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1 **Onshore and offshore evidences for four abrupt “warming” episodes during MIS 6 at**
2 **the westernmost tip of continental Europe: did they control the migrations of**
3 **Neanderthals?**

4
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20 Monnier).

21
22 **Abstract**

23
24 The total shell production typical of the *Pupilla* association in the onshore site of Nantois
25 (Brittany, France) evidenced for the first time four brief, abrupt, warm and humid episodes
26 during the Upper Saalian (MIS 6) loess deposition. These “warming” events were also found
27 in the marine deposits of the Celtic Sea (MD03-2692 core). Comparison with the variations of
28 the sea-level, show that the “warming” episodes were not only of regional interest but
29 corresponded to global events ruled by precession and insolation cycles. Other comparisons
30 with biomarker records (molluscs, charcoal and rodents) of the Paris Basin (Villiers-Adam)
31 and Jersey Island (La Cotte de Saint Brolade) confirm the existence of these warmer events.
32 Tentative correlations with the discontinuous Neanderthal dwelling phases recorded in
33 Brittany suggest that these populations were mainly (only?) present in Westernmost Europe
34 during the warmer episodes.

35

36 *Keywords:* MIS 6 climatic changes, Westernmost Europe, malacology, “warming” episodes,
37 Palaeolithic migrations.

38

39

40 **1. Introduction**

41

42 During the recent investigations of the loess that make up the Nantois cliff (Northern Brittany
43 - France) located in the eastern part of Saint Brieuc Bay (48°35'50.57"N, 2°31'51.46"W), (that
44 is to say almost at the westernmost end of continental Europe), we discovered the existence of
45 four short and abrupt Late Saalian (MIS 6) “warmer” episodes. This discovery was based on
46 detailed malacological, physical and geochemical studies (Danukalova et al., 2017). In order
47 to better understand the origin of these unexpected climatic phases, it was decided to compare
48 these events with contemporaneous sites already studied onshore and offshore. These sites
49 were selected because they are located at about the same latitude as Nantois (47°N) and thus,
50 received the same amount of insolation. They are also all located at about the same distance
51 (450 kilometres) respect with the British ice sheet (Fig. 1).

52 This discovery was also the opportunity to check if the discontinuous middle Palaeolithic
53 dwelling of Neanderthal in Brittany (Monnier, 1973) was a valid hypothesis.

54

55 Fig. 1 here

56

57 **2. The Upper Saalian background in Europe**

58

59 The Late Saalian period represents the penultimate glacial episode. At a small scale it was
60 characterized by the huge development of the boreal ice-sheet and especially by its large
61 geographical extension over northeastern Europe. At that time, the Barents-Kara ice-sheet
62 represented one of the largest glacial area (Svendsen et al., 2004; Astakhov et al., 2016). The
63 Late Saalian was contemporaneous with the Moscow glaciation and was encompassing the
64 multi-stepped Termination 2 (Seidenkrantz et al., 1996). The studied area was located at the
65 transition between a cold domain associated with this huge ice-sheet and the warmer North
66 Atlantic realm. All the sites cited in this paper were under the influence of a steep temperature
67 gradient and were, thus, affected by rapid climatic changes. The cold periods were
68 characterized by the deposition of loess in the East and a rapid regression of the sea in the

69 West. On the contrary the climatic improvements were responsible for an important melting
70 of the southern border of the boreal ice-sheet in the East and for the formations of onshore
71 incipient soils (and for the southward drift of icebergs) in the West (Lefort et al., 2017).

72

73 **3. The Upper Saalian background in the western part of France**

74

75 Four well-documented Upper Saalian sites are known in the Western half of France. One is
76 located in the Paris Basin (Villiers-Adam), one in Saint Brieuc Bay (Nantois) and one on
77 Jersey Island (La Cotte de St Brelade). The last site corresponds with a marine borehole
78 drilled in the Celtic Sea (core MD 03-2692). The site of Nantois has been often visited since
79 the first study of Mazeres (1938) but it is only recently that a complete stratigraphical and
80 malacological study of this section has been reappraised (Danukalova et al., 2017).

81

82 *3.1. The Nantois site (Brittany)*

83

84 It is the place where the stratotype of the Nantois Formation was first defined (Monnier,
85 1973; Monnier and Bigot, 1987). The Eastern part of this cliff is characterized by the
86 superimposition of two loess formations of Saalian and Weichselian ages. This outcrop is
87 important in the regional geology because it is one of the very few places where the Saalian
88 loess is not completely decalcified. Out of this zone the pre-Eemian sediments are very
89 patchy. The general stratigraphy of the Nantois cliff will not be described here in details, all
90 the information can be found in Monnier (1973) and Loyer et al. (1995). The complete
91 reappraisal of this outcrop has been proposed because the aspect of the cliff, continuously
92 eroded by the sea, was modified since the first stratigraphic description. The main results of
93 this study are summarized below.

94

95 - Main characteristics of the Upper Saalian Nantois section:

96

97 Section A of figure 2 displays the initial layers numbering proposed by Monnier (1973). In
98 this diagram, the Upper Saalian section is located between layers 26 and 37. Nowadays layers
99 36 and 37 look thicker and more complex than previously estimated. Section B displays more
100 details, either because some of the layers have been subdivided or because they were not
101 observed before their erosion by the sea. In this diagram, the Upper Saalian is located

102 between layers 1 and 10. We send back the reader to a recent paper (Danukalova et al., 2017)
103 for more stratigraphical details.

104 The bottom and the top of the Upper Saalian section can be clearly observed on the field
105 (Monnier, 1973). The limit between the Inter-Saalian warming and the Upper Saalian glacial
106 deposits is underlined by poorly rounded fragments of rock associated with remnants of an
107 old soil and a yellowish-grey loess-like loam incorporated in a gravelly “head” formation
108 (Fig. 2A). An altered “head” associated with a reddish loam marks the contact between the
109 Upper Saalian and the Eemian. Between these two limits a typical calcareous loess was
110 continuously deposited.

111 Quantification of the number of shells was made between layers 2 and 10 (Fig. 2 B). Apart
112 the previous discoveries of Mazeres (1938) and Puissegur (see Monnier, 1973) no systematic
113 mollusc study was undertaken in this area. The sampling of the section was made at 10 cm
114 intervals following the methodology of Sümegei and Krolopp (2002) but with a closer spacing.
115 The quantity of extracted shells was very different depending on the examined level (Table
116 1). Their abundance is given according to the method of Ložek (1964) and determinations
117 were made following the various sources cited in Danukalova et al. (2013). Because the
118 number of mollusc shells is important in the interpretation of the Upper Pleistocene terrestrial
119 deposits, shells were examined and extracted individually. The number of complete shells
120 plus the number of apices or apertures (considered as equivalent to one shell when taken
121 together) were counted. Additionally, undetermined shell fragments were counted in order to
122 get quantitative environmental information. The percentage of the different species in each
123 sample was not counted, because the method needs more than 200 shell specimens (White et
124 al., 2008) to be valid.

125
126 Table 1 here

127
128 The Nantois malacofauna is usually poor in species, which reflects a cold environment. If the
129 number of shells is given for 2.5 kg of sediment, a total amount of 397 terrestrial mollusc
130 shells (and 2038 fragments) belonging to 7 species (*Succinella oblonga*, *Pupilla muscorum*,
131 *Cochlicopa lubrica*, *Vertigo* cf. *alpestris*, *Vallonia pulchella*, Hydromiidae, and Limacidae)
132 were identified (Fig. 2). It has been observed that Limacidae (which cannot live in very dry
133 environments) always appear at the same time as the maximum production of shells, which
134 suggests that a wetter and warmer environment was at the origin of their multiplication.

135 The groups of molluscs were classified according to their modern ecological preferences in
136 temperature, humidity, and vegetation cover following the criteria proposed by Ložek (1964),
137 Likharev and Rammelmeier (1952) and Puisségur (1976). After the analysis of the different
138 species, five mollusc zones were recognized. Basically, the general environment was very
139 cold even if the installation of the permafrost was very late (Van Vliet-Lanoë in Monnier et
140 al., 1997). Malacozones 1b, 3 and 5 correspond with limited “meadows” or littoral dunes
141 associated with a tundra-like open habitat with a grassy vegetation. During these episodes the
142 production of shells was very low which suggests a rather dry and cold environment.
143 Malacozones 1a, 2 and 4 correspond with wet “meadows” probably associated with bushes
144 and trees. During these periods of milder climatic conditions the production of shells was
145 increasing. In total, severe environmental conditions, which did not favoured the biotic
146 production, alternated with improved climatic episodes that generated larger populations of
147 gastropods.

148

149 Fig. 2 here

150

151 Although the decalcification of the upper part of the section does not permit to give any
152 malacological information on the climate existing at that time, the presence of “*limon à*
153 *doublets*” (LAD, Fig. 2) provides interesting information. The “*limon à doublets*” (Lautridou,
154 1985) which consists of a thin alternation of sandy and silty loess (often rich in illite and
155 hornblende) with iron-coated silt grains, can be considered as a low-energy overland flow,
156 which developed during one, or successive seasonal snow melts. This facies corresponds to
157 the product of freezing and thawing (Derbyshire et al., 1988). The variability in the anisotropy
158 of the “*limon à doublets*” facies has been assessed elsewhere by image analysis of scanning
159 electron microscopy (SEM) and optical microscopy. This strong anisotropy has been
160 measured in thin section imagery of loess from Normandy and Poland and is considered as
161 the product of freezing and thawing. This was confirmed by scanning electron microscopy
162 and by experimental freezing of different silts.

