MICROMORPHOLOGICAL STUDY OF THE TERRACE SANDS (UNIT 4) AND 'LOAMS' (UNIT 5) AND THEIR PALAEOSOLS IN THE BELVÉDÈRE PIT NEAR MAASTRICHT, SOUTHERN LIMBURG, THE NETHERLANDS

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CONTENTS

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ABSTRACT

The micromorphological study of the Units 4 (Terrace Sands) and 5 ('Loams') in the Belvédère pit revealed that the site mainly can be regarded as a sediment receiving area, with sedimentation during unstable periods (Ku-cycles) and formation of palaeosols during stable periods (Ks-cycles). Three unstable periods are distinguished: K1u, K2u and K3u with deposition of Units 4a-c, Unit 5.1 and Unit 5.2 respectively, mainly in a shallow fluvial and backswamp-like environment and to a lesser extent by sheet flow (rainwash and afterflow).

From the stable periods in between (K1s, K2s and K3s) strongly to moderately truncated buried palaeosols are found. The palaeosol remnants suggest the formation of a well-drained Luvisol on the higher parts and a Gleyic Luvisol in the lower parts of the landscape during the first stable cycle (K1s). Indications for soil formation during the K2s-cycle are very limited, suggesting the presence of a weakly truncated incipient soil or of a strongly truncated Luvisol. During the K3s-cycle the palaeosol remnants suggest formation of a mainly well-drained Luvisol.

This type of soils could be formed in a temperate climate under deciduous forest.

It is suggested that prehistoric man visited the Belvédère site only shortly during the unstable periods.

Tephra layers are not indicated in the pit.

INTRODUCTION

Micromorphological analysis, using thin sections, makes it possible to study under the polarization microscope the components in sediments and soils in their mutual relationship. Features resulting from primary sedimentation can be distinguished from pedological phenomena, as a result of soil formation in the past, e.g. pedorelicts, or due to soil formation in situ after deposition. The pedological features can often subsequently be arranged in their sequence of formation.

The complicated history of Quaternary sedimentation and soil formation is considered to be determined by frequent sharp changes in the environment, resulting from climatic fluctuations.

The K-cycle (K for Kronos = time) concept proposed by Butler (1959) divides the Quaternary period into stable periods (Ks-cycles), dominated by soil formation, and unstable periods (Ku-cycles), dominated by erosion, sedimentation and the formation of slope deposits. From a sedimentary point of view, two types of environment can be recognised in the landscape (see Fig. 1): sediment producing or erosional areas, and sediment receiving areas.

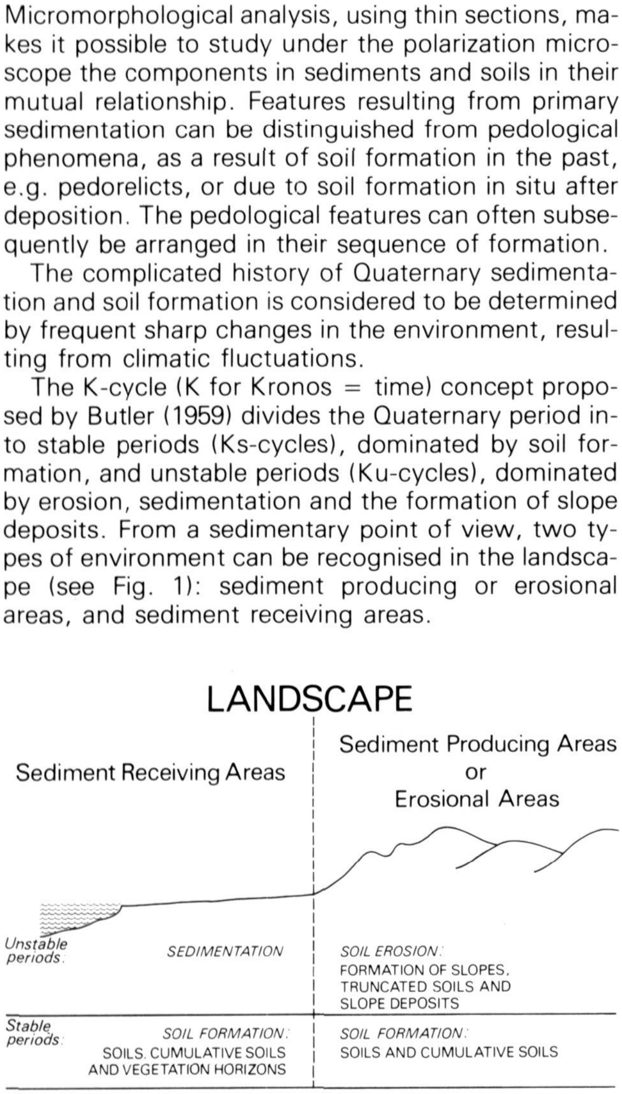

Fig. 1. Schematic presentation of the events in the landscape during stable and unstable periods.

During Ku-cycles in sediment producing areas, as a result of erosion, soil profiles are truncated, and slope deposits are formed. In sediment receiving areas sedimentation occurs and soils are buried, forming so-called palaeosols (e.g. buried soils which have formed in landscapes of the past).

During Ks-cycles in the sediment-producing areas, soil formation keeps pace with removal of material by erosion, and in the sediment receiving areas soil formation occurs during periods of non-deposition or relatively thick soils are formed by deposition of fresh material, forming so-called cumulative soils (Birkeland, 1974; Mücher and Morozova, 1983).

The French geologist Erhart (1956) distinguished two types of periods in geological history. In periods of biological equilibrium, the so-called 'periodes de biostasie', soil formation occurred, whereas in periods of instability, the so-called 'périodes de rhexistasie' most sediments are formed.

The macromorphological identification of palaeosols in the field is, according to Valentine and Dalrymple (1975, 1976), only possible if they occur in a palaeocatenary sequence, showing an ecological catenary relationship. Such lateral variations in unweathered Quaternary sediments cannot be reproduced by sedimentation and diagenesis. If a palaeocatena is poorly developed or exposed in the field, which often occurs, micromorphology can contribute by identifying the inferred palaeosols either as in situ or as consisting of transported (soil) material (Mücher, 1973a, b; Mücher and Morozova, 1983).

As will be illustrated, the Belvédère site can mainly be regarded as a sediment receiving area with sedimentation during unstable periods and formation of palaeosols during stable periods. However, the occurrence of buried truncated palaeosols in the excavation testify that the site has also acted in the past occasionally as a sediment producing area.

The micromorphological study of the Terrace Sands (Unit 4) and 'Loams' (Unit 5) in the Belvédère pit is firstly focussed on the composition and structure of the sediments, so as to reveal evidence concerning the environmental conditions at the time of their formation during unstable periods. Secondly, attention is given to soil formation after deposition in a stable period, and thirdly to the tracing of features which could be the result of human activity in the past.

