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The Neogene and Lower Pleistocene crags of Upper Normandy: Biostratigraphic revision and paleogeographic implications

Les faluns Néogène et Pléistocène inférieur de Haute-Normandie : révision biostratigraphique et implications paléogéographiques

Olivier Dugué [a,*,b], Chantal Bourdillon [c], Florence Quesnel [d], Jean-Pierre Lautridou [b,†]

[a] *Université de Caen, département des sciences de la terre, esplanade de la Paix, 14032 Caen cedex, France*
[b] *UMR 6143 CNRS, laboratoire de morphodynamique continentale et côtière (M2 C), 24, rue des Tilleuls, 14032 Caen cedex, France*
[c] *ERADATA, 170, avenue Félix-Geneslay, 72100 Le Mans, France*
[d] *BRGM, GEO/G2R, BP 36009, 45060 Orléans cedex 2, France*

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A B S T R A C T

The biostratigraphic revision of the benthic foraminifera present in the coastal Cenozoic quartzose and shelly sands (crags) at Fécamp and Valmont (Seine-Maritime) reveals Early Pliocene (Fécamp) and Early Pleistocene (Valmont) ages. The Tortonian-Messinian thanatocœnosis contained in the Fécamp Crag shows the presence of a former bryozoan-rich platform on the floor of the Channel that was reworked during the Lower Pliocene transgression. Tortonian-Messinian and Lower Pliocene deposits have been found in Belgium, England, Brittany, and at Fécamp, but are absent in Cotentin (North-West Normandy), which was uplifted at this period. The Lower Pleistocene tidal sands and crags described in Cotentin, Upper Normandy and the southern North Sea Basin indicate a marine passage between the Channel and the North Sea.

R É S U M É

La révision biostratigraphique des foraminifères benthiques trouvés dans les sables coquilliers et quartzeux côtiers cénozoïques de Fécamp et de Valmont (Seine-Maritime) propose un âge Pliocène inférieur (Falun de Fécamp) et Pléistocène inférieur (Falun de Valmont). La mise en évidence d'une thanatocœnose tortono-messinienne conservée dans le Falun de Fécamp indique l'existence d'une plate-forme à bryozoaires à cette époque sur les fonds de la Manche, remaniée lors de la transgression au Pliocène inférieur. Les dépôts tortono-messiniens et du Pliocène inférieur sont trouvés en Belgique, Angleterre, Bretagne et à Fécamp, mais sont absents dans le Nord-Ouest de la Normandie (Cotentin), soulevé à cette époque. Au Pléistocène inférieur, la présence de faluns et de sables tidaux décrits dans le Cotentin, en Haute-Normandie et dans le Sud de la mer du Nord atteste une communication marine entre les mers de la Manche et du Nord.

* Corresponding author.
E-mail address: olivier.dugue@unicaen.fr (O. Dugué).
† Deceased author.

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1. Introduction

The Neogene and Pleistocene sediments of NW Europe record many periods of erosion and emergence due to eustatic variations, compressive Alpine deformation and continued opening of the Atlantic during a period of generalised climatic cooling (King, 2006). Neogene and Pleistocene deposits are very extensive offshore in the western English Channel and its western approaches (Evans, 1990), on the Armorican margin, and also onshore in Cotentin (north-western Normandy) (Dugué, 2007; Dugué et al., 2005) (Fig. 1). Transgressions from the Atlantic periodically deposited coastal shelly sands or crags on the Armorican Massif whilst, at the same time, northward propagation of the Neogene compressive deformation caused repeated uplift and emergence of the Armorican block (Anderton, 2000; Ziegler, 1990). Conversely, Neogene and Pleistocene deposits in eastern Normandy (Roumois and Pays de Caux) are less well preserved on the chalky plateaux, consisting mainly of non fossiliferous fluviatile quartz sands (Sables de Lozère normands Fm.) (Kuntz et al., 1979) (Figs. 2 and 3). Forming a belt approximately 50 km wide on either side of the current Seine valley, these sands outline a paleo-Seine river draining the Massif Central and southern Paris Basin. The absence of any reliable dating for these sands explains the difficulty in arriving at paleogeographic reconstructions for the Neogene and Early Pleistocene and of comparing them with the thicker contemporary marine series of Cotentin. The only elements for biostratigraphic age determination are provided by the coastal shelly sands (Fécamp and Valmont Crags), previously dated as Early Pliocene or Brunssumian (= Zanclean) from their "warm temperate" marine foraminiferal and bivalve fauna (Bassompierre et al., 1972; Cavelier and Kuntz, 1974) and as Late Pliocene (Reuverian) and basal Pleistocene (Pretiglian) from pollen-rich clays and peats (Argiles de la Londe Fm.) (Clet-Pellerin and Huault, 1987). In NW Europe, the Pliocene-Pleistocene boundary fixed by climatic criteria, with a major cooling during the Late Pliocene defining the Pretiglian stage, at about 2.58 Ma, now corresponds to the international stratigraphic Tertiary/Quaternary boundary.