163 The zone of “*limon à doublet*” (or stripped loam) located below layer 26 has been considered
164 (Monnier et al., 1997) as dating from 140 ka and would be equivalent to the Zeifen-Linexert
165 Interstadial (Seidenkrantz et al., 1996). It corresponded to an “early” phase of “boreal”
166 pedogenesis. After the development of this “soil”, a short cooling phase degraded the
167 vegetation and it is only after this period that the stability of the Eemian was reached (Van
168 Vliet-Lanoë and Guillocheau, 1995). Taken as a whole, four sedimentary zones witnessing

169 slightly milder climatic conditions have been recognized during this severe tundra climatic
170 episode.

171 It must be also observed that the largest shell developments are often superimposed onto
172 darkest zones on the field (Fig. 2). These zones correspond to incipient soils, very poor in
173 total organic matter (TOC). Pilot measurements made in these zones and on the “*limon à*
174 *doublet*” zone (Dergacheva written communication and work in progress) show that their total
175 organic carbon is ranging between 0.07 and 0.25% of the total weight. Despite this very low
176 TOC content some darker zones still evidence a very weak magnetic susceptibility
177 (Dergacheva written communication). Those incipient soils cannot be compared with the well
178 developed soils of Eemian age but confirm the existence of very low climatic improvements
179 during MIS 6. No major disruption or gap between the slightly pedogenized loess and the
180 non-pedogenized sediment have never been observed on the field.

181

182 3.2. Contributions of Villiers-Adam and La Cotte de Saint Brelade sites

183

184 These two sites, previously studied by Loch et al. (2003) and Callow and Cornford (1986)
185 are mainly interesting for the distribution of their faunas. The main results of these studies are
186 shortly summarized below.

187

188 3.2.1. The Villiers-Adam site (Paris Basin)

189

190 The site of Villiers-Adam is located in the Paris basin at 35 km north of Paris city (Fig. 1).
191 Various sections were studied in this area. The Upper Saalian has been particularly studied in
192 detail in the site of Le Chamesson. Although the main purpose of these studies concentrated
193 on archaeology, researches in stratigraphy, geochronology and malacology (Limondin-
194 Lozouet and Gauthier, 2003) were also undertaken. In this area Saalian as well as
195 Weichselian sections were sampled. For more details the reader can refer to a comprehensive
196 paper published by Loch et al. (2003).

197

198 - Main characteristics of the Upper Saalian section at Le Chamesson

199

200 The Upper Saalian has been recognized between layers 19 and 15 (Fig. 3A). The lower limit
201 of the formation corresponds with a contact between a carbonate-free interglacial sandy and
202 clayish loam (a truncated Bt luvisol) and a reworked sandy loam marking the beginning of the

203 Upper Saalian (Locht et al., 2003). The abrupt upper limit with the Eemian is located at the
204 boundary between typical calcareous loess and a non-calcareous loam (Bt horizon of the
205 15a/b soils) (Locht et al., 2003). Between these two limits and overlying a layered stony and
206 sandy formation, the typical calcareous loess accumulated.

207 Only the carbonated loess of Le Chamesson contains molluscs (units 16 and 17) (Limondin-
208 Lozouet and Gauthier, 2003) (Fig. 3B). The diversity of the molluscs is very low since only
209 five taxa were found. Like in Nantois, the best-represented taxon is *Pupilla muscorum*, typical
210 of open and dry environments well represented in central and Western Europe (Kerney and
211 Cameron, 1999). It is followed by the mesophyll *Trichia hispida* that lives in versatile
212 environments except in very dry biotopes. Limacidae are well represented and witness of a
213 relative local moisture. The other species are *Succinella oblonga* and an aquatic gastropod
214 *Lymnaea truncatula*. Because of the poor number of species it was suggested that gastropods
215 were living in an environment difficult to colonize (Limondin-Lozouet and Gauthier, 2003)
216 but relatively stable since their number increased upwards. In general this association (*Pupilla*
217 *muscorum*, *Trichia hispida* and *Succinella oblonga*) is considered to be typical of a
218 Pleniglacial steppe loess environment (Puisségur, 1976). The paucity in gastropod species is
219 even larger than in Nantois, maybe because this outcrop was more continental and thus far
220 from the warming effects of the Saalian Sea (Fig. 1). The assumption that “the paucity” of the
221 malacologic assemblage is typical of the Western part of France” (Rousseau et al., 1990) is
222 not fully supported by the results obtained in Nantois since there are more gastropod species
223 in Nantois than in Villiers-Adam.

224 The total number of gastropod shells was calculated with the same technique as in Nantois, it
225 clearly shows that the living conditions were harsher in Villiers-Adam (Fig. 3). In the present
226 study, the total number of gastropod shells was calculated after the data of Limondin-Lozouet
227 and Gauthier (2003). Here again, the total number of terrestrial taxa increases when the
228 number of Limacidae is increasing, which evidences the role of moisture in shells
229 development. Indirectly, this result also supports the existence of brief warming and humid
230 episodes.

231 Taking account of data already published (Limondin-Lozouet and Gauthier, 2003) we
232 delineated a series of malacozones following the same criteria as those defined for Nantois
233 (Fig. 3B). The subdivision in sub-malacozones which enhance the importance of some taxa
234 will not be discussed since we are mainly interested in this paper in the total amount of shells.
235 1/ Malacozones a₁, b₁ and c, correspond with milder climatic conditions. The environment
236 was less dry than during stages a₂ and b₂. The landscape which probably prevailed during the

237 accumulation of these deposits corresponded with open habitats rich in vegetation cover and
238 possibly with bushes and trees. 2/ Malacozones a_2 and b_2 suggest dryer climatic conditions.
239 The landscape which probably prevailed during the accumulation of these deposits
240 corresponded with an open habitat, some vegetation cover and possibly bushes and trees in
241 depressions. In total and, like in Nantois, we can observe the alternation between cold
242 environments (which did not favour the development of molluscs) and milder climatic
243 conditions (which generated a larger shells production).

244 The physical and chemical study of the sediment evidenced, like in Nantois, a decalcification
245 of the uppermost part of the Upper Saalian under the Eemian soil. The isotopic interpretation
246 of the organic matter sampled in the same zone support the existence of a very dry
247 environment (Locht et al., 2003) which is not fully compatible with the study of the mollusc
248 community (presence of many Limacidae and of an aquatic gastropod – Limondin-Lozouet
249 and Gauthier, 2003). This apparent discrepancy could be explained if the malacological study
250 concentrated locally on deposits neighbouring a valley or a small depression. The erosive
251 limit of the lower part of layer 18 and the abrupt contact of the base of level 17 as well as the
252 slope imaged at depth on this section may support this possible interpretation.

253 The TL-IRSL ages obtained on loess deposits have been considered as over or underestimated
254 when compared with the regional environment. An estimation of the possible ages, based on
255 the SPECMAP/GRIP-CISPII data was proposed (Locht et al., 2003). The origin of the
256 underestimated ages observed in some pedo-complexes has been already discussed elsewhere
257 by Frenchen (1999).

258

259 Fig. 3 here

260

261 3.2.2. La Cotte de Saint Brelade site (Jersey Island)

262

263 This very important site located at the southwest corner of Jersey Island and at 50 km north of
264 the onshore Nantois site (Fig. 1) was mainly excavated for archaeology but was also studied
265 for sedimentology, palaeontology and geochronology. We will summarize here the salient
266 points of this site and mainly those that are useful for a comparison with the two sites
267 described above, even if shells were not taxonomically determined at this place. This site
268 which was inhabited by Neanderthals during various periods corresponded with a massive
269 rock arch that was partly filled by a great volume of loess deposits.

270

271 - Main characteristics of the Upper Saalian section at La Cotte de Saint Brelade

272

273 Because the Pleistocene stratigraphy of this site was established progressively during the
274 successive archaeological excavations we will present only here a simplified reconstitution
275 (Fig. 4) based on the global synthesis of Callow and Cornford (1986).

276 The Upper Saalian corresponds to the stage III of the authors in which they recognized 5
277 different periods ranging between units 13 and 21. The lower limit of the Upper Saalian
278 which is made of a typical loess deposited in extremely cold conditions (it is associated with
279 the rodent *Dicrostonyx*) is in contact with the upper part of the MIS 7 formation made of
280 disturbed occupation floors showing a granitic sand matrix with few large blocks. The upper
281 limit of the Upper Saalian made of soliflucted and cryoturbed loess containing on top
282 *Juniperus* and *Hippophae rhamnoides* pollen (indicating the beginning of a climatic
283 improvement) passes to the Eemian (characterized by a clear pedogenesis and the beginning
284 of a marine transgression).

285 The stratigraphic description of the site suggests that there was a more or less continuous
286 loess sedimentation between these two limits. Layer 15 is characterized by the presence of
287 oak charcoal and layer 18 by *Quercus*, *Fraxinus* and *Ulmus* which suggest the existence of a
288 well-expressed climatic “warming”. The presence of a high herbaceous percentage in this
289 layer is also questionable (A. Shaw, oral communication).

290 Even if some reworking of the deposits have been suggested in the upper and lower parts of
291 stage III (Callow and Cornford, 1986), the presence of two well expressed episodes of
292 climatic “warming” alternating with three periods of strong gelifluction with permafrost and
293 cold-living rodents seems to be clear even if not totally equivalent with the four warming
294 stages evidenced in Nantois and in Villiers-Adam. This can be partly explained by the
295 erosional surfaces separating the 14th and 15th climatic episodes.

