



Palaeoenvironment and dating of the Early Acheulean localities from the Somme River basin (Northern France): New discoveries from the High Terrace at Abbeville-Carrière Carpentier

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ABSTRACT

Dating the earliest human occupations in Western Europe and reconstructing links with climatic and environmental constraints is a central issue in Quaternary studies. Amongst the discovery of Palaeolithic artefacts ascribed to the Early Pleistocene in southeast Britain and central France the Somme Basin, where the Acheulean type-site Amiens Saint-Acheul is located, is a key area for addressing this topic. Research undertaken over the past 20 years on both Quaternary fluvial and loess sequences of this area has provided a unique dataset for the study of the relations between human occupations and environmental variations. Studies based on an interdisciplinary approach combining sedimentology, palaeontology and geochronology have highlighted the impact of the 100 kys cycles on terrace formation during the last million years. In this terrace system, the earliest *in situ* Acheulean settlements known in the 1990s were dated to early MIS 12 (± 450 ka), but new field discoveries, at Amiens "Rue du Manège", dated to ± 550 ka, significantly increase the age of the oldest human occupation in the area. In this context, new fieldwork has been undertaken in Abbeville at the Carrière Carpentier site, famous for its White Marl deposit attributed to the Cromerian and in the same terrace level where the former discoveries of "Abbevillian bifaces" were made by d'Ault du Mesnil. This research is based on an interdisciplinary approach, combining sedimentology, paleontology, dating (ESR on quartz and ESR/U-series on teeth) and archaeology. According to the various bio-proxies (molluscs, large vertebrates, small mammals), the White Marl was deposited during the early part of an interglacial phase in an aquatic slow-flowing environment, as emphasized by the development of oncoliths and the presence of fish and aquatic molluscs. The landscape was composed of a mosaic of open bush and forest areas, in which wet

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and grassy vegetation developed on riverbanks. On the basis of terrace stratigraphy, ESR and ESR/U-series dating results, and biostratigraphic data, the fluvial deposits of the White Marl can be securely attributed to MIS 15. In addition, some Acheulean bifaces were discovered at the base of the slope deposits, directly overlying the fluvial sequence. These artefacts are most likely coeval with the end of MIS 15 or an early stage of MIS 14, between 550 and 500 ka, and represent, together with the artefacts from Amiens “Rue du Manège”, the oldest *in situ* evidence of Acheulean occupation in Northern France. However, no unquestionable artefacts have been discovered in the White Marl or in the underlying gravel layer. These discoveries contribute to the chronology of the earliest evidence of hominin occupations in north-western Europe which may be related to *Homo heidelbergensis*.

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1. Introduction

The Quaternary deposits of the Somme Valley have been known since the middle of 19th century for their rich Palaeolithic localities (Boucher de Perthes, 1847; Prestwich, 1860; Commont, 1910a,b; Breuil, 1934; Breuil et al., 1939a,b; Agache et al., 1963; Bourdier, 1969, 1974a,b; Bourdier and Lautridou, 1974; Haesaerts et al., 1984; Lautridou, 1985; Lautridou et al., 1999; Haesaerts and Dupuis, 1986; Sommé et al., 1984; Antoine, 1994; Antoine and Tuffreau, 1993; Tuffreau and Antoine, 1995). The Abbevillian lithic “culture”, considered as Early Acheulean, was first described at Abbeville after the crudely-shaped bifaces found there (Breuil, 1932). These discoveries contributed to discussions focusing on the onset of bifacial technology during the 20th century and were included in the technological schemes published by Breuil and other prehistorians.

The Somme Valley is also known for its stepped fluvial terrace system incised into Upper Cretaceous Chalk and protected by a well-developed loess-palaeosol cover reaching thicknesses of up to 10 m (Antoine, 1994; Antoine et al., 2003, 2007). In this area, the Cretaceous Chalk bedrock is extremely rich in flint, which undoubtedly influenced the high density of Palaeolithic sites that characterises this region. During periods of low sea level, which prevailed during most of the Pleistocene, the present-day Somme Basin was located at a considerable distance upstream of the Palaeo-Somme fluvial system, which was at that time a tributary of the Channel River (Auffret et al., 1982; Gibbard, 1988, 1994; Lericolais et al., 2003) (Fig. 1).

Research undertaken over the past 20 years on the fluvial terraces and loess sequences of the Somme Basin and on interactions between human settlement and environmental change are based on an interdisciplinary approach to Quaternary sequences and associated Palaeolithic settlements (Antoine et al., 2000, 2003, 2006, 2007, 2010). These studies, mainly performed on fluvial formations, have highlighted the impact of cyclic climatic changes on sedimentation and river morphology, and in particular, the role of 100 kyr climatic cycles for the last million years (stepped terrace formations) (Antoine et al., 2007). Moreover, they situate the numerous deposits of the Somme basin and surrounding areas within a global regional chronological framework, and enable us to propose a detailed history of the evolution of valleys and to address the relationship between hominins and the environment (chronoclimatic context, palaeotopography, sources of raw material...) (Antoine et al., 2003, 2006, 2015a,b).

In the Somme Basin, results from modern excavations conducted in the 1980s (Tuffreau, 1980, 1989; Tuffreau et al., 1982), combined with geochronological data (ESR and combined ESR/U-series, Laurent et al., 1994; 1998; Bahain et al., 2002, 2007) and palaeoenvironmental studies (Munaut, 1988, 1989; Limondin-Lozouet and Antoine, 2006) show that the first *in situ* and well dated human occupations in the area go back to about 450 ka (Early

MIS 12, Cagny la Garenne II), and that they are represented by advanced Acheulean industries (Antoine et al., 2010). Acheulean bifaces were formerly found in the gravels of the Fréville Formation in Amiens (Commont, 1909a,b) and at the Moulin Quignon site in Abbeville (Aufrère, 1937; Breuil et al., 1939b), but their exact stratigraphic location is still difficult to establish. In contrast, the highest terraces of the Somme River system, such as the fluvial deposits of the Grâce-Autoroute Formation (Antoine et al., 2003), dated to approximately 1 Ma (Bahain et al., 2007), have yielded no Palaeolithic artefacts. In the context of new discoveries in central France (Despriée et al., 2011; Moncel et al., 2013, *in press*) and in the south and east of the United Kingdom (Parfitt et al., 2005, 2010), this probably indicates that the earliest human occupation of north-west Europe goes back to the beginning of the Middle Pleistocene. This question is of considerable importance for understanding the first human settlement of the valley and the chronology of occupations in Northern European latitudes. Indeed, during the Cromerian Complex (MIS 21–13 according to Cohen and Gibbard, 2011, or MIS 19–13 according to Preece and Parfitt, 2012), the river valleys from the south side of the Channel, such as the Somme, represented major migration routes during glacial periods with low sea level. During this long period, Acheulean occupations contained within the alluvial deposits are contemporaneous of the younger part of the Cromerian Complex (± 500 –650 ka).

However, intensive field research on the oldest part of the terrace system of the Somme Basin during the past 20 years has shown that these deposits, formerly exposed in old quarries in Amiens and Abbeville (Commont, 1909a,b; 1910a,b, Bourdier, 1969; Tuffreau, 1980, 1989), were poorly preserved (Antoine, 1990, 1997). In the light of these results, and despite the numerous test-pits made since the 1990s by rescue archaeology teams, it is extremely difficult to document new *in situ* Acheulean sites dating from the early Middle Pleistocene in the Somme Valley. For a long time the Acheulean site of Cagny-la-Garenne, excavated by Tuffreau in 1985–1986 and dated to the MIS 12 Early-Glacial, around 450 ka, was thus the oldest *in situ* evidence of Acheulean occupation in the area (Tuffreau, 1989; Antoine et al., 2010). Recently, the dating of the “Rue du Manège” site to 550 ka attests to the antiquity of hominin presence in the Somme Valley (Locht et al., 2013; Antoine et al., 2015a).

Preliminary results from research on the Abbeville Carrière Carpentier site were included in a recent paper on the earliest human occupations in the fluvial terraces of the Somme Basin (Antoine et al., 2015a,b). Here, we present new results concerning bioproxies (molluscs, large and small mammals), dating (ESR on fluvial quartz and ESR/U-series on teeth) and the archaeological evidence from the reference sites of the alluvial formation of Carrières Carpentier and Léon (2011–2014). These data are considered from the perspective of the expansion of the earliest Acheulean in Western Europe.

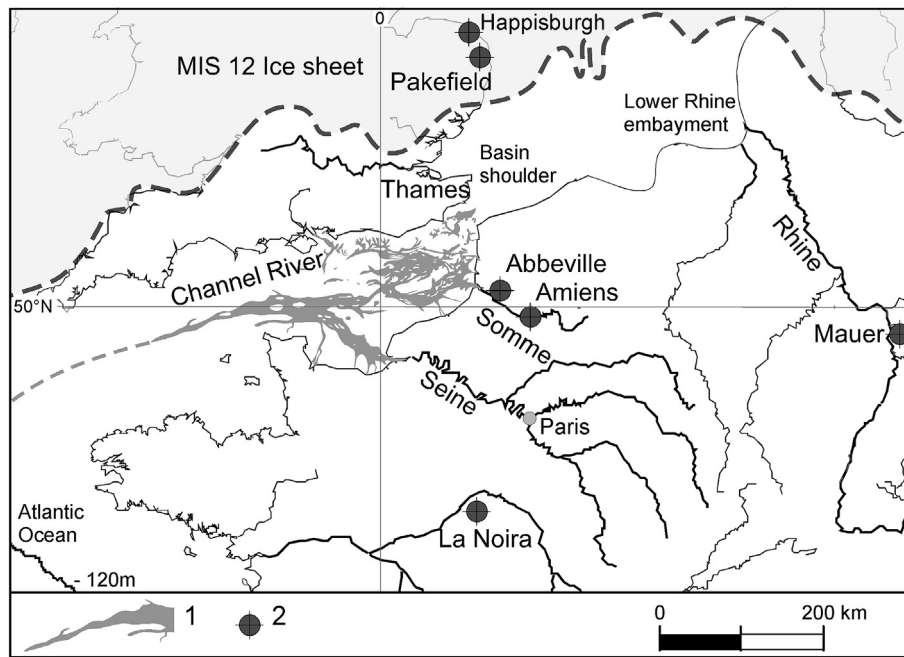


Fig. 1. Location of the research area in Northern France and extension of the rivers into the Channel (Channel River, according to Auffret et al., 1982). 1- Palaeochannels of the Channel River, 2- Palaeolithic sites.

2. Historical perspective

The Carrière Carpentier Quaternary sequence is located in Abbeville at the confluence of the Somme and the Scardon Rivers (small right-bank tributary) in the lowest part of the middle Somme (Fig. 1). The Quaternary sequence ($50^{\circ} 06' 24''/1^{\circ} 50' 50''$) is preserved in the upper part of the slope in the north-eastern part of the town, a few metres below the plateau at a relative altitude of 40 m above the present-day valley incision (Figs. 1–3). On the right bank of the Somme River, in the area of Abbeville, Pleistocene alluvial formations (Fig. 3) are well developed owing to a confluence position favourable to gravel preservation (Antoine, 1990). These Pleistocene alluvial formations correspond to the downstream extension of the stepped terrace system of the middle Somme Valley (Antoine, 1990; Antoine et al., 2007) (Table 1). These alluvial formations have disappeared beneath the expansion of the town since the end of the Second World War.

In this context, the Carrière Carpentier, acquired by the French Government in 1938, is the only accessible evidence of the High Terrace of the Somme Valley in this area (Alluvial Formation VII, Antoine et al., 2000; Table 1). Indeed, Carrière Léon, located ~100 m to the south in the same alluvial formation, and acquired at the same time by the National Museum of Natural History of Paris, is presently completely filled with refuse. A new excavation in 2014 at this former quarry showed that only a few square metres of *in situ* calcareous alluvial deposits are preserved below 3–4 m of modern embankments.

Carrière Carpentier is thus of paramount importance for our understanding of the oldest record of the Somme terrace system and for assessing the association between the Middle Pleistocene large mammal remains and Acheulean bifaces, which are among the oldest evidence in Western Europe.

According to publications from the early 20th century, the discovery of bifaces in the White Marl of the Carrière Carpentier was first reported by Léon Auffrère and Franck Bourdier (Auffrère, 1937; Breuil et al., 1939a; Bourdier, 1969, 1974a,b; Agache et al., 1963).

These bifaces were classified as “Abbevillian” on account of their crude shaping, rare removals and large preserved cortical zones, and were considered to belong to an early Acheulean phase. Nevertheless, Victor Commont (1910b), who studied the site carefully during quarry working, always claimed that bifaces or flint artefacts were absent from the White Marl.

In the same area, 450 m to the south-south-east, the gravels of the famous Moulin Quignon site yielded typical bifaces described by Boucher de Perthes (1847). The site is now totally hidden by urbanisation, but on the basis of the relative height of the contact between the fluvial gravel sequence and the chalk bedrock, reconstructed according to the detailed observations and measurements published by Breuil et al. (1939b), the Moulin Quignon alluvial formation is clearly located on the same bedrock as the Carrière Carpentier sequence (Fig. 2). However, the extremely abundant bifaces gathered in Abbeville derive mainly from the “Champ de Mars”, “Stade” and “St. Gilles” sites, which are clearly located in a younger terrace formation (around +30 m, relative altitude, i.e. 10 m below the Carrière Carpentier formation, Table 1).

The stratigraphic sequence at Carrière Carpentier (average altitude of the top of the sequence +31 m a.s.l.) was first described by Victor Commont (1910b). It is composed of a succession of fluvial gravels covered by whitish fluvial calcareous sandy silts with calcareous nodules (White Marl). The fluvial succession is covered by a slope sequence made up of hillwashed colluvial sands and thick clayey soliflucted gravel beds, trapped in places in deep sinkholes. This quarry is famous for the abundant large mammal remains discovered in the White Marl, and studied by Marcellin Boule (in Commont, 1910b), and later by Pontier (1914, 1928). The Carrière Carpentier sequence was subsequently incorporated by F. Bourdier in his synthesis of the terraces, “Quaternary and Prehistory of the Somme Basin”, in which the White Marl was allocated to the “Gunz-Mindel” Interglacial (Bourdier, 1974b).

In 1989, a complete cleaning of the section along 15 m led to the recording of a new detailed stratigraphic scheme and an accurate levelling of the basal contact between fluvial deposits and chalk

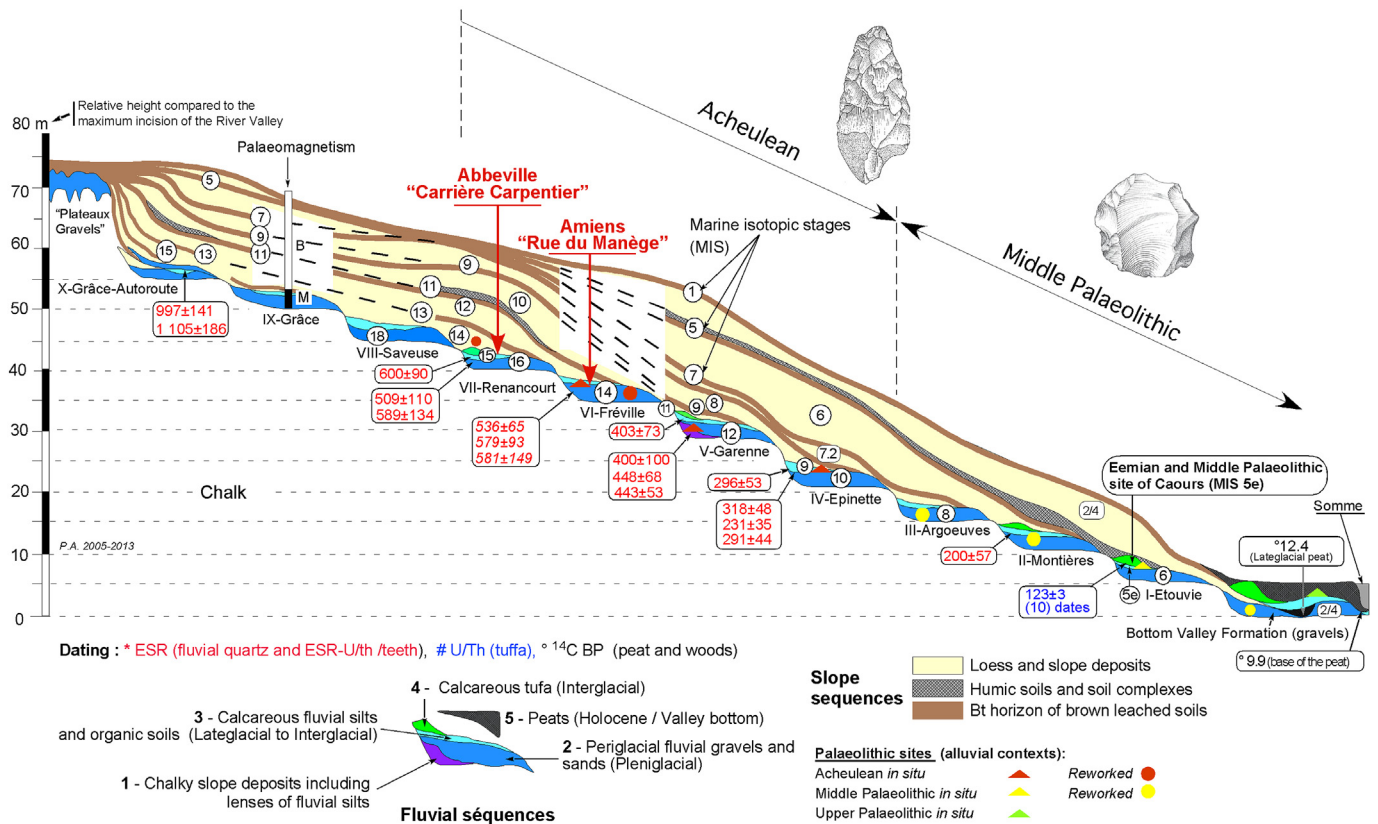


Fig. 2. Fluvial sequences cross section of the middle Somme terrace system (after Antoine et al., 2007; modified).

bedrock. At the same time, a few large mammal remains were discovered in the upper part of the White Marl, and sediment samples were taken from sandy lenses for ESR dating on fluvial quartz, palaeomagnetism and palynology (Antoine, 1990).

According to its relative altitude (+39–+40 m), the alluvial formation of the Carrière Carpentier represents the downstream extension of Alluvial Formation VII of the terrace system at Amiens (Renancourt Formation), corresponding to the third incision stage following the highest terrace (Fig. 2, Table 1). The upper part of the alluvial sequence includes particularly well preserved calcareous silts for such an old terrace sequence. Although sediments are relatively poor in pollen, the palynological data obtained in the White Marl by A.-V. Munaut (1989) provide evidence of boreal and temperate trees, associated with steppic herbaceous plants. This pollen assemblage reflects a mosaic landscape (forest and steppe) interpreted as corresponding to a temperate continental climate (Munaut, 1989).

In the basal units of the White Marl, directly overlying the gravels, fragments of aquatic mollusc shells (*Pisidium* and *Valvata*) were reported by V. Comment (1910a,b). Finally, according to Boule, in Comment, 1910b), the abundant large mammal remains from the Carrière Carpentier are related to two distinct levels: the gravels (lower unit), which yielded a few bones, and the marly and oncolithic sands (Upper unit/White Marl) from which most of the discoveries derived.

Nomenclature of mammal species described from old collections were revised and updated by Auguste (1995a,b,c, 2009). According to this revision, assemblages can be described as follows:

Lower unit (gravels): *Hippopotamus*, *Rhinoceros* and *Equus* aff. *stenonis*.

Upper unit (White Marl): typical *Mammuthus meridionalis*, *M. trongontherii*, *Palaeoloxodon antiquus*, and *M. primigenius* with

archaic characteristics, *Dicerorhinus etruscus*, *D. mercki* and *Elasmotherium*, *Cervus solihacus*, *C. (Dama) somonensis*, *C. elaphus*, *C. capreolus*, *C. belgrandi* and *C. canadensis*, *Bos priscus* and *B. elatus* or *etruscus*, *Equus stenonis*, *E. stenonis robustus* and possibly *E. hydruntinus*, *Rhinoceros etruscus* and *R. leptorhinus*, *Sus scrofa*, *Hippopotamus*, *Homotherium latidens*, *Hyaena* cf. *crocota*.

Former ESR dating results of 600 ± 90 ka (Laurent et al., 1994, 1998) led to the allocation of the White Marl to the end of the Cromerian Complex, in good agreement with the relative altitude of the alluvial formation in the Somme terrace system (Antoine, 1994) and with the interpretation of the large mammal assemblages from the White Marl.

From an archaeological point of view, it has always been difficult to attribute the numerous “Abbevillian-type” bifaces, retrieved from old museum collections, to the alluvial sequence of Carrière Carpentier and the ‘*M. meridionalis*’ fauna level. Indeed, the stratigraphic location of these bifaces has long been discussed and remains highly uncertain (Bourdier, 1969, 1974a,b; Agache, 1971).

3. New research and discoveries at Abbeville Carrière Carpentier

A new research project on this protected area was initiated in 2011. It began with the cleaning of the section along an 18 m length and was followed by an archaeological excavation (1 m wide along the 18 m long sequence and ~6 m²/1–1.5 m depth in front of the sequence).

