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Early Levallois core technology between Marine Isotope Stage 12 and 9 in Western Europe

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A B S T R A C T

Early Levallois core technology is usually dated in Europe to the end of Marine Isotope Stage (MIS) 9 and particularly from the beginning of MIS 8 to MIS 6. This technology is considered as one of the markers of the transition from lower to Middle Paleolithic or from Mode 2 to Mode 3. Recent discoveries show that some lithic innovations actually appeared earlier in western Europe, from MIS 12 to MIS 9, contemporaneous with changes in subsistence strategies and the first appearance of early Neanderthal anatomical features. Among these discoveries, there is the iconic Levallois core technology. A selection of well-dated assemblages in the United Kingdom, France, and Italy dated from MIS 12 to 9, which include both cores and flakes with Levallois features, has been described and compared with the aim of characterizing this technology. The conclusion supports the interpretation that several technical features may be attributed to a Levallois technology similar to those observed in younger Middle Paleolithic sites, distinct from the main associated core technologies in each level. Some features in the sample of sites suggest a gradual transformation of existing core technologies. The small evidence of Levallois could indicate occasional local innovations from different technological backgrounds and would explain the diversity of Levallois methods that is observed from MIS 12. The technological roots of Levallois technology in the Middle Pleistocene would suggest a multiregional origin and diffusion in Europe and early evidence of regionalization of local traditions through Europe from MIS 12 to 9. The relationships of Levallois technology with new needs and behaviors are discussed, such as flake preference, functional reasons related to hunting and hafting, an increase in the use of mental templates in European populations, and changes in the structure of hominin groups adapting to climatic and environmental changes.

1. Introduction

Early Levallois core technology is usually dated in Europe to the end of Marine Isotope Stage (MIS) 9 and particularly from the beginning of MIS 8 to MIS 6. This technology is considered as one marker of the transition from the Lower to Middle Paleolithic or from Mode 2 to Mode 3 (Clark, 1969), resulting in the general adoption of more complex flaking strategies and a higher standardization of products (White and Ashton, 2003; Monnier, 2006; Scott, 2011; White et al., 2011; Moncel et al., 2011, 2012; Fontana et al., 2013; Adler et al., 2014; Wiśniewski, 2014; Villa et al., 2016; Picin, 2017). Recent discoveries show that some lithic innovations actually appeared earlier in Western Europe, from MIS 12 to MIS 9, contemporaneous with changes in subsistence strategies and the first appearance of early Neanderthal anatomical features. Evidence of progressive or gradual developments in behavior is recorded from ca. 400 ka with fire use (Roebroecks and Villa, 2011; Gowlett, 2016) and ca. 300 ka through organized hunting strategies (e.g., at

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Schöningen in Germany; Thieme, 1997; Blasco et al., 2013; Conard et al., 2015; Rodriguez-Hidalgo et al., 2017). Likewise, paleontological studies and recent DNA analyses suggest the appearance of the earliest Neanderthal features across Western Europe in *Homo heidelbergensis* populations between 600 and 450 ka (Krings et al., 1997; Hublin, 1998, 2009; Hublin and Pääbo, 2005; Orlando et al., 2006; Bischoff et al., 2007; Rightmire, 2008, Endicott et al., 2010; Green et al., 2010; Stringer, 2012; Meyer et al., 2014, 2016).

Among the lithic innovations, the first evidence of Levallois technology can be reinvestigated, as recent findings seem to attest to an earlier practice. A fresh look at old collections named proto-Levallois, pre-Levallois, or Prepared Core Technology (PCT) before MIS 9/8 has to be undertaken in the context of these new discoveries. Levallois technology was first identified by Boucher de Perthes (1857) with the recognition of three main criteria (preparation of the core surface, role of the convexities, and subsequent detachment of one flake). The definition varied over time, changing from the production of one main end-product to various predetermined end-products (De Mortillet G., 1883; Commont, 1909; Bordes, 1950; Boëda, 1986). Experiments clarified the definition and technological requirements, often (but not always) facetted platforms, angles of percussion, and management of the volume of the core (Breuil and Kelley, 1954; Boëda, 1995; Lenoir and Turq, 1995). All the definitions recognized that this technology enabled control of the shape and standardization of the end-products, and required general preparation of the core volume and management of core convexities. Recognition of these technological features on cores and flakes allows identification of Levallois core technology.

We have selected well-dated assemblages from MIS 12 to 9, where in the past, both cores and flakes were described as Levallois, proto-Levallois, or 'prepared cores' or have recently been found by new fieldwork. They are located from the northwest to the south of Europe in the UK (Purfleet and consideration of other occurrences), France (Cagny-la-Garenne I-II, Orgnac 3), and Italy (Guado San Nicola, Cave dall'Ollio; Fig. 1) and described as the earliest evidence for each country of Levallois core technology. These assemblages are frequently discussed with the consideration that not all the classical Levallois characteristics are found together (i.e., Malinsky-Buller, 2016b; Soriano and Villa, 2017). We aim to review the attribution of these cores and flakes in the light of the new data to characterize this technology (accidental or evidence of technical innovation), which coexisted for an extended period with earlier technologies. These technologies will be discussed by region with ideas on its origin, such as technological roots in the Middle Pleistocene, arrival of populations, or diffusion from multiple areas, the relationship with new needs and behaviors, and the evolution of European populations. In the light of the recent findings, the period of MIS 12 to 9 can be considered as a threshold in cultural human evolution and testing of new technological behaviors, raising questions on how we term this important period. Are we dealing with a phase of invention, deliberate or by chance (Renfrew, 1978), or innovation, namely the adoption of an invention by a large number of individuals? Determining the timing and mode of the onset of Levallois core technology in Europe is crucial to understanding how these behavioral changes developed at the inception of the Neanderthal (or *H. heidelbergensis*) way of life.

2. Materials and methods

2.1. The corpus of sites

From the north to south of western Europe, there are well-dated archaeological sites that show isolated examples of core technologies that have been identified in the past by the originality of the preparation of the flaking surface and the control of the form of the end-products. A selection of these sites, dating from MIS 12 to the end of MIS 9 and from a range of environmental and geological contexts, is reviewed to describe the variation in this technology and to discuss the attribution (or not) to an early form of Levallois core technology. These assemblages are often, but not always, associated with bifaces.

While from MIS 8, the recognition of Levallois is not questioned, and the definition of Levallois core technology is largely agreed, the multitude of terms for earlier Levallois indicates that the recognition of this core technology older than MIS 8 is more problematic. The terms used include proto-Levallois, pre-Levallois, prepared cores, or simple prepared cores (Wymer, 1968; Roe, 1981; White and Ashton, 2003). Discovery of some sites in the earlier years of the subject led to the use of the terms proto-Levallois or pre-Levallois because of the unusual nature of the cores, which did not resemble the 'classic' Levallois cores from sites such as Baker's Hole in Britain. In the UK, this led to the adoption of the term 'simple prepared cores' in part to try and avoid the implication of an evolutionary progression that was promoted by the terms proto-Levallois or pre-Levallois (White and Ashton, 2003). Despite the adoption of the new term, it was still sometimes used to imply an early date (e.g., Bolton, 2015), even though such cores are found in both pre-MIS 8 and post-MIS 8 contexts (see below).

The background of the selected sites for this review are briefly described below in chronological order. The site of Cagny-la-Garenne is located in fluvial deposits of the Middle Terrace of the Somme Valley (North France). Human occupations took place between the alluvial plain and the limestone slope. The gravels have been attributed to MIS 12 based on the strong regional geological framework of the Somme (i.e., Antoine et al., 2007, 2016). The terrace system of the Somme is particularly well represented in the middle part of the valley, between Amiens and Abbeville, where a set of stepped alluvial formations is preserved by a covering of well-developed loess and paleosols. In this area, 10 stepped alluvial formations have been recognized between +5/6 m and +55 m relative height above the maximum incision of the present day valley. The summary of the data (sedimentology, bioindicators, and geochronology) shows that each alluvial formation corresponds to the morphosedimentary budget of a single glacial-interglacial cycle. The glacial stages are characterized by a braided river system and mainly sand and gravel deposition, whereas interglacial stages correspond to a meandering river system, with overbank silt deposition and marshy soil formation at the top interglacial.

The electron spin resonance (ESR) date of the formation at the site of Cagny-la-Garenne I is of 400 ± 101 ka, while other dates on the same alluvial formation (n°V Garenne Formation + 27–29 m) have given ages of 448 ± 68 ka, 443 ± 53 ka, and 403 ± 73 ka (Antoine et al., 2003, 2007, 2016). The dates in combination with the evidence of deposition in a cold environment suggest an MIS 12 age for the formation.

At Cagny-la-Garenne I, the six artifact assemblages (Level CA to CXB) were made from the locally available flint and consist of bifaces and core and flake manufacture with notches and denticulates (Tuffreau, 1987; Lamotte, 1994, 2012). Assemblages CXCA and CA are in primary context close to the Chalk slope, LJ and LG come from fluvial silts, CXB from limestone gravels, and at the top CXV comes from coarse, periglacial gravels (Tuffreau and Lamotte, 2010). At Cagny-la-Garenne II, 100 m from Cagny-la-Garenne I, four archaeological levels (I, J, K, and L) were recovered, whereas at the top, five archaeological levels (I0–I4 and J) came from gravels (Lamotte and Tuffreau, 2001). Once again, the fluvial sequence is banked up against the Chalk slope. Raw material was available on site in the form of large flint nodules. All stages of core working and biface manufacture are present.