296 If the “limons à doublets” observed during episode 20 in La Cotte de Saint Brelade is more or
297 less equivalent to the “limons à doublets” observed in Nantois we may correlate these two
298 climatic improvements with the two uppermost warmings observed in Nantois and Villiers-
299 Adam, but this correlation is questionable because the “limon à doublets” of Jersey developed
300 during a very cold episode after the illustration of Callow and Cornford, (1986) (Fig. 4: G).

301

302 Fig. 4 here

303

304 It is important to underline that rodents *Sicista* sp., *Dicrostonyx torquatus* (Pallas, 1778),

305 *Microtus malei* (Hinton, 1927), *Microtus arvalis* (Pallas, 1779) and *Microtus gregalis* (Pallas,
306 1779) collected in the Upper Saalian sediments were living in temperatures ranging between -
307 45° and +15° (Chaline and Brochet, 1986). On the contrary the presence of *Quercus* suggests
308 milder temperatures since the ideal root temperature for the normal development of *Quercus*
309 *robur* (Linnaeus, 1753) is known to be around 25°C (Lyr and Garbe, 1995), the ideal
310 temperature for *Quercus* development being around 13°C (Rodrigues, 2009).
311 The simultaneous presence of bones of reindeer and of oak during episode 15 and the
312 existence of “cold” and “warm” remnants in other layers, show that the original deposits have
313 been locally disturbed. This reworking is also clear where rodents, typical of taiga, were
314 mixed with rodents living in a tundra environment (A.Yakolev, written communication).
315 Finally, the main contribution of the palaeontological study of La Cotte de Saint Brelade is
316 not to demonstrate the existence of a well-established stratigraphy but rather to show that it
317 existed “warmer” phases during the very cold Late Saalian episode. This type of large
318 climatic contrasts is usually impossible to estimate with the mere presence of mollusc taxa
319 which are more sensible to moisture than to temperature differences.

320

321 Fig. 5 here

322

323 This part of the stratigraphy of La Cotte de Saint Brelade is suspect to some archaeologists
324 working in Northern Brittany. They consider that oaks and other deciduous trees could not
325 survive in Jersey during the Upper Saalian (Y. Chantreau, oral communication). They
326 consider that the discovery of oak and pollens of deciduous trees may result from a
327 sedimentary pollution originating in the overlying Eemian. In the absence of a definitive
328 conclusion, we must keep in mind that the different ingressions coming from the Western
329 English Channel were reaching the -60 and -70 metres during the highest MIS 6 sea levels
330 (Waelbroeck et al., 2002), bringing warmer water to Jersey and Cotentin shores (Fig. 5).

331

332 **4. The offshore data (Celtic Sea)**

333

334 Over the last decades, several high resolution marine archives have been obtained at the outlet
335 of the paleoriver “Manche” allowing to reconstruct and improve the deglacial history of the
336 two last Terminations (Zaragosi et al., 2001; Mojtahid et al., 2005; Eynaud et al., 2007;
337 Penaud et al., 2009; Toucanne, et al., 2009, 2010). Amongst these marine archives, a specific
338 sedimentological pattern was associated with the retreat of the onland European glaciers, then

339 mainly routed via the paleoriver “Manche” (Toucanne et al., 2010). Actually, laminated
340 deposits attributed to high meltwater discharges have been identified coherently and
341 synchronously to each Terminations (Eynaud et al., 2007; Penaud et al., 2009). Among the
342 key sites sampled on the Celtic margin, cores MD 03-2692 represents the most complete
343 record, registering systematic laminae deposits well stratigraphically constrained.

344

345 4.1. Core MD 03-2962

346

347 Core MD 03-2962 was retrieved at the western side of the Trevelyan escarpment (northern
348 Bay of Biscay) (Fig. 1) at 4064 m water-depth during the SEDICAR cruise on-board the RV
349 Marion Dufresne II. This long hemi pelagic core nearly 40 meters long covers the last 360 ka
350 (Mojtahid et al., 2005). The stratigraphy of this core was established thanks to a direct
351 comparison with the SPECMAP stable $\delta^{18}\text{O}$ record. For this paper the possibility of updating
352 the MIS 6/MIS 5 section by comparisons with the LR04 age model (Lisiecki and Raymo,
353 2005) could have been proposed but no revision was made because of the good coherency
354 obtained when comparing with the ages of the SPECMAP/ LR04 references records (Fig. 6).

355

356 Fig. 6 here

357

358 - Main characteristics of the Upper Saalian section of MD 03-2692 core

359

360 This section located between 2000 and 2900 cm in the core, comprises a thick interval of
361 laminated sediments spreading over 150 cm and corresponding to the Upper Saalian / Eemian
362 transition. These laminae actually correspond to the onset of the European ice-sheet
363 penultimate deglaciation and coincide with the first insolation maxima (Eynaud et al., 2007;
364 Penaud et al., 2009) marking the Termination 2 inception. They were synchronous to/or
365 ended a drastic cooling event at the sea-surface of the Bay of Biscay as testified by the nearly
366 monospecific abundances of the polar taxa *Neogloboquadrina pachyderma* (sensu stricto. i.e.
367 sinistral form *Nps*) at that time. Following their occurrence, a progressive warming which
368 preceded the MIS 6/MIS 5 interglacial shift can be observed. It is however interrupted by
369 various transient laminae/ *Nps* events, the later and most pronounced of them being
370 assimilated to the Zeifen-Kattegate climatic oscillation (Seidenkrantz et al., 1996; McManus
371 et al., 2002).

372 Age models of the studied cores have been established on the basis of AMS 14C

373 dates between 0 and 30 ka. Radiocarbon ages were calibrated to calendar years before present
374 (yr BP) using the CALIB programme (version 5.1.0 with the MARINE 04 data set). Beyond
375 that age range, the stratigraphy has been constrained by stable isotope and carbonate content
376 measurements which were tied to the SPECMAP delta ¹⁸O reference curve (Martinson et al.,
377 1987). The software used for this peak to peak correlation was the “AnalySeries” software
378 (Paillard et al., 1993). Stable isotope carbonate, and light reflectance records obtained on
379 closely related sequences were used to valid the obtained stratigraphy at a regional scale
380 (see Mojtahid et al., 2005; Eynaud et al., 2007 for methodological details).

381 The synchronicities of laminae deposits and of *Nps* excursions in the MD 03-2692 record
382 suggest important local advections of melt waters coming mainly from the proximal British-
383 Irish Ice sheet which was waning at that time. The nearly monospecific values of *Nps* could
384 be, at a first glance, considered as resulting from a southward migration of the polar front over
385 the Celtic margin (Eynaud et al., 2009) and thus related to freezing sea-surface conditions
386 (less than 10°C) in summer. However these fauna excursions occurred concomitantly with
387 large amounts of melt water associated with positive sea-level changes, which support the
388 existence of local “warmings”, which could have mitigated the continental temperatures
389 inland (Mojtahid et al., 2005; Eynaud et al., 2007).

390

391 **5. Methodology**

392

393 *5.1. Normalization of data*

394

395 Onshore, the studied sites are characterized by Upper Saalian formations of different
396 thicknesses. Field studies show that there are no major gaps or erosion during their deposition
397 except in Jersey, which will not be incorporated in our comparison for this reason. In order to
398 better compare the different malacological and sedimentological (laminae) signals their
399 thicknesses have been normalized. The normalization assumes a constant thickness between
400 the upper and lower Upper Saalian limits. It is responsible for a deformation of the
401 wavelength of the original signals but is necessary if we want to check the possible
402 simultaneity of the main malacological pulses respect with the upper and lower limits of the
403 Late Saalian. Because this normalization does not change the amplitude of the original signal,
404 but only its wavelength, we can observe that the malacological production of the Late Saalian
405 of Nantois is far better developed than that observed in Villiers-Adam (Fig. 7). This higher

406 malacological production also corresponds with a site which was closer to the Late Saalian
407 limits of the sea, Villiers-Adam being more continental (Fig.1). The accuracy of the
408 correlations that will be now proposed depends on the precision of the measure of the
409 thicknesses of the sampled layers. Errors will be very limited if the thickness of the
410 considered section is close to the normalization module (Nantois site) but can be a little bit
411 larger if we are dealing with a section showing a compress stratigraphy like in Villiers-Adam.
412 After normalization of the onshore data all the sections have been fitted to the offshore Upper
413 Saalian limits in order to display a regional pattern of the warming events typical of MIS 6 in
414 westernmost Europe.

415

416 5.2. Tentative dating of the warming episodes

417

418 Because all the ages previously calculated for Villiers-Adam site have been discarded (Locht
419 et al., 2003) we will first only correlate the offshore and Nantois “warming” episodes.

420 - The “limon à doublets” of Nantois (Monnier et al., 1997; Danukalova et al., 2017)) and the
421 younger group of offshore “laminae” (Eynaud et al., 2007) have been both attributed to the
422 Zeifen-Linexert Interstadial (Seidenkrantz et al., 1996) known in many places in the Northern
423 Hemisphere. They both correspond with the youngest “warming phase” followed by a short
424 cooling phase which just predate the Eemian episode. It is, thus, its stratigraphical position
425 which helps to attribute an age to this climatic improvement. An age close to 140 ka was
426 adopted both onshore (Van Vliet-Lanoë and Guillocheau, 1995) and offshore (Eynaud et al.,
427 2009).