METHODS

The field survey was carried out by means of observations in the pit. For the description of soils and sediments use is made of the 'FAO Guidelines for Soil Profile Description' (FAO, 1968), and their colours are

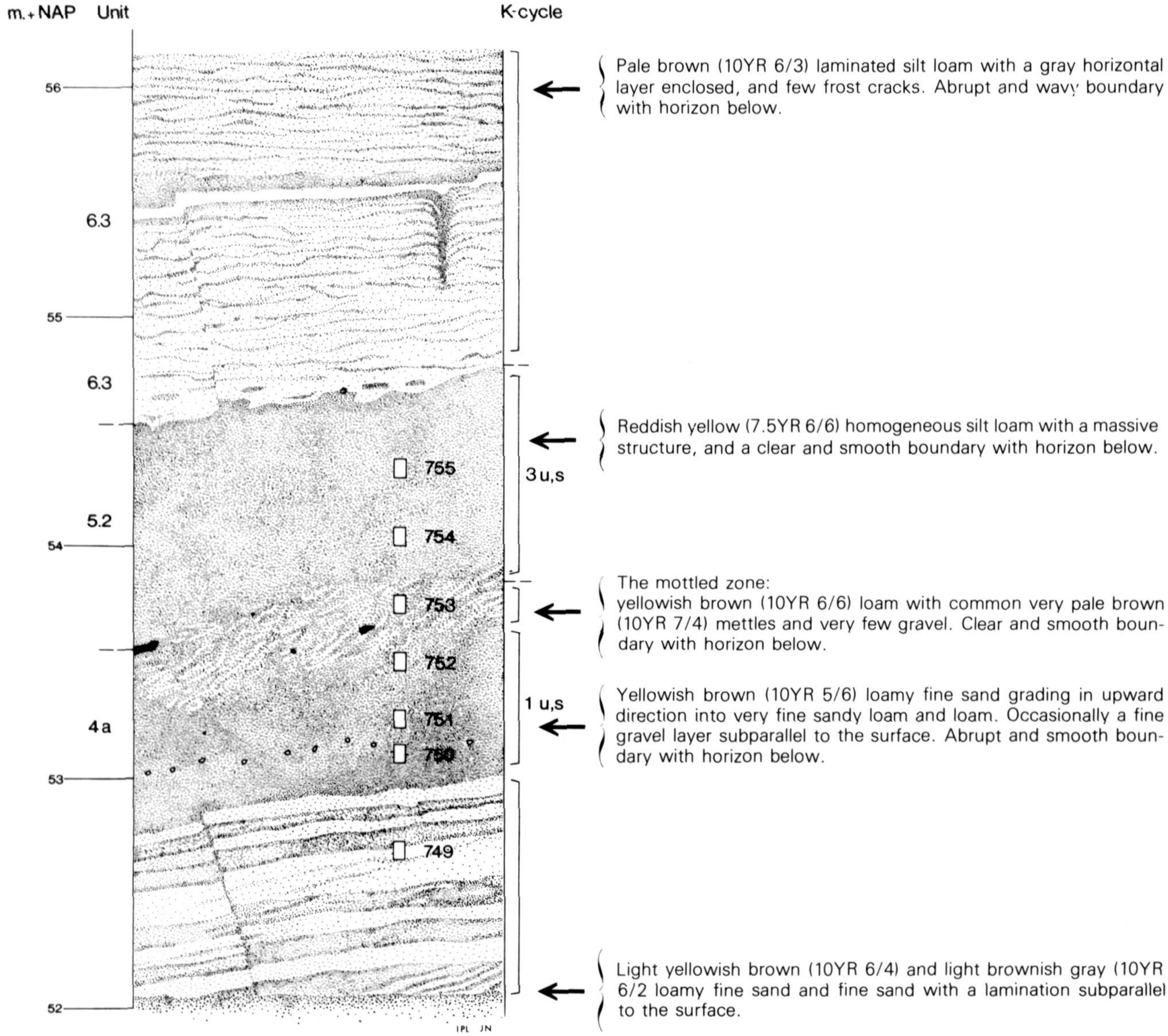

Fig. 2. Profile Mi.2 (archaeological site A at the base of Unit 5.2) at the eastern side of the levee, with the locations of the thin sections, nrs. 749-755.

described according to the 'Munsell Soil Color Charts' (Anonymous, 1954). The soils are classified according to the 'Legend of the Soil Map of the World' (FAO, 1974).

As a matter of fact the soil classifications had to be based on the actual characteristics of the buried soil profiles, which are mostly moderately to strongly eroded, resulting in the disappearance of the A horizons. Consequently the classifications must be regarded as approximations.

For micromorphological study undisturbed samples are taken with tins. The undisturbed samples, first air-dried, and then dried in an oven at 40°C, are impregnated under vacuum with unsaturated polyester resin, Frencken-Synolite, type no. 544-64-0050, using monostyrene as a thinner. To improve impregnation, a pressure of 8 atmospheres is exerted on the samples for one hour with nitrogen, finally followed once again by evacuation of the air. After six weeks of hardening in a fume cupboard the thin sections are prepared following the method described by Jongerius and Heintzberger (1975). The thin sections (8 x 5 cm, occasionally mammoth-sized: 15 x 8 cm, and 20 μm thick) are studied in transmitted light with a 'Leitz' orthoplan polarizing microscope. For the description and interpretation of the thin sections, based on the method and schemes of Bolt and Mücher (1984), the terminology of Brewer (1976) is used, supplemented with terms introduced by van Schuylenborgh et al. (1970).

RESULTS AND INTERPRETATION

The topographical location of the archaeological sites which profiles have been investigated (Mi.1 to Mi.6) is given in Roebroeks (1985), figure 1. The vertical position of Mi.2, Mi.3, Mi.4 and Mi.6 is indicated in the cross-section in figure 7 (Vandenberghe et al., 1985).

Unit 4: *Terrace sands*

Unit 4a.

Unit 4a occurs in the profiles Mi.2 and Mi.6 (see Figures 2 and 3), situated at the east and west side of the levee respectively.