A biostratigraphic revision of the Upper Normandy crags has consequently made it possible to determine the Neogene and Pleistocene chronostratigraphy and paleogeography for the NW Paris Basin in a key area between the Atlantic domain and the North Sea.

2. Biostratigraphic revision of the Neogene and Pleistocene crags of Upper Normandy

Two formations of marine quartzose and shelly sands are known at the edge of the Pays de Caux plateau (Seine-Maritime); one at Fécamp (Bassompierre et al., 1972) and the other approximately 10 km to the southeast, at Valmont (Cavelier and Kuntz, 1974; Kuntz et al., 1979). The quartzose and calcareous sands of the Fécamp Crag were discovered on left bank of the Valmont valley, in the foundations of a building in Fécamp (Bassompierre et al., 1972). The section is no longer accessible, but four samples of crag collected in 1970, and already split into three size fractions per sample, were passed to us by J.-P. Margerel. The Valmont Crag is a mediocre exposure (1.5 m) at the top of an abandoned sand-pit; auger drilling at the edge of the sand-pit plateau (altitude: +120 m NGF [French datum]) showed the crag to be lenticular. Six samples were collected from the working face, three from the crag facies and three from the more indurated interstratified beds and prepared at the Eradata laboratory (Bourdillon, 2004).

2.1. The Fécamp Crag

The relative frequency and the state of conservation of the microfauna in the four preserved samples are similar and so are treated together (Bourdillon, 2006). The quartzose and calcareous sands of the Fécamp Crag lie on a bed of avellaneous flint pebbles and are covered by brown clays passing laterally to medium to coarse quartzose sands (Sables de Lozère normands Fm.). The impoverished gastropod fauna had previously allowed dating them as Latest Miocene, with transition forms from the Helvetian, whereas the equally impoverished bivalves, the benthic bryozoans and above all the foraminifera indicated a Pliocene age characterizing warm temperate faunas and Mediterranean affinities (Bassompierre et al., 1972). The biostratigraphic revision (Bourdillon, 2006) distinguishes three associations of benthic foraminifera:

- a well-worn association with a whitish patina mainly comprising *Pararotalia serrata*, miliolids and *Ammonia*, plus mollusc and bryozoan bioclasts;
- an association with a russet-red patina dominated by large *Ammonia punctatogranosa*, *Monspeliensina* and *Elphidium*;
- an association that has preserved its transparency, with *Ammonia*, *Bolivina*, cibicids and polymorphinids.

The Fécamp Crag thus represents a mixture of two thanatocoenoses. The one derived from the dismantling of a bryozoan-rich platform attributed to the Tortonian-Messinian, and containing offshore detrital components caught up and abraded in the coastal domain; the other a biocoenosis of Late Miocene–Early Pliocene age (Upper Messinian to Lower Zanclean) with *Ammonia*, *Bolivina*, cibicids and polymorphinids. All these foraminifera are deposited in an agitated proximal infralittoral environment, a strong hydrodynamism giving rise to faunal displacement and thanatocoenosis accumulation. These foraminifera characterise temperate or warm sea, no typical cold sea form as *Buccella frigida frigida* or *Faujasina* has been found.

2.2. Other Upper Miocene to Lower Pliocene sedimentary features in Europe

The association of benthic foraminifera found in the Fécamp Crag is very similar to those described in Belgium, during the Late Miocene to Pliocene (Van Voorthuysen, 1958), in Vendée and in Brittany (Andreieff et al., 1969), although with a few differences due to a more open environment than at Fécamp (Fig. 2). On the other hand, for paleogeographic reasons, it differs from those found in the

