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PALAEOHYDROLOGY OF THE TEMPERATE ZONE

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Abstract

The authors study the Würm Lateglacial evolution of the drainage, the morphology of the Lateglacial coversand ridges and their Holocene alterations. Special attention is drawn to sedimentological structures in relation to the reconstruction of the palaeo-environment and to the process of deposition. Palaeoenvironmental and stratigraphical interpretations are based on lithological and sedimentological characteristics and successions. Palynological and ^{14}C datings are being used but are not discussed here.

Key words: coversand, eolian river damming, sedimentalogy of coversands

Introduction

Northern Belgium, below 200 m altitude, is part of the northwest European lowlands. Geologically the Flanders belong to the Tertiary North Sea Basin. Hence the geomorphological substratum consists of alternating Tertiary marine clay and sand layers, slightly dipping to the north. After final regression of the Tertiary and Plio-pleistocene seas in northern direction the emerged surface was lowered by a dominantly consequent fluviatile drainage system, one of whose main branches was that of the Schelde and the Leie rivers (Tavernier & De Moor 1974). During Quaternary evolution several terraces have been formed. The main incision along Schelde and Leie occurred during Riss time. It formed a low-level valley system, whose deepest thalwegs reached —20 north of Ghent, and which later on developed into the »Flemish Valley» (De Moor & Heyse 1974).

This Pleistocene valley pattern has been buried partly by fluvio-periglacial Riss sediments, fluviatile, marine and perimarine Eem sediments, and partly by outcropping fluvioperiglacial Würm sediments reaching, locally, a thickness of 30 m (De Moor & Heyse 1974). During the Pleni-Würm, the general fluvio-periglacial drainage ran in a northwestern direction, north of Ghent (Fig. 1), resulting in a smoothy sloping surface from +8 m near Ghent to +4 m near Eeklo. The Würm Lateglacial drainage gradually changed to a more northeastern direction resulting in a microrelief of small parallel ridges and depressions with small rivers and streams. This drainage direction however was dammed up during the Würm Lateglacial by eolian activity, which produced a continuous west-east coversand

