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THEMATIC DAY BELGIAN SOIL SCIENCE SOCIETY, 10 NOVEMBER 1999
"SOILS AND PALAEOENVIRONMENT RECONSTRUCTION – APPLICATIONS IN GEO- AND ARCHAEOPEDOLOGY"

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Vertical and lateral variability of soil structure-potentials for environmental reconstructio - Case of study of the Middle Palaeolithic alluvial plain of the Wallertheim site (Germany)

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Introduction

Among a large spectrum of disciplines, the study of soil characteristics can contribute substantially for the reconstruction of past environments. This work presents some of the potentials of the pedological research for terrestrial environmental reconstruction on the complex Wallertheim site. This site, situated 25 km SW of Mainz (Germany) is famous for its significant Middle Palaeolithic finds (Schmidtgen and Wagner, 1929, Fauler, 1938). Between 1991 and 1994, Dr. Nick Conard conducted new archaeological excavations (Conard *et al.*, 1995a, Conard *et al.*, 1995b) and the team of the University of Ghent had the task of environment reconstruction based on soil characteristics. The data presented here are part of a larger document, which has been elaborated in the frame of a PhD research (Becze-Deák, 1997).

Three main stratigraphic units have been studied along the approx. 45 meters long and up to 8-10 meter high section. In this paper, the first stratigraphic unit, the alluvial soil-sedimentary complex (1st and 2^{d} sedimentary cycle on Fig. 1) will be discussed. The 6 archaeological layers recognised during the excavations are part of this alluvial plain soil-sedimentary complex (Conard *et al.*, 1995a). Based on stratigraphical arguments, as well as on faunal assemblages and TL dating, this alluvial complex has been attributed to the Last Interglacial (most of the alluvial sediments) and to the transition between the Last Interglacial and Last Glacial period (upper part of the alluvial sediments) (Conard *et al.* 1996, see also Fig.1).

Research methods

The pedological research consisted first in detailed field observations, spread over several field sessions in function of the advances of the archaeological excavations. The field observations were oriented to detect the fingerprints of various processes that can give indications on the environmental conditions. This was followed by meso- (stereomicroscope) and micromorphological (polarising microscope and scanning electron microscope) observations. During all the levels of morphological observations the individual soil characteristics, their vertical and lateral variability and their related distribution has been carefully recorded. The morphological observations have been further completed with standard soil physical and chemical analyses, X -ray analyses and Energy Dispersive X-ray analyses (Becze-Deák, 1997).

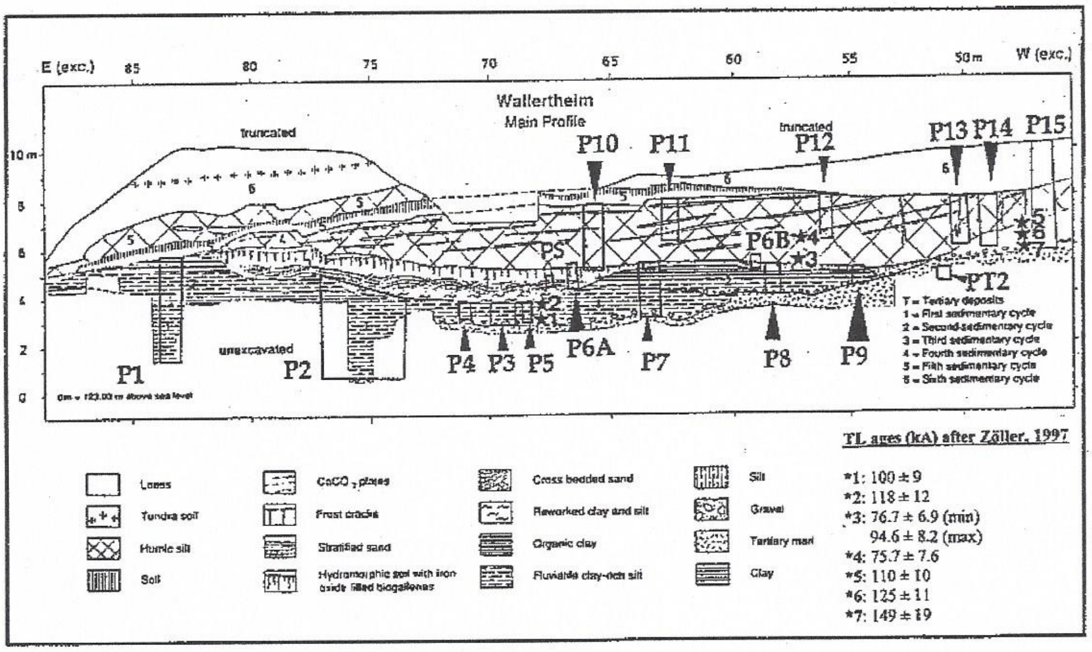

Fig. 1 Wallertheim site - main section, after Conard *et al.*, 1995a. Location of the studied profiles and the TL data.

