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IMPACT OF KATABATIC WINDS ON THE ENVIRONMENT OF NEANDERTHALS DURING THE MIDDLE PALAEO-LITHIC IN WESTERNMOST EUROPE

Running title: Katabatic winds and Neanderthals

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ABSTRACT

Compilation of the offshore and onshore altitudinal limits of the loess deposits of western France and southern England shows that they were deposited by low-level wind fields. These relate to (1) the deflation of silt-rich sediment extracted from the outwash plains of the not far distant British-Irish Ice Sheet and from the palaeo-rivers of the Channel, (2) the existence of north and north-western palaeo-winds deduced from particle size analysis and heavy mineral distribution and suggest (3) that loess particles were transported by strong katabatic winds blowing from the northern ice-covered regions towards Brittany and Normandy. Comparison between the main orientation of Neanderthal shelters and the direction of the katabatic winds shows that they were perpendicular to each other. The

dominant orientation of the shelters was apparently ruled by these winds. A small-scale study concentrating on the penultimate glaciation shows that [in contrast](#) to Brittany and Normandy where loess deposits accumulated on north facing cliffs, in England the same particles were deposited on the leeward side of the hills. The existence of deflation zones, violently swept by MIS 6 katabatic winds south of the British-Irish ice sheet, was probably at the origin of the restricted number of Neanderthals at that time in England.

Keywords: Pleistocene loess, Brittany, British-Irish Ice Sheet, Katabatic winds, Neanderthal shelters.

Introduction

More information is now coming out on the living conditions of the Middle and Late Pleistocene hunter-gatherers in westernmost Europe. However, the recent highlighting of the existence of katabatic winds during their movements into and around Brittany and Normandy complicates the migration schemes formerly established. We must now consider the different solutions Neanderthals developed to survive the strong and cold winds they endured during the more extreme episodes. In Brittany it has been known for a long time that the discontinuous occupation of Neanderthals resulted from climatic changes and it was speculated that these discontinuities reflected the main glacial-interglacial alternations (Monnier 1980, 1982, 2006). A big step was made when it was understood that [such](#) discontinuities also occurred during the short climatic improvements that occurred within the different glacial episodes (Lefort et al., 2019a). During these particular periods, a small climatic deterioration of the climate, usually limited to a few degrees, was enough to trigger strong katabatic winds confronting Neanderthals enjoying acceptable living conditions with fairly severe northern conditions. The present paper aims to compare the palaeoclimatic and archaeological information in order to

better understand how these populations responded to these critical episodes.

Regional background and Previous Research

Two main conceptual models are currently proposed to explain the transport and deposition of loess particles during the Pleistocene in Brittany and Normandy. One favours the existence of an eastward drift of periodic storms passing over the Western English Channel (Antoine et al., 2009) while another involves a long-standing eastward atmospheric circulation above Western Europe (Sima et al., 2009; Rousseau et al., 2011). Other models, summarized in Renssen et al. (2007), have also been published for Western Europe but they describe areas found east of our region of interest and are located at a greater distance from the Celtic ice mass and from the British-Irish Ice Sheet. All these models only considered 2D wind fields.

Since a wind field corresponds with a physical volume it must be studied in three dimensions (3D) and not just in two dimensions (2D). This approach is an entirely new one **when** compared to the former models. In the present review the physical parameters used in the study by Lefort et al. (2019b) will only be summarised; details of this study can be found in the full article. The original extent of the loess deposits and the altitudes of their lowest and highest boundaries in Brittany and western Normandy **are** a key point since it is the only way into calculating the thickness of the low-level palaeo-wind field that transported these particles (Figure 1a). A discussion **of** the original extent of the loess deposits in westernmost Europe must incorporate both the onshore and offshore regions (Lefort et al., 2019a). This is particularly important because the Channel was mostly exposed as a result of low sea-stand levels during the processes of subaerial loess accumulation in both the present off- and on-shore areas. The relationship between these two phenomena is discussed at length in Danukalova and Lefort (2009).

Because the previous offshore loess deposits no longer exist on the bottom of the sea, having been washed out during the various Pleistocene

transgressive episodes, their initial extent can only be recognized thanks to the existence of remnant cemented conglomerates that formed at their base (Lefort et al., 2019b).

In spite of the most recent and intense mapping surveys no loess outcrops south of the Brittany and Normandy hills have been found (Figure 1c). Re-evaluation of previous studies reveals that the absence of loess in the southern part of Brittany was not the result of recent erosion and it is possible to show that the original loess limits are still more or less identifiable.

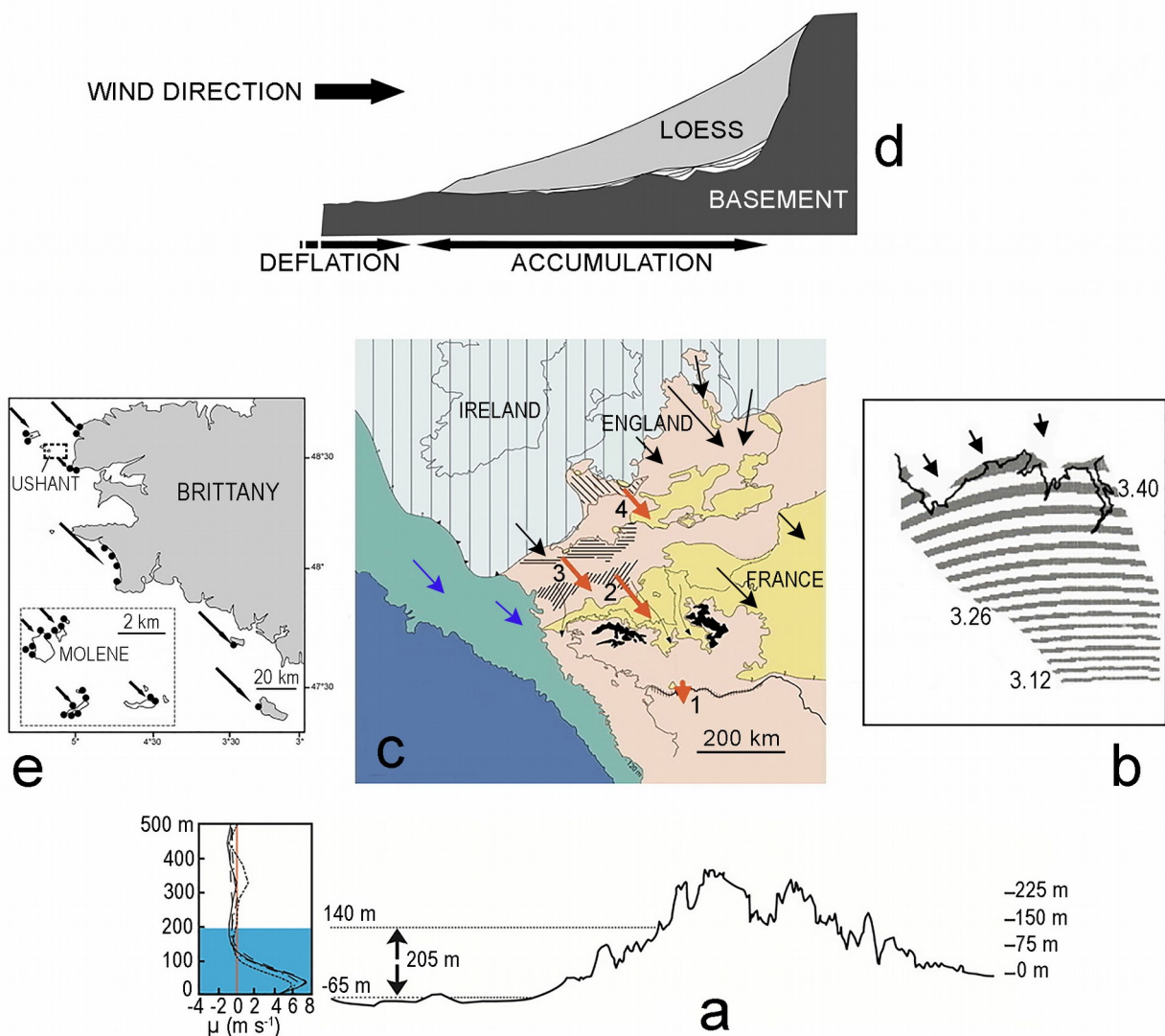


Fig. 1.

