Pedo-geomorphic response to Late Glacial/Holocene climate fluctuations and human impact: A case study of combined micromorphology and luminescence dating

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Abstract
Combined application of micromorphology and luminescence dating allows us to distinguish pedogenic processes and phases of sediment accumulation. Near Frankfurt/M., Germany, a section provides an exceptional pedosequence from the termination of the Last Glacial Maximum to the youngest Holocene period in Middle Europe. The distinct sequence of buried soil horizons and colluvial deposits is a key sequence for the comprehension of pedogenic response to climate fluctuations and anthropogenically induced formation of colluvial deposits as they are typical for Middle Europe. Besides we also get a better understanding of the evolution of surface soils in loess landscapes and have herewith the possibility of predicting soil evolution against the background of climate change. The pedosedimentary reconstruction is based on both OSL-dating, using different irradiation techniques, and the vertical occurrence of pedogenic micromorphological features such as microstructure, secondary carbonate precipitation and clay coatings. Lateglacial and Holocene pedogenic processes can be separated, as there were decalcification and distinct clay illuviation in the Lateglacial followed by Chernozem and Luvisol formation until 7.5 to 6.5 ka. Interrupted by two events of colluvial deposition Luvisol formation went on until the Subboreal/Subatlantic period. Renewed colluvial deposition of calcareous material on top of the sequence led to secondary calcification of the upper part of the pedosequence.

Key Words
Soil formation, luminescence dating, micromorphology, loess, soil evolution.

Introduction
For a reconstruction of the pedo-geomorphic response to climate fluctuations and human impact precise information about the age of sediment deposition as well as exact information about occurring pedogenic processes and their succession are necessary. Such data are obtainable by combined micromorphology and luminescence dating methods. Thus we get a better understanding of soil formation rates and soil evolution through time. Only some investigations with combined micromorphology and luminescence dating methods were carried out so far (Hülle *et al.,* 2009; Kadereit *et al.,* 2009; Kaiser *et al.,* 2009; Kemp *et al*., 1996; 2003; Suchodoletz *et al.,* 2009).
Since more than three decades luminescence dating methods provide an independent dating tool for the determination of deposition ages of aeolian sediments (e.g. Hilgers, 2007; Huntley *et al.,* 1985; Lai *et al.,* 2009; Lian and Roberts, 2006; Singhvi *et al.,* 1982; Wintle and Huntley, 1979; Zöller *et al.,* 1988). Aeolian sediments such as loess or dune sands are particularly suitable for the application of luminescence dating methods, which reveal the time since feldspar and quartz grains were exposed to heat or sunlight. This technique was further developed and applied to the dating of colluvial sediments (e.g. Kadereit *et al.,* 2009; Lang 2003) and recently of periglacial slope deposits in Middle Europe (Hülle *et al.,* 2009; Völkel and Mahr, 1997).
Micromorphology is an excellent tool to analyse results of *in situ*-pedogenic processes (e.g. Stoops in press). It gives information about the intensity and succession of soil forming processes and allows to distinguish between pedosediment and sediment. When combined properly both methods provide therefore essential information that lead to an improved understanding of soil evolution and landscape genesis. Here we present results of combined micromorphology and OSL-dating studies and the pedosedimentary reconstruction of a unique Lateglacial/Holocene pedosequence in Middle Europe which formed on loess, periglacial and colluvial deposits.

Methods
Luminescence measurements were carried out on polymineral fine grain samples (0.1 - 0.2 mm) following the multiple aliquot regenerative-dose protocol. To calculate the annual dose derived from the decay of

lithogenic radionuclides in the sediment, the concentration of uranium, thorium, and potassium was determined by neutron activation analysis (analysed by Becquerel Laboratories, Sydney, Australia). In addition, for some samples radionuclide contents have been determined by gamma-spectrometry. Soil description followed FAO Guidelines (FAO, 2006). Particle size distributions of fine earth (< 2 mm) were determined by sieving and analysing the <63 µm fractions by pipette using $Na_4P_2O_7$ as a dispersant. Those samples containing appreciable amounts of humus or carbonate were pre-treated with H_2O_2 and HCl, respectively. For micromorphological analysis, undisturbed samples were collected with tin boxes (4.5 x 2.5 x 2.5 cm and 10 x 6 x 3 cm) at depths shown in Figure 1. The blocks were air dried, impregnated with Oldopal P80-21 and sliced into 4.0 x 2.4 and 9.0 x 6.0 cm thin sections. Thin sections were described at 25 - 400 magnification under a petrological microscope mainly using the terminology of Stoops (2003).