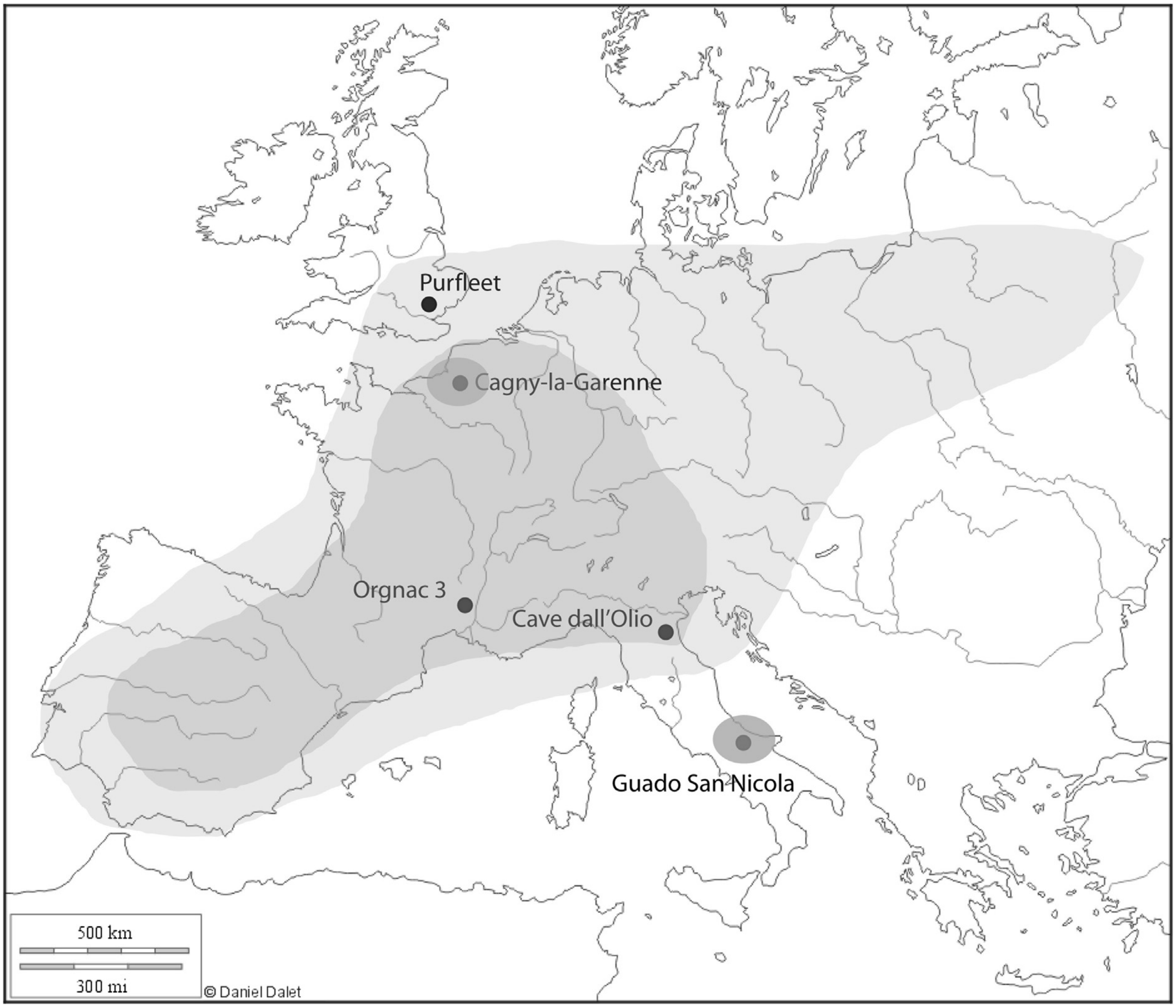

Figure 1. Location of the sites with some early evidence of Levallois core technology (black rounds). The gray surface indicates the Levallois extension at the end of the MIS 9. The dark gray surface indicates the extension from the MIS 8.

The site of Guado San Nicola is located in south central Italy (Molise Region). It is an open-air site systematically excavated from 2008 to 2015 over an area of 98 m^2 (Peretto et al., 2015). A 20 m stratigraphic core in the immediate vicinity of the excavation and a series of stratigraphic sections investigated in the area have confirmed the sequence of the excavation. From bottom to top, the sequence is composed of eight stratigraphic units (S.U.). The 2 m-thick sequence is of polygenic gravelly silty and clayey deposits and contains interstratified tephra layers. It has been dated on the basis of morphostratigraphic considerations and radioisotopic dating of volcanic deposits. The $^{40}Ar/^{39}Ar$ and ESR/U-series dates clearly place the archaeological occupation at the transition between MIS 11 and 10 (400 and 345 ka). Unit S.U.C., rich in lithic and faunal remains, is dated to 400 ± 9 ka by $^{40}Ar/^{39}Ar$ (Pereira et al., 2016). The faunal assemblage can be attributed to the typical Galerian and to the Fontana Ranuccio Faunal Unit. The faunal assemblage is mainly composed of the remains of *Cervus elaphus acoronatus*, Cervidae indet., *Equus ferus* ssp., followed by *Palaeoloxodon* sp., *Bos primigenius,* and *Stephanorhinus kirchbergensis*, *Ursus* sp. and *Dama* sp. The sedimentary succession consists of four archaeological levels (C, B*C, B, A*B) with lithic assemblages composed of reduction sequences of both debitage and shaping. The raw material (mainly flint of good quality with a high degree of silicification and, more rarely, limestone) was collected from a secondary context in the form of cobbles or slabs. The main flaking methods are an opportunistic exploitation (cf. alternate platform), followed by discoidal and centripetal debitage. The reduction sequences for bifaces are not complete and lack preparation phases (Muttillo et al., 2014). They were made by direct percussion with a hard hummer and final retouch by soft hammer.

The site of Orgnac 3 in southeast France first developed as a cave and then became an open doline. The archaeological sequence of 10 levels is dated through biostratigraphy and ESR, U/Th dating from MIS 9, whereas for levels 2 and 1 at the top of the sequence, dated by volcanic mineralogy to the beginning of MIS 8 (Combier, 1967; Debard and Pastre, 1988; Falguères et al., 1988; Masaoudi, 1995; Moncel et al., 2011, 2012). ESR and U/Th give ages of 288−45/+ 82 ka, 309 ± 34 ka, and 374−94/+ 165 ka for the bottom of the archaeological sequence (levels 5b and 6; Falguères et al., 1988; Masaoudi, 1995), attributed to the MIS 9. Four pure calcite samples of the levels 5b−6−7 (bottom of the sequence) have been dated by U/Th by MC-ICPMS (high-precision mass spectrometry) at the Environment Change Laboratory (HISPEC, Taiwan). Dates vary between 255 and 319 ka (Michel et al., 2013). Level 2 contains volcanic minerals from an eruption of the Mont-Dore volcano, eruption dated to the beginning of the MIS 8 (298 ± 55 ka; Debard and

Pastre, 1988). Direct dating by $^{40}Ar/^{39}Ar$ on sanidine grains (cineritic material) has been applied to level 2 (Org-C1). The 12 dates are between 276 and 326 ka with an average age of 308.2 ± 6.8 ka. The result is in agreement with the age of 298 ± 55 ka by fission track dating on zircons (Khatib, 1994). The biostratigraphy associating large mammals, micromammals, and pollen date the bottom of the sequence (levels 7 to 3) to an interglacial of the Middle Pleistocene (Mourer-Chauvire, 1975; Tillier, 1991; Jeannet, 1981; Guerin, 1980; Gauthier, 1992; El Hazzazi, 1998; Aouraghe, 1999; Sam, 2009; Sam and Moigne, 2011). Level 1 is indirectly attributed to the MIS 8 by *Hemitragus bonali* and *Ursus deningeri*. Levels 2 and 1 attest of open landscape with the replacement *Equus mosbachensis* by *Equus steinheimensis* (Forsten and Moigne, 1988).

Pre-Neanderthal human remains were discovered in the lowest layers (Lumley de, 1981). The lithic assemblages record a mosaic of changes over time toward Early Middle Paleolithic strategies (Moigne, 1999; Moncel et al., 2012; Moigne et al., 2016). Debitage activity is dominant, and bifaces have variable ratios through the sequence with less than 1% in the top levels. Thin slabs of flint were the main blanks collected locally.

The open air site of Cave dall'Olio is located in an alluvial context along the Northern Apennine edge near Bologna, northern Italy. The lithic assemblage was recovered in the 1970s along a stratigraphic profile brought to light by quarry activities at the top of a fersiallitic paleosol within the gravels of the River Idice at a depth of about 20 m below the present surface. The fersiallitic paleosol has been referred to the Molino Unit of the Apennine-Po Plain Quaternary stratigraphic framework dated to MIS 9, indicating a terminus ante quem for the chronology of this assemblage (Farabegoli and Onorevoli, 1996, 2000; Fontana et al., 2010). The dating of the gravels and the soil containing the lithic industry of Cave dall'Olio, as well as their paleoenvironmental interpretation, are based on the integration of data derived from the study of the profile of S. Mamante (Faenza); 22 shallow marine to terrestrial Quaternary units were produced by the long-term activity of a right transcurrent fault with various outcrop segments distributed across a sector of the Emilia-Romagna Apennines edge for a total length of more than 150 km (Farabegoli and Onorevoli, 1996). Within the reconstructed scheme, the first continental units are dated to the Upper Matuyama chron reverse period and to the Bruhnes direct paleomagnetic chron. The latter contains the earliest evidence of human occupation in this area (on a stratigraphic basis, Bel Poggio and Romanina Bianca are considered to be of the same age as Ca' Belvedere di Montepoggiolo with Mode 1 assemblages). The sediments of the continental units correspond in most cases to the glacial-interglacial transition periods and are intercalated with 8 fersiallitic soils typical of warm interglacial phases. Correlations have been established between the different portions of the outcropping terraced deposits, which are recognizable upstream along the valley flanks. These have allowed the fersiallitic paleosoil identified at Cave dall'Olio to be referred to as the Molino Unit of the Apennine-Po plain Quaternary stratigraphic framework dated to MIS 9. Initial studies led to classification of this lithic industry, which is dominated by debitage with evidence of manufacturing of bifaces as ancient Clactonian and proto-Levallois (Bisi et al., 1982; Lenzi and Biagioli, 1996) after the original definition by Palma di Cesnola (1967).

In the UK, at Purfleet, Essex, Paleolithic artifacts have been recovered from sediments exposed in four chalk quarries, in the Lower Thames Valley. From east to west, these are the Bluelands, Greenlands, Esso, and Botany Pits. The pits reveal terrace deposits occupying an abandoned meander loop of the Thames as part of the Lynch Hill/Corbets Tey terrace (Bridgland, 1994), banked up against the north facing chalk slope of the Purfleet anticline. The sequence comprises gravel (Little Thurrock Member) overlain by interglacial deposits rich in faunal material (Purfleet Member) fining upward to a silty clay and surmounted by gravel (Botany Member). An assemblage of artifacts excavated and collected by Andrew Snelling from the Botany Gravel at Botany Pit was initially described as 'Proto-Levallois' (Wymer, 1968) and 'reduced' Levallois with simplified preparatory stages (Roe, 1981). This gravel reflects a return to cold climate gravel deposition following a fully temperate episode, suggesting an MIS 9/8 date, an attribution which is supported by an OSL date of 324 ka (MIS 9) from an equivalent position at Greenlands Pit (E. Rhodes, quoted in White and Ashton, 2003).

2.2. Methods

In this article, we use the terminology of Boëda (1986, 1993, 1995) for the overall concepts of Levallois: a volumetric concept with 6 technological criteria: (1) core maintenance (lateral and distal convexities), (2) predetermination of end-products, (3) normalization of end-products, (4) potential for resharpening, (5) ramification, and (6) productivity. The lower surface of the core is devoted to the striking platform and the upper surface to Levallois flake production. To distinguish between cores, such as those from Purfleet, we use the term 'simple prepared core', without implication for an early date. As defined by White and Ashton (2003), they are cores where the striking platform has been selected, minimally prepared, and orientated in relation to the preexisting lateral and distal convexities of one flaking surface. The flakes removed from this surface tend to be larger than any of the preparatory flakes (by which the platform was created) and to flake along the surface at an angle close to 90° to the platform, rather than biting excessively into the core volume. For cores, such as those from Baker's Hole where there is a preferential, single removal, we use the term 'classic Levallois', as for the other sites of our corpus, Cagny-la-Garenne I-II, Orgnac 3, Cave dall'Olio, and Guado San Nicola.