Direction and propagation of the katabatic winds

Various criteria can be put forward to identify the blowing direction of the wind-field responsible for loess transport in westernmost Europe [during the Upper Saalian and the Weichselian](#):

- The provenance of loess in Brittany, Normandy and Northern France and the associated wind directions has long been a scientific issue. 97 samples [of a series](#) taken from the youngest loess of N Brittany were studied (Bigot, 1986). Because the variation in altitude always influences the ratio of mean grain size, the methodology of Hodder and Orton (1976) has been preferred. The results of the final calculation have been used to draw a gradient map, which indicates that the wind [transporting](#) the loess particles was coming from the [north](#) or the [northwest](#) (Figure 1b).
- Most of the Weichselian loess studied in Brittany and Normandy [is](#) characterized by a malacofauna rich in *Pupilla muscorum* (Danukalova et al., 2017). It is also sometimes possible to observe the presence of coccoliths or foraminifera in the same loess formations. Because these latter [marine](#) faunas never existed in Brittany, it is possible to infer that these very small calcareous shells were extracted from Cretaceous or Tertiary outcrops known in the western Channel (Lefort, 1978). This suggests a southward or southwestward transport of these shells.
- The results obtained by geochemical analysis (Gallet, 1997) on Weichselian loess show that the major elements contained in these deposits experienced at least one cycle of sedimentary differentiation before reaching the French side of the Channel. Rare Earth Elements data are important since they suggest that the origin of the onshore loess deposits was in pre-existing muddy sediments such as the fluvial terraces of the Seine and the Channel Rivers (Lericolais, 2007) which implies the existence of a south-easterly or southward transportation of dust particles.
- In addition to the broad study of the heavy minerals [from](#) 141 sites collected in the western Channel (Duplaix and Boillot, 1968), the results of the study of the heavy and silt minerals undertaken in more restricted zones have been compiled and reinterpreted (Figure 1c).

The study of the garnets between the mid-Channel, where this mineral accumulated [as likely](#) fluvial placers, and N Brittany shows that the garnet rich sands do not reach the shore (Duplaix and Boillot, 1968). This observation suggests that the many garnets found in the loess of N Brittany were not coming from the nearby continental shelf (Lefort et al., 2011) but were transported by winds coming from the [north](#) or [northwest](#) over a distance of about 90 kilometres before reaching the Brittany cliffs (2, Fig. 1c).

Calculation of the offshore global percentage of anatase shows that this mineral is relatively rare in the Western Channel and always of a small size. In the [Fosse de l'Île Vierge](#), the concentration of dredged anatases is about the same, but they are always of a larger size (up to 0.31 and 0.5 millimetres). This size is equivalent to the size of the crystals of anatase collected in the altered offshore Permo-Triassic outcrops located along the southern margin of Wales and Cornwall (Duplaix and Boillot, 1968). The presence of larger anatase in the deep [Fosse de l'Île Vierge](#) suggests a minimum south-eastward transportation of 110 kilometres (3, Fig.1c).

The source of augites found North of Vendée originates in the stock of augites and olivines [found](#) at the foot of the Massif Central volcanoes located over 700 kilometres to the southeast (Ters et al., 1968) and transported by the Loire River. This finding suggests a short displacement, probably shorter than 6 to 8 kilometres of this mineral towards the south, since there are no augites in the Brittany sediments (1, Fig. 1c).

The region located between the Bristol Channel and Cornwall possesses well-developed silty assemblages. Studies of the Cornish loess suggest that part of the sheet silicates were coming from the Irish Sea (Catt and Staines, 1982), the other part originating in the North Sea. The extensive Late Devensian outwash deposits which extended up to the Irish Sea basin represent a likely source for most of the loess of Cornwall. The origin of chlorites, which were deposited in Swansea Bay clearly show the onshore and local origin of these particles that often exceed 25% of the total amount of the heavy mineral suite in many estuaries (Barrie, 1980). If we exclude a

small part of these minerals coming from the East, this marker suggests a southward or south-eastward migration for the sheet silicates (4, Fig.1c).

The main interest of the study of the heavy minerals is in showing that there is a northward increase in the distances of transit of the selected heavy minerals between the Loire River and southern England. The transit of augite was between 6 and 8 kilometres, that of garnet was about 90 kilometres, while it was of 110 to 120 kilometres for anatase and close to 150 kilometres for most of the flaky minerals. The southward decreasing distances of transportation of the heavy and other minerals is interpreted as being related to decreasing strength of the katabatic winds.

- Thick loess deposits coat most of the north or northwest-facing basement cliffs in Brittany (Figure 1d). These cliffs acted like dust collectors (windbreaks) when the wind was blowing from the north (Lautridou, 1985) or the northwest (Danukalova et al., 2013). In this province the north facing basement cliffs always collected more loess than the other orientations and the south, west and east-facing cliffs appear to be always free or very poor in loess deposits (Monnier, 1973). The same preferential accumulations have been also observed in northern France and Belgium (Antoine, 2002). The case of the Jersey and Guernsey cliffs which represent a peculiar distribution of the loess deposits will be discussed separately.

- Many basaltic boulders can be collected on the Ushant (Lefort, 2016) and Molène Island beaches (Figure 1e) as well as along the west facing coast of Brittany (Chauris and Hallégouët, 1989). Because these rocks are unknown offshore (Lefort, 1975) and in western France, they have always been considered as “exotic” (Brousse et al., 1972). The presence of basalts is interesting because their ages range between 3.6 and 1 Ma and are similar to the ages measured on olivine basalts in Iceland, which suggest an Icelandic origin since there is no volcanism of the same age known around the North Atlantic. The movement of the ice rafts (Figure 1c) suggests that the winds blew generally from Iceland towards the southeast.

- Many unusual micro-granites, red granites and other “exotic” pebbles have also been found in the Ushant archipelago, on the island of Groix and in Audierne bay (Figure 1e). In these areas, basalts, trachy-andesites and

“exotic” boulders always accumulated in north or north-westerly oriented bays and seacoasts. It is now widely accepted that all these rocks were transported by ice rafts during Pleistocene time (Brousse et al., 1972; Hallégouët and Van Vliet-Lanoë, 1989). The facing orientation of the onshore dust traps and of the beaches ending up with the “exotic” boulders is consequently almost the same.

In summary, cold katabatic winds were generated by the British-Irish ice sheet and propagated over long distances at a very low altitude ranging up to between 170 and 220 metres and transporting thick clouds of loess particles (Lefort et al., 2019b). The only information which cannot be extracted from the field data is that they were able to reach a velocity of 300 km/h and above (Parish and Cassano, 2003). Because of the unique orientation of the dust traps in Brittany we infer that the katabatic wind field was characterized by an almost constant direction.

The archaeological data

During the cold Pleistocene periods, the first peoples that moved to westernmost Europe probably had to endure the effects of the katabatic winds from time to time. If we consider the general direction of the shoreline south of the Channel we can infer that most of the possible cliff-shelters were open to the north with very few facing south (Figure 1c); this is why it was interesting to study the Lower and Middle Palaeolithic sites which are well represented in northern Brittany (Monnier, 2006; Monnier et al. 2016) (Figure 2). Before discussing their orientations it is important to note that Brittany has only basement rocks such as granites, sandstones or schist and that limestones are very rare and thus that karsts and true caves are absent from the studied area. As a consequence, Neanderthals were faced with hard rock accumulations, steep slopes and granitic or loess cliffs to protect themselves from the elements.

The distribution of the Lower and Middle Palaeolithic sites shows that most of them are located along the northern Brittany shore (Figure 2). The vast majority of these sites are, moreover, wedged between a loess cliff (Figure 1c) and the foreshore associated with the current sea level

limit. This particular configuration was often at the origin of significant remobilizations [and even displacements](#) of the archaeological [artifacts](#). The sites which are older than the Eemian were often remobilized by the solifluction which affected the loess cliffs at the beginning of the Eemian or by the Eemian transgression itself which exceeded by two metres the level of the current Channel. Those which are more recent than the Eemian have also often been affected by the solifluction that followed the Last Glacial Maximum or by the Flandrian transgression which slightly exceeded the current [sea level](#).

