large fans were built up whose gradually fining up aprons extended into the more central parts of the thalweg system of the Flemish Valley. Later during the Vistulian, similar but smaller fans developed again (G. De Moor, 1974).

During the whole Vistulian-pleniglacial, fluvioperiglacial aggradation, originating in the reworking of the outcropping terrains in the hilly surroundings, dominated the morphological evolution of the Flemish Valley. Although a cut and fill channel activity characterized the braided river activity pattern, large floodplains with tabular deposition of alternating sand, loam and peaty-loam beds (R. PAEPE, 1967; I. HEYSE, 1975) also occurred. Bound to climatic variations, intermittent intense channel cutting followed by fluvioperiglacial infilling still took place.

The whole complex of early- and pleni-Vistulian fluvioperiglacial deposits shows numerous levels of distinct casts of secondary periglacial structures such as frost wedges, ice wedges, involutions, cryoturbations, droptail levels, ice rafting phenomena, water extrusion structures and small thermokarst structures. Even in this valley bottom and since the end of the Earliest Vistulian incision phase, an at least discontinuous permafrost seems to have occurred over more or less long periods, perhaps shifting by the braided river pattern displacements and disappearing temporarily by climatic improvements. It nevertheless helped by the fixation of the braided river deposits and by the valley colmatation under low sea level conditions.

Towards the end of the Vistulian Pleniglacial (morphogenetical Finiglacial) and during the Vistulian Tardiglacial the intensity of the fluvioperiglacial drainage lowered, the climate became dryer, the drainage pattern changed from braided to more stabilized channels and river incision started. Meanwhile eolian activity became important by deflation and local blown out of the fluvioperiglacial surface, but also by formation of transversal sand dunes. The northwestern drainage direction was gradually barried and diverted to the east. Drainage damming by dune formation and ground-water level fluctuation changed lot of blown outs and dune depressions into meres, whose deposits in turn were buried by advancing dune sands (G. DE MOOR & I. HEYSE, 1978). It also becomes more and more evident that the cold phases of the Vistulian Tardiglacial not only witnessed seasonal frozen ground with development of levels of frost cracks and thin congelifluxion horizons, but that there also occurred patches with active layer and permafrost conditions.

The later Holocene evolution was mainly one of renewed river incision followed up by Boreal, Atlantic Sub-boreal and Sub-atlantic infilling by some river dune formation and by smaller changes in the drainage pattern but it also was marked by increasing tidal action in the lower northern part, due to the postglacial sea level rise.

EXCURSION POINTS

Four excavations cutting the Vistulian infilling of the Flemish Valley have been visited. They are classified here mainly after the chronostratigraphic position of the deposits, but they show as well some of the Vistulian sedimentation types in the Flemish Valley.

THE UPPER PLEISTOCENE INFILLING AT UITBERGEN

The excavation (51° 02′ 28″ N lat., 3° 58′ 45″ E long., elevation +5 m a.s.l.) is situated within a Holocene meander bench of the eastward running lower Scheldt river. The peaty surface lays at about 3 m below the low, flat and hardly microridged

Vistulian fluvio-periglacial aggradation surface (+8 m a.s.l.) of the main eastern embranchment of the Flemish Valley. The southern edge of the Flemish Valley is at 2 km to the south. A tributary valley (Dender), leaving the hilly interfluve after attacking the Paleozoic substratum farther upstreams, débouches at about 5 km to the east.

Between —8 and —4 m (a.s.l.): scoured Eemian fluviatile sediments. They consist of a vertical succession and lateral interfingering of large clayey and sandy through shaped lithosomes. The sands contain scattered pebbles of silex, quartz and reworked Tertiary sandstone. They show a megaripple stratification in a large cut and fill pattern and are considered as low water channel and levée deposits. The clayey deposits present a thin alternating lamination of clay, silt and peaty clay, with lateral laminar interfingering with sands. They are considered as flood plain and oxbow lake deposits. Peaty laminae show typical Eemian E4A and Eemian E5 palaeobotanical characteristics (V. De Groote, *in*: G. De Moor & I. Heyse, 1978).

