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Climate variability and storm impacts as major drivers for human coastal marsh withdrawal over the Neolithic period (Southern Brittany, NW France)

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ABSTRACT

Relationships between climate variations, vegetation dynamics, and early human activities during the Neolithic have been reconstructed from high-resolution pollen and foraminiferal records obtained from cores retrieved from coastal wetland located in southern Brittany (Guidel, NW France). Our data show that the area around Guidel corresponded to a dense temperate forest locally replaced by riparian forest in the marsh, without any human disturbance during the early Neolithic. During the mid-Neolithic, between 6500 and 5500 cal years BP, the first episode of probable human settlement is recorded, as suggested by the increase of anthropogenic plants. This early record of human impact is consistent with archeological studies that find a high concentration of funeral monuments around Guidel during this cultural period. This complex first phase is interrupted by the disappearance of anthropogenic influence coinciding with a cold/humid climate period in the region characterized by recurrent major storms. Then, at the transition between the middle to late Neolithic, at 5500 cal years BP, a second phase of human retreat is signaled by both vegetation dynamics and archeological records; this interval also coincides with a climatic deterioration marked by cold/humid conditions recorded in the region (Sorrel et al., 2012). The results of the present study imply that human settlement/departure over the Neolithic was probably influenced by climatic variations. During the Bronze Age, Iron Age, and Middle Ages, a progressive decline of the arboreal forest, synchronous with an increase of anthropogenic plants, confirms the high and persistent human activity around the site. Furthermore, our results at Guidel suggest a different anthropogenic trend recorded between north and south Brittany. The human impact is well recorded during the Neolithic at Guidel, while in northern Brittany human settlement is not recorded before the Bronze Age, consistent with existing archeological data.

1. Introduction

High-resolution paleoclimate and paleoenvironmental studies over the Holocene are crucial in order to understand past forcing mechanisms and future climate trends superimposed on increasing human impacts. Millennial-scale climate oscillations are now well recognized throughout the Holocene (O'Brien et al., 1995; Bond et al., 2001; Mayewski et al., 2004; Wanner et al., 2011) and there is a rise in paleoclimate studies worldwide so as to better understand the nature, timing, and causes of these oscillations, e.g. solar activity and/or internal forcing mechanisms relative to the climate system, and the changing atmospheric and oceanic re-organizations through time (Bond et al.,

2001; Mayewski et al., 2004; Wanner et al., 2008, 2011; Fletcher et al., 2013). Holocene mechanisms and global-scale representations of climate are still far from being well-understood and regional studies are required to understand the spatiotemporal complexity of our interglacial period.

This is especially true at a local scale when considering coastal zones that evolve fast, specifically to global changes including sea level, air temperature, continental precipitation changes, and human disturbances. Bio-indicator analyses are therefore crucial for detecting ecosystem changes in response to climatic and anthropogenic controls. Maritime marshes are remarkable coastal ecosystems in temperate regions, with dynamic ecological systems responding to changing environmental conditions such as sea level or river discharge variations. Hence, they are influenced by both continental and marine factors. The Grand Loc'h (GL) of Guidel, located south of Brittany (NW France, Fig. 1), consists of an ancient ria progressively transformed into a coastal salt marsh during the Holocene transgression. It is protected from direct

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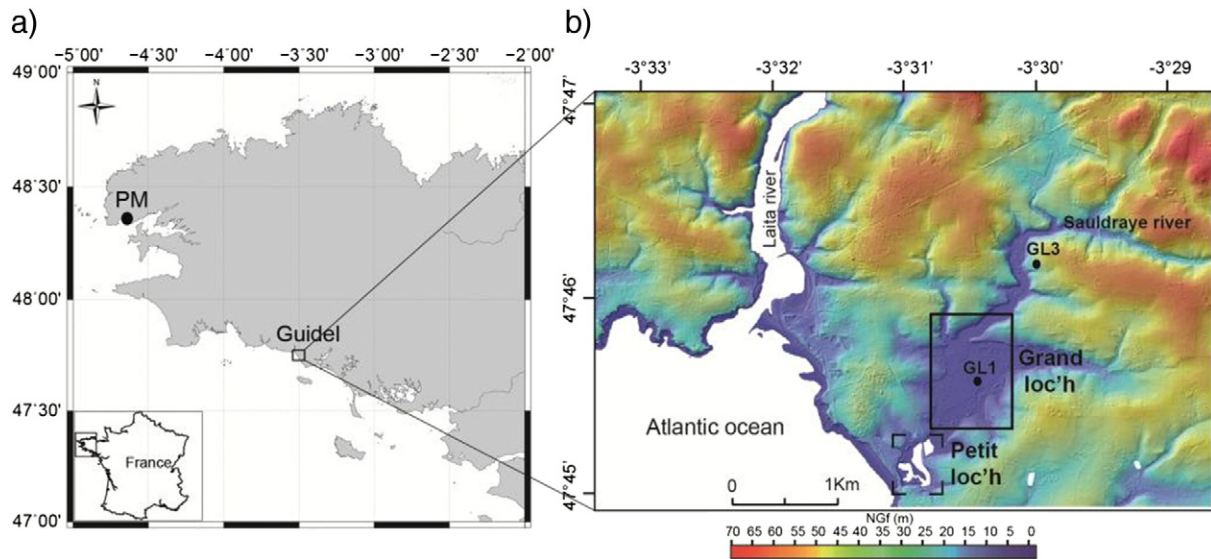


Fig. 1. a) Location map of the Guidel study area, b) sediment precise core locations: GL3 (47°46'13.90"N, 3°30'2.60"E; 6 m long, pollen analysis: this study), and GL1 (47°45'43.70"N, 3°30'10.75"E; 11 m long, foraminiferal analysis: Fernane, 2014).

marine intrusion by a late Holocene sandy dune barrier. The GL marsh is therefore a perfect area to perform paleoenvironmental studies of the Holocene period using comprehensive sediment records. Additionally, several studies conducted around Brittany previously confirmed that coastal environments represent pertinent and key study areas to decipher Holocene climatic and/or anthropogenic changes (Sorrel et al., 2009, 2012; Baltzer et al., 2014; Fernane et al., 2014; Van Vliet-Lanoë et al., 2014).