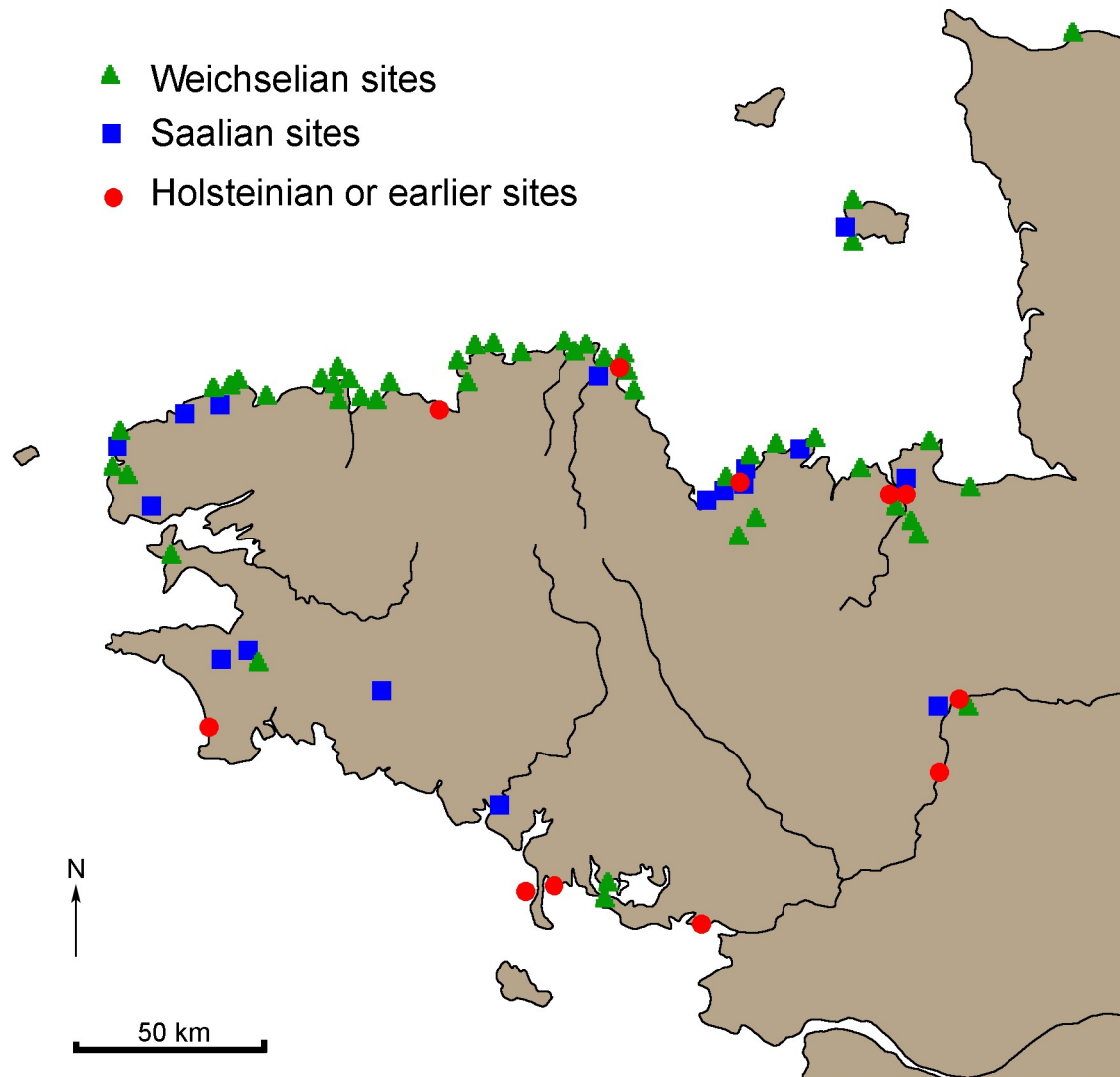


Fig. 2

It is known that a number of case studies, methods and discussions on the orientation of Neanderthal shelters (Kolen, 1999; Roebroeks and Tuffreau, 1999) have been published after the first study of Monnier (1982). However, [some](#) of these studies are dedicated to the remains of Upper Palaeolithic built shelters (Maher and Conkey, 2019) which did not exist during the Middle Palaeolithic of Brittany where no trace of built refuges have ever been observed. In

addition, and considering the solifluction and transgressive phenomena previously described, the existence of remains of “walls” (Stapert, 1990) or the presence of artefacts, bones or hearths still totally in place (Clark, 2017) is extremely rare. This difficulty makes any analysis based on their spatial distribution and therefore on their initial orientation very uncertain. Examples of sites chosen in the interior of the European continent, far from the marine foreshores or at the edge of the Mediterranean Sea (with its very low tidal range) cannot be compared to the sites studied [here](#).

In northern Brittany, the orientations of the Lower Palaeolithic sites (Hosfield, 2020) are not significant since they are limited to two sites. The Upper Palaeolithic is only represented by a few sites since most of them are at present under the sea (Monnier, 1988). Because of the sparse data, the distribution of these sites cannot be studied statistically. However, their distribution is interesting when compared [to](#) the Middle Palaeolithic: 5 sites are oriented towards the south or the southwest; 3 sites are oriented towards the east or the southeast and none of them is oriented towards the north or close to the north.

In order to evaluate the possible disturbances generated by katabatic winds on the Lower and Middle Palaeolithic populations, the orientations of the 82 sites previously described by Monnier (1982) were [re-analysed](#). Following recent studies (Huet, 2002, 2012; Monnier et al., 2011; Bahain et al. 2012; Danukalova et al, 2017; Lefort et al., 2019 a,b; Laforge, 2012; Laforge and Huet, 2013; Laforge et al., submitted) it was possible, [even](#) after forty years of erosion by the sea, to check the orientation of [most](#) of these sites. As a result of this comparison, we noted that [apart from](#) the small cavities in rock collapses, crevices or overhangs in loess or granite cliffs ([representing 40% of the sites](#)) and the sites very close to a cliff (38%) with clear orientations, [most](#) of the other directions (22%) of Monnier (1982) matched the direction of the maximum topographic dip [at or by](#) the archaeological site. [This technique being a simple adaptation of a classic method allowing, in geology, the determination of the direction of the maximum dip of a layer using a compass \(Earle and Panchuk, 2019\).](#)

In short, the orientation of the studied sites is easy to determine when they correspond with cliff-shelter [habitats or are very close \(a few meters\) to cliffs or rock collapses \(representing in](#)

total 78% of the sites). The orientation of the open-air sites located far from a cliff or of rock collapses can be correctly estimated by the dip technique if they are located on a well expressed slope (13%) but the orientation of the other open-air sites (9%) is more speculative. It is also important to know that the sites located on a slope are distributed between the NW and the S-SE sector and that 75% of the sites located at the foot of a cliff range between the NNW and the SE sectors. The wind-rose diagram (Figure 3b) displays a preferential orientation towards the southwest (22.6%), followed by the southward orientation (12%) and by the southeast orientation (10.7%). The northward orientations represent only 10.7% of the sites. We must also point out that 50% of the open-air sites showing a well-defined orientation, are oriented towards the SW. In Brittany, the choice of south-westward oriented shelters was probably not only related to a better exposure to the sun but also to escape the strong (Chu, 2009), cold and dusty winds coming from the north or northwest.