3. Results

3.1. Cagny-la-Garenne I and II (North France)

At Cagny-la-Garenne I, from the base of the sequence (level CA) toward the top (level CXV), the appearance of flakes and cores, described in the past as proto-Levallois increases but always in low quantity. In the sandy levels of the middle of the sequence (levels Lj, Lg), this kind of production is rare or absent. At Cagny-la-Garenne II, three levels yielded one or two cores (levels I3, I4, J; Table 1).

For each layer, the main core technology is unipolar and unifacial with few scars and a prepared/cortical platform. On a small quantity of cores, various methods (lineal, unipolar, bipolar, and centripetal) are employed for the extraction of the end-products with evidence on the cores of management of the distal and lateral convexities and plain or facetted platforms (Figs. 2–4). The removals extend over at least half of the main length of the core surface, and their morphology is because of the organization of the convexities. The preparation of the convexities tends to change from unipolar toward centripetal at the top of the sequence for Cagny-la-Garenne I. Most core sizes vary between 50 and 110 mm in maximum dimension. Among the flakes, we can identify some core edge flakes (débordant flakes) with many scars, which are probably from the preparation of the core convexities. In assemblage CXB at Cagny-la-Garenne I, there are several biface-cores with invasive removals interpreted as attempts at Levallois.

3.2. Guado San Nicola (south central Italy)

The Levallois assemblage is fresh, and the main raw material is aphanitic and microbrecciated flint or occasionally macrobrecciated flint and silicified limestone. It is of better quality than

Table 1
Number of Levallois pieces at Cagny-la-Garenne I and II among the lithic assemblages.

Sites and levels	Total number of artifacts	Unipolar cores	Bipolar cores	Levallois or Levallois-like flakes	Levallois cores	Levallois core technology
Cagny-la-Garenne I						
Series CXV	197	22 unifacial 1 bifacial	–	13	3	Lineal Unipolar
Series CXB	776	65 unifacial 1 bifacial	1 unifacial	172	2	Lineal
Series LJ	335	24 unifacial	1 unifacial 1 bifacial	53	1	Bipolar
Series CA	513	17 unifacial 1 bifacial	2 unifacial	41	0	–
Cagny-la-Garenne II						
Series I3	575	3 unifacial	–	9	2	Centripetal Unipolar
Series I4	1348	10 unifacial	–	8	1	Lineal
Series J	833	7 unifacial		2	1	Bipolar

that used for the bifaces. The supports were ovoid cobbles and quadrangular slabs or occasionally large flakes. Different stages of the reduction process can be identified and reveal careful preparation, management, and maintenance of flaking platforms (angles ranging from 55 to 85°) and convexities (mainly centripetal), indicating the ability to prepare and re-prepare cores for predetermined flakes (Fig. 5). Various methods were used in equal quantity (single preferential flake, recurrent centripetal, unipolar, and bipolar), and there is evidence of facetted platforms for lineal and recurrent unipolar debitage (Table 4; Figs. 5 and 6). The Levallois cores are exhausted, and some were made on flakes.

Overshot flakes managed the lateral and distal convexities, except for the lineal debitage with centripetal removals. Levallois flakes ($n = 55$) mostly result from 'plein debitage' or repreparation of the convexities, produced by unipolar and centripetal recurrent method (Fig. 6). The striking platforms are dihedral or flat, rarely facetted. Levallois points and blades, as well as retouched Levallois flakes, are extremely rare.

3.3. *Orgnac 3 (southeast France)*

In the lowest levels (5b and 5a), less than 10% of the cores and less than 3% of the flakes, can be classified as Levallois (Table 2; Figs. 7 and 8). The cores are unipolar/bipolar or centripetal recurrent. The knapping surface indicates the utilization of the core edges, one or two partially prepared striking platforms, and maintenance of lateral and distal convexities. The 'Levallois' cores are very different to the frequent unexhausted unifacial and bifacial centripetal cores on slabs or thick flakes, where there is no sign of management of the convexities. Centripetal and Levallois cores are associated with some prismatic, polyhedral, and orthogonal cores. Some 20% of the rare Levallois flakes are débordant flakes, while 30% of platforms are facetted and 10% dihedral.

In levels 4b and 4a, around 40% of the cores and 2–8% of flakes can be defined as Levallois (Figs. 8–10). The Levallois cores are associated again with centripetal cores. The cores on flakes again indicate evidence of predetermined flaking, preparation of distal and lateral convexities, use of hard hammer, and distinctions between striking platform and flaking surface. The methods applied are again unipolar and bipolar recurrent, but the preferential flake method, not used in the lower levels, becomes the most common. In contrast to the underlying levels, the predetermined removals never cover the flaking surface. As for levels 5b–5a, the quantity of Levallois flakes is very low, suggesting export of flakes. Débordant flakes total between 20 and 50% of the assemblage. The removals are mainly centripetal, and the ratio of flakes with an invasive scar on the upper face increases. The size of flakes is more variable than the cores.

3.4. *Cave dall'Olio and other assemblages of the Northern Apennine margin (northern Italy)*

The assemblage totals 494 lithic artifacts, with 71 cores, 403 retouched and unretouched blanks, 5 pebble tools, and 15 bifaces (Table 3; Fontana et al., 2013). Most of the assemblage was obtained from a dark colored silicified siltstone that is very abundant locally and available in large-sized nodules and pebbles (10–40 cm). Bifaces were mostly obtained from large flakes and were always worked with a small number of deep removals.

Cores are dominated by unidirectional recurrent schemes with either parallel or convergent removals and represent around 30% of the assemblage. Recurrent crossed methods predominate, whereas lineal, recurrent bipolar, and centripetal flaking methods are rarer (Fig. 11). The flaking surfaces were prepared by either débordants or orthogonal removals, and core platforms were variably prepared. Levallois cores are associated with a few prismatic types resulting from the application of a laminar reduction process sensu lato—also reported as 'direct non-Levallois reduction sequence' (Révillon, 1995)—and with a small group of cores featuring mixed characteristics between Levallois and laminar reduction. Other methods include Kombewa, opportunistic and possibly discoid reduction.

Levallois end-products vary in shape and elongation according to the method applied. There are elongated blanks with parallel edges and frequently characterized by a backed edge from unidirectional parallel and bidirectional methods (with some items possibly obtained from a laminar reduction). There are also flakes with convergent and frequently déjétés lateral margins derived from application of the recurrent unidirectional convergent scheme, small middle-sized oval-shaped flakes from the lineal method, and small oval and subtriangular flakes extracted with centripetal debitage. Most products measure between 40 and 90 mm in length. Platforms are generally flat, whereas facetted types are rare (7%, including one 'chapeau de gendarme'). Although in several cases the condition of the artifact surfaces was altered by fluvial deposition, around 30 retouched blanks were identified, especially scrapers and denticulates, including some on Levallois flakes.

Several other assemblages recovered during field surveys from the river terraces of the Northern Apennine edge, which are dated to the same age as Cave dall'Olio, are characterized by similar technological features. The general features of such assemblages show that this area was intensively occupied by human groups that

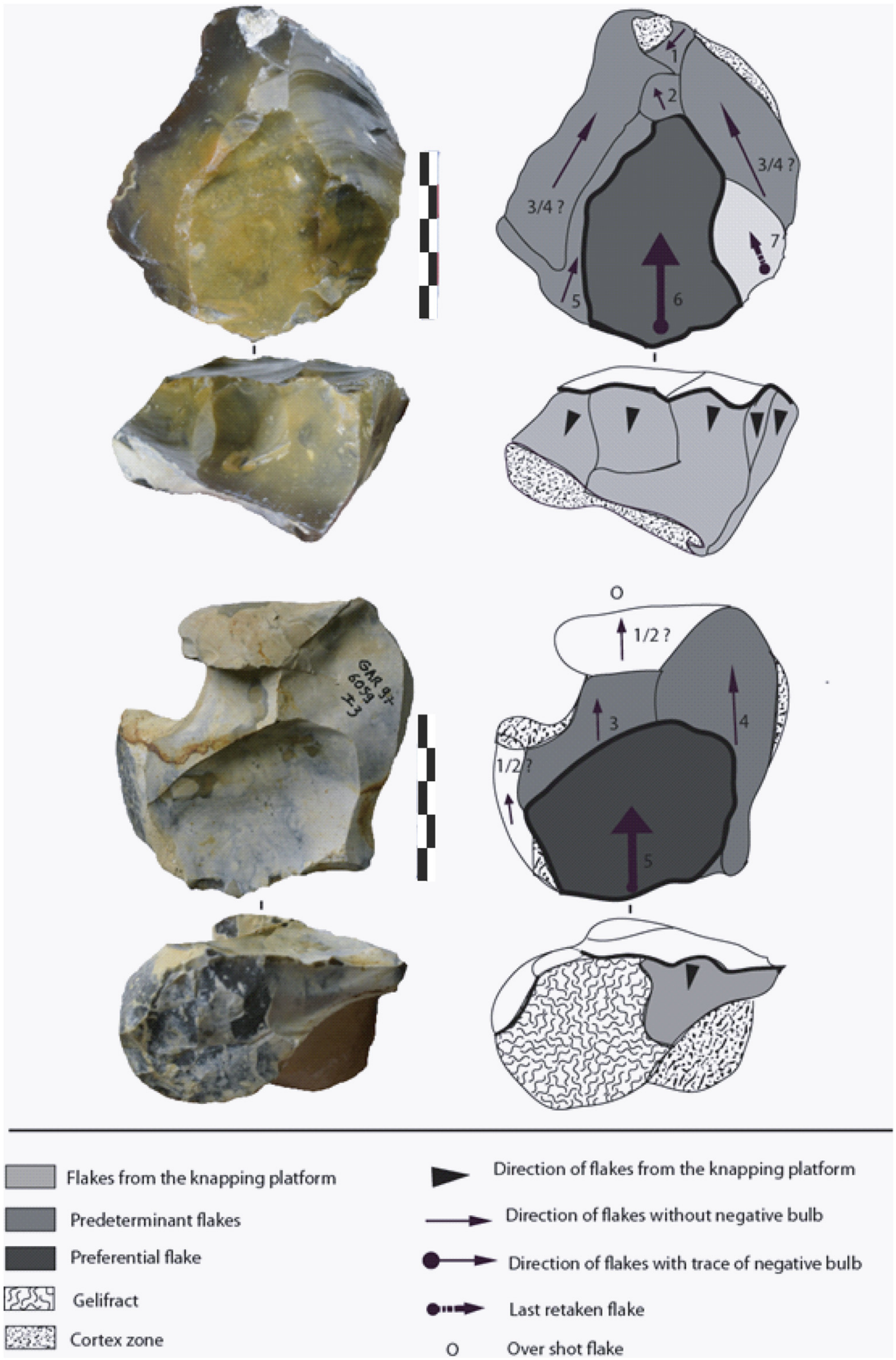

Figure 2. Cagny-la-Garenne I. Level I3 (Middle of the alluvial sequence): preferential Levallois cores. The numbers indicate the order of the removals. Drawings and pictures: A. Lamotte.

were able to apply different predetermined debitage reduction sequences before MIS 9/8 (Lenzi and Nenzioni, 1996).

