WHY THE SUBMERGED SEALED BEACHES, LAST REMNANTS OF THE LOW STANDS OF THE UPPER PLEISTOCENE REGRESSION, ARE BETTER EXPRESSED IN THE WESTERN THAN IN THE EASTERN ENGLISH CHANNEL?

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Abstract. It is known that the Pleistocene conglomerate found under the English Channel results from the cementation of old beaches under a loess cover when the seawater was at lower levels. This conglomerate represents the only remnants of the Upper Pleistocene low stands of the sea. In the Western English Channel the various remnants of the beaches are clearly separated and always follow the bathymetry on their western side, which suggests a discontinuous cementation. On the contrary, in the Eastern English Channel, it seems that the cementation has been continuous, even during the high stands of the sea. Since an underwater cementation cannot be envisaged during these cold periods of time, a study of the now submerged river valleys and of the onshore neighbouring loess has been developed. They suggest that the observed discrepancy is not related: 1/ to a local erosion of the conglomerate by the rivers during lower stands of the sea; 2/ to the thickness of the initial loess cover; 3/ to their carbonate concentration. This discrepancy is more likely the result of a local overlap of some of the consolidated beaches during the little transgressions which interrupted the general regression.

Highlights

- The conglomerate of the English Channel corresponds with old cemented beaches.
- The beaches were cemented under Weichselian loess during low stands of the sea.
- The distribution of the old beaches is different in the Western and Eastern English Channel.
- This discrepancy is not the result of different cementation processes or of erosion.
- It results from a different orientation of the beaches with respect to the general EW loess deposits coating the submerged basement cliffs.

Key words: English Channel, Quaternary, submerged conglomerate, Upper Pleistocene regression, loess deposits, submerged riverbeds

1. INTRODUCTION

The Pleistocene conglomerate sampled in the English Channel (Fig. 1) is a unique formation apparently never described elsewhere in the world. Its formation has been at the origin of long debates during the sixties. It is only in 1969 (Lefort, 1969), thanks to the presence of loess particles infilling some gastropod shells incorporated in the conglomerate, that its formation was better understood. More recently a new study of this submerged formation provided a better understanding of its relationship with the past loess formations (Danukalova and Lefort, 2009; Lefort *et al*., 2011). However, these two papers were only concentrating on the Western English Channel. The incorporation of unpublished sedimentological data previously collected in the Central and Eastern English Channel to the scheme already established for the Western English Channel evidences a very different distribution of the submerged conglomerate in the Western and in

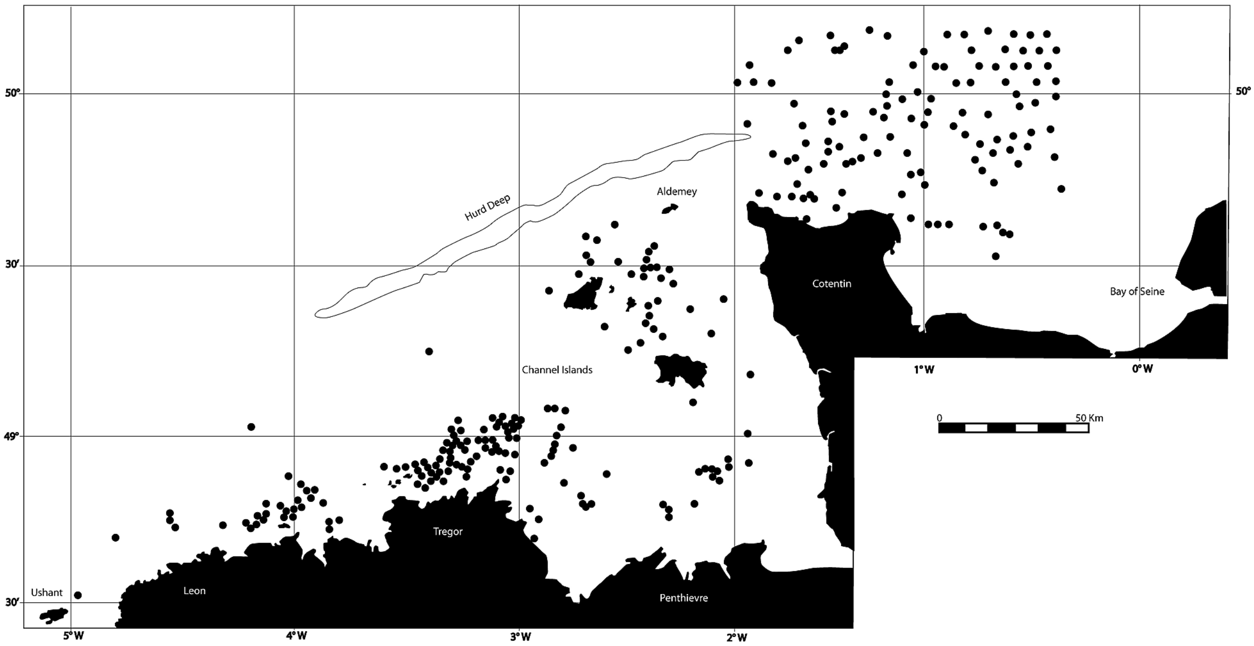

Fig 1. Location of the conglomerate samples dredged or cored in the Western and Eastern English Channel.

the Eastern English Channel. In the Western English Channel the various outcrops are always limited by clear isobaths on their Western side (Fig. 2). On the contrary, in the Eastern English Channel, the distribution of the samples (Fig. 3) suggests the existence of a large and continuous outcrop which developed during the same period of time. In order to be sure that this discrepancy was not related with an heterogeneous sampling procedure, we have checked if there were other conglomerate outcrops off the bathymetric limits observed in the Western English Channel. Only three samples of conglomerate seem to be located a little bit out of the main limits shown on Figure 2. This is not due to an error in the location of the samples or to an exception in the conglomerate distribution, but to the smoothing of the bathymetric isolines at the scale of Figure 2.

The purpose of the present paper is to try to understand the origin of this discrepancy. The main consequence of this different organization raises the following question: why the discontinuous cementing process of the beaches observed in the West appears to be continuous in the Eastern English Channel?

2. REGIONAL SETTING

Although the English Channel is usually subdivided in three parts, the Western, Central and Eastern English Channel, in the following text we will only speak of the Western and Eastern English Channel since the Central English Channel only represents a narrow zone of the Eastern English Channel. No loess has ever been sampled under the English Channel. This very fragile formation has been eroded during the various Pleistocene transgressive episodes and mainly during the Holocene transgression. It is clear that the submarine Pleistocene conglomerate which will be described below does not represent the only marine formation which deposited at that time, but we are actually unable to separate their contribution from the actual sedimentation since they were not cemented. This is mainly true for the large boulder formation which is spreading between Brittany, Normandy and the Hurd Deep (Lefort, 1969; Quesney, 1983; Larsonneur *et al*., 2006).