Case study of the soil structure

At the Wallertheim site several soil characteristics have been studied in detail: humiferous aspect, morphology of the boundaries, bioturbation, pedality, secondary carbonates, gypsum and barite, silica remobilisation, redox-features, clay coatings. In this paper the type, gradient and environmental significance of the soil structure in the alluvial plain soil-sedimentary complex will be discussed. It has to be emphasised that it is considered (Langohr, 1994) that the soil structure is composed of two aspects: pedality and porosity. The pedality is made up of peds or aggregates, which are of natural origin, and which are related to particular environmental conditions such as wetting-drying, freezing-thawing and bioturbation.

The archaeologically rich alluvial plain sediments are situated at the boundary between the ancient alluvial plain and the neighbouring hills, where Tertiary and Quaternary calcareous sediments outcrop. The alternation of more or less coarse and more or less calcareous sediments appeared to be related with the interfingering of alluvial plain (non-calcareous and more clayey) and slope (calcareous and silty to gravely) deposits. Careful observation of the soil pedality, showed the following sequence (see also Fig. 2).

1. *The lower part of the sequence is mostly massive, without traces of stratification and shows the presence of abundant biopores.*

This is interpreted as an indicator of ***a slow, but more or less continuous sediment aggradation on a continuously vegetated surface of the alluvial plain***. The absence of humiferous surface horizons and of secondary carbonates with particular gradients are further arguments for these conclusions.

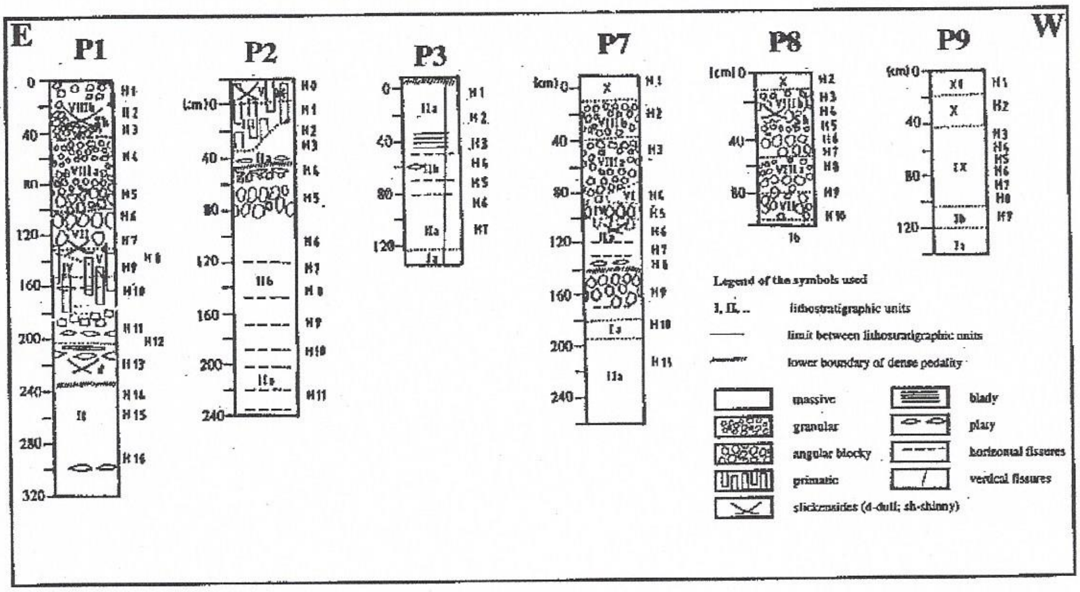

Fig. 2 **Distribution of the pedality gradient in the alluvial plain soil-sedimentary complex of the Wallertheim site. Location of the profiles, see on Fig. 1.**