428 - The US-ESR measurement of a bone of *Bos primigenus* extracted from the boundary
429 between a loessy head and the loess formation (corresponding to layer 35 on figure 2A or to
430 the upper part of layer 4 on figure 2B), superimposed to the base of the second “warming”
431 episode of Nantois, delivered an age of 166 ± 8 ka (US-ESR by Bahain et al., 2012). This
432 “warming episode” also corresponds to the penultimate group of “laminae” of core MD 03-
433 2692 dated at around 164 ka by SPECMAP $\delta^{18}\text{O}$ benthic record (Eynaud et al., 2007).

434 - In between, there is no onshore criterion to date the overlying “warming” episode “(Fig. 7:
435 c) but it is perfectly in line with the largest group of “laminae” dated offshore at around 148
436 ka by SPECMAP (Eynaud et al., 2007). This prominent offshore “warming” signal was also
437 contemporaneous with the largest group of *Neogloboquadrina pachyderma* which was
438 associated with an active icebergs melting (Eynaud et al., 2009).

439 - At last, there is no onshore data to date the oldest “warming” phase which can be dated at
440 around 182 ka after SPECMAP data (Eynaud et al., 2007).

441

442 Fig. 7 here

443

444 *5.3. Correlation between biological and sedimentological data*

445

446 The methodology to locate the biological and sedimentological peaks and the technique used
447 to delineate the “warming” stripes must be clearly separated:

448 a/ The location of the different peaks is the direct result of the shells and laminae numbering.

449 Their location is perfectly determined respect with the upper and lower stratigraphical limits
450 recognized during the field study (they correspond with the intra-Saalian-Upper Saalian
451 boundary and with the Upper Saalian-Eemian contact). Two of these peaks have been dated at
452 140 and 166 ka by direct (“warming” b) or indirect (“warming” d) dating and by offshore
453 SPECMAP correlation. The age of the two other peaks is only known after comparison with
454 the offshore SPECMAP data (see the previous paragraph). The location of the peaks relies
455 consequently on two different types of information.

456 b/ The “warming” signals are different in nature, wavelength and shape and there is no
457 possible common rule to draw the “warming” stripes summarizing the regional climatic
458 changes. These correlations are only based on a visual system. Because this system is not
459 based on any calculation, the upper and lower boundaries of the “warming” stripes may not be
460 totally accurate. However, the correlations adopted for this publication, are strengthened by the
461 excellent fits which can be observed with the Late Saalian “warming” episodes recognized in
462 the Batajnica cliff (Serbia) (Osipova et al., 2013) and with the variations of the sea surface
463 temperatures recorded in the North Atlantic core M23414 (Kandiano, 2002).

464

465 *5.4. Correlations at the global scale*

466

467 The increasing production of shells from East to West (Fig. 7) during relatively short periods
468 suggests a possible influence of the sea. This gradient can be either attributed to the
469 modification of the North Atlantic thermo-haline circulation since the course of the Gulf
470 Stream changed as a function of the position of the Polar Front (Mörner, 1996). But it can be
471 also associated with the existence of short-living marine invasions of the palaeo-Manche
472 system (palaeo-English Channel) during abrupt and short ice melting phases (Fig. 5). It is the

473 reason why the contemporaneous variations of the sea level have been checked. Figures 8b
474 and c show the evolution of the sea level during this episode (Waelbroeck et al., 2002). This
475 curve, based on the oxygen isotopic ratios of the benthic foraminifera sampled in the North
476 Atlantic and equatorial Ocean, was completed by the data of Shackleton (1987) which display
477 more details for the recent geological periods (see the green curve).

478

479 Fig. 8 here

480

481 Figures 8a and c clearly show that the “warming” episodes occurred at the same time as the
482 four positive oscillations of the Late Saalian Sea. This correlation is confirmed by the
483 evolution of the temperatures recorded in EPICA and VOSTOK boreholes (Berruyer, 2013)
484 (Fig. 8d). We completed these figures with the $\delta^{18}\text{O}$ values measured in the MD 03-2692
485 offshore Celtic Sea core, which visually strengthen the proposed correlations (upper part of
486 Fig. 8 a and b).

487

488 *5.5. Correlations with the astronomical cycles*

489

490 Correlations between the four Late Saalian “warming” episodes and the astronomical
491 parameters recognized by Milankovitch (1904) reveal a reasonable fit with most of the data.
492 However, for a better precision, the correlations were made with the variations of the
493 astronomical cycles calculated by Berger and Loutre (1991) showing their impact on the
494 boreal hemisphere insolation (July insolation at 15 and 65°N). The most recent “warming”
495 (Fig. 9: d) perfectly fits with a precession maximum and a minimum insolation. Warming c
496 can be correlated with an insolation maximum and a precession minimum (Fig. 9: c).
497 “Warming” b displays the same characteristics as warming d (Fig. 9: b). At last, warming a
498 does not fit with any major astronomic signal but corresponds with the mid-amplitude of a
499 positive insolation phase and with the mid-amplitude of a precession maximum (Fig. 9: a).
500 The addition of the effects of both signals being probably responsible for the first warming
501 episode observed during the Late Saalian climatic oscillations. These correlations are still
502 valid even if we take account of the small uncertainties attached to the upper and lower limits
503 of the “warming” episodes since the wavelengths of the insolation and of the precession
504 cycles are much larger than these uncertainties.

505

506 Fig. 9 here

507

508 **6. Scientific results**

509

510 Taken as a whole, sedimentary and biological markers permitted to recognize four phases of
511 low “warming” during MIS 6. These “warming” episodes were contemporaneous with four
512 positive variations of the sea level and with four variations of the astronomical cycles.
513 Indirect (“*limon à doublets*”) and direct (US-ESR) dating permitted to correlate two of these
514 episodes with the offshore stratigraphy characterized by clear evidences of contemporaneous
515 ice melting. This discovery was the opportunity to check the hypothesis of a possible
516 relationship between the irregular dwelling of Neanderthals in Brittany and the short climatic
517 improvements.

518

519 **7. Discussion**

520

521 This short discussion will be devoted to the possible relationship between the irregular
522 dwelling of Neanderthals in Brittany and the short MIS 6 climatic improvements.

523

524 *7.1. Compilation of Neanderthals sites*

525

526 Three main Neanderthal sites are now dated in Brittany; they are all located in Northern
527 Brittany close to Nantois cliff (Fig. 5).

528 - The Nantois site is a typical Palaeolithic site corresponding to a hunting rest area that
529 evidences well preserved cut up remnants. The archaeological layer (layer 35, Fig. 2A)
530 located 20 m below the Eemian paleosoil delivered few Mousterian artefacts and a bovid bone
531 (Monnier, 1986). Clear stratigraphic similarities with nearby sites where radiometric dating
532 has been carried out (Bahain et al., 2012), confirm the general chronostratigraphic scheme
533 previously suggested on the basis of field observations and major stratigraphic landmarks
534 (Monnier et al., 2011). Recent measurements show that layer 35 can be dated at 166 ± 8 ka
535 (Bahain et al., 2012).

536 -The 15 m thick stratigraphic sequence of Piégu site is made of 14 layers indexed from A to N
537 from the bottom to the top. It incorporates two beach deposits (units D and H) considered as
538 remnants of high sea levels during interglacial stages (Hallégouët et al., 1993). The sequence
539 includes also an interglacial palaeosoil (unit K) and several archaeological layers (units D, F,
540 G and J) with a Mousterian lithic industry and, for some of them, paleontological remains.

541 Layer G is the main archaeological level; it corresponds to a “head” deposit (a periglacial
542 solifluxed frost shattered debris assemblage deposited during a glacial stage) (Danukalova et
543 al., 2015). This level delivered Mousterian flint flakes and a fossil fauna assemblage
544 indicating a wet temperate climate and a forested environment with local grasslands. Layer G
545 can be correlated with late MIS 7 or early MIS 6, with a quadratic mean age of 193 ± 6 ka
546 (Bahain et al., 2012). The archaeological assemblage witnesses the existence of a human
547 occupation on top of the cliff during an interglacial stage, in accordance with the
548 biochronological framework of Northern France (Auguste, 2009). The date proposed by
549 Monnier et al. (2011) for level J is confirmed by the dating results. Lastly, the Piégu’s marine
550 level H, with a quadratic mean age of 122 ± 23 ka can be attributed to Eemian (MIS 5e), by
551 US-ESR dates.

552 -The shelter-cave of Grainfollet is known for many years. It is made of two very close but
553 different units. The archaeological unit corresponds with a river shelf located at the foot of a
554 rocky cliff. On the shelf itself two remnants of fires associated with charcoals, burnt bones
555 and many artefacts have been sampled. It is not completely sure that some of the observed
556 Palaeolithic remnants have not been partly disturbed by solifluxion or by the tides (Monnier,
557 1982). The cliff is made of an alternation of loam, loess and stony levels. This area which
558 probably corresponded with a butchery was initially considered to be of Wûrm 1 age (Giot
559 and Bordes, 1955). Recent reappraisal of the cliff permitted paleo-densimetry measurement as
560 well as dating on bones and teeth (Laforge et al., 2018). Six ages were calculated, but one was
561 discarded because of the bad preservation of a tooth, they can be divided in two groups
562 ranging between 138 and 171 ka.