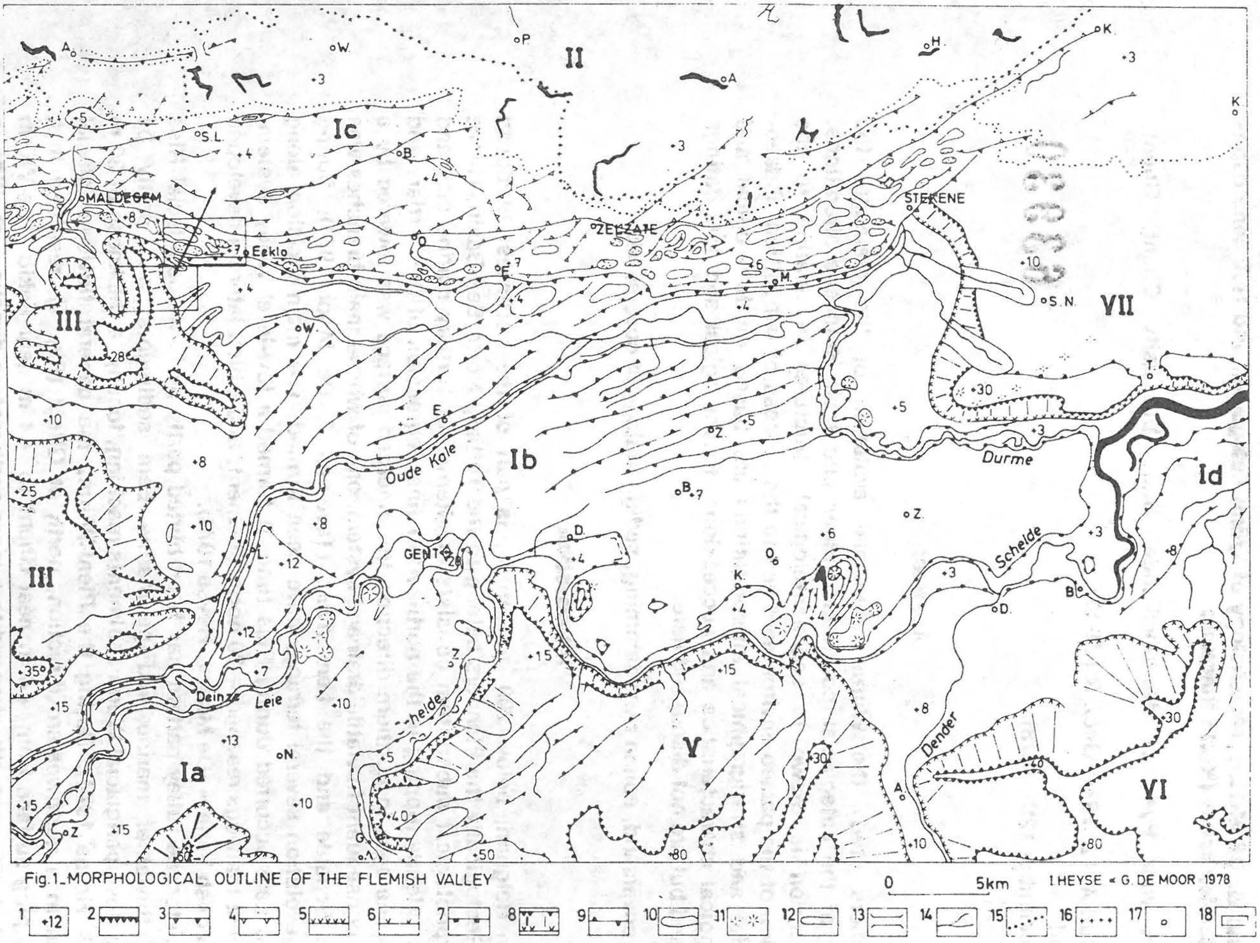

Fig.1_MORPHOLOGICAL OUTLINE OF THE FLEMISH VALLEY

Fig. 1. Morphological outline of the Flemish Valley landscape. I. Flemish Valley landscape, a, b, c, d subregions. II. Polder landscape. III. Hilly regions of West-Flanders. IV. Hilly region of Leie-Schelde interfluvium. V. Hilly region of Schelde-Dender interfluvium. VI. Hilly region of Dender-Dyle interfluvium. VII. Cuesta landscape of Land van Waas. Legend: 1. absolute altitude, 2. regional convexity, 3. distanct convexity, 4. indistinct convexity, 5. regional concavity, 6. distinct concavity, 7. talud, 8. slopes, 9. ridges, 10. depression, 11. dunes, 12. valley, 13. watergap, 14. river, 15. polder limit, 16. state limit, 17. village, 18. detailed study area.

ridge from Maldegem to Stekene (De Moor & Heyse 1972, Heyse 1973, De Moor & Heyse 1978).

The present drainage of the dominantly flat »Flemish Valley Landscape» runs in an eastern direction (Durme and Schelde, east of Ghent), turns northwards by Antwerp and reaches the North Sea near Flushing (Westerschelde).

It is the aim of this paper to discuss only the eolian deposits, their sedimentological characteristics and morphology, the palaeohydrographical consequences for the Flemish Valley and the palaeoclimatological environment.

Situation and morphology of the Würm Lateglacial deposits in the Flemish valley

The eolian deposits of Würm Lateglacial age in the northern part of the Flemish Valley landscape occur dominantly as a west-east running coversand ridge. It crosses the Flemish Valley for more than 50 km from Maldegem to Stekene (Fig. 1). This complex ridge (2 to 4 km broad) shows an asymmetric profile characterized by a steep southern slope, which dominates the fluvioperiglacial surface of the Flemish Valley to the south by a few meters.

Detailed morphological examination reveals a complex of small ridges running in different directions and separated by shallow depressions of different size. East — west and southwest — northeast ridges occur frequently, sometimes splitting and joining. Northwest — southeast ridges are also present but less important. On the highest zones small dunes are common and sometimes show a typical parabolic form with horns pointing to the west or to the southwest. The individual micro-ridges also occassionally show an asymmetric topography. They are separated by small (Figures 2 & 3) and large depressions of irregular size. The main ridge has only one small watergap (by the Ede near Maldegem).

South of the main ridge important elongated depressions or valleys are lined up in the Flemish Valley at a level of + 4 m. Between the depressions small ridges with a west-south-west orientation, typical of the relief of the Flemish Valley to the south, join the main ridge. The most important Moervaart depression is drained by the Oude Kale — Durme system to the Schelde river.