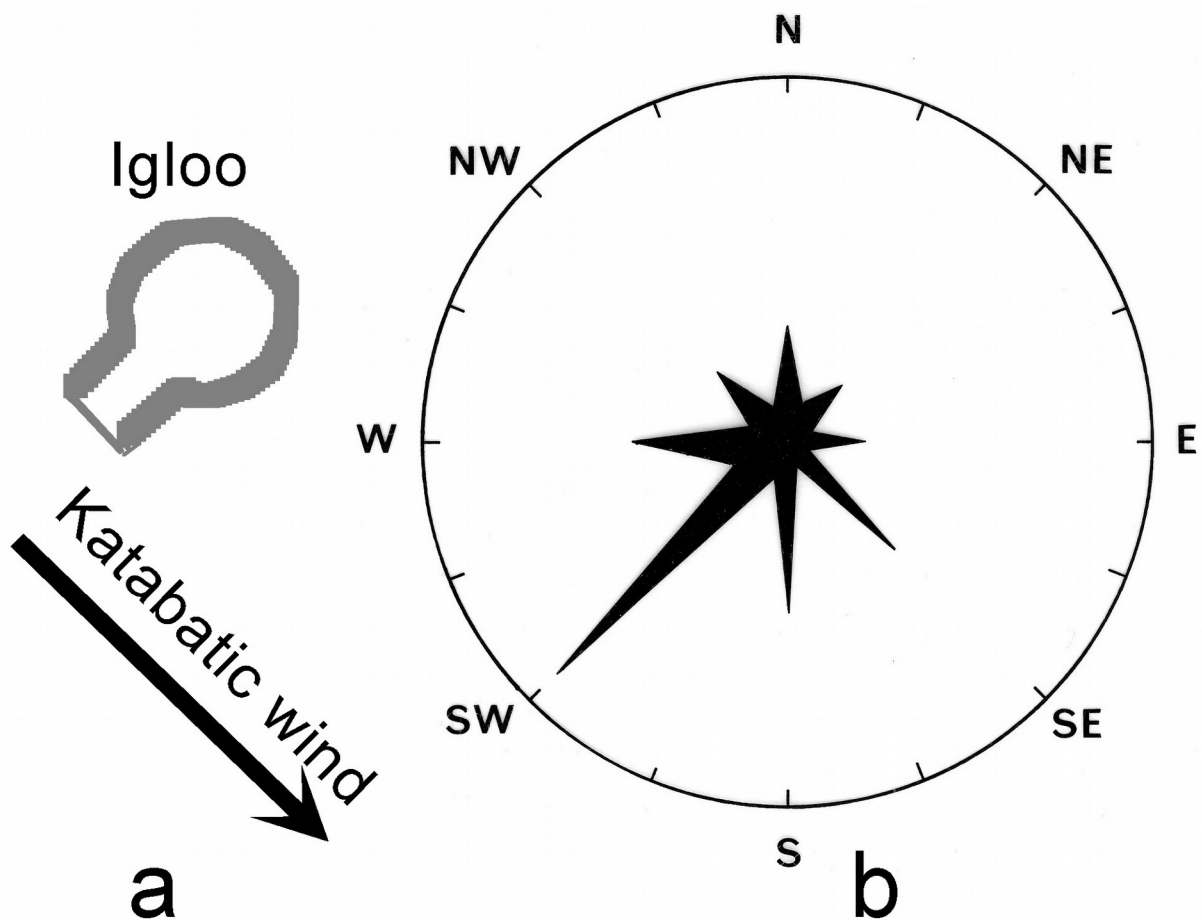


Fig. 3.

Impacts of the katabatic winds

The impact of katabatic winds on [the](#) Neanderthal environment can be assessed on three levels. It can be estimated at the scale of a single refuge, at the level of a limited region, or even at the scale of all Western Europe. [Time-wise](#) the following discussions will [cover](#) the last two [Glacials](#) in general while the regional study will focus more particularly on the Upper Saalian episode.

Local impact of katabatic winds

Comparison between the main direction of the katabatic winds (Figure 3a) and the prominent opening direction of Neanderthal shelters in Brittany (Figure 3b) shows that they were oriented at right angles (perpendicular) to each other. This spatial relationship is *a priori* surprising. In order to better understand this particular geometry, we were interested in the results obtained by a software dedicated to the relationships between a windy environment and a building in terms of architecture (Vilar et al., 2020)

In order to show the effects of a large rocky volume on a low altitude wind flow, we replaced the initial cuboid shape of an ideal building by a rocky block showing the same size and characteristics. A small shelter has been excavated in this block and a red flame symbolizing a small fire was designed at its entrance (Figure 4). Two solutions were proposed by Vilar et al., (2020): a/ in the first calculation, the entrance of the building is facing the wind (the windward side) (Figure 4a); b/ in the second calculation the opening of the same building is located on the opposite side of the blowing wind (the lee side) (Figure 4b). In the first case, because of the swirling air affecting the lower part of the rocky block, the katabatic winds penetrate inside the shelter; in the second case because of the “cavitation” phenomenon, the same winds also enter [into](#) the shelter. As a consequence, the only solution [for](#) [escaping](#) the katabatic winds is to select a shelter with its entrance at right angles to the wind. Additionally, in this condition the smoke of the fire is advantageously transported laterally.

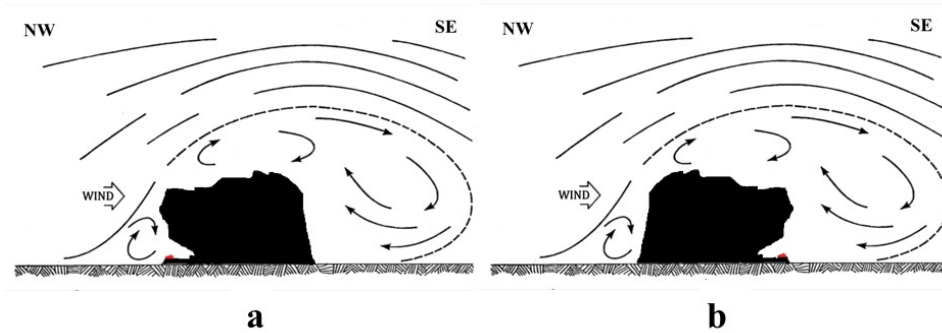


Fig. 4.

An identical choice on the orientation of the entrance of a tent in a very windy environment is also suggested in a recent guidebook describing the different outdoor activities in the US (Tawrell, 2011). This choice is probably inspired by the orientation of the tepees of the Indian tribes, who were living in the Great Plains of the American Midwest, regularly swept by strong and cold northerly winds during winter and by southerly winds during summer (Rosenberg, 1987). A painting of K. Bodmer dated from 1834 illustrates, for example, the traditional solution used by the Indians. The same spatial organisation was also discovered by Inuits who oriented the entrance of their igloos at right angle with respect to the katabatic winds. This last example is often cited in schools of architecture (Figure 2a) (Carlopio, 2010; Tawrell, 2011).

Regional impact of katabatic winds

Since katabatic winds were only developed during glacial episodes, the interpretation of the wind-rose diagram established for Brittany suggests that the Neanderthals consciously chose southwest oriented shelters during these cold episodes. By contrast, the random and poorly developed orientations which characterize the remaining shelters (Figure 3b) were probably selected during the Interglacial episodes when there were no katabatic winds. This reasoning is valid for MIS 6, 5a-d and partly MIS 4,

which broadly correspond with the Middle Palaeolithic [times](#) in Brittany (Monnier, 1988).

It is interesting to check if this general conclusion can be applied in an area where we have a more complete understanding of the climatic variations and to see if the broader Middle Palaeolithic model is supported by MIS 6 data.

In Brittany, the best documented sites dealing with the Pleistocene environment and the migrations of Neanderthals are all located along the north coast (Figure 2) and it is here that the largest amount of stratigraphic and geochronological data is to be found. This is the reason why the discussion of the katabatic winds and the living conditions of the Neanderthals is focused on this area.

It is now known that four small “warming” episodes interrupted the MIS 6 Glacial episode in Brittany (Lefort et al., 2019a). These short “warming” improvements were evidenced: 1/ by the abrupt development of *Pupilla muscorum* gastropods (Danukalova et al., 2017); 2/ by a [weak](#) pedogenesis that transformed part of the loess deposits into incipient soils (Monnier, 1973; Danukalova et al., 2017) and 3/ by the offshore development of sedimentary laminae (Lefort et al., 2019a).

Comparison with data on a global scale such as the variations of the sea level (Waelbroeck et al., 2002) or the evolution of temperatures recorded in EPICA and VOSTOK boreholes during MIS 6 in Antarctica (Berruyer, 2013) shows that the warming episodes do not only correspond to local or regional events but were also recognized on a global scale (Lefort et al., 2019a).

