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*Supplement of*

## **Loess formation and chronology at the Palaeolithic key site Rheindahlen, Lower Rhine Embayment, Germany**

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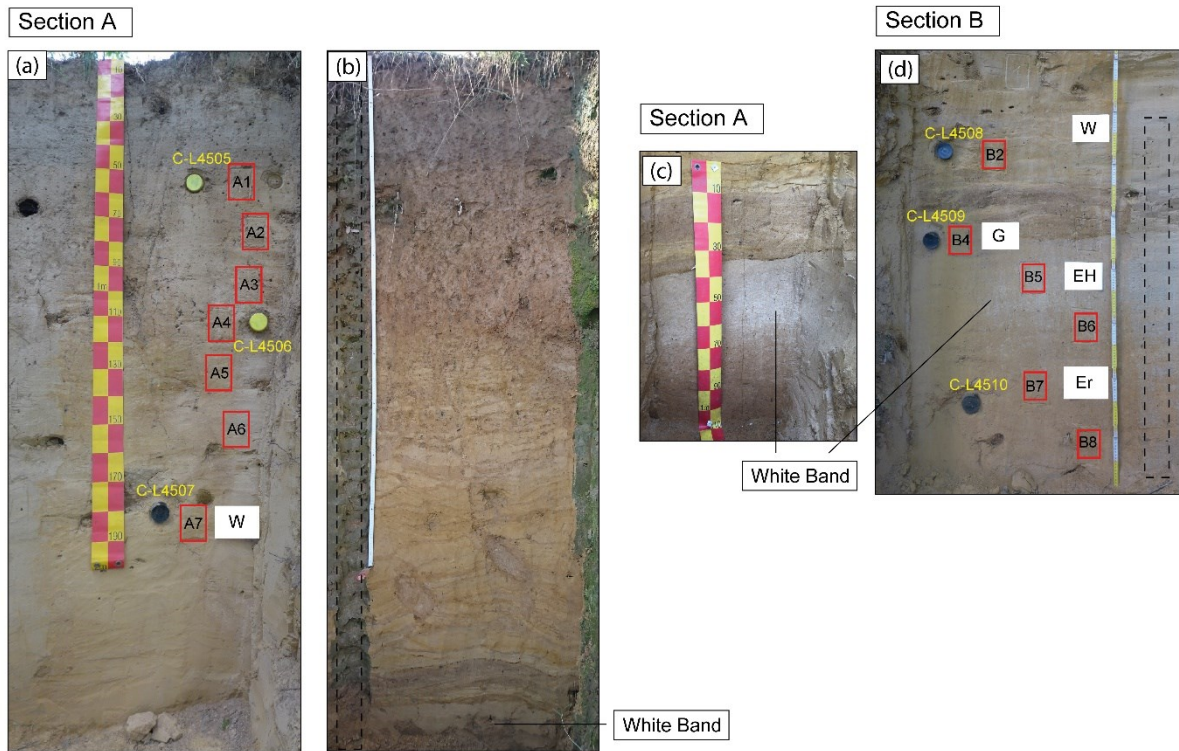


Fig. S1: Sections A and B of Profile 5 at Rheindahlen with loess layers according to Schirmer (2002), sample locations for micromorphology (red squares) and luminescence dating (yellow or black plastic caps) as well as sampling columns for sedimentology (dashed rectangles). (a) The profile was very dry at the time of sampling for micromorphology and luminescence. (b) Same as (a) but in a moist state and after sampling for sedimentology. Note the network of brown bands and presence of two burrows in the lower half of the section. (c) In section A, the white band is truncated by the erosional discontinuity, whereas a thin layer of brownish loess (presumably the Gilgau Loess of Schirmer, 2002) is preserved on the left side of section B (d).

