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# Intra-interstadial environmental changes in Last Glacial loess revealed by molluscan assemblages from the Upper Palaeolithic site of Amiens-Renancourt 1 (Somme, France)

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1 Intra-interstadial environmental changes in Last Glacial loess revealed by molluscan  
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3

4 A molluscan record depicts intra-interstadial environmental phases

5

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16

17 ABSTRACT: The Amiens-Renancourt 1 site recently yielded one of the most important  
18 Upper Palaeolithic Human occupations of northern France by the number of flint artefacts and  
19 especially by the presence of Venus figurines. All the material comes from a single  
20 archaeological layer located in a tundra gley bracketed by loess units. A multi-proxy study  
21 combining a detailed stratigraphy, luminescence and radiocarbon datings and high-resolution  
22 (5 cm/sample) grain size and molluscan analyses was therefore carried out to reconstruct and  
23 date the associated environmental changes and to determine the exact context of the Human  
24 occupation. The chronological frame thus established supports the correlations of the  
25 archaeology-bearing tundra gley and of an underlying arctic brown soil with Greenland  
26 interstadials GI-4 and GI-3. Composition changes in the molluscan population enabled the  
27 identification of transitional and optimum phases and sub-phases within these two  
28 pedogenetic horizons. A conceptual correlation model linking molluscan phases with  
29 millennial-timescale variations of Greenland ice-core and Sieben Hengste speleothem climate  
30 records is proposed. The Human occupation appears contemporaneous to the end of the  
31 stadial-interstadial transition of GI-3. Synchronous in Amiens-Renancourt 1 and Nussloch,  
32 subsequent micro-gleys may also result from a regional/global forcing. Such a level of detail  
33 is unprecedented in a loess sequence.

34

35 KEYWORDS: Terrestrial molluscs, Loess, Upper Weichselian, Interstadial, Upper  
36 Palaeolithic

37

## 38 Introduction

39 In continental Europe, only a few (sub)continuous speleothems and sedimentological, pollen  
40 and diatom records from lacustrine and peat deposits document the environmental impact of  
41 the millennial-timescale milder oscillations, i.e. interstadials, of the last glacial period  
42 (Weichselian) north of the Mediterranean domain (Ampel et al., 2010; Luetscher et al., 2015;  
43 Fankheuser et al., 2016; Sirocko et al., 2016; Duprat-Oualid et al., 2017).

44 Conversely, loess deposits cover vast areas in European plains (Lehmkuhl et al., 2021) and  
45 offer numerous sequences showing alternations of loess units and pedogenetic horizons, i.e.  
46 tundra gleys or arctic/boreal brown soils (Antoine et al., 2001, 2013, 2014; Jary & Ciszek,  
47 2013; Meszner et al., 2013; Haesaerts et al., 2016; Zens et al., 2018), which respectively  
48 deposited during stadials and formed during interstadials (Antoine et al., 2009). This scheme  
49 is particularly well-expressed between 35 and 20 ka owing to high sedimentation rates, i.e.  
50 about 1 m/ka, and supported by radiocarbon chronologies derived from classical (charcoal,  
51 bones, terrestrial mollusc shells) or new (earthworm calcite granules, *n*-alkanes) dating  
52 materials (Haesaerts, 2009; Moine et al., 2017; Újvári et al., 2017; Zech et al., 2017).

53 Contrary to pollen, terrestrial mollusc shells are present in most European loesses (Ložek,  
54 1990). Their 5-40 % calcium carbonate (CaCO<sub>3</sub>) content (Bosq et al., 2020) favoured both  
55 shell construction and preservation, but also the preservation of bone remains in Human  
56 occupation layers as well. As assemblages of these organisms are highly sensitive to their  
57 medium, they are well-suited to reconstruct millennial timescale palaeoenvironmental  
58 changes (e.g. Moine et al., 2008, 2011; Sümegi et al., 2019). They thus provide a useful  
59 complement to the chronostratigraphical frame for Middle and Upper Palaeolithic sites of  
60 northern France (Antoine et al., 2016).

61 Continuous molluscan records compiled for the 35-20 ka period revealed a similar  
62 environmental response to stadial-interstadial cycles across western Europe. Increases in both  
63 the total abundance of molluscs and the proportions of hygrophilous and palustral species  
64 respectively indicate warmer and more humid conditions during the formation and  
65 degradation of tundra gley horizons (Remy, 1969; Kerney, 1971; Schiermeyer, 2000; Moine  
66 et al., 2008, 2011). The disappearance of the most vegetation-requiring taxa systematically  
67 leads to a richness minimum at the top of tundra gleys interpreted as a harmful effect of  
68 ground ice on vegetation (Moine, 2014). In northern France, due to the poor mollusc  
69 diversity, this effect is less marked and a few species may even briefly appear at the basis of  
70 tundra gleys, indicating a short phase of vegetation improvement following harsh stadial  
71 conditions.

72 The Amiens-Renancourt 1 site offered us a new opportunity to document environmental  
73 changes associated with stadial-interstadial cycles with a time resolution rarely reached until  
74 now but which is necessary to characterise features specific to each cycle and event. This site  
75 also yielded the youngest Gravettian occupation of northern France preceding the  
76 abandonment of the region during the Last Glacial Maximum (LGM) (Antoine et al., 2016).  
77 Its study will thus also allow for the precise positioning of the archaeological layer in its  
78 climatic and environmental context.

79 This is thus a fundamental test to demonstrate that such an approach may improve  
80 correlations between archaeological layers and regional or global climate and environmental

81 records. Such correlations basically rely on the relative – by typology – or absolute – by  
82 radiocarbon or thermoluminescence – dating of the archaeological material, especially when  
83 the stratigraphy has been reworked, is unclear or complex and environmental proxies are  
84 absent or inconclusive. However, combining high resolution palaeoenvironmental information  
85 from bioindicators for open air sites located in clearly stratified loess sequences may allow  
86 much more precise correlations. Reaching the expected (multi-)centennial-timescale will  
87 definitely deepen the comprehension of the relationships between climate and human  
88 settlements in the European Plain during the last glacial period.

89

## 90 **Site settings**

91 The archaeological site of Amiens-Renancourt 1 is located in northern France (Fig. 1) at the  
92 edge of the western suburb of Amiens in the Renancourt district (49°54'5.21"N;  
93 2°15'50.58"E). The excavation is located on the left-hand side of the Somme River valley,  
94 several meters above the level of its present alluvial plain, at the foot of the north exposed  
95 slope of a slight promontory separating the Grâce dry valley from the Selle River valley  
96 (Fig. 2).

97 The most complete loess succession is 6.75-m-thick and overlies a chalky flint gravel bed  
98 reached at a depth of 8.3 m using a manual auger (Fig. 3). No Quaternary sediments are found  
99 below this gravel bed. It overlies the bedrock constituted of Upper Cretaceous chalk  
100 outcropping westward at short distance and constituting the promontories that separate the  
101 different valleys (Kuntz & Dupuis, 1972).

102 The first archaeological discoveries in the surroundings date back to the beginning of the 20<sup>th</sup>  
103 century (Commont, 1913) owing to the numerous brickearth quarries in operation at that time.  
104 A concentration of Palaeolithic flint artefacts and large mammal bone remains was excavated  
105 on this occasion in the former Devalois quarry, but then lost. Fortunately, a new  
106 concentration, named Amiens-Renancourt 1, was discovered in 2011. Excavated every year  
107 since, the archaeological layer has already yielded many horse bone fragments, thousands of  
108 lithic remains attributed to the Recent-Final Gravettian technocomplex as well as ornamental  
109 items and several Venus figurines in chalk (Paris et al., 2017, 2019).

110 Based on these archaeological discoveries, Amiens-Renancourt 1 is thus one of the best  
111 preserved and most important Gravettian sites for northern France (Paris, 2020), and is even  
112 unique regarding the presence of Venus figurines. It is clearly positioned in the stratigraphy,  
113 almost undisturbed and with a very limited vertical dispersion. The high-resolution  
114 palaeoenvironmental study of this site, along with an adequate chronology, will thus  
115 contribute to documenting the impact of the millennial-timescale climate variability on  
116 continental loess environments and to exploring their relationship with this Human settlement.

117

## 118 **Material and methods**

### 119 *Sampling strategies*

120 The studied profile was positioned on a side of the excavated area so that it passes through the  
121 archaeological layer, which can be optimally associated with palaeoenvironmental proxies.

122 After a careful cleaning of the profile, a precise drawing of the sequence was made at the  
123 scale 1:20 annotated with pedostratigraphic features and the position of all the samples  
124 (Fig. 3). Following the continuous column sampling (CCS) established by Antoine et al.  
125 (2009), 48 samples were collected for grain size analyses by cutting successive 5-cm-thick  
126 and 200-g-large slices of sediment, as well as 44 5-cm-thick and 10-litre-large samples for  
127 molluscan analyses taken side by side in parallel (Fig. 3) for precise comparisons. Samples  
128 (H: -60/-65, H: -65/-70, H: -70/-75) located at the base of the upper profile close to and within  
129 the archaeological layer were taken afterwards during the excavation of the square crossed by  
130 the profile. As their volume was respectively 30, 20.25 and 16.80 litres of sediments, their  
131 molluscan abundances were normalised to 10 litres to be comparable with those of the other  
132 samples.

133 In addition, 6 samples were taken for optically stimulated luminescence (OSL) datings using  
134 copper cylinders (L = 14 cm,  $\varnothing$  = 3.5 cm) hammered horizontally into the sediment. After  
135 extraction they were sealed at both ends to prevent exposure to light. To measure dosimetric  
136 parameters, about 2 kg of the sediment were taken for each sample in a radius of 30 cm  
137 around each cylinder. Ten radiocarbon (hereafter  $^{14}\text{C}$ ) datings were also performed on  
138 samples of earthworm calcite granules (hereafter ECG) extracted from molluscan samples  
139 following the methodology of Moine et al. (2017) to complete the four obtained on bone,  
140 burnt bone and charcoal fragments from the archaeological layer (Paris et al., 2013, 2017). All  
141 dating samples were distributed throughout the record to constrain the age of the  
142 archaeological layer and of the main pedostratigraphic horizons of the studied part of the  
143 sequence.

144

## 145 *Analytical protocols*

### 146 *Granulometry*

147 Grain size analyses were performed on 2 to 5 g homogenised samples using a Beckman  
148 Coulter LS1330XR laser particle size analyser. The samples were first dispersed by sodium  
149 hexametaphosphate (5 %) during a period of one night in a rotating agitator, and then sieved  
150 at 160  $\mu\text{m}$  to remove the coarse fraction including non-sedimentary Fe-Mn concretions,  
151 calcified roots and shell fragments that may bias the analysis. The coarse fraction was dried  
152 and weighed. For the decarbonated analyses, carbonates were removed using HCl (4 %) until  
153 the effervescence subsided. Then 1 to 2 ml of HCl (20 %) was added to check that the  
154 reaction was complete. The samples were rinsed by centrifugation before dispersion. Finer  
155 fractions were measured on the analyser at least three times to ensure good reproducibility.  
156 The limits of the grain size classes (clay:  $\leq 6 \mu\text{m}$ ; coarse silts: 20-61  $\mu\text{m}$ ; fine sands: 61-  
157 160  $\mu\text{m}$ ) were adjusted using the comparison between classical sieve-pipette and laser grain  
158 size analyses for a set of test samples from the loess sequence of Havrincourt about 60 km to  
159 the north-east (Antoine et al., 2014). The grain size index (hereafter GSI) defined as the ratio  
160 between coarse silts and fine silts plus clay (Rousseau *et al.*, 2002), which is sensitive to  
161 minor changes in the loess deposition dynamics, was calculated for the characterization of  
162 millennial-timescale climate changes, using class size limits defined for the laser particle size  
163 analyser (Antoine et al., 2009).