Comparison between the age of the “warming” episodes and the dated Neanderthal sites (Bahain et al., 2012) reveals that these [Neanderthal](#) populations only moved into Brittany when the climatic conditions were improving (Lefort et al., 2019a) (Figure 5). Three main sites (encompassing 14 sub-sites) have been studied in detail: The Piegu and Grainfollet sites linked to butcheries, are oriented towards the southwest, confirming the bulk analysis previously discussed. It is not known if the Nantois site had the same orientation since the collected artefacts were not found in place (Monnier, 1982). These are discontinuous occupations which suggest that Neanderthals were only temporarily coping with the katabatic winds during

MIS 6. Outside these short “warming” episodes the effects of the katabatic winds were probably much stronger since temperatures were much cooler but there is no archaeological evidence to prove this.

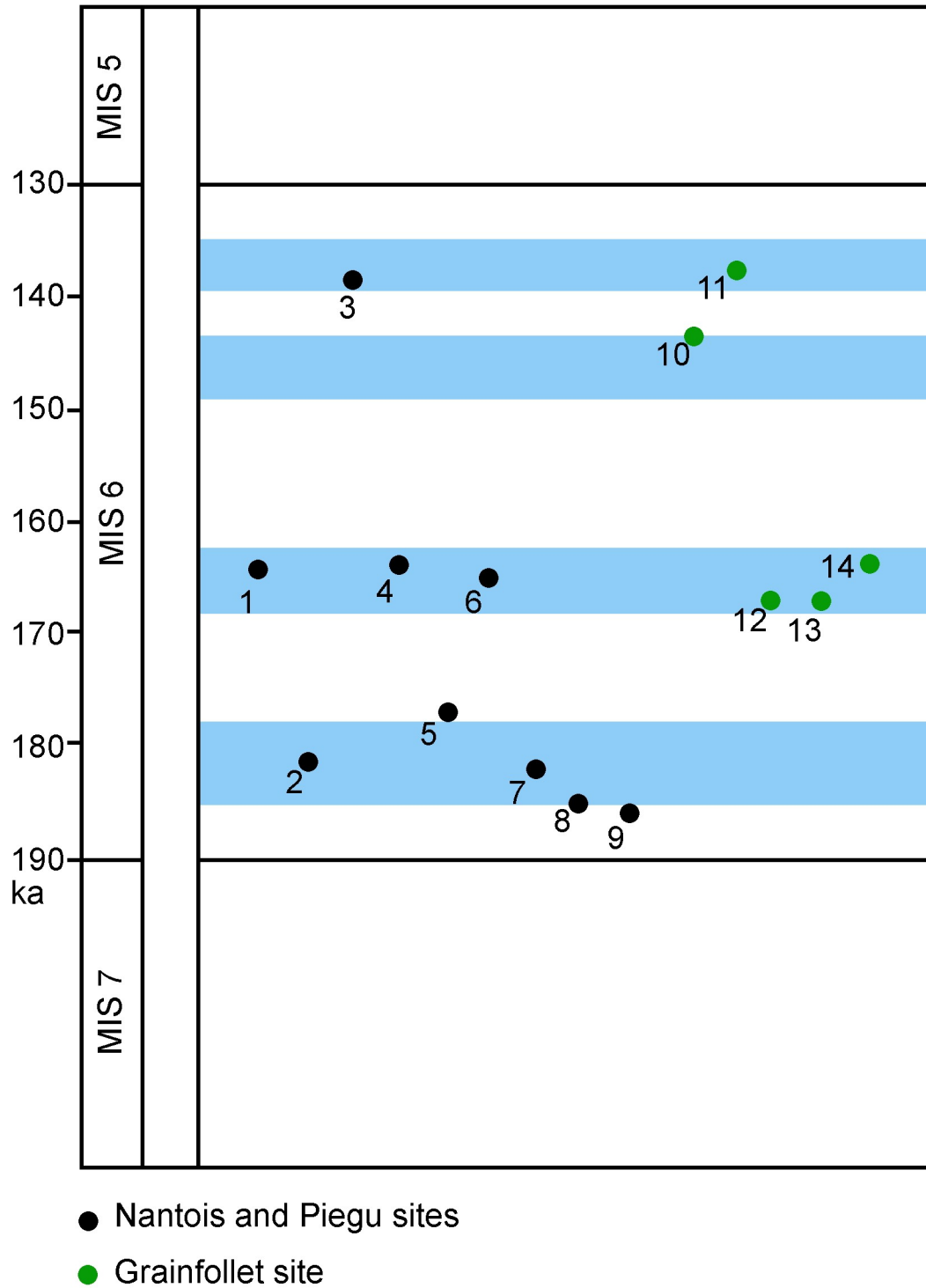


Fig. 5

Small-scale impact of katabatic winds

In Brittany and in England the Upper Saalian loess deposits are often pedogenized and patchy because they were deeply eroded and sometimes transformed during the Eemian interglacial episode (Danukalova et al., 2013). It is also known that the MIS 6 glaciation was very cold and extended further south than the entire Weichselian glaciation cycle in Eurasia (Colleoni, 2009). By contrast, the southern limits of the British-Irish ice sheet did not change very much latitudinally during the same episodes (Ehlers et al., 2011; Danukalova et al., 2017). Because of these closely similar boundaries and because, **overall**, the same causes produce the same effects, the extension of the younger loess (**Weichselian**) can be employed as a good approximation to the likely original distribution of the Upper Saalian loess deposits.