3. MATERIAL AND METHODS

Our research is based on the study of 277 samples of conglomerate. 23 samples were collected around the Channel islands (Hommeril, 1967), 2 were gathered West of Alderney (Fily, 1972), 92 samples were dredged north of Tregor (Lefort, 1969) and 46 others north of Leon (Boillot, 1964). The information recorded west of Brittany shows that only one sample of conglomerate was dredged in the Ushant deep (Hinschberger, 1969). The general map (Fig. 1) also incorporates qualitative information resulting from various coring surveys organized in the St Brieuc Bay (Lefort and Deunff, 1971, 1974) and around the Channel islands (Andreieff *et al*., 1975).

On this figure it can be observed that the conglomerate is always located south of the Hurd Deep Trough in the Western English Channel, in contrast to the Eastern English where it is also found on its Northern side. Considering that this paper is dealing, both with marine and continental data, we have compared in a systematic way the onshore and offshore information (Plate 1). The same proceeding has been adopted for the Eastern English Channel where most of the data were unpublished.

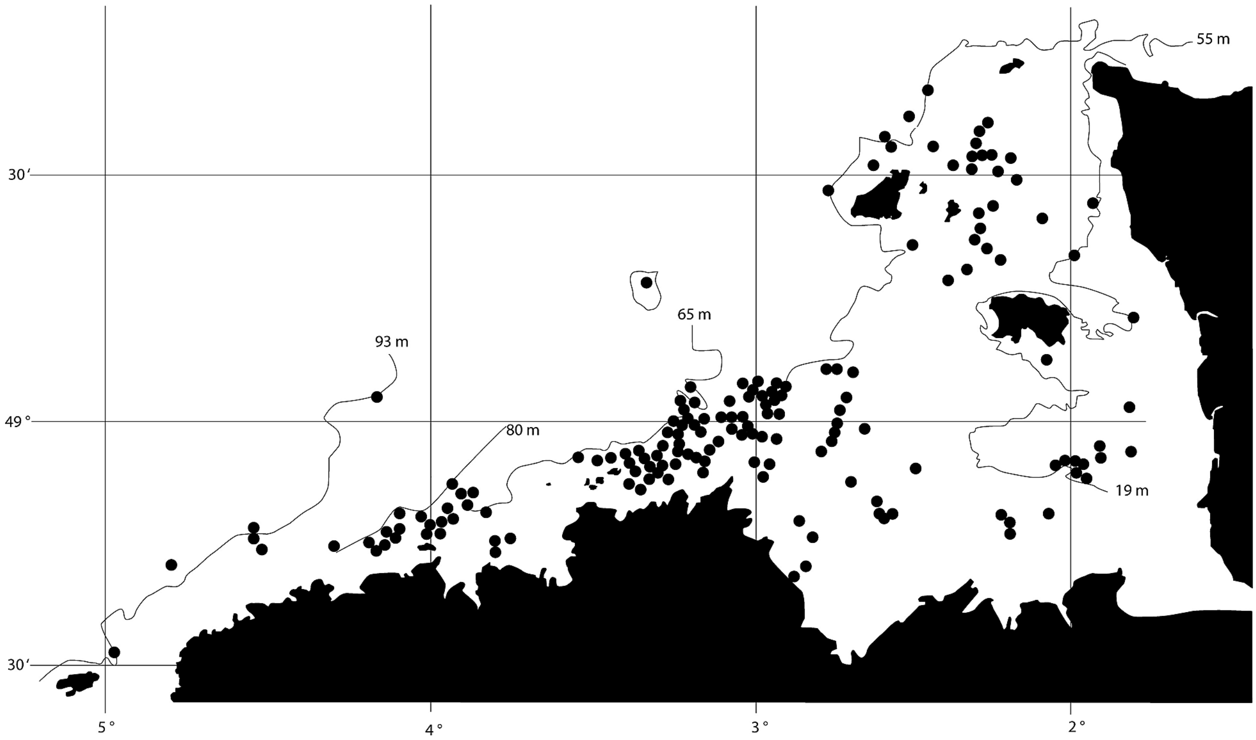

Fig 2. Delineation of the western boundaries of the conglomeratic belts recognized in the Western English Channel. The bathymetry is given in meters.

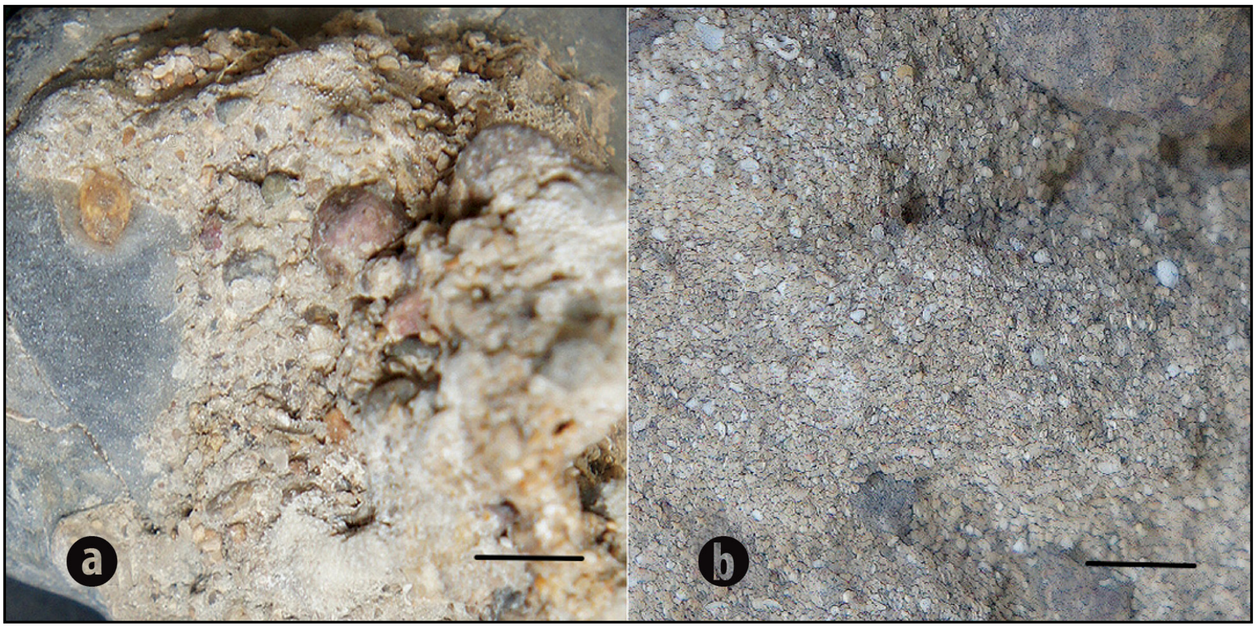

Plate 1. a) Dredged marine conglomerate (note the remnants of a bryozoan in the upper right corner of the slide); **b**) Infra-loessic conglomerate collected onshore at the base of the Nantois cliff. Black scales: 1cm.