164

165 *Luminescence dating*

166 Luminescence analyses were performed on the fine (4-11  $\mu\text{m}$ ) quartz fraction. Preparation  
167 techniques followed usual procedures (Lang et al., 1996) and aliquots were prepared by  
168 settling of a 1 mg/ml suspension on 10 mm diameter stainless steel discs. The final quartz  
169 deposit was about 1 mg/cm<sup>2</sup>. All luminescence measurements were performed using a Risø  
170 TL/OSL-DA-15 system equipped with blue (470 nm) light-emitting diodes and an IR  
171 (830 nm) laser diode (Bøtter-Jensen et al., 2002). The luminescence signals were detected  
172 through a 7.5 mm thick Hoya U-340 filter. Irradiations were performed with the <sup>90</sup>Sr/<sup>90</sup>Y  
173 source of the TL-OSL reader (dose-rate on 01/01/2015 was 0.132 Gy/s).

174 The determination of equivalent doses was achieved using a single-aliquot regenerative-dose  
175 (SAR) procedure (Murray & Wintle, 2000). We used a measurement protocol identical to the  
176 SAR datings of quartz from Havrincourt loess (Guérin et al., 2017) as all samples have an  
177 OSL behaviour close to those of this site. Thus, the parameters of the SAR protocol were  
178 fixed individually for each sample so as to satisfy the preheat plateau test performed for  
179 preheat temperatures ranging from 180 to 320°C with 20°C steps. For all samples it was  
180 checked that the recycling ratio was unity within a few percent as well as the dose recovery  
181 test (Murray & Wintle, 2003). The alpha efficiency factor was set to  $0.0420 \pm 0.0020$ , the  
182 mean value measured on quartz from Havrincourt loess.

183 Annual dose rates were calculated using the data in table 1 and the last revised conversion  
184 factors (Guérin et al., 2011). The contribution of cosmic rays was calculated using the depth  
185 from the surface and a sediment density of 2 (Prescott & Hutton, 1994). U, Th and K  
186 concentrations were measured on the sediment samples taken around the OSL cylinders. Prior  
187 to gamma spectroscopy, the sediment was dried for 3 days at 105°C. Th and K activities were  
188 calculated using the specific activities of <sup>234</sup>Th, <sup>228</sup>Ra and <sup>40</sup>K, the latter only used for K. The  
189 water saturation content was measured for each sample and the incidence of moisture was  
190 calculated by assuming a mean water content of the sediment since its deposition between 60  
191 and 100 % of the saturated value (Aitken, 1985).

192

193 *Radiocarbon dating*

194 For the archaeological layer, four samples (two bones, one burnt bone and one charcoal) were  
195 carefully selected for radiocarbon dating. Earthworm calcite granules were also selected  
196 following the protocol of Moine et al. (2017). For each molluscan sample, the 50 selected  
197 granules ( $0.8 < \text{Ø} < 1$  mm) provided between 50 and 70 mg of CaCO<sub>3</sub>. Radiocarbon  
198 measurements were performed in Poznan, Saclay and Lyon radiocarbon laboratories (Tab. 2).  
199 From the basal auger sediment sample, 3 granules were extracted for each of the three  
200 aliquots, providing between 1.1 and 1.51 mg of CaCO<sub>3</sub>. Given the small volume of the  
201 sediment sample, the minimum size limit of selected granules was lowered to 0.5 mm. They  
202 were treated at LSCE, Gif-sur-Yvette (GifA/ECHO prefixes as chemistry ID and measurement  
203 ID respectively) according to the same chemical protocol. CO<sub>2</sub> evolved from carbonate acid  
204 attack was collected and flame-sealed in Pyrex tubes. Physical measurement was handled on  
205 the CO<sub>2</sub> gas itself (no graphitization step) by ECHO MICADAS (Synal et al. 2007; Tisnérat-  
206 Laborde et al., 2015) through the gas source (Ruff et al., 2007). This procedure makes it  
207 possible to measure samples as small as some dozens of micrograms of carbon.

208

209 *Malacology*

210 Sediment samples taken for the molluscan analysis were wet sieved on a 425 µm mesh and  
211 then dried. All useful shells and fragments were sorted, identified, counted and stored. The  
212 number of individuals per taxa was estimated according to Ložek (1964). Taxonomic  
213 attributions were based on Welter-Schultes (2012), the results of Nekola et al. (2015) for  
214 *Pupilla* species and the latest additions to the MolluscaBase (<https://molluscabase.org/>), and  
215 the ecological classification of taxa followed the groups established by Ložek (1964) and  
216 Puisségur (1976).

217

218 **Results**

219 *Stratigraphy and sedimentology*

220 According to the field description (Fig. 3), five sub-sequences can be distinguished:

221 - Sub-sequence I (unit 13 to 12) is made of loessic material partly reworked by hillwash  
222 processes and accumulated at the foot of the slope directly on the chalk bedrock, testifying to  
223 the occurrence of a major erosion event directly preceding the deposition of the first sandy  
224 loess of unit 13. The decreasing content in chalk granules and gelifRACTED flint fragments from  
225 the base to the top suggests that the contribution of the bedrock, eroded on the overlooking  
226 plateau, progressively decreased with the increasing loess cover deposition in the area.  
227 Unit 12 features are characteristic of a tundra gley horizon;

228 - Sub-sequence II (unit 11 to 6) is made of homogeneous loess units alternating with a weakly  
229 developed arctic brown soil (unit 10), a tundra gley (unit 8) and two micro-gleys. Its lower  
230 boundary is marked by the onset of both high GSI values and of an increasing trend in clay,  
231 suggesting an enhanced contribution of aeolian deposition processes (Fig. 4). In the absence  
232 of a synchronous GSI decrease, the decrease in fine sand percentage in the middle of unit 11  
233 associated with the disappearance of sandy layers probably indicates the end of hillwash  
234 processes. A few meters away from the profile, unit 10 turns into a tundra gley horizon.  
235 Locally, its brownish facies may thus result from a better drainage favouring oxidation  
236 processes owing to a steeper slope. This recalls the BS5 units described at Ringen as an  
237 “intermediated tundra gley/boreal soil” (Zens et al., 2018). The archaeological layer is in the  
238 median part of the tundra gley (unit 8). Each of these two horizons is characterised by fine  
239 sand and GSI decreases with minima occurring 5-10 cm below the surface of unit 10 and 10-  
240 15 cm above that of unit 8. Slight decreases in the fine sand percentage are associated with the  
241 micro-gley located in the middle of unit 7 and in the thin upper tundra gley horizon (unit 6),  
242 whereas GSI values respectively show a plateau and an increase;

243 - Sub-sequence III (unit 5 and 4) is made of laminated sandy loess with cryo-desiccation  
244 micro-crack levels corresponding to small ( $\varnothing \sim 20\text{-}30$  cm) polygons. Its sharp lower boundary  
245 and the associated GSI increase (Fig. 4) highlight a rapid change toward a stronger loess  
246 deposition dynamics;

247 - Sub-sequence IV (unit 3 and 2) is made of homogenous loess. It began with an erosive  
248 humid and cold event marked by a humic tundra gley in which one ice-wedge cast was

249 observed. The loess deposition dynamics reverts to similar conditions to those prevailing  
250 during sequence II, albeit much more stable;

251 - Sub-sequence V (unit 1 and 0) is made of two horizons belonging to the  
252 Lateglacial/Holocene soil complex strongly eroded by anthropogenic processes (agriculture).

253

## 254 *Chronology*

255 Distributed from the top of unit 12 to the top of unit 7, ECG  $^{14}\text{C}$  ages range from 40926-  
256 45484 to 26036-26929 cal BP without inversions (Tab. 2; Fig. 4). Scattered between 40926-  
257 45484 and 30667-31646 cal BP, the three ages provided by the three small aliquots of the  
258 lowermost sample indicate that ECG of different ages were gathered along the slope by  
259 reworking processes. The younger one provides a minimum age estimate of the reworking  
260 phase. Such a mix explains the gap of about 6 ka that separates both ages from unit 11. The  
261 two lowermost ages of column B and the two oldest ones of the auger sample were therefore  
262 rejected. The  $^{14}\text{C}$  age obtained on earthworm calcite granules in the archaeological layer is in  
263 very good agreement with those obtained on burnt bone and charcoal. This demonstrates the  
264 reliability of this material for  $^{14}\text{C}$  datings in loess contexts from north-western Europe. The  
265 other two ages obtained on bone appear significantly younger (no recovery between their  $2\sigma$   
266 age ranges and that of the ECG  $^{14}\text{C}$  of the archaeological layer). Such shifts between ages  
267 obtained from different materials of a unique layer often occur in archaeological contexts.  
268 They may result from the quality of the samples or from the dated carbon fraction, which  
269 depends on the nature or the preservation state of the samples. The two  $^{14}\text{C}$  ages (Lyon-632  
270 and Lyon-633) obtained on an isolated bone found in a test pit in 1997 about 100 m SE of the  
271 excavation site (Fagnart et al., 2013) demonstrate the occurrence of erosional events and  
272 hillwash processes during the deposition of the thick laminated loess of sequence III. The  
273 topographically higher position of this bone also suggests an occupation of the area by  
274 prehistoric humans that largely exceeded the limits of the excavation. According to the  
275 uppermost  $^{14}\text{C}$ , i.e. 26036-26929 cal BP, sequence II should end around 26.5-26 ka.  
276 Statistically different, the  $^{14}\text{C}$  ages obtained in unit 10 and 8 confirm the occurrence of two  
277 independent pedogenic phases.

278 Distributed between units 13 and 7, OSL ages range from  $31.0 \pm 1.6$  to  $27.2 \pm 1.5$  ka (Tab. 1).  
279 Both  $^{14}\text{C}$  and OSL age ranges are thus in good agreement. The uppermost one, i.e. REN1 14-  
280 03 ( $27.6 \pm 1.4$  ka), is slightly younger than the closest  $^{14}\text{C}$  age of sample H: -15:-10 (26036-  
281 26929 cal BP), though this difference is not statistically significant. Nor is the apparent shift  
282 of the youngest OSL age of the archaeological layer, i.e. REN1 14-04 ( $27.2 \pm 1.5$  ka), which  
283 takes the error bars into account. The discrepancy is greater for the OSL age located in  
284 unit 13. Sample REN1 15-01 appears significantly younger than sample REN1 14-02 located  
285 above (Tab. 1). However, its water content ( $23.3 \pm 2.3$  %), which is significantly lower than  
286 that of all the other samples, is certainly incorrect and was therefore assumed to result from  
287 the destructuring of the sample between the field and the laboratory, leading to a decreased  
288 capacity to absorb water. Recalculated with the water content value of a physically close  
289 sample taken on another profile of the site (Fig. 3, Tab. 1), REN1 15-01\* yields an age of  
290  $30.5 \pm 2.0$  ka, close to that of sample REN1 14-02 and to the  $^{14}\text{C}$  of sample A: 0-20 (30667-  
291 31646 cal BP). It is assumed here that the strong reworking undergone by unit 13 may have  
292 reduced its porosity and water absorption capacity, leading to younger ages. Furthermore, the



293 lower positions of samples REN1 15-01\* and A: 0-20 suggest a rapid deposition of reworked  
294 units 13 and 12, possibly during Greenland interstadial (GI) 5.1.