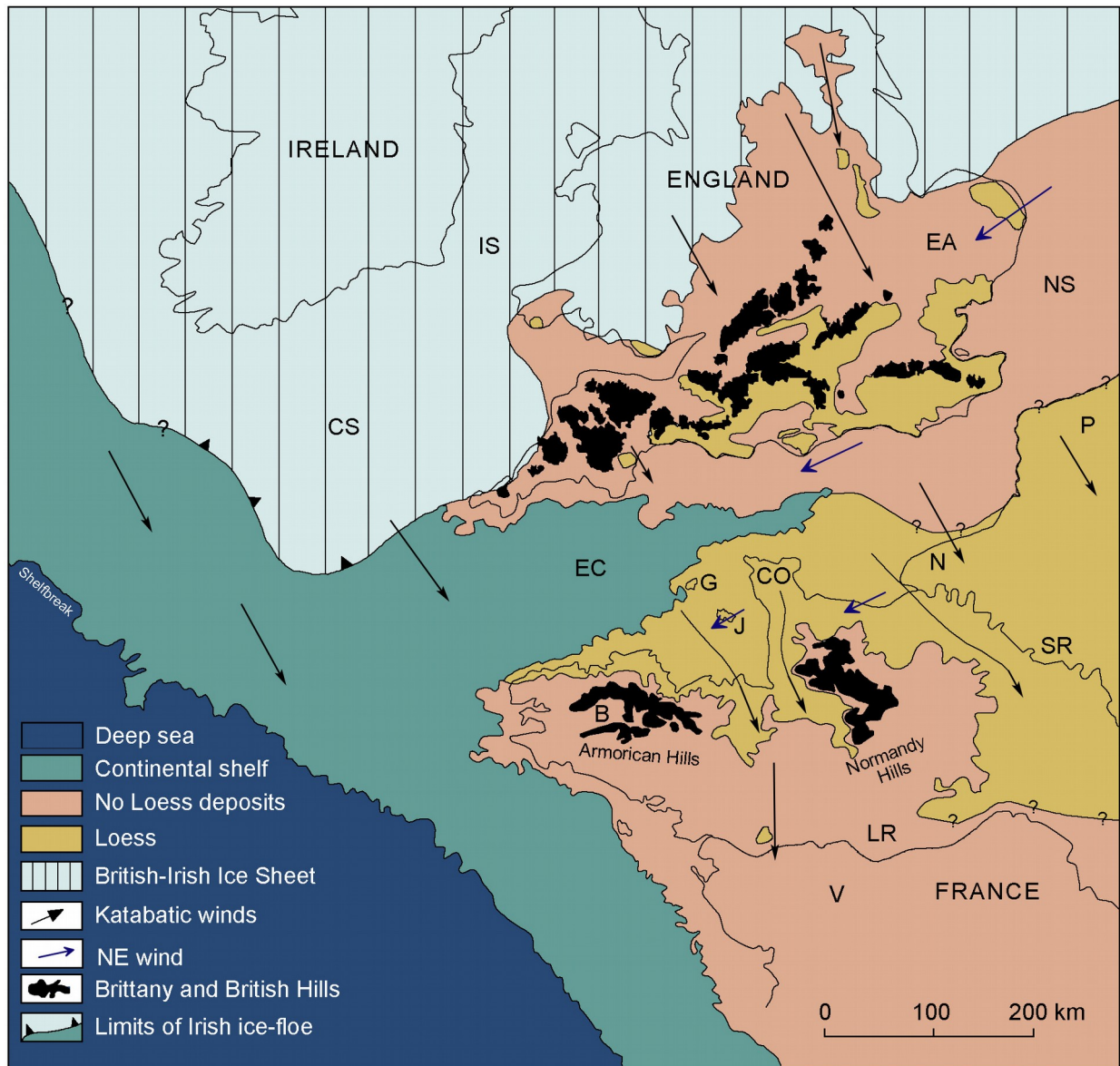


Fig. 6

Figure 6 shows the main stratigraphic events on both sides of the Channel during MIS 6. The sea-level shown (-65 m) is based on the data of Waelbroeck et al. (2002) and refers specifically to the approximate maximum sea-level attained during MIS 6 at MIS 6.1. North of the Channel the location of the loess deposits is taken from Antoine et al. (2003); in Brittany the extension of the onshore loess is based on Lefort et al, (2019 a, b) and offshore on Danukalova and Lefort, (2009) and Lefort et al. (2011). Comparison between study of the location of the loess deposits and the topography of the local relief points to two types of depositional processes.

In Brittany loess deposits, which can be up to 6 metres thick (Monnier, 1973), are always found on north facing slopes, while in England, where they are often less than two metres thick (Jefferson et al., 2003), loess is always found on the south facing hill slopes. This arrangement is systematic except along the North Sea (Figure 6) where two limited loess outcrops were deposited by winds blowing from the northeast (Antoine et al., 2003). The existence of a different situation on either side of the Channel reflects the weakening of the katabatic wind as one moves away from the ice sheet. A cross-section (Figure 7) modified from Lehmkuhl et al. (2016) illustrates this difference and shows how loess thicknesses can vary depending on the distance from the source area and the geomorphological setting.

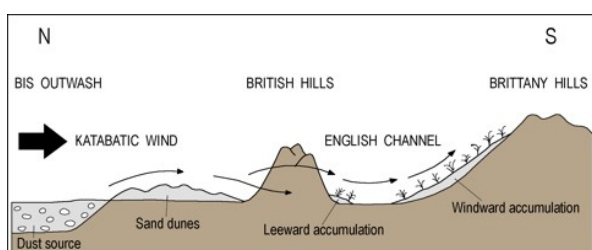


Fig. 7

When compared to northern France and Brittany, it is clear that MIS 6 sites with a human presence (Scott et al., 2016) are under-represented in England. It is sometimes considered that this discrepancy is the result of a different research methodology. Most of the British records derive from fluvial sites, a situation contrasting with that of the French data that usually come from loess or sand dune environments (Monnier, 1980, 1988; Antoine, 2002; Antoine et al., 2003). Because loess preserves artefacts and landscapes better than beds of gravel, an increase in loess sedimentation also automatically increases the chances of gaining archaeological material. However, there is another possible way of viewing this discrepancy; past studies, even where past climatic variations were considered, showed little interest in associated wind regimes and neglected their study. This absence of interest was probably due to a lack of understanding of how katabatic winds, when blowing at as much as 240 km/h, even 320 km/h, (Renfrew, 2004) would have disturbed the lives of Neanderthals. Renfrew's chapter

dedicated to the local impact of katabatic winds on the orientation of Neanderthal shelters is a good demonstration of the importance of these winds in archaeology.

A good example of the impact of katabatic winds on the migrations of early peoples is also to be found in Alaska (Thorson and Bender, 1985). Modelling of katabatic winds generated by ice sheets predicts that palaeo-wind velocities greatly exceeded the entrainment thresholds required for aeolian deflation. During katabatic wind blow an area in front of an ice sheet is a deflation zone where no loess can be deposited and no prehistoric peoples could have survived for long. As a consequence, it is only when the wind is weakening that loess can be deposited. In Alaska it was observed that colonisation occurred at the same time as loess deposits were forming. The presence of strong katabatic winds in front of former glaciers or ice sheet limits has thus significant implications for late Pleistocene paleoecology and archaeology.

Taking account of these data it is possible to infer that the limited presence of Neanderthals in England during MIS 6 was linked to the existence of strong katabatic winds blowing from the not too distant British ice sheet.

Contribution of Jersey and Guernsey to the environment of Neanderthals.

Because of the presence of the very important archaeological site of La Cotte de St Brelade (Callow and Cornford, 1986; Renouf, 2015) and the isolated position of the islands in the Normanno-Breton Gulf, it is important to look in detail at the data previously collected in this area in order to check if they could improve our conclusions even if the relatively low number of stratigraphic data collected in the Islands compared with the many sites studied in England, Brittany and Normandy cannot completely change our main conclusions.

- The gradual westward thinning of the loess formations observed on the islands by Keen (1978) has also been observed in Brittany (Lefort et al.,

2011, 2013). It is partly associated with the progressive lowering of the sea-level in the Channel during the glacial episodes which were exposing new deflation zones to be swept by the katabatic winds (Lefort et al., 2019a). The older deflation zones had begun to generate loess particles earlier than the surfaces recently released by the sea.

- Northern Brittany, represented [topographically](#) a massive east-west elongated high during the low stands of the sea (Figure 5) with north facing coastal and other cliffs behaving like dust collectors for the katabatic winds (Lefort et al., 2019a). By contrast, the Islands of the Normanno-Breton Gulf represented prominent isolated hills able to catch the dust coming from any direction. This is illustrated by the loess deposits coating also the east and northeast facing cliffs in Jersey and Guernsey, an observation that suggested an eastern loess source (Keen, 1978). The same orientation has been observed in the Caen Basin in Normandy where 5 metres of loess are coating northeast basement cliffs (Aubry and Gigot, 2020). This type of accumulation is also observed in eastern England (Figure 6) where loess deposits are considered to have been blown from a source area of glacial outwash deposits in the North Sea Basin (Catt et al., 1971). This assumption is now confirmed by the high concentrations of Hafnium (Hf) and Zirconium (Zr) in East Anglia (Scheib and Lee, 2010). It is also considered, in some localities of southern England, that loess deposits were, at least partly, derived from subjacent glacial sediments of pre-Weichselian age coming from the east (Catt et al., 1971). The patchy distribution of the areas where evidence of westward or south-westward blowing winds is still preserved, suggests that many of them have been erased during winters by the strong and intermittent katabatic winds (Rusciano et al., 2013; van As et al., 2015). The preserved sedimentological evidences of south-westward wind flows can be explained by a peculiar characteristic of the katabatic winds (Refrew, 2004) which always blow at a very low ground level (Figure 1a). It seems that in Jersey and Guernsey, the katabatic winds did not completely disturb the loess previously deposited on the highest parts of the flat-topped morphological "hills".

- The distribution of the loess accumulations in Jersey is an interesting problem since it seems, compared to Brittany, that there was not a clear preferential process of directional deposition. Extensive observations made by one of us show that loess lenses are equally abundant in all head deposits no matter what the slope position. This important observation may be the result of the solifluxion during the slightly warmer episodes which incorporated in the "head", « primary » loess previously deposited uphill at the same time as gelifRACTED pieces of rocks (Culshaw et al., 2017).