Between —4 and —2 m (with trough shaped cuttings to —6 m): early Vistulian coarse high-energy fluvioperiglacial fan deposits. The sediment shows an extremely well developed through cross stratification with cut and fill structures of medium width and depth and with parallelly and diagonally layered infillings. The infillings consist of coarse sands with pebbles, layered gravels, scattered small boulders (up to 20 kg), clay and peaty pebbles, plates of reworked Eemian peat (C. Verbruggen, *in*: G. De Moor & I. Heyse, 1978), and also wood fragments and whole thermophyle tree trunks. The sediment also contains numerous fragments of *Bos priscus*, *Coelodonta antiquitatis*, *Cervus*, e.a. and *in situ* bivalves of *Pisidium* but also reworked Eemian *Corbicula fluminalis* shells and pre-Quaternary fossils (even brachiopods). The large reworked peat plates and tree trunks suggest a fast degradation and erosion of a wooded landscape with peat and clay filled valley bottoms.

The gravelly elements consist mainly of silex and quartz reworked from older terraces and of sandstone eroded from the Eocene substratum. The bouldery elements consist of reworked Eocene sandstone but also of schist, microdiorite, sandstone and limestone reworked from the Palaeozoic substratum outcropping in the Dender thalweg at 40 km southwards. Their dimensions and lack of rounding suggest an ice rafting transport. Proof of periglacial conditions is also given by the presence of syngenetic ice wedge casts, sand wedge casts, cryoturbation horizons, water extrusion structures. The fluvioperiglacial nature of the palaeo-environments is stressed by the presence of skull fragments of *Bos priscus*, infested by *Protophormia Terraenovis* (A. Gauthier, 1974). This indicates a high mortality of mammalia, blocked in valley bottoms under harsh winter conditions, followed up by the infection of the carcasses at spring time and their very fast transport by spring high stages, sweeping the valley bottoms and quickly burying the carcasses at their debouching in the Flemish Valley depression.

Between —2 and 0 m: pleni-Vistulian sandy deposits of braided channels in a large fluvioperiglacial valley bottom. Base and top are erosional. The sediment shows a through cross stratification. Cut and fill structures however are smaller and especially shallower, suggesting a more lateral than vertical scouring, presumably due to less deep seasonal thawing of an aggradative frozen soil. The infillings are well layered. They consist of sands with small gravelly elements and diminished pebbles of wood, peat and clay mainly reworked from the underlying sediment. They contain also loamy and peaty-loamy lenses. Those especially form basic beds in the through infillings. *In situ* fresh water shells (*Succinea, Pisidium*) are frequently encountered and reworked Eemian (*Corbicula fluminalis*) and Tertiary fossils have been encountered. The sediment shows patches with syngenetic cryoturbation casts (ice wedges, frost wedges, regular cryoturbations, droptail horizons).

Between 0 and +2 m: Vistulian Tardiglacial floodplain deposits. They consist of very fine sands, locally rich in fine plant debris and containing a few small silex, quartz or sandstone granules. The deposit is characterized by a subhorizontal, macroplanar stratification with fine internal lamination, patches climbing ripple lamination and rather rarely channel cuttings. It contains fresh water shells *in situ* (*Pisidium, Succinea*). This sediment originated by a river drainage with more regular discharge in an already stabilized channel after incision below the fluvioperiglacial aggradation surface. Locally several horizons of syngenetic small frost wedges occur below the eroded too. They show that short periods of severe cold still occurred. The allochtonous bleached sand infilling of the eroded uppermost frost wedge row suggests eolian activity in a dryed up valley bottom before an erosional phase took place.

Between +2 and +5 m: Holocene floodplain deposits. Above a basal granule lag, follow loamy fine sands with clayey intercalations and fine plant and shell debris in a planar ripple lamination with patches climbing ripple lamination.

They are covered with alluvial loams with lensic clayey and marl intercalations, show horizons with desiccation cracks and date from the Atlanticum as indicated by the marls age (7956±247 BP; IRPA 149). The uppermost part consists of subboreal peat (C. Verbruggen *in* G. De Moor & I. Heyse, 1978).

EARLY VISTULIAN DEPOSITS AT BEERNEM (WARANDA)

The excavation (canal cut) (51° 09′ N lat., 3° 21″E long.) is situated at +11 m a.s.l. near the water-divide in a low, subsequent, saddleshaped valley (depression of Beernem), cutting the hills of northwestern Flanders and linking the coastal Plain to the Flemish Valley.