295 Consequently, the Amiens-Renancourt 1 loess sequence covers the period between about 31  
296 and 22 ka. Its four main pedogenic horizons are synchronous with GI-5.1, GI-4, GI-3 and GI-  
297 2, the third one including a unique archaeological layer solidly dated around 27.5-28 ka  
298 (Fig. 4).

299

### 300 *Malacology*

301 The number of individuals per assemblage (hereafter abundance) varies between 8 and 3855,  
302 and the number of taxa (hereafter richness) between 3 and 6 (Tab. 3; Fig. 5). Extreme values  
303 of both parameters are similar to those from other northern France molluscan records (Moine,  
304 2008; Moine et al., 2011). Moreover, owing to the occurrences of *Arianta arbustorum*,  
305 *Vallonia costata*, *Punctum pygmaeum* and *Clausilia rugosa parvula*, the composition of the  
306 molluscan fauna is in agreement with the position of the site at the boundary between the  
307 western and central malacological domains (Moine, 2014). The poor diversity and the  
308 ecological preferences of the few molluscan taxa (Tab. 4) almost always reflect a micro-  
309 environmental mosaic dominated by damp areas in which palustral and dry loci of variable  
310 extension occur. Moreover, the limited changes in the composition of the molluscan fauna and  
311 in taxa relative abundances (Fig. 5) indicate that the vegetation cover was most of the time  
312 discontinuous and poorly diversified, with only short phases of densification possibly  
313 accompanied by isolated patches of shrubs. However, despite the relative stability of the  
314 composition of the molluscan fauna, the thorough observation of variations in absolute and  
315 relative taxa abundances revealed the existence of four types of phases (Tab. 5) succeeding in  
316 a pattern of seven cycles (C1-7) (Fig. 5).

317

#### 318 *Phase I*

319 All the samples attributed to this type of phase are located in homogeneous (units 11, 9 and 7)  
320 or laminated (unit 5) loess units. Their very low abundance rarely exceeds 100 individuals  
321 (Tab. 5, Fig. 5). As most taxa of the site are able to survive freezing temperatures down to -12  
322 to -15°C (Ansart et al., 2014), cold temperatures during the activity period most probably  
323 limited the development of the molluscan population during these phases. Indeed, rearing  
324 experiments at less than 15°C attempted during the cited study proved to be ineffective.

325 The relative abundances of dominant taxa indicate that the environmental conditions  
326 attributed to phase I differ slightly from one cycle to another. They can be rather dry (cycles  
327 C2 and C7), damp (cycles C3, C5 and C6), or well-balanced between the different  
328 components (dry, damp, palustral) of the micro-environmental mosaic (cycle C4). Although  
329 phase I molluscan faunas almost always reflect a discontinuous and poorly diversified  
330 vegetation cover, occasional occurrences of *Vallonia costata* indicate short phases of  
331 densification as during C2, C4 and C5.

332

#### 333 *Phase II*

334 This type of phase is characterised by a simultaneous increase in all common taxa of the site,  
335 with a first weak (“start”) sub-phase up to a few hundred individuals then a stronger  
336 (“acceleration”) sub-phase up to several thousands. Moreover, as the hygrophilous species  
337 *Succinella oblonga* reacts more promptly and slightly more intensively than the others, it  
338 always predominates in phase II. The “start” sub-phase is common to all cycles from C2 to  
339 C6. It occurs at the top of loess units underlying the main pedogenic horizons in the full  
340 cycles C3 and C4, and in the micro-gleys and thin tundra gley of the incomplete cycles C2,  
341 C5 and C6. Although dominated by the palustral species *P. alpicola*, the sample of the  
342 uppermost micro-gley was included in phase II of cycle C6 given its 40 % of *S. oblonga* and  
343 low abundance. The “acceleration” sub-phase occurs only in the full cycles C3 and C4 and is  
344 located at the basis of the main pedogenic horizons (units 10 and 8).

345 In the full cycle C3, the “acceleration” sub-phase is also characterised by the appearance of  
346 the mesophilous species *Trochulus hispidus* and the presence of *Clausilia rugosa parvula* and  
347 *Punctum pygmaeum*, two vegetation-demanding species, which all benefit from the moderate  
348 moisture increase. In cycle C4, only *Trochulus hispidus* is present. During the “start” sub-  
349 phase of cycle C5 *Clausilia rugosa parvula* briefly occurs with half-forested species *Arianta*  
350 *arbustorum*. The richness thus increases from phase I to phase II. Consequently, both the  
351 increases in abundance and the progressive predominance of *S. oblonga* indicate a two-step  
352 increase in both temperature and moisture throughout phase II. A damp micro-environmental  
353 mosaic develops in which wet loci extend and the vegetation cover densifies including a few  
354 shrub patches during the “acceleration” sub-phase or from the “start” sub-phase.

355 In the uppermost sample of phase II in cycle C4, the taxa relative abundance remains the same  
356 as in the underlying one also included in the “acceleration” sub-phase, despite a sudden drop  
357 in species abundances. Contemporaneous to the dense archaeological layer, this abundance  
358 drop rather results from anthropic effects (trampling, etc.) than from a marked temperature  
359 decrease in such an improved climatic context.

360

### 361 *Phase III*

362 This phase occurs in the full cycles C3 and C4, and also possibly in cycle C1. In cycle C3, a  
363 “humid” sub-phase precedes a “dry” one. In the “humid” sub-phase, the total abundance is  
364 maximum and richness decreases mostly due to the disappearance of the vegetation-  
365 demanding taxa that appeared in phase II. *P. alpicola* prevails as it increases slightly more  
366 than slugs and *P. muscorum*. *S. oblonga* begins to decrease, slightly in C3 but much more in  
367 C4, i.e. in the sample overlying the archaeological layer. However, it remains unclear here  
368 whether this strong decrease results from environmental conditions or from the incapacity of  
369 *S. oblonga* to recolonize this anthropized area as all other dominant taxa return to almost the  
370 same level of abundance as before the Human occupation. During the “dry” sub-phase, the  
371 total abundance remains maximum, as *P. muscorum*, which predominates, and slug increases  
372 compensate the decreases in *S. oblonga* and *P. alpicola*. *T. hispidus* increases significantly but  
373 none of the vegetation-demanding taxa reappear.

374 Phase III occurs only in the arctic brown soil (unit 10) and in the tundra gley (unit 8). It is  
375 characterised by milder temperatures in C3 than in C4 and by a damp micro-environmental  
376 mosaic. During the “humid” phase, the extension of wet loci was maximum and more

377 prominent in C4 than in C3. This is coherent with the typical reduced facies of the tundra gley  
378 (unit 8) inherited from the waterlogging of the active layer which was less well drained than  
379 during the formation of the arctic brown soil (unit 10). During the “dry” sub-phase, most of  
380 the damp areas turn to dry ones, which become prominent, whereas wet loci only slightly  
381 regress. In the absence of aquatic taxa and of a marked micro-topography, the succession of a  
382 seasonal thaw followed by a drier phase during the activity period appears more probable than  
383 the persistence of localized water ponds or releases in a drier landscape to explain the  
384 persistence of wet loci. During both sub-phases, the vegetation remains discontinuous and  
385 poorly diversified, owing to the harmful effects of waterlogging and ice lenses on plant roots,  
386 as in other tundra gley horizons (Moine, 2014).

387

#### 388 *Phase IV*

389 This phase only follows phase III in the full cycles C1, C3 and C4. As all taxa decrease, the  
390 total abundance drops strongly but remains above 500 individuals in most of the samples. As  
391 slugs decrease less sharply, their proportions peak and the taxon sometimes prevails as in  
392 cycle C3. Phase IV of cycles C1 and C3 takes place in the upper part of geliflucted tundra  
393 gley (unit 12) and arctic brown soil (unit 10). In cycle C1, the micro-environmental mosaic  
394 resembles that of phase III in cycle C3 despite lower temperatures. The co-dominance of  
395 *P. alpicola* and *P. muscorum* indicate the development of a micro-environmental mosaic with  
396 both wet and dry areas. The low proportion of the hygrophilous species *S. oblonga* suggests  
397 that water is restrained in delimited loci or in time, e.g. during the seasonal thaw, which fits  
398 with the geliflucted facies of unit 12. Though scarce, the occurrence of *Pisidium* sp. suggests  
399 at least temporary local ponds. As for the brief occurrence of *V. costata*, it indicates an  
400 increase in the herbaceous component of the vegetation cover in dry areas. In cycle C3, the  
401 micro-environmental mosaic appears well-balanced between dry, damp and wet areas.  
402 However, the vegetation remains sparse despite a moderately moist and stable soil resulting  
403 from a higher clay content which favoured the development of slugs.

404 Phase IV of cycle C4 takes place at the base of the homogeneous loess (unit 7) directly  
405 overlying the tundra gley (unit 8). The molluscan fauna reflects a cooling context and a damp  
406 micro-environmental mosaic in which wet loci tend to disappear. Only a slight increase in the  
407 herbaceous component is indicated by a brief occurrence of *V. costata* in the basal sample.  
408 This environmental trend is contrary to that observed in phase II. The presence of *Pisidium* sp.  
409 suggests the persistence of temporary ponds in the surroundings. Despite relatively high  
410 temperatures, the moderate moisture increase, the absence of water-driven sedimentological  
411 features and the resumption of loess deposition underline the limited seasonal water release  
412 but its possibly longer persistence during the activity period of the previous phase III.

413

## 414 **Discussion**

### 415 *Stadial-interstadial cycles*

416 The 5-cm sampling resolution of the Amiens-Renancourt 1 molluscan record provides a new  
417 opportunity to confirm the conceptual model linking palaeoenvironmental changes associated  
418 with loess-tundra gley alternations with Weichselian Upper Pleniglacial stadial-interstadial

419 cycles (Antoine et al., 2009) based on the combination of high resolution stratigraphy, grain  
420 size (Antoine et al., 2001; Rousseau et al., 2002) and molluscan (Moine et al., 2008) analyses  
421 at Nussloch (Rhine Valley, Germany). The correlation of large abundance increases, which  
422 occur in tundra gley horizons and imply milder temperatures, with interstadial phases (Moine  
423 et al., 2008) was recently confirmed by radiocarbon datings (Moine et al., 2017). Conversely,  
424 all low abundance samples from loess units were linked with stadial phases.

