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

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 (CaCO₃) 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 20th
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}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 μm 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 μm ; fine sands: 61-
157 160 μm) 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 μm) 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/cm². 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 ⁹⁰Sr/⁹⁰Y
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 ± 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 ²³⁴Th, ²²⁸Ra and ⁴⁰K, 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 CaCO₃. 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 CaCO₃. 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. CO₂ evolved from carbonate acid
204 attack was collected and flame-sealed in Pyrex tubes. Physical measurement was handled on
205 the CO₂ gas itself (no graphitization step) by ECHOMICADAS (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 ¹⁴C 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 ¹⁴C 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 ¹⁴C datings in loess contexts from north-western Europe. The
265 other two ages obtained on bone appear significantly younger (no recovery between their 2σ
266 age ranges and that of the ECG ¹⁴C 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 ¹⁴C 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 ¹⁴C, i.e. 26036-26929 cal BP, sequence II should end around 26.5-26 ka.
276 Statistically different, the ¹⁴C 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 ± 1.6 to 27.2 ± 1.5 ka (Tab. 1).
279 Both ¹⁴C and OSL age ranges are thus in good agreement. The uppermost one, i.e. REN1 14-
280 03 (27.6 ± 1.4 ka), is slightly younger than the closest ¹⁴C 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 ± 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 ± 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 ± 2.0 ka, close to that of sample REN1 14-02 and to the ¹⁴C 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}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}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

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850

851

Unit / Depth	Sample	U (ppm)	Th (ppm)	K (%)	W (%)	D α (Gy/ka)	D β (Gy/ka)	D γ (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 α , β , γ 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)	¹⁴ 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	Phases
H: 15:10	0	12	0	1	0	0	0	1	0	0	0	14	0	0	0	0	0		
H: 10:5	0	5	0	1	0	0	0	2	0	0	0	8	0	0	0	1	0	C7	I
H: 5:0	0	12	0	2	0	0	4	10	9	0	0	37	0	0	0	2	0		
H: 0:-5	0	0	0	1	0	0	1	8	10	0	0	20	1	0	1	5	0		
H: -5:-10	0	1	0	0	0	0	2	200	1	0	0	204	1	0	1	2	0	C6	II
H: -10:-15	0	0	0	0	0	0	3	438	0	5	0	446	1	0	1	2	0		
H: -15:-20	0	5	0	1	0	0	1	77	5	0	0	89	1	0	1	1	0		I
H: -20:-25	0	5	0	1	0	0	5	29	0	0	0	40	1	0	1	1	0		
H: -25:-30	0	0	0	1	0	0	5	91	12	0	0	109	2	0	2	4	0		II
H: -30:-35	1	24	0	1	1	0	5	97	0	0	0	129	0	0	0	1	0	C5	II
H: -35:-40	0	12	1	2	0	0	17	45	12	0	0	89	1	0	1	0	0		I
H: -40:-45	0	24	0	1	0	0	9	98	0	0	0	132	1	0	1	4	0		
H: -45:-50	0	16	0	0	0	0	18	488	24	0	0	546	1	0	1	3	0		
H: -50:-55	0	7	0	0	0	0	33	499	57	0	0	596	0	0	0	1	0		IV
H: -55:-60	0	19	1	1	0	0	64	290	57	0	0	432	1	0	1	2	0		
H: -60:-65	0	92	0	0	0	0	51	174	372	0	0	689	0	0	0	1	0		III
H: -65:-69	0	7	0	1	0	0	14	102	40	0	0	164	0	0	0	1	0		
H: -70:-75	0	162	0	1	0	0	131	1245	542	0	0	2081	0	1	1	4	1	C4	Ila
B: 0:-5	0	84	0	0	0	0	53	1309	249	0	0	1695	0	0	0	2	0		
B: -5:-10	0	34	0	0	0	0	21	235	39	0	0	329	0	0	0	1	0		
B: -10:-15	0	25	1	1	0	0	22	82	15	0	1	147	0	0	0	4	0		IIs
B: -15:-20	0	13	0	1	0	0	22	26	25	0	0	87	0	0	0	7	0		
B: -20:-25	0	21	0	1	0	0	18	26	23	0	0	89	1	0	1	8	0		I
B: -25:-30	0	27	1	1	0	0	18	31	21	0	0	99	0	0	0	8	0		
B: -30:-35	0	38	0	1	0	0	31	35	47	0	0	152	2	0	2	13	0		
B: -35:-40	0	58	0	1	0	0	64	79	58	0	0	260	1	0	1	7	0		IV
B: -40:-45	0	162	0	7	0	0	276	265	194	0	0	904	1	0	1	7	0		
B: -45:-50	0	1320	0	28	0	0	503	791	1155	0	0	3797	1	0	1	2	0		IIIId
B: -50:-55	0	507	0	2	0	0	293	1590	1463	0	0	3855	0	0	0	4	1		IIIh
B: -55:-60	0	310	0	3	0	1	146	2055	699	0	0	3214	2	0	2	1	0		Ila
B: -60:-65	0	41	0	0	1	0	26	711	75	0	0	854	0	0	0	0	0		
B: -65:-70	0	6	0	0	0	0	6	58	5	0	0	75	0	0	0	5	0		IIs
B: -70:-75	0	2	0	0	0	0	1	25	3	0	0	31	0	0	0	5	0		
B: -75:-80	0	6	0	0	0	0	2	17	2	0	0	27	0	0	0	0	0		
B: -80:-85	0	6	0	0	0	0	0	13	4	0	0	23	0	0	0	0	0		I
B: -85:-90	0	7	0	0	0	0	0	6	5	0	0	18	0	0	0	4	0		
B: -90:-95	0	11	0	0	0	0	7	30	18	0	0	66	0	0	0	0	0		
B: -95:-100	0	4	0	0	0	0	2	20	16	0	0	42	0	0	0	2	0		II
B: -100:-105	0	4	0	3	0	0	0	6	5	0	0	18	0	0	0	1	0		
B: -105:-110	0	17	0	1	0	0	7	1	3	0	0	29	0	0	0	2	0		I
B: -110:-115	0	20	1	1	0	0	6	1	18	0	0	47	0	0	0	1	0		
B: -115:-120	0	29	0	1	0	0	10	3	33	0	0	76	0	0	0	1	1		
B: -120:-125	0	66	1	2	0	0	42	9	87	0	0	207	1	0	1	0	0		IV
B: -125:-130	0	71	0	2	0	0	93	20	432	0	0	618	0	0	0	1	0	C1	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 screes".	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 ⁱ)	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>parvula</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.