Results

Study area

In Tertiary limestone, situated in the area south of the mountainous ranges of the Taunus, numerous karst depressions contain sediment fillings, which are excellent archives of soil and landscape history. The pedosequences have been developed since the older Pliocene, but they are particularly well documented during the Late Pleistocene and Holocene (Hilgers *et al.,* 2003; Semmel, 1995). The investigated pedosequence (Dyckerhoff outcrop) is situated in the loess covered and gentle rolling southern Taunus foreland around 40 km west of Frankfurt/M (Germany).

OSL-Dating

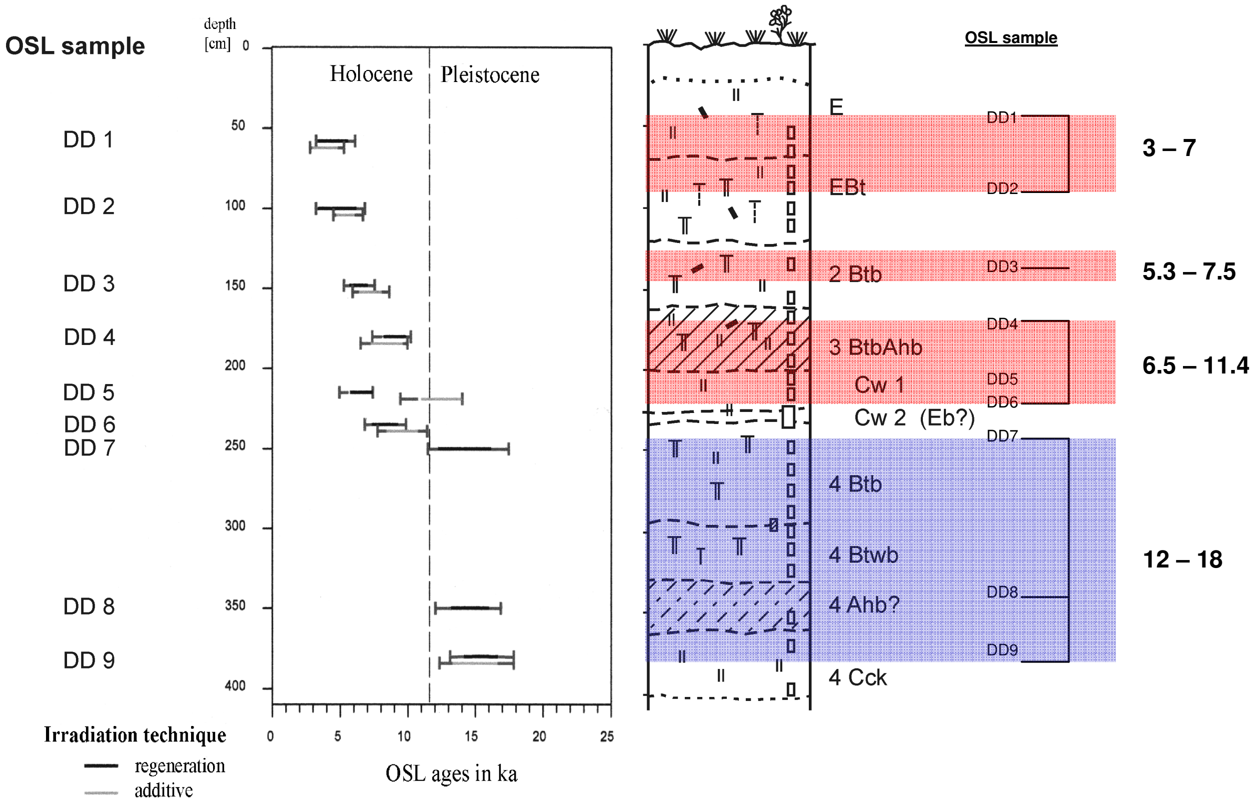

Figure 1. OSL-dating results of polymineral fine grain samples (multiple-aliquot method). Rectangles on the right hand side of the profile sketch indicate micromorphology samples.

Micromorpology

Table 1. Selected micromorphological features of the Dyckerhoff pedosequence. The micromorphological property is shown by the presence (cross) or absence (no cross).

Horizon	Groundmass						Pedofeatures										
(sample depth cm)	Micromass[a]						Redoximorphic features[b]					Translocation features[c]					
	b-fabric						nodule			hypocoating		clay coating					
	u	ms	ss	gs	s	c	t	n	a	gm	cc	vd	d	l	s-c	f	li-f
E (56)			x					x				x				x	x
E (67)			x					x						(x)		(x)	
E (78)	x			x				x		x			(x)			x	
EBt (89)			x					x					x			(x)	
EBt (103)			x		x			x					x	x			
EBt (113)			x		(x)[d]			x					x			x	x
2 MBt (134)			x					x	x	x			x	x			x
MBt (154)			x					x		x			x	x			x
3 Ahb (169)			x					x						x			x
Ahb (181)			x					x		x				x			x
Ahb (195)			x					x						x			x
Cw1 (210)			x					x	x					(x)			x
Cw2 (fE?) (216)			x						x			x	x	(x)		x	x
Cw2/Btb (224-235)			x	(x)				x		x		x	x	x		x	(x)
4 Btb (248)			x					x	x	x	x		x	x	x	x	x
Btb (258)		x	x				x		x	x	x		x	x		x	
Btb (273)			x		x				x	x			(x)	x		x	x
Btb (287)			x					x	x	x			x	x			
Btwb (300)			x					x	x	x			x	x			
Btwb (314)				x				x	x	x			x			(x)	
Btwb (325)			x					x	x	x			x				
Ahb (?) (355)			x					x					x				
Cc (370)						x							x				
Cc (393)						x							x				