425 Furthermore, by combining the intra-interstadial environmental succession reconstructed from  
426 the molluscan record and its chronological frame, a correlation is proposed between  
427 molluscan phases and major variations of several high-resolution global and regional climate  
428 records. NorthGRIP (NGRIP)  $\delta^{18}\text{O}$  and calcium ion concentrations ( $[\text{Ca}^{2+}]$ ), hereafter dust  
429 concentration, in ice core records mostly reflect local temperature and atmospheric dust  
430 loading respectively (Rasmussen et al., 2004), whereas the Sieben Hengste (7H) speleothem  
431  $\delta^{18}\text{O}$  record reflects the balance between moisture reaching the site directly from the North  
432 Atlantic and by crossing the Alps from the south (Luetscher et al., 2015). Indeed, at the depth  
433 of the site (215 m below the ground surface), the temperature was assumed to be constant and  
434  $\delta^{18}\text{O}$  variations to result from precipitation isotope values, i.e. provenance. Luetscher et al.  
435 (2015) also pointed out that since the North Atlantic is the main moisture source in the  
436 northern Alps, the total moisture amount increases with its proportions.

437

#### 438 *Phase I*

439 According to the cold temperatures implied by its low molluscan abundances, phase I is  
440 linked with stadials (Fig. 7). The molluscan assemblages of Amiens-Renancourt 1 reflect poor  
441 and discontinuous steppe/tundra vegetation. This is in agreement with the rare pollen data in  
442 loess sequences. North-eastward, Weichselian Upper Pleniglacial pollen samples from Kesselt  
443 (eastern Belgium) indicate a grass-dominated steppe (Bastin, 1969). Southward, Weichselian  
444 Middle Pleniglacial pollen samples, from Villiers-Adam (northern France), Upper Pleniglacial  
445 being sterile, also indicate a grass dominated vegetation with rare woody taxa resembling  
446 modern Nordic tundra (Limondin-Lozouet & Gauthier, 2003). At Amiens-Renancourt 1,  
447 owing to the low local richness, no cyclical variations of molluscan richness occur during  
448 stadials as in Nussloch, except brief occurrences of *V. costata* in phases I of C4 and C5  
449 (Fig. 6). The ecological preferences of additional taxa present in Nussloch reflect a much  
450 more diversified vegetation with the presence of shrubs. The Bergsee Lake (Black Forest,  
451 Germany) pollen record shows a “steppe dominated landscape with some elements of boreal  
452 forest” during stadials, and GS-3 and GS-5.1 are distinguished by their maximum of  
453 xerophytic steppe element, i.e. *Artemisia* (Duprat-Oualid et al., 2017). Interestingly, the driest  
454 phases I at Amiens-Renancourt 1, i.e. in C2 and C7, are respectively correlated with these two  
455 stadials contemporaneous to HE 3 and 2 respectively, whereas at Nussloch molluscan richness  
456 maxima suggest a densification of the vegetation cover and increases in shrubs.

457

#### 458 *Phase II*

459 Phase II, and especially its two sub-phases (start and acceleration), had not yet been precisely  
460 depicted. At Curgies (northern France), “MZ2” located at the basis of a tundra gley presents  
461 the characteristics of phase II, including a short occurrence of a vegetation-requiring species

462 typical of cold and wet mountain environments, i.e. *Columella columella* (see Moine et al.,  
463 2011). At Nussloch, only a “MP-3” phase with higher frequencies in hygrophilous *Succinella*  
464 *oblonga* was recognized (Fig. 6) and occurred within all tundra gley horizons and micro-  
465 gleys. Increases in the proportions of *S. oblonga* also preceded the high abundance “MP-0”  
466 phases at the basis of both G3 and G4 tundra gleys. It must be kept in mind here that  
467 hydromorphic processes leading to gley formation are linked to the functioning of a  
468 permafrost active layer and develop mainly downward in previously deposited sediments  
469 (Antoine et al., 2009). This can explain the apparent discrepancy between the two phases II  
470 taking place at the base of tundra gleys at Nussloch and in underlying loess at Amiens-  
471 Renancourt 1. Hence, as the large molluscan abundance increase occurs only during the  
472 “acceleration” sub-phase, “start” sub-phases are correlated with small excursions of 7H  $\delta^{18}\text{O}$   
473 towards less depleted values contemporaneous to limited NGRIP dust concentration decreases  
474 that precede GI-4 and GI-3 but also occur within GS-3 based on  $^{14}\text{C}$  dating. As for  
475 “acceleration” sub-phases, they are linked with a subsequent increased shift in both 7H  $\delta^{18}\text{O}$   
476 and NGRIP dust concentration preceding GI-4 and GI-3. Active layer annual freeze-thaw  
477 cycles probably began during the “acceleration” sub-phase given its high abundances and  
478 trend toward palustral conditions. The 7H  $\delta^{18}\text{O}$  record also indicates a larger and earlier  
479 moisture increase before GI-4 than before GI-3. In the absence of local effects, this may  
480 explain the greater thickness of both the arctic brown soil (unit 10) at Amiens-Renancourt 1  
481 and G3 tundra gley at Nussloch compared to the above (unit 8) and G4 tundra gleys  
482 respectively (Fig. 6). At Amiens-Renancourt 1, the untypical arctic brown soil (unit 10) also  
483 implies reduced waterlogging periods and soil moisture content, and thus a limited harmful  
484 impact of diurnal freeze-thaw cycles on plant roots (Walker & Walker, 1991).

485 In addition, the richer molluscan fauna occurring in GI-4 phase II in both sites also suggest a  
486 greater lengthening of the growing season allowing for a more complex seasonal succession  
487 of vegetation resulting in an apparently more diversified micro-environmental mosaic. The  
488 occurrences of *Clausilia rugosa parvula* and *Punctum pygmaeum* in phase II of cycle C3 and  
489 C5 (only *C. r. parvula* for the latter) are also remarkable as original in northern France and as  
490 no other elements suggest their possible allochthonous or reworked origin in this sequence.  
491 Contrary to *Arianta arbustorum* and *Vallonia costata*, which are present eastward and  
492 southward in loess from the Paris Basin, *C. r. parvula* and *P. pygmaeum* are only known in  
493 the Rhine Valley during the Weichselian Upper Pleniglacial (Moine, 2014). Their discovery  
494 raises the question of whether they persist in cryptic refuge areas in the region or come from  
495 abroad and by which means of transport. Surprisingly, *P. pygmaeum* also occurs at Nussloch  
496 (Rhine Valley, Germany) only at the top of the loess underlying G3 tundra gley during the  
497 studied time interval. Otherwise, such scarce occurrences indicate cryptic populations that  
498 may have been missed elsewhere in the sequence whereas these rarer taxa were still living in  
499 the surroundings. The lack of precise knowledge on Last Glacial loess molluscan fauna still  
500 prevents any conclusion as to whether occurrences of *C. r. parvula* and *P. pygmaeum* at  
501 Amiens-Renancourt 1 result from brief passive colonization phases from the Rhine Valley by  
502 an efficient means of transport, or from active expansion phases from local cryptic refuges.  
503 Whatever the case, the development of shrub patches at Amiens-Renancourt 1 may have  
504 benefited from its position sheltered from (north-)western winds by the higher Ferme de  
505 Grâce plateau on the opposite slope of the Grâce valley (Fig. 2).

506

507 *Phase III*

508 In all Weichselian Upper Pleniglacial loess sequences where they have been detected, large  
509 abundances characteristic of phase III (e.g. “MP-0” phases at Nussloch) only occur in thick  
510 cryoturbated tundra gley horizons or arctic brown soils (Remy, 1969; Schiermeyer, 2000;  
511 Moine et al., 2008, 2011), and never in thin micro-gleys (Fig. 6). In most cases associated  
512 with maximum proportions in hygrophilous and/or palustral taxa, they formed during the  
513 functioning of the active layer, which requires milder temperatures (Moine et al., 2008;  
514 Antoine et al., 2009). This thus supports the correlation of the different phases III with  
515 interstadial phases marked by maximum  $\delta^{18}\text{O}$  values and minimum dust concentration in  
516 NGRIP records (Fig. 7). Accompanying changes in the structure of the *Pupilla* populations  
517 support a lengthening of the activity period of snails over the year implying milder  
518 temperatures in spring, and to a lesser extent in autumn, rather than in summer (Moine et al.,  
519 2008, Moine, 2014). This is in agreement with palaeoenvironmental reconstructions from Les  
520 Echets (central-eastern France) diatom assemblages (Ampel et al., 2010) and modelling  
521 results from Flückiger et al. (2008). As already underlined above, interstadial environmental  
522 conditions did not favour the diversification of the vegetation, but at least benefited the  
523 development of *Betula* populations as recorded in the Bergsee Lake (Duprat-Oualid et al.,  
524 2017) but also in a tundra gley from the loess sequence of Kesselt (Bastin, 1969), most of the  
525 other tree taxa being allochthonous, e.g. *Pinus* (Duprat-Oualid et al., 2017).

526 Interestingly, the 7H  $\delta^{18}\text{O}$  signal shifts back to its stadial level in the middle of GI-4 and GI-3.  
527 Slight decreases in NGRIP  $\delta^{18}\text{O}$  values occur synchronously. The shift back to stadial values  
528 follows immediately in GI-3 but occurs after a period of stability in GI-4. Both interstadials  
529 have thus their own course and different palaeoenvironmental responses. During GI-4, the  
530 decrease in North Atlantic moisture supply whereas temperatures are still high probably  
531 explains the occurrence of an additional dry sub-phase after the humid one within phase III in  
532 the arctic brown soil (unit 10). During this dry sub-phase, the dust concentration in the  
533 NGRIP ice core remains low, which fits with minimum grain size values in Amiens-  
534 Renancourt 1. Owing to the strong cryoturbation of the top of thick tundra gley horizons that  
535 generally leads to their mix with the basis of the overlying loess unit (Fig. 6), this  
536 environmental phase has to our knowledge never been described up to now.

537 Finally, the correlation of phase III of cycle C1 must be considered with caution owing to the  
538 strongly cryoturbated facies of the sediment of the lowest tundra horizon (unit 12). A possible  
539 reworking of older material cannot be excluded though the composition changes in the  
540 molluscan fauna at the basis of the record appear realistic and the shells are well-preserved  
541 despite being sensitive to transport owing to their thinness.

542

543 *Phase IV*

544 As for phase III, pending phase IV is only linked with thick tundra gleys. Its large molluscan  
545 abundance decrease to minimum values reflects a strong temperature shift towards stadial  
546 levels, which obviously leads to correlating it to interstadial-stadial conditions characterised  
547 by a large decrease in the NGRIP  $\delta^{18}\text{O}$  record. During phase IV of cycle C3, the molluscan  
548 abundance decrease is significantly sharper than during phase IV of cycle C4, which fits the  
549 quicker  $\delta^{18}\text{O}$  decrease in GI-4 than in GI-3. Regarding the aeolian dynamics, the loess GSI, as

550 well as the fine sand percentage (Fig. 4), at the top of the arctic brown soil (unit 10) increases  
551 in parallel to the dust concentration at the top of GI-4 (Fig. 7).