3.5. *Purfleet (UK) and other UK sites with simple prepared cores*

The assemblage from Purfleet consists of over 4000 artifacts, including 30 bifaces, but the vast majority are flakes (White and Ashton, 2003; Scott, 2011; Bolton, 2015). Distinguishing end-products is problematic, and only rare examples of potential Levallois flakes can be identified. A sample of more than 300 cores has been examined in more detail (Scott, 2011). They consist of 170 migrating platform cores, 28 discoidal cores, 80 simple prepared cores, and 25 cores that are considered as Levallois. The simple prepared cores conform to the description above, whereas the few

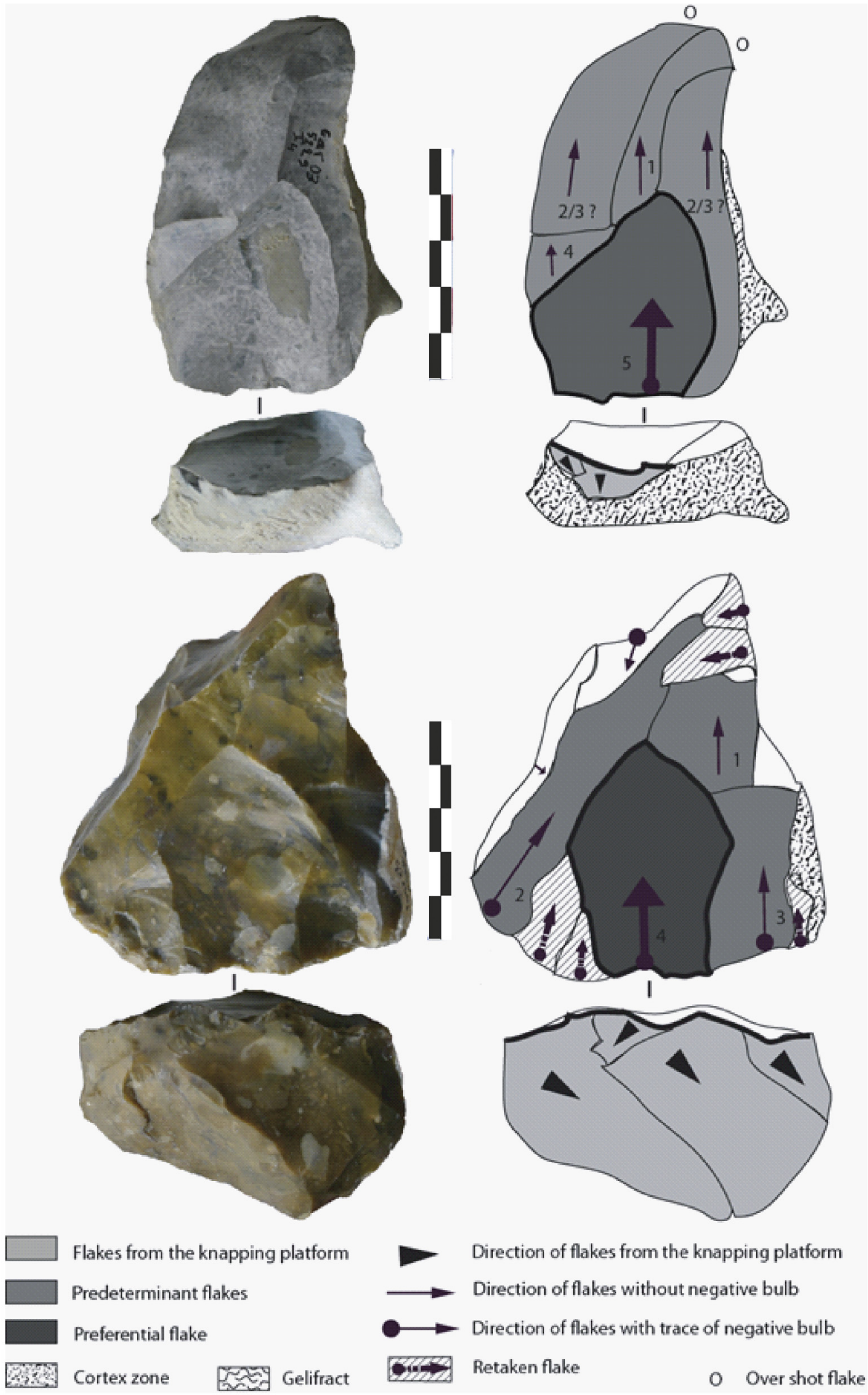

Figure 3. Cagny-La Garenne I—Level I4 (Middle of the alluvial sequence): preferential Levallois cores. The numbers indicate the order of the removals. Drawings and pictures: A. Lamotte.

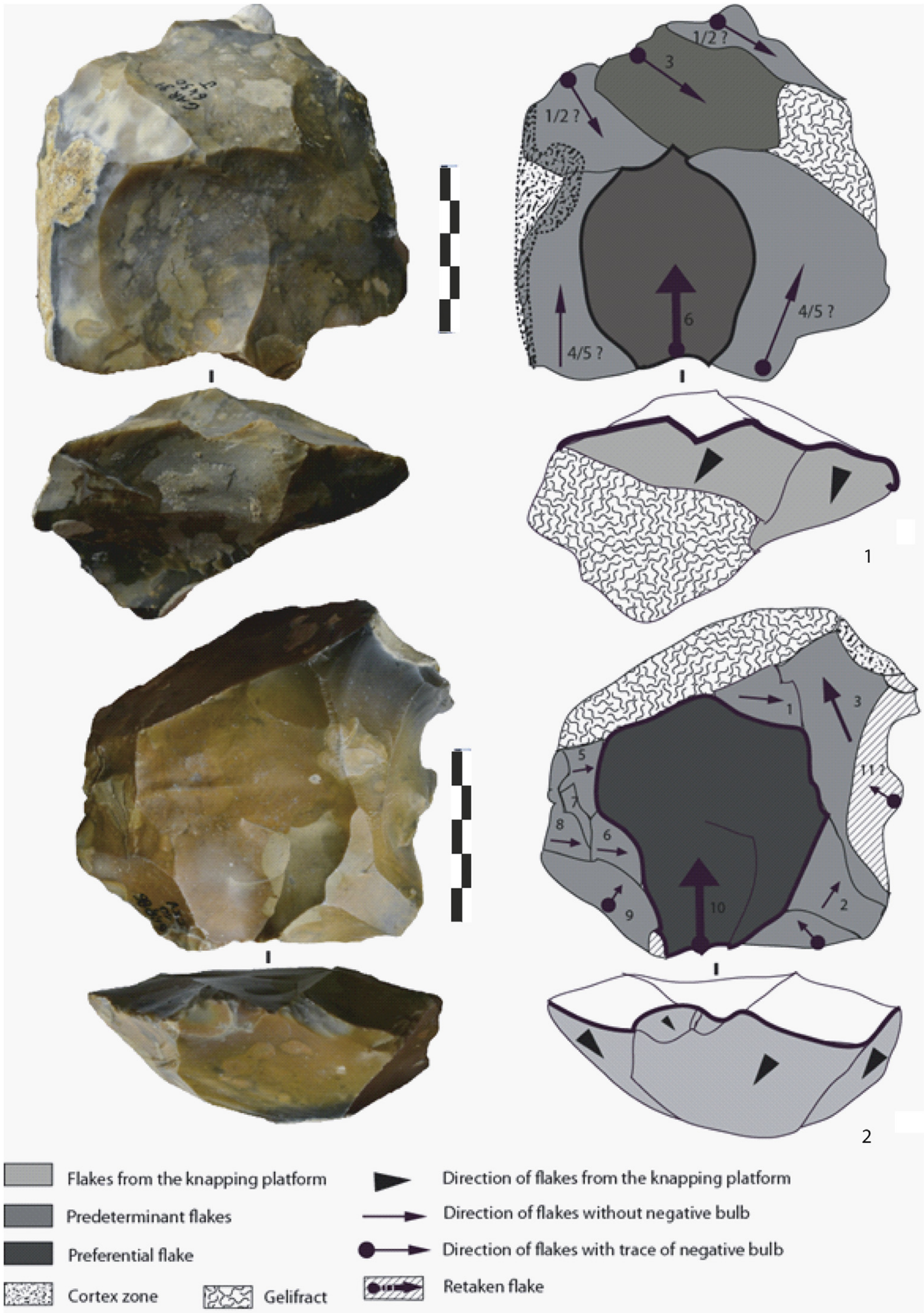

Figure 4. A) Cagny-La-Garenne II—Level J (beginning of the alluvial sequence). B) Cagny-la-Garenne I—Level CXV (final alluvial sequence). Both preferential Levallois cores. Drawings and pictures: A. Lamotte.

Levallois cores have mainly lineal exploitation (84% with one invasive removal) with a few examples showing unipolar, bipolar, and recurrent techniques (with 2–3 removals on the flaking surface). The mean length of Levallois cores is 87 mm. The preparation method is mainly centripetal (96%), and there are also cores with proximal, lateral, and/or distal preparation of the convexities (Fig. 12). The striking platform is mainly partial. There are also four core débordant flakes and overshot distal flakes. A total of 26 flakes are considered as Levallois. They are large and elongated (mean length of 115 mm) and result from lineal exploitation with a centripetal preparation. None has facetted platforms. As the assemblage was recovered from fluvial gravel, it is not certain whether all the elements of the assemblage are contemporary. The condition of the bifaces is broadly similar to most of the cores, although some of the Levallois cores are fresher in condition. Purfleet remains the best dated and described British site showing application of the principles of Levallois flaking prior to MIS 8.