Based on pollen analysis conducted on a sediment core retrieved from southern Brittany, we discuss the paleoenvironmental history of the region over the last 7000 cal years BP. Pollen analyses will allow us to discuss, in parallel, both climate fluctuations and agro-pastoral activities over the surrounding GL watersheds. Hence, the present paleoenvironmental study should enable us to: 1) detect past environment changes, 2) try to relate these changes to the climate pattern, and 3) supply information about the impact of human expansion on ecosystems through time.

2. Environmental context

2.1. Geomorphological context

The study area, Guidel ("Grand Loc'h", GL, Fig. 1), is a maritime coastal marsh located in southern Brittany (NW France). The site is fully incised in weathered Paleozoic bedrock; the gneiss is saprolite, mostly impervious, and induces rapid and superficial drainage over the watershed as well as toward the ocean. Despite its present low altitude, less than +2 m NGF ("Nivellement Général de la France", French reference system for sea level elevation), and the prevailing macro-tidal regime, the marsh is protected from marine intrusion by a coastal dune ridge. Since 1989, these coastal dunes support a road that isolates GL from a sandy beach about 500 m long (Fig. 1).

The present-day GL marsh surface, stretching from north to south, covers 70 ha, and its surrounding catchment covers about 2600 ha. GL marsh consists of two asymmetrical parts: the northern part or "Grand Loc'h" (GL) and the southern part or "Petit Loc'h" (PL), this latter being partly embanked during the 1960s (Fig. 1). The two parts are separated by a small dam constructed during the 19th century in order to stop marine intrusion toward GL and to allow agriculture activities. Furthermore, between 1942 and 1945, the Germans created an airport, the superficial ground scraping then perturbed the top of the stratigraphical sequence. According to these anthropogenic morphological

configurations, hydrological differences can be observed between the GL and PL Loc'h's. Brackish hydrological conditions dominate in PL due to its connection to the sea via a tide gate (1884 AD). During the summer period, PL is dry with few permanent brackish ponds, while the rest of the year PL marsh is subject to marine submersion. In contrast, the GL surface waters today are fully protected from the influence of seawater, and GL shows more complex environmental processes over the year. Hence, the GL marsh is subject to fluctuating fresh (river discharges) and marine water conditions (via PL) from winter to late spring while, during late summer, the marine water prism may reach the surface, resulting in brackish to salty vegetation establishment. In the upstream part of GL, a persistence of high groundwater levels leads to a continuous freshwater peat development, within a depression separated from the Sauldraye river by a fluvial sandy bank (Fig. 1a). The spatial heterogeneity of the Guidel marsh, consisting in a total of 5 km of channeled rivers, as well as in permanent/temporary small ponds, offers diversified and numerous habitats for floral and faunal species.

2.2. Present-day climate and associated vegetation

The climate in Brittany is characterized by temperate oceanic conditions (due to the North Atlantic Ocean influence) with generally cool, rainy winters and fresh summers. Mean annual temperature ranges between 10.9 and 12.6 °C with weak thermic seasonal amplitudes. Mean annual precipitation rate ranges from 800 to 850 mm. The climate of Brittany is strongly influenced by the North Atlantic Oscillation (NAO) pattern that governs the strength and persistence of the westerly winds (Hurrell, 1995). This natural pattern of atmospheric variability directly influences temperatures and hydrological conditions (precipitation, river discharges, and water table levels), which in turn influence vegetation cover.

Regarding current vegetation, the Guidel marsh was extensively cultivated until the last decade of the 20th century. Nowadays, only pastoral activities continue. In this area, vegetation is constituted by several kinds of meadows characterized by associations of different species. Among these, notable and rare species are observed, such as *Salicornia ramosissima*, *Puccinellia distans*, *Agrostis stolonifera*, *Potamogeton crispus*, *Eleocharis palustris*, *Trifolium fragiferum*, *Trifolium resupinatum*, *Prunus* sp., and *Potentilla neumanianna*. Some other species such as *Carex punctata*, and *Orchis laxiflora* are classified as endangered species. The landscape throughout the Guidel marsh is mainly open and the sparse

and scattered woodland of the surrounding area is dominated by *Salix*, *Quercus*, *Fraxinus*, *Fagus*, and *Corylus*.

3. Archeological context

Human settlement and development in Brittany are shown by several well-preserved coastal archeological sites and megalith monuments erected between 6700 and 4000 cal years BP. At Guidel, the presence of several megaliths attest to high human settlement during the Neolithic in this area. Numerous studies carried out in this region were mainly focused on architectural and typological issues, however information related to human organization, occupation strategy, and spatial distribution are still under-documented (López-Romero González de la Aleja, 2008). Furthermore, data related to the beginning of agricultural activities are discrete and still debated. Several studies based on pollen reconstructions from the Armorican Domain have reported the presence of *Cerealia* pollen grains in association with ruderal taxa such as *Plantago lanceolata* since the late Mesolithic (8700 cal BP) (Visset et al., 1996; Joly and Visset, 2009). These works suggested an early regional Neolithization. Nevertheless, this hypothesis has been rejected by Marchand (2005, 2014) because of issues regarding pollen identification and chrono-stratigraphical uncertainties. Then, from the Bronze Age (4500–1450 cal BP) to the Middle Ages (1450–450 cal BP), southern Brittany was subjected to persistent and increasing agro-pastoral activities. Nowadays and since the 1970s (“green agricultural revolution”), Brittany has become a leading French agricultural region.