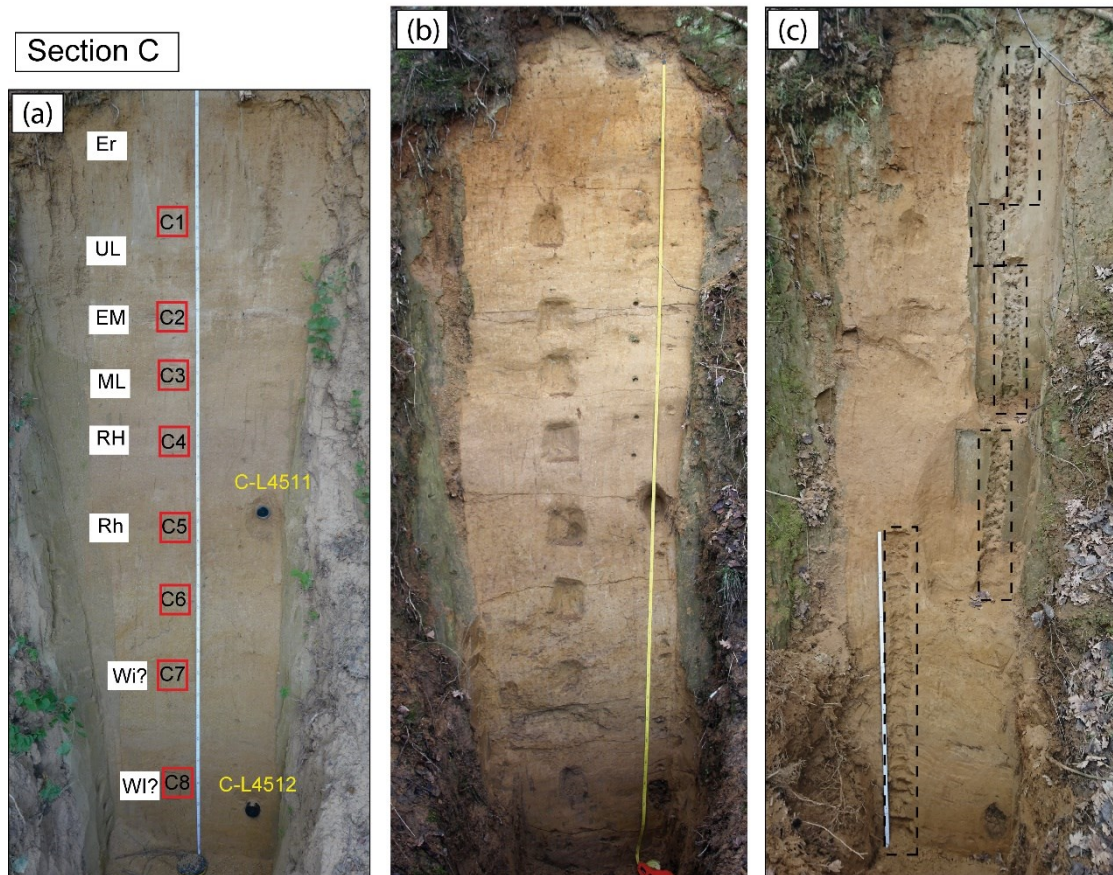


Fig. S2: Section C of Profile 5 at Rheindahlen with loess layers according to Schirmer (2002), sample locations for micromorphology (red squares) and luminescence dating (black plastic caps) as well as sampling columns for sedimentology (dashed rectangles). (a) In a dry state, colour differences are hardly detectable. (b) Same as (a) but after sampling for micromorphology and luminescence in a slightly moister state, when layers are clearly visible. (c) The section after sampling for sedimentology.

Table S1: Luminescence measurement protocols used in this study.

<b>a) Quartz SAR protocol</b>		
Step	Treatment	Observe
1	Preheat (240 °C for 10 s)	
2	Blue OSL (LEDs) for 40 s at 125 °C	Lx (OSL)
3	Test dose	
4	Cutheat (220 °C)	
5	Blue OSL (LEDs) for 40 s at 125 °C	Tx (OSL)
6	Regenerative dose (R1–4, R0, RR, DR)	
7	Return to step 1	
<b>b) IR<sub>50</sub> protocol</b>		
Step	Treatment	Observe
1	Preheat (250 °C for 10s)	
2	IRSL (LEDs) for 300 s at 50 °C	Lx (IR <sub>50</sub> )
3	Test dose	
4	Preheat (250 °C for 10s)	
5	IRSL (LEDs) for 300 s at 50 °C	Tx (IR <sub>50</sub> )
6	Regenerative dose (R1–4, R0, RR)	
7	Return to step 1	
<b>c) pIR<sub>50</sub> IRSL<sub>290</sub> protocol</b>		
Step	Treatment	Observe
1	Preheat (320 °C for 60s)	
2	IRSL (LEDs) for 200 s at 50 °C	
3	IRSL (LEDs) for 200 s at 290 °C	Lx (pIR <sub>50</sub> IRSL <sub>290</sub> )
4	Test dose	
5	Preheat (320 °C for 60s)	
6	IRSL (LEDs) for 200 s at 50 °C	
7	IRSL (LEDs) for 200 s at 290 °C	Tx (pIR <sub>50</sub> IRSL <sub>290</sub> )
8	IRSL (LEDs) for 100 s at 325 °C	
9	Regenerative dose (R1–4, R0, RR)	
10	Return to step 1	