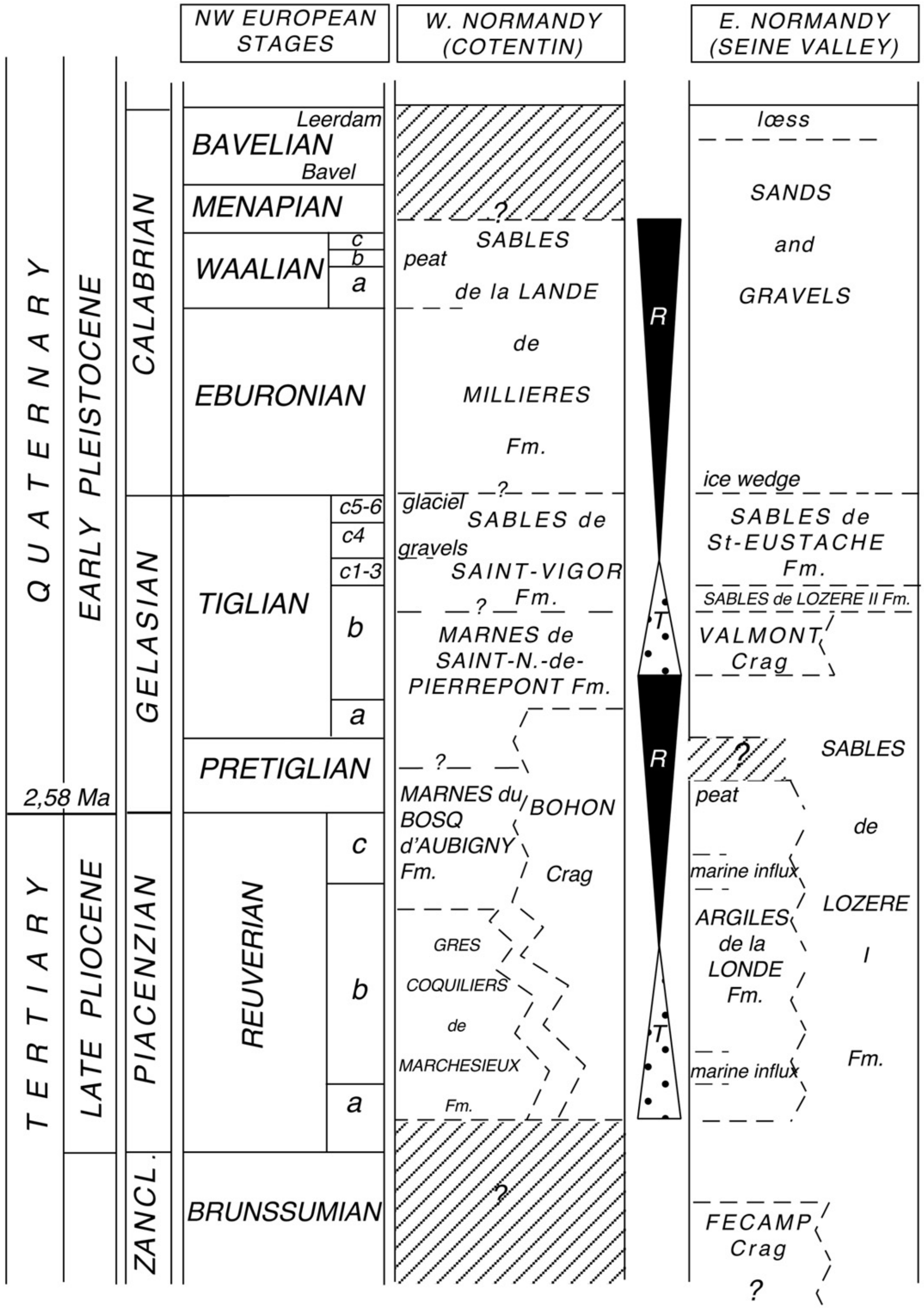

Fig. 1. Stratigraphic correlations of the Pliocene to Pleistocene formations in the Cotentin Peninsula (western Normandy) and the Seine valley (eastern Normandy). Transgression (T) - Regression (R) cycles.

Fig. 1. Corrélations stratigraphiques des formations du Plio-Pléistocène dans le Cotentin (Normandie occidentale) et la vallée de la Seine (Normandie orientale). Cycles de Transgression (T) - Régression (R).