The area north of the main ridge is almost flat with scarce very small ridges 1 to 2 m high. They have the same orientation as the main ridge. Sometimes the ridges

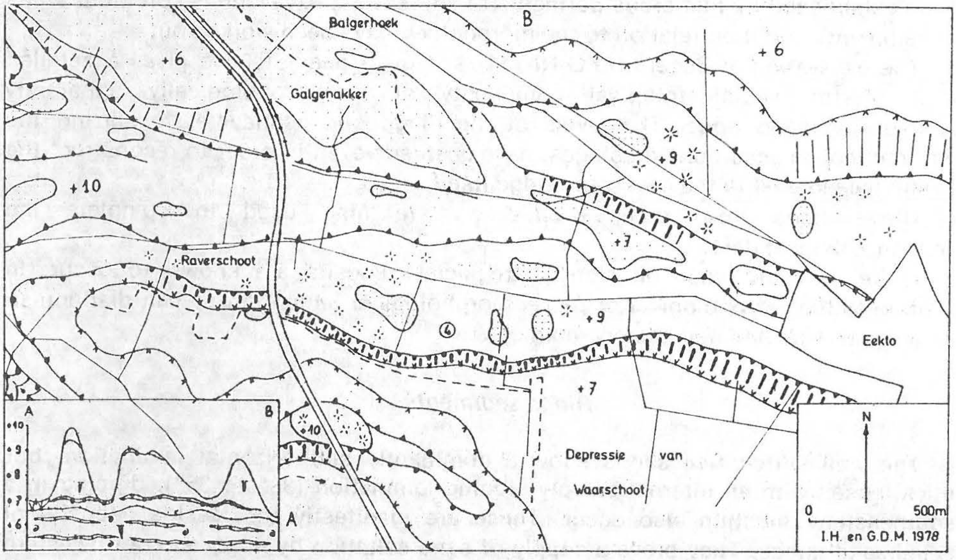

Fig. 2. Detailed morphology of the main coversand ridge near Eeklo. For legend see Fig. 1.

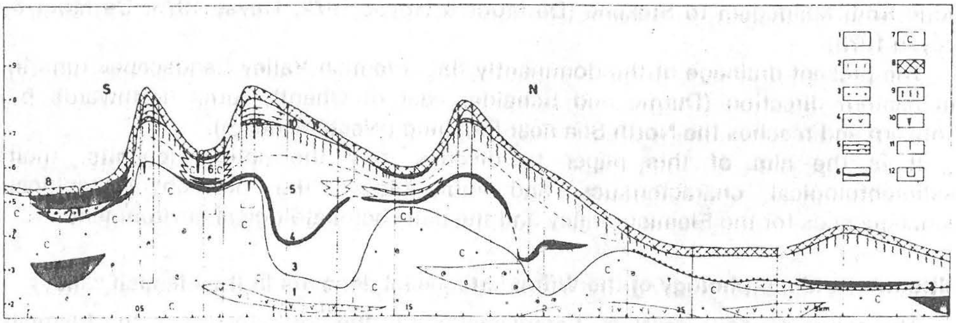

Fig. 3 — Section through main coversand ridge near Eeklo

Layer	Lithology	Genesis	Age
L1	fine sand with calcareous loamy and peaty lenses	fluvioperiglacial	Würm Pleniglacial
L2	gravel layer of flint, sandstone and quarts (mean diameter 0,5 cm)	deflation lag	Würm Lateglacial
L3	yellow fine sand	eolian coversand	Würm Lateglacial
L4	undulating peat layer	vegetation horizon	
L5	fine sorted sand	eolian depression	Würm Lateglacial
L6	fine calcareous sand with peat laminae	depression sediments colluvium	
L7	marl	marshy sediment	Würm Lateglacial
L8	peat	marshy sediment	
L9	fine humeous sand	fossile culture layer	Holocene
L10	fine laminated sand	eolian dune	Holocene
L11	fine humeous sand	culture layer	recent

split and surround small elongated depressions and some form and angle of about 30° to the northwest with the main coversand ridge. The zones between the micro-ridges are extremely flat and poorly drained.

Lithological and sedimentological characteristics

A generalised cross-section of the main coversand ridge near Eeklo (Fig. 3) has been established by numerous borings (15) and several excavations. Different types of sediments and their relation to the morphology have been worked out.