4. RESULTS

The three papers already published about the Pleistocene conglomerate discovered in the Western part of the English Channel (Lefort, 1969; Danukalova and Lefort, 2009; Lefort *et al*., 2011) show that the Pleistocene conglomerate represents the only remnant of old beaches which existed during the various Upper Pleistocene low stands of the sea. For a better understanding of the following discussion, we will remember very shortly some of the conclusions previously obtained for the Western English Channel. We will also incorporate in this summary many data previously unpublished.

4.1. The conglomerate sampled in the Western English Channel and its relationship with the onshore loess

The complete description of the clastic component of this conglomerate is given in Lefort (1969). It is mainly composed of granites, schists, sandstones and volcanic rocks. Aplites, flints and quartz are less well represented. Save flints, all these rocks are of a local origin. Their shape is very similar to the pieces of rocks found in the onshore "head" formation. The calcareous cement also incorporates small gravels and a few grains of quartz which do not show any sign of transportation.

The conglomerate contains also a marine fauna previously described by Boillot (1964), Lefort (1969), Hommeril (1967) and Fily (1972). The shells included in this conglomerate represent a large variety of species identical to the actual fauna. A detailed study of this fauna shows that we are usually dealing with a mixture of faunas which were previously living at different depths (Danukalova and Lefort, 2009). When the limits of the conglomeratic belts are clear, the easternmost side of each belt is always characterized by a typical littoral association (Peacock, 1993; Funder *et al*., 2002; Mikhailova and Bondarenko, 1997), the mixture of the different associations being always located at a deeper depth than the littoral association. This distribution can only be generated during a regressive movement of the sea level otherwise the pure littoral associations would have not been preserved at a shallower depth.

Five belts limited by the isobaths –19m, –55, –65, –80 and –93m have been recognized (Fig. 2), but the separation between the –19m and –55m belts is not clear. More details about the extension of the sealed beaches are given in Danukalova and Lefort (2009). The Western side of each belt can be followed with precision contrary to the Eastern limit which is sometimes less clear.

Unfortunately, because the collected samples are almost always alterated, no valid age has ever been obtained, either on the cement, or on the poorly preserved marine shells. Nevertheless, it is clear that this conglomerate must correspond with a recent formation otherwise it would have been completely destroyed because of its fragility. In order to obtain an estimation of the ages of the different belts of conglomerate, the depths of the limits of the fossil beaches have been projected on one of the Shackleton's sea level curves (Shackleton, 1987). Other more recently published sea level curves could have been used (Siddall *et al*., 2006), but the projection of the marine and continental data on these curves is not as clear as on the smoothed (Buchdahl, 1995) Shackleton's curve which seems to better fit for the English Channel. The ages of the continental sediments (dated at 140 ka by stratigraphy – Monnier, 1980) and at 103, 82, 67, 27, 22, 21 and 18 ka by OSL technique (Loyer *et al*., 1995; Folz, 2000) have been also projected on the same curve. On this curve we can evidence a clear alternation between the sealed beaches and the loess or loess-like deposits known onshore (Fig. 4). More details about this alternation can be found in Danukalova and Lefort (2009) and Lefort *et al*. (2011). Only the long lasting low stand episodes permitted the accumulation of enough loess sediment to develop a basal conglomerate by decalcification.

4.2. The conglomerate sampled in the Eastern English Channel and its relationship with the onshore loess

North of Cotentin, in the Central English Channel and West of the Bay of Seine, the conglomerate displays a very different distribution since it has been sampled at all the depths ranging between –15 and –93 meters without any disruption (Fig. 3). Like in the Western English Channel, the calcareous cement incorporates gravels and boulders of various origins (Larsonneur, 1971), but in this particular area, flints, often well rounded, represent the most important petrographic class of rocks. The predominance of flints is clearly associated with the bedrock which is constituted by Jurassic, Cretaceous and Cainozoic outcrops. Contrary to what was observed North of Brittany, the quartz grains show evidences of water polishing. It was also found a tooth of mammoth showing remnants of a Pleistocene calcareous cement (Larsonneur, 1971). Taken as a whole the environment of the sealed beaches of this area suggests a more open space than that located immediately North of Brittany.

Some of the samples contain a fauna identical to the actual fauna save a few rare species which show a thicker shell and some little differences in shape with the modern fauna. It is the reason why they were considered to show an "archaic" character (Larsonneur, 1971).

Here again we have projected the limits in depth of the conglomerate and the dates obtained onshore on loess in Normandy by thermoluminescence (Wintle *et al*., 1984) on the 1987 Shackleton's sea level curves (Fig. 5). It must be stressed that all the available ages were obtained on "true" loess and not partly on loess-like deposits like in Brittany. Ages of 139, 125, 88, 80, 75, 18, 14, 13 and 11 ka were obtained. The most important observation is that the cementing process of the buried beaches seems to have been continuous during all the period ranging between 110 ka and 30 ka.

This observation is difficult to interpret since it implies that some cementing process was also possible during the short transgressive episodes which affected the general Upper Pleistocene regressive phase (Figs. 4 and 5). The hypothesis of an underwater cementation is not satisfactory since this evolution is only possible in a very warm climate (Ginsburg, 1954; Nesteroff, 1954; Ranson, 1955).

5. DISCUSSION

The purposes of the following discussion is to try to understand the origin of the discrepancy observed in the distribution of the submerged conglomerate sampled in the Eastern and Western English Channel.