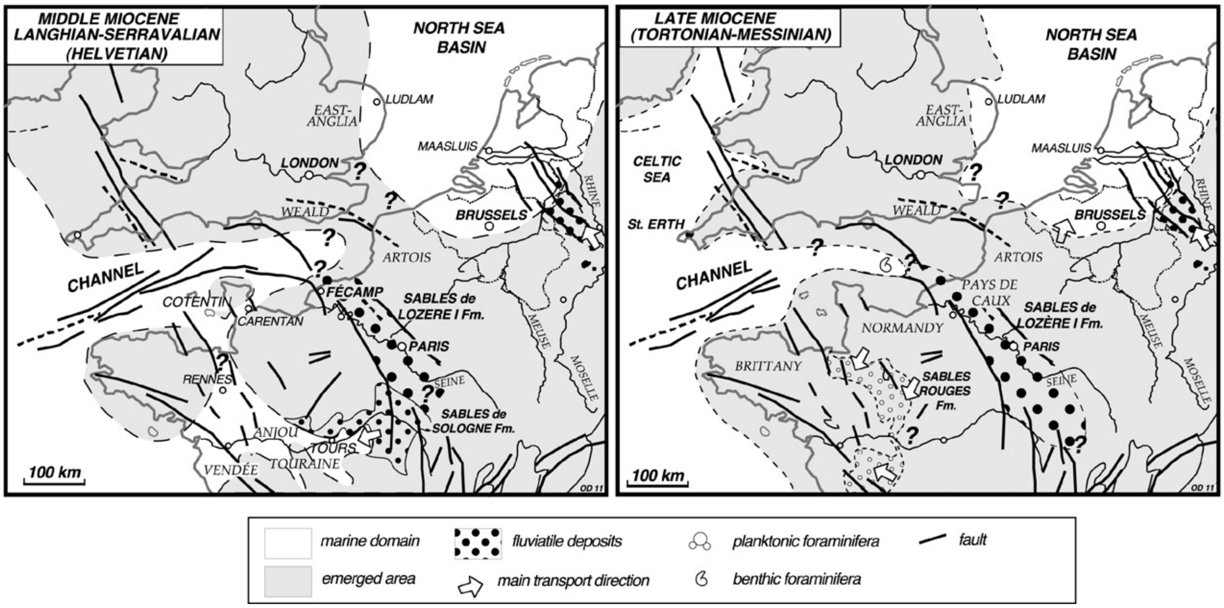

Fig. 2. Revised paleogeographic maps of the Atlantic Ocean–North Sea area for the Middle Miocene (after Bignot, 1972–1973; Cavelier et al., 1979; Gibbard and Lewin, 2003; Pomerol, 1973; Thomas, 1999) and Upper Miocene (after Brault et al., 2004; Cavelier et al., 1979; Pomerol, 1973).

Fig. 2. Cartes paléogéographiques révisées entre océan Atlantique et mer du Nord, au Miocène moyen (d'après Bignot, 1972–1973 ; Cavelier et al., 1979 ; Gibbard and Lewin, 2003 ; Pomerol, 1973 ; Thomas, 1999) et au Miocène supérieur (d'après Brault et al., 2004 ; Cavelier et al., 1979 ; Pomerol, 1973).

Miocene–Pliocene of England and the North Sea Basin (Funnell, 1981; King et al., 1981; Kuhlmann et al., 2006).

The biostratigraphic correlation can be clarified by comparing the associations found in the Fécamp Crag with the planktonic foraminifera found on the Armorican plateau. Off Sein Island (Brittany), at latitude 48°N (Andreieff et al., 1969), drilling yielded various associations of benthic foraminifera, including one with *Monspeliensina pseudotepida* and *Ammonia punctatogranosa*, *Ammonia beccarii* Linné, etc., juxtaposed with a planktonic microfauna. The re-studied samples (nos. 436, 441 and 450) yielded *Globorotalia plesiotumida* Banner & Blow, *Globoquadrina altispira* Cushman & Jarvis, *Globorotalia puncticulata* Deshayes, *Globorotalia crassaformis* Galloway & Wissler, *Globigerina nepenthes* Todd, and *Neogloboquadrina acostaensis* Blow. This association, attributed to the Pliocene *s.l.* by Andreieff et al. (1969) is today assigned to the non-basal Zone PL1 dated as Early Zanclean (Berggren et al., 1995; Wade et al., 2011) or to the top of the calcareous nannofossil Zone NN12. These Zanclean (Early Pliocene) deposits contain a benthic foraminifera identical to the biocoenosis found in the Fécamp Crag. Moreover, the