In Brittany, evidence for Neolithic wooden houses is rare and it is difficult, if not impossible, to infer the size, structure, and distribution of the Neolithic population, i.e. paleodemographics, at that time. However, funeral stone monuments are abundant all over Brittany and the concentration of these Neolithic structures in the region is the highest recorded in France (Blanchard, 2012). The Neolithic is commonly divided into three sub-periods, early, middle, and late Neolithic (early Neolithic: 8500–6700 cal BP, mid-Neolithic: 6700–5500 cal BP; late Neolithic: 5500–4500 cal BP), each period being marked by specific burial monuments (Giot et al., 1981). The concentration of these monuments is then indirectly used to infer human densities. Migratory population dynamics may then be reconstructed by careful study of the spatial distribution of the burial monuments through time. At Guidel and its surroundings, numerous archeological explorations have been carried out and recent inventories exist for the Neolithic cultural period (Gouézin, 1994, 2007; González de la Aleja, 2008; Nicolas et al., 2013; Pailler and Nicolas, 2014).

4. Methods

4.1. Field work and radiocarbon analyses

The Guidel core (GL3: 47°46'13.90"N, 3°30'2.60"O; 6 m long) was extracted with a Russian corer from a freshwater peatbog, core sections are 1 m long and 8 cm wide. Eleven sediment samples composed of bulk peat were dated using the conventional radiocarbon method AMS ¹⁴C (Table 1). Sampling was performed prior to the palynological study, before any oxydation of the organic matter, both above and below macroscopic changes in peat fabric. Calibration of all dates was performed at 2σ using the Clam program (version 2.2; Blaauw, 2010) associated with the statistical software R (version 3.0.1; “R Development Core Team”, 2013). Non-marine (IntCal13) AMS ¹⁴C dates were converted to calendar ages using the radiocarbon calibration curve (Reimer et al., 2013). The age model of the GL3 core is based on linear interpolation between the ten radiocarbon dates obtained from the core (Fig. 3).

4.2. Pollen analysis

Seventy-seven samples were analyzed for pollen on the GL3 peat core with a sampling resolution ranging from 5 (Neolithic period) to 10 cm. The pollen extraction followed the classical technique (Moore et al., 1991) in which samples are treated by 10% NaOH (10 min), 10% HCl (24 H), 58% HF (24 H), and then warm concentrated HCl (15 min) followed by acetolysis (5 min). Pollen frequencies are expressed relative to the main pollen sum composed of trees and herbs; *Pinus*, helophytic and hydrophytic plants, Pteridophyta (monolet and trilete spores), and *Cyperaceae* were excluded from this main pollen sum. Riparian forest pollens, including *Alnus*, *Salix*, *Fraxinus*, and *Chenopodiaceae* pollen grains were also excluded from the total pollen sum since they are over represented in coastal marsh environments. A minimum of 300 pollen grains per sample (out of excluded taxa) were counted under a transmitted light microscope at × 1000 magnification. In this study, pollen types have been identified according to Hyde and Adams (1958), Moore et al. (1991), Nilsson et al. (1977), and Reille (1995, 1999).

5. Pollen assemblages (GL3 core)

The radiocarbon dates suggest that the well-preserved GL3 core covers the last 7000 years (Fig. 2). This sediment record is characterized by homogeneous and continuous sediments, mainly composed of peat deposits (Fig. 2).

Table 1
List of all ¹⁴C dating obtained on Guidel cores (* rejected dates for GL stratigraphy).

Depth (m)	Altitude NGF (m)	Laboratory code	Dated material	¹⁴ C date BP	Age cal. BP min–max	Age cal. BP mean
<i>GL1 + 1.73 m NGF</i>						
1.6	0.33	Poz-49809	Bulk	1760 ± 35	1567–1740	1653
1.7	0.23	Poz-49805	Bulk	1300 ± 70	1062–1332	1197
3.7	–1.97	Poz-49806	<i>Scrobicularia</i>	4395 ± 35	4480–4783	4631
9.6	–7.87	Poz-47039	Bulk	6650 ± 40	7459–7587	7523
<i>GL3 + 2,20 m NGF</i>						
0.53	1.67	SacA 29575	Bulk	760 ± 30	667–729	698
0.85	1.35	SacA 29576	Bulk	1585 ± 30	1407–1542	1474
1.88	0.32	SacA 29578	Bulk	2905 ± 30	2957–3083	3020
2.23	–0.03	SacA 29577	Bulk	3050 ± 30	3174–3350	3262
2.64	–0.44	SacA 29579	Bulk	3730 ± 30	3981–4154	4067
3.02	–0.82	SacA 29580	Bulk	4105 ± 30	4521–4663	4592
3.74	–1.54	SacA 29581	Bulk	4605 ± 30	5377–5450	5413
4.34	–2.14	SacA 29582	Bulk	4930 ± 30	5600–5719	5659
4.92	–2.72	SacA 29583	Bulk	*5380 ± 30		
5.33	–3.13	Poz-49810	Bulk	5450 ± 40	6186–6308	6247
5.92	–3.72	SacA 29584	Bulk	6105 ± 30	6889–7030	6960