Pedosedimentary reconstruction

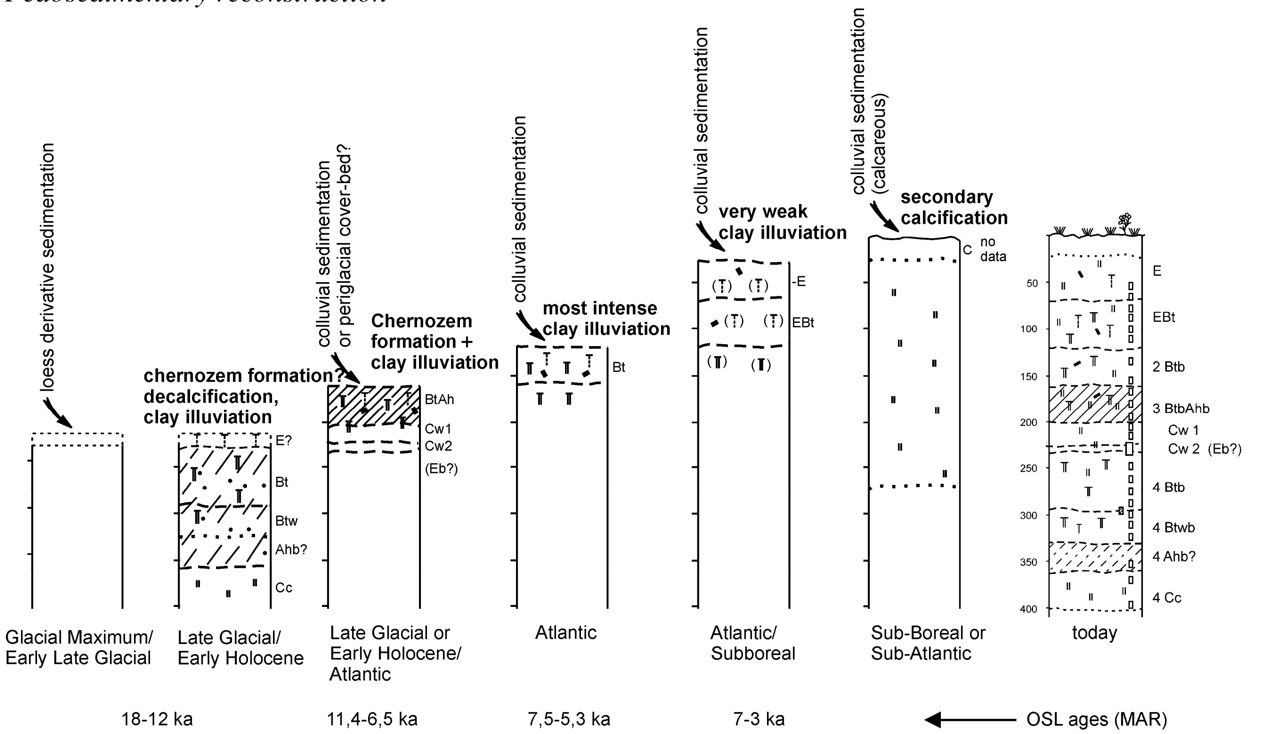

Figure 2. Pedosedimentary reconstruction of the pedosequence in the Dyckerhoff outcrop near Frankfurt, Germany. Colluvial sedimentation is anthropogenically induced.

Conclusion

Combined application of micromorphology and luminescence dating on the Dyckerhoff pedosequence reveals a distinct sequence of buried soil horizons and colluvial deposits from the termination of the LGM to the youngest period in the Holocene. Pedogenesis responds to Lateglacial interstadial climate with Luvisol formation, with Chernozem formation to Early Holocene climate conditions and again with Luvisol formation from the beginning of the Atlantic period. Many surface soils of loess landscapes of Middle Europe have experienced the same evolution (Luvisol – Chernozem – Luvisol) that is often completely masked by the last phase of soil formation. Human impact on soils and relief in form of forest clearances and agriculture led to soil erosion and formation of colluvial deposits since around 7.5-6.5 ka, which is also characteristic for loess landscapes with early human occupation.

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