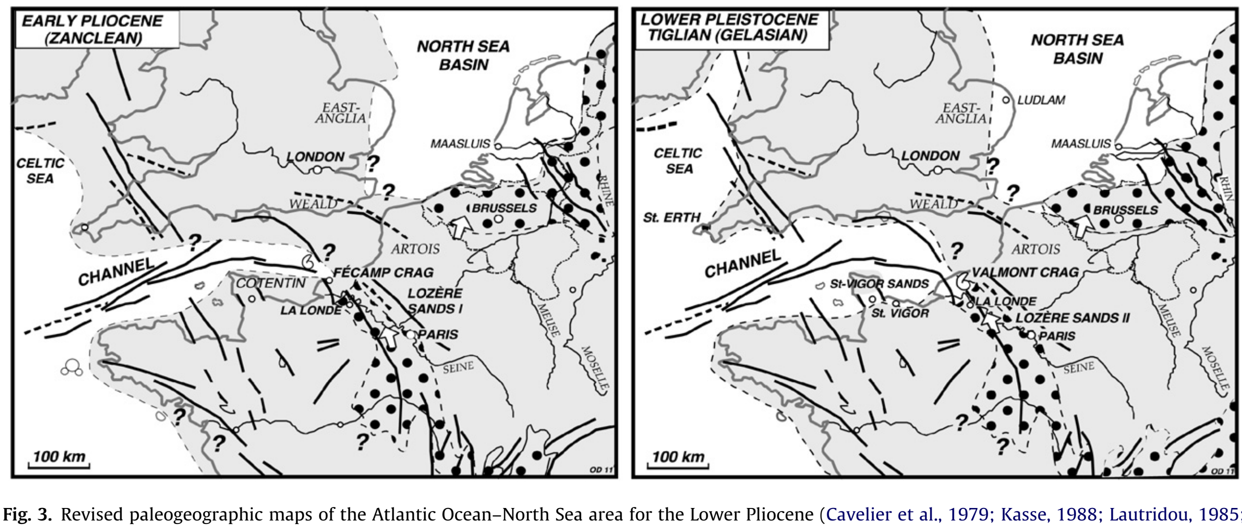

Fig. 3. Revised paleogeographic maps of the Atlantic Ocean–North Sea area for the Lower Pliocene (Cavelier et al., 1979; Kasse, 1988; Lautridou, 1985; Tourenq et al., 1991) and Lower Pleistocene Tiglian b to c 5-6 (Dugué, 2003; Funnell, 1995; Gibbard, 1995; Kasse, 1988; Tourenq et al., 1991).

Fig. 3. Cartes paléogéographiques révisées entre océan Atlantique et mer du Nord, au Pliocène inférieur (Cavelier et al., 1979 ; Kasse, 1988 ; Lautridou, 1985 ; Tourenq et al., 1991) et au Pléistocène inférieur (Tiglien b à c 5-6) (Dugué, 2003 ; Funnell, 1995 ; Gibbard, 1995 ; Kasse, 1988 ; Tourenq et al., 1991).

samples from below the marl beds also contain reworked benthic foraminifera. These marls, dated by Zanclean plankton, also contain a reworked circalittoral Tortonian-Messinian association similar to certain "Redonian" deposits of Vendée and Brittany (Margerel, 1972, 1989).

Sedimentation in the North Atlantic was continuous between the Tortonian and Zanclean (Zhang and Scott, 1996), except for the gap of an Upper Tortonian biozone. The Messinian is identified in all the boreholes drilled off the Portuguese and Irish coasts, and their non-basal Zone PL1a (Zanclean) is characterized by the same planktonic species as those determined offshore from Brittany by Andreieff et al. (1969) (Bourdillon, 2006).

In short, all these data enable us to deduce that the autochthonous foraminifera of the Fécamp deposits are most probably from the non-basal Zone PL1 and NN12 (Early Zanclean) and one of the thanatocoenoses of the Fécamp deposit comes from the dismantling of a Tortonian-Messinian bryozoan-rich platform.

2.3. The Valmont Crag

The Valmont Crag is a medium quartzose and shelly sand, locally hardened, with many detrital glauconite grains. The bioclasts represent bryozoans, bivalvias, echinoderms and rarer small gastropods. The formation overlies Upper Santonian chalk via a layer of flint pebbles and gravel, one of which yielded foraminifera attributed to the lower part of the Middle Campanian (Bourdillon, 2004). It is overlain by a thick non-fossiliferous sandy series comprising coarse quartzose sand at the base, followed by medium sand with argillaceous intercalations (Sables de Lozère normands Fm., 13 to 16 m) and very well-sorted whitish fine quartzose sand with flaser-bedding (Sables de Saint-Eustache Fm., 15 to 20 m) at the top.