The excavation at Zegers (ZEG-NI-144-1) (Fig. 4) near Stekene gives a detailed idea of the sedimentological complexity of a morphologically apparently simple coversand ridge. The levels of the diagnostic peatlayers, fossilizing the different eolian accumulation stages, have been surveyed in order to reconstruct the eolian palaeorelief in the coversand ridge itself.

Observations from other excavations are also used to complete the sedimentological data.

Quite different types of Würm Lateglacial deposits are known to occur. In relation to the morphological or palaeomorphological situation one can distinguish ridge sediments and depression sediments.

Ridge sediments

The well sorted fine sands show a dominantly subhorizontal lamination, but thick lenses with an internal steeply sloping lamination (30° to 35°), dipping in a southeastern direction also occur. These are manifestly the leeside deposits of small sand dunes. They prove a supply of sand saltation by north and northwestern winds. These eolian sands have been deflated from the flat area north of the main

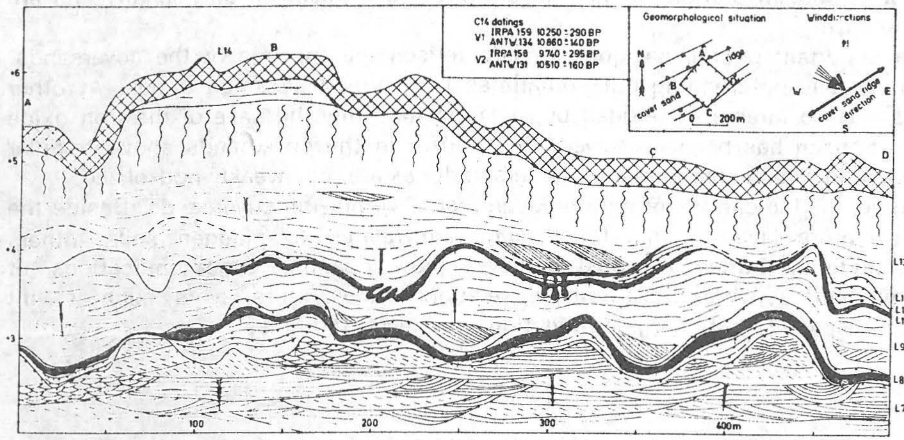

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Fig. 4 — Exposure Zegers (ZEG-NI-144-1)

Layer	Lithology	Genesis	Age
L7	white fine sand with ripple lamination, horizontal strata and channel stratification; small frost wedges and locally involutions	fluvioperiglacial	Würm Pleni- or Lateglacial
L8	undulating peat layer; numerous vegetation horizons under and above the diagnostic peat layer	fossil vegetation cover	Würm Lateglacial
L9	fine sorted sands; subhorizontal lamination with some sigmoidal laminated sets; small frost wedges	eolian coversands	»
L10	undulating peat layer passing laterally into a fine sand loam lamina; numerous vegetation horizons above the diagnostic peat layer; locally involutions	fossil vegetation cover	
L11	fine sorted sands; horizontal lamination: fine frost wedges at the top level	eolian coversands	»
L12	thin peat lamina only locally developed; involutions	fossil vegetation cover	»
L13	fine sorted sands with horizontal lamination and sets with steep sloping lamination: small frost wedges at different levels; podzol soil at the top	eolian coversands	»
L14	fine loose sands	eolian dune	Holocene
L15	fine humeous sand	culture layer	recent

ridge. A layer of weathered gravelly elements still cover the deflated fluvioperiglacial surface (Fig. 3) as a gravel lag.

One or several peat layers and vegetation horizons occur within these eolian lateglacial sands. Generally they are discontinuous and lateral transitions to loam or marl have been observed. Sometimes peat layers split up and envelop undulating eolian sand layers or even small dunes (up to 1 m high) which have been deposited at the edge of peaty depressions. The peat layers locally pass into thin loamy laminae, By and large the surface of buried successive sand and peat layers do not show coinciding microrelief features. Locally peat layers have been eroded completely. Sometimes an undulating organic layer with scattered charcoal fragments appears in the uppermost part of the coversands. Especially at the base of the coversands, numerous small frostcracks appear mostly in a remarkably dense pattern suggesting a repetition phenomenom. The frost wedges developed from higher levels within the coversand itself are characterized by a well developed head widening. Involutions of peat layers have been observed only locally and are of small size.