563

564 7.2. *Improvement of the age error bars*

565

566 Comparison between the different ages dating the MIS 6 occupation of Neanderthals in
567 Brittany evidences large error bars. These error bars are often larger than the duration of the
568 “warming” episodes. However, the ages which were finally retained for publication (Bahain
569 et al., 2012), almost always perfectly fit with the “warming” episodes. If we take account of
570 the error bars this excellent superimposition (based on 14 dated sites) is surprising. It is why
571 the error bars have been recalculated (Ludwig, 2000), not only for individual ages but also for
572 the three groups of dates showing neighbouring ages (Fig. 10). Two solutions can be
573 considered, depending on the dating techniques. It seems that the 2 sigmas solution can be
574 selected for the sites studied in northern Brittany.

575

576 Fig. 10 here

577

578 *7.3. Possible correlation between the “warming episodes” and the age of Neanderthal sites*

579

580 The left column of Fig. 10 shows the superimposition of the “warming” episodes onto the age
581 of the Neanderthal sites with no error bars. The two columns on the right side show the same
582 superimposition after recalculation of the age error bars for the three groups of neighbouring
583 ages. The two sigmas error bars are still a little bit large but we believe that the almost perfect
584 superimposition of the “warming” episodes and of the mean quadratic age of the Neanderthal
585 sites must be also considered. It is mainly because the same superimposition of data repeats
586 14 times that we suggest that Neanderthal migrations were possibly controlled by the
587 successive climatic improvements recognized during MIS 6.

588 The dated “Les vallées” site located close to Nantois cliff (Fig. 5) was not considered during
589 these correlations. This site provided ages ranging between 138 and 182 ka (138 ± 22 , $163 \pm$
590 23 and 182 ± 29 ka) on teeth (Bahain et al., 2012). Those ages which were supposed to date
591 the same stratigraphic unit correspond, after our correlations (Fig. 7), to three different
592 “warming” episodes questioning the correlations. However, a careful study of the technical
593 report concerning the excavation (Huet, 2010) arises various difficulties. The indurated sand
594 excavated for archaeology outcrops in the middle of a small plateau usually hidden under the
595 sand and the sea. The archaeological site (which investigated only 40 cm of sediment)
596 evidenced a poorly preserved horse mandible. No complete or intact bones or teeth were
597 found. All the fauna remnants were very fragmented and often soft, fragile and deeply
598 impregnated with salt. The spatial distribution of the pieces of bones evidenced the existence
599 of a clear solifluction casting. Furthermore, the archaeological site was established on a sand
600 dune which was probably more or less active at the time of its occupation by Neanderthals
601 and a general disturbance of the site was observed after this period of occupation. If we take
602 account of all these observations, we don't know if the large dispersal of the published ages is
603 a reality, was associated with the bad condition of preservation of the teeth or if it resulted
604 from the mixture of faunal pieces of different origins.

605

606 **8. General conclusions**

607

608 -Study of the frequency of loess gastropods in Brittany, of animal and vegetal fossils markers

609 of temperatures in Jersey and of the offshore laminae, permitted to recognize four short and
610 abrupt “warming” episodes during MIS 6.

611 -The contemporaneous variations of the sea level and the evolution of temperatures recorded
612 in EPICA and VOSTOK boreholes confirm the reality of the “warming” episodes found in
613 Brittany.

614 -Measurements of marine oxygen isotopes on foraminifera and on land snails currently
615 underway show that the “warming” episodes were not all characterised by the same
616 temperature.

617 -The “warming” episodes, which were responsible for an elevation of 30 to 40 metres of the
618 sea-level generated large incursions of seawater in the mid-Channel valley. These
619 incursions could have been at the origin of the development of oaks in Jersey, interrupting
620 during a short period, the cold continental tundra environment characterized by lemmings.

621 -Although the ESR/U dating of the archaeological sites, recalculated for the three main group
622 of ages, are still affected by error bars a little bit larger than the duration of the “warming”
623 episodes, we believe that their systematic association might suggest a relationship between
624 the climatic improvements and the migration of Neanderthals during MIS 6.

625

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627

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638

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819

820 Captions

821

822 Figure 1. Location of the four sites where MIS 6 sections have been recognized west of
 823 Europe. The sites are shown at the time of the maximum Late Saalian regression. LCSB: La
 824 Cotte de Saint Brelade; MD 03-2692: Celtic Sea core; N: Nantois; Va: Villiers-Adam. Black
 825 arrows: direction of the katabatic winds. Vertical ruling: British Ice Sheet.

826

827 Figure 2. Stratigraphy and frequency of the various terrestrial molluscs observed in loess of
 828 the Nantois Formation (Saalian) of Nantois site. A: Nantois cliff section: stratigraphic
 829 sequence according to Monnier (1973). Small Arabic numbers indicate the initial numbering
 830 of the lithological units. B: Re-investigated loess interval (Upper Saalian). Numbers
 831 correspond to the total land snail shells found in each sample. Symbol + indicates shells
 832 detritus found in samples. Lithology: 1: soil (A horizon); 2: soil (B horizon); 3: colluvium
 833 (angular rocky fragments) (=head); 4: loess or loess-like loam; 5: loamy sand; 6: sand; 7:
 834 basement; 8: pebble; 9: loam; 10: published age; 11: incipient soils observed on the field.
 835 Granulometry and CaCO₃ data are shown. f: limit of decalcification; g: calcareous
 836 concretions. LAD: “Limon à doublets”. The small stratigraphic differences observed between
 837 sections A and B result from the erosion of the cliff during the last 40 years. For more details
 838 see Danukalova et al., 2017.

839

840 Figure 3. A: Synthetic stratigraphic section of Villiers-Adam at Le Chamesson after Antoine
 841 in (Locht et al., 2003). B: Section sampled for malacology, reinterpreted after the data
 842 published by Limondin-Lozouet and Gauthier (2003). Numbering of the different layers by
 843 Antoine (Locht et al., 2003). Simplified caption: 1: Sandy loam; 2: Sandy and clayish loam;
 844 3: Stony and sandy layer; 4: Calcareous loess; 5: Sand; 6: Layered calcareous loess (niveo-

845 eolian sediment with small ice-drying cracks); 7: Layer number; 8: Stony and sandy layer
846 (heterometric stones association made of grindstones mixed in a brown and red clayish sand
847 matrix). The total number of each shell taxon is given for 10 kilos of sediment. Small letters
848 a₁₋₂, b₁₋₂ and c are malacozones and subzones according to Limondin-Lozouet and Gauthier
849 (2003) with authors' additions.

850
851 Figure 4: Synthetic Upper Saalian section of La Cotte de Saint Brelade (Jersey Island) taken
852 directly from Callow and Cornford (1986). Note the place of the erosion levels and the
853 alternation between “cold” and “warm” fossil remnants

854
855 Figure 5. Extension of the Western English Channel ingressions during the different MIS 6
856 “warming” episodes. The archaeological sites of Northern Brittany and Jersey are shown. Sea
857 contours after P. Stephan, IUEM Brest (slightly modified).

858
859 Figure 6. Multiproxy data measured in core MD03-2692 sampled in Celtic Sea. XRF ratio of
860 Ca/ Fe; $\delta^{18}\text{O}$ benthic record; N° of laminae /cm; CLG c.: coarse lithic grain concentrations
861 and relative frequencies (%) of the polar species *Neogloboquadrina pachyderma*. Note that
862 the comparison with the SPECMAP $\delta^{18}\text{O}$ benthic record (Martinson et al., 1987 at
863 <ftp://ftp.ncdc.noaa.gov/pub/data/paleo/paleocean/specmap>) and the LR04 $\delta^{18}\text{O}$ benthic stack
864 (Lisiecki and Raymo, 2005) underlines the robustness of the MD03-2692 age model
865 (Mojtahid et al., 2005). ZK: Zeifen-Kattegate episode.

866
867 Figure 7. Correlation between laminae and the different biological peaks recognized in the
868 Upper Saalian of Westernmost Europe; LAD: “Limon à doublets”; a, b, c, d: Correlation
869 stripes. Large numbers: Direct and indirect dating of the “warming episodes”.

870
871 Figure 8. Comparison between the four “warming” episodes that affected the Late Saalian
872 glacial stage and the contemporaneous variations of the sea level. a: Variations of the sea-
873 level during the last 450 ka after Waelbroeck et al. (2002) (black curve) completed by the
874 Shackleton's (1987) sea-level curve for the younger periods (in green), b: enlarged sketch for
875 the period of interest. $\delta^{18}\text{O}$ values measured offshore (MD 03-2692) are also shown. c:
876 Correlation between laminae and the different biological peaks shown on figure 7; LAD:
877 “Limon à doublets”. d: Evolution of temperatures recorded in EPICA and VOSTOK
878 boreholes during MIS 6. Inset: photograph of a “limon à doublets” facies.

879

880 Figure 9. Comparison between the four “warming episodes” recognized during the Late
881 Saalian and the orbital parameters computed by Berger and Loutre (1991). A: Correlation
882 between biological peaks and laminae; B: Orbital parameters.

883

884 Figure 10. Comparison between MIS 6 “warming episodes” and Neanderthal dwellings. Left
885 column: ages of the various Neanderthals sites measured in Brittany during MIS 6 (Bahain et
886 al., 2012) superimposed onto the four “warming” episodes recognized onshore with no error
887 bar. Right columns: Calculation of error bars after the ISOPLLOT software (Ludwig, 2000).