One of the problems with using the term simple prepared core is that this approach to core working is not rigidly defined or necessarily early but rather reflects variation in the application of the

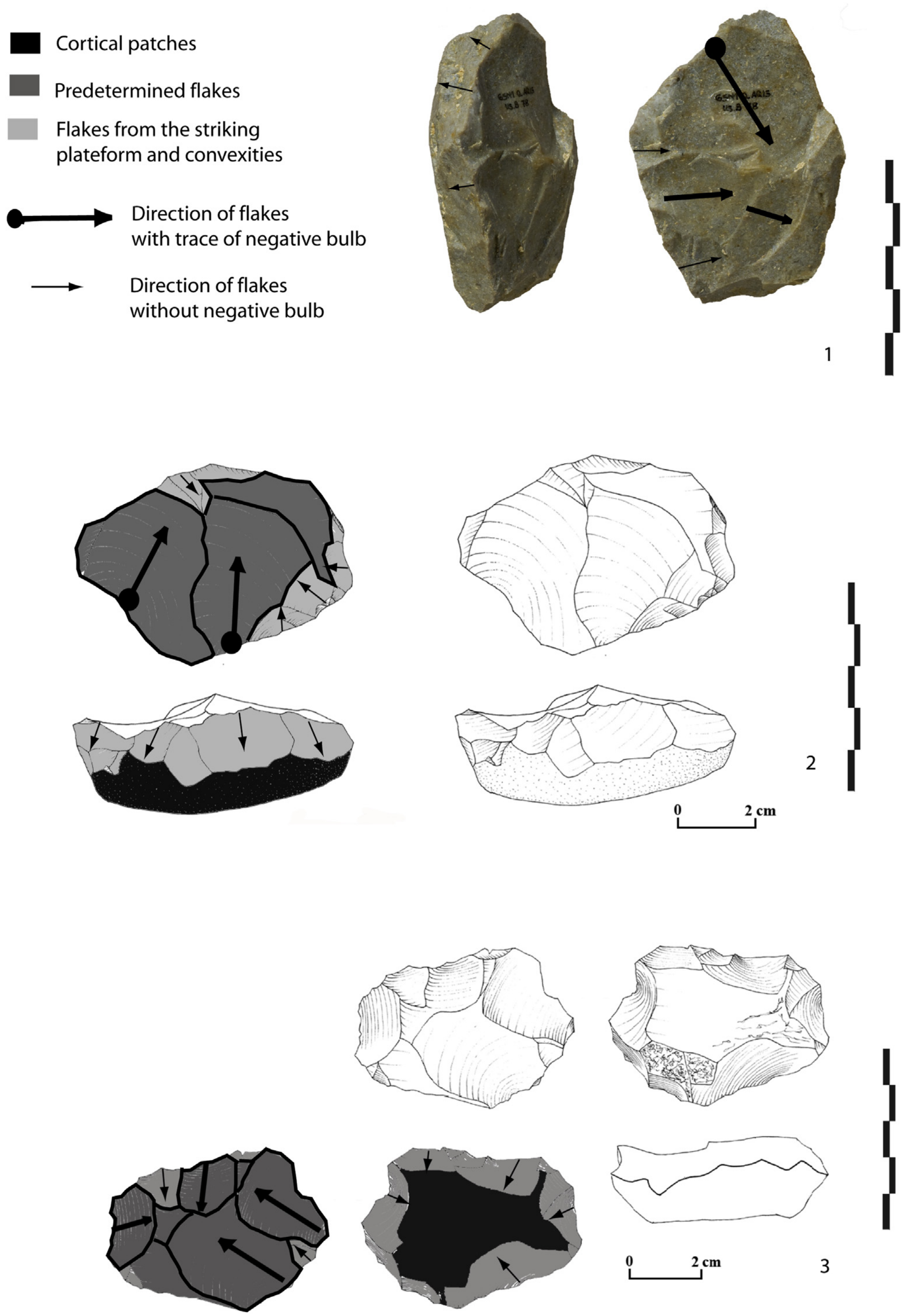

Figure 5. Guado San Nicola: A–C) recurrent Levallois core on flint. Arrows indicate the direction of the removals (thick arrows for the 'Levallois' removals and thin arrows for the striking platform). Drawings B. Muttillo, modified.

volumetric principles of Levallois flaking. Apart from Purfleet, there are several UK sites within which simple prepared cores, or cores previously described as proto-Levallois or reduced Levallois, have been noted. Some of these are of MIS 7 age, such as Ebbsfleet in the Lower Thames Valley, where simple prepared cores are merely the application of the Levallois flaking system to small pebbles alongside full Levallois applied to larger material (Scott et al., 2010).

There are occasional sites that are pre-MIS 8 in age with individual pieces being reported as simple prepared cores. These include a piece described as coming from the 'upper brickearth' at Rickson's Pit, Swanscombe (Burchell, 1931; Roe, 1981), where the Thames terrace deposits date to MIS 11 and Baker's Farm in the Middle Thames from terrace deposits assigned to MIS 10–8 (Wymer, 1999). Although the cores are illustrated, it is not clear in which museum they are curated and cannot be physically located. They may (as with much of the Levallois material from the Middle Thames) actually come from colluvial sediments overlying and sealing the terrace (Scott, 2011). Alternatively, the cores only make

Table 2
The core technologies and Levallois cores and flakes for the lower and middle part of the sequence at Orgnac 3.

Levels	Centripetal cores	Orthogonal cores	Multidirectional cores	Other core types and crude cores	Levallois unipolar cores	Levallois bipolar cores	Levallois centripetal cores	Levallois preferential flake cores	Total Levallois cores	% cores	Levallois flakes	% flakes
Level 4a	9 56.2%	5	–	6	1	–	2	5	8	33%	64	8%
Level 4b	11 61.1%	2	2	1	1	1	1	8	11	39%	37	2%
Level 5a	21 63.6%	5	2	2	2	–	–	1	3	8%	14	0.3%
Level 5b	28 71.8%	6	1	1	2	2	–	–	4	9%	54	3%

Table 3
Variety of reduction methods identified on cores at Cave dall'Olio based on core analysis.

Cores	*n*	%
Opportunistic (unidirectional)	6	8.4
Opportunistic (multidirectional)	8	11.3
Centripetal/discoid	8	11.3
Levallois lineal	4	5.6
Levallois recurrent unidirectional	7	9.8
Levallois recurrent bidirectional	2	2.8
Levallois recurrent crossed	6	8.4
Levallois recurrent centripetal	1	1.4
Levallois on a flake	2	2.8
Levallois passing to laminar	3	4.3
Recurrent unidirectional semitournant (laminar s.l.)	2	2.8
Recurrent bidirectional semitournant (laminar s.l.)	3	4.3
Kombewa	9	12.7
Undetermined	10	14.1
Total	71	100.0

up a very small component of the whole assemblage and may reflect the fortuitous end result of exploiting a nodule which favored the application of this strategy.

There are other sites which contain simple prepared cores but which are difficult to date. These include assemblages from the middle terraces of rivers, such as at Biddenham, Cuxton, Dunbridge, and Woodston. The age of these sites could range anywhere between MIS 11 and possibly as late as MIS 7. The Cottages Site is one of several dolines at Caddington and is also undated but contains simple prepared cores alongside classic Levallois material, including refitting sequences (Sampson, 1978; Roe, 1981).

Finally, one intriguing site is Frindsbury in the Medway Valley but again unfortunately undated. The assemblage originally consisted of thousands of artifacts recovered from within a shallow hollow in the chalk (Cook and Killick, 1924). Only 500 artifacts now survive but include refitting groups of flakes. White and Ashton (2003) described this material as similar to that from Purfleet, with 14 of the 16 cores from the site as simple prepared. They suggested that a sequence of large refitting flakes might provide insight into the flake production at Purfleet (Fig. 12). More recent analysis of the material suggests that five of the simple prepared cores actually result from unipolar recurrent Levallois flaking, as does the refitting sequence of 5 Levallois flakes. There are also 3 classic Levallois flakes in the assemblage. Further dating is required to understand this potentially important site.

4. Discussion

4.1. Characterization of these early technologies: Levallois or Levallois-type?

The hypothesis of a controlled but not fully standardized technology has sometimes been suggested for these early lithic assemblages (i.e., White and Ashton, 2003; Malinsky-Buller, 2016a, 2016b; Soriano and Villa, 2017). The production of classic Levallois flakes could have been accidental because these flakes did not share all the characters. Several technical features are however common to most of the assemblages:

(a) Flaking is already organized around a plane of intersection with asymmetrical faces hierarchically related.
(b) Flaking surfaces on cores show maintenance of peripheral convexities with short or more invasive removals (distal and lateral), respecting the plane of intersection. This phase precedes the removal of the predetermined product(s). One face of the core is devoted to the debitage, and the opposite face is for preparing the suitable striking platform, which is made by oblique removals and is often a partial function of the form of the support and the type of management of the flaking surface. The location of the removals for the convexities determines the shape of the predetermined products. There is a hierarchy in the management of the two faces of the core.
(c) Flake platforms are usually plain but occasionally dihedral and facetted.
(d) Selection of raw material is of good quality and with a specific morphology to reduce the shaping phase.
(e) Unipolar and bipolar schemes, sometimes crossed, dominate over centripetal and lineal ones.
(f) Some cores are on flakes with evidence of a fragmentation of the reduction sequences. Some cores show a final retouch or series of small removals on a short section of the periphery of

Table 4
Composition of the lithic assemblage of Guado San Nicola.

Layer	Total number of pieces	Centripetal and discoid cores	Opportunistic cores	Levallois cores	Levallois flakes	Retouched blanks	Handaxes
C	1.417	24	40	4	4 (1 point)	68	43
B*C	626	18	26	8	16	15	13
B	2.018	50	103	15	32	138	85
A*B	107	2	5	1	3	3	2
Total	4.168	94	174	22		224	143