Sedimentation in the K1u-cycle

The lower part of profile Mi.2 shows that in the first unstable cycle, K1u, sedimentation occurred of mainly fine (100-250 μm) and very fine sand (50-100 μm), and only a few silt-sized particles (2-50 μm), showing only a weak parallel lamination (thin section 749). It contains also silt aggregates with the size of medium to very coarse sand, very few sand-sized rounded nodules of dominantly clay, socalled mud balls (Pettijohn, 1976), and very few fine sand-sized lithorelicts such as shale, sandstone and chert fragments. Only very few thin argillaceous laminae are observed parallel with the surface. In an upward direction (thin sections 750 to 753) lamination is only incidentally observed: - a gravel layer in thin section 750; - thin laminae, (sub)parallel to the surface, consisting of silt-sized grains and covered by a layer of very fine and fine sand grains, less than 2 mm thick in total. Locally, infillings of less than 8 mm deep depressions occur, consisting of a well-laminated deposit of (from below to above): very fine silt and clay particles, silt and very fine sand, and finally completely filled with a mixture of silt, very fine and fine sand. In an upward direction the composition of the matrix material remains the same, albeit that the content of silt-sized grains increases upwards, resulting in loam to silt loam in thin sections 752 and 753. Only locally (thin section 752) do further shale and sandstone fragments occur with the size of medium sand to gravel. In the top of Unit 4a (thin section 753), where silt particles are dominant, still coarser grains occur as medium sand-sized grains up to 450 μm, shale and quartzite fragments up to 700 μm in diameter. Additionally in the top of Unit 4a, a piece (150 x 1100 μm) of a mud crust is observed, composed of clay and fine silt, with a weak unistrial plasmic fabric. The sharp horizontal boundary in the upper part of thin section 753 is regarded as an erosional surface of Unit 4a deposited in K1u-cycle.

The following characteristics of Unit 4a in profile Mi.2: slightly laminated, poorly sorted material with enclosed lithorelicts, soil nodules, mud balls and a gravel layer, suggest that the unit is largely a fluvial deposit. The well-laminated infillings of small depressions could be deposited by afterflow (without raindrop impact) or meltwater flow, compared with the structures obtained by laboratory experiments of Mücher and De Ploey (1977, 1984) and Mücher et al. (1981). In addition, the occurrence of mud crust fragments, the nearly absence of lamination to the top of the unit, and the better sorting in upward direction, could be indications for a decreasing fluvial activity, and an increasing deposition by overland flow and rainsplash activity.

In profile Mi.6 Unit 4a occurs only in the lowest section (thin section 903). The deposit consists mainly of silt and very fine sand and less fine sand, occasionally medium sand-sized grains, embedded in a groundmass of light gray unistrial clay (parallel with the surface) in a porphyric arrangement. Quartzites with a diameter of 200-800 μm occur only locally. Thin, 1 mm thick, laminae parallel to the surface, consisting of very fine and fine sand, occur in the lowest part. In the upper part there are locally laminae of almost pure clay, 50 to 300 μm thick, with a strong unistrial plasmic fabric.

The parallel lamination, the fining in upward direction, and the unistrial fabric of the clay, suggest a low energetic fluvial sedimentation during the beginning of the first unstable cycle (K1u). This could be in agreement with the presumed backswamp-like environment.

Soil formation in the K1s-cycle

After sedimentation of Unit 4a in the K1u-cycle in profile Mi.2 soil formation occurred during the first stable phase (K1s). The soil is characterized by following micromorphological features:

- biological activity resulted in the formation of biopores by roots and soil animals, pedotubules and matric fecal pellets. Firstly observed in thin section 750 and increasing upwards.
- illuviation of ferriargillans, starting in thin section 749 (in this thin section mainly concentrated in thin horizontal bands), with a maximum in thin sections 751 and 752, and decreasing again in upward direction (thin section 753).
- illuviation of matriargillans, consisting of clay, silt and small amounts of organic matter (van Schuylenborgh et al., 1970), and mainly observed in thin sections 751 and 752,
- papules, e.g. fragments of illuviated ferriargillans, with the same distribution pattern in the profile as the illuviation argillans.
- sharply bounded, rounded ferric nodules, sometimes irregular and angular shaped (thin section 753), mostly present in thin sections 750 till 752.
- very few carbonate nodules in the upper part of the profile (thin sections 752 and 753).
- illuviation cutans of carbonate are only incidentally observed in thin section 752. If occurring together with argillans, the carbonate cutans are observed closest to the remaining void.

The occurrence and distribution pattern of the illuviation cutans strongly suggest that in Unit 4a an argillic horizon has been formed, consisting of a B3t (thin sections 749 and 750), a B2t (thin sections 751 and 752) and a B1t horizon (thin section 753), which is subsequently truncated by erosion in a following unstable cycle, resulting in the disappearance of the A and partly of the argillic horizon. The thin horizontal bands with illuviated clay in the lower part of the profile give rise to the wrong impression in the field that the sediment is strongly laminated.

The matriargillans may be the result of soil degradation in the soil surface horizon. The sharply bounded ferric nodules are regarded not as a formation in situ, but as remnants of an older soil formation in the past, e.g. as pedorelicts, which were present already in the sediment. The absence of hydromorphic phenomena, as sesquioxidic cutans and neocutans, is in agreement with this.