888

889 Table 1. Composition of the mollusc species recognized in the Nantois formation.

890

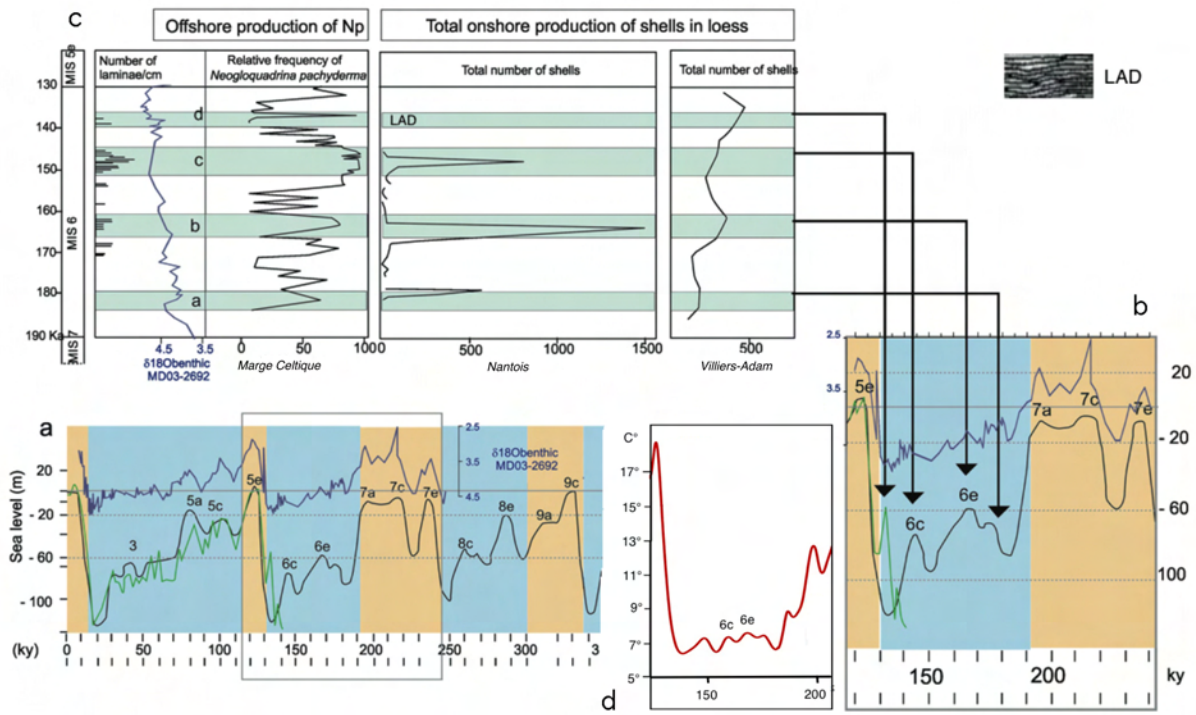
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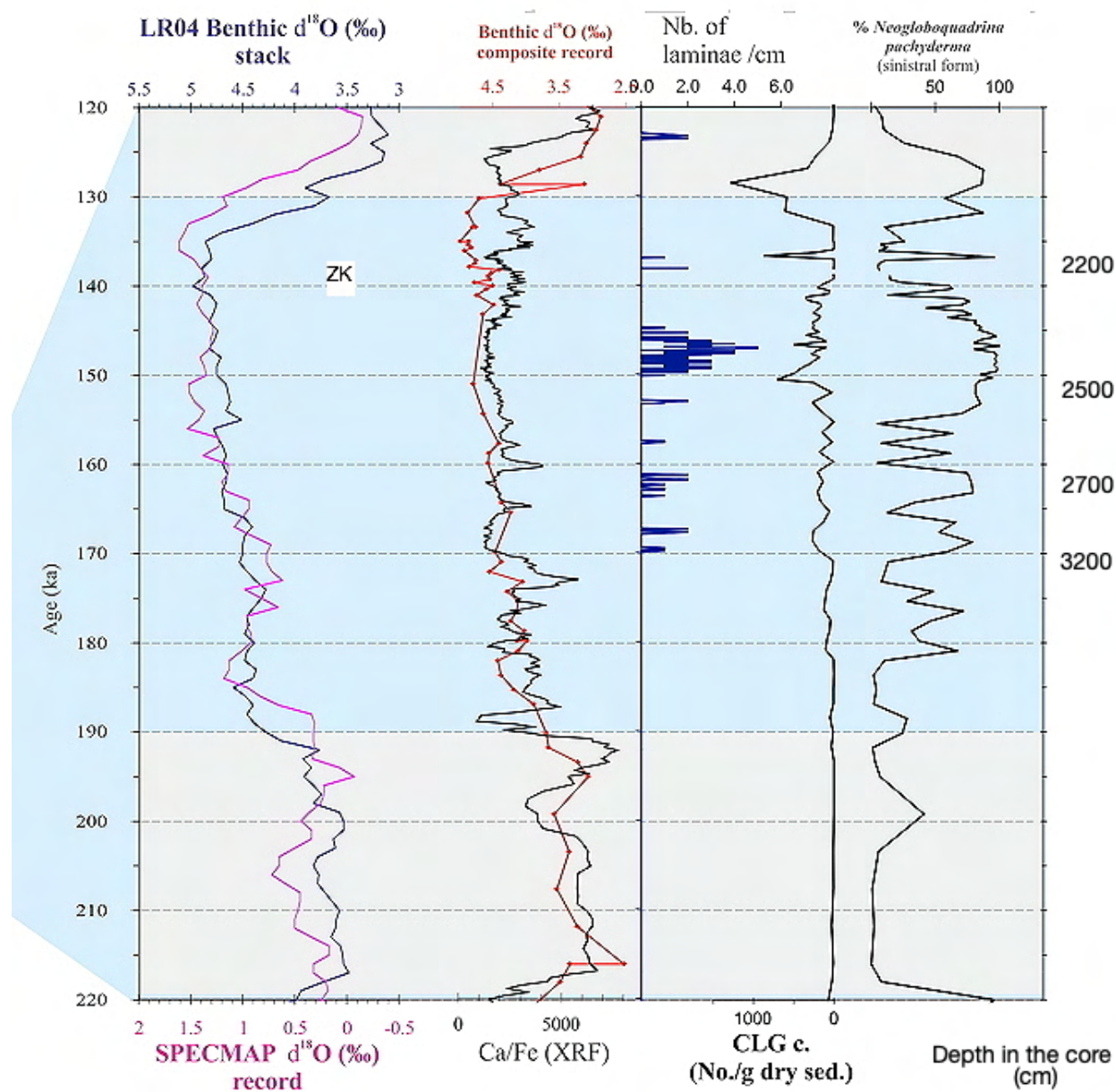
Table 1.

Registration N	Layer N	Sample N	Sampling interval, m	<i>Succinella oblonga</i> (Draparnaud, 1801)	<i>Pupilla muscorum</i> (Linnaeus, 1758)	<i>Cochlicopa lubrica</i> (Müller, 1774)	<i>Vertigo cf. alpestris</i> Alder, 1838	<i>Vallonia pulchella</i> (Müller, 1774)	Hydromiidae	<i>Limax</i> sp.	Shell detritus	Total (quantity) Determined terrestrial mollusc shells	Gastropoda (marine)	Malacozone
3728	2	1	0-0,10	-	46	-	-	-	-	2	1	48	-	1
3729		2	0,10-0,20	-	-	-	-	-	-	-	8	0	-	
3730		3	0,20-0,30	-	1	-	-	-	-	-	-	168	1	
3731	3	4	0,30-0,40	-	-	-	-	-	-	-	65	0	-	
3732		5	0,40-0,50	-	1	-	-	-	-	-	130	1	3	
3733	4	6	0,50-0,60	-	5	-	-	-	-	-	29	5	3 juv.	
3734		7	0,60-0,70	-	1	-	-	-	-	-	46	1	1	
3735		8	0,70-0,80	-	4	-	-	-	-	-	28	4	5	
3736		9	0,80-0,90	-	5	-	-	-	-	-	29	5	2	
3737		10	0,90-1,00	-	5	-	-	-	-	-	+	5	-	
3738		11	1,00-1,10	-	9	-	-	-	-	-	13	9	1	2
3739		12	1,10-1,20	-	53	1	-	-	-	-	42	54	2	
3740	13	1,20-1,30	-	148	-	1	-	-	-	1	12	150	-	
3741	14	1,30-1,40	-	2	-	-	-	-	1 juv.	-	30	3	-	
3742	15	1,40-1,50	-	-	-	-	-	-	-	-	228	0	-	3
3743	16	1,50-1,60	-	-	-	-	-	-	-	-	82	0	-	
3744	17	1,60-1,70	-	-	-	-	-	-	-	-	102	0	-	
3745	5	18	1,70-1,80	-	1	-	-	-	-	-	246	1	3	
3746		19	1,80-1,90	-	-	-	-	-	-	-	39	0	-	
3747		20	1,90-2,00	-	3	-	-	-	-	-	86	3	-	
3748		21	2,00-2,10	-	1	-	-	-	-	-	39	1	-	
3749		22	2,10-2,20	-	2	-	-	-	-	-	6	2	-	
3750		23	2,20-2,30	-	-	-	-	-	-	-	10	0	-	
3751	6	24	2,30-2,40	-	-	-	-	-	-	7	0	1		
3752	7	25	2,40-2,50	-	3	-	-	-	-	-	53	3	1	4
3753		26	2,50-2,60	-	1	-	-	-	1 juv.	-	5	2	-	
3754	8	27	2,60-2,70	-	2	-	-	1	-	-	2	3	-	
3755		28	2,70-2,80	-	7	-	-	-	2 juv.	-	80	9	6	
3756		29	2,80-2,90	-	55	-	-	6	19	1	390	81	-	
3757	9	30	2,90-3,00	1	5	-	-	-	-	-	48	6	-	5
		31	3,00-3,10	-	-	-	-	-	-	-	-	-	-	
3758		32	3,10-3,20	-	-	-	-	-	-	-	2	0	-	
		33	3,20-3,30	-	-	-	-	-	-	-	-	-	-	
		34	3,30-3,40	-	-	-	-	-	-	-	-	-	-	
		35	3,40-3,50	-	-	-	-	-	-	-	-	-	-	
3759		36	3,50-3,60	-	-	-	-	-	-	-	2	0	-	
		37	3,60-3,70	-	-	-	-	-	-	-	-	-	-	
		38	3,70-3,80	-	-	-	-	-	-	-	-	-	-	
	10	39	3,80-3,90	-	-	-	-	-	-	-	-	-	-	
		40	3,90-4,00	-	-	-	-	-	-	-	-	-	-	
		41	4,00-4,10	-	-	-	-	-	-	-	-	-	-	
		42	4,10-4,20	-	-	-	-	-	-	-	-	-	-	
		43	4,20-4,30	-	-	-	-	-	-	-	-	-	-	
		44	4,30-4,40	-	-	-	-	-	-	-	-	-	-	
		45	4,40-4,50	-	-	-	-	-	-	-	-	-	-	
		46	4,50-4,60	-	-	-	-	-	-	-	-	-	-	
		47	4,60-4,70	-	-	-	-	-	-	-	-	-	-	
		48	4,70-4,80	-	-	-	-	-	-	-	-	-	-	
		49	4,80-4,90	-	-	-	-	-	-	-	-	-	-	
			Total	1	360	1	1	7	23	4	2038	397	44	