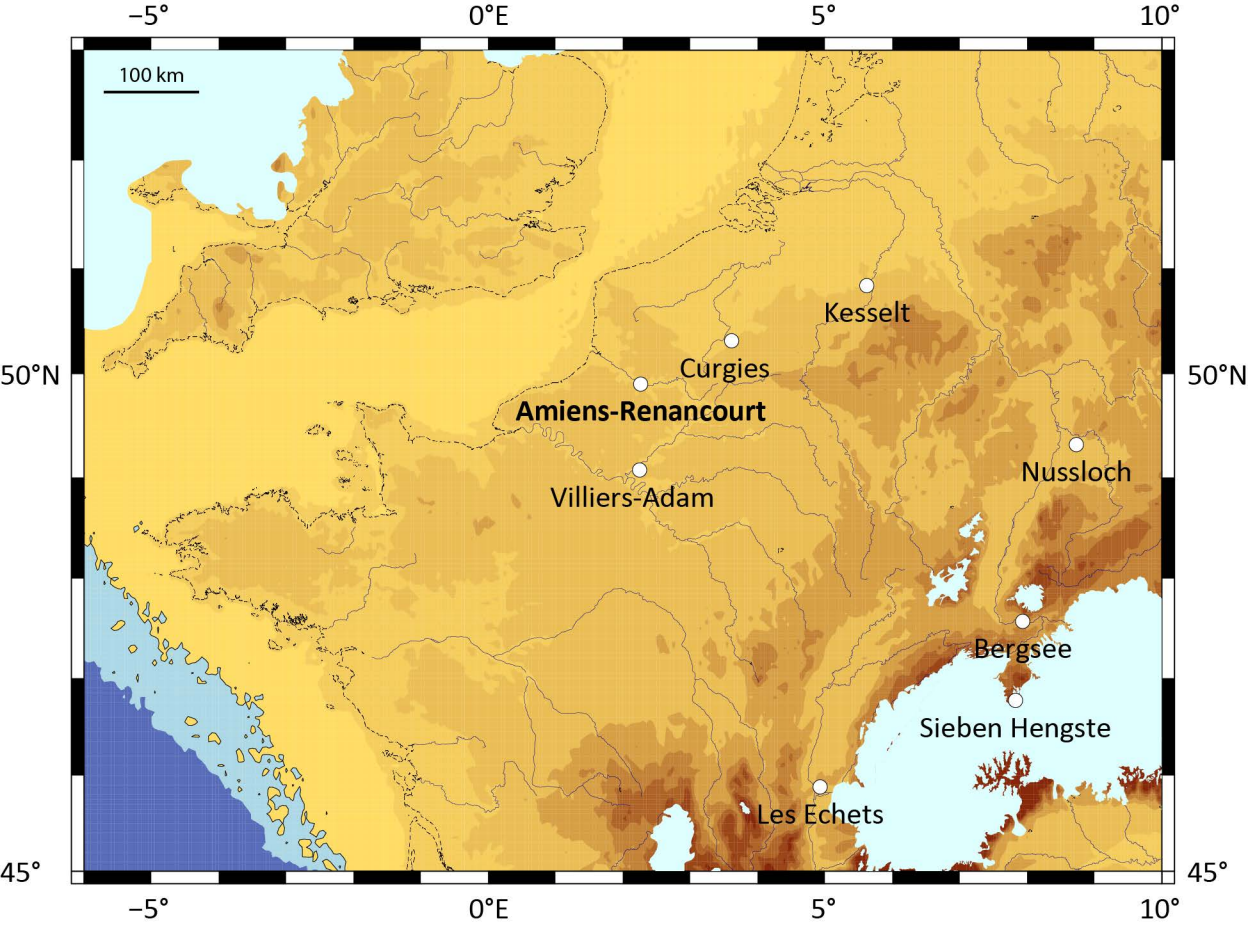
892 **Figure 3.** Pedostratigraphical record of Amiens-Renancourt 1 excavation with positions of all
893 studied samples. The typology of pedological horizons follows the IUSS Working Group
894 WRB (2015). H: upper profile; B: lower profile. Samples marked with a cross were not
895 analysed due to the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