An important postglacial podzol characterises the topzone of the coversands. Generally it is outcropping but sometimes it is buried by small dunes. At other places it is so intensively eroded by deflation that only the base of the iron oxide illuvial horizon has been preserved. The podzol in the coversands show irregular laminated iron oxide enrichment. The inland dunes are only weakly podzolized.

Numerous indications of culture layers occur within the coversands. Beside the recent culture layers, some fossil ones are related to plaggen soils, others are completely buried by post-medieval blown sands. Other indications of anthropogenic activities were found in relation to the culture layers, such as flint artefacts, spade turbations, pile fundations and levelled ditches.

Depression sediments

The fine sands frequently become calcareous, loamy or peaty as in the Moervaart depression. Especially in the neighbourhood of outcropping Tertiary layers near the limit of the Flemish Valley lense-like intercalations appear, consisting of laminated calcareous sandy loam with plant debris. These pass locally into marl with fresh water shells showing that the depressions received drainage water from the surrounding area and the hilly regions.

Steep sloping laminated sandy infillings of small microdepressions show sometimes a fluidal bending pattern. They can be explained by cryoturbation, by load casting, or sometimes by sand flow. The loamy shell-rich marl, originally deposited in a depression, is locally cryoturbated in droptail structures. Peat layers also show regular turbations, involutions and droptail structures. In any case they involve the occurrence of a water saturated superficial layer and thaw-frost alternations. Locally the peat layer developed in small depressions show a special type of disturbance. It consists of abruptly walled indentations of the peat over about 10 cm. The mean diameter is about 10 cm as well on a vertical section as on a horizontal one. They are grouped, their maximum distance being about 50 cm and are considered hoofprints of Mammalia (reindeers) (Fig. 5.)

Grain size analysis

The results of the grain size analysis (calculated after the moment method of Friedman, 1961) are grouped according to the genetic origin of the layer, determined by field observations (Table 1). Underlying fluvio-periglacial Würm sediments are distinguished from eolian Würm Lateglacial sediments and overlying eolian Holocene sediments.

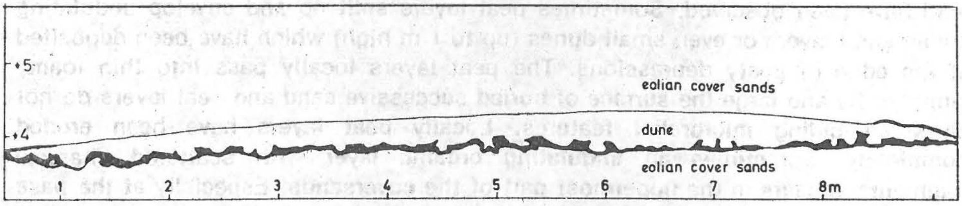

Fig. 5. Exposure Dhondt (DHO-MO-132-6). Hoofprints in Würm Lateglacial peat.

Table 1. Granulometric characteristics

	Number of samples	Mean diameter Mz ψ		Standard deviation γ	Skewness SK	Kurtosis K	Modality %
fluvio-periglacial Würm sediments	80	min.	+ 2,16	0,34	—2,00	—1,04	uni- 50,2
		mean	+ 3,22	0,98	+ 1,55	+ 5,66	bi- 30
		max.	+ 7,70	3,08	+ 3,37	+ 15,45	tri- 19,8
eolian Late Würm sediments	140	min.	+ 1,77	0,41	—1,55	—0,02	uni- 81,4
		mean	+ 2,79	0,65	1,14	+ 6,66	bi- 18,6
		max.	+ 3,47	1,19	+ 2,59	+ 22,5	tri- —
eolian Holocene sediments	25	min.	+ 2,35	0,41	—0,46	—0,08	uni- 80
		mean	+ 2,82	0,61	+ 0,76	+ 4,31	bi- 20
		max.	+ 3,20	0,93	+ 1,99	+ 10,03	tri- —

In order to examine the relations between the parameters (mean diameter Mz, standard deviation γ, skewness SK and kurtosis K), several parameter diagrams have been drawn and the data are grouped in characteristic parameter fields (Fig. 6).