Numerous well-preserved large mammal remains were found and special attention was paid to possible anthropic artefacts. Quantitative sampling of flint nodules was carried out to describe the natural processes occurring in the deposits. Various sampling and *in situ* measurements were performed during this study for

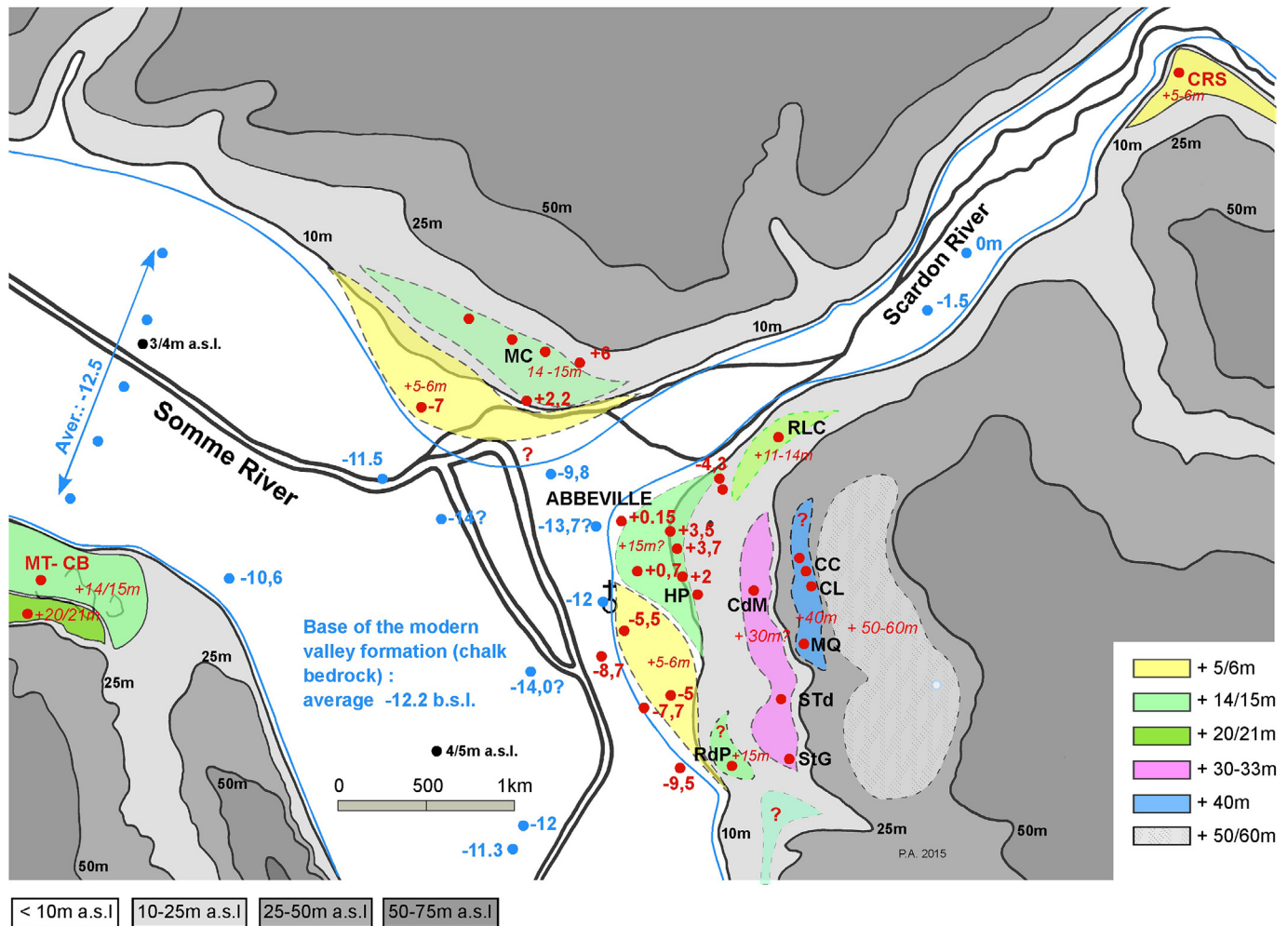


Fig. 3. Map of the fluvial terraces in the Abbeville area. MC: Menhecourt; MT-CB: Mautort-Cambron; CRS: Caours; RLC: Rue du Lieutenant Caron; HP: Hôpital; CC: Carrière Carpentier; CL: Carrière Léon; CdM: Champ de Mars; MQ: Moulin Quignon; StD: Stade; StG: Saint-Gilles; RdP: Rue de Paris. White area: modern valley formation (gravels/silts/peat). Bedrock measurements: blue dots: base of the modern valley gravels; red dots: base of the various terrace gravels. +5/6 to +50/60 m: relative height of the bedrock of the various terraces above the bedrock of the modern valley gravels. Local names of the terrace formations (after Antoine, 1990): +5/6 m: Port le Grand Formation; +14/15 m: Cambron-Menhecourt Formation; +20/21 m: Mautort Formation; +30–33 m: Mareuil Formation; +40 m: Carrière Carpentier Formation; +50–60 m: Caubert Formation and plateau gravels. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

sedimentology, malacology, palynology, large mammals, micro-vertebrates and dating (ESR on fluvial quartz and combined ESR/U-series on large mammal teeth, including *in situ* dosimetry measurements with a gamma-ray spectrometer, Fig. 4A,B).

3.1. Stratigraphy

According to the synthesis of new observations and former descriptions, the Carrière Carpentier sequence can be divided into two main fluvial units, covered by a poorly developed cover sequence. The boundary between fluvial (units 5 and 4) and slope deposits (units 3 to 1) is marked by a sharp erosion boundary (Fig. 5A), associated with irregular decalcification pockets or sinkholes (the so-called “Pots de Terre” described by former authors Figs. 4A and 5B), reaching depths of several metres.

3.1.1. Slope sequence (units 1 to 3, Fig. 4)

In the Carrière Carpentier profile, the boundary between fluvial and slope sequences is underlined by a sharp contact corresponding to an erosive contact (discordance). This contact was later modified by dissolution processes in the underlying calcareous

White Marl deposits as well as in the chalky substratum, leading to the formation of sinkholes up to 3 m deep (Figs. 4A and 5).

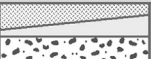
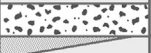
From the base to the top, the slope sequence is composed of two sets of irregular sandy and gravelly layers separated by discordance, only visible in the centre of the sinkhole in the eastern part of the profile (dotted line in Fig. 4A).

The lower part (units 3D to 3C) is made up of a succession of irregular beds and lenses of white to yellow stratified hillwashed colluvial sands, alternating with discontinuous sandy-clayey gravel beds. Within this part of the sequence, the upper part of sub-unit 3D-1 is represented by finely laminated brown to brown-greenish clayey silts (10–20 cm in thickness), deposited by slow hillwash processes in which Acheulean bifaces were discovered during the excavation (Figs. 4A and 5B).

Above the discordance underlining the top of unit 3C, resulting from a sudden deepening of the sinkhole (dissolution of the chalk), a new set of sandy and gravelly slope deposits (units 3B and 3A) is preserved in the centre of the sinkhole. The last unit of the slope sequence is then represented by the heterogeneous brownish gravel bed Cx1 made of multi-dimensional and strongly patinated flint blocks and flakes (shattered by frost), embedded in a thick

Table 1

The Quaternary stepped terrace system of the middle Somme Valley: distribution of the various alluvial formations according to the relative altitude of their basal contact with the chalk bedrock compared to the maximum incision below the present-day valley formation, in the reference areas of Amiens (upstream) and Abbeville (downstream). Modified from [Antoine, 1990](#)). Correlation between the various alluvial sequences and the MIS sequence. 1 - Heterogeneous slope deposits (early part of the cold period cycle: only at the base of Formations IV and VII). 2 - Flint and chalk gravels representing the main part of all the alluvial formations (periglacial environment/full glacial conditions). 3 - Fluvial calcareous overbank silts (temperate climate/Interglacial). 4 - Calcareous tufa (Interglacial optimum in Fm IV and I). 5 - Cross-bedded gravelly sands (only at the top of Fm X: Early glacial?).

Upper Middle Somme valley (Amiens)		Lower Middle Somme Valley (Abbeville)			
RH (m)	Number	Alluvial Formation	Alluvial Formation	Fluv. sequence	
+ 5-6m	I	<i>Etouvie Fm</i>	<i>Port-le-Grand Fm</i>		5e 6
+ 10-12	II	<i>Montières Fm</i>	?		7.1 7.2
+ 14-15	III	<i>Argoeuves Fm</i>	<i>Cambron-Menchecourt Fm</i>		7.3 8
+ 20-21	IV	<i>Epinette Fm</i>	<i>Mautort Fm</i>		9 10
+ 27-29	V	<i>Garenne Fm</i>			11 12
+ 35	VI	<i>Fréville Fm</i>	<i>Mareuil Fm</i>		13 14
+ 40	VII	<i>Renancourt Fm</i>	<i>Carrière Carpentier Fm</i>		15 16
+ 44-45	VIII	<i>Saveuse Fm</i>	<i>Mareuil-Caubert Fm</i>		17 18
+ 50-52	IX	<i>Grâce Fm</i>	<i>Caubert Fm</i>		19 20
+ 55	X	<i>Grâce-Autoroute Fm</i>	?		≤ 21
+ 59-60	XI	<i>Chaîne d'Or</i>	?		
+ 70 / 75		Plateau gravels	?		



sandy-clayey matrix indicating a final but very intense gelifluction event. Finally, the whole sequence was strongly truncated and then covered by sandy-silty colluvial deposits, including numerous scattered flint flakes and blocks (unit 1).

The units composing the cover slope sequence at Carrière Carpentier derive from the reworking by hillwash and periglacial gelifluction processes of Tertiary sediments and older weathered terrace deposits from the nearby slope. The only typical brown leached soil horizon (unit 2) is preserved in place in a depression at the top of this last gravel bed and shows no specific characteristics. This sequence thus presents no particular interest for the pedostratigraphic approach and the relative dating of the underlying fluvial deposits. Indeed, according to the relative height of the fluvial sequence within the Somme Valley terrace system (Alluvial Formation VII), and thus to its likely age, the cover sequence should be composed of at least five Interglacial-glacial cycles and as many interglacial palaeosols ([Antoine et al., 2007](#)).

3.1.2. Fluvial sequence

The fluvial deposits are preserved over more than 18 m between two large sinkholes and represent a unique and extremely rich record of fluvial sedimentation and Quaternary palaeoenvironments of the High Terrace of the Somme system (Renancourt Formation/Alluvial Formation VII, [Table 1](#)).

This fluvial sequence overlies an erosion surface in the chalk at ± 27 m a.s.l. It is divided into two main units individualised by very

different sedimentary facies: (1) “basal chalky gravels”, generally poorly sorted, including large chalk blocks and flint nodules slightly retouched by fluvial activity (sub-units 5C to 5A), and (2), calcareous sandy silts and oncolithic sands (sub-units 4D to 4A).

The lower unit 5 consists of chalky gravels including irregular lenses of calcareous sandy silts (sub-unit 5B). The basal part contains large un-rolled blocks of chalk and flint in a coarse sandy calcareous matrix (sub-unit 5C). The upper gravels (sub-unit 5A) are better stratified and sorted and characterised by smaller than average grain size.

The upper fluvial unit 4 corresponds to the “greenish marly sands” (M1) and the White Marl of [Commont \(1910a,b\)](#). It consists of large lenticular layers of calcareous sandy silts and calcareous sands with stratification typical of a fluvial environment.

3.1.2.1. Basal gravels. The proximity of a chalky slope (former embankment of the river) in the basal gravels is indicated in sub-unit 5C by: (1) the rapid rise of the contact between gravels and chalk bedrock to the north-east towards the slope (±10 m to the end of profile, see [Fig. 4A](#)) (2) the occurrence of large chalk and flint blocks (up to 40 cm) with no fluvial shaping at the base of 5C, and (3) the thinness of this unit compared to those generally raised by the gravels of the alluvial formations of the Somme River in their central and internal parts (3–4 m).

The boundary between the two main gravel sub-units (5A and 5C) is marked by the occurrence of a 10 cm thick lens of calcareous

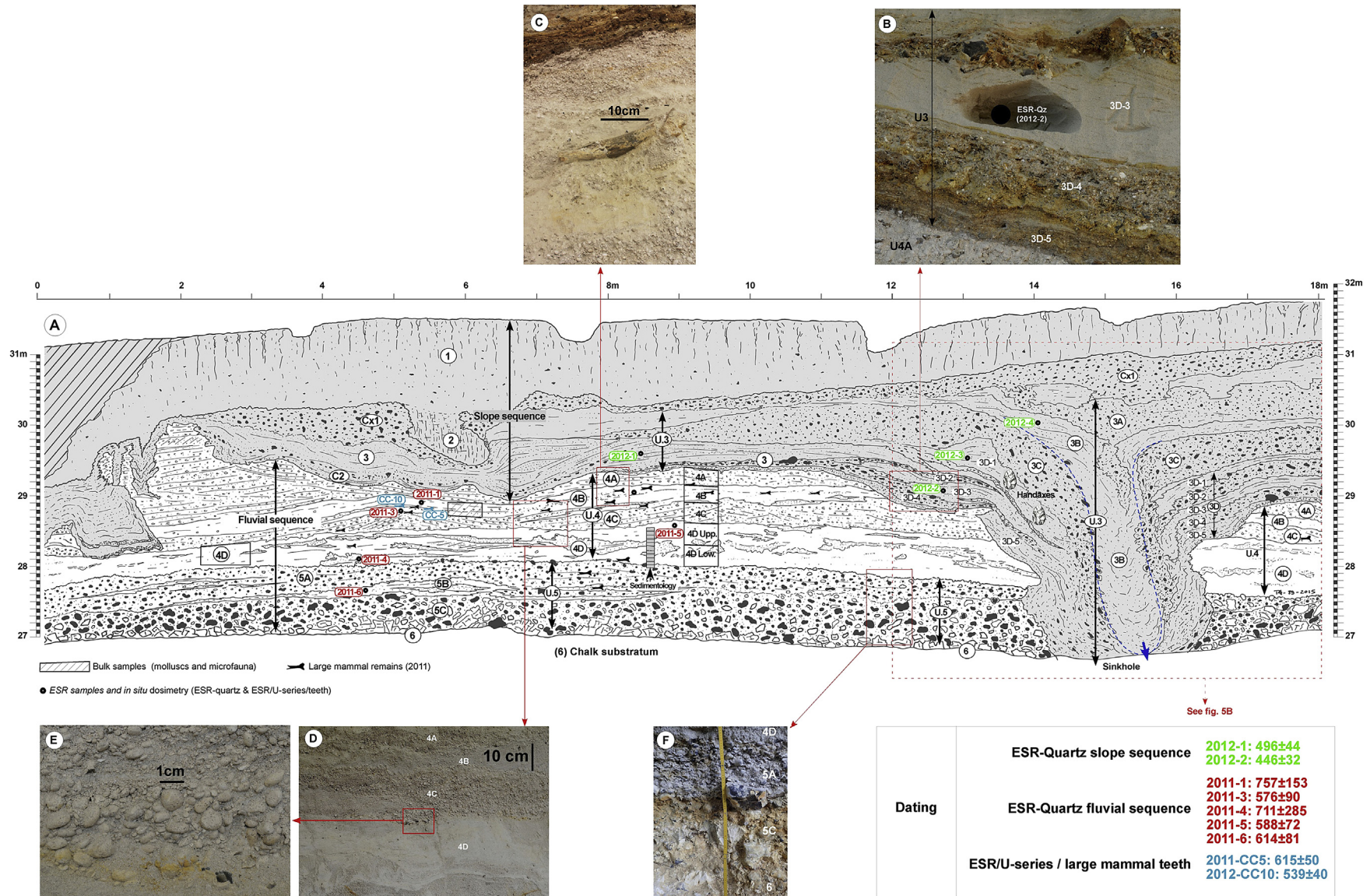


Fig. 4. (A) Detailed sketch of the Carrière Carpentier section with location of the various sampling zones. B - Detailed view of the base of the sandy and gravelly layers at the base of unit 3 (3D3 to 3D5). C - Rhinoceros tibia recovered *in situ* in sub-unit 4B (*Stephanorhinus hundsheimensis*). D - Detailed view of the White Marl deposits (sub-units 4A to 4D). E - Detailed view of the oncoliths from the base of sub-unit 4C. F - Detailed view of the coarse gravels in units 5A and 5C. Photographs by P. Antoine. Description of the stratigraphic units: 1 - Compact brown greyish silt (10 YR 4/3) with numerous root traces and abundant flints with white patina. 2 - Compact brown-red sandy-clayey silt (7.5 YR 5/6) with prismatic structure and root tracks (Bt horizon of brown leached soil preserved in a small depression). Cx1. Heterogeneous brownish gravel bed made up of heterometric and strongly patinated flint blocks and flakes produced by freezing processes and pebbles embedded in a thick sandy-clayey brown-red weathering matrix. 3. This unit, with very significant variations in thickness (0.7 m to more than 3 m), is composed of the alternation of irregular beds of white to yellow stratified sands and sandy loams and discontinuous gravel beds. 3A: heterogeneous flint gravel bed with abundant clayey-sandy matrix. 3B: Yellow to reddish sands mainly preserved in the centre of the sinkhole in which they progressively include reworked rounded flint nodules (Figs. 4A and 5B). 3C: heterogeneous flint gravels with a mainly sandy matrix. 3D: (mainly recorded on the borders of the sinkhole (Figs. 4A and 5B) Succession of yellow laminated sand lenses (sub-units 3D1 to 3D5) and of flint gravel beds with an abundant pure sandy matrix (sub-units 3D2 and 3D4). The upper part of sub-unit 3D1 is composed of finely laminated brown to brown-greenish clayey silts and corresponds to the level of discovery of the Acheulean bifaces. 4 - White Marl. Sequence of stratified sandy to sandy-silty calcareous deposits, relatively rich in oncoliths. 4A - Finely stratified calcareous deposit composed mainly of ovoid oncoliths (1–30 mm in diameter) in a quartz sandy matrix and some scattered rolled flints. The stratification is clearly oblique and underlined by thin beds of pure coarse quartz sands. 4B - Light grey slightly sandy silt, finely laminated in places, including rolled flint pieces and some scattered oncoliths mainly in the middle part. 4C - Second unit of oncolithic sands differing from the previous unit on account of a larger proportion of fine-grained matrix (sand, oncolith fragments of 1–2 mm) and more marked oblique and cross stratifications. 4D - Yellow grey to greenish sandy calcareous silts with scattered oncoliths and small flints, a few mollusc shells, and irregular orange oxidation bands. The middle part of this unit exhibits irregular quartz sand beds including very fine oncoliths. 5 - Coarse gravels subdivided into three sub-units: 5A - Fluvial gravels with weak planar stratifications, mainly composed of rolled flints in a sandy matrix including numerous chalk grains (<4 mm). 5B - Irregular lens of greyish sandy silt with some scattered molluscs and thin oxidation bands. 5C - Coarse and heterogeneous deposit with slightly to unrolled large flint nodules and chalk blocks in a compact sandy and chalky matrix. At its base, this deposit is characterised by the occurrence of larger flint and chalk blocks without any evidence of fluvial

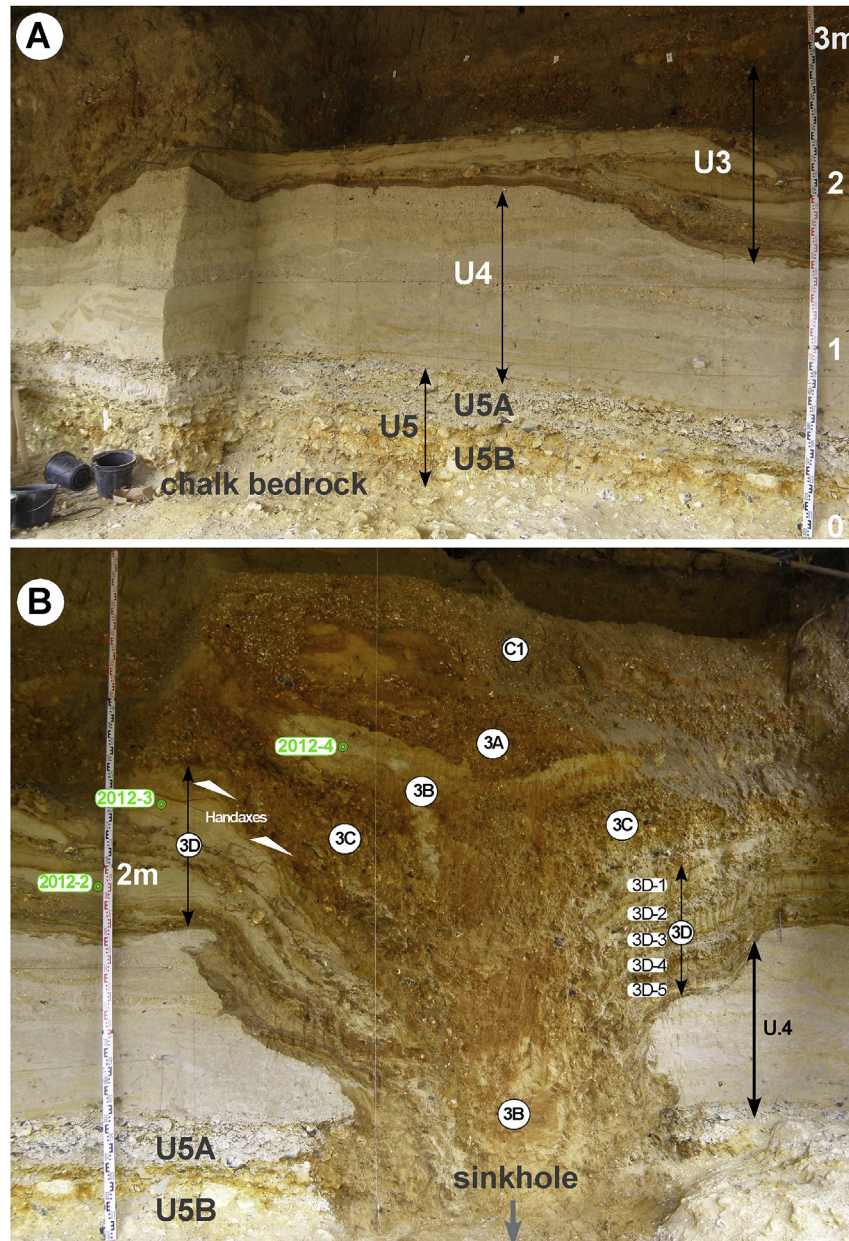


Fig. 5. Photographs of the Carrière Carpentier section (2011–2013). See Fig. 4A for labelling and description of the units. A - General view of the central part of the section. B - View of the eastern part of the section showing a deep sinkhole filled by slope deposits (2012–2 to 2012–4: ESR samples, see Fig. 4A for results).

sandy silts (sub-unit 5B), showing a facies similar to sub-unit 4D, and indicating an abrupt and probably short decrease in river energy. A long bone fragment (rhinoceros tibia) was found close to the contact between the sub-unit 5B and the overlying gravel of sub-unit 5A.

3.1.2.2. Calcareous silts and oncolithic sands (sub-units 4D to 4A). The upper alluvial level is characterised by a typical fluvial deposit in which a succession of four main phases (corresponding to sub-units 4D to 4A) can be individualized. The oldest unit (4D) is represented by homogeneous calcareous sandy silts with scattered oncoliths and discontinuous sandy lenses. A detailed grain-size analysis of unit 4D was published in Antoine et al. (2015a,b). The occurrence of oncoliths (Fig. 5C&D) of varying abundance depending on the layers, and of freshwater molluscs shells, confirm the fluvial origin of these sediments.