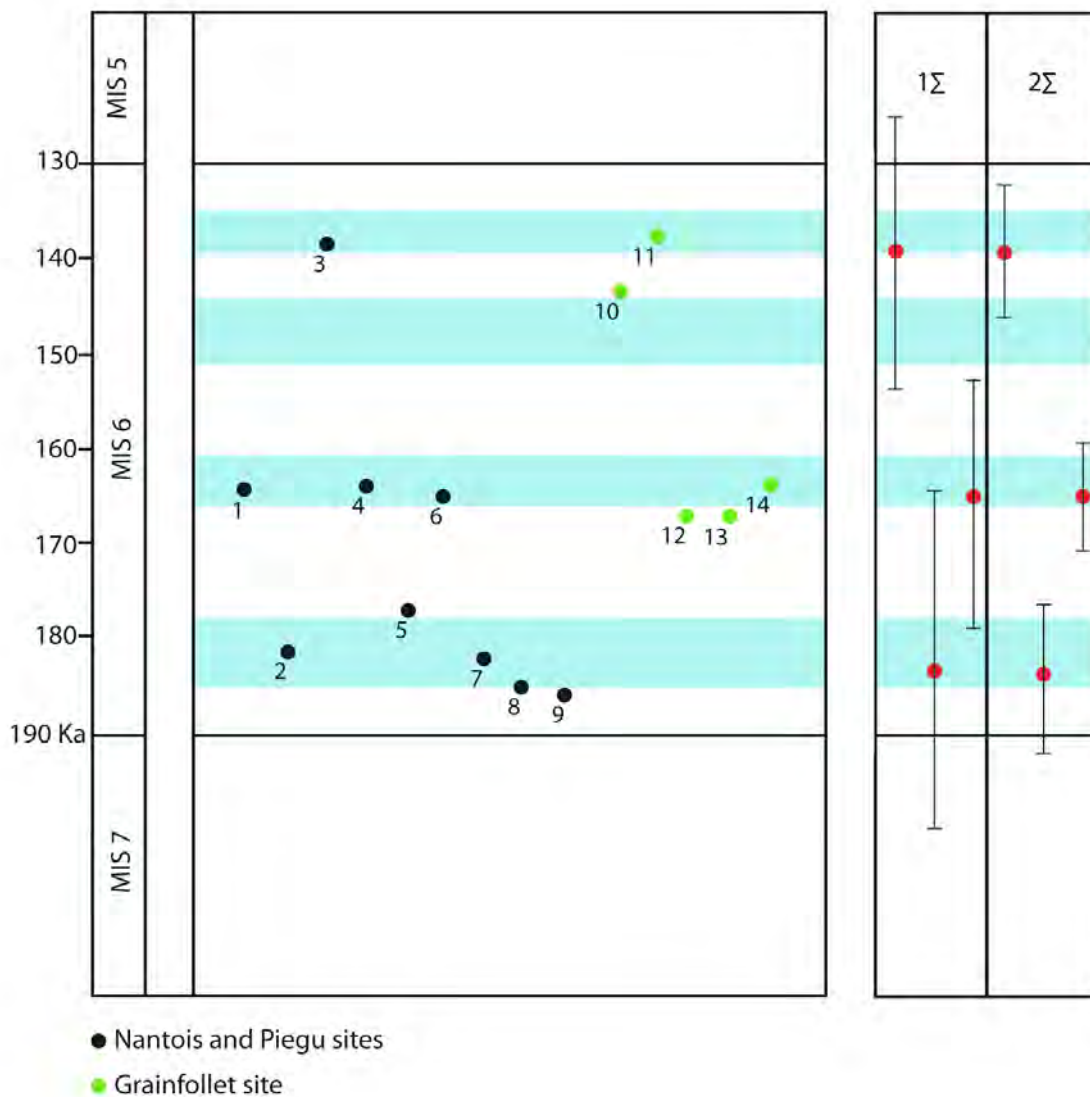
Legend: + – shell fragments (size less than 1 mm); juv. – juvenile mollusc shell