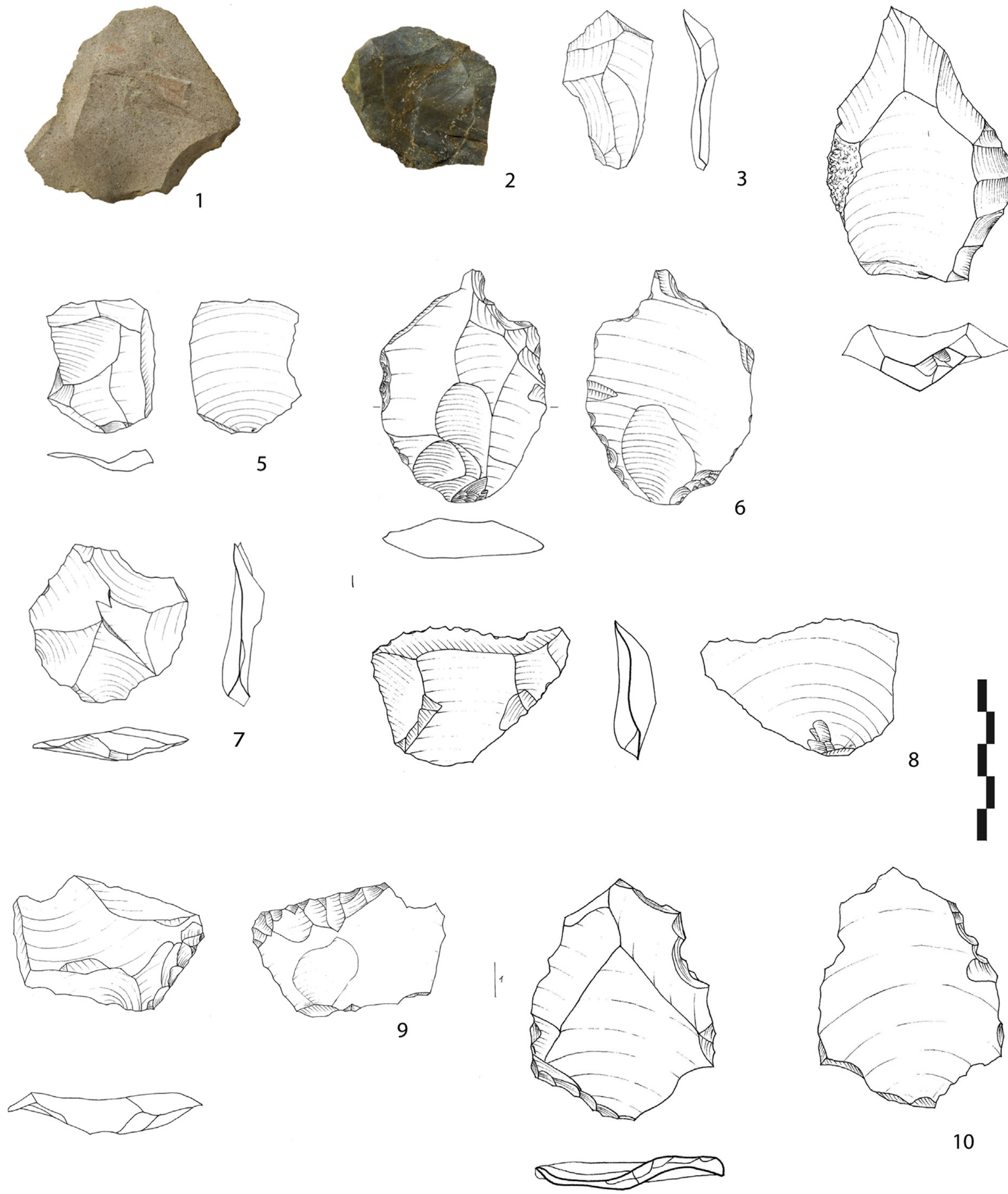

Figure 6. Guado San Nicola: A) Levallois flake on silicified limestone; B–J) recurrent Levallois flakes and points on flint. Drawings B. Muttillo, modified.

the flaking surface, perhaps recycling as a tool or for future debitage.

(g) Few flakes can be related to this technology in the lithic assemblages due perhaps to a higher mobility than other flakes. Alternatively, they are just more difficult to recognize than classic Levallois flakes, especially when resulting from shaping reduction sequences. Débordant flakes and maintenance flakes exist, although in low quantity, in the assemblages.

These features indicate a control of the core flaking surface for some pieces and of the form of the end-products with a recurrent management of the cores and a plane of intersection. If we refer to the definition (Boëda, 1986, 1993, 1995; Boëda et al., 1990), these features may be attributed to a Levallois technology similar to those observed in younger Middle Paleolithic sites.

However, two options exist: (1) these pieces are evidence of a mastery of Levallois technology, with occasional evidence before MIS 9 and certainly MIS 8 and (2) they are the result of accidental

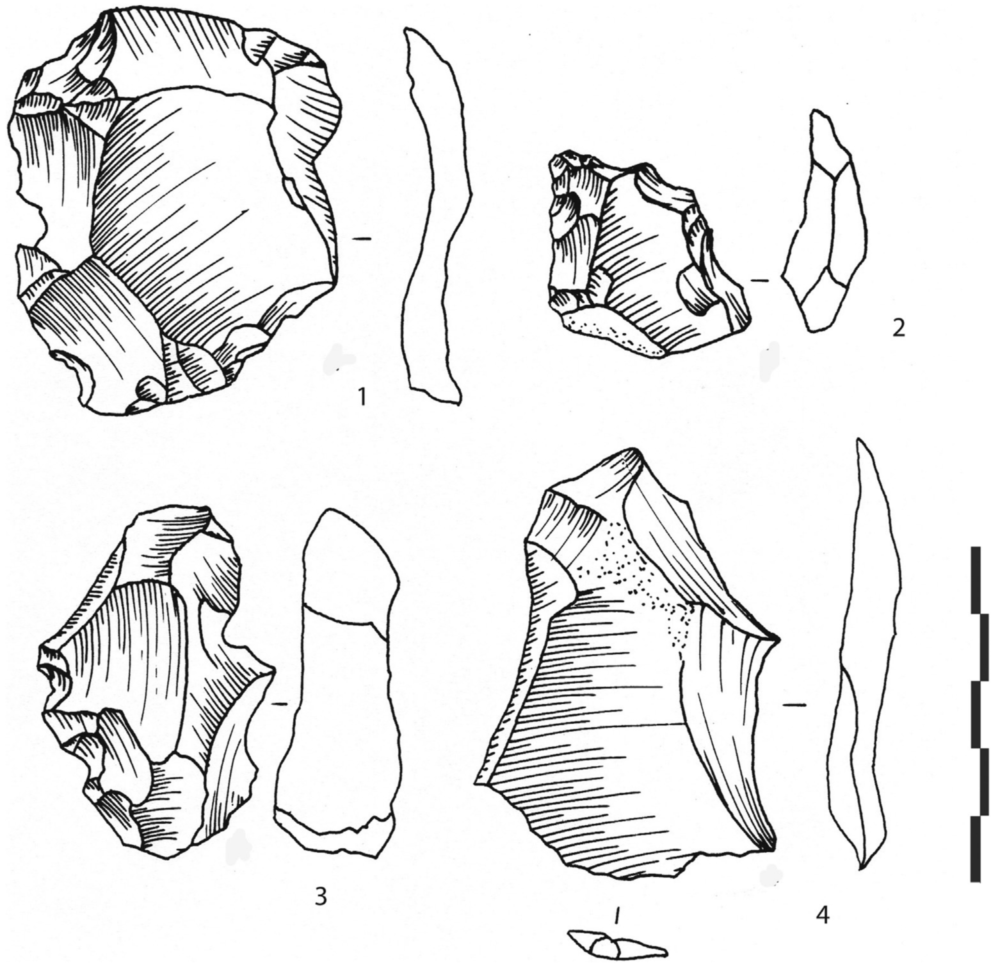

Figure 7. Orgnac 3: flakes described as Levallois (level 5b): A) Flake with centripetal removals and convexity scars, curved cross-section; B) flake with convexity scars; C) backed flake with centripetal removals and convexity scars; D) flake with centripetal removals, curved cross-section Drawings: M.H.M., modified from Moncel et al. (2016).

technological events within the main core technology; because of the low number of pieces, we have to consider whether these cores and flakes result by chance without application of a predetermined concept. Our corpus of sites can be divided in two groups: one dated confidently before MIS 9 (Cagny-la-Garenne and Guado San Nicola) and one with sites dated to MIS 9 (Orgnac 3, Cave dall'Olio and some UK sites), which is usually considered as a period, where the Levallois core technology is well mastered in several European regions.

In support of the first hypothesis (Levallois core technology), these cores do not seem to be subgroups of the main core technologies of the assemblages, where there is no sign of management of the convexities. The associated core technologies can be summarized for each site:

(a) At Cagny-la-Garenne I-II, cores were on flint nodules. The surfaces of these nodules were mainly flaked by a few unipolar and unipolar convergent removals using the natural, flat cortical convexity of the nodules. The cores are abandoned after some removals when the flaking surface becomes too flat.
(b) At Guado san Nicola, the numerous discoidal cores were managed on slabs with typical features of a discoidal debitage (unifacial or bifacial pyramidal cores). A few cores are centripetal unifacial with a plane surface, and there is no evidence of a hierarchy in the debitage and the preparation of the striking platform and the convexities.
(c) At Orgnac 3, the lower levels mainly used flat flint slabs. Cores are thus asymmetrical with centripetal removals covering one or two surfaces, using the natural shape of the slab and the plane cortical surfaces. There is no hierarchy of the two faces and the debitage stopped when the surface became too flat, as at Cagny-la-Garenne.
(d) At Cave dall'Ollio, cores with centripetal removals on cortical surfaces existed in the assemblages taking advantages of the natural convexities with no evidence of preparation of convexities.

In support of the second hypothesis (accidental debitage), the cores attributed to Levallois share common technological features with the main production of the assemblage. These cores could be the result of accidents supported by the small number of pieces. So, how do we interpret the innovative behavior, which are removals and thus the management of convexities controlling the forms of the end-products all over the flaking and maintaining the plane debitage surface? The presence and the specific location of removals of convexities helped the flaking to become independent of the geometry of the stone and of the natural convexities. The flaking could continue even if the natural convexities did not exist anymore and increased the productivity. In most of the Lower Paleolithic core