The strongly erosive contact occurring between the 4C and 4D sub-units marks a dramatic increase in fluvial dynamics and the beginning of the massive formation of calcareous oncolithic sands. This change is not necessarily related to an important variation in environmental parameters, such as vegetation cover, and is interpreted as the result of an increase in the activity of springs, located in the Somme Basin at the bottom of the slopes during interglacial periods, as observed on the Eemian site of Caours (Antoine et al., 2006). The contact between sub-units 4B and 4C is more progressive and the deposition of sub-unit 4B, which is similar in facies to 4D, implies a return to a lower energy context favourable to fine carbonated sedimentation and to better mollusc shell preservation. This unit contained most of the bone material (see part 3.5).

The upper part of the White Marl sequence (sub-unit 4A) corresponds to the last episode of significant increase in fluvial dynamics, underlined by the new occurrence of strongly stratified

coarse oncolithic sands and gravels, and the decrease in the number of shells. The base of this sub-unit is marked by an erosional contact and a bed of encrusted flints (~5 cm max. in size). The composition and stratification of these deposits indicate a generalized increase in the fluvial activity of the lateral channels of the Somme River in the vicinity of the slope very similar to the Carrière Carpentier sequence. According to the observations made in the reference tufa sequence of Caours, dated to the Last Interglacial, this process could indicate a new increase in flow from springs, linked to the elevation of the top of the chalk aquifer.

3.2. Micromorphology of the oncoliths from unit 4

The Carrière Carpentier oncoliths have a diameter of 1–2 cm and exhibit a finely laminated structure in cross-section concentrically organised around a millimetric flint nucleus. The formation of such calcareous ovoids is induced, in a stabilised fluvial system, by continuous or cyclical water flow at the bottom of a pool, upstream of a dam or other obstacle, which rolls nuclei then oncoliths, leading to concentric precipitation (Casanova, 1981; Lang, 1981). Oncoliths are mostly composed of calcite, resulting from unicellular algae/cyanobacterial activity (Pentecost, 2005). In the 1970s, Adolphe interpreted the Carrière Carpentier oncolith facies, displaying irregular wavy laminations, as the result of seasonal Rhodophyceae and Cyanophyceae activity (Adolphe, 1974).

New microscopic observations of the Carrière Carpentier oncoliths were recently performed on four randomly picked samples from sub-units 4A and 4C. Thin sections were made at the PACEA laboratory (UMR 5199 CNRS, University of Bordeaux, Pessac, France) without impregnation.

On two of the observed oncoliths, the nucleus is intersected by the thin section. In both cases, rounded nuclei are constituted by black and white microcrystalline silica (chalcedony) in which microfossil tests are trapped (foraminifera). One of these flint nuclei presents intense internal alteration of brownish-orange, more or less opaque impregnation that does not affect the outermost 300 µm of the nucleus (Fig. 6A) and which is also visible to the naked eye. This alteration is typical of flint gravels from old fluvial formations located on the slope and the plateau and in which the flint nodules were subject to deep weathering processes in a clayey matrix during the various periods of interglacial soil development throughout the Pleistocene.

The four oncoliths show concentric laminae mainly composed of micritic to micro-sparitic calcite, including some detrital components, mostly rounded quartz with diameters ranging from tens of micrometres to a hundred micrometres, as well as rare small organic clots (with diameters of a few tens of micrometres). The largest quartz crystals are generally concentrated at boundaries between laminae, which can also be marked by relatively continuous sub-linear breakages. The laminations and observed microfacies, featuring filaments and/or fascicules, attest to the biologically induced origin of the calcite oncolith coatings.

At least three algae/cyanobacteria morphotaxa were identified according to freshwater fossil taxa descriptions by Freytet (1997, 1998). Morphotaxa have no biological significance (Freytet, 1997), and refer to a microfacies of biogenic calcite described on the basis of micromorphological/petrographic criteria. These are the only criteria available to describe biofacies in fossil oncoliths, where most organic matter and DNA that might be identified with algal/bacterial communities, has decayed. Nevertheless, the determination of morphotaxa can provide palaeoecological information based on comparisons between fossil and modern taxa (Dabkowski et al., 2010).

The formation of calcareous oncoliths at Carrière Carpentier was induced mainly by cyanobacteria (Cyanophyceae), particularly *Dichothrix gypsophila* and *Schizothrix*, associated with the

Chlorophyceae *Gongrosira*. The presence of “*Phormidium incrustatum* communities”, including *Schizothrix* and *Gongrosira*, is observed episodically. These new microscopic observations challenge Adolphe's (1974) interpretations as no Rhodophyceae were identified, but the author does not provide details as to the stratigraphic origin of his samples. They include, without distinction, oncoliths from different sites (mainly Montières-Grâce and Abbeville-Carrière Carpentier). However, he notes that the fossil “calcareous beans” present macroscopic similarities with those from the modern rivers in this area, known to be induced by Cyanophyceae (including *Schizothrix*) and Chlorophyceae (including *Gongrosira* sp.), which is consistent with our new data.

Cyanophyceae and Chlorophyceae are photosynthetic organisms requiring environments with low turbidity, indicating that river banks were well stabilised by the development of vegetation and soil. The predominance of *Doubingerella fonticola* (corresponding to *Dichothrix gypsophila*) clearly indicates shallow waters. The oncoliths always show regular concentric laminae and are well preserved at Carrière Carpentier. The only secondary alteration appears to be micro-sparite precipitation in the porosity. Their formation and the recurrent presence of detrital material (especially rounded quartz up to a hundred micrometres in diameter) demonstrate that the water flow was dynamic enough to roll them.

Oncoliths, like other open-air freshwater carbonates deposited in fluvial contexts (i.e. calcareous tufas), are characteristic of interglacial conditions (Capezzuoli et al., 2014; Pentecost, 2005), and none of the identified cyanobacteria/algae taxa require different temperatures to modern conditions (Whitton, 2002). There is thus no proof of warmer conditions than today, as suggested by Adolphe (1974).

3.3. Radiometric dating studies

Two methods were used to date the Carrière Carpentier samples: electron spin resonance (ESR) on optically bleached quartz extracted from the sediments and combined ESR and U-series (ESR/U-series) approach on teeth.

ESR is a palaeodosimetric dating method in which the sample is used as a dosimeter having recorded the total dose of radiation received from the event to date, in this case the last exposure of quartz grains to solar light or the burial of palaeontological remains.

In ESR dating of sediment, it is necessary to study quartz grain reactions to both irradiation and insolation, in order to determine the amount of radiations received by the quartz grains for each sample since they were geologically deposited. 100–200 µm quartz grains are thus extracted from the sediments by sieving following a physical and chemical protocol (Yokoyama et al., 1985; Voinchet et al., 2004). The obtained grains are split into aliquots, and most of them are then irradiated by gamma-ray doses ranging from 200 to 10,000 Gy, with one aliquot being kept as a reference (natural point) and another exposed to light for thousand hours in a SOL2 solar simulator. All the aliquots are then measured by ESR at liquid nitrogen temperature (see conditions in Voinchet et al., 2004) and the total dose of radiation recorded by the samples is deduced from the extrapolation of the dose-response curves of the quartz Aluminium (Al) centre intensity, after subtraction of the unbleachable component signal intensity, determined from individual intensity decay curves under artificial light exposure (Tissoux et al., 2012). The obtained palaeo-dose is then divided by the dose rate, calculated from *in situ* gamma measurements and from the radionuclide contents measured by gamma-ray spectrometry in the laboratory. The following parameters and assumptions were made for age calculation: alpha and beta attenuations estimated from the tables of Brennan (2003) and Brennan et al. (1991) respectively; k-value of 0.15 (Yokoyama et al.,

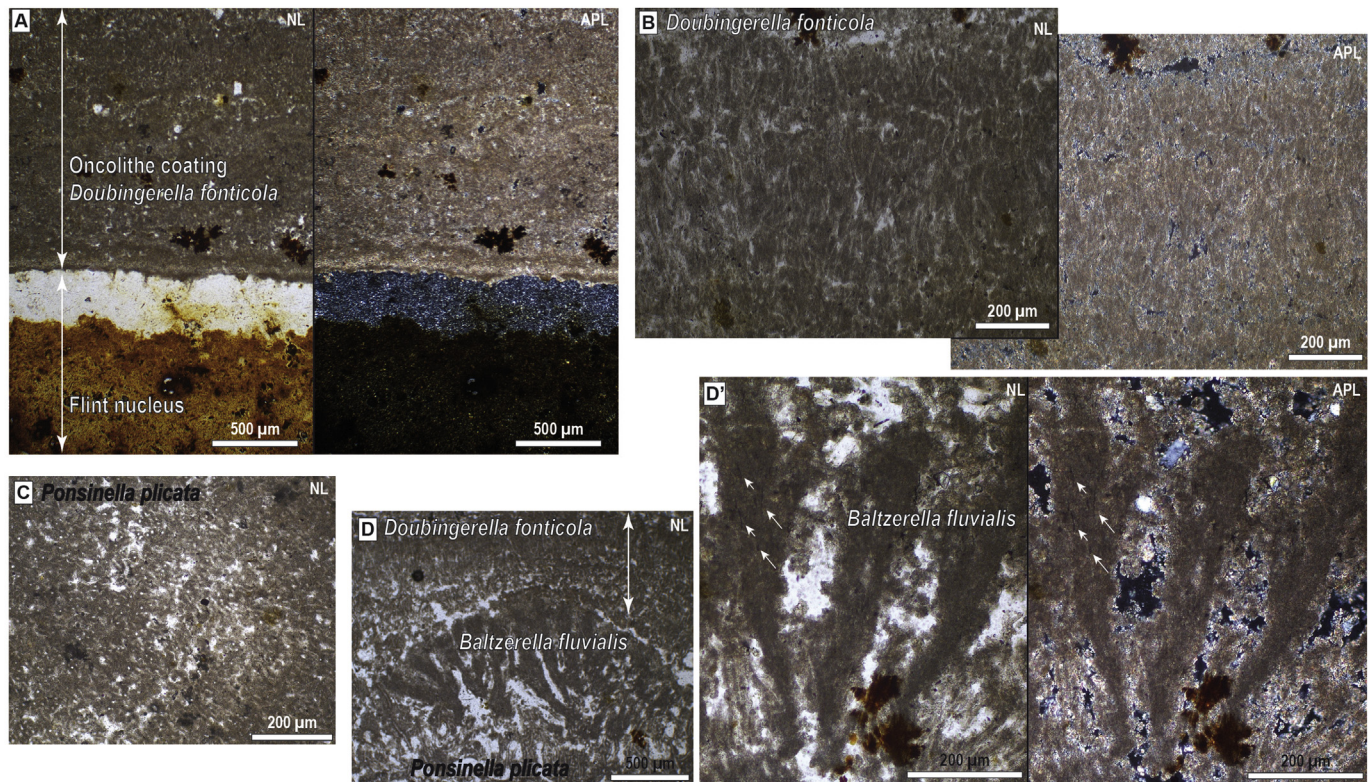


Fig. 6. Microphotographs of oncoliths from Carrière Carpentier (NL: 'natural' non-polarised light; APL: analysed polarised light). A: *Doubingierella fonticola* incrusting on an altered flint nucleus, alteration does not affect the outermost 300 µm of the flint; B: *Doubingierella fonticola* making tufa-like layers; C: *Ponsinella plicata* (growth direction from the upper left corner to the lower right) with typical transversal sections of filaments, which are then prostrate and finally erected and form no fascicules; D and D': *Baltzerella fluvialis* fascicules; photograph D shows how *B. fluvialis* fascicules are associated with *P. plicata* in thick laminae inserted in the main *D. fonticola* lamina pattern; some of the thin blackish filaments included in the micritic fascicules of *B. fluvialis* are shown by arrows on photographs D', note the porosity partly filled by micro-sparite. Photographs by J. Dabkowski. Caption: The commonest microfacies exhibit erect, nearly vertical, weakly branched, more or less spaced filaments with a diameter of a few µm, included in micrite (A). They formed fascicules 100–300 µm high and about 100 µm wide where they can be laterally delimited; fascicules are more often badly delimited and seem to be arranged in parallel sets making turf-like layers (B). These features are diagnostic of *Doubingierella fonticola* (Freytet, 1997). One of the oncoliths shows at its centre (nucleus not intersected by the thin section) numerous empty rounds about 10 µm in diameter, which should correspond to transversal sections of algae/cyanobacteria of prostrate filaments (C). They mix with non-flexuous, inclined or mostly erected filaments 50–100 µm long and similarly 10 µm in diameter. Erected filaments are the longest (up to 150 µm) and are nearly parallel, with spacing 2–5 times the diameter (20–100 µm). All filaments have a thick dark micritic coating included in micrite or micro-sparite. The size, shape and organisation of the filaments, which do not form fascicules, are diagnostic of the morphospecies *Ponsinella plicata* (Freytet, 1998). This microfacies also shows porosity of 5–20% in places. Voids are irregular in shape and their size does not exceed a few tens of µm; they are frequently filled by micro-sparite. The third identified morphotaxon makes dark micritic, fingered fascicules, 600–700 µm high, 40–150 µm wide. Filaments are difficult to observe (D'). They are very thin (a few µm), with spaced blackish lines, up to 100 µm high, parallel or weakly divergent, comprised in the micritic matrix of fascicules. These features, especially the size of filaments and fascicules are diagnostic of *Baltzerella fluvialis* (Freytet, 1998). In the Carrière Carpentier oncoliths, this morphospecies is associated with *Ponsinella plicata* in thick laminae (up to 1 mm high), inserted in the main pattern of 100–500 µm high laminae by *Doubingierella fonticola* (D). In *B. fluvialis*/*P. plicata* laminae, porosity is important in places, both in size and frequency (up to 40%; elongate voids, 10–500 µm long). Micro-sparite generally coats the edge of voids.

1985); cosmic dose rate calculated after Prescott and Hutton (1994); water content of 15 ± 5 wt%. The internal dose rate was considered to be negligible due to the low content of radionuclides in the quartz grains.

For dating teeth, the combination of ESR and U-series analyses allows for the determination of the U-uptake kinetics in dental tissue, prior to the calculation of the corresponding dose rate contribution to the archaeological dose. Sample preparation and age calculation are described in Bahain et al. (2007). At Carrière Carpentier, despite U-leaching evidence for all the dental tissues, the use of the AU model (Shao et al., 2012) allowed for the calculation of ESR/U-series ages and associated dose rates. The following parameters were thus used: k-value of 0.13 ± 0.02 (Grün and Katzenberger-Apel, 1994); water content of 3 ± 1 wt% for enamel, 7 ± 5 wt% for dentine and 15 ± 5 wt% for sediments; conversion factors nuclide content-dose of Adamiec and Aitken (1998); beta attenuations in enamel from Brennan et al. (1997); cosmic dose rate from Prescott and Hutton (1994); effect of Rn losses in each tissue

using the method of Bahain et al. (1992).

Eight sediments sampled from the Carrière Carpentier main geological section (Fig. 4A) were analysed, six from the fluvial sequence (but quartz quantities were insufficient in sample CC2012-2 and only 5 ages were obtained) and two from sands from the overlying slope deposit sequence (Table 2). Two teeth from the fluvial sequence (unit 4B) were also analysed by ESR/U-series (Table 3, Fig. 7).

The combination of the whole set of ages obtained in the alluvial levels (including the date of Laurent et al., 1994, 1998) (Fig. 7) provides a mean age of 584 ± 48 ka for the fluvial sequence of Carrière Carpentier and suggests that the fluvial deposition of the White Marl was coeval to MIS 15. The mean age of the laminated yellow sands from the base of unit 3 (463 ± 51 ka) indicates that the sinkhole in which the sediment was sampled formed relatively quickly after the end of fluvial sedimentation. This date may be considered as a preliminary result and requires confirmation by additional analyses.

3.4. Molluscs

The malacological fauna from Carrière Carpentier was extracted from five samples covering the so-called White Marl deposit, from the base to the top (Fig. 4A: sub-unit 4D to sub-unit 4A). Samples of 15 kg each, taken at 20 cm intervals, were sieved with a 500 μ m screen. Shells are poorly preserved and only a few taxa were identified, most of which occur in the basal sample (unit 4D) (Table 4).

The terrestrial species are only present in the lower part of sub-unit 4D; they indicate wet and grassy habitats commonly developed on riverbanks. These snails are ecologically tolerant and can withstand interstadial or interglacial climatic conditions. Aquatic molluscs are present throughout the whole sequence although the shells are highly fragmented. The best preserved remains are the *Bithynia* opercula which offer better resistance to fluvial abrasion. No shells of this taxon were recovered. Careful observation of the opercula led to their attribution to *Bithynia troschelii* rather than *B. tentaculata* as previously reported (Antoine et al., 2014). This new identification makes an important difference to the biostratigraphic attribution of the sequence, as discussed below. From the base to the top of the White Marl, both the decline in the number of preserved shells and the rapid disappearance of the few terrestrial species indicate an increase in fluvial dynamics. In sub-units 4A and 4C, no shells could resist the mechanical abrasion and only a few *Bithynia* opercula were recovered, indicating that both layers were deposited during more dynamic episodes characterised by stronger fluvial currents and coarser sediments. The aquatic assemblages of sub-units 4D and 4B evidence clear and running water. Shallow waters are also indicated by the occurrence of Characeae oogonia (Table 4).

The sedimentary sequence observed at Carrière Carpentier is attributed to the Alluvial Formation VII of the Somme River system (Antoine, 1994, 2000 Table 1). Two other sites belonging to the same fluvial formation have yielded mollusc faunas: Carrière Léon and Moulin Quignon. The first locality is located right next to Carrière Carpentier, and the second is about 300 m south-eastwards.

At Carrière Léon, a bulk sample taken from the White Marl formation produced a very similar malacological record to those from Carrière Carpentier (Table 5). Shells are poorly preserved and include a few terrestrial snails from open humid habitats (*Nesovittia hammonis*, *Trochulus hispidus*, *Cochlicopa*, *Pupilla muscorum*, slugs). Aquatic molluscs are more numerous and mainly represented by *Bithynia troschelii* opercula, along with some *Valvata cristata*, *Radix* sp. and *Pisidium henslowianum* specimens. Ostracods and Characeae were recovered with mollusc shells indicating the same clear and shallow water environment as in the Carrière Carpentier levels. At Moulin Quignon the malacological assemblage appears richer (Table 5). The numbers of shells are not comparable because the record comes from the reappraisal of an old collection (Breuil et al., 1939a,b), and nothing is known about the sampling process. However, the deposits are described as sandy layers

(Boucher de Perthes, 1847). Similarly to the previous localities, terrestrial species indicate open and humid habitats typical of a riverbank and which can survive under interstadial or interglacial climatic conditions. Among the aquatics, unlike the other sites, *Bithynia* is not present but as this species is only identified on the basis of the opercula, it is possible that previous collectors overlooked these remains. The aquatic mollusc community is similar to that recovered at Carrière Carpentier and Carrière Léon but also includes two noteworthy species: *Borysthenia naticina* and *Tanousia* cf. *stenostoma* (Fig. 8). Both are important biostratigraphical markers of Cromerian fluvial deposits from north-western Europe (Meijer and Preece, 1996; Preece, 2001). Specimens of *Tanousia* from Moulin Quignon are very similar to those from Little Oakley in Great Britain (Preece, 1990) and have been named in the same way, *T. cf. stenostoma*, to underline their common characteristics. The association of *B. troschelii*, *T. cf. stenostoma* and *B. naticina* corroborates the strong correlation with Little Oakley and the sites of Germany and The Netherlands belonging to Interglacial III of the Cromerian Complex (group C of Meijer and Preece, 1996). Recent work undertaken on amino acid measurements of *Bithynia* opercula suggest a probable attribution of Little Oakley to MIS 15, thereby consolidating the Cromerian age of this malacological assemblage (Bates, 1993; Penkman et al., 2013). Malacofauna from the sites from Alluvial Formation VII of the Somme River system exhibit the same group of essential species (*B. troschelii*, *T. cf. stenostoma*, *B. naticina*), which reinforces the attribution of these deposits to an interglacial period of Late Cromerian age.

3.5. Microvertebrates

Microvertebrate remains (Fig. 9) were extracted from a set of test samples using first dry sieving and then wet sieving with a 1 mm mesh (some samples were sieved at 0.5 mm, but they did not yield more material than those sieved at 1 mm). Material was extracted from 63 samples (10 L each), taken from unit 4 (White Marl), and additional samples from unit 5C proved to be azoic (Table 6). About 160 small vertebrate bone remains were recovered, allowing the identification of at least 12 species of lagomorphs (*Oryctolagus* sp.), rodents (*Allocricetus/Cricetulus* sp., *Arvicola cantiana/mosbachensis*, *Clethrionomys* cf. *glareolus*, *Pliomys* sp., *Microtus* cf. *gregaloides*), soricomorphs (small shrew aff. *Sorex minutus*, *Sorex* cf. *araneus/coronatus*, *Talpa* cf. *minor*), amphibians (*Bufo* sp.) and reptiles (Testudines indet., Serpentes cf. *Coluber* sp.), along with fish remains (*Scardinius erythrophthalmus*, *Tinca tinca*, *Esox lucius*, *Abramis brama*, cf. *Cyprinus carpio*). Despite the meagre quantity of material, interesting taphonomic, biochronological and palaeoenvironmental data were obtained.

The majority of the lagomorph remains presents a similar morphology and size to modern *Oryctolagus cuniculus* specimens. However a few fragmented remains appear to be smaller (young individuals?), while other specimens display a larger size, approaching that of *Lepus europaeus*. The paucity and fragmentation of the material prevent more exact identifications but several

Table 2
ESR results obtained on the Carrière Carpentier sediments.

	Stratigraphic unit		Depth (cm)	Bleaching percentage (%)	Archaeological dose (Gy)	Dose rate (μ Gy/a)	Ages (ka)
Carpentier Quarry 2012–1	<i>Slope deposits</i>	3	200	38	289 $\pm$ 24	582 $\pm$ 17	496 $\pm$ 44
Carpentier Quarry 2012–2		3	200	36	217 $\pm$ 14	487 $\pm$ 15	446 $\pm$ 32
Carpentier Quarry 2011–1	<i>Fluvial sequence</i>	4B	260	49	521 $\pm$ 105	688 $\pm$ 13	757 $\pm$ 153
Carpentier Quarry 2011–3		4C	280	43	278 $\pm$ 43	483 $\pm$ 11	576 $\pm$ 90
Carpentier Quarry 2011–5		4C	300	42	236 $\pm$ 28	401 $\pm$ 10	588 $\pm$ 72
Carpentier Quarry 2011–4		4D	350	41	308 $\pm$ 123	433 $\pm$ 9	711 $\pm$ 285
Carpentier Quarry 2011–6		5B	400	41	292 $\pm$ 38	476 $\pm$ 14	614 $\pm$ 81

Table 3
ESR/U-series dating results of Carrière Carpentier large mammal teeth.