2. *The sequence described above is overlaid by sediments characterised by a total absence of biopores and a clear gradient of small microgranular pedality in the upper part, becoming coarser and angu lar blocky, in the more clayey material or platy in the mo re silty material in the deeper part of the unit. The peds have a dense matrix, they are densely packed, but present packing pores and fissures, that locally can reach a thickness of 1-2 mm. Starting from the surface of this pedostratigraphic unit, the pedality gradient is affecting the sediments down to a depth of 240 cm in the eastern part of the section and up to 130 cm depth in the western part of the section. Moreover several millimetres thick open vertical fissures, starting from about 130 cm of the top of this unit and going 120 cm deep have been observed. The sediments adjoining these cracks are also compressed. This type of structure gradient has been recorded all through the site and at all the observation scales.*

The shape and the distribution of this pedality and porosity are characteristic for the impact of frost on silty and clayey layers. Indeed the impact of frost is strongly moisture and texture dependent, the speed of freezing being also an important factor. A granular pedality is characteristic for more clayey, clayey-silty material, possibly in a water rich environment and affected by rapid freezing (Van Vliet-Lanoë, 1976, Pawluk, 1988). Blady, platy and lenticular pedality is typical for silty material, affected by slow penetration of the freezing front (Van Vliet-Lanoë, 1976, Van Vliet *et al.,* 1984). Angular blocky pedality with smooth surfaces is characteristic for clayey and silty sediments occurring in the deeper part of a frost influenced sequence, with or without permafrost (Van Vliet-Lanoë, 1976), at a condition that the frost penetration is slow .

The high density of the peds is another argument for the impact of frost. Several experimental studies have demonstrated that freezing produces extremely compact peds (e.g. Bertouille, 1972, Chamberlain and Blouin, 1978, Radke and Berry, 1995). The process of growing ice crystals exerting pressure on the soil matrix and the ultradessication are considered responsible for the reduction of the internal porosity of the aggregates (Pawluk, 1988, Van Vliet-Lanoë, 1985). The pressure of growing ice crystals can explain the presence of the striated b-fabric lining the ped faces, observed during the micromorphological study. Such aggregates compacted by ice are very stable, they are well preserved even if they are stored at relatively high water content (Perfect *et al.*, 1990) and they can even resist water transport (Van Vliet-Lanoë, 1985).

The micromorphological observations permitted to detect a very particular aspect of the horizons supposed to be affected by frost. In the *western* part of the section, the granular to angular blocky peds and the horizontal fissures are highlighted by an iron hypocoating, while the ped interiors seem to be Fe depleted. The Fe concentrations on these ped faces can be explained by freeze-thaw cycles. Indeed the migration of the soil solution from the reduced soil matrix towards the ped faces and precipitation of the Fe at the contact with the less reduced environment between the peds can best explain the observed features. Solute migration and concentration induced by freezing was monitored by field measurements (e.g. Fullerton and Pawluk, 1987, Radke and Berry, 1995, Cary *et al.*, 1979) and was experimentally demonstrated by several authors for various solutes (e.g. De Jong, 1981, Datsko *et al.*, 1983). Remobilisation and precipitation of Fe has been experimentally observed by Adolphe, 1966 and described based on field observations by Cailleux in Antarctica, 1964 (in Vogt, 1991) and by Christine Siegert along the Lena River, Central Yakutia (verbal communication, July 1996, documented also by pictures sent). Iron accumulations on the edge of the platy pedality has been described also by Fedorova and Yarilova (1972) for silty soils in the taiga region of Siberia affected by prolonged seasonal frost.

In conclusion the pedality gradient and the associated features presented above indicate that the alluvial soil-sedimentary complex records the ***sudden impact of a severe cold period, associated with freezing processes.*** The depth of frost penetration and the presence of open vertical fissures in depth suggest ***conditions favourable for permafrost development***. This ***period of permafrost was short***, possibly the time span of tens of years and with no strong differences between the winter and summer temperatures, as no traces of ice wedge casts could be observed. The absence of visible evidences of cryoturbation features in the active layer can be related with **i.** the short duration of freeze-thaw; **ii.** the relative homogeneity and fine texture of the material

The impact of frost erased many of the previously existing soil characteristics. All the traces of former bioturbation and former pedality have been erased by the development of the new pedality.