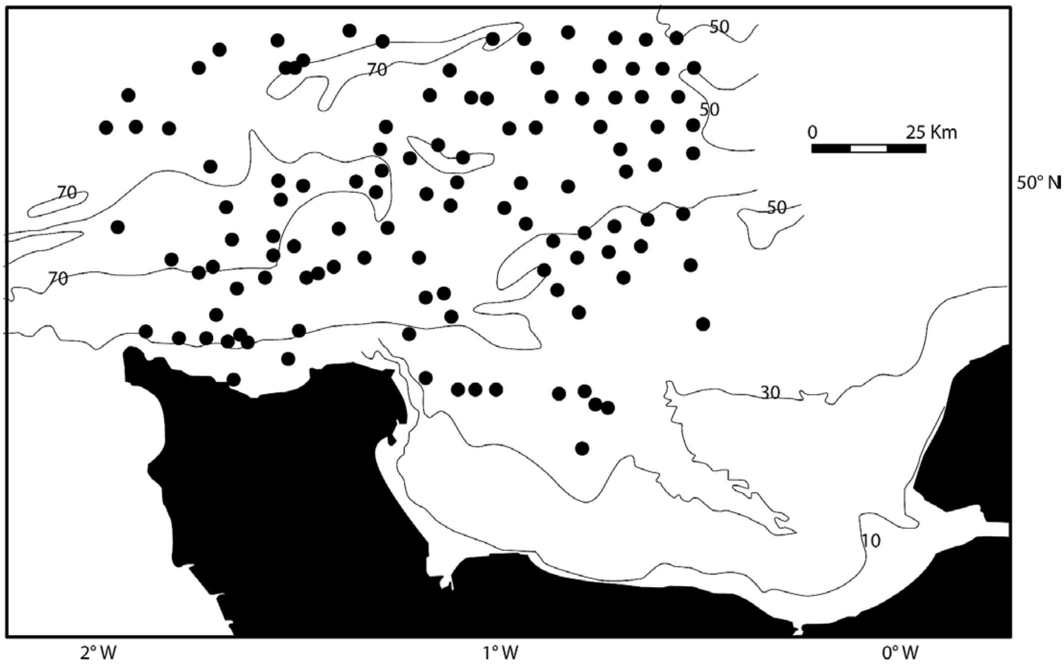

Fig 3. Location of the conglomerates sampled north of Cotentin (Normandy) (partly after Larsonneur, 1971). The bathymetry is given in meters.

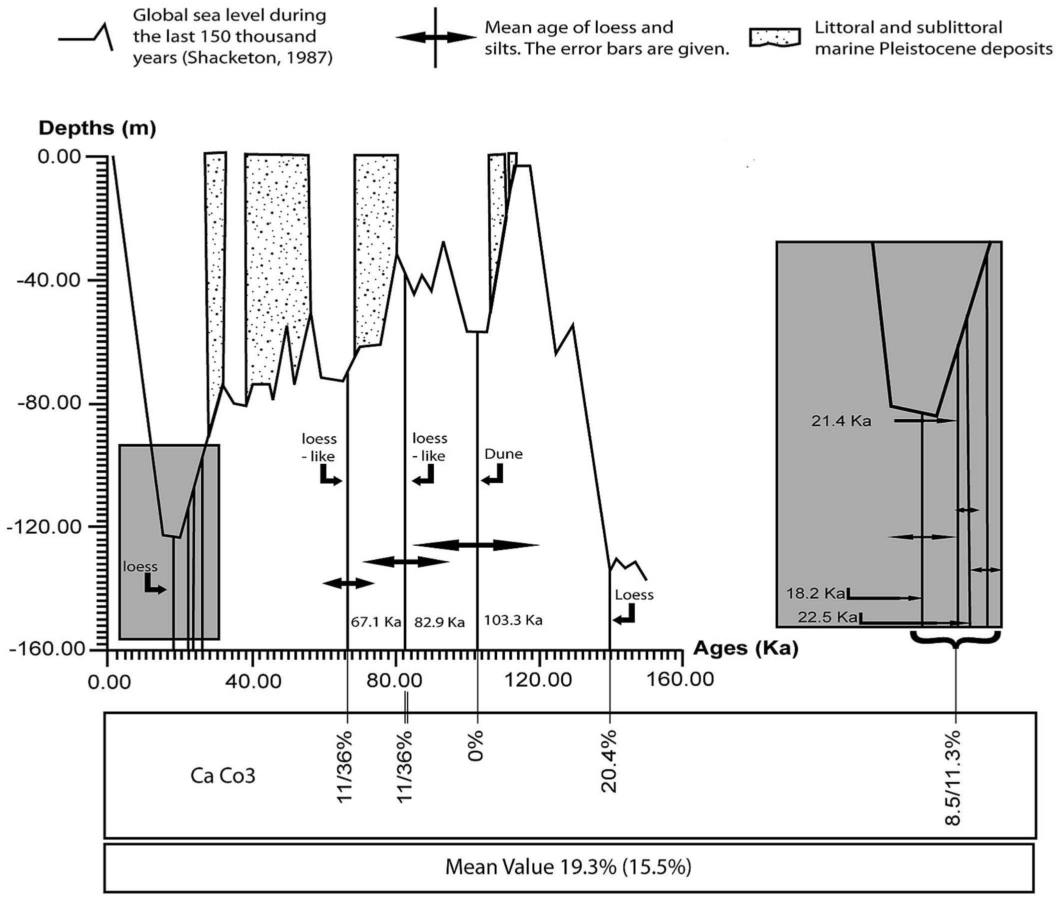

Fig 4. Comparison between the depths of the submarine cemented beaches recognized in the Western English Channel and the mean age of the continental sediments deposited in Brittany during the last 150 thousand years. Both data are projected on the global sea level curve of Shackleton (1987). Modified from Danukalova and Lefort (2009). The carbonate concentration of the dated samples is given under the sea level curve.