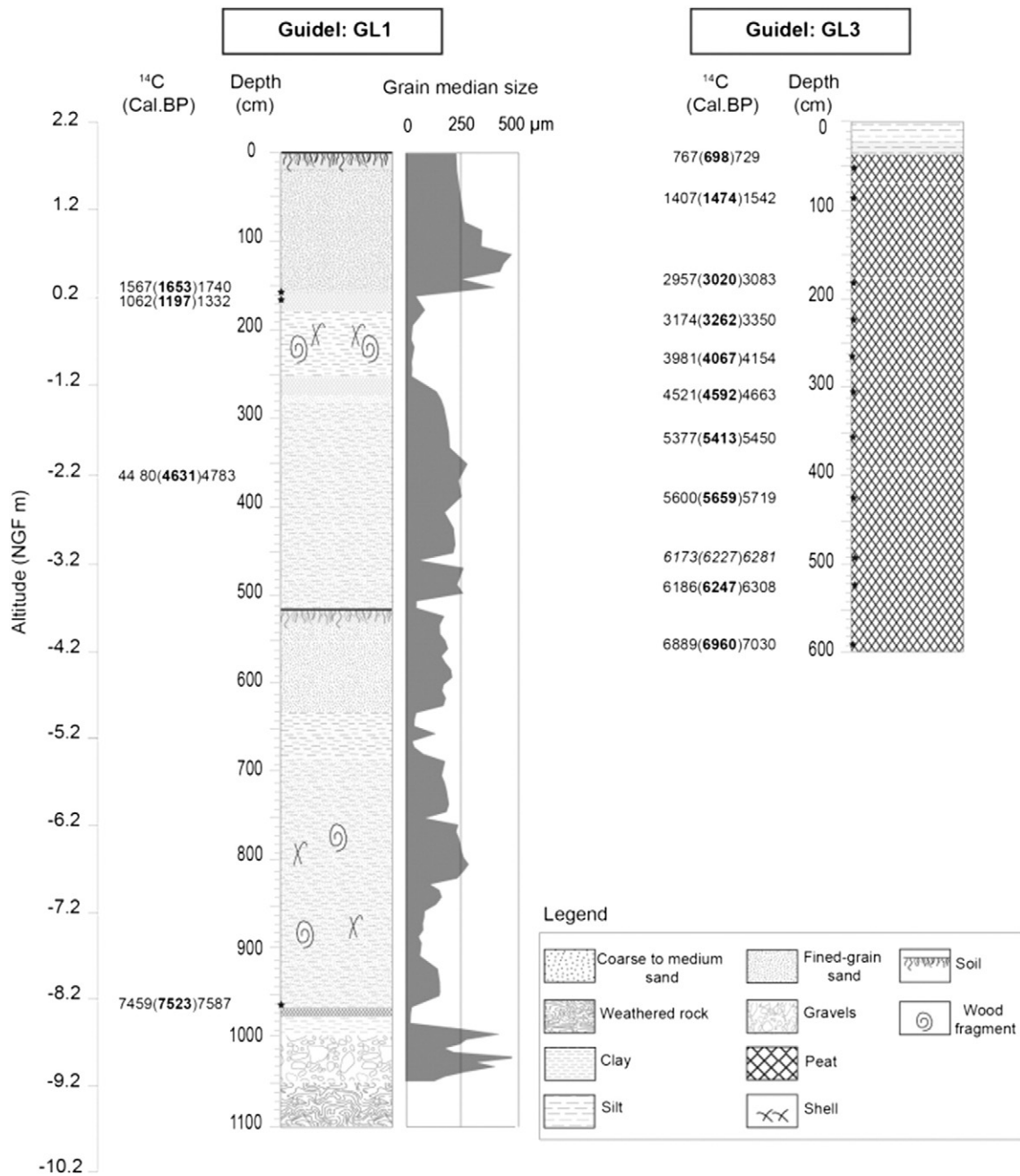


Fig. 2. Stratigraphic logs of the 2 study cores GL1 and GL3: lithofacies (modified from Goslin, 2014) and granulometric analyses.

Ninety-four different pollen taxa have been identified on the GL3 core. Distribution of main pollen taxa (recorded at least once > 2%) observed in the core is shown in Fig. 5, as well as *Castanea* and *Juglans* distributions (even if recorded below 2%). Based on the evolution of arboreal pollen (AP) percentages, three main palynozones have been established (GL3p1 to GL3p3) using Broken stick model (Bennett, 1996), and additional zones were added visually. Subsequently, additional sub-zones have been proposed based on some specific taxa dynamics (Fig. 4). Overall, our pollen analysis shows a progressive transformation of both the marsh and its surrounding catchment, from a closed/wooded area to an open/cultivated or meadow area.

The first palynozone (GL3p1: 6989–5689 cal BP) is characterized by high AP percentages (80% in average). Pollen results characterize GL3p1 as a sub-zone (5618–4618 cal BP) (90% of deciduous *Quercus* and *Corylus*), suggesting the establishment of a temperate continental mixed oak forest around the site, on the drained watershed. Synchronously, in

the marsh, *Alnus* is the dominant wetland tree with percentages reaching 40% on average. High percentages of *Plantago* (up to 20%) together with low percentages of *Artemisia* and some occurrences of *Cerealia*, are also recorded in this sub-zone which suggests probable episodes of landscape clearance. Nevertheless, very low values of *Cerealia* cannot allow us to categorically attribute this clearance event to human activities such as agricultural practices. *Plantago* extension is currently attributed to extensive trampling and nitrogenous enrichment of soils by megafauna (Stewart, 1996). Hence, significant representation of *Plantago*, associated to the attested record of an open landscape through occurrences of *Artemisia* and *Poaceae*, could be related to probable pastoral activities in the Guidel marsh. At the start of GL3p1b (4618–3602 cal BP), the sharp decrease of *Plantago*, *Artemisia*, and *Poaceae*, accompanied by a rise in AP percentages such as *Tilia*, suggest the recovery of the forest. *Quercus* shows increasing percentages within the following sub-zone GL3p1c (3602–3249 cal BP) where its