3. *The upper part of the sequence is characterised by local presence of biopores and a compacted, angular blocky pedality in the Western part of the site and microgranular pedality in the Eastern part of the site. These sediments are greyish to black coloured and are characterised by higher organic carbon content in comparison with the underlying material, indicating less intense sedimentation dynamics in marshy conditions.*

Western part of the section (P7-P9, see Fig. 1):

The clayey layers are weakly structured, but two surfaces of stabilisation could be detected, based on the study of the pedality gradient and the field observed colours, latter roughly confirmed by the organic carbon content analyses. The pedality gradient, as well as the oriented b-fabric (observed during the micromorphological study) suggests that, ***although marshy conditions prevailed, temporary alternation of dry and wet periods did also occur***. This is also highlighted by the occurrence of few shiny slickensides, which is typical for swelling and shrinking in such highly clayey material. The mixture of soil material from the adjacent horizons observed at microscale are most probably also related with the argiloturbation associated to wetting and drying, in such clay rich material (59-71 % clay). The micromorphological characteristics of these layers are very similar to clayey soils that undergo some swelling and shrinking as described by Blokhuis *et al.* (1990). The wetting and drying however was not very pronounced, and it mainly affected the upper 10-20 centimetres. The underlying pedo-sedimentary sequence does not seem to be particularly influenced. The mixing aspect present only at microscale and the absence of turbation observable in the field is another argument for very short and not very deep wetting and drying processes. The cracks filled with humiferous material and plant fragments, observed in the extreme Western part of the section (P9, see Fig. 1) resembles desiccation cracks. However there was no possibility to check horizontal sections, in order to elucidate if they are related to wetting and drying or only to ripening (irreversible shrinking due to drainage of a water-laid material). Their occurrence only in the western part of the section might be related with their close position to the surrounding hillslopes, being less under the influence of the high water table of the alluvial system. Although preserved biopores have been observed (mainly during the field observation), the peds are generally compactly packed, suggesting ***that possibly they have been also affected by freezing or compaction from the overlying sediments***. The frost impact however was related with later periods, from a much higher soil surface.

Eastern part of the section

In the eastern part of the section (P1, see Fig. 1), starting from the surface of the dark clayey layers, i.e. the surface of the alluvial soil-sedimentary complex, a complete, densely packed microgranular to small angular blocky pedality could be observed. As it was presented above this pedality is typical for freeze-thaw in such clayey material. Besides the microgranular-angular blocky pedality, 1-2 cm thick vertical cracks, forming a polygonal pattern of about 60 cm diameter and penetrating to a depth of about 70 cm are present. These cracks are filled with secondary CaCO3. The size of the polygonal pattern indicates that these cracks are related to a desiccation processes, while the freeze-thaw pedality of the surrounding clay suggest that they are in fact cryodesiccation cracks (Hujzer, 1993). Moreover this part of the alluvial sequence is also characterised by evidences of soil creep of the upper $\pm$ 70 cm of the soil-sedimentary complex, including the CaCO3 accumulations along the vertical cracks. The impact of the creep is clearly visible also in thin sections, where the strong mixing of the clays and Fe nodules is evident.

The pedality of this part of the section strongly suggests the impact of repeated freeze-thaw. The absence of a similar impact in the western part of the section (see discussion above) suggests that ***at the moment of this frost impact the western part of the section was buried***, while the eastern part was at the surface. The occurrence of the creep suggests the existence of a slope towards the East that at the moment of its activity. Further observations could not be made as towards the East the soil-sedimentary record is completely disturbed by earlier excavations. ***The creep might b e related with the occurrence of the clayey and densely packed substratum*** described above. ***It might also suggest the existence of another period cold enough for permafrost development***. The considerable deeper impact of frost pedality in this part of the section compared to the western part (see discussion above) is an argument for superposition of several phases of permafrost development. Nevertheless there are not enough morphological evidences to favour any of the above-presented hypotheses.

To conclude, by the study of the soil structure, the pedality types and their gradients, as well as the related distribution with other soil characteristics, we are able to propose the following environmental evolution reconstruction:
- slowly, but continuously aggradating alluvial plain;
- severe, but short, climatic cooling, with possible permafrost development;
- renewed alluvial sedimentation in marshy conditions, with occasional dry seasons; - very cold climate, with probably permafrost, occurring at a moment when the western part of the section was buried by new sediments, while the eastern part was at or close to the surface.

Final comments

This study highlights the potential contributions of soil studies to environmental reconstruction. The case study shows also that the observation of the ***vertical and lateral variability of the soil characteristics***, as well as ***their related distribution on large sections*** enables to detect the impact of various climatic and environmental conditions, even in situations where they are overlapping each other. The record of the ***absence of the soil characteristics*** appears to be as important as their presence.

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