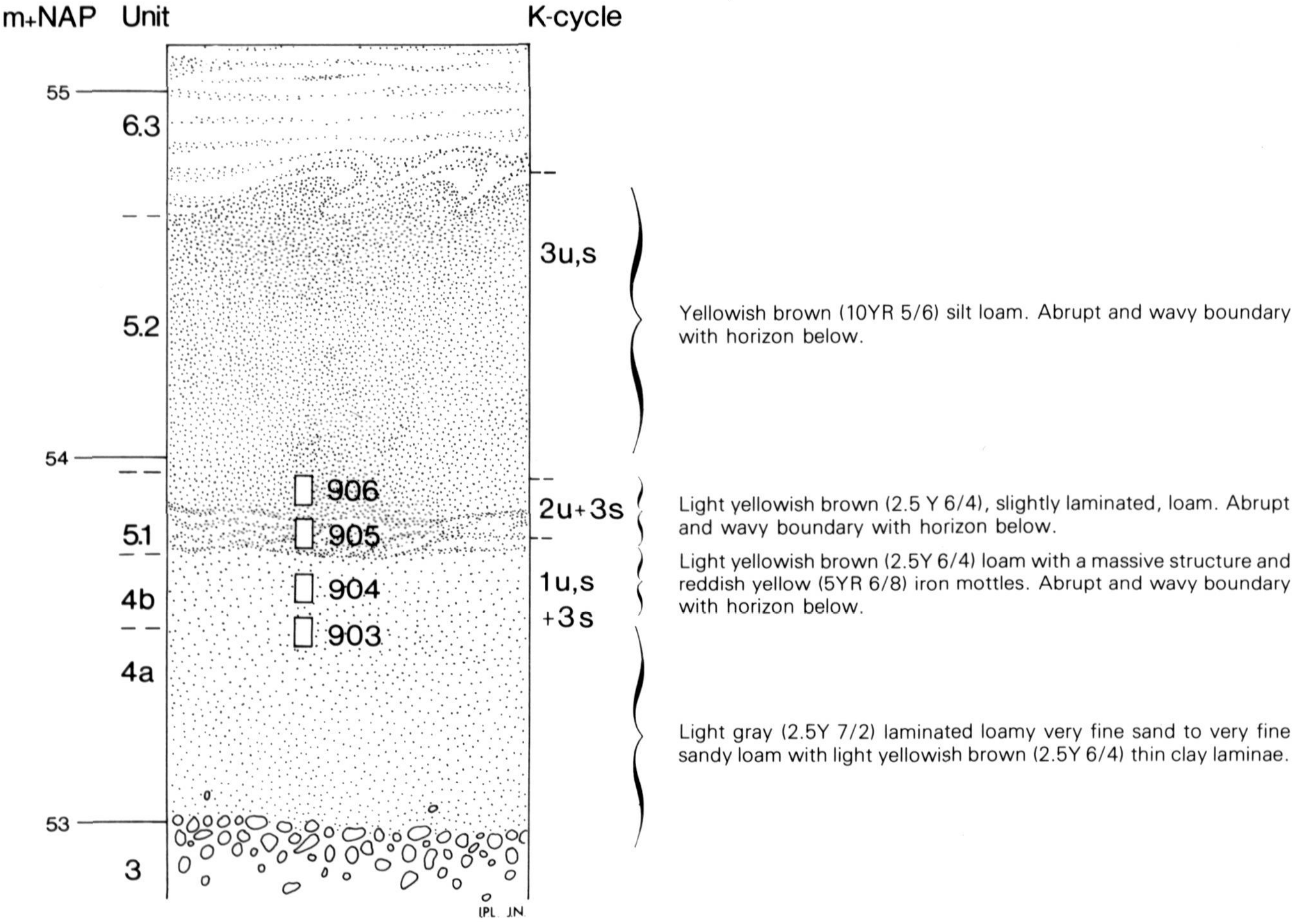

Fig. 3. Profile Mi.6 at the western side of the levee (archaeological site C in Units 4a and 4b), with the locations of the thin sections, nrs. 903-906.

The carbonate (presumably calcite) nodules and cutans, based on their position in the profile and on the argillans, are regarded as formations in a more recent K-cycle, due to dissolution of carbonates from the overlying calcareous Middle Silt Loam (Unit 6).

The bulk of the papules occurs in a similar way as the illuviation argillans in the profile and resemble each other morphologically. It is suggested that the papules are the result of a disturbance of illuviation cutans mainly by biogenetic pedoturbations, although cryogenic deformations can not be excluded. However, indications for frost action are very limited. Only the silt-capping, as mentioned previously already in thin section 753, can be formed by meltwater after thawing of the surface soil (see Romans et al., 1966; Collins and O'Dubhain, 1980). However, other phenomena, which could be formed by cryogenic processes, mentioned, for example, by Coutard and Mücher (1985), Mücher and Morozova (1983) and Van Vliet-Lanoë et al. (1984), are not observed.

This palaeosol of the first stable phase (K1s), largely based on the presence of a well-drained argillic horizon, is classified as a Luvisol, formed under a deciduous forest in a temperature climate. In the absence of an A horizon this classification can only be tentative.

Indications for human activity are not found in Unit 4a of this profile.

In Unit 4a in the lower part of the profile Mi.6 little soil formation occurs. In the first stable K-cycle (K1s) the pedogenesis is characterized by: reduction of the largest part of the unit, locally iron segregation by oxidation with formation of ferric nodules, additionally few argillaceous papules occur. Biological features are not observed. The papules can be the result of deformation of some illuviated argillans from a horizon above by shrinkage and swelling movements.

Based on the hydromorphic phenomena and the nearly absence of other pedological features, this horizon is classified as a Cg (parent material with gley characteristics), formed in a mainly wet environment.

Indications for human activity are not found in this unit.

Units 4b and 4c

Units 4b are sampled in the profiles Mi.6 (Fig. 3) and in profile Mi.3 (Fig. 4) somewhat further to the west. Locally, at site Mi.5, the unit is calcareous (Unit 4c).

Sedimentation in the K1u-cycle

In profile Mi.6 Unit 4b corresponds largely with Unit 4a (thin section 903) of the same profile. The sediment (thin section 904) is somewhat finer textured, only incidentally medium sand-sized grains up to a maximum of 300 μm in diameter are observed. Laminae of sand hardly occur any more, sometimes sand-