Below +3 m (a.s.l.); Eocene glauconitic sands with sandstone layers. Near the southern valley edge, these sands are less deeply incised and show intense (2 m high) involutions into the Quaternary cover.

Between +3 and +9/+10 m: Early Vistulian low-energetic fluvioperiglacial valley bottom deposits. The formation consists of a succession of subhorizontal tabular or planar units, up to 2 m thick. They correspond to a rhythmic sedimentation, each cycle of which comprised a phase of peat formation (or of a peaty-loamy lamination), a phase of sand snow melt runoff deposition, a phase of major cryoturbation, scars of a phase of fluvial channel incision and generalised erosion, a phase of sandy fluvioperiglacial channel infilling and valley bottom aggradation affected by syngenetic cryoturbation and indications of a final slight and shallow truncation phase. The profile shows at least six cycles.

C^{14} ages of 4 successive peat layers proved to be older than 50,000 B.P., even the uppermost layer dating from more than 50,300 B.P. (GRN 7241) and the complex resting laterally upon Eemian peats (G. De Moor *et al.*, 1978).

The thickness of the peat layers varies between less than 5 and 60 cm, and laterally it is quite changing. The top of layer underlying the peat generally presents a more or less distinct zone of alternation and root development, dropping from the peat. A central and most important peat layer is laterally linked up with a paleosol of podzol type on slightly higher paleorelief positions. It indicates swampy patches surrounding slight sandy embossements within a valley bottom. According to its paleobotanical characteristics (AP content reaching more than 60 %), its lithostratigraphic position and its correlation with a podzol, this peat layer has been correlated with the Amersfoort interstadial (pollen-zones EWII, Zagwijn) (V. De Groote, *in*: G. De Moor *et al.*, 1978). According to their paleobotanic characteristics (with an AP content reaching 40 %), the underlying peats have been put in the EWI zone (Zagwijn). Paleobotanically they have been formed under wet conditions in a fairly open landscape but without indications of severe colds. Sand layers of the lower part contain thin lenses or laminae of peat or peaty loam. The peat layers superposed to the Amersfoort layer contain less than 20 % and mostly even less than 5 % AP. Their spectra refer to a wet tundra vegetation with very scarce trees. Paleobotanically they correspond to a wet and cold environment (V. De Groote, *in*: G. De Moor *et al.*, 1978).

The snow meltwater runoff deposits consist of dominantly planar stratified laminated sands, interfingering with scattered small, ripple laminated, gully infillings.

The main gully incisions occurred after cryoturbation of the peat and snow meltwater deposit. The gullies cut or truncate the peat. Sometimes they reach depths of more than 2 m and their true width attains up to 20 m. Sometimes they even cut underlying peat layers.

The fluvioperiglacial sandy infilling consists of through cross stratified sands passing upwards to a more general sheet of rather laminated sands. Some laminated sands and most of the gully infillings contain lenses and laminae of reworked peat. Locally slump structures and sand blocks occur along the banks of the major gullies. Sand blocks seem to have been displaced in a frozen condition, mostly after thermo-erosive undermining and by sliding, but without long distance transport.

Laminated sands and some gully infillings, especially those younger than the Amersfoort peat, contain laminae of white, bleached quartz sand which proved to originate from the A2 horizon of the podzol. They refer to erosion and deposition mainly by snow meltwater runoff.

The laminated sands as well as the gully infillings show numerous levels of casts of syngenetic frost cracks, of frost wedges, of droptail structures and of rather small involutions. They depart also from the top of the peat layers and the buried paleo-podzol. Ice wedge casts, having a width up to 2 m and a depth up to 4 m, mostly show an autochtonous infilling, sometimes with glaciotectonic pseudofaulting. They mainly depart from horizons within the gully-infillings, sometimes are truncated. They often show related water extrusion pipes crossing overlying gully deposits and reaching the peat base. A major horizon starts from the truncated top of this formation.

The peat layers themselves do not show synchroneous cryoturbation, but they are affected by general and, locally very important, separate regular cryoturbations. These seem to have occurred each time a laminated sand layer of snow meltwater runoff origin, covered a peat layer and before gullying started.