Sample	Tissue	Equivalent dose (Gy)	Uptake parameter n (AU model)	Dose rate ($\mu\text{Gy/a}$)	ESR-AU age (ka)
CC5	Enamel	314.97 ± 17.39	-0.0022 ± 0.0002	512 ± 50	615 ± 50
	Dentine		-0.0022 ± 0.0002		
CC10	Enamel	245.97 ± 11.44	-0.0026 ± 0.0002	442 ± 40	539 ± 40
	Dentine		-0.0025 ± 0.0002		

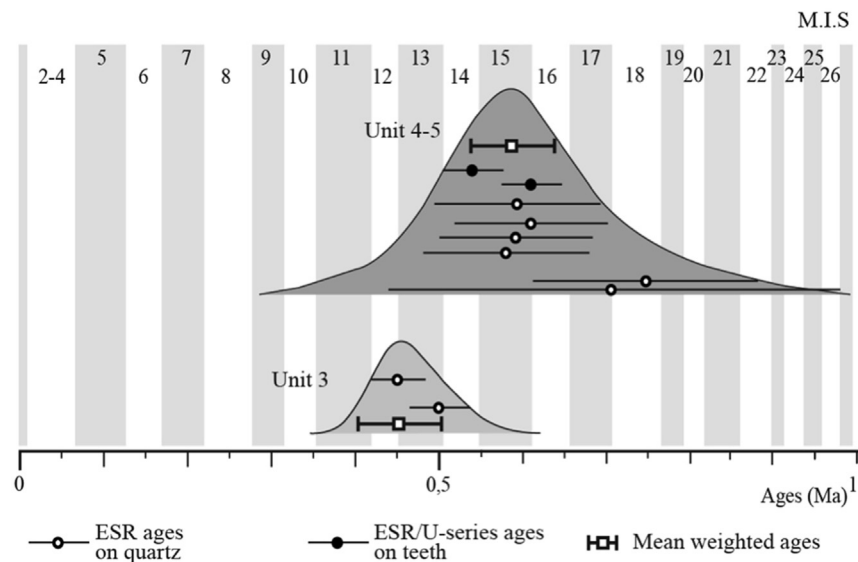


Fig. 7. Probability plot of the ESR and ESR/U-series ages obtained on sediments and teeth from Carrière Carpentier.

Table 4
Malacological data from the White Marl.

Carrière Carpentier	4D lower	4D upper	4C	4B	4A
<i>Vallonia enniensis</i>	2				
<i>Nesovitrea hammonis</i>	1				
<i>Trochulus hispidus</i>	1				
Slugs	2				
<i>Valvata piscinalis</i>	5	2			
<i>Bithynia troschelii</i> (opercula)	23	6	3		1
<i>Pisidium henslowanum</i>	22	13		10	
Other fossils	Ostracodes			Characeae	Fish vertebra

species may be represented here. Several *Oryctolagus* species have been recorded in Western Europe since the Pliocene (e.g. Lopez-Martinez, 2008; Pelletier et al., 2015). During the Middle Pleistocene, *Oryctolagus* occurred in Mediterranean areas, in Hungary (Lopez-Martinez, 2008), and in several sites in UK, such as Swanscombe, Barnham, Boxgrove and Westbury (Parfitt, 1998; Schreve, 2001; Preece et al., 2007 and references therein). The persistence of open areas even during interglacials provided the continuous grassland necessary to allow the spread of rabbits from their refugia in Iberia or Southern France, along the western continental margin and then across the landbridge linking Britain to the continental mainland (Preece et al., 2007; Lopez-Martinez, 2008; Pelletier et al., 2015). The probable record of rabbit from Carrière Carpentier would fit with this scenario.

The single *Cricetidae* molar was attributed to *Allocricetus* or *Cricetulus*, mainly according to its small size. *Allocricetus* occurred in Central Europe during the Pleistocene, and was found in several sites dating from the Middle Pleistocene and early Late Pleistocene

(e.g. Janos, 1997; Paunescu, 2001; Cuenca Bescos, 2003; Hanquet, 2011). This fossil species is close to the modern species *Cricetulus migratorius*, which was subjected to several waves of migration from Eastern to Western Europe from the Early Pleistocene to the early Late Pleistocene (Paunescu, 2001). A small hamster attributed to *Cricetulus migratorius* was notably found at West Runton and Westbury (Preece and Parfitt, 2000; Stuart and Lister, 2010). Tooth remains of the semi-hypsodont-rhizodont species *Clethrionomys* cf. *glareolus* and *Pliomys* sp. do not show 'true roots', but a rather pronounced closure at the base of the crown, pointing to young individuals. *Clethrionomys glareolus* is known from the Pliocene to the present in Western Europe. Only two *Pliomys* teeth were found at Carrière Carpentier (m2 and M1), which are not distinctive enough for species attribution. *Pliomys episcopalensis* is the common species of *Pliomys* found in sites of Cromerian Complex age (Maul and Parfitt, 2010). *Pliomys lenki* is known in Western Europe during Middle and Late Pleistocene, with a progressive increase in hypsodonty and the length of the m1, and the appearance

Table 5

List of mollusc species collected at Carrière Léon and Moulin Quignon in the Alluvial Formation VII of the Somme River and compared with the assemblage from Carrière Carpentier. Species are separated in terrestrial (upper part) and aquatic (lower part) taxa.

Carrière Carpentier	Carrière Léon	Moulin Quignon
<i>Vallonia enniensis</i>		<i>Oxyloma elegans</i> <i>Succinella oblonga</i> <i>Cochlicopa lubrica</i> <i>Vallonia costata</i> <i>Vallonia pulchella</i>
	<i>Cochlicopa</i> cf. <i>nitens</i> (?)	<i>Pupilla muscorum</i> <i>Punctum pygmaeum</i> <i>Zonitoides nitidus</i>
<i>Nesovitrea hammonis</i>	<i>Nesovitrea hammonis</i>	<i>Nesovitrea hammonis</i>
<i>Trochulus hispidus</i>	<i>Trochulus hispidus</i>	<i>Trochulus hispidus</i> <i>Xerocrassa geyeri</i>
Slugs	Slugs	Slugs
<i>Valvata piscinalis</i>	<i>Valvata piscinalis</i>	<i>Valvata piscinalis</i>
<i>Bithynia troschelii</i> (opercula)	<i>Bithynia troschelii</i> (opercula)	<i>Borysthenia naticina</i> <i>Tanousia</i> cf. <i>stenostoma</i> <i>Galba truncatula</i>
	<i>Radix</i> sp.	<i>Radix</i> sp. <i>Pisidium amnicum</i> <i>Pisidium henslowanum</i> <i>Pisidium milium</i>
<i>Pisidium henslowanum</i>	<i>Pisidium henslowanum</i>	
	<i>Pisidium nitidum</i> <i>Pisidium subtruncatum</i> (?)	
Characeae	Characeae	
Ostracods	Ostracods	

of cement in the re-entrant angles (Bartolomei et al., 1975; Paunescu, 2001; Hanquet, 2011). The *Pliomys* remains from Carrière Carpentier do not show a final evolution stage, as we observe a moderate size and a lack of cement in the re-entrant angles. *Microtus* cf. *gregaloides* shows a very similar morphology to that of *Microtus gregaloides* (notably confluent T4-T5 = “*Pitymys-rhombus*”), but a slightly smaller size (length $\approx$ 2.20 mm) compared to other *M. gregaloides* fossil specimens (Cuenca-Bescos et al., 1995), as well as modern and fossil *M. gregalis* (pers. obs.; Desclaux, 1992; Paunescu, 2001; Hanquet, 2011). However, only one tooth was found, preventing statistical estimations. *M. gregaloides* appears at the end of the Early Pleistocene, and occurs in Central Europe until the Cromerian Interglacial III or IV (MIS 15–13), while the first occurrence of *M. gregalis* dates from the Cromerian Interglacial II (MIS 17) (Maul and Markova, 2007). At Carrière Carpentier, we have not observed any element belonging to the primitive semi-hypsodont-rhizodont *Mimomys*, but only its more recent relative *Arvicola*, displaying strictly hypsodont-arhizodont teeth (neither rooted molars nor closing of the basis of the teeth, no “enamel islet”, no “*Mimomys* fold”). However, it must be noted that very few molars were found (Table 6), most of them being fragmented (only two m1 could be measured). Consequently, whether the Carrière Carpentier water voles represent a transitional population or a true *Arvicola* population is difficult to answer, as it is the case for other ‘Cromerian Complex’ assemblages with small samples of water vole teeth (Preece and Parfitt, 2012). By limiting our conclusions strictly to the observed specimens, we tentatively attribute the Carrière Carpentier specimens to *Arvicola cantiana/mosbachensis*. Primitive forms of *Arvicola* appear during the Middle Pleistocene, belonging to *A. cantiana* (Escudé et al., 2008a,b), also named *Arvicola mosbachensis* (Maul et al., 2000; Kalthoff et al., 2007), while the modern species *A. sapidus* and *A. amphibius* (= *Arvicola terrestris*) only appear at the beginning of the Late Pleistocene (von Koenigswald and van Kolfschoten, 1996; Desclaux et al., 2000). The measurements obtained from Carrière Carpentier specimens match well with Cromerian/Holsteinian *A. cantiana/mosbachensis* (see bio-chronological section).

Soricomorph remains are very scarce and fragmented, preventing any asserted identification at a specific level. However, size criteria can yield some information. In this way, the *Talpa* remains found at Carrière Carpentier show a similar morphology to the modern European mole, but are significantly smaller in size than *T. europaea*, or even *T. caeca*. The smaller species *Talpa minor* is found as a fossil in several Early and Middle Pleistocene sites in Europe (Desclaux, 1992; Rzebik-Kowalska, 2006). In France this species is mentioned in a single Middle Pleistocene site (Gargas Cave; Reumer, 1996), but *T. minor* is well established from several Middle Pleistocene sites in Great Britain (Preece, 1990; Schreve, 2001; Preece et al., 2007). Two species of shrews of different sizes are observed at Carrière Carpentier: one very small mandible, similar to *Sorex minutus*, and one mandible with a similar size and morphology to the *Sorex araneus/coronatus* group. *S. minutus* is known since the Pliocene in Central Europe, and then spread widely throughout Europe during the Pleistocene (Rzebik-Kowalska, 1998, 2006). *S. araneus* and *S. coronatus* are considered to be sister species (morphologically very similar), which diverged in Western Europe just 100 ka (Taberlet et al., 1994; Wilson and Reeder, 2005). The *araneus/coronatus* group occurred during the Pleistocene and is well represented in Middle Pleistocene fossil assemblages (Rzebik-Kowalska, 2006). However, *Sorex runtonensis*, another medium-sized shrew commonly found in sites dating to the Cromerian Complex, cannot be totally excluded (Osipova et al., 2006; Rzebik Kowalska, 2006; Maul and Parfitt, 2010).

Fish remains are essentially represented by dental elements (pharyngeal, palatine and lower jaw teeth). Five species are present in the White Marl: *Scardinius erythrophthalmus* (rudd); *Tinca tinca* (tench); *Esox lucius* (pike); *Abramis brama* (bream); Cyprinidae (doubt persists as to the attribution of isolated teeth to *Cyprinus carpio* and because of the context [Gaudant et al., 2014], we keep it in open nomenclature). These fish are typical of shallow, slow flowing or standing water bodies, in the same way as the fish recorded at the German pre-Cromerian site of Voigstedt (Maul et al., 2013). According to the modern European river zonation

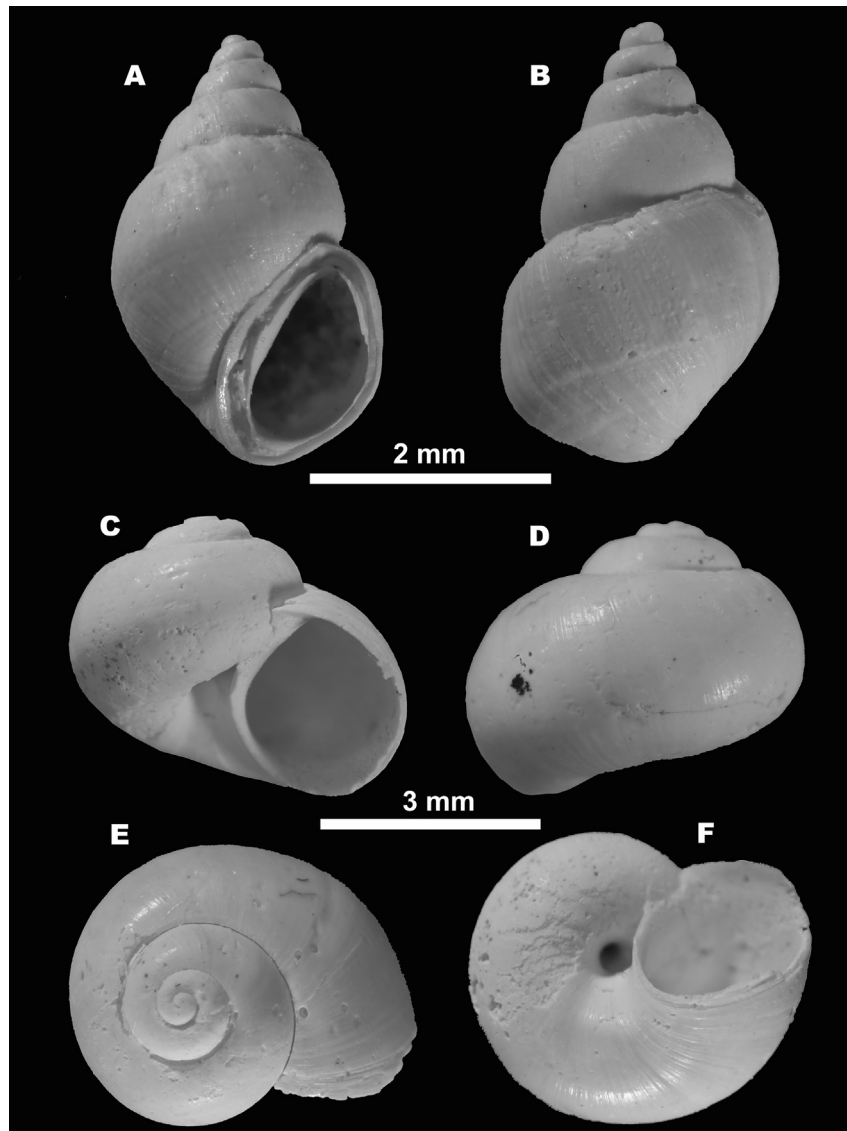


Fig. 8. Rare shells from Moulin Quignon, A and B: *Tanousia* cf. *stenostoma* (Nordmann, 1901) (Mollusca, Gastropoda, Hydrobiidae); C to F: *Borysthenia naticina* (Menke, 1845) (Mollusca, Gastropoda, Valvatidae).

(Aarts and Nienhuis, 2003), the identified species correspond to the central part of the river.

3.5.1. Taphonomy

The preliminary taphonomic analysis of the microvertebrate assemblage indicates that the material is relatively scarce with few determinable remains. The percentage of fragmentation is very high and all skeletal elements are not represented. Indeed, the profiles of anatomical representation show a clear lack of elements from Voorhies categories I and II (Dodson, 1973; Korth, 1979; Fernandez-Jalvo and Andrews, 2003). This points to secondary accumulations, with post-depositional dispersion in a medium-energy fluvial context. Only two microvertebrate remains show a rounded aspect (polishing by water), excluding an extended stay in a highly dynamic water flow for the majority of the bones. These observations are consistent with those made on large fauna (rounding was observed on a few small bone splinters) and with the formation of oncoliths in a mid to low dynamic fluvial context. The origin of the microfaunal assemblages of Carrière Carpentier remains to be determined, but it does not seem to result from

predation (no digested elements). Some other traces were observed: Mn and Fe oxides (of limited extent), soil corrosion, weathering (of low intensity), root marks (rare), fine parallel striations (probably due to osteophage insects, trampling or transport). To conclude, owing to probable taphonomic disturbances, we should be cautious about biochronological and palaeoenvironmental interpretations deduced directly from the faunal list. Data obtained from small vertebrates need to be compared with other disciplines for greater reliability.

3.5.2. Palaeoecological interpretation

For palaeoenvironmental reconstruction, we have to bear in mind the very limited quantity of material and the previously highlighted taphonomic biases. For these reasons, and also because the sediments in unit 4 (White Marl) show a certain homogeneity and were deposited over a very short time (see part 3.1), we chose to consider unit 4 as a single entity without differentiating sub-units A, B, C and D (further studies on more abundant material may differentiate the different sub-levels). We used different and complementary palaeoecological methods (Figs. 10 and 11). In

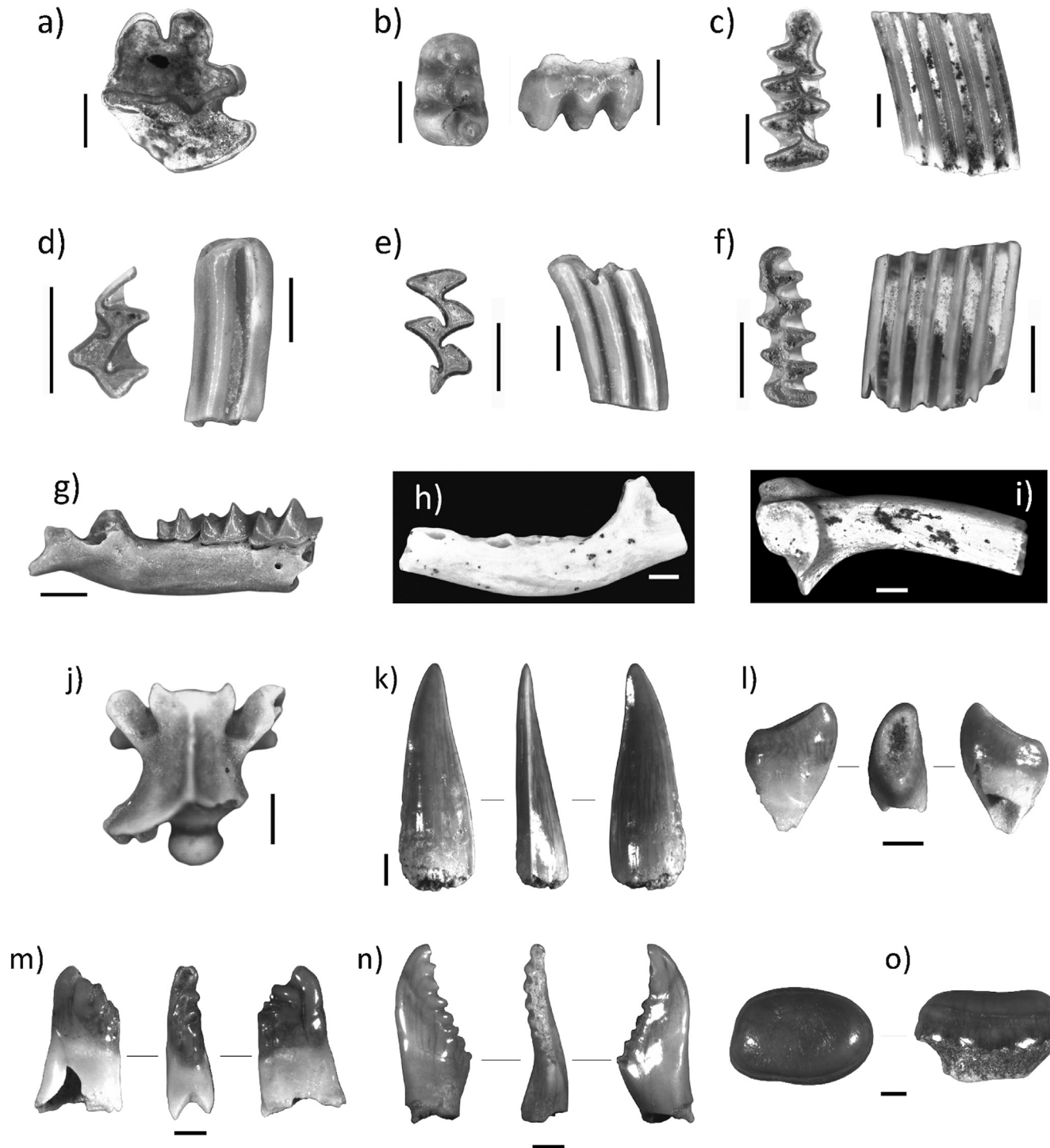


Fig. 9. Some examples of microvertebrate remains from the White Marl (Units 4B and 4C mainly) of Carrière Carpentier. a - *Oryctolagus* sp. (right p3); b - *Allocricetus/Cricetulus* sp. (left M1); c - *Arvicola cantiana/mosbachensis* (right m1); d - *Clethrionomys* cf. *glareolus* (left M2); e - *Pliomys* sp. (right M1); f - *Microtus* cf. *gregaloides* (left m1); g - *Sorex* cf. *araneus/coronatus* (right mandible); h - *Talpa* cf. *minor* (left mandible); i - *Bufo* sp. (ilium); j - Colubrinae indet. cf. *Coluber* sp. (trunk vertebrae); k–o: fish teeth: k - *Esox lucius*; l - *Tinca tinca*; m - *Abramis brama*; n - *Scardinius erythrophthalmus*; o - Cyprinidae (cf. *Cyprinus carpio*). Scale = 1 mm. Photos E. Stoetzel.

addition, according to the method of Jeannet (2010), we use the modern distribution and ecological requirements of current species to evaluate past climatic conditions, by (arbitrarily) considering the closest species for fossil taxa (except *Pliomys*): mean values of *A. sapidus* and *A. amphibius* for *A. cantiana/mosbachensis*, *M. gregalis* for *M. gregaloides*, *C. migratorius* for *Allocricetus/Cricetulus* sp. and *T. europaea* for *T. minor*. Using the method of Jeannet (2010) for the

whole of unit 4 we obtain an average annual temperature of 6.8 °C. But another method, the transfer function (based on the relationship between the number of Arvicolinae species and mean annual temperatures) gives an average annual temperature of 9.2 °C, which is closer to the present mean annual temperature at Abbeville, estimated at around 10 °C (Stoetzel and Montuire, 2016). All the data point to a temperate climate similar to present conditions,

Table 6

List and frequency (NISP = Number of Identified Specimens) of the small vertebrates found in the White Marl of the Carpentier Quarry, Abbeville.