552 Conversely, the link is not that clear in phase IV of cycle C4 which shows an almost flat loess  
553 GSI signal, and only a slight increase in the fine sand percentage, at the top of the upper  
554 tundra gley (unit 8), whereas the dust concentration increases at the same pace at the end of  
555 GI-3 as at the end of GI-4 (Fig. 7). Other striking features are the relatively high molluscan  
556 abundance, intermediate between interstadial and stadial values, and the high proportions in  
557 hygrophilous taxa throughout this phase IV, suggesting the persistence of a moisture supply,  
558 whereas 7H  $\delta^{18}\text{O}$  values are the same for both phases IV. Up to now, these discrepancies  
559 remain unexplained, but interestingly the same evolution characterises this transition at the  
560 top of the upper tundra gley horizon at Amiens-Renancourt 1 and at the top of G4 tundra gley  
561 at Nussloch (Fig. 6), suggesting in both sites a similar forcing that affected neither NGRIP nor  
562 7H records.

563

#### 564 *Early LGM interstadial-like oscillations*

565 Owing to the reliable and precise radiocarbon chronology, more tenuous stratigraphical  
566 horizons than loess units and arctic brown soil/tundra gleys can be correlated between  
567 Amiens-Renancourt 1 and Nussloch sequences. Indeed, careful field observations revealed the  
568 presence at Amiens-Renancourt 1 of micro-gleys (Fig. 3, unit 6 and thin diffuse horizons with  
569 oxidation stains within units 7 and 11) presenting the same features as those already described  
570 in several profiles from Nussloch, i.e. P3 (Fig. 4). There, they are characterised by GSI  
571 minima (Antoine et al., 2009) and both increases in the percentage of hygrophilous taxa and  
572 decreases in molluscan richness (Moine et al., 2008). At Amiens-Renancourt 1, this concerns  
573 molluscan cycles C5 and C6 (Fig. 5). They are marked by a slowdown in the increasing trends  
574 of both GSI and the fine sand fraction (Fig. 4), increases in the percentage of hygrophilous  
575 and to a lesser extent of palustral taxa, a decrease in molluscan richness, slight and only in C5  
576 as it is already minimum at the top of unit 7, and slight abundance increases (Fig. 5). These  
577 features are similar to those characterising the “start” sub-phase of stadial-interstadial  
578 transitions at the beginning of full cycles associated to the arctic brown (unit 10) soil and the  
579 tundra gley (unit 8). Further east, the loess section of Krems-Wachtberg (Austria) also  
580 exhibits supernumerary micro-gleys characterised by slight decreases in GSI and middle plus  
581 coarse sand values and similar, though weaker, trends in colorimetric parameters to those of  
582 tundra gleys (Sprafke et al., 2020). According to the correlations established with Greenland  
583 climate records, the micro-gleys IV-b and IV-d of profile KW-A 2015 could be  
584 contemporaneous of unit 6 and the diffuse horizon with oxidation stains of unit 7 at Amiens-  
585 Renancourt 1. In between at Remagen (Germany), recent high-resolution total organic carbon  
586 (TOC) measurements were performed along several cores drilled in a plateau loess sequence  
587 (Fischer et al., 2020). Along the thickest of these cores (REM 3), TOC increases of 0.1 to  
588 0.3 % characterised pedogenetic horizons. Based on correlations with the RP1 profile located  
589 on the edge of the plateau and dated by radiocarbon and optically stimulated luminescence,  
590 excursions 10 and 9 associated with tundra gleys could be correlated with interstadials GI 4  
591 and GI 3 respectively. Three weaker (0.4-0.5 %) TOC excursions (8, 7 and 6) were measured  
592 between GI 3 and the Eltville tephra dated around 24.3-24.4 ka (Zens et al., 2017). Though  
593 only excursion 6 appears associated with a tundra gley, all constitute potential equivalents for

594 Amiens-Renancourt and Nussloch micro-gleys, but require, as do the Krems-Wachtberg ones,  
595 direct radiocarbon dating to ensure precise correlations.

596 The comparison between the Nussloch GSI record and a few different ice, oceanic and  
597 continental proxy records of the Northern Hemisphere has highlighted the resemblance of  
598 their signals and suggests the occurrence of millennial-timescale variations between 28 and  
599 20 ka. Their absence from the NGRIP  $\delta^{18}\text{O}$  record, though present in the dust record, indicates  
600 that climatic cycles of minor amplitude and/or limited to the mid-latitudes occurred during the  
601 first half of the Last Glacial Maximum (Moine et al., 2017). However, both proxy sensitivity  
602 and chronological model precision still hamper their discrimination. Presently, although these  
603 tenuous changes in the composition of the molluscan fauna may be considered as a response  
604 to local changes, their resemblance and contemporaneity in both sites located about 500 km  
605 apart, as well as the similar trends of associated loess grain size variations with NGRIP dust  
606 concentration ones (Fig. 7), rather support that they result from global mid-latitude  
607 interstadial-like climate oscillations during the early Last Glacial Maximum.

608

### 609 *Age and context of the Human occupation*

610 Gravettian open-air sites are rare in northern France (Paris, 2020), and some of them found in  
611 loess sequences have been discovered in brownish loam units at the base of the Weichselian  
612 Upper Pleniglacial sequence, e.g. at Havrincourt (Antoine et al., 2014). However, despite the  
613 high resolution (5-cm-thick samples) of the molluscan records, the low sedimentation rate of  
614 these horizons prevents the precise reconstruction of associated palaeoenvironmental changes.  
615 Amiens-Renancourt 1 is thus the first site for which we have both a precise stratigraphical  
616 location and a favourable context for the preservation of carbonated proxies. The  $^{14}\text{C}$  ages  
617 obtained on various materials (charcoals, burnt bones, bones, earthworm calcite granules)  
618 support the correlation of the Amiens-Renancourt 1 archaeological layer with the GI-3  
619 interstadial (Rasmussen et al., 2014). Furthermore, after a precise description of the  
620 palaeoenvironmental evolution of the site, the relative position of the Human occupation  
621 within the succession of molluscan phases at the end of the “acceleration” sub-phase of  
622 phase II supports its occurrence at the end of the stadial-interstadial transition, during an  
623 optimum of vegetation diversification favoured by mild temperatures and moist conditions.

624

### 625 **Conclusion**

626 Our study is the first attempt to combine a high-resolution (5 cm) molluscan study with  
627 earthworm calcite granule radiocarbon dating throughout a calcareous loess sequence  
628 encompassing two Dansgaard-Oeschger (D-O) cycles and one important Palaeolithic  
629 occupation layer. It strengthens and refines the scheme of (multi-)centennial environmental  
630 phases succeeding during both interstadials and stadials established in northern France and  
631 Nussloch (Rhine Valley, Germany), and especially the role of milder and more humid  
632 conditions that progressively set in from the end of stadials to interstadial optimums. It allows  
633 for the characterization of the environmental context of a unique archaeological layer and its  
634 exact positioning at the end of the stadial-interstadial transition of a D-O cycle, and the  
635 highlighting of interstadial-like environmental changes during the Last Glacial Maximum.



636 In the future, such high-resolution studies of open-air sites will thus be crucial, not only to  
637 better constrain the millennial-timescale environmental dynamics, but also to specify the  
638 Human settlement dynamics in the cyclically changing environmental and climatic context of  
639 the end of the Last Glacial in the north-western side of the European periglacial domain.

640 Indeed, compared to studies carried out in caves, such a combination of palaeoenvironmental  
641 proxies and dating methods with high-resolution stratigraphy results in a better constrained  
642 chronology. Consequently, this type of high-resolution approach needs to be systematically  
643 applied in archaeological open-air sites presenting suitable characteristics such as a clear  
644 stratigraphical succession, no or minor reworking processes, a sufficient sedimentation rate,  
645 carbonated sediments, and an appropriate palaeontological content, as at Amiens-  
646 Renancourt 1.

647 Owing to the diversity of facies included in the Gravettian lithic techno-complex, the precise  
648 and respective chronological positioning of a maximum of well documented and typical  
649 archaeological layers from open-air sites in loess sequences appears as the best way to  
650 reconstruct the succession of Gravettian lithic trends that spread across the European Great  
651 Plain during the ten millennia preceding the Last Glacial Maximum.

652

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658

### 659 *Data statement*

660 The data that support the findings of this study are available from the corresponding author  
661 upon reasonable request.

662

663

664 **References**

- 665 Aitken MJ. 1985. *Thermoluminescence Dating*. Academic Press: London.
- 666 Ampel L, Bigler C, Wohlfarth B, *et al.* 2010. Modest summer temperature variability during  
667 DO cycles in western Europe. *Quaternary Science Reviews* **29**: 1322–1327.
- 668 Ansart A, Guiller A, Moine O, *et al.* 2014. Is cold hardiness size-constrained? A comparative  
669 approach in land snails. *Evolutionary Ecology* **28**: 471–493.
- 670 Antoine P, Coutard S, Guérin G, *et al.* 2016. Upper Pleistocene loess-palaeosol records from  
671 Northern France in the European context: Environmental background and dating of the  
672 Middle Palaeolithic. *Quaternary International* **411**: 4–24.
- 673 Antoine P, Goval E, Jamet G, *et al.* 2014. Les séquences loessiques pléistocène supérieur  
674 d’Havrincourt (Pas-de-Calais, France) : stratigraphie, paléoenvironnements, géochronologie  
675 et occupations paléolithiques. *Quaternaire* **25**: 321–368.
- 676 Antoine P, Rousseau DD, Degeai JP, *et al.* 2013. High-resolution record of the environmental  
677 response to climatic variations during the Last Interglacial–Glacial cycle in Central Europe:  
678 the loess-palaeosol sequence of Dolní Věstonice (Czech Republic). *Quaternary Science*  
679 *Reviews* **67**: 17–38.
- 680 Antoine P, Rousseau D-D, Moine O, *et al.* 2009. Rapid and cyclic aeolian deposition during  
681 the Last Glacial in European loess: a high-resolution record from Nussloch, Germany.  
682 *Quaternary Science Reviews* **28**: 2955–2973.
- 683 Antoine P, Rousseau DD, Zöller L, *et al.* 2001. High-resolution record of the last Interglacial-  
684 glacial cycle in the Nussloch loess-palaeosol sequences, Upper Rhine Area, Germany.  
685 *Quaternary International* **76-77**: 211–229.
- 686 Bastin B. 1969. Premiers résultats de l’analyse pollinique des lœss en Belgique. *Bulletin de*  
687 *l’Association Française pour l’Etude du Quaternaire* **18**: 3–11.
- 688 Bosq M, Bertran P, Degeai JP, *et al.* 2020. Geochemical signature of sources, recycling and  
689 weathering in the Last Glacial loess from the Rhône Valley (southeast France) and  
690 comparison with other European regions. *Aeolian Research* **42**: 100561.
- 691 Bøtter-Jensen L, Bulur E, Murray AS, *et al.* 2002. Enhancements in luminescence  
692 measurement techniques. *Radiation Protection Dosimetry* **101**: 119–124.
- 693 Boycott AE. 1934. The Habitats of Land Mollusca in Britain. *Journal of Ecology* **22**: 1–38.
- 694 Cameron RAD, Palles-Clark MA. 1971. *Arianta arbustorum* (L.) on chalk downs in southern  
695 England. *Proceedings of the Malacological Society of London* **39**: 311–318.
- 696 Clark PU, Dyke AS, Shakun JD, *et al.* 2009. The Last Glacial Maximum. *Science* **325**: 710–  
697 714.
- 698 Commont V. 1913. Les hommes contemporains du Renne dans la Vallée de la Somme.  
699 *Mémoires de la Société des Antiquaires de Picardie* **37**: 207–638.