Table S2: Radionuclide content and environmental dose rate for all samples of this study.

Sample ID	Depth (m b.s.)	Water content (%)	Radionuclide content			Q Dose rate (Gy/ka)	IR <sub>50</sub> Dose rate (Gy/ka)	pIR <sub>50</sub> IRSL <sub>290</sub> Dose rate (Gy/ka)
			U (ppm)	Th (ppm)	K (%)			
C-L4505	0.55	18±5	3.32±0.15	10.26±0.52	1.60±0.03	2.82±0.10	-	-
C-L4506	1.10	18±5	3.16±0.14	10.02±0.50	1.56±0.03	2.71±0.10	-	-
C-L4507	1.80	18±5	3.37±0.15	11.37±0.62	1.58±0.03	2.84±0.11	3.82±0.14	4.30±0.24
C-L4508	2.20	18±5	4.24±0.18	14.92±0.78	1.55±0.03	-	4.42±0.16	5.04±0.29
C-L4509	2.50	18±5	3.39±0.15	11.13±0.55	1.44±0.03	-	3.66±0.13	4.14±0.23
C-L4510	3.10	18±5	2.70±0.12	11.66±0.63	1.56±0.03	-	3.57±0.13	-
C-L4511	5.10	18±5	2.86±0.13	11.34±0.57	1.74±0.03	-	3.73±0.13	-
C-L4512	6.50	18±5	3.13±0.14	12.44±0.68	1.69±0.03	-	3.86±0.14	-

Table S3: Micromorphological characterization of thin sections from Rheindahlen: Pores, aggregation, microstructure and groundmass properties.

Key: Porosity: l: low, m: medium, h: high, vh: very high; Pedality, ped separation: w: weakly, m: moderately, s: strongly, d: developed, s: separated; Pore type: ch: channels, chb: chambers, cdpv: compound packing voids (between aggregates), pl: planes, vu: vughs, bur: burrows; Microstructure: ab, sb: angular blocky, subangular blocky, cha: channel, chb: chamber, com: complex, cru: crumb, gr: granular, ma: massive, pla: platy, spo: spongy, vug: vughy, sg: single grain; c/ ratio:coarse/fine-ratio; Sand: f: few, vf: very few sand grains; c/f rdp: coarse/fine-related distribution: cpor, opor: close or open porphyric, m: monic, chi: chitonic; colour code see Table S4; Limp.: limpidity, here dotted; b-fabric: un: undifferentiated; stsp: stipple-speckled, mosp: mosaic-speckled, grstr: granostriated, parstr: parallel striated