Species/stratigraphic unit	4A	4B	4B/C	4C	4D	Total NISP
Lagomorphs						60
<i>Oryctolagus</i> sp.	1	6	6	9	38	60
Rodents						48
<i>Allocrietus/Cricetus</i> sp.			1			1
<i>Arvicola cantiana/mosbachensis</i>	1	3	1	5	4	14
<i>Clethrionomys</i> cf. <i>glareolus</i>			2			2
<i>Pliomys</i> sp.		1			1	2
<i>Microtus</i> cf. <i>gregaloides</i>					1	1
Arvicolinae indet.			8			8
Rodentia indet.	1	2	9	4	4	20
Soricomorphs						3
Small Soricinae aff. <i>Sorex minutus</i>			1			1
<i>Sorex</i> cf. <i>araneus/coronatus</i>					1	1
<i>Talpa</i> cf. <i>minor</i>					1	1
Reptiles						12
Testudines indet.		6			5	11
Serpentes cf. <i>Coluber</i> sp.					1	1
Amphibians						3
<i>Bufo</i> sp.		2			1	3
Fishes	2	2	6	6	17	33
Total (NISP)	5	22	34	24	74	159

but slightly cooler and less humid, with a more marked continental influence (higher seasonal differences). A mosaic of wooded areas, bushes and wet meadows composed the landscape (Fig. 11), although the most open and arid environments are probably underestimated (fossil species). The majority of the species found at Carrière Carpentier still have a wide European distribution today, covering the studied area (*Clethrionomys glareolus*, *Sorex minutus*, *Sorex araneus/coronatus*), and fossil species appear to have mostly occurred in temperate areas of Western Europe (*Arvicola cantiana/mosbachensis*, *Talpa minor*), but also in more open continental regions (*Allocrietus/Cricetus*, *Pliomys*) or Asian cold steppes (*Microtus gregaloides/gregalis*). We note the absence of strict forest species such as woodmice (*Apodemus*), arboreal squirrels (*Petaurista*, *Sciurus*) and Gliridae. However, it should be noted that arboreal sciurids and glirids are generally scarce in the Quaternary localities of Western Europe. This would be partially due to the fact that they are less easily hunted by the predators at the origin of most of the small vertebrate accumulations. We also observe the absence of other vole species (*Microtus* spp.) characteristic of open areas or non-arid semi-open areas. All these taxa are however present in other pene-contemporaneous north-western European sites, such as Mosbach 2 (Maul et al., 2000), Miesenheim 1 (van Kolfschoten and Turner, 1996) and Mauer (Wagner et al., 2011).

The co-occurrence at Carrière Carpentier of species of temperate forests, wetlands (*C. glareolus*, *A. cantiana/mosbachensis*, Soricomorphs) and cold steppe environments (*Allocrietus/Cricetus*, *Pliomys*, *M. gregaloides*) leads to “non-homologous faunas” (Desclaux, 2013) or “paradoxical associations” (Jeannet, 2010) that could both be due to taphonomic mixing, or natural faunal mixing during periods of climatic transition, resulting in the co-occurrence of species with different ecological requirements. Such occurrences of “cold species” in a more temperate corpus have previously been documented, for example with *Lemmus lemmus* at Miesenheim 1 (van Kolfschoten and Turner, 1996) and Mosbach 2 (Maul et al., 2000). In addition, this type of intermediate and atypical palaeoecological signal, not cold, but not fully temperate, was indicated by former pollen analysis in the White marl (Munaut, 1974, 1989).

3.5.3. Biochronological interpretation

From a biochronological point of view, the absence of the primitive Arvicolinae *Mimomys* and the presence of *Arvicola*

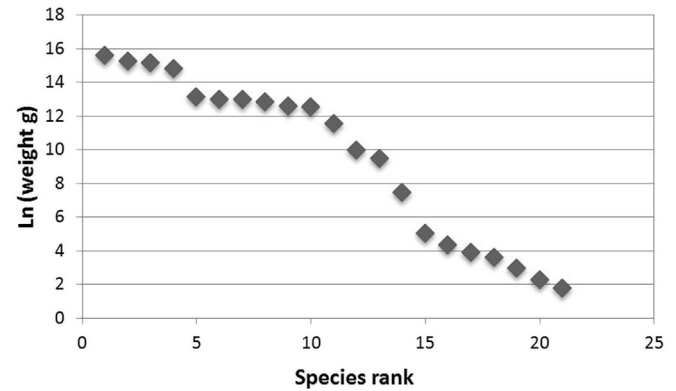


Fig. 10. Cenogram based on small and large mammals from the White Marl at Abbeville Carrière Carpentier.

cantiana/mosbachensis indicate a more recent age than the first stages of the Middle Pleistocene (more recent than MIS 19–17) (von Koenigswald and van Kolfschoten, 1996; Maul and Markova, 2007). Only two *Arvicola* m1 were complete enough for measurements: SDQ = 129 and 133, m1 length = 3.30 and 3.33 mm. These values correspond to those of several European Cromerian sites (Mosbach, Miesenheim 1, Hundsheim), or even some Holsteinian sites (Bilzingsleben, Neede) (Heinrich, 1987; Chaline, 1988; van Kolfschoten, 1990, 1992; Tuffreau et al., 1995; von Koenigswald and van Kolfschoten, 1996; Abbassi et al., 1998; Maul et al., 2000; Escudé et al., 2008ab). Note, however, that we should be cautious with the use of the SDQ, because (1) the Carrière Carpentier material is very limited, (2) important regional differences exist (Desclaux et al., 2000), and (3) Escudé et al. (2008a,b) showed that the observed changes would reflect high intra-specific variability linked to high phenotypic plasticity, rather than a real evolutionary trend. Thus the SDQ should not be used alone, but in addition to other biochronological criteria (von Koenigswald and van Kolfschoten, 1996).

The association of *Talpa minor*, *Trogotherium* (cited in Common, 1910b), *Arvicola cantiana/mosbachensis*, *Pliomys*, and also the presence of *Microtus gregaloides* indicates that the White Marl level should be older than MIS 12 (Maul et al., 2000; Maul and Parfitt, 2010; Wagner et al., 2010, 2011). The *Mimomys* - *Arvicola* and *Microtus gregaloides* - *M. gregalis* boundaries are supposed to occur during the Cromerian Complex, respectively during MIS 15, and between MIS 15 and MIS 13 (Candy et al., 2015). Some authors have argued that *Mimomys*, or a transitional *Arvicola* form with vestigial roots, was present until mid-MIS 15 (e.g. Preece and Parfitt, 2012; Candy et al., 2015). This is notably the case at Mauer in Germany (~609 ka, Wagner et al., 2010), and Isernia in Italy (~610 ka, Coltorti et al., 2005 - 583–561 ka, Peretto et al., 2015), while Little Oakley, older than MIS 13, is the youngest of the British sites having yielded *Mimomys* (Preece and Parfitt, 2012). Consequently, the occurrence of unrooted *Arvicola cantiana/mosbachensis* associated to *Microtus gregaloides*, as well as comparisons with other Middle Pleistocene sites (e.g. van Kolfschoten and Turner, 1996; Maul et al., 2000; Stuart and Lister, 2001; Maul and Parfitt, 2010; Wagner et al., 2011; Cohen et al., 2012; Preece and Parfitt, 2012; van Kolfschoten, 2014; Candy et al., 2015) suggest that subunits 4D to 4A of the Carrière Carpentier sequence were deposited during late MIS 15 or MIS 13.

3.6. Large mammals

After a long period of abandonment, new discoveries of large mammal remains were made at the Carrière Carpentier in

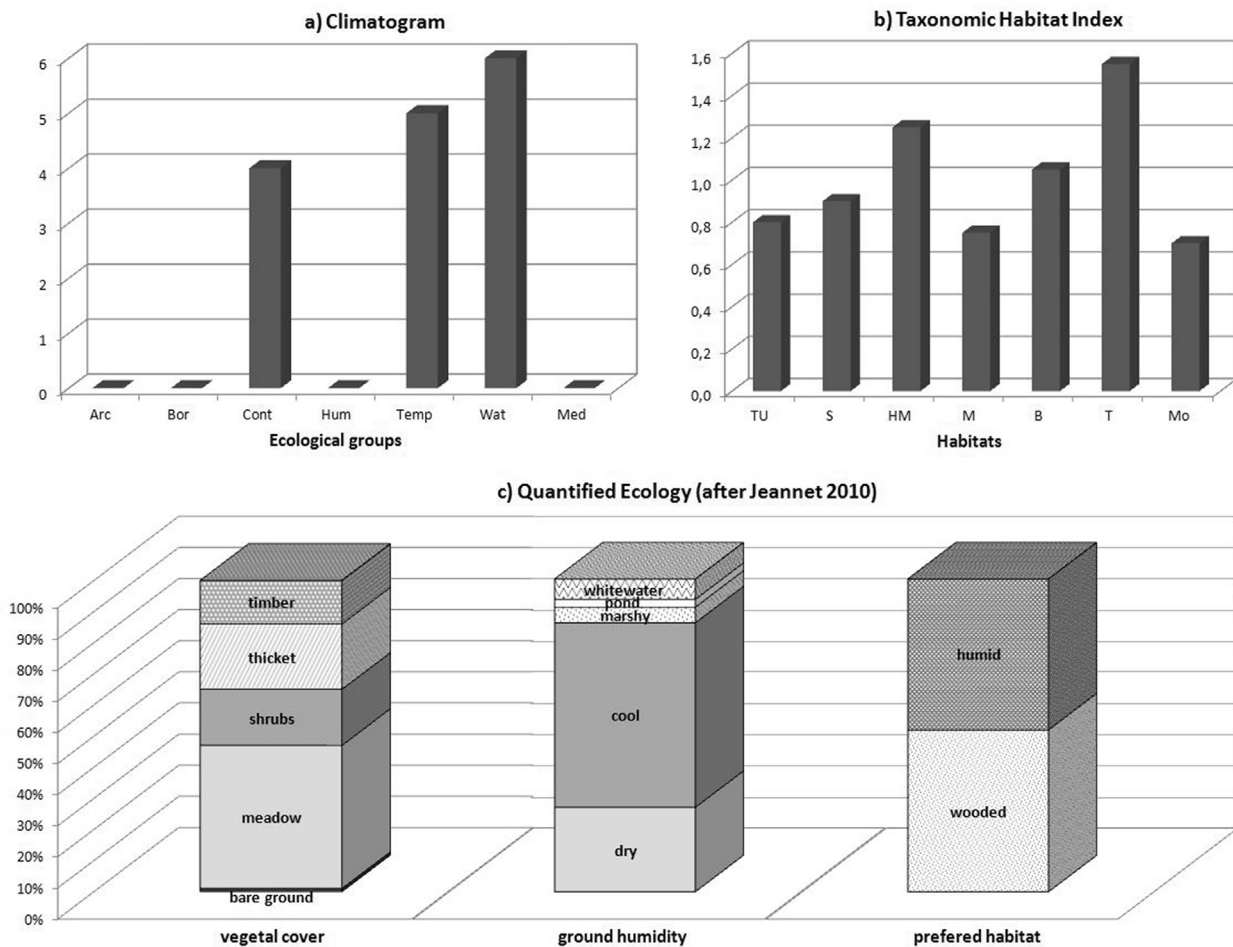


Fig. 11. Palaeoecological markers based on small vertebrate faunas: a) climatogram (based on the Minimum Number of Individuals (MNI) of each species classified in “ecological groups”): Arc = arctic steppe, Bor = boreal cold-humid habitats, Cont = continental arid steppe, Hum = meadows and humid areas, Temp = temperate forests, Wat = vegetated water pounds, Med = Mediterranean; b) Taxonomic Habitat Index (based on the presence/absence of species and their markers of several types of habitats): TU = tundra, S = arid steppe, HM = humid meadow, M = Mediterranean, B = boreal forest, T = temperate/deciduous forest, Mo = mountain; c) Quantified Ecology (describing the main types of vegetal cover, humidity and habitats on the basis of the [Jeannet method, 2010](#)).

1989–1990 during fieldwork mainly undertaken to collect samples for ESR quartz dating. At that time, some faunal elements were discovered during the preparation of the section: one large *Cervus elaphus* bone fragment and an upper premolar and a suidae upper molar attributed to *Sus scrofa priscus* (= *Sus scrofa mosbachensis*), representing the first species of modern wild boar recorded in a European Pleistocene assemblage ([Guérin and Faure, 1997](#); [Moullé et al., 2006](#); [Madurell-Malapeira et al., 2014](#); [Martínez-Navarro et al., 2015](#)). An updated faunal list was published including a revision of the fauna from old collections ([Auguste, 1995a,c, 2009](#)).

Since then, recent fieldwork has yielded a set of 165 large mammal remains. The material is in an excellent state of preservation on account of the calcareous sedimentary matrix. Eight taxa are present, with different levels of identification ([Fig. 12, Table 7](#)).

Most of the material comes from unit 4; remains are rare in unit 5. Red deer is the best represented species in unit 4 (the “cervid” item probably only covers this species). A large cervid was identified in sub-unit 4B. A large bovid is present in sub-units 4C and 5C. The rhinoceros is present in units 4 and 5A. The horse is recorded in sub-unit 4D. A proboscidean remain comes from sub-unit 5A. A bear tooth was discovered in sub-unit 4A. Three bones attributed to

a large herbivore and one to a carnivore complete the association, to which 108 elements that could not be specifically determined must be added.

The new list of taxa has been completed and updated. Furthermore, measurements undertaken on dental elements for deer and rhinoceros enable comparisons between the forms present in the White Marl at Carrière Carpentier with reference sites.

3.6.1. Wild boar

The tooth discovered in 1989 is actually the only specimen attributed to a suidae from recent works at Carrière Carpentier. It is a third upper molar, with the typical wild boar occlusal pattern, but with thick enamel and apparently (because of wear) simpler construction. The dimensions are very large in comparison with fossil and modern wild boar ([Fig. 12C](#)). These data argue for an attribution to the primitive form of the species, *Sus scrofa priscus*, present in many localities in Europe at the end of the Early Pleistocene and the early Middle Pleistocene ([Hünemann, 1969](#); [Guérin and Faure, 1997](#); [Moullé et al., 2006](#); [Madurell-Malapeira et al., 2014](#); [Martínez-Navarro et al., 2015](#)). The morphology of this wild boar molar is similar to those described from the British Cromerian site of West Runton ([Lister et al., 2010](#)).

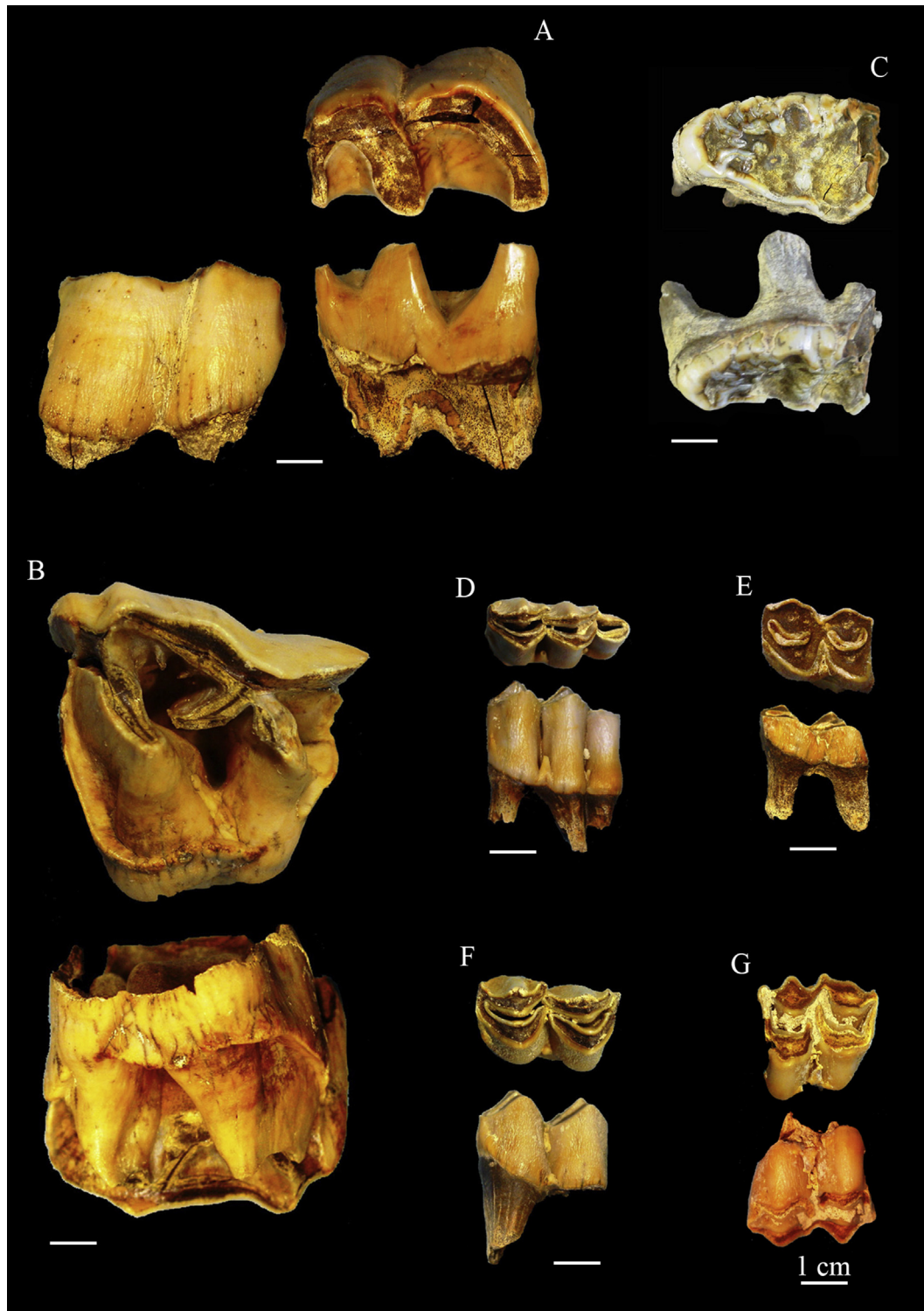


Fig. 12. Abbeville Carrière Carpentier, main large mammal taxa. A: Right second lower molar of Hundsheim rhinoceros *Stephanorhinus hundsheimensis* (2012, B4, unit 4A), top; occlusal view, left; vestibular view and right; lingual view; B: Left second upper molar of Hundsheim rhinoceros *Stephanorhinus hundsheimensis* (2012, F3, unit 4C), top; occlusal view, bottom; lingual view; C: Right third upper molar of wild boar *Sus scrofa priscus* (1989), top; occlusal view, bottom; vestibular view; D: Left third lower molar of red deer *Cervus elaphus* (2013, B4, unit 4A), top; occlusal view, bottom; vestibular view; E: Left first lower molar of red deer *Cervus elaphus* (2012, B4, unit 4A), top; occlusal view, bottom; vestibular view; F: Left second lower molar of giant deer cf. *Megaloceros* sp. (2012, C-E 3, unit 4B), top; occlusal view, bottom; vestibular view; G: Right second upper molar of red Deer *Cervus elaphus* (2011, unit 4B), top; occlusal view, bottom; lingual view. Bar scale: 1 cm. Photo: P. Auguste; composition: N. Sévère. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.6.2. Deer

Teeth and bones from a medium-sized cervid are present in the White Marl. The tooth patterns are typical of the red deer, *Cervus*

elaphus. However, it is not possible to specify the determination at a subspecies level, but it could be the archaic form of the red deer, *C. elaphus acoronatus*, with simplified antler (Azzaroli, 1978). The

Table 7
Counting by taxa and levels of large mammals from Carrière Carpentier (excavations 2011–2013).

	4A	4B	4C	4D	5A	5B	5C	Total
<i>Cervus elaphus</i>	4	12		2				18
Cf. <i>Megaceros</i>		1						1
Cervid	8	5	1	3	2	1		20
Bovid			1				1	2
<i>Stephanorhinus hundsheimensis</i>	1	2	1	2	1			7
<i>Equus</i> sp.				3				3
Large herbivore		1			1	1		3
Proboscidea					1			1
<i>Ursus</i> cf. <i>deningeri</i>	1							1
Carnivore			1					1
Indeterminates	17	37	27	15	6	3	3	108
Total	31	58	31	25	11	5	4	165

dimensions of the teeth and the bones (Fig. 12D, E and G) show that the Abbeville animal was large, like this extinct form (Lister, 1990b). Thus, for the red deer, the dimensions at the 'collar' for two third lower molars from sub-units 4A (length at collar = 30 mm, width at collar = 14.4 mm) and 4B (length = 31.3 mm, width = 15.3 mm) show animals of considerable size, which correspond well to the massiveness observed for the post-cranial skeleton. The comparison of these dimensions with those of the British Cromerian deer clearly indicates that the Carrière Carpentier specimens are very close to the Pakefield and West Runton deer, but much larger than the deer from Boxgrove (Lister et al., 2010). The subspecies *C. elaphus acoronatus* is present in Europe during the Cromerian and the Elsterian. After the Elsterian/Anglian (MIS 12), it was replaced by the typical red deer *C. elaphus elaphus* (Lister, 1990b).

3.6.3. *Megaloceros*(?)

A second lower left molar of a very large cervid was discovered in the White Marl in sub-unit 4B during the 2012 excavations. The dimensions are very large, in particular regarding the width at the collar (Fig. 12F). The presence of a very large cervid is mentioned in the old series, namely *Megaloceros verticornis* (= *Praemegaceros verticornis* according to the authors). However, a diagnosis based on this single tooth cannot lead to specific identification. Indeed several species can be encountered during this period, such as the fairly common *Megaloceros verticornis*, *Praemegaceros dawkinsi* or even *M. savini* (Lister, 1996; Pfeiffer, 2002; Croitor, 2006).

3.6.4. Bovid

Two bones have been attributed to a large bovid; a broken lunatum and a broken metapodial. It is not possible to determine either the species or the genus. *Bos* and *Bison* were formerly identified in the White Marl at Carrière Carpentier.

3.6.5. Rhinoceros

Seven rhinoceros elements, especially upper and lower teeth, were identified. The teeth helped to clarify the diagnosis of the taxa, namely the Hundsheim's rhinoceros *Stephanorhinus hundsheimensis* (= *Dicerorhinus etruscus brachycephalus* according to Guérin, 1980). The patterns of the upper and lower cheek teeth are identical to those described for this species (Guérin, 1980; Fortelius et al., 1993; Lacomat, 2005, 2006). For the upper teeth, the crochet is single, the crista is present, there is no antecrochet, the mediofossette is open, there is a mesial and a lingual cingula, the protocone constriction is not well marked and the paracone fold is wide and prominent (Fig. 12B). For the lower teeth, the anterior and the posterior valleys present a broad V-shape and the mesial and distal cingula are present (Fig. 12A). Brachiodonty is clear for both

the upper and lower teeth, in accordance with the browser alimentary status proposed for this species (Guérin, 1980; Lacomat, 2009). The bones are smaller in size compared to their Middle and Upper Pleistocene rhinoceros counterparts (meadow or forest rhino and woolly rhino, *S. hemitoechus*, *Stephanorhinus kirchbergensis* and *Coelodonta antiquitatis*). The morphology and dimensions of the rhinoceros from Carrière Carpentier are also close to those of the Hundsheim rhinoceros *S. hundsheimensis*. This taxon is one of the best represented in the old collections from Carrière Carpentier and Léon. Hundsheim rhinoceros is present during the Middle of the Early Pleistocene and disappears at the end of the Middle Pleistocene (Guérin, 1980; Mazza et al., 1993; Schreiber, 2005; Breda et al., 2010).