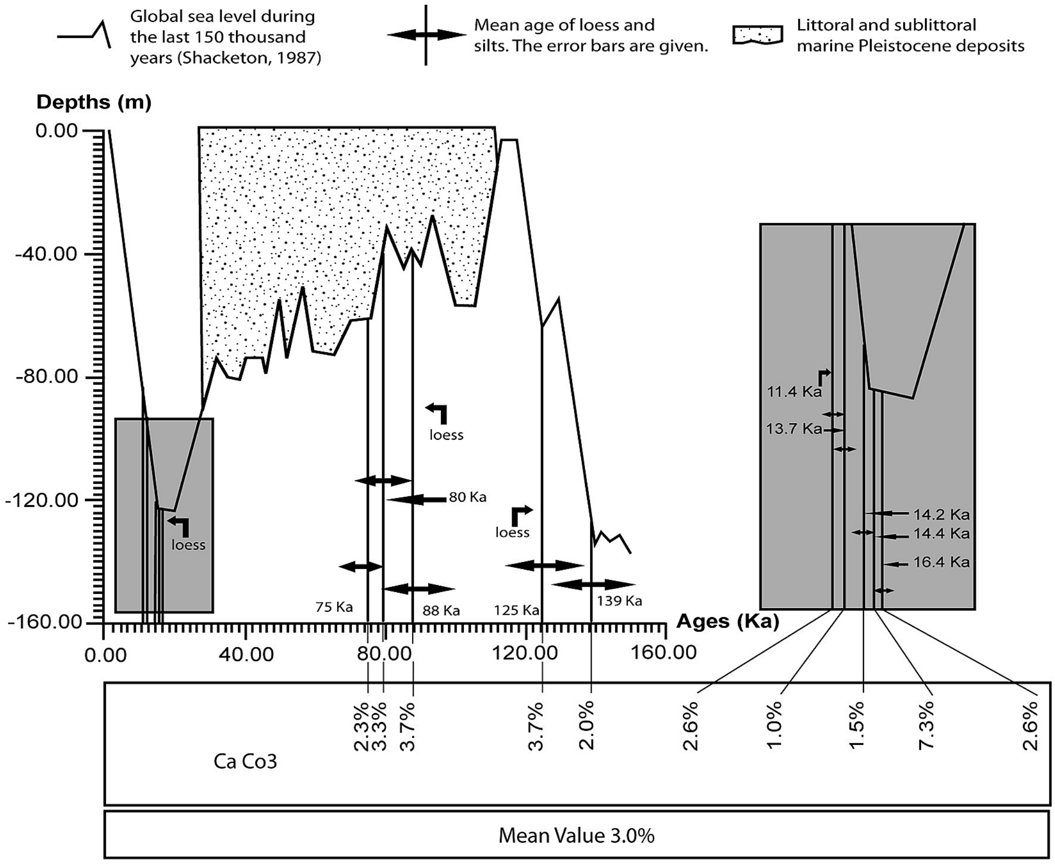

Fig 5. Comparison between the depths of the submarine cemented beaches recognized in the Eastern English Channel and the mean age of the continental sediments deposited in Normandy during the last 150 thousand years. Both data are projected on the global sea level curve of Shackleton (1987). The carbonate concentration of the dated samples is given under the sea level curve.

5.1. Is the observed discrepancy related with the past regime of the rivers ?

Because the Pleistocene conglomerate is usually thin and never thicker than 20 cm (Andreieff *et al*., 1975) it could have been locally dissected by the erosion of the rivers during the more recent low stands of the sea. It is now known that the distribution of the submerged river valleys is very different in the Western and Eastern English Channel (Alduc *et al*., 1979). The Eastern part of the Channel is characterized by the large development of braided rivers which were connected to the Seine, Somme, Rhine and Thames Rivers (Gibbard, 1988). On the contrary, the Western Channel is only crossed by the deep and narrow Hurd Deep Trough (Lefort, 1975) where the mid-Channel river was running during the regressive episodes of the sea (Fig. 6). However, when we superimpose the location of the conglomerates sampled in the Eastern English Channel (Larsonneur, 1971) (Fig. 3) with the map of the river valleys (Fig. 6) we can observe that the distribution of the sampled sites is not affected by these large valleys. So far, as the Western English Channel is concerned we can observe that the Northeast trending limits of the conglomerate boundaries (Fig. 2) are never superimposed on the course of the submerged rivers which are always trending in a North-West or East-West direction in this area (Quesney, 1983).

5.2. Was the observed discrepancy related with the carbonate concentration of the loess previously superimposed onto the beaches ?

As said above, the loess previously deposited in the English Channel does not exist anymore under the sea since it was removed during the various Quaternary transgressions. The last Weichselian loess was itself removed by the Holocene transgression. However, we can have an idea of the initial carbonate concentrations by looking at the neighbouring loess existing along the shore (Figs. 4 and 5). We already know that part of these carbonate particles were generated by frost shattering of the Cretaceous and Cainozoic cover (Lautridou, 1970, 1971; Murton, 1996; Murton *et al*., 2003; Murton and Lautridou, 2003). Another source was represented by the coccoliths and the foraminifers (Estéoule *et al*., 1971) sometimes found in the same sediments, but the relative contribution of frost shattering and coccoliths is unknown.

Figures 4 and 5 which also incorporate the $CaCO_3$ concentration of the samples (Wintle *et al*., 1984) and layers (Monnier, 1980) collected for geochronology, show that the mean