#	Depth cm	Horizon	Porosity	Pore type	Pedality	Microstructure	c/f ratio	Sand	c/f rdp	Colour	Limp.	b-fabric	Other
A1	56	M	vh	bur, ch, cdpv, vf pl	vf peds, wd, ws	spo, sb	85/15	f fS	fm, cpor	br	dot	un, stsp	Organic stains, pieces of charcoal
A2	74	MBtg	vh	bur, ch, cdpv, vf pl	f peds, wd, ws	spo, sb	80/20	f fS	fm, cpor	br	dot	stsp	Organic stains
A3	96	Bt1	h	chb, ch, vu, pla	f peds, md, ms	sb	80/20	vf fS	cpor	br	dot	stsp, mosp	
A4	113	Bt2	h	chb, ch, vu, cdpv	md, ms peds	sb, ma	75/25	f fS	cpor, fm	br	dot	stsp, mosp	
A5	132	BCt	m, h	ch, bu, chb, pla	vf sub peds and plates	ma, cha, pla	75/25	vf fS	cpor, fm	lbr, br	dot	grstr, stsp	
A6	153	BC(t)1	l	cha, chb, bur, vug, pla	0	ma, cha	80/20	f fS	cpor, fm	lbr	dot	stsp, grstr	
A7	184	BC(t)2	m	cha, bur, vu	0	ma, cha, pla	80/20	vf fS	cpor, chi/ fm	gr br	dot	stsp, grstr	
B2	217	BC1	l	spv, cha	0	ma, sg	90/10	nf	fm/chi	lbr	dot	grstr, stsp	
B4	251	BC3	l	pla, cha, bur	f peds, wd, ms	pla, sb	80/20	nf	cpor	br	dot	stsp	
B5	266	E1	l	vu, pla	f peds, wd, ms	ma, pla, lent	80/20	nf	cpor/fm	lbr	dot	stsp, grstr	
B6	284	E+Bt	l	vu, pla, cdpv	m peds, md, ss	sb, pla	80/20	nf	cpor/fm	br	dot	stsp	
B7	305	Bt	m	pla, cdpv, chb, bur	m peds, md, ms	sb, pol, pla	65/35	nf	cpor, chi	br	dot	most, stsp, parstr	
B8	325	Bt	m	cdpv, chb, vu	m peds, md, ms	sb, pla	70/30	nf	cpor-opor	br	dot	stsp, parstr	
C1	375	BCt	h	cha, chb, bur, vu	f peds, wd, ws	cha, ma, sb	75/25	nf	cpor, chi/fm	br	dot	stsp, grstr	
C2	420	BC1	h	cha, bur, vu, pla	vf peds, wd, ws	cha, ma, sb	80/20	nf	cpor/fm	lbr	dot	stsp	
C3	449	BC2	h	cha, bur, vu, pla	0	ma, vug	80/20	nf	cpor/fm	lgr, lbr	dot	stsp	
C4	482	E	m	cha, chb, bur	0	ma, cha	80/20	nf	cpor/fm	lbr, br	dot	stsp	
C5	524	Btg	m, h	bur, pla, cha	f peds, md, ms	ab, ma, cha, pla	70/30	nf	cpor	br	dot	stsp, mosp	
C6	557	BCg(t)	m	cha, chb, bur	f peds, wd, ws	ma, cha, sb	70/30	nf	cpor	lbr, dbr	dot	stsp	
C7	594	Bwg(t)	h	cha, pl, bur	f peds, md, ms	ma, pla, cha	70/30	nf	cpor	br	dot	stsp	
C8	644	Bwg(t)	h	cha, bur, pla	vf peds, vwd, vws	ma, cha	70/30	nf	cpor	br, dbr	dot	stsp	

Table S4: Micromorphological characterization of thin sections from Rheindahlen: Pedofeatures.

Key: P. feat. = passage features, Excr. = excrements, ped surf. = on aggregate surfaces; fragm. = fragmented; lbr, dbr, bl, orbr = light brown, dark brown, black, orange brown; or, dis = orthic or disorthic nodule; abundance: 0 = not observed, 1 = rare, 2 = occasional, 3 = many, 4 = abundant; \* in passage feature