- 700 Duprat-Oualid F, Rius D, Bégeot C, *et al.* 2017. Vegetation response to abrupt climate  
701 changes in Western Europe from 45 to 14.7k cal a BP: the Bergsee lacustrine record (Black  
702 Forest, Germany). *Journal of Quaternary Science* **32**: 1008–1021.
- 703 Evans JG. 1972. *Land snails in archaeology*. Seminar Press: London & New York.
- 704 Fagnart JP, Coudret P, Antoine P, *et al.* 2013. Le Paléolithique supérieur ancien dans le Nord  
705 de la France. *Mémoires de la Société Préhistorique Française* **56**: 197–214.
- 706 Fankhauser A, McDermott F, Fleitmann D. 2016. Episodic speleothem deposition tracks the  
707 terrestrial impact of millennial-scale last glacial climate variability in SW Ireland. *Quaternary*  
708 *Science Reviews* **152**: 104–117.
- 709 Fischer P, Jöris O, Fitzsimmons KE, *et al.* 2020. Millennial-scale terrestrial ecosystem  
710 responses to Upper Pleistocene climatic changes: 4D-reconstruction of the Schwalbenberg  
711 Loess-Palaeosol-Sequence (Middle Rhine Valley, Germany). *Catena* **196**: 104913.
- 712 Flückiger J, Knutti R, White JWC, *et al.* 2008. Modeled seasonality of glacial abrupt climate  
713 events. *Climate Dynamics* **31**: 633–645.
- 714 Guérin G, Antoine P, Schmidt E, *et al.* 2017. Chronology of the Upper Pleistocene loess  
715 sequence of Havrincourt (France) and associated Palaeolithic occupations: A Bayesian  
716 approach from pedomorphology, OSL, radiocarbon, TL and ESR/U-series data. *Quaternary*  
717 *Geochronology* **42**: 15–30.
- 718 Guérin G, Mercier N, Adamiec G. 2011. Dose-rate conversion factors: update. *Ancient TL* **29**:  
719 5–8.
- 720 Haesaerts P. 2009. Climatic signature and radiocarbon chronology of Middle and Late  
721 Pleniglacial loess from Eurasia: comparison with the marine and Greenland records.  
722 *Radiocarbon* **51**: 301–318.
- 723 Haesaerts P, Damblon F, Gerasimenko N, *et al.* 2016. The Late Pleistocene loess-palaeosol  
724 sequence of Middle Belgium. *Quaternary International* **411**: 25–43.
- 725 Horsák M, Juříčková L, Pícka J. 2013. *Měkkýši České a Slovenské republiky*. Nakladatelství  
726 Kabourek: Zlín.
- 727 Jary Z, Ciszek D. 2013. Late Pleistocene loess–palaeosol sequences in Poland and western  
728 Ukraine. *Quaternary International* **296**: 37–50.
- 729 Kerney MP. 1963. Late-glacial deposits on the chalk of South-East England. *Philosophical*  
730 *transactions of the Royal Society of London Series B, Biological sciences* **246**: 203–254.
- 731 Kerney MP. 1971. A Middle Weichselian deposit at Halling, Kent. *Proceedings of the*  
732 *Geologists' Association* **82**: 1–10.
- 733 Kerney MP, Cameron RAD, Jungbluth JH. 1983. *Die Landschnecken Nord- und*  
734 *Mitteleuropas*. Verlag Paul Parey: Hamburg & Berlin.
- 735 Kuntz G, Dupuis C. 1972. *Carte géologique de la France à 1/50 000 (n° 46), Amiens (XXIII-*  
736 *8)*. Bureau de Recherches Géologiques et Minières: Orléans.

- 737 Lang A, Lindauer S, Kuhn R, *et al.* 1996. Procedures used for optically and infrared  
738 stimulated luminescence dating of sediments in Heidelberg. *Ancient TL* **14**: 7–11.
- 739 Lehmkuhl F, Nett JJ, Pötter S, *et al.* 2021. Loess landscapes of Europe – Mapping,  
740 geomorphology, and zonal differentiation. *Earth-Science Reviews* **215**: 103496.
- 741 Limondin-Lozouet N, Gauthier A. 2003. Biocénoses pléistocènes des séquences loessiques de  
742 Villiers-Adam (Val d'Oise, France) : études malacologiques et palynologiques. *Quaternaire*  
743 **14**: 237–252.
- 744 Ložek V. 1964. *Quartärmollusken der Tschechoslowakei*. Verlag der Tschechoslowakischen  
745 Akademie der Wissenschaften: Praha.
- 746 Ložek V. 1990. Molluscs in loess, their paleoecological significance and role in  
747 geochronology - Principles and methods. *Quaternary International* **7/8**: 71–79.
- 748 Luetscher M, Boch R, Sodemann H, *et al.* 2015. North Atlantic storm track changes during  
749 the Last Glacial Maximum recorded by Alpine speleothems. *Nature Communications* **6**: 1–6.
- 750 Meszner S, Kreutzer S, Fuchs M, *et al.* 2013. Late Pleistocene landscape dynamics in Saxony,  
751 Germany: Paleoenvironmental reconstruction using loess-paleosol sequences. *Quaternary*  
752 *International* **296**: 97–104.
- 753 Moine O. 2008. West-European malacofauna from loess deposits of the Weichselian Upper  
754 Pleniglacial: compilation and preliminary analysis of the database. *Quaternaire* **19**: 11–29.
- 755 Moine O. 2014. Weichselian Upper Pleniglacial environmental variability in north-western  
756 Europe reconstructed from terrestrial mollusc faunas and its relationship with the  
757 presence/absence of human settlements. *Quaternary International* **337**: 90–113.
- 758 Moine O, Antoine P, Deschodt L, *et al.* 2011. Enregistrements malacologiques à haute  
759 résolution dans les loess et les gleys de toundra du Pléniglaciaire weichselien supérieur :  
760 premiers exemples du nord de la France. *Quaternaire* **22**: 307–325.
- 761 Moine O, Antoine P, Hatté C, *et al.* 2017. The impact of Last Glacial climate variability in  
762 west-European loess revealed by radiocarbon dating of fossil earthworm granules.  
763 *Proceedings of the National Academy of Sciences of the United States of America* **114**: 6209–  
764 6214.
- 765 Moine O, Rousseau D-D, Antoine P. 2008. The impact of Dansgaard-Oeschger cycles on the  
766 loessic environment and malacofauna of Nussloch (Germany) during the Upper Weichselian.  
767 *Quaternary Research* **70**: 91–104.
- 768 Murray AS, Wintle AG. 2000. Luminescence dating of quartz using an improved single  
769 aliquot regenerative-dose protocol. *Radiation Measurements* **32**: 57–73.
- 770 Murray AS, Wintle AG. 2003. The single aliquot regenerative dose protocol: potential for  
771 improvements in reliability. *Radiation Measurements* **37**: 377–381.
- 772 Nekola JC, Coles BF, Horsák M. 2015. Species assignment in *Pupilla* (Gastropoda:  
773 Pulmonata: Pupillidae): integration of DNA-sequence data and conchology. *Journal of*  
774 *Molluscan Studies* **81**: 196–216.

- 775 Paris C. 2020. *La période du Gravettien dans la zone loessique du Nord de la France. Traditions culturelles et dynamiques de peuplement*. Doctoral thesis, Université de Paris I  
776 Panthéon-Sorbonne: Paris.
- 778 Paris C, Antoine P, Auguste P, *et al.* 2019. Les gisements gravettiens d'Amiens-Renancourt 1  
779 et 2 (Somme, France) : premières données paléolithologiques. In *Préhistoire de l'Europe du*  
780 *Nord-Ouest : mobilité, climats et identités culturelles XXVIIIe Congrès préhistorique de*  
781 *France, Amiens 30 mai - 4 juin 2016 Volume 2 : Paléolithique supérieur ancien,*  
782 *Paléolithique final – Mésolithique*, Montoya C, Fagnart JP, Loch JL (eds). Société  
783 Préhistorique Française: Paris; 97–115.
- 784 Paris C, Deneuve E, Fagnart JP, *et al.* 2017. Premières observations sur le gisement gravettien  
785 à statuettes féminines d'Amiens-Renancourt 1 (Somme). *Bulletin de la Société Préhistorique*  
786 *Française* **114**: 423–444.
- 787 Paris C, Fagnart JP, Coudret P. 2013. Du Gravettien final dans le Nord de la France ?  
788 Nouvelles données à Amiens-Renancourt. *Bulletin de la Société Préhistorique Française* **110**:  
789 123–126.
- 790 Prescott JR, Hutton JT. 1994. Cosmic ray contribution to dose rates for luminescence and  
791 ESR dating: large depths and long-term time variations. *Radiation Measurements* **23**: 497–  
792 500.
- 793 Puisségur JJ. 1976. *Mollusques continentaux quaternaires de Bourgogne. Significations*  
794 *stratigraphiques et climatiques. Rapports avec d'autres faunes boréales de France*. Doin:  
795 Paris.
- 796 Rasmussen SO, Bigler M, Blockley SP *et al.* 2014. A stratigraphic framework for abrupt  
797 climatic changes during the Last Glacial period based on three synchronized Greenland ice-  
798 core records: refining and extending the INTIMATE event stratigraphy. *Quaternary Science*  
799 *Reviews* **106**: 14–28.
- 800 Reimer PJ, Bard E, Bayliss A, *et al.* 2013. IntCal13 and Marine13 Radiocarbon Age  
801 Calibration Curves 0–50,000 Years cal BP. *Radiocarbon* **55**: 1869–1887.
- 802 Remy H. 1969. Würmzeitliche Molluskenfaunen aus Lößserien des Rheingaus und der  
803 nördlichen Rheinhessens. *Notizblatt des Hessischen Landesamtes für Bodenforschung zu*  
804 *Wiesbaden* **97**: 98–116.
- 805 Rousseau DD, Antoine P, Hatté C, *et al.* 2002. Abrupt millennial climatic changes from  
806 Nussloch (Germany) Upper Weichselian eolian records during the Last Glaciation.  
807 *Quaternary Science Reviews* **21**: 1577–1582.
- 808 Ruff M, Wacker L, Gäggeler HW, *et al.* 2007. A gas ion source for radiocarbon measurement  
809 at 200kV. *Radiocarbon* **49**: 307–314.
- 810 Schiermeyer J. 2000. *Würmzeitliche Lößmollusken aus der Eifel*. Doctoral thesis, Universität  
811 Düsseldorf: Düsseldorf.
- 812 Sirocko F, Knapp H, Dreher F, *et al.* 2016. The ELSA-Vegetation-Stack: Reconstruction of  
813 Landscape Evolution Zones (LEZ) from laminated Eifel maar sediments of the last 60,000  
814 years. *Global and Planetary Change* **142**: 108–135.

815 Sprafke T, Schulte P, Meyer-Heintze S, *et al.* 2020. Paleoenvironments from robust loess  
816 stratigraphy using high-resolution color and grain-size data of the last glacial Krems-  
817 Wachtberg record (NE Austria). *Quaternary Science Reviews* **248**: 106602.

818 Stuiver M, Reimer PJ. 1993. Extended <sup>14</sup>C Data Base and Revised CALIB 3.0 <sup>14</sup>C Age  
819 Calibration Program. *Radiocarbon* **35**: 215–230.