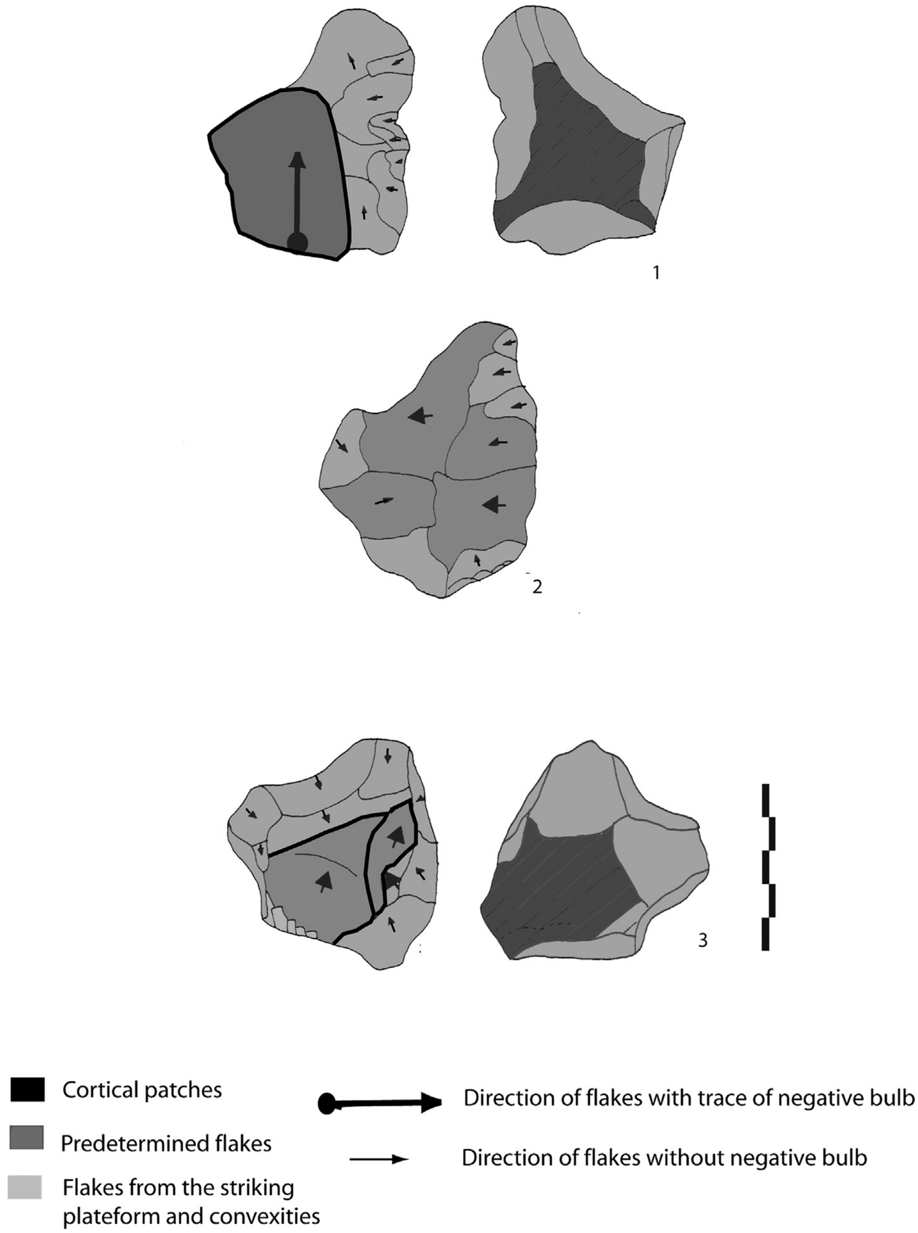

Figure 8. Orgnac 3, level 4b (A, B) and level 5a (C): A) Core with an invasive removal; B) flake described as Levallois; C) core with bipolar invasive removals. Arrows indicate the direction of the removals (thick arrows for the 'Levallois' removals and thin arrows for the convexities scars). Drawings: M.H.M., modified from Moncel et al. (2016).

technologies, the debitage is mainly related to the stone geometry, and when it was overcome, the debitage is above all discoid-type (pyramidal flaking surfaces) or polyhedral (Moncel et al., 2013, 2015). When the surface remains flat (centripetal debitage on flakes for instance), the number of removals is in general low, and the debitage is uncontrolled. That raises two questions: (1) why do we observe these removals and the possible management of convexities only on some cores? (2) Are these removals accidental, used by convenience to continue the flaking for longer?

A second feature that characterizes these cores is the location of the striking platform in close relationship to the location of the assumed controlled predeterminated or Levallois removals on the flaking surface. The peripherical striking platform (sometimes partial) was made before the management of the flaking surface, a feature often considered as a Levallois criterion by the angle and the location of the striking platform required to maintain the flaking surface.

If we analyze these 2 hypothesis in regard to our two groups of sites and the general technological features of all the cores, the small number of pieces suggest some innovations among the core technology without doubt for the MIS 11–9 assemblages but could be accidental in the MIS 12 sites.

4.2. Local innovations from existing technologies

To explain the early occasional presence of Levallois technology in some assemblages, if not accidental, 2 hypotheses can be investigated: introduction of external inventions (coming from one place) or local innovations (punctual experimentation of new ideas due to internal or external pressures) possibly with earlier roots, in this case mainly Acheulean-type or at least Lower Paleolithic-type technologies.

Some features in the sample of sites suggest a gradual transformation of existing core technologies with the elaboration of

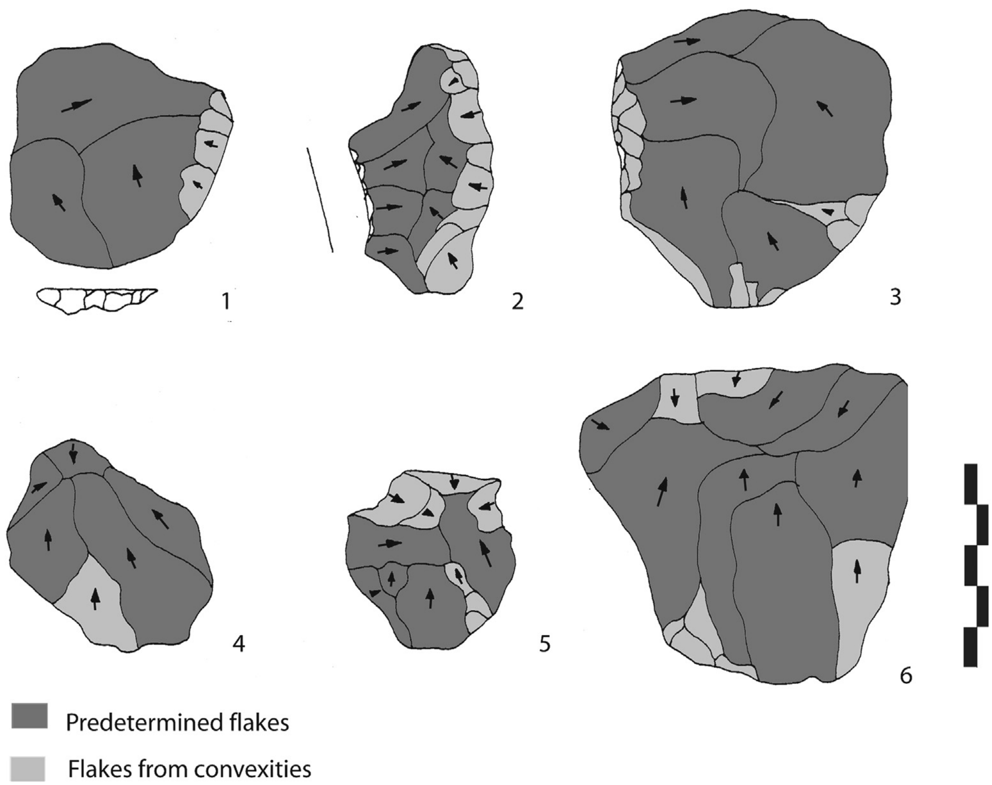

Figure 9. Orgnac 3, level 4b: A, C–F) flakes described as Levallois; B) backed flake. Arrows indicate the direction of the removals. Drawings: M.H.M., modified from Moncel et al. (2016).

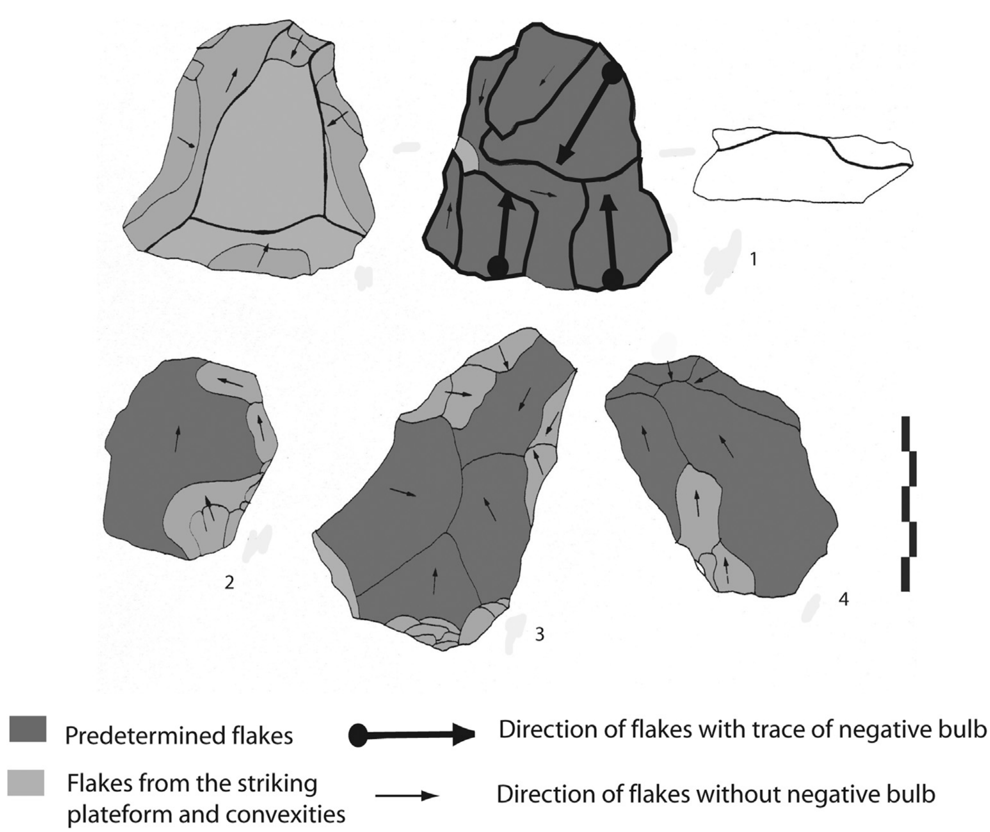

Figure 10. Orgnac 3, level 4a: A) core with centripetal removals; B–D) flakes described as Levallois. Arrows indicate the direction of the removals (thick arrows for the 'Levallois' removals and thin arrows for the striking platform/convexities scars). Drawings: M.H.M., modified from Moncel et al. (2016).