The unconsolidated samples taken at the base, middle and top of the Valmont Crag show similar faunal assemblages (Bourdillon, 2004). The microfauna consists exclusively of little diversified and worn benthic foraminifera characterizing a thanatocoenosis; planktonic foraminifera and radiolarians are absent. The foraminifera are represented primarily by poorly preserved *Ammonia* (*Ammonia beccarii* Linné; between 85% at the base and 98% in the middle part), *Cibicides refulgens* Montfort (approximately 10% at the base), *Cibicidoides subhaidingerii* Parr (middle part), very rare, very compressed specimens of *Elphidium* sp., *Globulina gibba fissicosta* d'Orbigny, *Pararotalia serrata* Ten Dam & Reinhold (middle part), *Polymorphina*? sp., *Rosalina* sp. (basal and middle parts), *Bolivina spathulata* Williamson (middle and top parts). These foraminiferal associations are attributed to a mainly temperate climatic period of the Early Pleistocene. They are deposited in an agitated, very proximal infralittoral to mesolittoral environment. The poor diversity is explained by a variable, very internal, shallow water environment (Bourdillon, 2004).

2.4. Other Lower Pleistocene sedimentary features in Europe

No planktonic species has been described in the Lower Pleistocene estuarine to littoral series and benthic foraminifera are also rare. However, the typical association with *Ammonia beccarii* and *Cibicides subhaidingerii* in the North Sea and English Channel (Funnell, 1981) indicates Early Pleistocene temperate or interglacial stages. In addition, a comparable biocoenosis, but better preserved and more diversified, is described in Cotentin (La Couture well: LCO 001; 1:50,000-scale Sainte-Mère-Eglise sheet (Bourdillon, 2003)) at the boundary of the Marnes de Saint-Nicolas-de-Pierrepont Fm. and Sables de Saint-Vigor Fm., establishing a Tiglian b to c 5–6 age (Fig. 1).

3. Discussion

3.1. Electron Spin Resonance dating of the Neogene and Lower Pleistocene crags and sands of Normandy

The two preserved episodes of crag deposition at Fécamp and Valmont in Seine-Maritime represent diachronous transgressive coastal deposits. The oldest feature (Fécamp Crag, Early Zanclean) indicates the existence of an old offshore Tortonian - Messinian bryozoan-rich platform bryozoans that were reworked during the Lower Pliocene transgression. These deposits, however, had been attributed to the Tortonian - Messinian through Electron Spin Resonance (ESR) dating of the quartz grains (Van Vliet-Lanoë et al., 1998) which consequently had been reworked and do not represent in situ material. The most recent shelly sands (Valmont Crag, Early Pleistocene) are contemporaneous with a thick marine sedimentary sequence preserved in Cotentin (Dugué, 2003; Garcin et al., 1997). ESR ages obtained on quartz grains in the Valmont Crag, the Sables de Lozère normands Fm., and the overlying Sables de Saint-Eustache Fm. (Van Vliet-Lanoë et al., 1998) or the Sables de Saint-Vigor Fm. at Bessin, have indicated a Miocene-Pliocene age, thus also attesting to reworked material.

3.2. Neogene and Lower Pleistocene paleogeographies around the Armorican Massif

The historical Cenozoic sections around the Armorican Massif in NW Europe (i.e. Brittany, Cotentin, Pays de Caux) are disseminated, relatively small exposures and show no geometrical relationship with one another, thus complicating stratigraphic correlation. The several crags deposited on the Atlantic (Brittany) and English Channel (Cotentin Peninsula, Cornwall, Pays de Caux) coasts between the end of the Neogene and the Early Pleistocene represent as many chronostratigraphic markers in commonly non-fossiliferous successions (Figs. 2 and 3).

"Helvetian faluns" with bryozoans (Langhian - Serravalian) cover the Atlantic edge of the Armorican Massif (Touraine, Brittany and Cotentin) (Dugué et al., 2005; Néraudeau, 2003; Pomerol, 1973) (Fig. 2). The uplifted Cotentin then underwent a long Upper Miocene to Lower Pliocene hiatus followed by two transgression/regression cycles marking the Late Pliocene-Pleistocene series (Dugué et al., 2005). The first cycle (Late Pliocene to Early Pleistocene) is restricted to Cotentin. The second begins with Tiglian C (Late Gelasian) shelly and marly quartzose sands (Marnes de Saint-Nicolas-de-Pierrepont Fm.), and then fine quartzose sands (Sables de Saint-Vigor Fm.). These transgressive Lower Pleistocene deposits (top of the Marnes de Saint-Nicolas-de-Pierrepont Fm. and base of the Sables de Saint-Vigor Fm.) are contemporaneous with the Valmont Crag, deposited more than 140 km to the east. Finally, in both regions, fine tidal quartzose sands (Sables de Saint-Eustache Fm. and Sables de Saint-Vigor Fm.) cover the underlying Lower Pleistocene series (Tiglian = Gelasian) (Fig. 3).