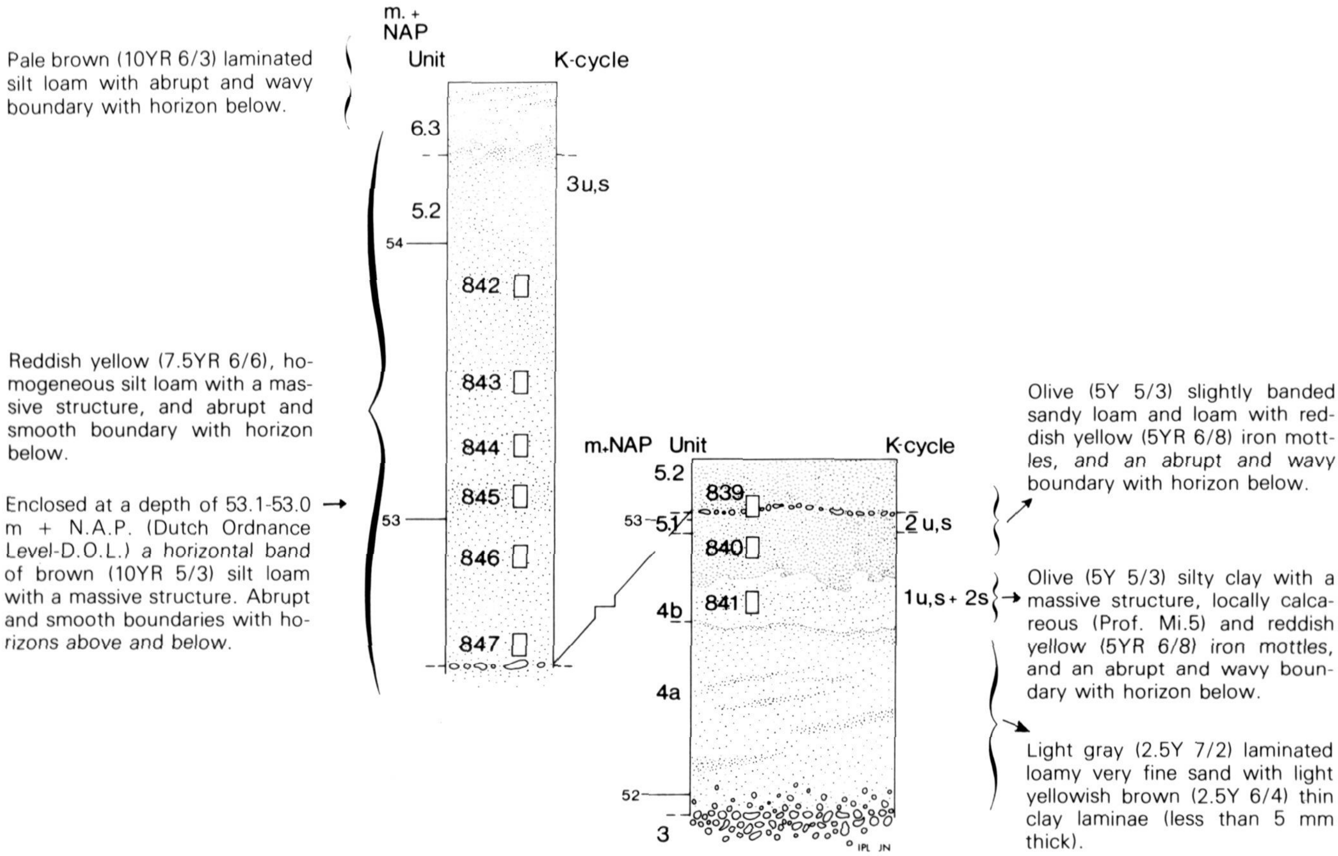

Fig. 4. Profile Mi.3 (at the right) in a backswamp-like environment (Unit 4b), with the locations of the thin sections, nrs. 841-839. At the left profile Mi.4 in Unit 5.2 ('Loams'), consisting of mainly homogeneous silt loam with the locations of the thin sections, nrs. 847-842, and a gravel layer at the base (archaeological site B with artefacts in Units 4b and in the base of Unit 5.2).

sized grains are observed in clusters. Lithorelicts are not observed. (Sub)horizontal and vertical planes occur, and locally also vughs. The skeleton grains are embedded in a groundmass of light gray unistrial clay (parallel with the surface) in a porphyric arrangement.

The unistrial fabric of the clay and the continuation of fining in an upward direction is similar to that seen in thin section 903, suggesting also fluvial deposition during the first unstable cycle (K1u) in a backswamp-like environment.

In profile Mi.3, the lower part of Unit 4b (thin section 841), contains more clay than the same unit in previous profile Mi.6. The fabric of the light gray clay is again unistrial, in which silt, fine and medium sand grains, up to a maximum of 300 μm in diameter, and occasionally lithorelicts of quartzite, are embedded in a porphyric arrangement. In an upward direction (thin section 840) the clay content decreases suddenly, and the s-matrix is mainly composed of silt and sand grains, commonly up to 500 μm in diameter, with little weak unistrial clay in between, forming a dense porphyric arrangement. Only very few fine to coarse sand-sized (up to 650 μm in diameter) quartzites occur. Additionally, micro depressions are observed with an infilling consisting of well-sorted laminae of: clay, or clay mixed with very fine silt, or very fine silt grains (less than 10 μm in diameter) or fine silt (less than 30 μm in diameter). The thickness of the individual laminae does not exceed 500 μm. Remnants of layers, consisting of unsorted silt, 600 μm thick, are also found.

The change from clayey to coarser deposits, with depression infillings of laminated fine material, suggest an alternation from a relative calm backswamp-like environment to a more intermitted environment. In the last-mentioned environment, sedimentation occurred of unsorted coarser material in shallow water, and erosion with formation of depressions on the one hand, and on the other hand giving rise to the formation of well-sorted thin laminae, possibly deposited by overland flow or by meltwater with a laminar flow and without simultaneous raindrop impact.

More to the west, at site Mi.5, in the vicinity of profile Mi.3, Unit 4 is calcareous, e.g. Unit 4c.

Three mammoth-sized thin sections (nrs. 848-850) were taken in this unit, showing from bottom to top:

- a layer of nearly 3 cm thick micro-cristalline carbonate material (micrite) in which silt, very fine and fine sand grains (up to 130 μm in diameter) are embedded in a porphyric arrangement. Additionally very few Bt-nodules (diameter 2 mm) are observed, e.g. pedorelicts of an older soil horizon, and shell fragments.
- an almost non-calcareous layer, 2 cm thick, consisting of gray unistrial clay in which is embedded some silt, very fine and fine sand grains (up to 150 μm in diameter), and shell fragments. In this, locally very thin (300-500 μm) unistrial clay laminae oc-

cur parallel with the surface. The boundary with the lower micrite deposit is gradual.
- a 5 to 7 cm thick layer of laminated fine sand (up tot 350 μm in diameter), loosely packed and with very few silt-sized grains enclosed. Only the packing voids in the top of this layer are partly filled with micrite, showing an agglomeroplasmic crystic fabric. The boundary with the horizon below is sharp.
- the almost 4 cm thick top layer, which resembles the bottom layer, consists of micrite, in which are embedded silt, very fine and fine sand grains, and many shell fragments, oriented parallel to the surface. This deposit is locally free of carbonates, showing an almost pure argillaceous matrix of which the original sedimentary unistrial fabric has been completely changed by soil formation, giving rise to an omnisepic plasmic fabric. Few thin, non-calcareous laminae are enclosed, parallel with the surface, consisting of silt, very fine and fine sand grains, less than 200 μm in diameter. The shell fragments occur with their convex side in upward as well as in downward direction. The boundary with the horizon below is sharp.

The unistrial fabric of the argillaceous deposit and the enclosed laminae, parallel to the surface, of fine sand and clay, could be formed in a backswamp-like environment. The clay content is masked in the microscope by micrite, except for the carbonate-free locations, where almost pure clay is observed.

The occurrence of micrite mainly in the argillaceous layers and only in depressional positions, suggests a post-sedimentary accumulation of carbonates, determined by the hydrological paleoregime, and giving rise to the formation of calcareous tufa, e.g. Unit 4c, in the first unstable cycle (K1u). Calcareous tufa is a less compact, more impure and porous variety of travertine (Fairbridge and Bourgeois, 1978, p. 819).

The presence of molluscs and other faunal remains (see van Kolfschoten, 1985 and Meijer, 1985) in this unit strongly suggests that the accumulation of carbonates must have taken place shortly after primary sedimentation and before the soil formation in the K1s-cycle. Due to the local carbonate-rich environment the fossils survived dissolution by soil formation, resulting in a zone of fossil finds no. 2.

Soil formation in Units 4b and 4c in the K1s-cycle

Soil formation in the first stable cycle in Units 4b and 4c of profiles Mi.6, Mi.3 and at location Mi.5 is very similar, showing the following pedological features:
- Biological activity with the formation of biopores (most common in Unit 4b of profile Mi.3), matric fecal pellets (only observed in Mi.3), and pedotubules (only in Mi.3).
- Reorientations of the clay minerals in the gray, reduced, argillaceous groundmass, resulting in vosepic (near cracks), masepic and skelsepic plasmic fabrics (around skeleton grains) in profiles Mi.6 and Mi.3. In thin section 904 the plasma reorientations are locally rounded features. At location Mi.5 the gray argillaceous groundmass has largely retained its primary unistrial sedimentary fabric, and shows only in local decalcified spots an omnisepic plasmic fabric.
- Light gray illuviation argillans occur only in profile Mi.6 (thin section 904).
- Brown and redbrown illuviation ferriargillans and matriargillans are incidentally observed in Mi.6 (thin section 904), common in Mi.3 (thin sections 841 and 840) and not at location Mi.5. If these ferriargillans are found in combination with the gray argillans, they occur closest to the remaining void.
- Accumulations of oxides and hydroxides of iron occur as ferrans in the voids and as neoferrans near the voids in the groundmass of Mi.6, Mi.3 and site Mi.5. At the two last-mentioned sites some ferrans are acicular in a radial fabric, which could be an indication of the mineral goethite.
- Sesquioxidic and manganiferous rounded or irregular nodules, and combinations of it, occur in both Units 4b and 4c. The manganiferous type is mainly observed in profile Mi.3.
- Brown argillaceous papules occur in Mi.6, but mainly in Mi.3.
- Carbonate solution phenomena followed by re-accumulation, as calcitans and neocalcitans, are only observed in Unit 4c at site Mi.5.