The same type of gully incision occurred by improving of temperature conditions, infillings followed under worser fluvioperiglacial conditions, as shown by the large ice wedge casts they contain and which indicate that each cycle lasted perhaps some thousands of years. The importance of the cryoturbations as well in the pre-Amersfoort as in the post-Amersfoort sequence proves that here in Northwestern Belgium quite early in the Early Vistulian mean annual temperature fell regularly below $-5\,^{\circ}C$, at least for longer periods. The difference between lower and upper Early Vistulian climatic conditions as shown by paleobotanical evidence is not confirmed by sedimentological data, as the primary sedimentological data as well as the periglacial structures suggest rather similar environmental conditions.

The peat layers — except the Amersfoort peat — seem not to correspond to important improvements of the paleoclimate. These rather coincide with gully incision phases. Moreover, it is not clear if they represent short slightly milder stages or if they were only sedimentological features in a low-energetic fluvioperiglacial environment.

Between +9 (+10) and +11 (+10) m: interlaminated silt and coarse sand to fine gravel covering the truncated and locally more deeply channel cut top of the early Vistulian deposits. Locally deep channel infillings consist of laminated sands with fine gravels. The loamy-gravelly layer shows very heavy irregular cryoturbations and in its lower part, frost kettle structures above deep ice wedge casts (up to 5 m depth) starting at regular distances from below the erosional base. They suggest a polygonal ice wedge network below an active layer consisting of the silt-coarse sand interlamination. As there is no erosional discontinuity at the base and lack of clear evidence for its age, its belonging to a Pleniglacial Vistulian sequence can only be presumed.

Above +10 m: a sandy layer which because of the lack of large cryoturbations, of its primary stratification and its occurrence seems to belong to a Late Vistulian, dominantly eolian deposit of local origin.

PLENI- AND FINI-VISTULIAN DEPOSITS AT DAMME

The sandpit at Damme-Vijvekapelle (51° 13′ 10″ N lat., 3° 18′ 30″ E long., elevation +6 m a.s.l.) is situated on the Maleveld coversand ridge. It belongs to the western extension of the Maldegem coversand ridge crossing the Flemish Valley. It dominates the slightly deflated fluvioperiglacial aggradation surface at the NW edge of the Flemish Valley, whose brink is at a few kilometers to the south.

At the moment of the visit, the excavation unfortunately reached a depth of only 5 m. Hence only the uppermost part of the pleni-Vistulian deposits could be observed.

Between +1 and +2.3 m: low-energetic fluvioperiglacial floodplain deposits at the edge of the main valley bottom of the Flemish Valley. The deposit consists of a succession of subhorizontal planar or interfingering sets, alternatively of sandy, of loamy and of peaty-loamy nature. The sandy sets show a subhorizontal to parallel lamination within a wide but shallow through cross stratification, locally with more important channel cuttings having an infilling sometimes rich on reworked peaty debris. The sands also contain lenses with fine gravelly elements. The loamy layers in particular often contain quite a lot of fresh water shells (*Succinea*, *Pisidium*, *Lymnea*, *Columella*), but also a few *Pupilla Muscorum*. The peat layers and some of the loamy layers show more or less regular cryoturbations, more especially small involutions, in a quite dense pattern. The top layer consists of a peaty to peaty-loamy layer of 10 to 20 cm thickness passing upwards by gradual transition into a horizontal sand and loam laminar alternation, the sand laminae becoming increasingly important in the upper part.

This uppermost part however extends discontinuously and its thickness is quite changing, as it kept only preserved within kettle-shaped cryoturbation pockets. The cryoturbation affected simultaneously the underlying peat layer and the sandy cover after which both have been truncated by a horizontal erosion surface. The peat layer also shows small shallow droptail structures. The erosion surface is affected by frost wedges which reach a depth of 1 to 1.5 m and seems also to have been truncated. It is covered by a lag of scattered fine gravelly elements.

Pollen analysis of this peat shows a 10% AP content with *Salix*, *Pinus* and *Betula* and moreover a striking dominance of *Cyperaceae* (V. De Groote, 1974, unpublished), stressing the wet character of the cold environment.

Age of this peat layer (19,800±130 B.P.; GRN 7117) is indirectly inferred from the age of a lithostratigraphically correlated peat layer (I. Heyse, 1975) situated at a distance of a few kilometers.