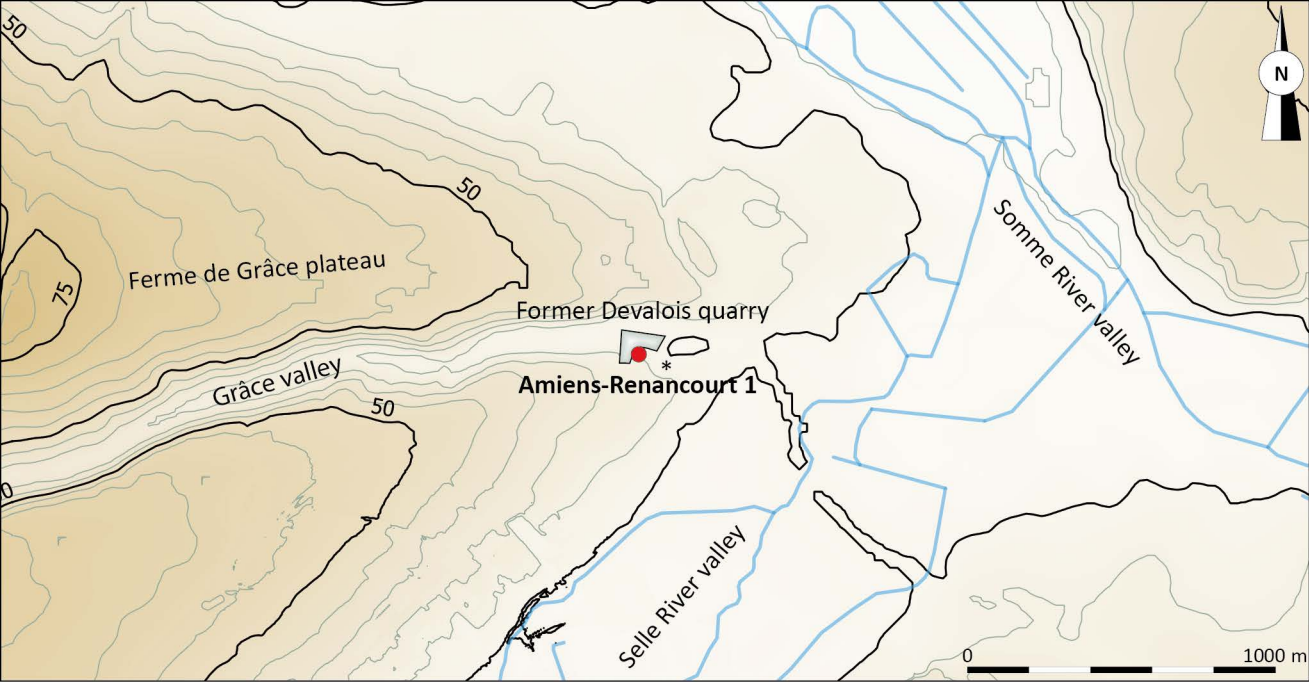
896 **Figure 4.** Granulometry, chronology and chronostratigraphy of the Amiens-Renancourt 1
897 loess sequence and correlations with the Nussloch loess sequence. Ages are laterally spaced
898 according to their respective depths, except those of the archaeological layer that are
899 artificially scattered on both sides of ^{14}C age H: -70:-65 for a better readability. ^{14}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 ^{14}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.





Former Devalois quarry

Amiens-Renancourt 1

Ferme de Grâce plateau

Grâce valley

Somme River valley

Selle River valley

1000 m