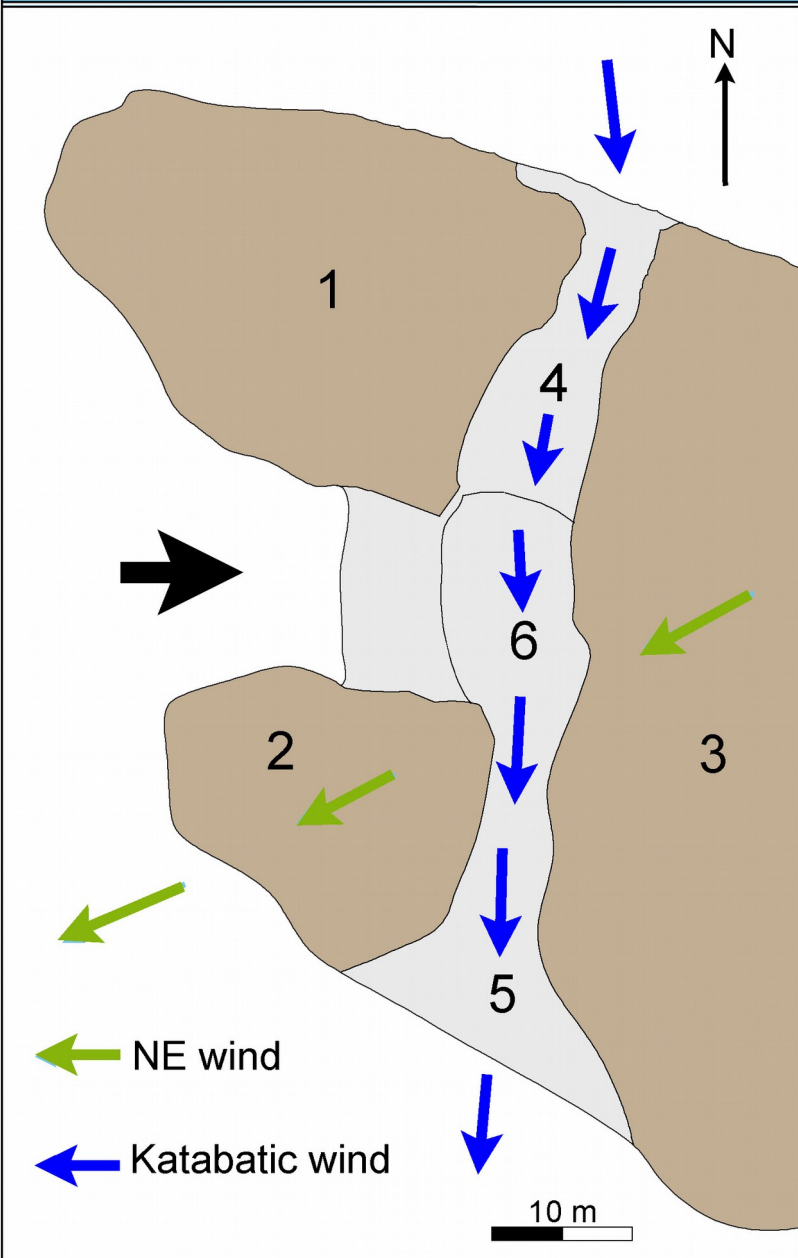
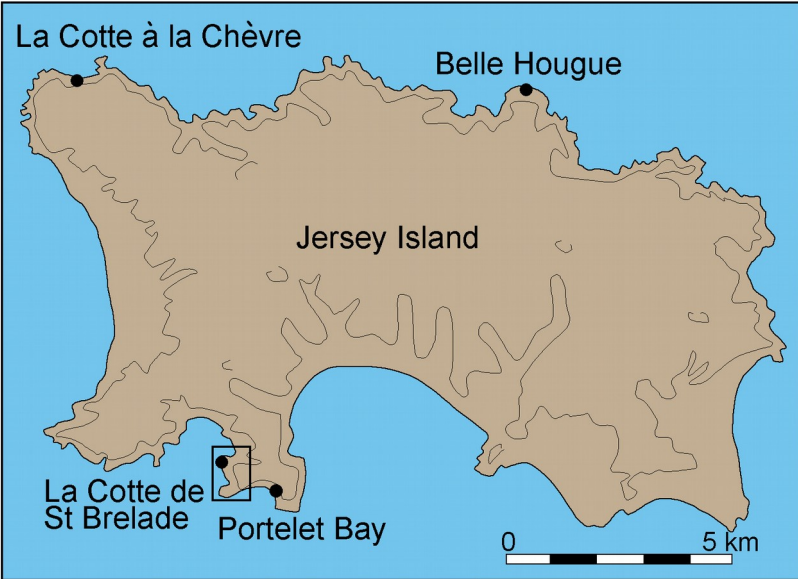


Fig. 8

The MIS 6 loess deposits coating the west and southwest facing slopes of the La Cotte de St Brelade area (Renouf, 1986) may correspond with leeward accumulations associated with the east and northeast blowing winds. It was probably the same for the younger loess deposits. On the contrary loess deposited on the north facing slopes would be equivalent to the deposits of northern Brittany and those of Portelet would represent leeward deposits associated with the katabatic winds.

- The absence of Neanderthals during the thicker loess sedimentation (Scott et al., 2014) confirms the previous observations made onshore in Brittany (Lefort et al., 2019b) since it is during these episodes that katabatic winds were stronger and Neanderthals absent (Figure 5). Comparison between the orientation of the shelters known in Brittany and the possible settlements in Jersey during the Upper Saalian suggests that the shelter of La Cotte à la Chèvre (Figure 8), because of its N orientation, and the orientation of the North (4, Figure 8) and South (5, Figure 8) Ravines of La Cotte de Saint Brelade (Figure 8), both swept by strong katabatic winds, were not favourable to the installation of Neanderthals. Under these circumstances, the West Ravine, the only realistic access route, would have been not only the sole option but, fortuitously, the best sheltered from both the northeasterly and the katabatic winds.

- The paleontological data collected in La Cotte de St Brelade located at 60 km from Northern Brittany also provide valuable environmental information. Because the Pleistocene stratigraphy of this site was established progressively during the successive archaeological excavations we present here a simplified description based on the synthesis of Callow and Cornford (1986). The Upper Saalian corresponds to the stage III of the authors in which they recognized five different periods. The lower limit of the Upper Saalian, which is made of a typical loess deposited under extremely cold conditions (since it is associated with *Dicrostonyx*), is in contact with the Upper part of the MIS 7 formation made of disturbed occupation floors. The upper limit of the Upper Saalian, made of soliflucted and cryoturbated loess containing in its upper levels *Juniperus* and sea-buckthorn pollen (indicating the beginning of a climatic improvement), passes into the

Eemian **which is** characterized by a clear pedogenesis and the beginning of a marine transgression. Between these two limits existed a more or less continuous loess sedimentation **though** layer 15, characterized by the presence of oak charcoal, and layer 18 **with** *Quercus*, *Fraxinus* and *Ulmus*, suggest the existence of well-expressed climatic warming episodes. Even if some reworking of the deposits have been suggested **for** the upper and lower parts of stage III the presence of two well expressed episodes of climatic warming alternating with three periods of strong gelifluction with permafrost and cold-living rodents seems to be clear even if not totally equivalent **to** the four warming stages evidenced in Brittany. **Such a** difference can be explained by the erosional surfaces which separate the 14th and 15th climatic episodes of the authors.

Discussion

Propagation of katabatic winds

Katabatic winds have attracted the attention of meteorologists because they may reach up to 327 km/h in exceptional conditions. They are also known as “gravity” or “down slope” winds and originate over glaciers or ice sheets particularly outside the summer season (Renfrew, 2004). Onshore, it is often considered that the propagation of katabatic winds is very limited. Long distance transport of dust particles by katabatic winds was first proposed (Tutkovsky, 1910) in an area located **some** 400 kilometres from the Fennoscandian Ice sheet. In Alaska, located close to an ice sheet but in a mountainous area, loess has been transported over a distance of 80 kilometres (Thorson and Bender, 1985). The assumption that katabatic winds may not travel over long distances and are limited to a displacement of 20 to 100 kilometres (Adolph and Wendler, 1995) is contradicted by NASA infrared satellite photos (Bromwich et al., 1992) which show that they may propagate over distances of more than 1000 km above the sea. In Brittany the results of the analysis of augites and other heavy minerals show that these winds were still operating at up to 450 km from the Ice Sheet (Lefort et al., 2019b). In the Western Channel most of the remnants of the initial loess cover (Lefort et al., 2019b) were deposited at about 250 kilometres from the British Ice Sheet (Chiverrell and Thomas, 2010) and at 200 kilometres from the Celtic ice floe (Praeg et al., 2013).