The facies is distinctly that of the low-energetic deposits of the braiding fluvioperiglacial drainage of the aggrading Flemish Valley bottom with numerous changes from swamp deposition and loamy floodplain sedimentation to shallow channel deposits and snow meltwater runoff rill sediments, moreover influenced by valley side supply due to the marginal position.

Between +2.3 and 3.1 m: Fini-Vistulian niveo-eolian and snow meltwater runoff deposits.

They consist of fine sands in subhorizontal laminated planar sets (up to 10 cm thick), alternating with lenslike sets and shallow throughlike cuttings with a parallel or diagonal infilling. This unit is particularly rich in periglacial structures. Syngenetic frost wedge casts depart from numerous successive adjacent sedimentation levels in polygonal patterns, crossing each other. Many of them show clear evidence of an at least restricted number of reactivation phases by opening of the wedges. They contain vertically parallel slices of autochtonous or allochtonous infillings, distinctly visible on horizontal cuttings. The wedge casts generally are wide on top (10—20 cm) but depth never reaches more than 50 cm. There are many examples of sediment bleaching parallel to the wedges. The sediment also shows patches of laminar small polygonal disiccation micro-cracks. That polygonal network reaches only 5—10 cm diameter and the depth of the micro-cracks does not exceed 1—2 cm. It contains locally well developed thin peaty-loamy laminae showing a typical small and shallow (up to 5 cm depth) droptail structure. It also shows characteristic inversed small frost wedges which depart from the lowest part of the layer and are considered as bound to an upwards freezing process. Typical of this sediment also are thin (10—20 cm) sandy lenses whose internal primary structure is completely disturbed (I. HEYSE, 1975). They are considered as superficially thawed sediment patches which moved in a water soaken condition by sliding over short distances above a frozen subsoil, and insofar as casts of a shallow active layer. Because of the frequently repeated succession of typical shallow periglacial structures these have been considered as proof for a shallow frozen ground upclimbing in a quickly but discontinuously aggrading sediment.

The top of the unit is characterized by a row of numerous casts of frost cracks, mainly truncated, indicating a transition to a slackened sedimentation and even to erosion but also to a disappearance of the permafrost. The truncation surface is covered by a lag of scattered gravelly elements.

Between +3.1 and +6 m: Vistulian Tardiglacial dune ridge deposits. They consist of a basal layer (30—50 cm thick) of fine sands in a horizontal planar lamination with some loamy laminae. Syngenetic small frost wedge depart from different levels, mainly however from the top. The top is not truncated but shows numerous roots dropping from a horizontal peat layer (10—20 cm thick and containing small tree twigs). Locally it passes to a peaty loam or shows sand intercalations. Small regularly spaced superficial turbations have been interpreted as hoof imprints (I. HEYSE, 1975). This peat has an AP content of 13%, reaching locally 26%, with a dominance of *Betula* and some *Salix* and *Pinus* (V. DE GROOTE, *in*: I. HEYSE, 1975). C^{14} dating yields an age of 11,950±65 B.P. (GRN 6045, *in*: VERBRUGGEN, 1971). Most of this unit consists of palish yellow, well sorted medium fine sand in a subhorizontal planar lamination. It shows different levels with small and shallow frost wedge casts. Primary and secondary sedimentary structures indicate an eolian deposit under thermal conditions characterized by numerous short but strong colds.

VISTULIAN TARDIGLACIAL DEPOSITS AT ROKSEM

The sandpit at Roksem (51° 10′ 33″N. lat., 3° 1′ 5″ E long., elevation +4 m a.s.l.) is situated at the western edge of the large coversand ridge which crosses the Flemish Valley between Stekene and Maldegem and continues westwards to reach the Coastal Plain.

At −2 m: truncated surface of Ypresian clay, covered with a scattered gravel lag.

Between −2 and 0 m: Pleni-Vistulian fluvioperiglacial deposits. They consist of fine sands with fresh water shell debris, stratified in a very shallow (10—20 m depth) but wide, nearly planar, through cross stratification with a mainly diagonal or lensic lamination, sometimes with distinct ripple lamination. The uppermost part contains more or less numerous lenses with small gravelly elements. The lower part shows horizons with small cryoturbations. The top layer consists of a subhorizontal, multilaminar layer (10—30 cm thick) of peaty loam and peaty sand laminae. Its pollen analytic content of 10—15% AP with dominantly *Salix*, indicates a wet and cold paleo-environment (V. De Groote, unpublished).