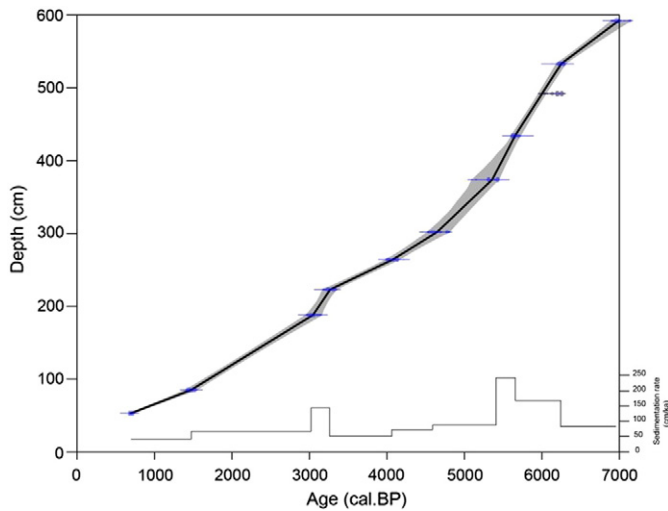


Fig. 3. Calendar age-depth model based on ten ^{14}C dates obtained from GL3 (cf. Table 1).

highest values are recorded (up to 65%), while *Corylus* and *Ulmus* decrease significantly.

The second palynozone (GL3p2: 3249–2697 cal BP) is marked by a sharp then progressive decrease of arboreal taxa (60% in average), synchronous with the first rise of several anthropogenic taxa abundances such as *Humulus/Cannabis* and *Rumex*. This rise is accompanied by: (i) increasing percentages of steppic plants such as *Artemisia*, and (ii) the first continuous presence of the *Cerealia* pollen type. More specifically, within GL3p2a (2697–2006 cal BP), a sharp decrease of arboreal taxa associated with an increase in herbs such as Caryophyllaceae and *Artemisia* is observed, later followed by an increase in *Cannabis/Humulus* and *Artemisia* within GL3p2b (2006–1548 cal BP). This marks the beginning of the arboreal forest collapse in the area. This trend is strongly expressed in GL3p2c, where low percentages of trees such as *Quercus* and *Corylus* are observed. *Tilia* definitively disappears, *Alnus* percentages strongly decrease, and high percentages of Poaceae are also recorded.

Finally, pollen results within the GL3p3 (1548–694 cal BP) zone show a continuous decrease of AP percentages in parallel with the rapid and progressive rise of agricultural pollen markers, i.e. *Cerealia* type pollen grains (20% on average). Sub-zone GL3p3a is marked by a

second drastic collapse of *Corylus* and *Quercus*, while Poaceae increase sharply. Within the GL3p3b sub-zone, *Juglans* and *Castanea* occur for the first time, probably growing into the surrounding cleared woodland. Anthropogenic taxa such as *Fagopyrum* occur at the end of the sub-zone. Synchronously, the wetland tree *Salix*, as well as aquatic/marsh taxa such as *Sparganium*, increase. Within the last sub-zone, GL3p3c, agricultural activity appears to be at a maximum, as suggested by the highest *Cerealia* percentages (about 20%) of the pollen record. *Fagopyrum*, *Plantago*, and *Cannabis/Humulus* occurrences then suggest diversified human activities at the end of the record.

6. Discussion

6.1. Mid-Holocene vegetation changes recorded at Guidel (6500–5000 cal BP)

At a regional scale (Brittany), vegetation dynamics at Guidel show coherent palynological trends corresponding to Holocene climatic and anthropogenic forcing (Morzadec-Kerfourn, 1974; Fernane et al., 2014), however at a local scale substantial differences are observed. Indeed, important differences exist between sub-regional areas making it difficult to model vegetation dynamics for the entire Brittany region (Gaudin, 2004). This highlights the necessity to undertake several local palynological studies in order to establish a precise paleoenvironmental scenario, as proposed in a recent synthesis of Holocene palynological studies in the Parisian Basin (David, 2014). At Guidel, significant occurrences of herbaceous taxa such as Poaceae, *Plantago*, and other ruderal plants, coupled with rare occurrences of *Cerealia* pollen grains, and decreasing percentages of arboreal taxa (*Quercus*) as well as riparian forest (*Alnus*), may suggest a moderate human presence in the area during the mid-Neolithic, from 6500 to 5500 cal BP (Fig. 5). Previous studies based on archeological evidence, suggest the start of anthropogenic forest clearance at 7000 cal BP (Marchand, 2014). Paleobotanical evidence in the Gulf of Morbihan, situated 35 km east of the Guidel marsh, also notes the occurrence of clearance events since the early Neolithic period (Visset, 1994; Visset et al., 1996). Finally, other studies based on pedological evidence have reported clear land degradation directly related to agricultural activities during the mid-Neolithic, especially in Brittany's coastal areas (Gebhardt, 1993; Gebhardt and Marguerie, 2006).