Because the highest glacial ridge running between Ireland and England (Boulton et al., 1977) at the origin of the katabatic winds blowing towards Brittany, is located at 300 km north of the southern limits of the British ice sheets, we can estimate that the maximum displacement of the

katabatic winds was around 750 km. This value is in the range of the displacements observed by Bromwich et al., (1992).

East of this ridge, in the northern part of the North Sea located between the British-Irish and the Scandinavian Ice Sheets (Toucanne et al., 2015) the North Sea represented a relative lowland. It is known that during glaciation maxima the North Sea floor was a polar landscape dissected by rivers (Cohen et al., 2014). However, abundant mammoth bones and other mammal skeletal remains dredged from the North Sea floor (van Kolfschoten and Laban, 1995), are evidence of less hostile circumstances and indicate that the severe polar-desert conditions were relatively short-lived. During the coolest glacial episodes the thickness of the ice was much thinner at the position of the North Sea (Cohen et al., 2014) and the topography much lower than the top of the British Ice sheet which was around 1200 to 1300 m high (see the discussion about this thickness in Boulton and Hagdorn (2006). It is why this subsiding low land was probably unable to generate any katabatic flow. This reasoning suggests that Neanderthals living in the different areas located south of the North Sea did not need to seek for cliff-shelters to escape the strong katabatic winds as they had in Brittany.

Other wind directions

- The main interest of the Jersey and Guernsey sedimentological studies was to demonstrate that the northeast wind blowing between southeast England (Stevens et al., 2020) and Guernsey, after crossing southernmost England and Normandy, also transported dusty sediments. At that time, the North Sea was swept by stormy or katabatic winds probably originating in the Fennoscandian Ice Sheet. Because the Brittany pie-chart (Figure 3b) displays a very low percentage of shelters oriented to the Northeast (7%) these winds were probably still active at this longitude whatever their origin.

Distribution of shelters

A review of the different Middle Palaeolithic archaeological sites previously studied in Brittany suggests that most of them did not correspond to permanent dwelling areas but to hunting sites or short stay refuges. It is also surprising to observe the limited protection offered by these shelters in an area mainly made of loess cliffs and hard basement rocks. By way of contrast, during the cooler episodes, as soon as the sea level was regressing, the Eocene and Cretaceous outcrops with dolinas and karstic holes, well developed in the different types of limestone, were being exposed. This so much so that one can only wonder whether the main permanent habitats weren't actually located offshore with Brittany representing over all a hunting and gathering domain.

Conclusions

The results of this study can be summarised thus:

- The southward transportation of loess particles by katabatic winds generated by the British-Irish ice sheet during the Upper Saalian and Weichselian Glacial stages is now well demonstrated in westernmost Europe. This conclusion was mainly based on a three dimensional study (3D) of the wind fields in Brittany. The decreasing strength of this wind towards the south is now also supported by the deposition of loess on the lee slopes of the southern British hills and by their accumulation on the windward side of Brittany hills. The unequal presence of Neanderthals in northern Brittany and Jersey on the one hand and Southern England on the other during MIS 6 was probably related to the southward weakening of the katabatic winds.

- The reappraisal of 84 sites of Early and Middle Palaeolithic age known in Brittany shows that the commonest orientation selected by Neanderthals during the two last Glacials episodes was perpendicular to the regional katabatic wind direction. The dominant southwest orientations of the shelters selected during the cold episodes is well explained by a software dedicated to architecture. Calculations with this software show that the only solution for escaping the strong and cold winds is to choose a shelter orientated at right angles with respect to the main wind direction. The same spatial organization is known to have been adopted by the Crow Indians and Arctic Inuits though the Neanderthals were probably the first peoples to understand the benefit they could derive from the selection of this shelter orientation under strong winds conditions.

- A detailed study focusing on the timing of Neanderthal sites during MIS 6 suggest that these hunter-gatherers selected the southwest orientations during the “warmer” Late Saalian phases. Outside of these “warmer” episodes the significantly stronger katabatic winds were pushing these populations southward to more hospitable regions.

- The data collected in Jersey and Guernsey, showing sedimentological

remnants of south-westward blowing winds allows their extension to the wind direction already recognized in Normandy, southern and southeastern England during the Saalian and Weichselian cold stages. Because this wind was also transporting dusty sediments and heavy minerals coming from the North Sea we can infer that they were transported by storms or katabatic winds originating in the Fennoscandian Ice Sheet.

- The west to southwest oriented wind flow blowing during the glacial episodes (probably also of katabatic origin), different from the stronger southward blowing katabatic winds generated by the British-Irish Ice Sheet, was blowing in an opposite direction with respect to the general atmospheric circulation system originating in the North Atlantic Zone during the glacial phases. This discrepancy clearly illustrates the vertical stratification of the winds during these periods: the low level intermittent katabatic wind flow directly controlled by the topography of the ice sheet being completely independent of the general atmospheric circulation system. In any case, there is no doubt that the life of the Neanderthals was much more disturbed by the katabatic winds often blowing at a high speeds and whose maximum effect was felt at around twenty-five meters above the ground than by the winds of medium altitude coming from the North Atlantic.

Author contributions

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Jean-laurent Monnier

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John Renouf

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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Captions

Figure 1. Selection of the most important data supporting the existence of katabatic winds (extracted from Lefort et al. 2019). a: Vertical thickness of the katabatic wind field (inset: usual wind velocities and altitudes); b: Granulometric gradient in northern Brittany; c: Regional orientation of the katabatic winds, Blue arrows: Transit of ice rafts; Black arrows: Transit of loess particles; Red arrows: Transit of heavy and flaky minerals: 1/ Transit of olivines and augites, 2/ Transit of garnets, 3/ Transit of anatases, 4/ Transit of flaky minerals; Yellow shading: Initial loess deposits; Pink shading: Fluvial deposits or no loess deposits; Light green shading: Maximum regression; Dark blue shading: Deep Sea. Vertical ruling: Ice sheets; d: Typical onshore loess accumulation in northern Brittany; e: drifting direction of ice-rafts.

Figure 2. Distribution of the Weichselian, Saalian and Holsteinian or earlier sites in Brittany and adjacent areas (after Monnier, 1982).

Figure 3. Comparison between the direction of the katabatic winds (a) and the different orientations of Neanderthals sites during the Lower and Middle Palaeolithic in Brittany (b); Grey igloo symbol: typical orientation of igloos with respect to katabatic winds in Greenland.

Figure 4. Details of the wind field pattern above a rocky relief showing a northwest facing shelter (a) and of a southeast facing shelter (b). Note the locations of the cavitation phenomena. The little red triangle corresponds with a schematized fire at the entrance of a cave.

Figure 5. Relationship between the limited warming episodes (blue stripes) and the 14 Neanderthal dated sites (dots) during MIS 6 in Northern Brittany. The SW orientation of the Neanderthal shelters correspond to the slightly warmer phases (after Lefort et al., 2019a).

Figure 6. Reconstruction of the relationships between the British and Brittany hills (in black) and the main loess deposits (in yellow) in Westernmost Europe. B: Brittany; CO: Cotentin; CS: Celtic Sea; EA: Eastern England; EC: English Channel; G: Guernsey; IS: Irish Sea; J: Jersey; LR: Loire River; N: Normandy; NS: North Sea; P: Picardie; SR: Seine River; V: Vendée;

Figure 7. Schematic transport and deposition of sands, sandy loess and loess between the outwash zone of the British ice sheet and Brittany. Note the leeward and windward loess deposits on both sides of the English Channel (not to scale). Adapted from Lehmkuhl et al. (2016).

Figure 8. La Cotte de Saint Brelade site based on Callow and Cornford (1986). Upper inset: Location of La Cotte de Saint Brelade in Jersey; Lower inset: Schematic plan of La Cotte de Saint Brelade: 1: North Pinnacle; 2:

South Pinnacle; 3: East Wall; 4: North Ravine; 5: South Ravine; 6: central site in the Western Ravine. The north-south wind circulation is shown on the assumption that the northern end of the cave was open to the north overlooking Ouaisné bay as at present.