Only the fluvio-periglacial sediments are characterized by trimodal populations contrasting with the eolian sediment, comprising only unimodal and bimodal samples. The mean diameter of the fluvio-periglacial sediments is relatively high + 3,22 ψ due to a mixture of sand and loam. The eolian sediments of Würm

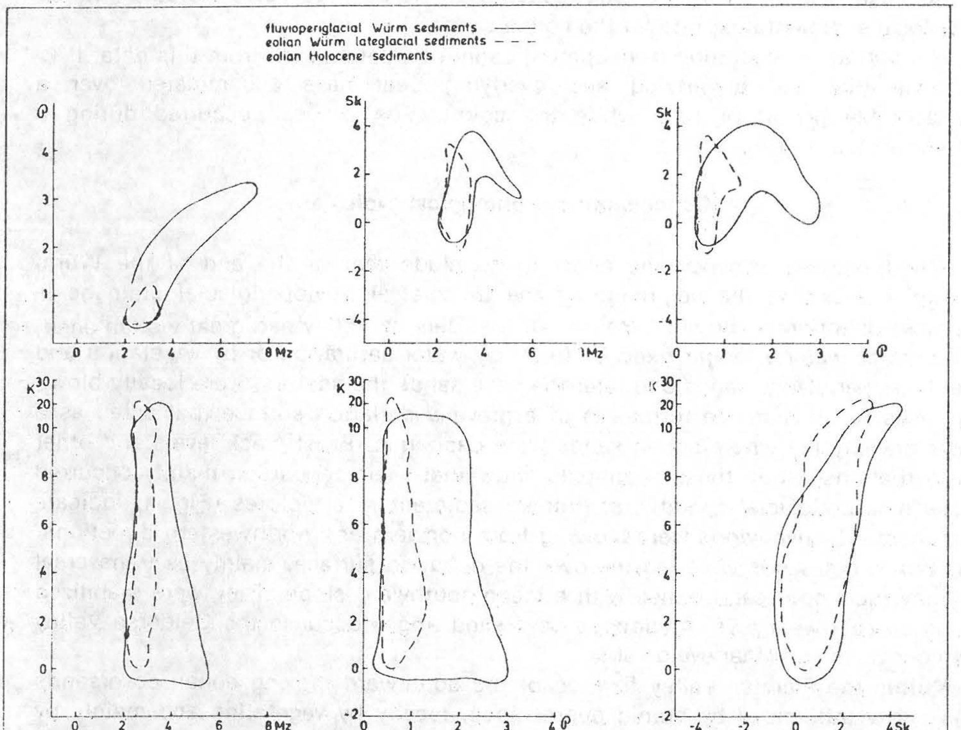

Fig. 6 — Sedimentological characteristics. Grain size analysis (parameter diagram). Mz: mean size. γ: standard deviation. SK: skewness. K: kurtosis.

Lateglacial age and of Holocene age have practically the same mean diameter +2,79 Ψ and +2,82 Ψ .

The very good sorting of the eolian sands (0,65 and 0,61) is important. The locally reworking of the eolian Würm Lateglacial sands has resulted in a still better sorting.

Absolute dating

The stratigraphical position of the Würm Lateglacial deposits has been controlled by carbon-14 datings of numerous samples from different peat layers occurring within these deposits (Verbruggen 1971, Van den Berghe, Van den Berghe and Gullentops, 1974, Van der Sluis and Maarleveld 1963, Vanhoorne and Verbruggen 1975, Heyse 1975, Verbruggen and van Dongen 1977, De Moor and Heyse 1978, Heyse 1979).

They all yield ages between extreme dating limits of 9300 and 12 600 years B.P.

The absolute ages of the peat layers in the exposure ZEG-Ni-144-1 have been dated twice.

V1	IRPA	159	10.250	± 290 BP
	ANTW	134	10.860	± 140 BP
V2	IRPA	158	9.740	± 295 BP
	ANTW	131	10.510	± 160 BP

The date of 9 740 seems to be too young. Contamination should not be excluded in this case. The differences in age respectively 510 and 350 years indicate a rather high local sedimentation rate for the eolian sands.

The period of vegetation development cannot be determined from this data. It is possible that the underlying and overlying peat have accumulated over a considerable period of time while the colmatation process occurred during a relatively short interval.