Between 0 and +2.5 m (+1): Fini-Vistulian and early-Tardiglacial niveo-eolian deposit. It consists of fine sands. In a lower part it shows a planar, diagonally-laminated stratification. In an upper part is consists of thick planar laminae of palish yellow fine-laminated, medium-fine sands alternating with fine-laminated, grayish very fine sands, each lamina of which (5—10 cm thick) shows distinct individual syngenetic micro-cryoturbation. The medium-fine sand laminae contain scattered, well-rounded small quartz and silex granules. Frost wedges depart from the limit between the upper and the lower part. They reach a depth of 1 m and show an allochtonous infilling. This complex is covered with a peaty layer of 10—20 cm thickness, resting upon the more or less alterated and rooted top of the underlying layer. This peat layer runs horizontally over a great part of the excavation, but on its northwestern edge it continues slightly sloping into a shallow depression, dropping over 0.5 to 1 m. In this depression the peat layer locally shows a greater thickness, a more distinct peaty-loam character and there it is affected by small involutions and shows patches with small droptail structures which reach a depth of 10 to 20 cm. They originated shortly after the peat was formed, as indicated by the fact that only a very thin layer of younger sediments show synchroneous cryoturbation while the bulk of the younger sediments is undisturbed by it. Pollen analysis of the peat shows AP peaks up to 50 or 60% and a dominance of *Hippophaes* (V. De Groote, unpublished). It suggests a growing dune environment with scattered small meres subject to formation of a peat canopy but also to infilling by moving sand. C^{14} datation of a lithostratigraphically correlated peat situated at short distance, yielded an age of 11,740±130 BP (GRN 129—67) and has been considered as Early Allerød (R. Van Hoorne & C. Verbrugge, 1969).

Between +2.5 (+1) and +4 m: Vistulian Tardiglacial eolian and lacustrine deposits. The eolian deposit (small dune deposit) consists of white fine sands, subhorizontally planar-laminated with lensic intercalations of medium, sometimes coarse sand and even granules. Locally occurs a horizon with thin peaty-loamy lenses affected by small cryoturbations (micro-droptails to 2 cm depth) and also a few horizons with syngenetic small frost wedges (with allochtonous infilling however similar to the deposit itself, up to 1 or 2 m depth). The top of the sand layer shows postglacial podzol development.

Above the already mentioned paleo-depression the peaty intercalation is much better developed as a continuous layer, showing a concordant depression pattern. It there has a peaty-loam character and contains fine shell debris. Pollen-analytically the peat contains 60—70% AP with *Pinus* dominance. It has been considered as an Allerød deposit (V. De Groote, unpublished). This shows that during the middle- and upper-Tardiglacial, small dune and lacustrine formation within the coversand ridge continued and that locally there was even some micromorphological stability. Quite important however is that the Allerød peat layer in the depression shows striking cryoturbation structures which do not occur outside the paleo-mire. They consist of giant droptails, having a diameter of 10—30 cm, reaching a depth of 1 to 1.5 m in the lowest part of the paleodepression and disappearing as well as the continuous peat itself on both sides of the lacustrine. In many places the droptails cut and traverse the underlying peat layer which has been bended downwards around them, while the sediment as well below as above the transversed peat layer shows intense irregular turbation. The droptails downmoving stopped on a fairly continuous horizon at 0.5 to 1 m below the transversed peat layer. In many places and mainly at that horizon the droptails either form a row of large balls (10—30 cm diameter), either they stretch out laterally and from a horizon of discontinuous peaty patches with more or less distinct vertically standing remnants of the droptails, in that way alike to bird feet (and more or less similar to the Wieme cryoturbation type) (C. Edelman *et al.*, 1936). The horizon is so regular that the down sunken peat fragments often seem to form a discontinuous layer *in situ*.

The droptails represent less consolidated peaty-loamy lacustrine deposits which sank downwards, or were pressed downwards, through a thawed and water soaken active layer reaching a 1.5 m depth, traversing an older, already buried peat layer and water soaken sands and stretched out horizontally at the top of a frozen ground. The cryoturbations are so important and the active layer structure so striking that the character of permafrost can hardly be denied. The age of this last permafrost appearance in North-western Belgium is shown to be Youngest Dryas.

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