The presence of Lower Pliocene (Lower Zanclean) deposits off Brittany has been determined from planktonic foraminifera in boreholes (Andreieff et al., 1969), and rare biostratigraphic index has been found onshore (Fig. 2) (Morzadec, 1982). In the Rennes Basin, non fossiliferous continental to estuarine quartzose sands (Sables rouges Fm.) (Brault et al., 2004) overlie and pass laterally into a warm Redonian (Margerel, 1972, 1989) or Tortonian-Messinian Crags (Néraudeau et al., 2003). ESR data obtained from these quartzose sands (Requigny, Rennes and Missilac) give two age groups; one Late Miocene (between 8.7 and 6.5 Ma, Tortonian-Messinian) and the other at the Zanclean-Piacenzian boundary (between 3.8 and 3.0 Ma) (Van Vliet-Lanoë et al., 1998). These sands are locally covered by Reuverian marine clays (Argiles de Saint-Jean-la-Poterie Fm.) dated by pollen (Fourniguet et al., 1989). Lastly, no Lower Pleistocene (Gelasian) deposits have yet been found (Brault et al., 2004).

3.3. Neogene and Lower Pleistocene paleogeographies of the North Sea (East Anglia, Belgium, Holland)

The Neogene to Pleistocene deposits are mainly preserved in the North Sea and on the east coast of England. After an episode of structural inversion which exhumed and eroded the South of the North Sea Basin between the Late Oligocene and beginning of the Miocene, the basin once again became marine during the Miocene, but shallow water and receiving sandy inputs from northern Belgium, the Netherlands and Germany. A delta, fed by the Rhine and Maas rivers and extending from Belgium to northern Germany, prograded towards this basin from the end of the Neogene to the beginning of the Pleistocene (Fig. 3). Paleogeographic changes in the Belgian and Dutch shorelines remained minor until the Middle Tiglian with the coast becoming similar to that of the Netherlands today. Then, during the Tiglian C1-4b (Gelasian), a new transgression began in the North Sea Basin leading to maximum extension of the marine domain (Maasluis Fm.) under a warm temperate climate. This transgressive tendency is also recorded in the Cotentin succession (Dugué, 2003) and Pays de Caux plateaux. Conversely, the Tiglian C4c is characterized by a return to colder climatic conditions and the beginning of a regression.

The Pliocene–Pleistocene marine deposits thin westward from the centre of the North Sea Basin in the direction of East Anglia, defining the Crags Basin where several episodes of marine mollusc- and foraminifera-bearing sands and clays, separated by many gaps, were deposited in coastal marine environments of limited geographical extent between the Pliocene and Early Pleistocene. Quartzose and shelly sands with bryozoans, molluscs, foraminifera (Coralline Crag) have been dated as Early Pliocene by their planktonic foraminifera (Brunssumian = -Zanclean; Funnell, 1995). The different crags of the Early Pleistocene (Red Crag, Norwich Crag, Wroxham Crag and Cromer Crag; Funnell, 1995; Gibbard and Zalasiewicz, 1988) correspond to thicker marine series laterally offshore. During the Tiglian (Gelasian), they were well-sorted fine to medium sands with trough cross bedding, horizontal planar bedding and flaser-bedding (Norwich Crag; Thurnian to Antian) which are exposed in southern and eastern Suffolk (Lewis, 1999).

3.4. Marine passage between the English Channel and North Sea

A Pliocene marine passage between the Channel and the North Sea has been both considered (Margerel, 1972; Van Vliet-Lanoë et al., 2002) and excluded (Gibbard, 1995). However, if one considers the latter hypothesis, then explaining the similarity of the cold Pliocene faunas on either side of the Dover Straits would require a roundabout connection via the north of the British Isles. In the same way, no Lower Pleistocene (Tiglian) marine passage has been proved between the two basins (Balson, 1999; Funnell, 1995; Gibbard, 1995; Murray, 1992; Van Vliet-Lanoë et al., 1998). The Tiglian marine transgression, which is well marked in the southern North Sea (Maasluis Fm., Norwich Crag) and on the Armorican coasts (Marnes de Saint-Nicolas-de-Pierrepont Fm., Sables de Saint-Vigor Fm.) has now been proved in Upper Normandy (Valmont Crag), with an association of similar foraminifera confirming the existence of marine circulation during the Tiglian high sea level (Funnell, 1995).