Conclusion: morphological evolution

The foregoing observations allow to conclude that at the end of the Würm Pleniglacial and at the beginning of the Lateglacial fluvioperiglacial drainage in northern direction in the northern part of the Flemish Valley had greatly slightened. The surface was no longer fixed by frost, by water saturation or by vegetation and the fluvio-periglacial sands and later the coversands themselves, were locally blown out. This resulted in the formation of a gravelly deflation surface that acted as a basal gravelly lag where eolian sands were deposited. Frost crack levels and other cryoturbations within these sediments show that their deposition mainly occurred under near-periglacial conditions. Primary sedimentary structures (Fig. 4) indicate that most effective winds were blowing from northern and northwestern directions. The blown out sands were moving over the deflation surface, mainly as transversal asymmetrical coversand dunes with a steep southward slope. They were stabilized along an east-west axis. Analogous coversand ridges occur in the Gelderse Valley (van der Sluis and Maarleveld 1963).

Within the Flemish Valley fixation of the southward moving eolian coversands was partly influenced by humid depressions, locally by vegetation and mainly by damming of the drainage by the eolian deposition itself, which also caused the raising of the groundwater table in the nearly depressions to the south. On the edges of the Flemish Valley the increased relief played an important role, especially near Maldegem and near Stekene. Thus a relatively high and complex coversand ridge crossing the Flemish Valley was formed in several phases of the Würm Lateglacial by juxtaposition and superposition of small sandridges and dunes. Hence closed depressions could be formed in relatively high positions. In some of them groundwater level was favourable for peat formation. Formation of colluvial deposits was much more complex: partly conditioned by water and suspended from the dammed riverlets, partly by local run-off, partly by deposition of the blown out fines. In the more northernly zones single coversand ridges are also known in the Netherlands (van der Sluis and Maarleveld 1963).

During the Würm Lateglacial eolian sedimentation, the most effective winds temporally turned to the southwest, resulting in a reworking of the upper sands, as indicated by the direction of sand laminae and the occurrence of small coversand dunes transversal to the main coversand ridges.

In the marshy depressions uninterrupted peat formation could continue during the whole Würm Lateglacial, as well during those colder phases. Eolian activity was the dominant process on the coversand ridge, as during the warmer and more humid Bölling and Alleröd phases.

Since the Early Holocene the coversand ridges were reworked by local eolian activity, resulting in a new microrelief with small dunes and deflation depressions. The effectiveness of the southwestern winds is proved by the direction of the southwest pointing horns of parabolic inland dunes. The dip direction of the steep sloping sand laminae also gives support to this view. The vegetation horizons in the eolian sands illustrate the discontinuity in the sedimentation or in the fixation of the moving sands. Meanwhile the deposition in some depressions was characterized by colluvium and by peat formation in the most humid zones. Podzolisation of the coversands was very important, contrasting with the weakly podzolisation in the inland dunes. During the whole Holocene the Würm Lateglacial morphology has been reworked superficially by eolian activity mostly by southwest effective winds. Small dunes and deflation blown-outs have been formed at short distance and within short time lapses. Sometimes relief inversion was involved. Deforestation and agricultural practices have intensified eolian processes, especially during the Middle Ages.

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Discussion

W. G. Jardine:

Do you think that some of the coversands were deposited in hollows that contained water? That such was the case is suggested by the presence of load structures at the junction between some coversands (above) and peat (below). Disturbed sand/peat junctions may be explained by periglacial action when the watertable is high, but still saturated below the ground surface. Load structures however, may be produced only when open water occurs above the ground surface and both the sand and the underlying peat are sufficiently water-saturated for movement, induced by loading, to occur.

I. Heyse:

The first aeolian sedimentation resulted in a damming effect on the drainage system. Consequently it is not excluded that small ponds could persist for a while in some brook valleys, e.g. Edevalley, which had been transformed into marshy depressions and were receiving consistently more meltwater from snow in the springtime. The aeolian sands were preferentially deposited at the northern rims of these depressions in open water or on a surface saturated with water. The second type of sedimentation was probably the more important one.

R. Vanhoorne:

Are you still convinced that the Flemish Valley was eroded during the Riss glacial?

I. Heyse:

The presence of *Azolla filiculoides* in the sediments of the Flemish Valley at levels of 0 and —5 north of Ghent has been interpreted stratigraphically as Holstein by V. de Groote. Erosion and sedimentation processes occurred even at a relatively high level. Fluvial sediments are even known at a level of +15 metres near Ghent (Melle). These Holstein sediments are dominant at the margins of the Flemish Valley. The deepest incision and erosion phase in this valley, however, is situated stratigraphically during the Riss period.