Soil formation during the first stable cycle in Unit 4b in profile Mi.6 (thin section 904) shows little biological activity, reduction of the largest part of the groundmass, with clay illuviation in an anaerobic environment (gray argillans), locally iron and manganese segregation by oxidation, giving rise to formation of ferric and manganiferous nodules and (neo)ferrans. Based on these hydromorphic phenomena, in combination with grayish clay illuviation, this horizon is classified as a B3tg horizon, formed in a mainly wet environment. The B3tg together with the Cg horizon in the lower Unit 4a, are possibly the remnants of a heavily truncated (during the following unstable phase) Gleyic Luvisol palaeosol, developed under a deciduous forest cover in a temperate climate. In the absence of an A horizon and of the main part of the B horizon, this classification can only be tentative.

The brown and redbrown illuviation phenomena (ferriargillans and matriargillans) associated with aerobic conditions, are regarded as pedological features from a more recent stable phase (K3s). The resemblance with the pedological features in the overlying Unit 5.2, and their occurrence at the grayish argillans, is in agreement with this interpretation.

The vosepic reorientations in the argillaceous groundmass along cracks are due to stress-induced deformations by swelling of the groundmass, along these cracks. The more or less rounded plasma reorientations and the formation of papules could be the result of cryogenic processes (cryoturbation) in a more recent unstable phase after the K3s-cycle. The indications for this type of process are however very weak. The papules could also be the result of swelling and shrinkage movements or of bioturbations in the soil.

Although the top of this truncated palaeosol is situated in the zone of finds of site C (Roebroeks, 1985), no indications are found for human activity.

The soil formation during the K1s-cycle in Unit 4b in profil Mi.3 (thin sections 841 and 840) is still weaker than in the previous profile Mi.6, showing mainly hydromorphic phenomena without clay illuviation under anaerobic conditions. Consequently this unit is classified pedologically as a Cg horizon. The brown illuviation features are the result of soil formation in the more recent K2s and, possibly, K3s-cycles. Indications for frost-induced phenomena are in this polygenetic horizon slightly stronger. These are: besides the formation of papules, locally developed platy structure (with in the planar voids brown illuviation argillans) and laminae bending in upward direction, probably caused by injection features (see Coutard and Mücher, 1985).

The soil formation during the K1s-cycle in Unit 4c at site Mi.5 (thin sections 848-850) is almost identical with Mi.3 in Unit 4b, showing hydromorphic phenomena and biological activity, and is consequently classified as a Cg horizon. Additionally this horizon is partly decalcified in the K1s-cycle. The possible goethite ferrans at this site and in profile Mi.3 are regarded more as a time-depending formation than as a climatologically determined phenomenon. It is likely that the heavily truncated paleosols, showing only a Cg horizon in Mi.3 and Mi.5, correspond with the eroded paleosol in Mi.6 in Units 4a and 4b in comparable position, and therefore remnants are of a Gleyic Luvisol.

Indications for human activity are not found in Mi.3 and Mi.5.

Unit 5: 'Loams'

Unit 5.1

In the micromorphologically analysed profiles Unit 5.1 is only recognized in the field in profile Mi.6 (Fig. 3) and additionally during the micromorphological analyses in profile Mi.3 (Fig. 4) in thin section 839.

Sedimentation in the K2u-cycle

The second unstable cycle started with a strong erosional phase, truncating the soils of the first stable cycle, followed by sedimentation.

The lower part, thin section 905, of Unit 5.1 in profile Mi.6 consists of light gray unistrial argillaceous groundmass in which are embedded dominantly silt and very fine sand grains, and less fine sand, and only incidentally medium sand grains (maximum diameter of 350 μm) in a porphyric arrangement. Only very few shale and quartzite fragments are observed with a diameter between 100 and 250 μm.

The sediment is coarsely laminated and inclined, at an angle of 35-40° to the horizontal. Occasionally in the sediment almost pure thin (50-100 μm thick) clay laminae occur with a strong unistrial fabric. Pure sand laminae hardly occur. Various laminae, with a maximum thickness of 5 mm, are more pronounced by the presence of sharply bounded, rounded, reddish brown ferric nodules with a diameter up to 500 μm. The void pattern is characterized by fine meso to fine macro (80-1000 μm) craze planes in directions normal and subparallel to the tilted lamination.

The upper part of Unit 5.1 in profile Mi.6, thin section 906, is more sandy, contains less clay and silt-sized particles than the lower part, and exhibits no lamination.

Unit 5.1 in profile Mi.3 is only recognized in the lower part of thin section 839. The 4 cm thick deposit shows a disturbed coarse lamination. Remnants still occur of wavy, horizontal layers of: unsorted silt (1 mm thick), unistrial clay with fine silt (150-1000 μm thick), and almost pure unistrial clay (50-700 μm thick). In between the laminae are yellow to light brown, (sub)angular soil nodules (probably eroded from a relatively nearby Bt horizon), ranging in size from medium sand to gravel size (2.5 mm in diameter). They show a porphyric arrangement with an omnisepic plasmic fabric. Common medium sand to gravel-sized (up to 3.4 mm) lithorelicts are observed, e.g. quartzite, siltstone and shale fragments.

The parallel lamination in the bulk of this Unit 5.1 showing an alternation of coarse material (soil nodules and lithorelicts up to gravel size) with fine material (laminae of silt, clay with silt, and clay) is attributed to an intermittent regime of intermediate shallow fluvial flow or sheet flow (rainwash and afterflow). The unlaminated upper part of Unit 5.1 in profile Mi.6 could be attributed to deposition by rainsplash. The soil nodules and the ferric nodules are probably locally derived, transported remnants of a Bt horizon, formed in an earlier stable phase. Tilting of lamination and formation of wavy laminae could be the result of deformations by cryoturbation after deposition.