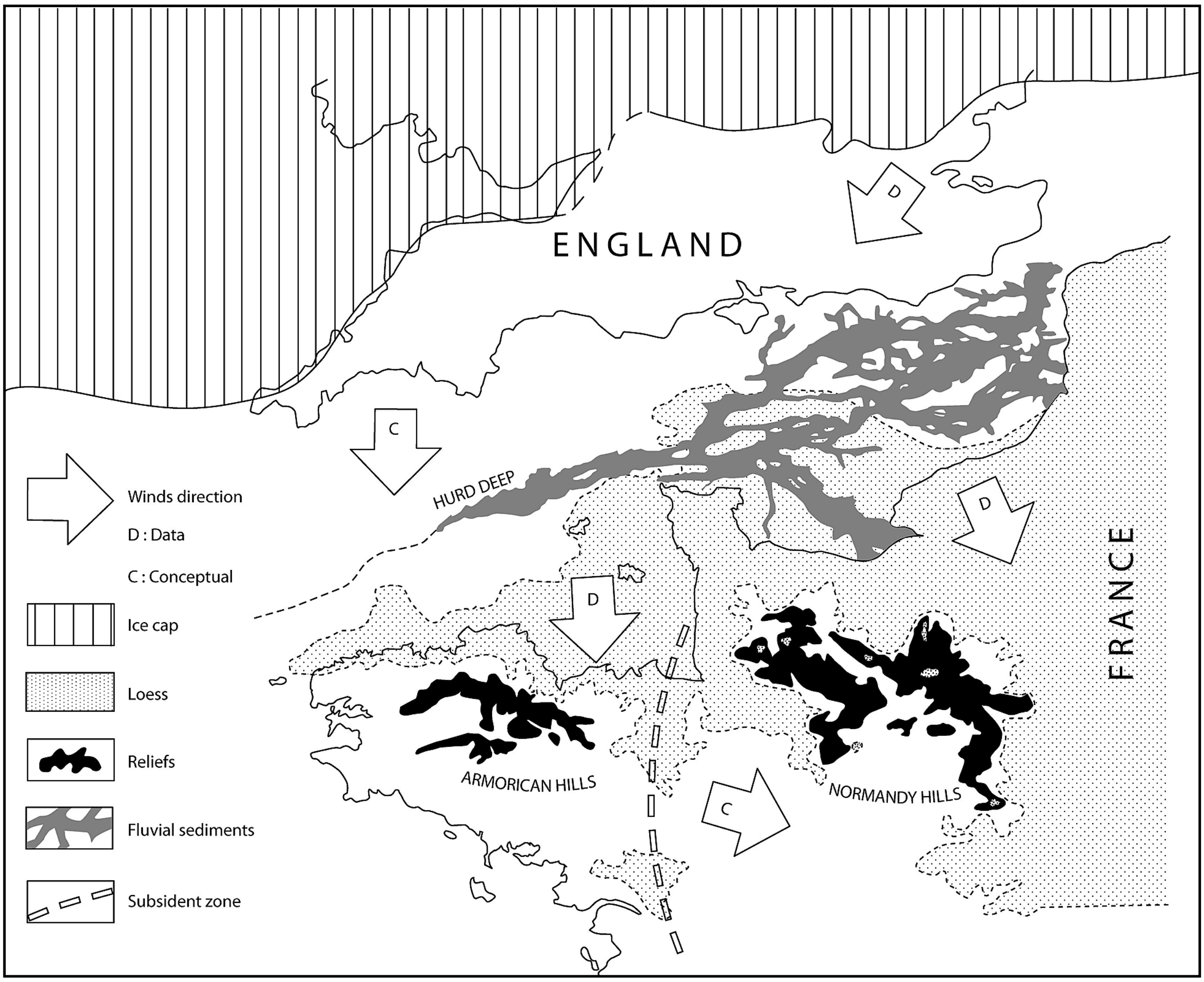

Fig 6. General distribution of the submerged fluvial and loess deposits recognized in Brittany, Normandy and under the English Channel during the Upper Pleistocene. The wind directions are given. Loess deposits and conglomerates are shown with the same pattern. The onshore contours are based on the map published by Basse de Menorval and Théobald (1974). The offshore contours are based on the extension of the conglomerates sampled under the English Channel. The contours of the fluvial deposits are taken from Lericollais (2007).

value obtained for Normandy is 3% whereas it reaches 19% (or 15% if we keep the result of the decalcified eolian dune of Nantois in our calculation) in Brittany. The concentration in $CaCO_3$ in the loess and loess-like formations deposited along the Brittany shore is thus, more than 6 times higher than in Normandy. Because the transfer of the loess particles was the same onshore and offshore (Lefort *et al*., 2011) it is difficult to accept that the discrepancy observed in the distribution of the conglomerate was associated with a higher carbonate concentration of the loess deposited off Normandy.

5.3. Was the observed discrepancy related with the thickness of the loess deposited on the beaches during the regressions ?

Since we know that the submerged conglomerate was generated by the decalcification of the superimposed loess formation, the thickness of the initial loess deposits is an important factor since a thin loess formation rich in carbonates could have generated more cement than a thick pile of loess poor in carbonates. This original thickness is impossible to estimate. However, if we refer again to the onshore data (Antoine *et al*., 2003) we can conclude that the general thickness of the loess cover (which is ranging between 2 and 4 meters onshore) was probably more or less of the same off Brittany and off Normandy.

Taken as a whole, it can be suggested that the larger development of the conglomerate observed off Normandy was neither related with the concentration in carbonates, nor with the thickness of the overlying loess.

5.4. Was the style of deposition of the offshore loess at the origin of the observed discrepancy ?

We already know that there were preferential places controlling loess accumulations (Lefort *et al*., 2011). Along the shore the thickest loess accumulations are usually coating the old basement cliffs (Danukalova *et al*., 2013). A few accumulations seem to be also associated with topographic depressions (Lefort, 2011) characterized by a high degree of moisture able to catch loess particles (Monnier, 1980). Although it is suspected that the depositional history of the offshore loess was the same as onshore, the location of the offshore conglomerate (and thus of the original extension of the loess deposits) has been studied along four north-south sections (Fig. 7). Sections 4, 3, 2 and the southern part of section 1 display the same depositional configuration as that observed onshore, that is to say that the loess particles were stacked onto North facing basement cliffs. It can be observed on the first three sections that the flat surfaces which were swept by the winds (the deflation zones) never display any conglomerate. However, the relatively „flat surface" of the northern part of section 1 is also sealed by a conglomerate where it is running across the braided river system (which was probably characterized by a high moisture environment). Section 1 of Figure 7 is also characterized by three bathymetric breaks located at -55, -80 and -93 m. Those breaks are equivalent to the limits of some of the cemented beaches shown on Figure 2. This convergence is a key observation since it shows that the apparent continuity observed north of Cotentin (Fig. 3) may result from the „condensation" of the different conglomeratic belts observed on Figure 2.

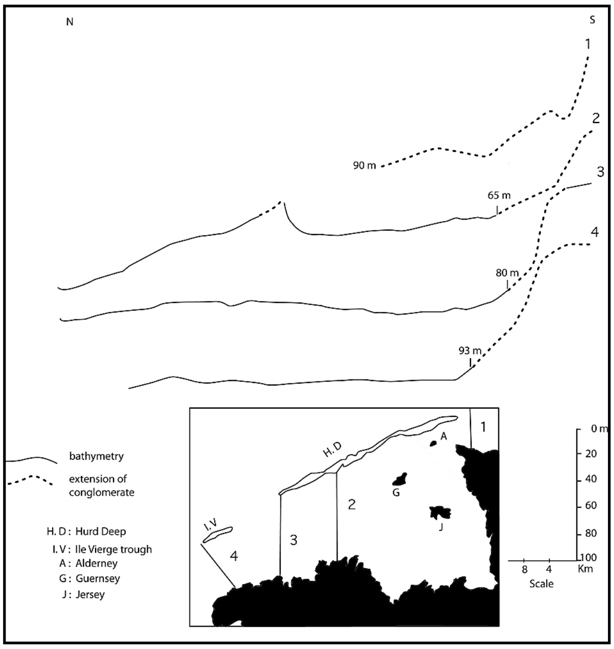

Fig 7. Bathymetric sections running between the Hurd Deep and the Brittany or Normandy (Cotentin) shorelines. Dashed lines represent the conglomerate outcrops. Depths are given in metres. Note that the lower limit of the conglomerate corresponds with the boundary between the flat Mesozoic and Cainozoic surfaces (deflation zones) and the Palaeozoic basement cliff (accumulation zones) on sections 2, 3 and 4.

We can conclude that the larger extension of the conglomerate delineated north of Cotentin Peninsula (Fig. 3) results from a cliff-catching process prolongated in the North by a marshy environment associated with the braided rivers (Fig. 6) able to stick loess particles and to generate a conglomerate. This conclusion explains the difference in size observed between the Western and Eastern extension of the conglomerate, but not the orientation of the belts of conglomerate mapped in the Western English Channel.