3.6.6. Horse

Three specimens indicate the presence of the horse in the White Marl; two dental fragments and a vestigial metapodial. These elements do not enable any specific diagnosis, but they are consistent with references to at least two types of equidae described in Abbeville; a Stenonian form (*Equus* cf. *altidens*) and a Caballine form (*Equus* cf. *mosbachensis*).

3.6.7. Proboscidian

One proboscidian bone was discovered at Carrière Carpentier during recent excavations. It was found in sub-unit 5A, and the dimensions and texture can only belong to an elephant or a mammoth, but the bone cannot be specifically determined.

3.6.8. Bear

During excavations at Carrière Carpentier in 2013, a large bear upper canine was discovered. The specific diagnosis of this tooth is problematic, but the data show that only one spelean bear is present during this period (*Ursus deningeri*). The tooth is of medium size, but as sexual dimorphism is very marked for this anatomical element, we cannot propose a detailed determination. However, in the old collections, the Deninger bear was identified, and an attribution of this canine to a female of this species, on account of its medium size, is probable.

3.6.9. Carnivores

A fibula fragment belonging to a small-sized carnivore was discovered in sub-unit 4C. It is not possible to attribute this bone to a specific taxon.

3.6.10. Palaeoecological interpretations

The large mammal association of the White Marl from Carrière Carpentier is homogeneous. Indeed, no taxa reflecting cold conditions and steppe landscapes are present. All the identified species are adapted to temperate climates and open grassland areas in association with wooded areas. However, forest landscape is not dominant, as evidenced by the coexistence of many forms of open areas, while species more typically encountered in forest environments are less abundant (namely the forest rhinos and wild boar). Such an observation is recurrent in Northern France, as for example at Biache-Saint-Vaast (Auguste, 2009). The term wooded parkland meadow is the biogeographic terminology that best characterises this ecological context. The application of the cenogram method to the Abbeville White Marl (Fig. 10) shows results close to those obtained at other sites (Biache-Saint-Vaast for example, Auguste, 1995d). According to this chart, the local environment is humid; the landscape includes woodland but also open areas. Species richness, with more than 20 taxa, is consistent with that observed in Northern France during Interglacial phases (Auguste, 2009).

Table 8

List of large mammal fauna taxa recovered from the fluvial deposits at Carpentier Quarry, Abbeville (including both old and recent collections).

Unit 5A	Unit 4D	Unit 4B
<i>Hippopotamus antiquus</i>	<i>Homotherium latidens</i>	<i>Oryctolagus</i> sp.
<i>Equus</i> of stenoian type (<i>Equus</i> cf. <i>altdens</i>)	<i>Sus scrofa priscus</i>	<i>Trogontherium cuvieri</i>
<i>Stephanorhinus hundsheimensis</i>	<i>Hippopotamus antiquus</i>	Hyenidae
	Cf. <i>Megaloceros verticornis</i>	<i>Ursus deningeri</i>
	<i>Cervus elaphus</i>	<i>Mustela nivalis</i>
	<i>Bison</i> sp.	<i>Cervus elaphus</i>
	<i>Bos primigenius</i>	<i>Capreolus capreolus</i>
	<i>Equus</i> of stenoian type (<i>Equus</i> cf. <i>altdens</i>)	<i>Stephanorhinus kirchbergensis</i>
	<i>Equus mosbachensis</i>	<i>Stephanorhinus hundsheimensis</i>
	<i>Stephanorhinus hundsheimensis</i>	
	<i>Mammuthus trogontherii</i>	
	<i>Palaeoloxodon antiquus</i>	

3.6.11. Biochronological interpretations

An updated and revised list of large mammal taxa from the White Marl at Carrière Carpentier is presented in Table 8.

The mammal remains from both sub-units 4B and 4D are the most informative for biochronology and palaeoecology. This large mammal assemblage indicates a forested landscape including some meadow and marshy zones, which developed under a temperate and wet climate.

This fauna is very close to the conventional mammal assemblages from the English Cromer Forest-bed at West Runton (Stuart, 1975, 1981; Stuart and Lister, 2010), but it does not include taxa indicative of warmer climatic conditions. However, from an evolutionary point of view, the taxa are identical. A clearer analogy exists with the typical temperate fauna from Pakefield in England, dated to MIS 17 or 15 (Stuart and Lister, 2001; Parfitt et al., 2005; Westaway, 2009a,b), or with the fauna of the main level “graues” from Mosbach in Germany (Brüning, 1980), coeval with the Mauer lower sands, dated to MIS15, circa 600 ka (Wagner et al., 2010, 2011).

The primitive wild boar, identified at Carrière Carpentier, is indeed present from 1.2 Ma in Europe (Untermassfeld, Le Vallonnet and Valparadis Estacio) and probably disappears around 400 ka (Guérin and Faure, 1997; Moullé et al., 2006; Madurell-Malapeira et al., 2014; Martínez-Navarro et al., 2015). It is clearly identified in West Runton and Boxgrove (Lister et al., 2010).

The Hundsheim rhinoceros, which is very common during the Early Pleistocene and the beginning of the Middle Pleistocene, disappears towards 500 ka, but is present at Boxgrove until late MIS 13 (Breda et al., 2010; Kahlke and Kaiser, 2011). The red deer is large in size and its occurrence in the White Marl mammal assemblage corresponds well to the primitive form, *Cervus elaphus acoronatus*, present during the first part of the Middle Pleistocene, at sites such as Pakefield and West Runton (Lister et al., 2010). This taxon is well represented in the European Cromerian sites (Lister, 1990a,b).

The recent analysis of the British Cromerian fauna (Lister et al., 2010; Breda et al., 2010) refines the correlation with White Marl mammal associations of Carrière Carpentier.

Thus, for the red deer, the dimensions of molars from sub-units 4A and 4B show animals of considerable size, similar to those from Pakefield and West Runton, but much larger than the deer from Boxgrove (Lister et al., 2010).

A similar comparison applies to the second upper molar of the rhinoceros from sub-unit 4C. The dimensions of this tooth (length at collar = 54.0 mm, width at collar = 61.2 mm) are included in the variability observed for animals from Pakefield and West Runton (Breda et al., 2010).

The presence of hippopotamus in the White Marl of Carrière Carpentier is another good biochronological marker. This animal is lacking in the West Runton mammal assemblage, but is present at

Pakefield (Stuart and Lister, 2001).

The Carrière Carpentier fauna is therefore part of the same group of Cromerian faunal association as those of West Runton and Pakefield. However, Pakefield is older than West Runton (Breda et al., 2010; Lister et al., 2010) and the time span covered by these two sites remains very wide, extending from MIS 19–15. Moreover, the occurrence of *Arvicola cantiana/mosbachensis* in the White Marl precludes a pre-MIS 15 age since in earlier stages the vole would have been *Mimomys*. Thus, the mammalian fauna of Carrière Carpentier (macro, meso and micro fauna), compared with the Cromer Forest-bed sites, seems contemporaneous with Pakefield, more recent than West Runton, but older than the Boxgrove fauna. The best biochronological consensus is to date the White Marl to MIS 15, to about 600 ka.

3.7. Archaeological data

3.7.1. Lithic artefacts

No bifaces were discovered *in situ* in the White Marl and the underlying layers (gravels) during our fieldwork. According to observations in the earliest works on the Carrière Leon and Champs de Mars at Abbeville by d'Ault du Mesnil (Carrière Carpentier was not known at this time by d'Ault du Mesnil, cf. Commont, 1910b and Breuil et al., 1939b), the archaeological pieces located in at least two layers were found dispersed over the whole quarry surface and were very rare. D'Ault du Mesnil mentioned the presence of some slightly rolled bifaces with a grey patina found in the White Marl, without precision on the discovery locality. The bifaces are shaped by limited removals, with sinusoidal edges and are described as amygdaloid-type or lanceolate-type pieces. They correspond to the definition given by de Mortillet to the Chellean biface and underpin the definition of the Abbevillian-type industry (Mortillet and Mortillet, 1883). Breuil was convinced by the discoveries of d'Ault and found one flake and one biface – unfortunately lost – above the White Marl with L. Aufrère at Carrière Leon in 1939 (cited by Agache et al., 1963; Bourdier, 1974b). The fact that our excavated area was limited to a few square metres could explain the absence of discoveries in the White Marl at Carrière Carpentier. However, the only unquestionable artefacts discovered at that time are located in unit 3, above the White Marl.

3.7.1.1. Unit 5/basal gravels. During the new surveys, a small set of atypical flint “artefacts” were discovered in sub-units 5C and 5B (alluvial gravels), in the nearest part of the slope to the north-east of the section (Figs. 4 and 5B). A detailed examination of these findings, taking into account a set of technical parameters and confirmed by four distinct experts in Palaeolithic archaeology, led to the conclusion that they were clearly geofacts and not human artefacts. As these pseudo-artefacts do not show any traces of

fluvial reworking, they must have been produced by natural processes linked to rockfall and mass movements from the nearby chalky slope. The second important point is the total absence of flint artefacts from the White Marl, even though hundreds of kilograms of sediments were sieved.

The question of geofacts and tephrafacts was raised very early on, from the beginning of the 20th century, and various papers took the existence of natural pieces very similar to artefacts into consideration (i.e. [Commont, 1909b](#); [Obermaier, 2012](#); [Pei, 1936](#); [Raynal et al., 1995, 1996](#); [Raynal and Magoga, 2000](#); [O'Connor, 2007](#); [Bertran et al., 2012](#); [Niang, 2014](#); [Wisniewski et al., 2014](#)). The distinction between artefacts and geofacts can be difficult to establish, but all the researchers clearly describe common features for geofacts, such as thin removals connected to the natural shape of the stones and the lack of clear percussion points.

Fourteen possibly flaked flint pieces come from the alluvial gravels of unit 5. Each artefact groups positive and negative technical criteria, such as the lack of plain platforms (only punctiform butts or lack of butt) or pellicular removals. No piece comprises the whole set of technical criteria that clearly identify an anthropic artefact ([Table 9](#) and [Fig. 13](#)).

In order to estimate the role of the alluvial gravels in producing the natural pieces, we made a database of more than 200 flint nodules from units 5A to 5C and described the stigmata observed on their surfaces. They show (1) frequent thin and pellicular removals located on rounded tips, (2) the occasional association of several unipolar removals, (3) lack of platform or possible presence of cortical platforms, (4) large crushing marks on the edges of quadrangular nodules due to recurrent pressure on the edges, and (5) rare deep removals on flat surfaces. These patterns correspond well to those observed on our corpus and point to the presence of geofacts at the site.

For our information, we tested some of these atypical flint artefacts for micro-wear traces and residues. On two flakes, wooden residues were preserved and micro-wear traces are visible on the edges. The hypothesis retained is repeated friction of the edges on roots. Moreover, a hair was preserved on one flake, considered to represent evidence of contamination.

3.7.1.2. Bifaces from unit 3s. During the new excavations at Carrière Carpentier, the only unquestionable artefacts, represented by flakes and bifaces, were discovered at the base of the slope sequence ([Fig. 14](#)).

Five flint flakes were recovered *in situ* from unit 3: (1) small elongated flake, with no cortex, with centripetal removals and a punctiform butt (40 mm long), (2) flake, with no cortex, with unipolar removals and a punctiform butt (40 mm long), (3) flake with a cortical back with transversal removals and a plain butt (50 mm long), (4) triangular flake with centripetal removals and a dihedral butt (70 mm long) and (5) triangular flake with orthogonal removals and a plain butt (65 mm long).

Three bifaces ([Fig. 14](#)) were discovered in 2012 (two in the brownish sandy-clayey silts above the White Marl and one in an uncertain position), and two in 2013 (in the brown-red clayey gravel bed sub-unit 3D). They were extracted from the north-eastern part of the section where the base of the slope deposits rapidly drops into a deep sinkhole ([Fig. 5B](#)). These artefacts are not archaeologically *in situ* but do not show any signs of severe reworking by slope processes, such as solifluction (no patina, weak abrasion of edges). This is hardly surprising given that the surrounding sediments are relatively soft. On account of their position and their relatively good state of preservation (fresh or slightly blunted cutting edges), it is highly likely that the Acheulean bifaces found at the base of unit 3 were transported by natural processes

Table 9
Description of the flint pieces and critical analysis of the technical marks (2012, square E1, layer 5b artefact with wooden residues and polishes; 2011, N°7 layer 5c and N°6 top layer 5b, refitting).

Year of discovery	Number and unit	Type	Positive technical criteria	Negative technical criteria
?	N°9	Cortical flake	Butt	Cortical butt 1 thin removal opposite to the technical axis Angle of a nodule
2010	N°8 unit 5A	Elongated flake with a cortical back	Butt Unipolar scars	Cortical butt Long thin removals Remains of natural surface
2010	N°5 unit 5C	Cortical flake	Butt 1 scar	Cortical butt 1 thin unipolar removal
2011	N°4 base unit 5A	Flake without cortex	3 crossed removals	Lack of butt (broken) Thin flake
2011	N°1 unit 5C	Flake with a partial back	Crossed removals Punctiform butt Large bulb	Remains of natural surface Crushed marks on the back Punctiform butt
2011	N°7 unit 5C	Cortical flake Refitting on a nodule	Crossed removals	Lack of butt (broken) Impact point on the cortical area (not logical) Fresh artefact
2011	N°6 top unit 5B	Cortical nodule with some removals	5 large unipolar removals. Hinged removals	Punctual crushed marks on the edge Not logical impact point
2012	square B3 top unit 5C	Small flake with few cortex	Unipolar removals Punctiform butt Crushed marks on the butt edge	Thin removals Crushed marks on the edge of the butt
2012	square E1 unit 5B	Flake with few cortex	1 unipolar scar Punctiform butt Large bulb	Thin removals Crushed marks on the edge of the butt
2012	square F1 unit 5A	Elongated and thick flake	3 unipolar removals +2 orthogonal removals	Lack of butt (broken) Fresh artefact
2012	square E3 unit 5B	Elongated flake	Several unipolar removals.	Punctiform butt Thin and deep removals
2013	square C4 unit 5C	Short flake with few cortex	Centripetal removals	Punctiform butt
2013	square F4 unit 5B	Thick flake with few cortex	Unipolar removals	Punctiform butt

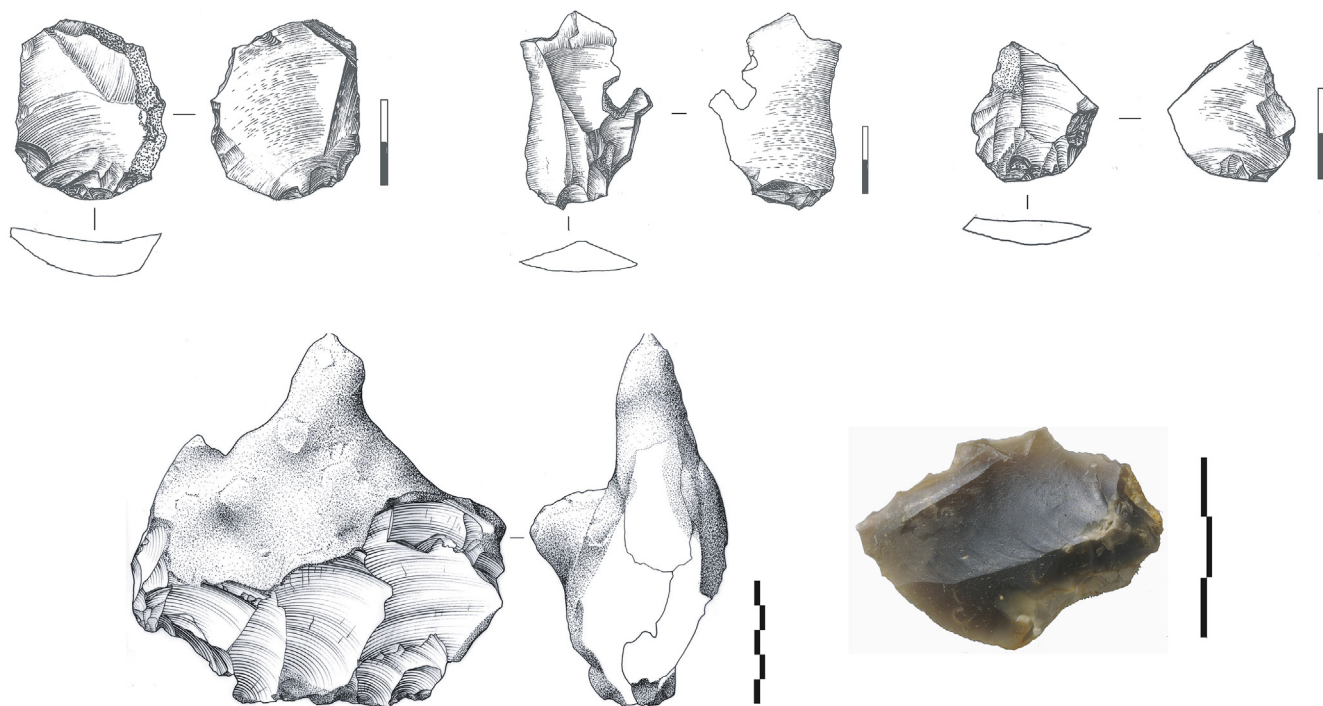


Fig. 13. Geofacts in flint (flakes and nodules with some removals) from unit 5 (drawings A. Theodoropoulou).

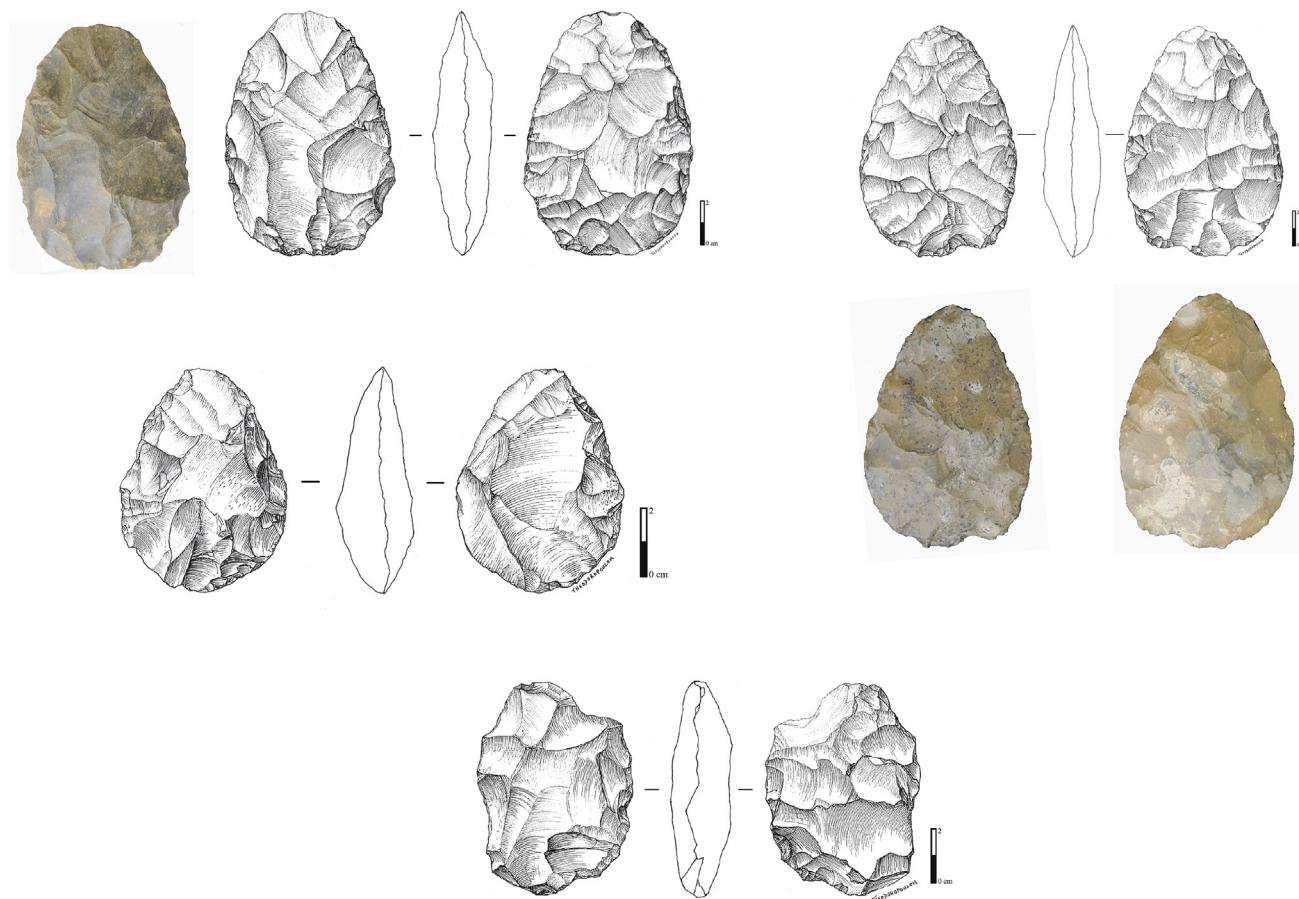


Fig. 14. Bifaces in flint recovered *in situ* in the clayey-silty sands of unit 3D1 overlying the White Marl (drawings A. Theodoropoulou). Most are cordiform-type and completely shaped. They do not show traces of displacement.

over a short distance from the slope.

The bifaces (10–12 cm long) discovered in 2012 are oval or cordiform, with reduced or no cortical zones. The two bifaces discovered in 2013 are smaller (65 and 80 mm) and are cordiform or amygdaloid.

These pieces were shaped in three phases. Shaping completely covers both faces with invasive removals, followed by short and thin removals. Partial bifacial retouch finishes regularizing the cutting edges. The cross-section and the biface are symmetric. For one biface, a “coup de tranchet”, a transversal removal on the tip, creates a notch. The amygdaloid biface is made by deep and wide removals and retouched in places by a final series of small removals. The cutting edges are sinusoidal. A hard hammer was used for the initial shaping phase and the soft hammer for the final shaping phase.