In our study, it is interesting to note that during this interval, from 6000 to 5800 cal BP, the anthropogenic pressure at Guidel probably declined, as suggested by the drop of herbaceous and ruderal plant percentages, synchronously with a full absence of *Cerealia* pollen grains (Fig. 5). The comparison between Guidel and Pors Milin (NW Brittany),

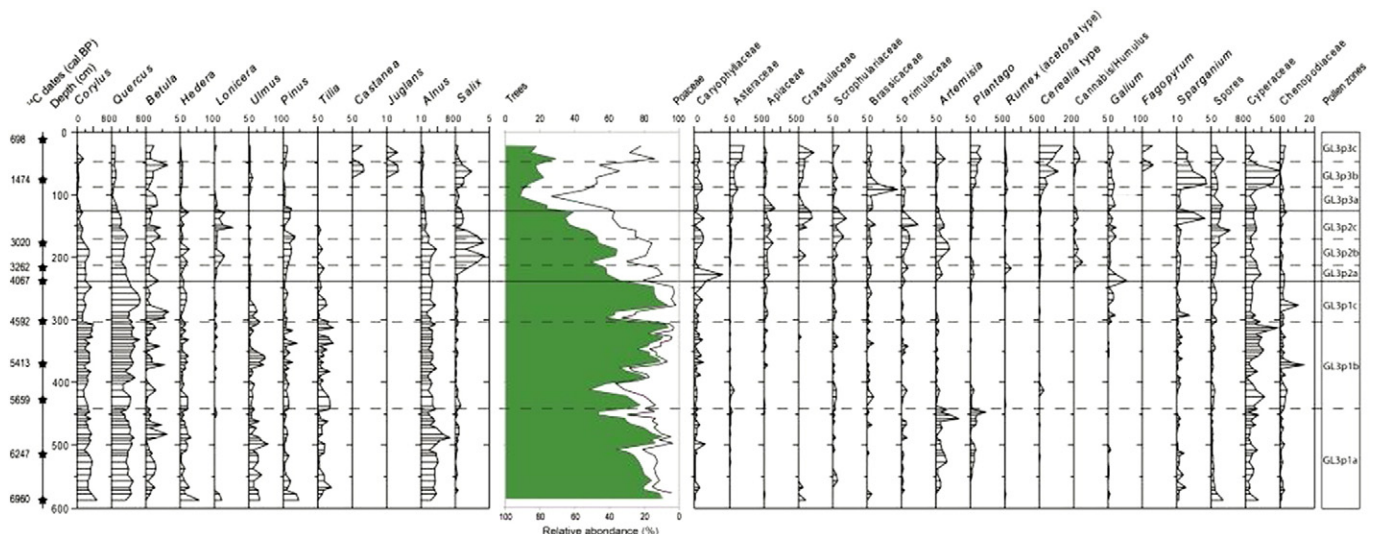


Fig. 4. Percentages of main pollen taxa identified in GL3 core (relative abundances above >2% except for *Castanea* and *Juglans*).