5.5. What tells us the large-scale onshore transverse sections across the loess deposits ?

It has been already said (§ 3) that the global thickness of the loess deposits was about the same in the East (Normandy) and in the West (Brittany). The same observation can be made at a large scale (that is to say in an East-West direction) along the Northern Brittany shoreline (Monnier, 1973). However this more or less regular thickness cannot be observed on the North-South sections (Fig. 8). In this case the thickness of the loess accumulation decreases slowly and regularly towards the North when moving away from the loess and basement cliffs. At the base of the loess accumulation, the water carrying the dissolved carbonate mineral (Billard *et al*., 1992) often generates a thick and hard limestone crust. This crust is thicker and more resistant under the thickest loess accumulations (Tricart, 1972). The main consequence of this regular variation in thickness is a lower degree of cementation when the loess cover is thinning (Fig. 8). In conclusion, and since the shore is oriented in an East-West direction, the possibility of cementation decreases towards the North and follow a gradient which is broadly perpendicular to the actual shoreline.

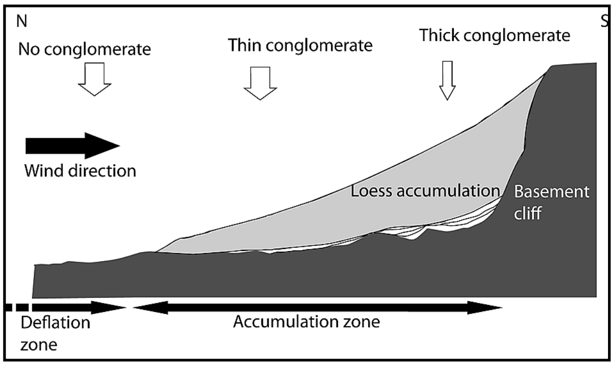

Fig 8. Typical North-South section across a coastal loess accumulation before its actual erosion (synthetic diagram).

All these data have been incorporated in the model presented below and explain why the eastern and western conglomerate outcrops display a different organization.

5.6. What were the main environmental and physical characteristics which controlled the cementation of the conglomerate ?

The main environmental and physical characteristics which controlled the cementation of the conglomerate sampled in the English Channel are summarized below:

5.6.1. Main features characterising the Western English Channel

The data previously discussed show that the Upper Pleistocene conglomerates sampled in the Western English Channel results from the intersection of two types of physical parameters showing two gradients decreasing in a different direction:

1. The first gradient corresponds to a northward decreasing aptitude of the loess to generate a basal conglomerate (Fig. 8).
2. The second gradient is represented by a North-West deepening of the bottom of the sea which is not parallel with the actual shoreline (Fig. 2). As a consequence the fossil beaches associated with the different transgressions and regressions were crosscutting obliquely the East-West loess belt.
3. A third constraint has been evidenced after a detailed study of two successive conglomeratic belts located off Leon area (Danukalova and Lefort, 2009). In this area it was shown that it may exist, in places, a small overlap between two successive submerged beaches (Fig. 9), the upper limit of the younger sealed beach overlapping locally the lower limit of the older beach. The same observation can be made in section on Figure 4 if we look at the boundaries of the submerged beaches. This particular organization is associated with the small transgressive episodes which developed during the general Upper Pleistocene regressive phase (Figs. 4 and 5).

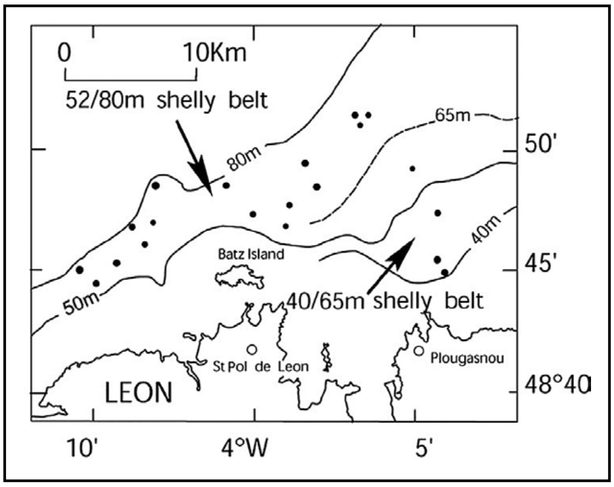

Fig 9. Detail of the superimposition between an old and a new conglomeratic belt delineated off Leon. After Danukalova and Lefort, 2009.

5.6.2. Main characteristics of the Eastern English Channel

The information collected in this area can be compared with the situation characterizing the Western English Channel.

It probably also existed in this area a northward decreasing aptitude of the loess deposits, stacked onto the basement cliff, to generate a basal conglomerate (Fig. 8). Here again the loess belt was broadly oriented in an East-West direction following the Cotentin and Normandy shorelines (Fig. 3). But contrary to the Western English Channel the deepening of the bottom of the sea is parallel to the shoreline. As a consequence the fossil beaches associated with the different transgressions and regressions were also trending in an East-West direction.

6. CONCLUSION

Since the Upper Pleistocene regressive history of the sea was necessarily the same off Normandy and off Brittany the interpretation proposed to explain the first area must be also valid for the other zone. Part of the difficulties we met to separate the different conglomeratic belts sampled in the Eastern part of the English Channel were due to the small overlap which may develop between two successive cemented beaches, but also to the parallelism which existed between the thickening loess cover and the East-West oriented isobaths. On the contrary, in the Western English Channel the thinning of the deposited loess was oblique with respect to bathymetry (Fig. 10). In this case, the poorly cemented zones, located away from the shore were easily destroyed during the little transgressive episodes (Fig. 11). It is the reason why we can now observe well-cemented beaches in front of poorly or now disappeared conglomeratic belts (Fig. 12). The observed discrepancy is an excellent example of how two identical stratigraphic successions (the regular alternation of marine and continental deposits through time) may display a different horizontal distribution, not because of sedimentological reasons, but because of local geometrical considerations associated with the geomorphological environment.

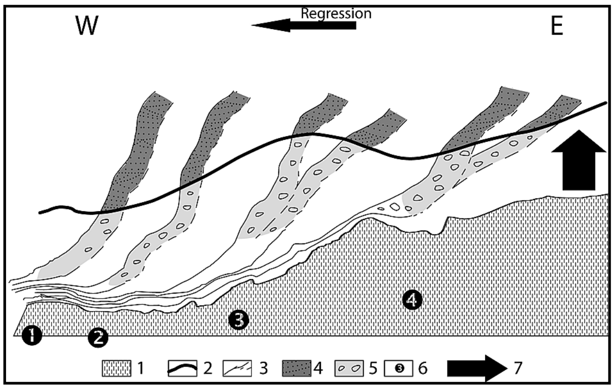

Fig 10. Conceptual model showing the possible relationships existing between various regressive beaches oriented in an oblique direction with respect to the general trend of the shoreline and the thinning of the loess deposits towards the North. Cases 1 to 4 show the possible superimposition of two fossil beaches. **1**: Continent; **2**: Northern limit of the loess deposits; **3**: Bathymetry; **4**: Unconsolidated beaches; **5**: Consolidated beaches; **6**: Examples of belts association; **7**: Decreasing thickness of the loess deposits.