3.7.2. Modified bones

Among the bones recovered in the White Marl, several show evidences of fractures and surface alteration. The new excavations led to the discovery of 23 fragments of long bone shafts displaying helicoidal fractures. Two bones were attributed to the red deer, eleven to a cervid (most likely the red deer), one bone to a bovid, one to a large herbivore, and eight were non-identified. All the field observations point to a context of slow fluvial activity transporting sands and small gravels and oncoliths (1–2 cm) (Haynes, 1983). A stronger river dynamic is only visible at the base of sub-unit 4A where flint nodules of 3–5 cm in size were rolled and coated in calcium carbonate. There is thus no evidence of sedimentary processes strong enough to break bones or to cause the marked abrasion of their edges or surfaces.

Four of these specimens show edge smoothing, suggesting carnivore gnawing or/and a weak abrasion by sediments. The bovid bone exhibits some peeling and small punching marks, which probably correspond to carnivore tooth marks.

Seven of the long bone fragments bear marks associated with fractures and for three of which, carnivore action is very likely; a serrated effect on one edge for the first, gnawing of the extremity for the second and marks for the third. All these elements indicate significant carnivore action, possibly caused by a wolf rather than a hyena on account of the small size of the marks and the morphology of the gnawing pattern.

Bone n° 15 (Fig. 15) appears to bear fracturing due to a dynamic action on fresh bone, but no additional marks are present, in particular, no percussion point, area of aftershock, or medullar and/or cortical flake. The trough marks visible on the cortical surface are similar to scratches caused by carnivore teeth and are not indicative of butchery cut marks. It should be noted that for all these bones, the full range of the anthropogenic fracturing parameters is never present, only the appearance of the oblique fracture zone, and smooth curves may indicate that the bone was fresh when broken. Bone n° 9 (Fig. 15) bears a helicoidal fracture.

Nine bone fragments from the 2011 and 2012 excavations at Carrière Carpentier were submitted for detailed surface taphonomic analyses (Fig. 15, Tables 10A,B). All of the bones are diaphysis splinters, either from cervids or cervid-sized mammals (Tables 10A,B).

The surfaces of these bones were examined under a low-power binocular microscope and no evidence at all of human surface modification or marrow fracturing was observed. A sample of the specimens was examined in greater detail using a Focus Variation

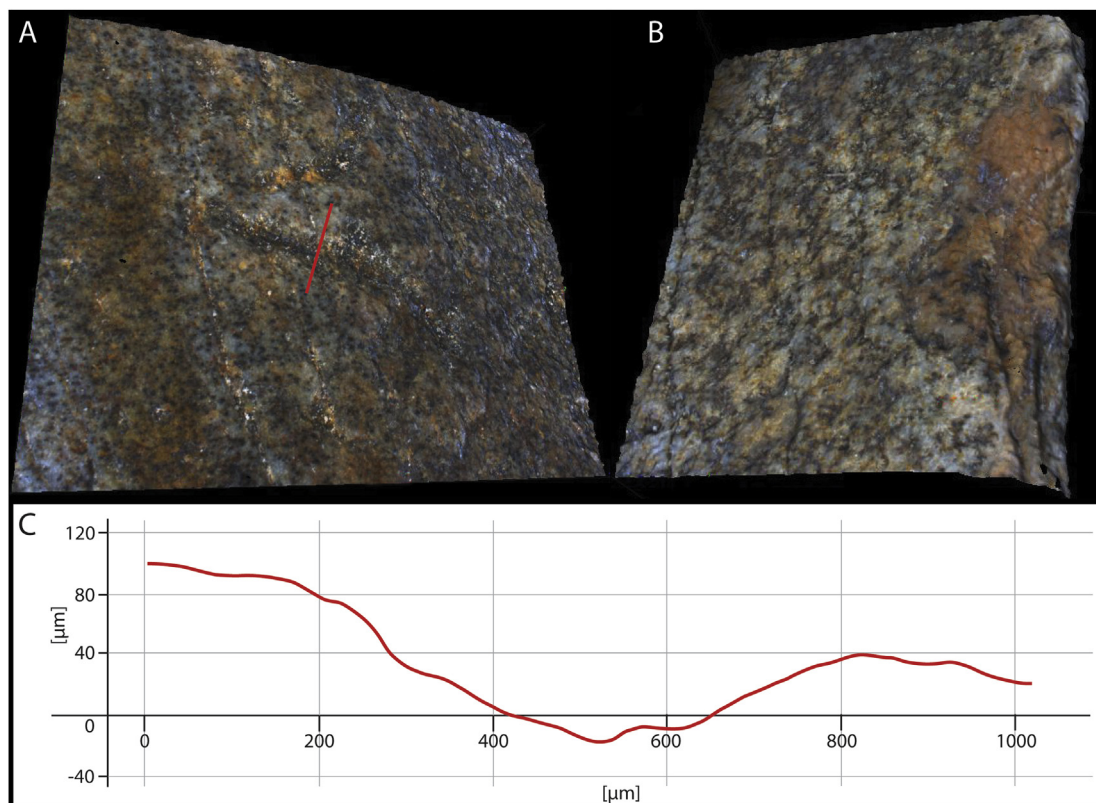


Fig. 15. (A) Alicona 3D image of shallow grooves on the shaft of a Carrière Carpentier specimen, Oct 2011 OS9, consistent with carnivore gnawing. The red line indicates the section where profile parameters were evaluated (see C); (B) Alicona 3D image of chipping of the edge fragment on specimen CC 2012, B3-4B; (C) Alicona linear measurements of the 3D model (red line in A) using MeX software of specimen Carpentier Oct 2011 OS9, consistent with carnivore gnawing. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 10A

Carpentier Quarry 2011–12. Summary of taphonomic alterations.

Number	Co-ordinates	Rounded grooves/pits	External chipping	Internal chipping	Random striae	Surface polish	Edge rounding	Weathering	Post-depositional pitting	Trowel marks & excavation damage
Carpentier 2012, BG-4A	$\Delta = 0,69$; Z = 0,22		■	■						■
Carpentier 2012, C3-GA	$\Delta = 0,84$; Z = 0,38		■	■			■	■	■	■
Carpentier Oct 2011 OS9	38 cm below LD	■	■		■	■			■	■
Carpentier 4b F3	$\Delta = 0,78$; Z = 0,53		■	■	■		■	■	■	■
Carpentier Oct 2011 OS1	49 cm below LD			■	■	■	■		■	■
Carpentier 2011 OS no 15	55 cm below LD	■	■							
Carpentier 2012, B3-4B	$\Delta = 0,84$; Z = 0,45	■	■	■	■	■		■	■	
Carpentier 2012, BG-GA	$\Delta = 0,68$; Z = 0,15		■	■	■	■				
Carpentier Oct 2011 OS3	95 cm below LD			■	■	■	■	■		■

Chipping – This category includes 'lunate scars' located along breaks; larger flaked areas are not included in this category.

Trowel marks are linear grooves that are clearly freshly-made with no sediment infill.

Excavation damage is scored for pieces with fresh breaks, chips or fractures.

Table 10B

Carpentier Quarry 2011–2012. List of bones examined for taphonomic alterations.

Number	Taxon	Element	Co-ordinates
Carpentier 2012, BG-4A	Cervid	Tibia shaft frag.	$\Delta = 0,69$; z = 0,22
Carpentier 2012, C3-GA	Large mammal (cervid-sized)	Femur shaft frag.	$\Delta = 0,84$; z = 0,38
Carpentier Oct 2011 OS9	Large mammal (cervid-sized)	?Femur shaft frag.	38 cm below LD
4b F3	Large mammal (cervid-sized)	Long bone shaft frag.	$\Delta = 0,78$; z = 0,53
Carpentier Oct 2011 OS1	Large mammal (cervid-sized)	Long bone shaft frag.	49 cm below LD
Carpentier 2011 OS no 15	Large mammal (cervid-sized)	Long bone shaft frag.	55 cm below LD
Carpentier 2012, B3-4B	Cervid	Tibia shaft frag.	$\Delta = 0,84$; z = 0,45
Carpentier 2012, BG-GA	Large mammal (cervid-sized)	Long bone shaft frag.	$\Delta = 0,68$; z = 0,15
Carpentier Oct 2011 OS3	Cervid	Radius shaft frag.	95 cm below LD

microscope (Alicona Infinite Focus microscope) to explore the topography of the bone surface in three dimensions (Bello and Soligo, 2008; Bello et al., 2009, 2011; Danzl et al., 2009). Images were captured using a $\times 2.5$ objective lens (magnification $\times 45.72$) and a vertical and lateral resolution of 10 μm and 3.47 μm respectively.

The grooves and pits on three of the shaft fragments are entirely consistent with carnivore gnawing (Fig. 15A, C). As well as tooth marks, external and internal chipping is also common on shaft fragments gnawed by medium-sized carnivores, such as the wolf. Chipping and flaking along the edges of the Carrière Carpentier shaft splinters conform to this pattern (Fig. 15B). Many of the bones have shallow scratches and abrasion marks covering the external surface, and sometimes extending to the edges and medullary surface. The striations are mostly random, but a marked transverse element (particularly for the deeper grooves) was also observed. These striations, surface polishing and edge rounding are probably the result of trampling and water transport in a sandy river-bed. Two of the bones exhibit early stages of weathering, but none bear rootlet marks that would indicate burial in a vegetated soil.

All the material in this sample shows the same pattern of surface characteristics. Some were gnawed by carnivores, several are weathered, and most specimens are abraded, possibly by a combination of trampling and fluvial processes. A similar range of modifications is observed on bones from Middle Pleistocene floodplain deposits at Swanscombe in the Thames Valley. At Swanscombe, convincing evidence for human modification of large mammal bones appears to be exceptionally rare; most, if not all of

the cut marks and marrow fractures described by Binford (1985) are of natural origin.

To conclude, no bones from the White Marl of the Carrière Carpentier present the full set of evidences characterising human action. However, almost all the marrow-bones show helicoidal breakage pattern typical of modifications on fresh bones. This observation cannot be a definitive argument to demonstrate human impact on the bones because the role of carnivores in the taphocenosis has been evidenced by the microscopic analysis. The bone accumulations from the White Marl indicate that all the long bones were fractured except the rhinoceros tibia. This can be explained by the fact that this type of bone has a poorly developed medullary cavity and presents no real nutritive interest. The taphocenosis of the White Marl is similar to that of fluvial Middle and Upper Pleistocene sites in Northern France where broken long bones are associated with flint industries. In many of these cases, no typical marks associated with human action (impact points, counter-points, cortical or medullary flakes) are observed and only a few butchery marks (cutting, scraping) occur on the bones. For example, in the Eemian Middle Palaeolithic site of Caours, located a few kilometres upstream of Carrière Carpentier (Fig. 2), almost 25% of the long bones (more than 2500 pieces) were fractured and exhibit helicoidal breaking patterns that appear to be extremely similar to those observed on the long bone fragments from the White Marl. Moreover, at Caours, the fragmented bone remains are perfectly preserved *in situ* in rapidly accumulated calcareous tufa beds and there is no doubt as to the human origin of this fragmentation (Antoine et al., 2006). In the example of Biache-Saint-

Vaast (Auguste, 1995b), the action of carnivores or other taphonomic effects (trampling, water action) are observed but they are clearly younger than to the initial modification of long bones by humans.

Even if it is presently difficult to demonstrate, we cannot rule out the hypothesis that the fragmentation of the long bones recovered from the White Marl at Carrière Carpentier could result from human activities, with subsequent superimposed traces of carnivore action or fluvial processes.

4. Synthesis and discussion

4.1. Environment and dating

The Carrière Carpentier alluvial sequence corresponds to a High Terrace of the Somme system at a relative altitude of 40 m above the bedrock of the modern valley formation (Table 1). As already noted by Commont (1910b), this sequence is located at the outer edge of the former alluvial plain, very close to the chalky slope. This morphology is favourable to the preservation of the best sedimentary records owing to low fluvial erosional processes and slope sediment inputs during specific phases such as Early Glacial periods (Antoine, 1994). This is a privileged location for the preservation of archaeological occupations located in the pivotal area between the base of the chalky slope and the riverside with a good access to raw materials suitable for tool manufacture. A similar configuration has already been reported in the area for the Acheulean site of Cagny-la-Garenne (Tuffreau, 1989; Antoine and Tuffreau, 1993).

The Carrière Carpentier sequence can be basically subdivided into a fluvial and a slope sequence (colluvium slope deposits and palaeosols). Both sub-sequences are separated by an erosion boundary that underlines a rapid shift from a fluvial to terrestrial environment. Subsequent dissolution processes, attributed to successive interglacial and Early Glacial periods (Antoine et al., 2014, 2016), later modify this contact, producing localised and deep large dissolution features (sinkholes).

The fluvial deposits, preserved over a length of more than 15 m between two sinkholes, represent unique and extremely rich evidence of fluvial sedimentation and Quaternary palaeoenvironments of the High Terrace of the Somme System (Renancourt Formation/Alluvial Formation VII, Table 1).

The palaeoenvironmental and geochronological interpretation of this sequence is based on: (1) geomorphology-stratigraphy-sedimentology; (2) mollusc and mammal assemblages and (3) ESR and ESR/U-series dating results.

The lower part of the fluvial gravel sequence of the Carrière Carpentier (sub-unit 5C) is composed of a highly heterogeneous and unstratified assemblage of large unrolled chalk blocks and flint nodules embedded in an abundant chalky sandy matrix, characterised by very slight fluvial reworking. This part of the sequence exhibits strong similarities with the Cagny-la-Garenne sequence located on the Alluvial Formation V of the Somme system and dated to MIS 12 and 11 (Antoine, 1994; 2007, 2009, 2012, Table 1). If we refer to the model of Cagny-la-Garenne, given the characteristics outlined above and its position in relation to the chalky slopes bordering the valley at that time, the deposition of sub-unit 5C at Carrière Carpentier should have occurred during the early part of the climatic cycle in an Early Glacial phase (continental temperate transitional context by analogy) with the reference record from the last Eemian-Weichselian climatic cycle (Antoine et al., 1999).

The overlying gravel bed (sub-unit 5A) exhibits a more typical fluvial facies and more active river dynamics, as indicated by much better sorting of the gravels and of the sandy matrix. However, the occurrence of bone remains attributed to rhinoceros and

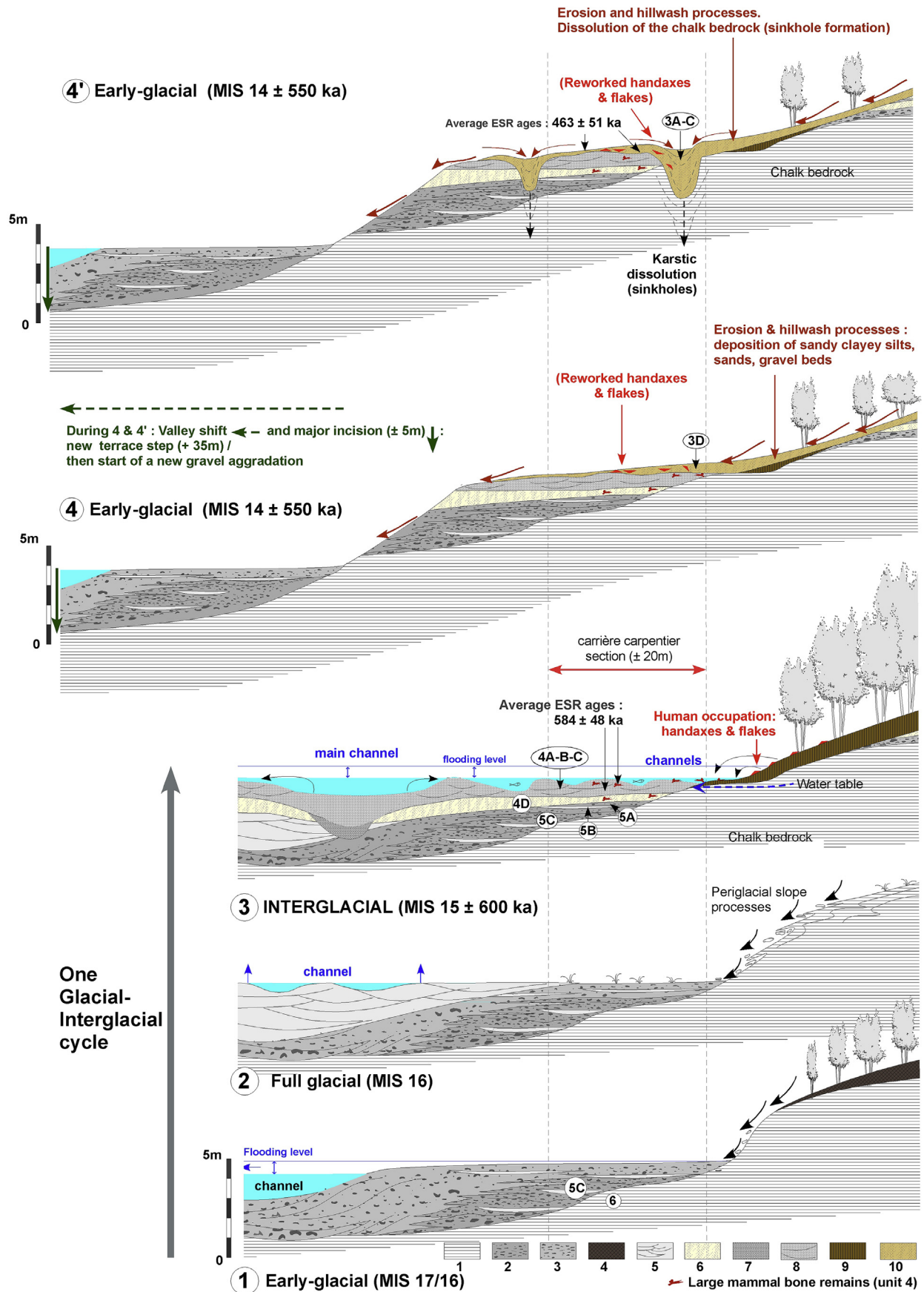
hippopotamus according to former authors, and of calcareous sandy silt lenses inter-stratified with gravel deposits (sub-unit 5B), do not correspond to the typical periglacial alluvial sequences of the Somme, and more generally to the model of periglacial rivers in north-western Europe (Vandenberghe et al., 1994, 2008). According to these observations, and in particular to the occurrence of temperate mammal species, sub-units 5B–5A are definitely not of periglacial origin and probably correspond to the reworking, during the beginning of the interglacial, of the upper part of the underlying sediments. The same type of observation was made in the interglacial sequence of Caours, where the remains of temperate large mammals (red deer, fallow deer, aurochs, meadow rhinoceros) occur within fluvial gravels deposited in small channels active during the Eemian (Antoine et al., 2006), and also at the base of the Holocene channel (Preboreal, with red deer) of the River Selle at Conty (Antoine et al., 2012).

Based on palaeontological and sedimentological data, the White Marl (unit 4) was deposited during a temperate interglacial event. The White Marl (unit 4) is rich in carbonates (50–60% of the total mass of the sediment) and attests to sedimentation conditions typical of a permanent and calm freshwater environment, partly invaded by vegetation (Charophyceae). This environment is favourable to carbonate precipitation processes around small flint gravel nuclei induced by cyanobacterial activity, leading to the formation of oncoliths. Fresh water conditions are indicated by fish and chelonian remains, aquatic molluscs and ostracods.

Palaeoenvironmental reconstructions inferred from molluscs (open riverbank) and micromammals (mosaic landscape) are consistent with the coexistence of woodland and humid meadows designated by the large mammal assemblage. These conditions are typical of climatic transition periods such as the beginning of an interglacial, when landscapes are characterised by a progressive expansion of forest cover, leading to a patchwork of open to closed habitats.

The absence of micromammals characteristic of deciduous forests can be explained by the fact that bio-indicators may represent different scales of biotopes (Limondin-Lozouet et al., 2006). At Carrière Carpentier, micromammals correspond to local riverbank open habitats while macromammals reflect the landscape of both the slope and alluvial plain, including wooded areas. All the bio-proxies (molluscs, large and small mammals) converge sufficiently well to ascribe unit 4 to an interglacial stage, although the described environmental conditions do not correspond to the climatic optimum. The composition of mollusc and mammal assemblages, as well as the succession of facies within unit 4 (calcareous sandy silts then oncolithic sands), suggest that the White Marl dates to the early phase of an interglacial.

The occurrence and biometric characteristics of *Arvicola cantiana/mosbachensis* are strong arguments for situating unit 4 between MIS 15 and 13. Both the mollusc assemblage, characterised by *Bythinia troschelii*, *Borysthenia naticina* and *Tanousia cf. stenostoma*, and the large mammal association with a very large *Cervus elaphus*, *Stephanorhinus hundsheimensis*, the primitive *Sus scrofa*, *Mammuthus trogontherii*, cf. *Megaloceros*, and *Trogontherium cuvieri* support a Late Cromerian age. This biochronological attribution is consistent with the mean age obtained from ESR and ESR/U-series analyses for unit 4 (584 ± 48 ka), clearly indicating a correlation with the MIS 15 interglacial. Finally, the White Marl is a freshwater calcareous deposit, extremely favourable to the preservation of a wide range of fossils but unsuitable for *in situ* human settlement. However, it could have preserved some artefacts (flint/bone fragments) incorporated from a human occupation located on the riverbank, although up until now no typical flint artefacts have been found in those deposits.



Given the specific lithological characteristics and the age of unit 4, the heterogeneous chalky gravels of the underlying sub-unit 5C should be attributed to the beginning of MIS 16, about 676 ka (Lisiecki and Raymo, 2005). According to this interpretation, a considerable hiatus (≤ 50 ka) is likely to have occurred between the gravels of sub-units 5C and the overlying calcareous silts 5B and gravels 5A deposited under (early) interglacial conditions (Fig. 16). The deposition of the typical periglacial alluvial formation (braided river gravels), during the coldest part of MIS 16 (ca. 630–650 ka) probably only took place in the inner part of the palaeo-valley, explaining why there is no evidence of these deposits in the Carrière Carpentier section located very close to the slope.

At the top of the alluvial deposits, the first slope processes are evidenced by the stratified yellow quartz sand deposits, including some gravel beds and thin lenses of clayey soils reworked by hillwash processes on the slope (Fig. 4A, unit 3D5 to 3D1). The upper part of sub-unit 3D1 is characterised by a silty-clayey facies bearing the bifaces. This first phase is followed by two thick lenses of soliflucted gravels imbedded in an abundant red-brown clay matrix (sub-units 3A–3C), alternating with hillwashed sand layers (sub-units 3D–3B) and covered by a final bed of flint gravels with a clayey matrix (unit Cx1).