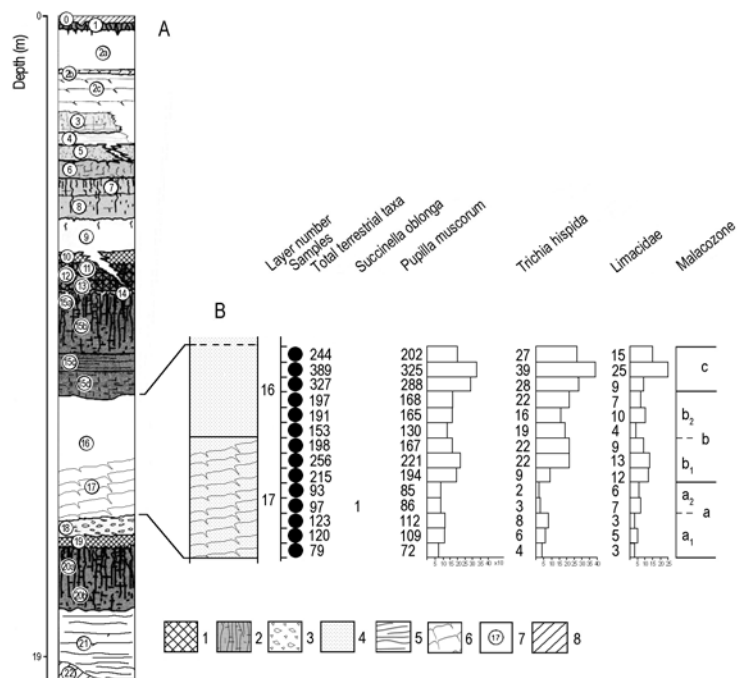


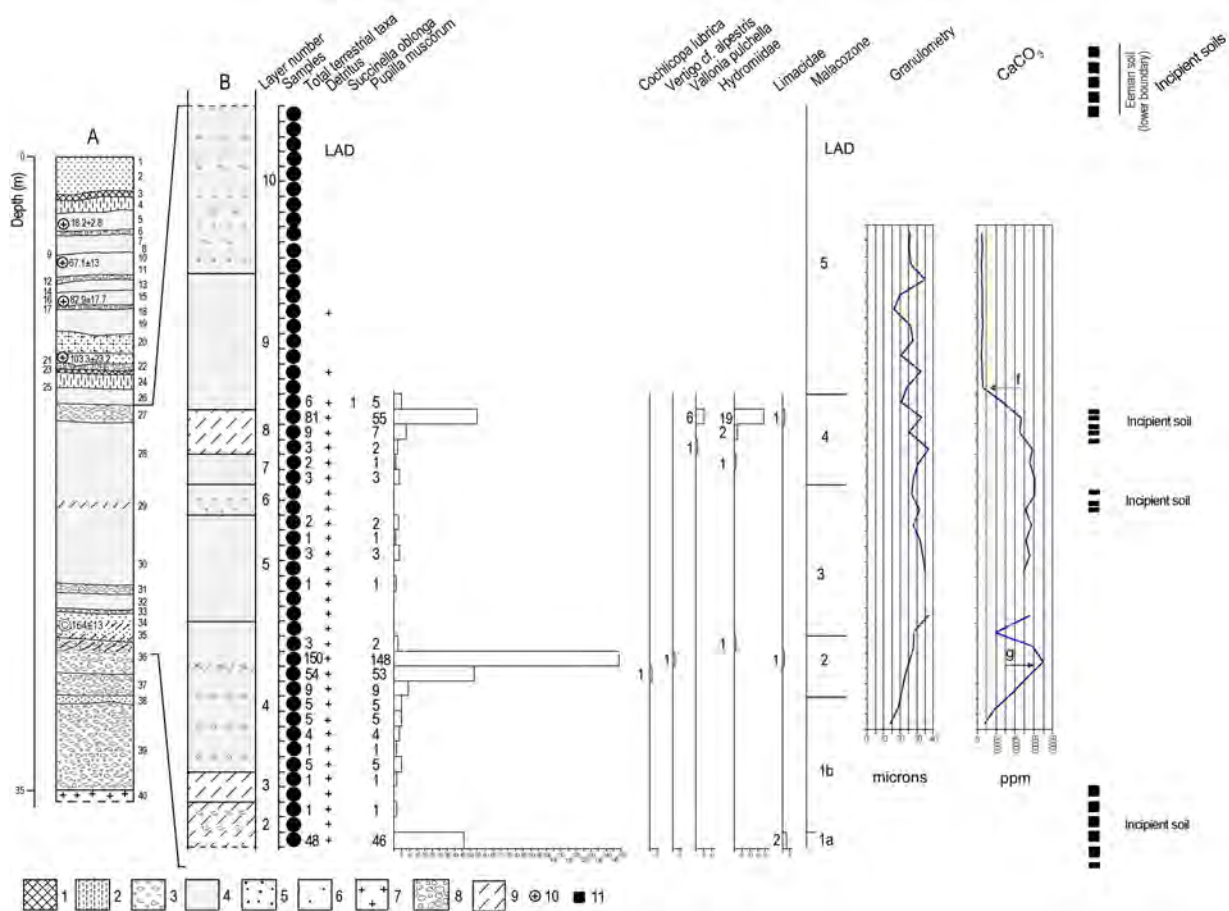
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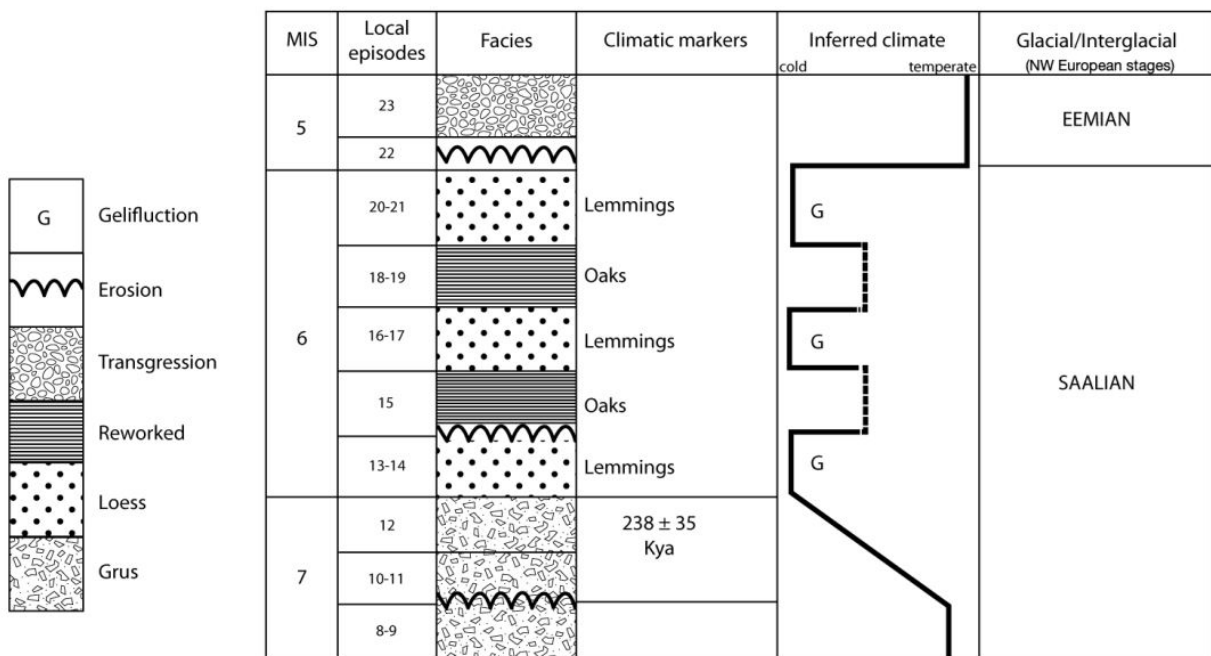


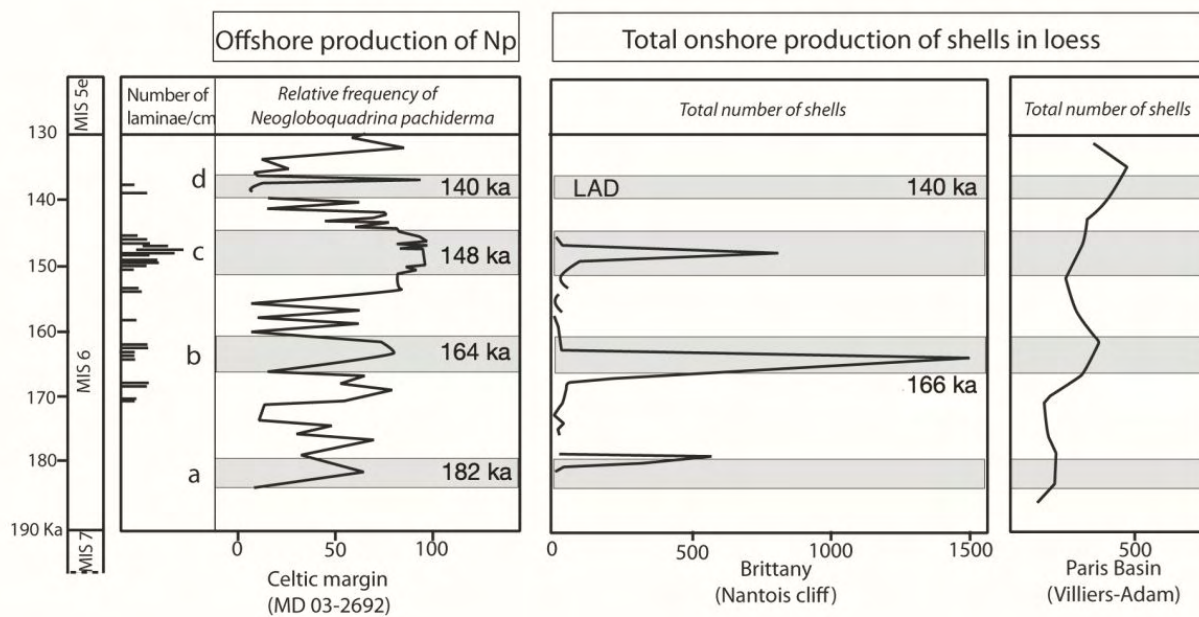


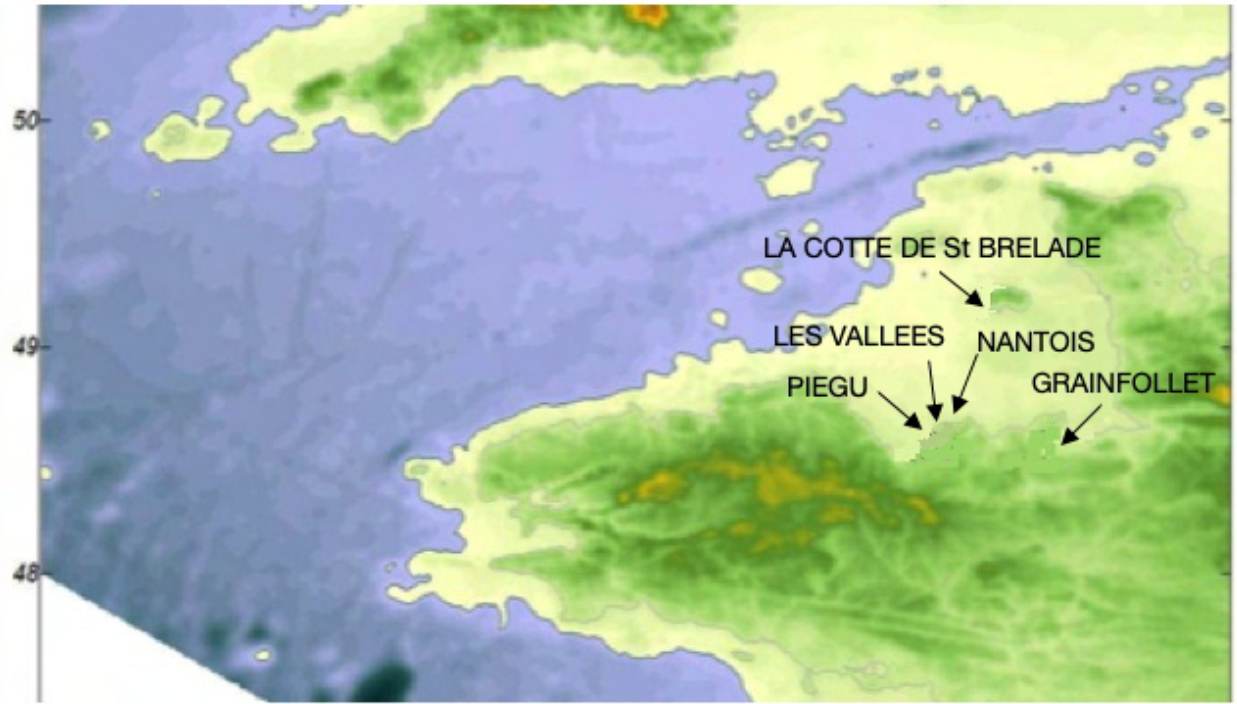




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