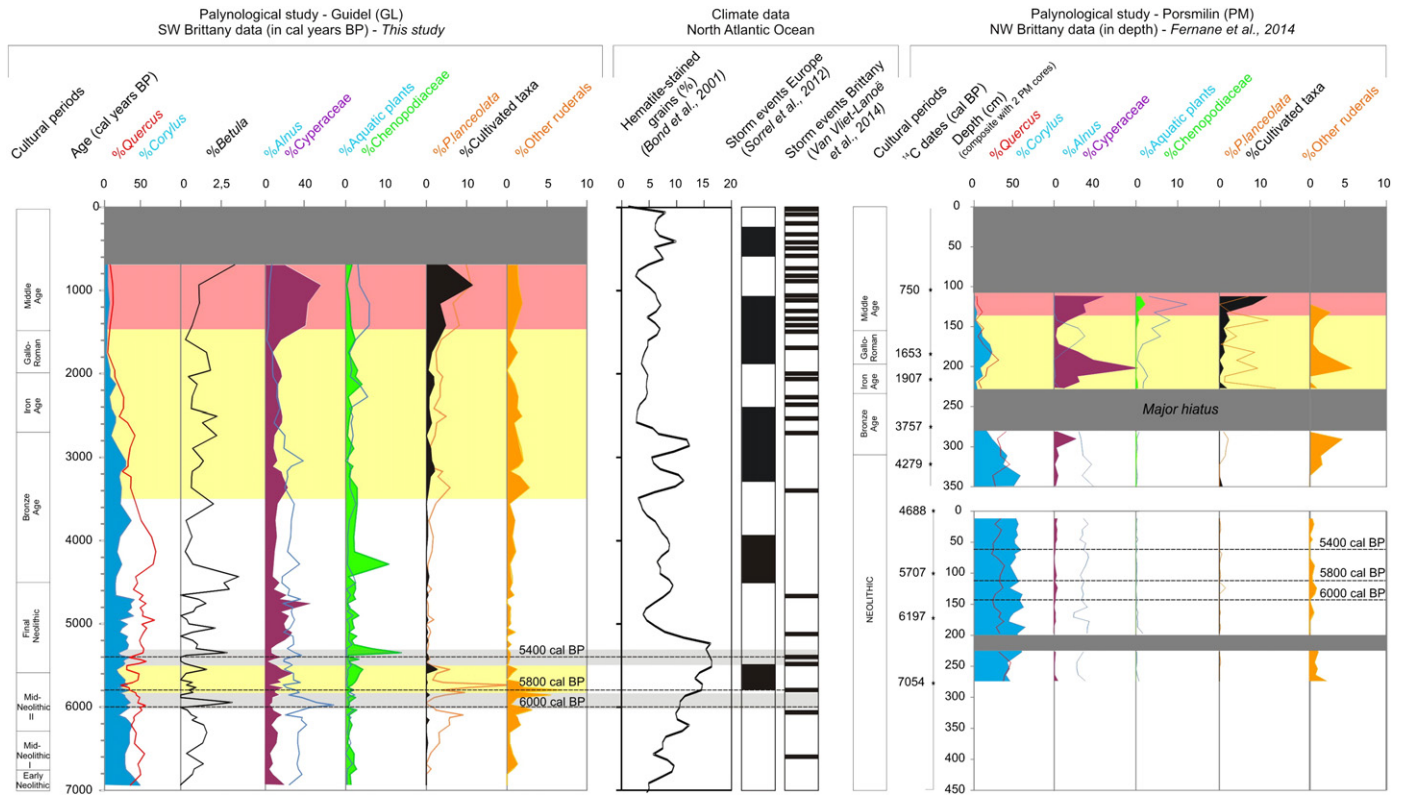


Fig. 5. Paleoenvironmental synthesis from Guidel (this study) and Pors Milin (Fernane et al., 2014) sites. Yellow bands underline increasing human activity. Red bands represent intensive phases of human activity starting mainly during Middle Age. Dotted lines mark three cold/humid periods (5.4, 5.8 and 6 ka BP) characterized by major storm events reported from the region during the Neolithic (cf. Van Vliet-Lanoë et al., 2014; Fernane et al., 2014). Light-gray bands represent agricultural activity collapses recorded at Guidel. Dark-gray bands represent sandy facies where no palynological studies have been conducted, a major sediment hiatus in Pors Milin related to the breaching of sandy dunes is recorded during the Bronze Age (cf. Fernane et al., 2014).

where no human influence is detected until the Bronze Age (Fernane et al., 2014), highlights major differences in regional vegetation trends (Fig. 5). The anthropogenic pressure difference observed between these two areas could be related to different geomorphological contexts. Northern Brittany is characterized by: i) loamy soils, difficult to cultivate with a swing plow, and ii) short and narrow watersheds evolving into narrow coastal marshes, limiting the development of a significant population. In contrast, the southern coast of Brittany is characterized by: i) sandy, easily-cultivated soils, and ii) wide watersheds and large coastal marshes, which probably favored human settlement, especially during the mid-Neolithic period when the sea level was lower (-7 m; Goslin et al., 2013; Goslin, 2014).

6.2. Forcing factors responsible for human settlement and departure at Guidel over the mid-Holocene (6500–5500 cal BP)

Various hypotheses can be assessed to explain the abandonment of GL by the population previously installed on the marsh and its surroundings around 6000 cal BP (Fig. 5). They can include climatic factors, resistance to adaptation, economic marginalization, mercantile exploration, and hostile neighborhood interaction (D'Andrea et al., 2011). Pollen-based quantitative climate reconstructions (combined with multi-centennial scale paleohydrological data) have been reported from a marine core retrieved in the Bay of Biscay (Naughton et al., 2007), but this kind of data is rare and discontinuous on the Brittany continental sites. It is then difficult to relate our observations to either population displacement, with a socio-economical perspective, or climate change. However, previous studies carried out in Europe have successfully related climate variability and archeological settlement (Magny and Haas, 2004). Indeed, based on hydrological reconstructions from mid-European lakes, Magny and Haas (2004) have previously

suggested that human establishment was favored by warm and dry conditions. At Guidel, the sharp decrease of ruderal plants synchronous with maximal values of *Alnus* growing in waterlogged soils (Barthelmes et al., 2010) suggests the establishment of wetter conditions around the site between 6000 and 5800 cal BP. In coastal areas, *Alnus* development is controlled by fluctuations of the water table, the latter being influenced by variations in sea level or precipitation. At Guidel, the stability of halophilous plants (e.g. *Chenopodiaceae*) suggests that wetter conditions probably resulted from increasing precipitation, and not from the expansion of the salt meadows related to the Holocene sea level rise. We thus propose a direct relationship between past hydro-climatic changes and human settlement in the Guidel fluvial and maritime plains.

Climate conditions recorded over Europe suggest sharp climate deterioration between 6500 and 6000 cal BP (Bond et al., 2001; Mayewski et al., 2004) (cf. Fig. 5). Besides, cold and humid conditions were reported between 6300 and 6000 cal BP in French and Swiss alpine lakes (Magny, 2004). Cooler summer temperatures were also reported around 6200–6000 cal BP in Sweden (Grudd et al., 2002), and climate deterioration occurred around 6000 cal BP in Ireland, responsible for a decline of human settlements (Stolze et al., 2013). Recent studies also cited more frequent storms in northwestern Brittany, leading to colder and wetter conditions around 6050 cal BP (Van Vliet-Lanoë et al., 2014; Fig. 5), and the same has also been reported for the western Mediterranean region (Sabatier et al., 2012). We therefore suggest that the collapse of agro-pastoral activities recorded at Guidel around 6050 cal BP could be connected to a climate deterioration characterized by cooler and wetter conditions. Storm-based morphological impacts at the coast are important in Brittany (Van Vliet-Lanoë et al., 2014), and they are mainly indicated by the breaching of coastal barriers and the consecutive recurrent inundation of the formerly-cultivated coastal marsh, which can ultimately result in human retreat.