#	P. feat.	Excr.	Clay coatings			Clay + silt coatings	Fe-Mn-nodules			Fe-Mn-depletion	Other	
			intact	fragm.	papules		amount	type	size			
A1	4	2	0	0	0	0	1	lbr, bl, typ	dis	< 1mm	0	
A2	3	2	1	0	1	0	3	lbr, dbr, bl, typ	f dis, m or	< 1mm, f < 6mm	0	
A3	3	1	3	0	1	1	4	br, dbr, bl, typ	or	< 2mm	3	
A4	3	0	4	0	1	2	2	dbr, bl, typ	or	< 2mm	4	
A5	3	0	3	0	1	2	2	dbr, bl, typ	or	< 2 mm	4	rare Mn hypocoatings
A6	2	0	1	0	0	1	1	lbr, bl, typ	or	< 1mm	2	
A7	3	0	3	0	1*	1	2	lbr, dbr	or	< 1mm	2	occasional Mn hypocoatings
B2	2	0	2	0	2	0	1	lbr	or	< 1mm	1	Clay granules
B4	1	0	0	0	2	0	2	lbr, dbr	or	< 5mm	1	
B5	0	0	0	0	1	0	3	lbr, dbr	or	< 5mm	2	Fe nodule superimposed by Mn nodule
B6	0	0	1	0	3	0	4	lbr, dbr	or, dis	< 5mm	2	
B7	1	1	3	2	3	2	1	lbr, bl	or	< 1 mm	1	
B8	2	1	4	3	3	2	1	lbr, bl	or	< 1 mm	1	
C1	2	0	3	2	2	2	1	lbr, bl	or	< 1 mm	1	
C2	1	0	1	1	1	0	1	lbr, bl	or, dis	< 1 mm	1	rare Mn incomplete infillings
C3	2	0	1	0	1	0	1	lbr, bl	or, dis	< 2 mm	1	rare Mn incomplete infillings
C4	0	0	1	0	0	0	2	lbr	or	< 2 mm	1	rare Mn incomplete infillings
C5	1	0	3	2	2	2	2	lbr, dbr	or	< 2 mm	1	
C6	0	0	2	1	2	3	3	lbr, dbr, bl	or	< 1 mm	2	rare Mn incomplete infillings
C7	1	0	3	1	1	2	4	lbr, dbr, bl	or	< 5 mm	3	rare Mn incomplete infillings and and coatings; clay coats in large biogenic pores
C8	1	0	2	0	0	1	4	orbr, lbr, dbr	or	< 2 mm	3	clay coats in large biogenic pores

Table S5: Micromorphological characterization of thin sections from Rheindahlen: Further characteristics of sediment structure and evaluation of micromorphological features regarding processes of sediment accumulation and post-depositional alteration including indications for the occurrence of extended frost.

Key: abundance/degree of compaction/intensity of process: 0 = not observed/-, 1 = rare/weak, 2 = occasional/moderate, 3 = many/strong, 4 = abundant, very strong, Acc. of org. mat. = accumulation of organic matter; Redoximorph. = redoximorphic, \* very few syngenetic biogenic pores, + in the lowest part of the thin section

#	Sediment structure				Deduced processes						Frost effects
	Platy structure	Silt patches	Banding	Degree of compaction	Reworking indicated by	Bioturbation	Acc. of org. mat.	Redoxim. bleaching	Redoxim. mottling	Clay illuviation	
A1	0	0	0	1		4	2	0	1	0	not found
A2	0	0	0	2		4	1	0	2	0	not found
A3	0	2	0	3		3	0	2	2	2	not found
A4	0	2	2	2	banding <sup>+</sup>	3	0	3	1	2	banding and silt pans <sup>+</sup>
A5	2	3	2	3	banding	2	0	3	1	1	banding
A6	0	1	3	4	banding	1*	0	1	1	1	strong banding
A7	0	2	4	4	banding	1*	0	1	1	2	strong banding
B2	0	1	0	4	cross-bedding	1*	0	1	1	1	(silt patches)
B4	3	2	2	4		1*	0	1	1	2	banding, silt patches, rounded peds, platy ms
B5	2	3	4	4	clay papules	0	0	2	2	0	banding, silt patches, platy structure
B6	2	2	3	4	clay papules, Bt aggregates	0	0	2	3	0	banding, silt patches, rounded peds, platy ms
B7	3	0	0	4	clay papules, but within horizon	1	0	2	1	4	rounded peds, platy ms, fragmented clay coatings, clay papules
B8	1	0	0	4	clay papules, by frost	1	0	1	1	5	rounded peds, platy ms, fragmented clay coatings, clay papules, microlayering (pans)
C1	1	2	1	3	clay papules, pans	1*	0	1	1	3	rounded peds, fragmented clay coatings, clay papules, microlayering (pans)
C2	1	2	1	3	ice wedge casts, pans	1*	0	1	1	2	ice wedge casts, fragmented clay coatings, clay papules, microlayering (pans)
C3	1	2	1	3		1*	0	1	1	1	silt patches, weak banding
C4	1	2	1	3		0	0	1	1	1'	silt patches, weak banding
C5	2	0	0	3		1	0	1	1	3	wedge-shaped aggregates, pans, fragmented coatings
C6	1	1	2	3		1	0	2	2	2	banding, wedge-shaped aggregates, pans, ice-wedge pseudomorphs, clay papules
C7	1	2	2	3		1	0	3	3	2	banding, wedge-shaped peds, platy ms
C8	1	1	1	3		1	0	2	2	2	banding, platy ms