820 Sümegei P, Molnár D, Gulyás S, *et al.* 2019. High-resolution proxy record of the  
821 environmental response to climatic variations during transition MIS3/MIS2 and MIS2 in  
822 Central Europe: The loess-paleosol sequence of Katymár brickyard (Hungary). *Quaternary*  
823 *International* **504**: 40–55.

824 Synal HA, Stocker M, Suter M. 2007. MICADAS: A new compact radiocarbon AMS system.  
825 *Nuclear Instruments and Methods in Physics Research. Section B, Beam Interactions with*  
826 *Materials and Atoms* **259**: 7–13.

827 Tisnérat-Laborde N, Thil F, Synal HA, *et al.* 2015. ECHoMICADAS: A new compact AMS  
828 system to measuring <sup>14</sup>C for Environment, Climate and Human Sciences. 22<sup>nd</sup> International  
829 Radiocarbon Conference 2015, Dakar, Sénégal: Books of abstracts. Université Cheikh Anta  
830 Diop, Dakar, PHYS-O.05.

831 Újvári G, Stevens T, Molnár M, *et al.* 2017. Coupled European and Greenland last glacial  
832 dust activity driven by North Atlantic climate. *Proceedings of the National Academy of*  
833 *Sciences of the United States of America* **114**: 10632–10638.

834 Walker DA, Walker MD. 1991. History and pattern of disturbance in Alaskan arctic terrestrial  
835 ecosystems: a hierarchical approach to analysing landscape change. *Journal of Applied*  
836 *Ecology* **28**: 244–276.

837 Welter-Schultes FW. 2012. European non-marine molluscs: a guide for species identification.  
838 Göttingen: Planet Poster.

839 Wessel P, Luis JF, Uieda L, *et al.* 2019. The Generic Mapping Tools version 6. *Geochemistry,*  
840 *Geophysics, Geosystems* **20**: 5556–5564.

841 Zech M, Kreutzer S, Zech R, *et al.* 2017. Comparative <sup>14</sup>C and OSL dating of loess-paleosol  
842 sequences to evaluate post-depositional contamination of n-alkane biomarkers. *Quaternary*  
843 *Research* **87**: 180–189.

844 Zens J, Schulte P, Klasen N, *et al.* 2018. OSL chronologies of paleoenvironmental dynamics  
845 recorded by loess-paleosol sequences from Europe: Case studies from the Rhine-Meuse area  
846 and the Neckar Basin. *Palaeogeography, Palaeoclimatology, Palaeoecology* **509**: 105–125.

847 Zens J, Zeeden C, Römer W, *et al.* 2017. The Eltville Tephra (Western Europe) age revised:  
848 Integrating stratigraphic and dating information from different Last Glacial loess localities.  
849 *Palaeogeography, Palaeoclimatology, Palaeoecology* **466**: 240–251.

850

851

Unit / Depth	Sample	U (ppm)	Th (ppm)	K (%)	W (%)	D $\alpha$ (Gy/ka)	D $\beta$ (Gy/ka)	D $\gamma$ (Gy/ka)	Dcos. (Gy/ka)	Dann. (Gy/a)	De (Gy)	Age (ka)
7 / 3.65 m	REN1 14-03	2.72 ± 0.10	8.08 ± 0.10	1.16 ± 0.01	34.4 ± 3.4	0.40 ± 0.03	1.15 ± 0.05	0.75 ± 0.03	0.13 ± 0.01	2.43 ± 0.11	66.95 ± 1.41	27.6 ± 1.4
8 / 4.17 m	REN1 13-01	2.86 ± 0.17	8.48 ± 0.17	1.15 ± 0.02	32.0 ± 3.2	0.43 ± 0.03	1.19 ± 0.06	0.78 ± 0.04	0.12 ± 0.01	2.52 ± 0.12	70.41 ± 1.84	27.9 ± 1.5
8 / 4.17 m	REN1 14-04	3.26 ± 0.18	8.68 ± 0.20	1.14 ± 0.02	31.5 ± 3.2	0.47 ± 0.04	1.24 ± 0.06	0.83 ± 0.04	0.12 ± 0.01	2.65 ± 0.13	71.98 ± 1.82	27.2 ± 1.5
9 / 4.40 m	REN1 14-01	3.00 ± 0.18	8.48 ± 0.17	1.15 ± 0.02	30.8 ± 3.1	0.45 ± 0.03	1.22 ± 0.06	0.80 ± 0.04	0.12 ± 0.01	2.59 ± 0.12	73.49 ± 1.63	28.4 ± 1.5
11 / 5.10 m	REN1 14-02	2.82 ± 0.18	8.68 ± 0.20	1.17 ± 0.02	30.6 ± 3.1	0.44 ± 0.03	1.21 ± 0.06	0.80 ± 0.04	0.11 ± 0.01	2.56 ± 0.12	79.25 ± 1.67	31.0 ± 1.6
13 / 6.30 m	REN1 15-01	2.61 ± 0.19	8.07 ± 0.08	1.18 ± 0.02	23.3 ± 2.3	0.43 ± 0.03	1.26 ± 0.05	0.80 ± 0.03	0.12 ± 0.01	2.61 ± 0.11	68.42 ± 1.86	26.2 ± 1.3
13 / 6.30 m	REN1 15-01*	2.61 ± 0.19	8.07 ± 0.08	1.18 ± 0.02	44.7 ± 4.5*	0.36 ± 0.03	1.07 ± 0.06	0.69 ± 0.04	0.12 ± 0.01	2.24 ± 0.13	68.42 ± 1.86	30.5 ± 2.0

852

853 **Table 1.** OSL datings performed in Amiens-Renancourt 1 excavation. U, Th and K: elemental  
854 concentrations measured by gamma spectroscopy. W: Saturated water content. Dx: annual  
855 dose rates of  $\alpha$ ,  $\beta$ ,  $\gamma$  and cosmic radiations, and equivalent dose. \*The age of sample  
856 REN1 15-01 was recalculated with a more realistic water content from another sample that  
857 was physically close and taken on another profile of the site.

858

Material	Laboratory code	Sample / Depth (m)	<sup>14</sup> C age (BP)	Calibrated age (a cal BP) [95.4% probability]	Median calibrated age	Source
Earthworm granules	Poz-73520	H: -15:-10 / 3.60-3.65	22190 ± 160	26036-26929	26415	this study
Earthworm granules	Poz-73521	H: -30:-25 / 3.75-3.80	22700 ± 160	26575-27389	27032	this study
Earthworm granules	SacA51278	H: -70:-65 / 4.15-4.20	23540 ± 150	27439-27907	27681	this study
Earthworm granules	Poz-73524	B: -50:-45	24610 ± 200	28154-29097	28645	this study
Earthworm granules	SacA51286	B: -70:-65 / 4.90-4.95	25220 ± 180	28811-29712	29262	this study
Earthworm granules	SacA46563	B: -95:-90 / 5.15-5.20	31410 ± 400	34584-36138	35313	this study
Earthworm granules	SacA46564	B: -125:-120 / 5.45-5.50	32540 ± 470	35472-38050	36569	this study
Earthworm granules	ECHo-3742.1.1/GifA 20375.1	A: -4.20 / ~6.70-6.90	30350 ± 490	33562-35271	34366	this study
Earthworm granules	ECHo-3742.1.2/GifA 20375.2	A: -4.20 / ~6.70-6.90	27160 ± 350	30667-31646	31142	this study
Earthworm granules	ECHo-3742.1.3/GifA 20375.3	A: -4.20 / ~6.70-6.90	39200 ± 1400	40926-45484	43138	this study
Bone	Beta-306063	Archaeological layer / 4.15-4.20	21890 ± 90	25898-26344	26092	Paris <i>et al.</i> (2013)
Bone	Lyon-9943/SacA32189	Archaeological layer / 4.15-4.20	22600 ± 170	26465-27333	26913	Paris <i>et al.</i> (2017)
Burnt bone	Lyon-9942/SacA32188	Archaeological layer / 4.15-4.20	23580 ± 180	27421-27996	27708	Paris <i>et al.</i> (2017)
Charcoal	Lyon-11659/SacA39279	Archaeological layer / 4.15-4.20	23250 ± 210	27158-27798	27500	Paris <i>et al.</i> (2017)
Bone	Lyon-632	Isolated bones found in unit 5 in a	23040 ± 220	26864-27721	27342	Fagnart <i>et al.</i> (2013)
Bone	Lyon-633	test pit about 100 m SSE of the site	22360 ± 240	26089-27208	26647	Fagnart <i>et al.</i> (2013)

859

860 **Table 2.** Radiocarbon datings performed in Amiens-Renancourt 1 excavation and on a bone  
861 found in Renancourt 2000 test pit. Ages were calibrated with the software Calib 7.0.4 (Stuiver  
862 & Reimer, 1993) and the IntCal13 calibration curve (Reimer et al., 2013).