3.5. Stratigraphic position of the Sables de Lozère Normands Fm

The Pays de Caux and Roumois plateaux contain several spreads of non-fossiliferous detrital sand (Sables de Lozère normands Fm.) deposited by a Cenozoic paleo-Seine draining the northern part of the uplifted Massif Central. Their age was long debated due to the lack of biostratigraphic data. Only mineralogical, sedimentological or geomorphological criteria can be used, although without providing a definitive answer (Larue and Etienne, 2000; Tourenq et al., 1991; Van Vliet-Lanoë et al., 1998). In Upper Normandy, however, these quartzose sands are framed by two groups of datings. On the one hand, they erode the Valmont Crag dated as Early Pleistocene. On the other hand, in the La Londe quarry some 55 km southeast of Valmont and southwest of Rouen, they are overlain by the Argiles de la Londe Fm. (10–13 m thick), black organic-rich silty clays deposited in a continental lagoon (Kuntz et al., 1979; Lautridou, 1985) and dated as Late Pliocene (Reuverian a to c) by palynology with the Pretiglian cooling being recorded at their top (Clet and Huault, 1987); moreover, the lagoon being close to the shoreline of the period was invaded by marine tongues at the beginning of the Reuverian b and Reuverian c (Huault, 1987). The

Argiles de la Londe Fm. is covered by fine tidal quartzose sands (Sables de Saint-Eustache Fm., 20 m) that extend over the Pays de Caux and northern Roumois (west and southwest of Rouen).

The Tiglian revision of the Valmont Crag reveals the diachronism of Sables de Lozère normands Fm., which are young downstream and erode the Valmont Crag near the coastline. It is necessary to distinguish two units in these quartzose sands; the one upstream and the other downstream of Rouen. Upstream of Rouen, a first detrital stock of fluviatile origin (Sables de Lozère normands I Fm., 30 m maximum in the La Londe forest) corresponds to very poorly sorted coarse quartz-feldspar sands with angular grains and a granite weathering profile facies similar to that of the Parisian Sables de Lozère Fm. (Kuntz and Lautridou, 1980, and unpublished boreholes). Upstream (Beauce), they overlie Aquitanian lacustrine limestone and downstream they form the substratum of the La Londe depression filled with the Argiles de la Londe Fm. of Reuverian to Pretiglian age. Downstream of Rouen, a second, better sorted, finer detrital episode with rounder grains defines the Sables de Lozère normands II Fm. (15 m thick) which include millimetre-thick beds of clay and rare runs of coarse sand, describing estuarine or deltaic environments (Tourenq et al., 1991); they disappear north of Le Havre. Intercalated between the Valmont Crag (Tiglian b to c5-6) and the fine tidal Saint-Eustache Sands, the Sables de Lozère normands II Fm. reworked the available stock of Sables de Lozère normands I Fm. in an estuarine context (Fig. 3).

4. Conclusion

The new acquired data on the benthic foraminifera found in the Cenozoic shelly sands (crags) of Seine-Maritime testifies to the complexity of the preserved microfaunal assemblages. The Fécamp Crag is an assemblage of thanatocoenoses and biocoenoses of different ages. Two episodes of transgressive coastal deposits are identified: the first of Early Zanclean age at Fécamp and the second of Early Pleistocene (Tiglian b to c5-6) age at Valmont. The Fécamp Crag, however, has preserved reworked microfaunas from a former bryozoan-rich platform on the floor of the Channel that was reworked during the Lower Pliocene transgression. Such reworking explains the common presence of Miocene species recognized among the "Redonian" faunas, as was often highlighted in the regional studies.

Tortonian-Messinian and Lower Pliocene deposits are described locally in Belgium, England, Brittany, on the Armorican plateau and at Fécamp, but are absent in Cotentin and its surroundings, confirming that NW Normandy was uplifted at the time. On the other hand, Tiglian b to c5-6 deposits are found in Cotentin, Upper Normandy and the southern North Sea. All these coastal crags and tidal sands indicate a marine passage between the English Channel and the North Sea during the Tiglian high sea level, whereas such deposits appear to be absent from Brittany, probably uplifted at the time.

The two episodes of crags are new markers for the stratigraphic position of the Sables de Lozère Normands Fm. and Sables de Saint-Eustache Fm. A first input of coarse and poorly sorted fluviatile sand (Sables de Lozère normands I Fm) was deposited in the Seine paleovalley. They cover the Aquitanian lacustrine limestone downstream of Beauce and in the Paris region, whilst in La Londe they are covered by the Argiles de la Londe Fm. of Reuverian to Pretiglian age. A second episode of finer and better-sorted quartzose sands (Sables de Lozère normands II Fm.) reworked the first stock downstream in the Seine paleo-estuary. These estuarine sands covered the Valmont Crag during the Early Pleistocene. The marine Sables de Saint-Eustache Fm. followed, covering a wider part of the Pays de Caux and Roumois plateaux.

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