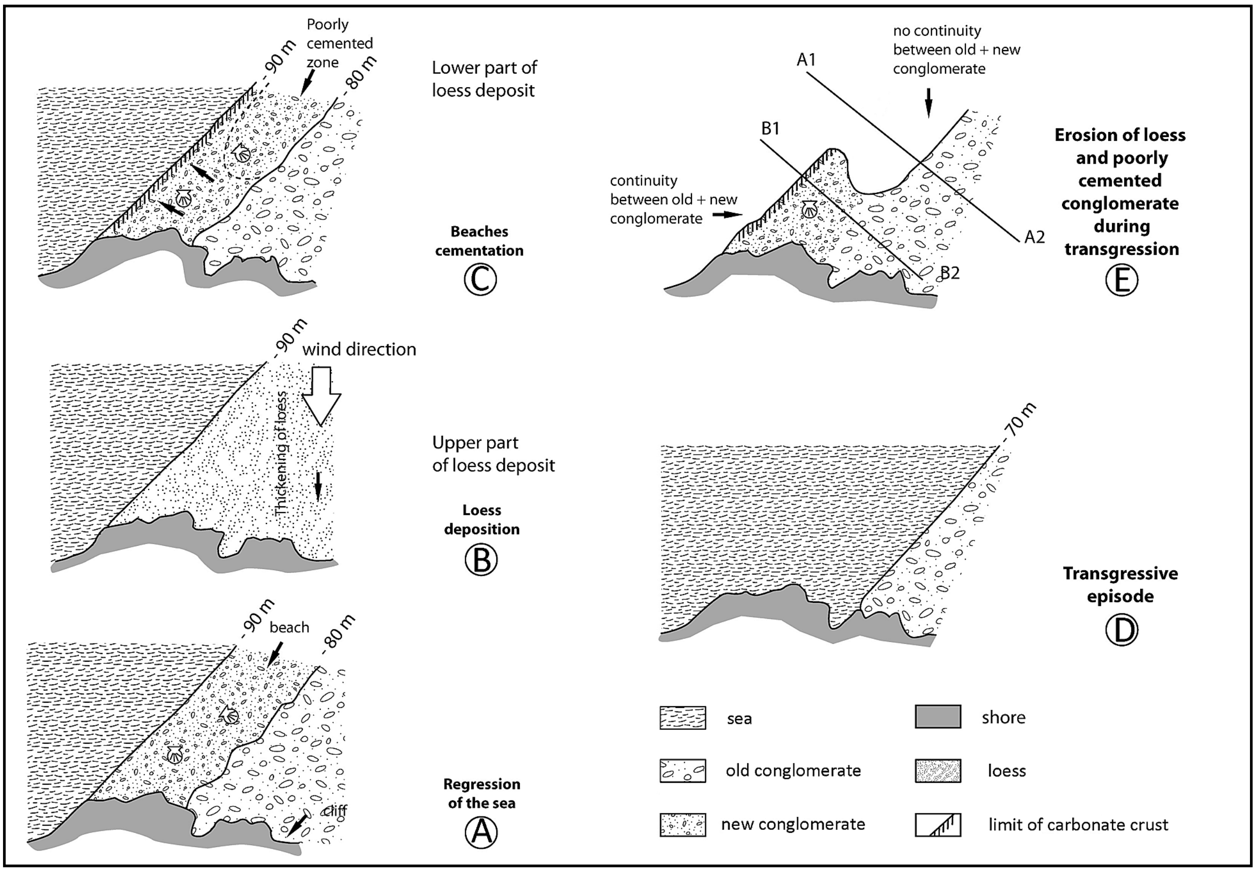

Fig 11. Possible evolution of the now submerged conglomerate of the Western English Channel. **A**) Beginning of a regression and formation of a beach; **B**) Deposition of loess, thickening towards the shore, over the beach and the old conglomerate; **C**) Irregular cementing process at the base of the loess deposits; **D**) New transgression and erosion of the poorly cemented beach; **E**) New regression. Section **A1-A2**: Only the old conglomerate appears; **B1-B2**: Apparent continuity between the old and the new conglomerate.

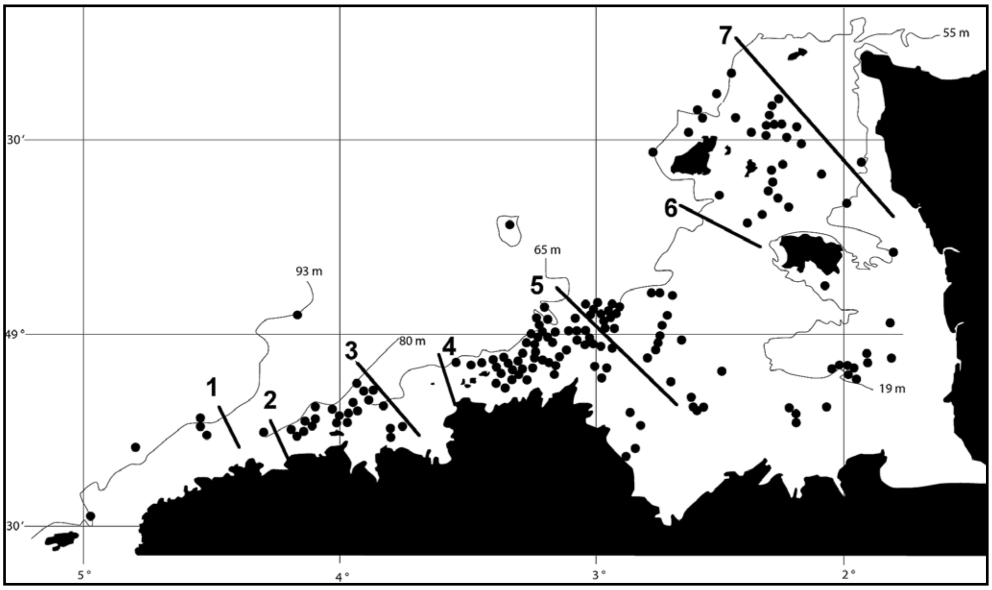

Fig 12. Selected sections running across the conglomeratic belts of the Western English Channel showing different types of associations between two neighbouring belts. Sections 2, 4 and 6 show the limits of the younger conglomerates; Sections 3, 5 and 7 show the continuity between a younger and an older conglomeratic belt.

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