The only evidence of interglacial soil (unit 2) is preserved in a small depression at the top of Cx1 unit. The whole sequence formed by unit 3 bears the signature of slope processes that could represent one or several major climatic degradation events, but no climatic cyclic pattern (Interglacial-glacial) can be evidenced in this sequence. However, the geometry of the sinkhole infilling indicates two distinct phases of deepening and sedimentation (Fig. 4A). They are separated by a discordance resulting from the sudden deepening of the feature linked to a dissolution event in the chalk occurring between units 3c and 3b (Fig. 4A: blue dotted line and arrow, and Fig. 5B).

In between the base of the slope sequence (unit 3) and the top of the alluvial deposits of the White Marl (sub-unit 4A), field observations provide no evidence of a long hiatus corresponding to a glacial-interglacial cycle. The absence of the MIS 15 interglacial climatic optimum record in the Carrière Carpentier fluvial deposits appears to result from systematic erosion at the beginning of each glacial stage, at the same time as major incision processes leading to a new terrace formation.

According to observations from the Last Interglacial-Glacial climatic cycle in loess sequences in Northern France, the development of deep dissolution features and sinkholes in the chalk bedrock systematically appears after the end of the Eemian

Interglacial during the first phases of the Early Glacial period characterised by temperate continental climatic conditions, grey forest soils and boreal forests (Antoine et al., 2016). It is thus likely that the large sinkholes in the Carrière Carpentier sequence began to develop during the beginning of the glacial stage following the end of the White Marl interglacial; i.e., at the beginning of MIS 14. In addition, the geometry of the infilling of the large sinkhole indicates a sequence of at least two distinct phases of deepening of the structure.

Based on the synthesis of all this information, and its integration into the model of development of the Somme Valley terrace system in relation to climatic variations, a reconstruction of the development of the alluvial sequence during one glacial-interglacial cycle and the following early-glacial period is proposed in Fig. 16 and associated caption.

Following this reconstruction of the environmental and chronological context of the Carrière Carpentier sequence, two scenarios are possible for the dating of the bifaces:

- 1) The bifaces originate from an occupation located on the lower part of the slope close to the riverbank, coeval with the sedimentation of the White Marl and of its mammal remains (interglacial/MIS 15). The bifaces were then reworked by hillwash processes on the slope and preserved in the silty-clayey deposits from the very base of the slope sequence.
- 2) The bifaces correspond to a human occupation located on the lower slope, close to the riverbank, during the beginning of the cold stage following the MIS 15 interglacial (MIS 14 “early glacial”). They were reworked during the same phase (early MIS 14) or at the end of this phase, in which case they could be dated between 550 and 500 ka.

In either case, there is no evidence of interglacial soil and no long hiatus between the end of the White Marl deposits and the beginning of the sedimentation of the slope deposits in which the bifaces were discovered (sands and sandy-clayey silts). This information points to a date of about 550 ka for the Acheulean bifaces from the Carrière Carpentier. According to the geological reconstruction of the Carrière Carpentier sequence exposed above, these Acheulean bifaces probably represent the oldest typical Acheulean artefacts from the Somme Basin and Northern France. Moreover, similar bifaces were formerly discovered at the Moulin Quignon site, located a few hundred metres south-west of the Carrière Carpentier on the same bedrock stage. It is thus highly likely that the bifaces from Moulin Quignon also represent evidence of the oldest Acheulean occupation of the Somme Basin during MIS 15,

Fig. 16. Placement of the Carrière Carpentier fluvial sequence within a reconstruction of the various stages in the evolution of the external part of the Somme Valley for the MIS 17–16 transition and MIS 15. 1 - Chalky substratum 2 - Poorly stratified coarse slope deposits (chalk and flint blocks without strong fluvial reworking) 3 - Coarse fluvial deposits (chalky gravels) 4 - Humic soil 5 - Periglacial gravels (chalk and flints in a calcareous coarse sand matrix) 6 - Sandy calcareous silts (lower White Marl) 7 - Coarse flint gravel deposit from the channel base (lag deposit) 8 - Stratified calcareous sands and oncolithic sand lenses with lenticular and cross bedding (Upper White Marl) 9 - Interglacial soil (Bt horizon). Phase 1 - EARLY-GLACIAL (early MIS 16) (main incision dating to the transition between MIS 17 and 16): deposition, close to the chalky slope, of badly sorted coarse slope deposits (flint and chalk blocks in a chalky-gravelly matrix), slightly reworked by fluvial activity (episodic flooding). Lateral transition to stratified coarse fluvial deposits (chalky gravels) in the main part of the valley (not recorded at Carrière Carpentier). Phase 2 - FULL GLACIAL (MIS 16): strong erosion and recession of the chalky slope by solifluction and landsliding processes. Coarse gravel deposition in a braided river system invading the entire valley corresponding to the main phase of infilling of the valley and of alluvial formation (not recorded at Carrière Carpentier). Phase 3 - INTERGLACIAL (stage 1) (MIS 15): slope stabilisation by vegetation and soil development, transition to a single meandering channel and incision of the previously deposited gravels. Reworking of the upper part of the gravels of sub-unit 5C in a lateral channel. Localised deposition of calcareous sandy silts (sub-unit 5B) then of gravels (sub-unit 5A), including temperate large mammal remains. Rise in the water table in the valley, deposition of calcareous fine fluvial deposits at the margins of a wide lateral channel in low energy conditions (sub-unit 4D). INTERGLACIAL (stage 2) (MIS 15): development of springs and lateral streams at the bottom of the slope linked to a rise in the water table. Deposition of stratified oncolithic sands in a large and shallow channel partly supplied by springs (sub-units 4C to 4A). Phases 4 and 4' - EARLY GLACIAL (Early MIS 14). A new early-glacial period (Early MIS 14) is marked by an incision phase leading to the erosion of the main part of the fluvial sediments deposited during MIS 16 and 15, then by the development of a new step in the chalk bedrock and of a younger alluvial formation. During the early part of this stage, slope processes started to erode the soils and sediments from the slope, mainly by hillwash and slow colluvial processes. These sediments, deposited directly above the White Marl, protected these fragile calcareous deposits from subsequent erosion. As there is no evidence of a long hiatus between the top of the fluvial deposits of the White Marl and the first sandy layers of the slope sequence, this stage is considered to directly follow the end of the MIS 15 interglacial. During the same stage, intense dissolution of the chalk bedrock induced the formation of large sinkholes in which these deposits were trapped. According to the data from the loess-palaeosol sequences of the last climatic cycle (Antoine et al., 2014, 2015b), this process probably occurred during a period characterised by a continental climate with strong seasonal contrast, deep freeze-thaw and important phases of vertical drainage during snowmelt episodes.

even if the exact location of the past discoveries from the alluvial stratigraphy remains unresolved.

4.2. Acheulean occupation

During the late 19th and early 20th centuries, the term “Abbevillian” was coined after the discovery of “archaic” bifaces from various gravel pits at Abbeville, thought to belong to the fluvial High Terrace deposits (Bordes, 1992; Breuil et al., 1939a,b). D'Ault du Mesnil (1896) worked at the Carrière Léon, located on the same terrace as Carrière Carpentier, and Champs de Mars, located on a lower terrace level. Carrière Carpentier was then studied a few years later by Commont (1910b). Prehistorians retained the term Abbevillian in subsequent publications to designate what was considered to be an Early or archaic Acheulean. However, as shown by geological studies (Figs. 3 and 4), the Carpentier, Léon and Moulin Quignon quarries correspond to the same fluvial formation, located at least 10 m above the terrace on which lie the gravels of the Champ de Mars and Saint-Gilles sites, where hundreds of crudely shaped bifaces were found. If we refer to the rare published drawings or photographs of these finds in the White Marl and the underlying gravels, most of them look like crude tools. The discoveries by d'Ault du Mesnil were defended by Breuil but it is likely that part or all of these finds actually came from another fluvial terrace level (Champ de Mars) or from another stratigraphic layer than the White Marl (Carrière Léon). No similar discoveries were made later in the White Marl at Carrière Carpentier during field-works conducted first by Commont, then Aufrère and finally the present authors. However a few bifaces have been discovered by all the investigators at the base of the sandy slope deposits directly overlying the white Marl.

The term Abbevillian was abandoned in recent years because (1)

“Abbevillian” crude bifaces are present in most of the lithic series with bifaces (before or after 500 ka), and (2) most of “Abbevillian” bifaces from the Somme Valley were formerly collected on surfaces without stratigraphical location. In Northern France we can no longer consider them as a chronological marker, as proposed by A. Tuffreau (i.e. Tuffreau, 1987; Tuffreau et al., 2008). However, in Great Britain, “handaxe group V” from Roe (1968) could be classified as “Abbevillian” bifaces. Recent revision of British lithic series have established that patterns of occurrence of “group V” within well-dated pre-Anglian British sequences might be a case for regarding these forms as of chronological significance (Bridgland et al., 2013; Bridgland and White, 2014, 2015). Nevertheless, according to considered European areas, the Early Acheulean evidence (whatever the definition given to this term of Acheulean) older than MIS 13, suggests diversity of technological behaviours, with or without continuity of occupations over time (Moncel et al., 2015, 2016).

The bifaces discovered at the base of the sandy deposits directly overlying the White Marl at the Carrière Carpentier can be considered and discussed in the chronological framework of the time period contemporaneous with the sequence, between 700 and 500 ka (Fig. 17). Such ovate type bifaces were described by Commont (1910a,b) and related to “archaic Acheulean” or “Early Acheulean”, although he never found any in the White Marl of Carrière Carpentier. According to the geology, palaeontological remains and ESR dates, these bifaces could be about 550 ka old. They would be thus contemporaneous with the flakes and cores discovered at the site of Amiens-Rue du Manège (Antoine et al., 2015a,b). These two localities could hence record the oldest evidence of hominin occupations in the Somme Valley and more generally in the north of France.

In the Western European context, the Carrière Carpentier site belongs to a key time period. Before 1 Ma, bifaces are absent from

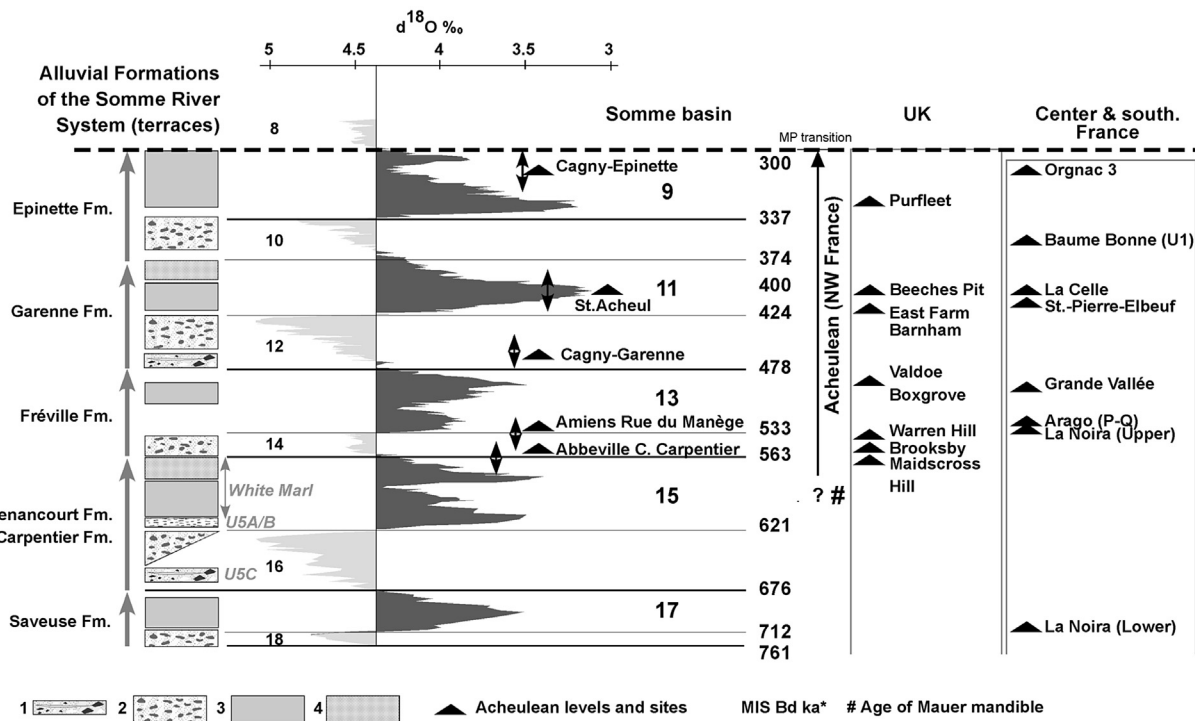


Fig. 17. Location of Acheulean levels from the Somme Valley compared to the global marine isotopic reference curve (according to Lisiecki and Raymo, 2005) and to other sites from England and central France (Gagnepain and Gaillard, 2005; Cliquet et al., 2009; Limondin-Lozouet et al., 2010; Herisson et al., 2012; Falguères et al., 2015; Moncel et al., 2012, 2013, 2015, in press; Voinchet et al., 2015). 1 - Heterogeneous slope deposits (early part of the cold period cycle: only at the base of Garene and Carpentier Formations). 2 - Flint and chalk gravels representing the main part of all the alluvial formations (periglacial environment/full glacial conditions). 3 - Fluvial calcareous overbank silts (temperate climate/interglacial). 4 - Calcareous tufa (interglacial optimum in the Garene Formation, interglacial in the Carpentier White Marl).

all assemblages, which may be qualified as core-and-flake series (Carbonell et al., 1999, 2010; Arzarello et al., 2006; Mosquera et al., 2013). Discoveries made during the past few decades in Western Europe attest to the sporadic onset of bifacial technology between 1 Ma and 500 ka, and especially between 700 and 500 ka. In both the north and the south of Europe, some series indicate that hominins mastered this technology prior to its widespread development after MIS 12.

The bifaces discovered in Carrière Carpentier are younger than the earliest assemblages with bifacial technology from Southern Europe, such as levels B, D and F of Notarchirico in Southern Italy (610–660 ka; Pereira et al., 2015) (Piperno, 1999; Lefèvre et al., 2010), Barranc de la Boella in Spain with two Large Cutting Tools (LCTs) dated to ca. 1 Ma (Vallverdu et al., 2014), and la Noira in the Centre of France, dated to 660 ka (Despriée et al., 2011; Moncel et al., 2013, 2015, 2016). These sites represent the earliest evidence of elaborate bifaces and bifacial tools in Western Europe.

Nevertheless, several European sites with comparable biface industries are similar in age to the Carrière Carpentier:

- 1) The Caune de l'Arago (Southern France), where levels P and Q, dated to MIS 14 (Barsky and Lumley de, 2010; Falguères et al., 2015) include carefully worked bifaces s.s. of various sizes and in different raw materials and some cleavers on flakes.
- 2) In north-western Europe, handaxes from Brandon Field, Maidcross Hill and Warren Hill (Bytham River, Great Britain) are dated to MIS 15 (Ashton et al., 2011; Ashton and Lewis, 2012; Moncel et al., 2015; Voinchet et al., 2015).

All the assemblages are made on locally available flint nodules from fluvial gravels, similar to the raw material of the Carrière Carpentier bifaces, including crudely fashioned bifaces and thin ovates and cordiform bifaces.

After MIS 15, younger sites are known, such as Happisburgh Site 1 (HSB1, probably MIS 13) (Preece and Parfitt, 2012), which yielded a flint assemblage comprising almost 300 artefacts (Ashton et al., 2008), and Boxgrove (Great Britain) at the end of MIS 13 (Roberts and Parfitt, 1999), where the artefacts come from *in situ* knapping and are associated with a huge quantity of well worked bifaces (ovates and with a “coup de tranche”). The bifaces recently found at Carrière Carpentier in the sandy deposits overlying the White Marl and attributed to the MIS 15/14 transition are close in morphology to the Boxgrove tools.

Finally, Cagny-la-Garenne I and II (France, Somme Valley, MIS 12, Antoine et al., 2007) yielded several assemblages made from locally available flint nodules. These sites are interpreted as workshops with crude bifacially worked tools alongside well-worked tools (Tuffreau and Lamotte, 2010).

Acheulean technology is also very well represented in Northern France and England during the MIS 11 and 9 interglacials (*i.e.* Tuffreau, 1987; Lamotte and Tuffreau, 2001; Antoine et al., 2010).

Evidence from sites with bifacial technology raises questions concerning the relationship between various groups of hominins, referred to as *Homo heidelbergensis* dispersals, and the onset of bifacial or Acheulean technology (including complexity in core technology and/or land-use patterns) (Moncel et al., 2013, 2015). The few hominin fossils dated between 800 and 500 ka (Gran Dolina TD6, Mauer, Boxgrove) are attributed to either *Homo antecessor* or *Homo heidelbergensis*, and the diversity of anatomical features suggests possible hominin intra- or inter-diversity in Europe. Dental anatomical analysis points to longitudinal migrations of new hominin groups from Asia and genetic data suggest speciation events in Africa or Eurasia prior to 600 ka (Bermúdez de Castro and Martín-Torrès, 2013; Martín-Torrès et al., 2007; 2011).

At the same time as the occurrence of these bifacial assemblages, core-and-flake industries persisted in Northern and Southern Europe: (1) The lithic series from level TD6 (Gran Dolina, Atapuerca, Spain, ~800 ka; Ollé et al., 2013; Parès et al., 2013) share both and common features with the earliest lithic series, (2) at Isernia (Italy, 583–561 ka, Peretto et al., 2015), a recent study of level 3c suggests that knapping choices and skills may not only have been opportunistic, but that in some cases, discoid cores result from a deliberate technological choice (Peretto et al., 2004; Gallotti and Peretto, 2015), (3) at Happisburgh Site 3 (900 ka, Great Britain), 78 flint flakes, cores and flake tools were excavated from fluvial gravels (Parfitt et al., 2010), (4) the technical features of the flint industry identified in the Cromer Forest bed Formation between Pakefield and Kessingland in Suffolk (Great Britain, ~700 ka) are difficult to evaluate as they comprise very few pieces (Parfitt et al., 2005, 2010).

Several scenarios have been advanced to explain this behavioural diversity: persistence of early traditions alongside the arrival of new traditions, local emergence of new traditions or the role of activities (Moncel et al., 2013, 2015). Technological data seem to point to a behavioural change after 700 ka in Europe and few series attest to a local origin, except the new site of Barranc de la Boella in Spain, dated to 1000 ± 0.068 Ma, with two crude LCTs (Vallverdu et al., 2014). The diversity of traditions with elaborate bifaces (see la Noira and Arago sites) between 700 and 500 ka might be due to the successive arrival (with or without extinction) of new traditions and know-how (by hominins or diffusion of behaviours) and bifacial technology may bear no connection to the local substratum.

The first unquestionable human occupation of Northern France is thus currently dated to MIS 15. This is consistent with hominin presence south of the Paris basin in the terraces of the Cher Valley dated to around 660 ka. To the north, older artefacts (flakes) reported from south-eastern England (Parfitt et al., 2005, 2010) support the hypothesis that older hominin occupations must have occurred further south, and particularly in the Somme Valley. Indeed, during low sea-level stands throughout glacial periods, the Somme River was one of the main routes connecting the Paris basin to the Channel area, then to Southern England.

5. Conclusions

New research by a multidisciplinary team at Abbeville Carrière Carpentier provides an important set of data for understanding the older Middle Pleistocene and Lower Palaeolithic deposits of the Somme Valley. This study leads to the following conclusions:

- 1) The White Marl of the Carrière Carpentier represents an exceptionally well preserved temperate calcareous fluvial sequence, contemporaneous with a late Cromerian Complex interglacial. During this interglacial the climate was favourable to the formation of well developed oncolithic tufa layers that represent, up until now, the oldest evidence of a calcareous tufa formation linked to bio-precipitation (cyanobacteria) in Northern France.
- 2) Molluscs and large vertebrates indicate interglacial climatic conditions for unit 4. The White Marl formed in an aquatic slow running environment, as emphasized by the development of oncoliths and the presence of fishes, chelonians and aquatic molluscs. According to the malacofauna and the small and large mammals, the contemporaneous landscape was a mosaic of open areas, bushes and forests, with wet and grassy vegetation on riverbanks. This palaeoenvironment is attributed to the early phases of a Middle Pleistocene interglacial.
- 3) New ESR and ESR/U-series dates and biochronological data (large mammals, micromammals, and molluscs) indicate that

this interglacial was coeval with MIS 15 (621–563 ka, Lisiecki and Raymo, 2005).

- 4) The *Mimomys-Arvicola* transition occurred during the Cromerian Complex, at the beginning of the Middle Pleistocene. The well-dated sequence of Carrière Carpentier is thus among the oldest occurrences of *A. cantiana/mosbachensis*, together with other sites such as Kärlich G, Mauer, Mosbach 2 in Germany and Isernia and Notarchirico in Italy.
- 5) The large mammal assemblage shows a typical Cromerian signature and is the best preserved faunal association from this period in Northern France. This fauna allows us to examine the evolution of Cromerian biodiversity in Europe and constitutes an important biochronological and palaeoecological marker.
- 6) The late Cromerian Complex interglacial mollusc assemblage recovered from the sites from the High Terrace, of the Somme system (Alluvial Formation VII) constitutes the second reference of Cromerian malacofaunas for Northern France.
- 7) Based on the proposed reconstruction for the formation of the whole alluvial sequence during one glacial-interglacial climatic cycle, the oldest Acheulean remains could be allocated either to late MIS 15 or early MIS 14. These flint artefacts are the first bifaces discovered *in situ* at this site since the beginning of the 20th century.
- 8) The presence of bifaces in the White Marl remains doubtful. Considering the aspect of the few “Abbevillian” bifaces clearly related to the Carrière Carpentier sequence we observe a diversity of types. Some could be “geofacts”, whereas others are clearly bifaces, such as those related to the sequence of Moulin Quignon. Generally, the origin of these pieces is uncertain and they could derive from formations other than the White Marl. The bifaces discovered by d'Ault du Mesnil at Carrière Léon are now difficult to replace in the stratigraphic sequence and unequivocal evidence for human presence coeval with the White Marl deposits thus remains elusive.
- 9) Palaeoenvironmental reconstructions and dating undertaken at the various Abbeville sites lead to a new reference for the knowledge of hominin occupation during the early Middle Pleistocene in the Somme basin and, from a broader point of view, new hypotheses on the chronology and environmental context of occupations in high latitudes before 500 ka. The human occupation of north-western Europe appears to be discontinuous (mainly occurring during interglacial phases) and starts markedly later than in Southern Europe, which was more largely and perhaps continuously inhabited from 1.4 Ma onwards.

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