863



Ecological groups	2		5			7			7'	8	9	U		10			Molluscan record	
	<i>Arianta arbustorum</i>	<i>Pupilla muscorum</i>	<i>Vallonia costata</i>	<i>Trochulus hispidus</i>	<i>Clausilia rugosa parvula</i>	<i>Punctum pygmaeum</i>	Slugs	<i>Succinella oblonga</i>	<i>Pupilla alpicola</i>	<i>Pupilla</i> sp.	cf. Chondrinidae	Total of terrestrials	<i>Pisidium</i> sp.	<i>Bithynia tentaculata</i>	Total of aquatics	Ostracods (valves)	Rodents (teeth, bones)	Cycles
H: 15:10	0	12	0	1	0	0	0	1	0	0	0	14	0	0	0	0		
H: 10:5	0	5	0	1	0	0	0	2	0	0	0	8	0	0	0	1	C7	I
H: 5:0	0	12	0	2	0	0	4	10	9	0	0	37	0	0	0	2		
H: 0:-5	0	0	0	1	0	0	1	8	10	0	0	20	1	0	1	5		
H: -5:-10	0	1	0	0	0	0	2	200	1	0	0	204	1	0	1	2	C6	II
H: -10:-15	0	0	0	0	0	0	3	438	0	5	0	446	1	0	1	2		
H: -15:-20	0	5	0	1	0	0	1	77	5	0	0	89	1	0	1	1		I
H: -20:-25	0	5	0	1	0	0	5	29	0	0	0	40	1	0	1	1		
H: -25:-30	0	0	0	1	0	0	5	91	12	0	0	109	2	0	2	4		II
H: -30:-35	1	24	0	1	1	0	5	97	0	0	0	129	0	0	0	1	C5	II
H: -35:-40	0	12	1	2	0	0	17	45	12	0	0	89	1	0	1	0		I
H: -40:-45	0	24	0	1	0	0	9	98	0	0	0	132	1	0	1	4		
H: -45:-50	0	16	0	0	0	0	18	488	24	0	0	546	1	0	1	3		
H: -50:-55	0	7	0	0	0	0	33	499	57	0	0	596	0	0	0	1		IV
H: -55:-60	0	19	1	1	0	0	64	290	57	0	0	432	1	0	1	2		
H: -60:-65	0	92	0	0	0	0	51	174	372	0	0	689	0	0	0	1		III
H: -65:-69	0	7	0	1	0	0	14	102	40	0	0	164	0	0	0	1		
H: -70:-75	0	162	0	1	0	0	131	1245	542	0	0	2081	0	1	1	4	C4	Ila
B: 0:-5	0	84	0	0	0	0	53	1309	249	0	0	1695	0	0	0	2		
B: -5:-10	0	34	0	0	0	0	21	235	39	0	0	329	0	0	0	1		IIs
B: -10:-15	0	25	1	1	0	0	22	82	15	0	1	147	0	0	0	4		
B: -15:-20	0	13	0	1	0	0	22	26	25	0	0	87	0	0	0	7		
B: -20:-25	0	21	0	1	0	0	18	26	23	0	0	89	1	0	1	8		I
B: -25:-30	0	27	1	1	0	0	18	31	21	0	0	99	0	0	0	8		
B: -30:-35	0	38	0	1	0	0	31	35	47	0	0	152	2	0	2	13		
B: -35:-40	0	58	0	1	0	0	64	79	58	0	0	260	1	0	1	7		
B: -40:-45	0	162	0	7	0	0	276	265	194	0	0	904	1	0	1	7		IV
B: -45:-50	0	1320	0	28	0	0	503	791	1155	0	0	3797	1	0	1	2		IIIId
B: -50:-55	0	507	0	2	0	0	293	1590	1463	0	0	3855	0	0	0	4		IIIh
B: -55:-60	0	310	0	3	0	1	146	2055	699	0	0	3214	2	0	2	1		Ila
B: -60:-65	0	41	0	0	1	0	26	711	75	0	0	854	0	0	0	0		
B: -65:-70	0	6	0	0	0	0	6	58	5	0	0	75	0	0	0	5		IIs
B: -70:-75	0	2	0	0	0	0	1	25	3	0	0	31	0	0	0	5		
B: -75:-80	0	6	0	0	0	0	2	17	2	0	0	27	0	0	0	0		
B: -80:-85	0	6	0	0	0	0	0	13	4	0	0	23	0	0	0	0		I
B: -85:-90	0	7	0	0	0	0	0	6	5	0	0	18	0	0	0	4		
B: -90:-95	0	11	0	0	0	0	7	30	18	0	0	66	0	0	0	0		
B: -95:-100	0	4	0	0	0	0	2	20	16	0	0	42	0	0	0	2		II
B: -100:-105	0	4	0	3	0	0	0	6	5	0	0	18	0	0	0	1		
B: -105:-110	0	17	0	1	0	0	7	1	3	0	0	29	0	0	0	2		I
B: -110:-115	0	20	1	1	0	0	6	1	18	0	0	47	0	0	0	1		
B: -115:-120	0	29	0	1	0	0	10	3	33	0	0	76	0	0	0	1		
B: -120:-125	0	66	1	2	0	0	42	9	87	0	0	207	1	0	1	0		IV
B: -125:-130	0	71	0	2	0	0	93	20	432	0	0	618	0	0	0	1		III

864

865 **Table 3.** Molluscan taxa abundances of the Amiens-Renancourt 1 excavation. Ecological  
866 groups: half-forested (2), open (5), mesophilous (7), slugs (7'), hygrophilous (8), palustral (9),  
867 aquatics (10) and undetermined (U). See table 5 for the description of molluscan phase types.

868

ECOLOGICAL GROUP	TAXA	HABITAT	ECOLOGICAL REMARKS	REMARK'S AUTHOR
Hygrophilous (8)	<i>Succinella oblonga</i> (Draparnaud, 1801)	Wet stations with a sparse vegetation (humid meadows, swamps and near brooks).	It lives on "damp mud or rock surfaces, whether on the banks of rivers or lakes, or high up on scree".	Kerney (1971)
Palustral (9)	<i>Pupilla alpicola</i> (Charpentier, 1837)	Very wet mountain stations (fens with sparse vegetation, peat bogs, wet grasslands), preferentially in calcareous areas.		
Slugs (7 <sup>i</sup> )	Limacidae Lamarck, 1801 Milacidae Ellis, 1926	Various habitats, preferentially with clayey soils retaining moisture and offering shelters and hiding places		
Open habitat (5)	<i>Pupilla muscorum</i> (Linnaeus, 1758)	Open, dry and sunny, calcareous stations (dry meadows, sand dunes).	It tolerates "earth bare of vegetation" and "a considerable range of diurnal temperature as well".	Evans (1972)
	<i>Vallonia costata</i> (O.F. Müller, 1774)	Varied open, dry and humid, stations with stones; rarely found in woods or swamps.	It "prefers more stable grassland".	Kerney (1971)
Mesophilous (7)	<i>Trochulus hispidus</i> (Linnaeus, 1758)	Various moderately dry to humid stations (flood plains, marshy places, damp meadows, shrublands, light forest).	It is qualified as "relatively thermophilous"(*) and considered as an "early coloniser of damp broken ground before the development of a binding cover of vegetation"(**)	(*) Kerney (1963); (**) Kerney (1971)
	<i>Punctum pygmaeum</i> (Draparnaud, 1801)	fairly wet habitats with a developed vegetation cover (e.g. wood litter). Also in open stations and poor habitats offering a sufficient moisture or hiding places.	It is "characteristic of short-turf grassland and of open habitats where there is much bare ground"(*) and "often appear in places at an early successional stage" (**).	(*) Evans (1972); (**) Horsák <i>et al.</i> (2013)
	<i>Clausilia rugosa parvula</i> A. Férussac, 1807	Little humid to very dry shaded open stations with rocks and short vegetation. Rare in woods. Calciphile.		
Half-forested (2)	<i>Arianta arbustorum</i> (Linnaeus, 1758)	Very wet and vegetated stations. Also in sufficiently moist open stations. Cold resistant.	"It is commoner in river valley bottoms, (...) occurs more often in thick vegetation (...) and it is also favoured by steep north-facing slopes".	Cameron <i>et al.</i> (1971)
Aquatic (10)	<i>Pisidium</i> C. Pfeiffer, 1821	Various habitats: (periodic) swamps, standing and flowing waters		
	<i>Bythynia tentaculata</i> (Linnaeus, 1758)	Slowly flowing waters, but also in periodic pools on muddy bottom and plants when water dries out.		

869

870 **Table 4.** Taxa ecological preferences synthesised after (Boycott, 1934), Ložek (1964), Kerney  
871 *et al.* (1983), Welter-Schultes (2012) and Horsák *et al.* (2013) and additional remarks. Taxa  
872 are listed by ecological groups, which are ordered by decreasing importance in the site.  
873 Taxonomical remarks: (i) while internal shells of Limacidae and Milacidae can be  
874 distinguished, they cannot be identified at the species rank; (ii) according to their finely ribbed  
875 microsculpture, the two apices of *Clausilia rugosa* (Draparnaud, 1801) found at Amiens-  
876 Renancourt 1 were attributed to the sub-species *C. rugosa parvula* A. Férussac, 1807; (iii)  
877 valves and fragments of *Pisidium* were too few to allow for a reliable identification at the  
878 species rank; (iv) the single opercula attributed to this taxa cannot belong to another *Bithynia*  
879 species such as *Bithynia leachii* (Sheppard, 1823).

880

Phases (and sub-phases)		Abundance	Richness	<i>Succinella obonga</i> (hygrophilous)	<i>Pupilla alpicola</i> (palustral)	<i>Pupilla muscorum</i> (open habitat)	Slugs (stable clayey soil)	<i>Trochulus hispidus</i> (mesophilous)	Vegetation-demanding taxa ( <i>V. costata</i> , <i>C. r.</i> , <i>P. pygmaeum</i> , <i>A. arbustorum</i> )
I: Stadial		MIN	(MIN)						
II: Stadial-interstadial transition	Start	↗	↗	↗(↗)	↗	↗	↗	(↗)	(↗)
	Acceleration	↗↗↗	↗	↗↗↗ (→ MAX)	↗↗↗	↗↗↗	↗↗	(↗)	(↗)
III: Interstadial optimum	Humid	MAX	↘	↘	↗(↗) MAX	(↗)	(↗)		(↘)
	Dry	MAX		↘(↘)	↘	(↗) MAX	↗	↗	
IV: Interstadial-stadial transition		↘↘(↘)		↘(↘)	↘(↘)	↘(↘)	↘(↘) MAX	(↘)	

881

882 **Table 5.** Definition criteria of molluscan phases identified at Amiens-Renancourt 1. Symbols  
883 are bracketed when changes do not systematically occur.

884

885 **Figure 1.** Location of Amiens-Renancourt 1 site and of other sites mentioned in this study.  
886 Legends: ice caps (light blue), modern coast lines (dashed lines), palaeo-coastlines at -120 m  
887 (plain line) around 27 ka according to Clark et al. (2009), elevation (level curves every 200 m  
888 from -120 m). Map realised with GMT 6 (Wessel et al., 2019) using a Mercator projection.

889 **Figure 2.** Local topographical context of the Amiens-Renancourt 1 site. Altimetry in metres  
890 NGF. The asterisk indicates the position of the Renancourt 2000 test pit. Map realised with  
891 version 3.4 of QGIS software (<http://www.qgis.org>) using the IGN BD Alti® at 5 m.

892 **Figure 3.** Pedostratigraphical record of Amiens-Renancourt 1 excavation with positions of all  
893 studied samples. The typology of pedological horizons follows the IUSS Working Group  
894 WRB (2015). H: upper profile; B: lower profile. Samples marked with a cross were not  
895 analysed due to the strongly reworked facies of the units concerned.

896 **Figure 4.** Granulometry, chronology and chronostratigraphy of the Amiens-Renancourt 1  
897 loess sequence and correlations with the Nussloch loess sequence. Ages are laterally spaced  
898 according to their respective depths, except those of the archaeological layer that are  
899 artificially scattered on both sides of <sup>14</sup>C age H: -70:-65 for a better readability. <sup>14</sup>C ages  
900 Lyon-632 and Lyon-633 come from another profile (see table 2 and part 4.2). Rejected ages  
901 are marked by a dashed contour; they include H3 not figured. GI: Greenland interstadials. ET:  
902 Eltville tephra; LS: Lohne soil. Correlations between the Nussloch pedostratigraphy and the  
903 NGRIP were established in Moine et al. (2017). Dashed lines highlight correlations that are  
904 not supported by <sup>14</sup>C ages.

905 **Figure 5.** Diagrams of molluscan taxa absolute and relative abundances, and curves of several  
906 molluscan population parameters. Asterisks highlight successive specific abundance maxima.

907 **Figure 6.** Correlations between molluscan fauna parameters and grain size index variations of  
908 Amiens-Renancourt 1 and Nussloch loess sequences. NGRIP data: Rasmussen et al. (2014).

909 **Figure 7.** Correlation attempt between Amiens-Renancourt 1 molluscan phases and stadial-  
910 interstadial cycles. NGRIP data: Rasmussen et al. (2014). 7H (Sieben Hengste) data:  
911 Luetscher et al. (2015). The dashed vertical line symbolizes the equilibrium between the  
912 Mediterranean (depleted values) and the North Atlantic (enriched values) advection. NGRIP  
913 and 7H signals have been averaged to fit with the resolution (~100 years per sample) of  
914 Amiens-Renancourt 1 proxies.