Soil formation in the K2s-cycle

Unit 5.1 of profile Mi.3 (Fig. 4) shows only little soil formation from the second stable phase, consisting of very little biological activity (biopores and pedotubules), plasma reorientations as skel-, ma- and omnisepic plasmic fabrics, and medium to thick, dirty brown speckled, continuous illuviation ferriargillans. This type of argillan and pedotubule also occur in the lower Unit 4b, but not in the overlying Unit 5.2. The presence of the clear renewed lamination in Unit 5.1. in combination with another type of illuviation phenomena is in support of another second cycle with sedimentation and soil formation, and not of a continuation of the first cycle.

The yellow illuviation ferriargillans and matriargillans in this unit are identical with those in the overlying horizon, and are consequently regarded as pedological phenomena from a more recent stable phase (K3s).

This soil is so thin and weakly developed that it is no longer possible to determine whether it is the remnant of a weakly truncated incipient soil, or of a strongly truncated well-developed Luvisol. In Figure 4, the erosion of Unit 5.1 is evidenced by the presence of a gravel layer.

Soil formation in Unit 5.1 of profile Mi.6 mainly caused few gray illuviation argillans in the beginning (thin section 905), followed by light brown illuviation ferriargillans (thin section 905). The argillans are dominantly observed as infillings in the inclined planar voids. A large part of these cutans are subsequently broken down into papules. The amount of argillans increases in upward direction filling almost completely all voids (thin section 906).

This illuviation horizon is interpreted as a B3t horizon, which continues in upward direction in Unit 5.2, and will be discussed later. Consequently, this Bt formation is regarded as belonging to the third stable phase (K3s) and not to the second one (K2s).

Although the top of Unit 5.1 in profile Mi.3 (thin section 839) is situated on the zone of finds no. 3 (Roebroeks, 1985) no indications are found for human activity.

Unit 5.2.

Unit 5.2. was studied in profiles Mi.2 (Fig. 2), Mi.3 (Fig. 4) and mainly in profile Mi.4 (Fig. 4). During the third unstable phase (K3u) the soils developed in the K1s and K2s cycles are firstly heavily truncated and secondly buried by deposition of Unit 5.2. Subsequently soil formation occurred in the stable phase (K3s).

Sedimentation in the K3u-cycle

In the top of thin section 753 in profile Mi.2 (Fig. 2) the boundary between Unit 4a and 5.2 occurs. The erosion of the palaeosol of the K1s-cycle is followed by deposition of the gravel layer. Immediately above the erosion level one chert fragment of 1 x 2.9 mm occurs, covered by a 700 μm thick silt capping, consisting mainly of silt and minor proportions of clay and very fine sand grains.

Unit 5.2 in profile Mi.2 (Fig. 2) consists of poorly sorted material: mainly silt, common very fine and fine sand, and little medium sand-sized grains with a maximum diameter of 300 μm, some lithorelicts, as quartzites and sandstone fragments (maximum diameter: 600 μm), and occasionally fragments of mud crusts with a weak unistrial fabric (only observed in thin section 755). In between the closely packed skeleton grains brown fine clayey material is found, giving rise to an intertextic related distribution pattern. Locally the skeleton grains occur in a granular arrangement, without clay in between the grains. The difference between the lower and upper parts of the profile (thin sections 754 and 755) is restricted to an increase in the silt-sized particles in an upward direction and to the appearance of subrounded soil nodules (above 54.28 m + N.A.P.), ranging in size from 200 to 2100 μm, composed of material which is almost identical with that of the matrix of the profile itself.

Unit 5.2 in profile Mi.3 (upper part of thin section 839) is very similar in composition: mainly silt with sand-sized particles up to 600 μm in diameter (coarse sand) and very few lithorelicts (shale, silt- and sandstone fragments) with a maximum diameter of 0.5 mm. Divergent from the previous profile Mi.2, the deposit is slightly horizontally laminated and the argillaceous material in between the skeleton grains shows a weak unistrial fabric parallel with the lamination.

Unit 5.2. in profile Mi.4 has a composition similar to the previously mentioned profiles. The unit consists mainly of silt and less very fine and fine sand, and little medium sand-sized grains up to 400 μm in diameter. In between these skeleton grains brown clay occurs in an intertextic to close porphyric arrangement. This clayey groundmass exhibits mainly in the lowest part of Unit 5.2 an unistrial fabric, which disappears gradually in upward direction. Lithorelicts, as fragments of quartzite, shale, silt- and sandstone, are observed throughout the unit. The coarsest lithorelicts occur however in the lowest part (thin section 847), with a diameter up to 1.3 mm. In common they are not larger than 0.5 mm. In the last-mentioned thin section there is an inclined fissure, 1.5 cm wide, with an infilling of silt and fine sand. Near the rims the infilling is laminated parallel to the fissure walls, consisting of silt, or very fine sand or thin unistrial argillaceous laminae.

Occasionally in Unit 5.2 are observed: thin horizontal layers of fine sand (thin sections 846 and 845), layers (150 μm thick) of unsorted silt (thin section 844) and layers of silt enriched with opaque grains (thin section 843). Fragments of mud crusts and of clay laminae occur in thin section 846.

Clear indications for specific environmental conditions during the formation of Unit 5.2. are not found. The unistrial fabric, the poorly sorted grainsize composition and the locally observed laminae could indicate a fluvial deposition in shallow water (with in upward direction decreasing energy of flow), alternating with short periods of non-deposition (formation of mud crusts) or periods with overland flow, with the formation of rainwash deposits.

The well-laminated fissure infilling in the lowermost part of this unit suggests a filling-up of an incipient frost crack by meltwater.

Soil formation in the K3s-cycle

Soil formation in profile Mi.2 (thin sections 754 and 755) is characterized by biological activity, clay illuviation and hydromorphic features, with the formation of ferric and manganiferous nodules, and neoferrans around voids.

Soil formation in Unit 5.2 in the upper part of thin section 839 of profile Mi.3 shows the same characteristics: clay illuviation, ferric nodules, neoferrans, and additionally accumulations of ferrans in the voids. The hydromorphic features contrast with the former soil features of the K2s-cycle, being red brown in colour, and not dark brown or black.

Soil formation in the same unit in profile Mi.4 shows the following characteristics:

- Biological activity with biopores, pedotubules and fecal pellets, increasing in upward direction, and developed most strongly in thin section 843 and higher in the profile.
- Clay illuviation, showing several types of illuviation cutans such as yellow and brown illuviation ferriargillans, dirty brown speckled ferriargillans and matriargillans. They appear still faint in the lower part of the profile (thin section 847), distinct in thin sections 846 to 844, and decrease again gradually in upward direction (thin sections 844 to 842).
- Hydromorphic phenomena occur mainly in the lower part of the profile, decreasing upwards, such as: ferric nodules, ferrans and neoferrans.
- Accumulations of carbonates, although in very small quantities, are observed, starting from thin section 846 in upward direction, in the whole of the profile. They occur mainly as carbonate nodules and sometimes as calcitans, for example in thin section 843.