After this collapse, and from 5500 to 4500 cal BP, the complete retreat of human presence is confirmed by the absence of cultivated taxa and the subsequent recovery of the forest (*Quercus* and *Corylus*) while the riparian forest stays stable (Fig. 5). This period is also marked by a sharp increase of Chenopodiaceae, especially around 5300 cal BP, suggesting marine influences of the study site (Gandouin et al., 2009). Hydrological disturbances in the coastal area, and the consequent human retreat, can either be attributed to more frequent storms or to sea level rise. A regional sea level curve has recently been reconstructed for Brittany, for the last 8000 cal BP, showing sea level rise characterized by progressive decelerating rates with no significant pulses and several stabilization periods around 7000, 6000, 4600, and 3200 cal BP (Goslin et al., 2013; Goslin, 2014). Furthermore, Van Vliet-Lanoë et al. (2014) showed that climatic deterioration marked by major storm events was recorded in western Brittany around 5500 cal BP (Fig. 5). According to pollen data analysis conducted in central Europe (Davis et al., 2003) and Alpine lakes (Magny, 2004), this period of climate deterioration is also recorded on a Europe-wide scale. We therefore suggest that human abandonment during the late Neolithic at Guidel may have been induced by the persistence of cold and frequently humid conditions commonly associated with the recurrence of major storm events (Meurisse-Fort, 2009; Sorrel et al., 2012; Van Vliet-Lanoë et al., 2014). Furthermore, stratigraphic and foraminiferal analyses were also undertaken at Guidel (cf. Figs. 1 and 2 for the location of GL1 core; Fernane, 2014). Main foraminiferal results clearly show successive faunal changes according to two different patterns. The first recorded assemblage is characterized by high percentages of non-calcareous taxa (*Trochammina inflata* and *Jadammina macrescens*), while the second type of foraminiferal assemblage is characterized by the dominance of calcareous taxa (*Astergerinata mamilla*, *Haynesina germanica*, *Elphidium williamsoni*, and *Lobatula lobatula*). From an ecological point of view, it has already been shown that non-calcareous species dominate in the upper part of the salt marsh in Brittany (Rossi et al., 2011; Stéphane et al., 2015) while calcareous foraminifera dominate in sub-tidal, tidal, and marine environments (Liu and Fearn, 1993; Collins et al., 1999; Scott et al., 2001; Murray, 2006). Even if the stratigraphy of GL1 is not robust enough, this sediment sequence is evidence that the downstream part of the Guidel marsh was submitted to continuous marine influences over the last 7000 cal BP (Fernane, 2014) with a high tide level close to -7 m NGF (Goslin et al., 2013; Goslin, 2014). These observations appear consistent with archeological data showing high concentrations of mid-Neolithic passage graves only in the upstream part of the Guidel marsh (Bailloud et al., 1995; Gouézin, 2007). According to Gouézin (2007), no funeral structures are recorded for the downstream part of Guidel. This discrepancy could be explained by recurrent marine inundations at Guidel, especially storm surges and floods, preventing human settlement close to the coast in the study area.

The study of gallery graves (passage graves) shows that human populations previously installed around Guidel moved from the coast inland at that time, as proven by the absence of burial monuments in the surrounding area (Gouézin, 1994, 2007; Paillet and Nicolas, 2014). This is even true during the late Neolithic for the entirety of Morbihan, where archeological data also revealed landward migration at that time (Tanguy and Lagree, 2002; Gaudin, 2004; González de la Aleja, 2008).

6.3. Land use from Bronze Age to Middle Ages

At the beginning of the Bronze Age (from 4500 cal BP), *Quercus* forests are well developed at Guidel suggesting limited human impact on the forest cover (Fig. 5). Archeological studies of population distribution around Guidel show that humans progressively moved inland during the transition between the Neolithic and the Bronze Age (González de la Aleja, 2008; Nicolas et al., 2013). This may explain low percentages of ruderal plants recorded over this period. The reappearance of *Plantago*, associated with significant decreases of arboreal and riparian

taxa, is then recorded at 3500 cal BP, reflecting a re-cultivation of the Guidel marsh (Fig. 5). During the Iron Age, the agricultural activity continues at a low level, while decreasing arboreal taxa, in parallel with increasing ruderal plants, suggest episodes of massive clearing for pastoral activities rather than for agricultural practices (Fig. 5). Regarding agricultural activities, archeological studies mention the presence of Iron Age villages in the upstream part of the Guidel site (González de la Aleja, 2008). The first significant increase of *Cerealia* pollen grains is observed during the Gallo-Roman period (Fig. 5), associated with a sharp decrease of the arboreal and riparian forests, this latter being relatively stable throughout the record until the Gallo-Roman period. This is also confirmed by archeological data, which attests to the Gallo-Roman occupation along the Sauldraye River (González de la Aleja, 2008). This population may have cleared the Guidel marsh in order to intensively develop cultivation. In the Bay of Brest (Pors Milin), the same observation has been made from a sharp decrease of the alluvial forest (mainly *Alnus*) at the start of the Gallo-Roman period (Fig. 5). The introduction of *Juglans* in the Armorican Domain, especially in the southern part of the region, indicates commercial practices, especially by the Venetii tribe. An early introduction, since the late Mesolithic period (8700 cal BP), of *Juglans* is suggested by several authors (Barbier and Visset, 1997; Visset et al., 2002), while it is commonly recognized that this taxon was introduced by Romans (Pitte, 1986) (Fig. 5). At the top of the record, covering the Middle Ages, the appearance of *Fagopyrum* signals a regional introduction of exotic plants imported from Asia. Also, the occurrence of *Juglans*, synchronous with a maximum development of *Cerealia*, suggests periods of intensification of agricultural activities, probably related to a major population expansion during the Middle Age Optimum.

7. Conclusion

Brittany is a perfect location in which to study past human settlement because of the numerous archeological sites and monuments found inland and along the coast. The present multiproxy study based on fossil bio-indicators (pollen) permits the reconstruction of environmental changes that took place on multi-decadal to centennial-time scales. At Guidel, both paleoenvironmental and archeological data allow us to discuss the role played by human and natural factors on vegetation changes. Comparison of vegetation shifts recorded at Guidel with mid-Neolithic archeological records suggests that human activity was important around the site and has impacted vegetation fluctuations between 6500 and 5500 cal BP, but also that human displacement was provoked by climate shifts involving major storms. Our study suggests that during the Mid-Neolithic at Guidel the increase of storm events, combined with sea level change, has provoked coastal geomorphological changes (breaching of barrier dunes and redistribution of tidal channels also induced by increasing humidity), which caused abandonment of the coastal area by human societies. This study also points out substantial differences existing between the Neolithization process of northern and southern Brittany that may be explained by different geomorphological contexts: large coastal marshes in southern Brittany allowing human settlement and expansion, versus narrow coastal marshes in northern Brittany.

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