The faint illuviation horizons in Mi.2 (Fig. 2; thin sections 754 and 755) and Mi.3 (Fig. 4; upper part of thin section 839) are interpreted as B3t horizon formations of the K3s-cycle. In this same cycle, in profile Mi.4 (Fig. 4; largely based on the distinct clay illuviation in thin sections 846 to 844, but, less distinct above and below in the profile) a B3t (thin section 847), a B2t (thin sections 846-844) and a B1t horizon (thin sections 844-842) have developed.

The strong truncation of profiles Mi.2 and Mi.3, and moderate truncation of Mi.4 is attributed to an erosional phase in a following unstable cycle.

The accumulations of carbonates in profile Mi.4 (presumably calcite), based on their position in the profile, are regarded as formations in a more recent K-cycle, due to dissolution of carbonates from the surmounting calcareous Middle Silt Loam (Unit 6).

The buried truncated paleosol remnants in the profiles Mi.2, Mi.3 and Mi.4, of the third stable phase (K3s), largely based on the presence of an argillic horizon, initially with impeded drainage, showing however no reduction phenomena, and later on well-drained, is classified as a Luvisol, formed under deciduous forest in a temperate climate. In the absence of an A horizon this classification can only be tentative.

Indications for human activity are very limited, although at the base of Unit 5.2 in profile Mi.2 artefacts are found (Sites A and D; see Roebroeks, 1985. Only the angular chert fragment at the erosional surface of Unit 4a (thin section 753) could be an artefact.

At location Mi.1, a thin section was made of a sediment initially considered to be the top of Unit 5.2, which showed a large resemblance with the Luvisol from the K3s-cycle, but in sloping position. Investigation of thin section 633 revealed: firstly, a micro lamination, and secondly, that the individual laminae are composed of rounded soil nodules with varying diameter, derived from various soil horizons of a Luvisol. This suggests that the top layer has been formed by overland flow during rainfall (rainwash), derived from a Luvisol of presumably the K3s-cycle.

More upwards at the same location Mi.1, Unit 6.3 was sampled: a calcareous laminated silt loam with locally enclosed very thin black laminae, less than 3 mm thick. The black laminae showed in the field a large resemblance with the Eltville Tuff Layers as observed already in many other loess exposures in southern Limburg, Belgium and West Germany (see among others: Meijs et al., 1983). To examine this possibility, thin section 634 was made. Analysis of this thin section shows that:

- The black layers are composed of fine calcareous silt enriched with opaque minerals and anisotropic heavy minerals, without volcanic ones as occur in the Eltville Tuff Layers.
- In between the black laminae thin layers (0.4 to 8.4 mm thick) are observed of fine silt (smaller than 30 μm in diameter), or of very fine silt (smaller than 10 μm in diameter), and incidentally of unsorted silt (10-50 μm), or of silt with very fine and fine sand (less than 200 μm in diameter), and sporadically with aggregates, smaller than 250 μm in diameter.

Up until now no tephra layers have been found in the Belvédère pit. Compared with experimental results (Mücher and De Ploey, 1977; Mücher et al., 1981; Mücher and De Ploey, 1984) the above described laminae of Unit 6.3 could be formed as a result of deposition by afterflow, without simultaneous raindrop impact, or by meltwater flow.

CONCLUSIONS

The various features described and discussed in the foregoing units may be ordered in time as follows:

- During K1u-cycle formation of Unit 4a largely by fluvial action and less by afterflow or meltwater flow. In upward direction deposition by overland flow and rainsplash increases (profile Mi.2). In the topographical lower parts (profile Mi.6) this unit is formed in a backswamp-like environment, just as the Units 4b (Mi.3 and Mi.6) and 4c (Mi.5). In the last-mentioned unit post-sedimentary accumulation of carbonates followed, giving rise to the formation of calcareous tufa.
- Soil formation during K1s-cycle resulted in the formation of a well-drained Luvisol in Unit 4a (Mi.2) in a relatively topographically higher position. In Units 4a (Mi.6), 4b (Mi.3 and Mi.6) and 4c (Mi.5), all in lower position, dominantly remnants are found of a Gleyic Luvisol, developed in a mainly wet environment.
- In the K2u-cycle erosion of the soils formed in the K1s-cycle and deposition of Unit 5.1 (Mi.3 and Mi.6) in an alternating regime of shallow intermittent fluvial flow on the one hand, and on the other hand of sheet flow (rainwash and afterflow) and deposition by rainsplash.
- From the soil formation in the K2s-cycle in Unit 5.1 only few remnants are found (Mi.3). They could be an indication for a weakly truncated incipient soil formation or of a strongly truncated well-developed Luvisol.
- In the K3u-cycle erosion of the soils formed in the K1s and/or K2s-cycle, followed by water-laid deposition of Unit 5.2 (profiles Mi.2, Mi.3 and Mi.4). The sedimentation occurred mainly in shallow water alternating with short periods of non-deposition, or periods of overland flow resulting in the formation of rainwash deposits. Although Unit 5.2 in the field shows a large resemblance (caused by its homogeneous silty structure over a large area, about 2 ha) with the loess deposits of pre-Weichselian age in other exposures in southern Limburg, it is explicitly not regarded as such. This is mainly based on the sedimentary structure and composition of the deposit in thin section which do not correspond with those of loess. However, it cannot be excluded that the silt fraction is partly or largely derived from a loess deposit, subsequently reworked and mixed with terrace materials during redeposition (see also Meijs, 1985).
- Soil formation in the K3s-cycle in Unit 5.2 (profiles Mi.2, Mi.3 and Mi.4) giving rise to the formation of a well-drained argillic horizon, showing only initially phenomena of impeded drainage, which could indicate a truncated buried Luvisol palaeosol.

Luvisols, classified in The Netherlands as 'radebrikgronden' (de Bakker, & Schelling, 1966) and in West Germany as 'Parabraunerden' (Mückenhausen, 1962), can be formed under deciduous forest in a temperate climate. According to Blum and Ganssen (1972) are Köppen's Cf-climates favourable for the formation of argillic horizons. FitzPatrick (1971) describes the environmental conditions for this formation in terms of a moist to wet climate with a dry season.

The archaeological site C occurring in Unit 4, deposited during the first unstable cycle (K1u), is according to the paleontological assessment of the faunal assemblage (See van Kolfschoten, 1985 and Meijer, 1985) formed during a relatively warm temperate climate. However, thin section analysis revealed no indications for specific climatic conditions.

Well-preserved locations of archaeological finds are recognized in sediments deposited in unstable periods, whereas translocated artefacts are mainly observed in the beginning of Ku-cycles (see Roebroeks, 1985). In this respect, the in situ finds in the lowest part of Unit 5.2 in profile Mi.2, formed in the beginning of K3u-cycle, are an exception. In fact, this is the only location where indications for human activity have been observed in thin sections. The foregoing suggests that short-term human occupation at the Belvédère site is only documented in unstable phases.

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