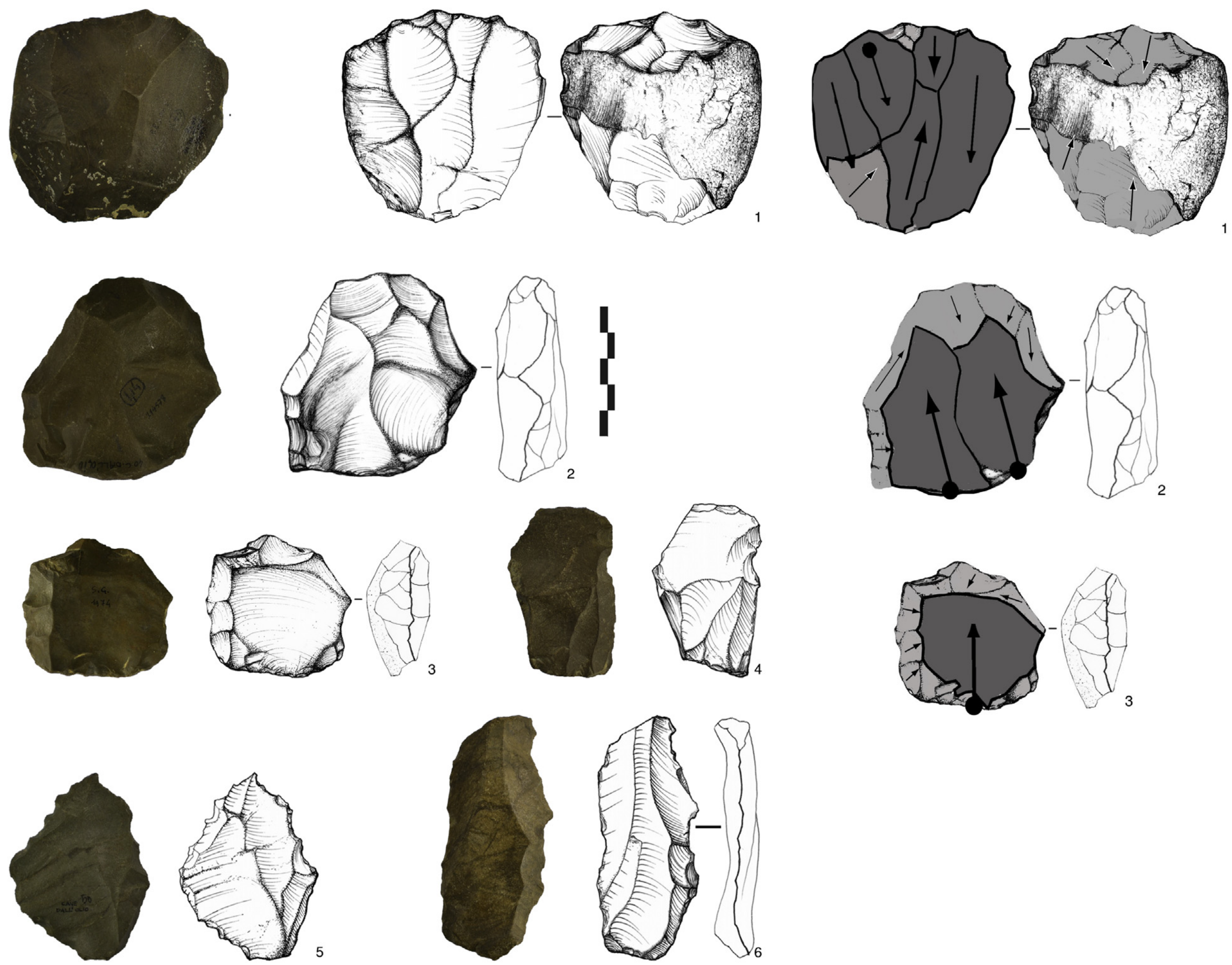

Figure 11. Cave dall'Olio, Levallois cores and blanks: A) bidirectional core; B) unidirectional convergent core; C) lineal core; D—F) Levallois blanks. Arrows indicate the direction of the removals (thick arrows for the 'Levallois' removals and thin arrows for the striking platform/convexities scars). Drawings and pictures: F. Fontana.

reduction processes, such as the use of flakes for the debitage and, as already suggested, a fusion of elements of both façonnage (bifaces) or/and debitage (discoidal and centripetal cores; 'hierarchical cores'; Dibble and Bar-Yosef, 1995; White and Ashton, 2003; Malinsky-Buller, 2016a, 2016b). The main core technologies at each site share some common technological features. These common characteristics between the main core technologies and the limited evidence of Levallois or Levallois-like core technology could indicate occasional local innovation from different technological backgrounds, with possible connections between groups, and would explain the diversity of Levallois methods that is observed starting with MIS 12 (Fig. 13). Evidence of removals to manage convexities with a plane of intersection on cores and Levallois and débordant flakes tend to distinguish the few cores and flakes from the rest of the assemblages. This may be evidence of technological innovation from a wider pool of knowledge. Levallois technology in Europe is sometimes suggested to be a progressive phenomenon preceded by a preparation phase, i.e., a protostage. This protostage could be observed with use of the hierarchical method, which could be described as intermediate, with a limited preparation of the striking platform and lateral-distal convexities (Picin, 2017). This comes under the umbrella of 'prepared core technology' in the UK. Technological data from the selected sites suggest that this interpretation cannot be applied to all sites (from MIS 12—10) as in some cases, such as Guado San Nicola, Levallois technology seems to have been mastered from an early stage.

The emergence of this technology could also have been associated with bifacial artifacts. An in situ evolution from handaxe technology has been suggested for Cagny-la-Garenne, where biface convexities were used as core faces (Tuffreau, 1987; Mellars, 1996; DeBono and Goren-Inbar, 2001; Villa, 2009; Adler et al., 2014; White and Pettitt, 2016; Tuffreau et al., 2017). In fact, the recycling of bifaces as Levallois cores is a common feature of Somme Valley sites from MIS 12 to 7 (Tuffreau et al., 2008; Lamotte and Tuffreau, 2016). However, other sites in our sample do not provide any evidence of a technical relationship of bifaces and the emergence of Levallois flaking (Fig. 14). It could be considered as a local innovative circumstance to either reduce the thickness of a biface or produce an expedient flake. Similar behavior is observed in Spanish and Levantine Lower Paleolithic sites with evidence of recycling (Baena et al., 2018).

4.3. Early evidence of regionalization of local traditions across Europe

While Adler et al. (2014) and Akhilesh et al. (2018) suggested an arrival of the technology from the Levant and Africa, the Levallois features of the sample of sites used in the current article look similar to other early European assemblages with a Levallois component, suggesting a multiregional origin and diffusion of this technology. In addition, there are other early occurrences, such as the sites of Atapuerca TD10 (MIS 11—10) and Ambrona (Middle

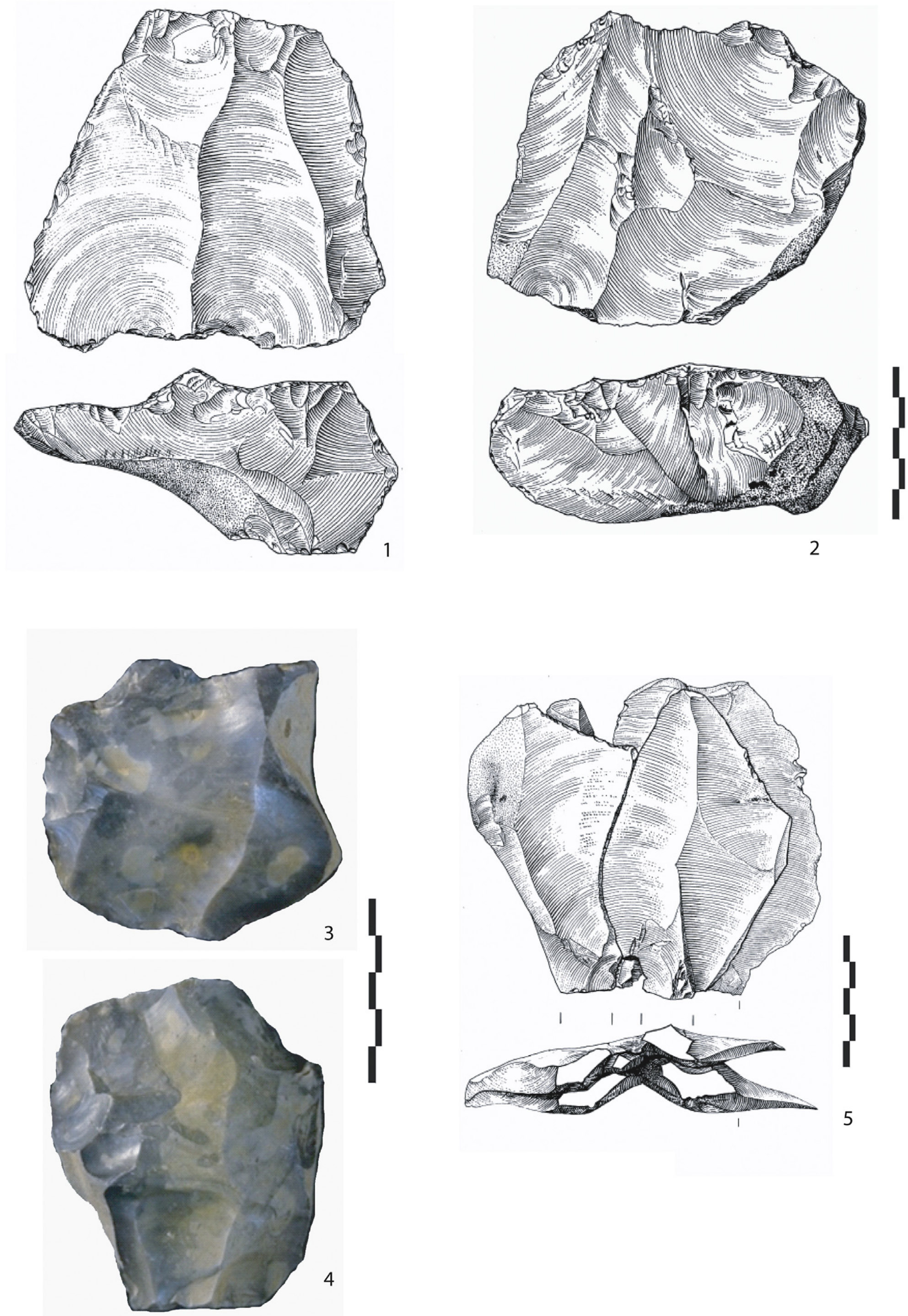

Figure 12. British sites: A–D) simple prepared flint cores at Purfleet Botany Pit (Essex); E) group of refitting flakes from Frindsbury (Kent). Pictures: N. Ashton.

complex, MIS 10?, various Levallois methods) in Spain or Kesselt-Op-de Schans (MIS 11–8?, Levallois recurrent centripetal) and Petit-Spiennes (MIS 10) in Belgium, the French sites of Aldene (TU IV, MIS 9, Levallois recurrent centripetal), Petit Bost (MIS 9, level 2, various Levallois methods), and Etricourt (layer HUD, MIS 9, some Levallois flakes), and in the Netherlands Maastrich-Belvedere (possibly MIS 9, Site C, subunit IV–B (Roebroeks, 1988; Bourguignon et al., 2008; Brenet et al., 2006; Meijer and Cleveringa, 2009; Fontana et al., 2013; Lamotte and Tuffreau, 2016; Peretto et al., 2015; Di Modica et al., 2016; Di Modica and Pirson, 2016; Hérisson et al., 2016a, b; Ollé et al., 2016; Pereira et al., 2016; Rossoni-Notter et al., 2016; Baena et al., 2017; Van Baelen, 2017; Santonja et al., 2018). Moreover, in Italy, the assemblage from Torre in Pietra, layer m, dated between 400 and 200 ka, indicates the application of discoid schemes associated with Levallois reduction (Villa et al., 2016). Therefore from the end of the MIS 9, there is a large diffusion of technological choices sharing common rules, but with diverse methods, rather than isolated attempts to produce

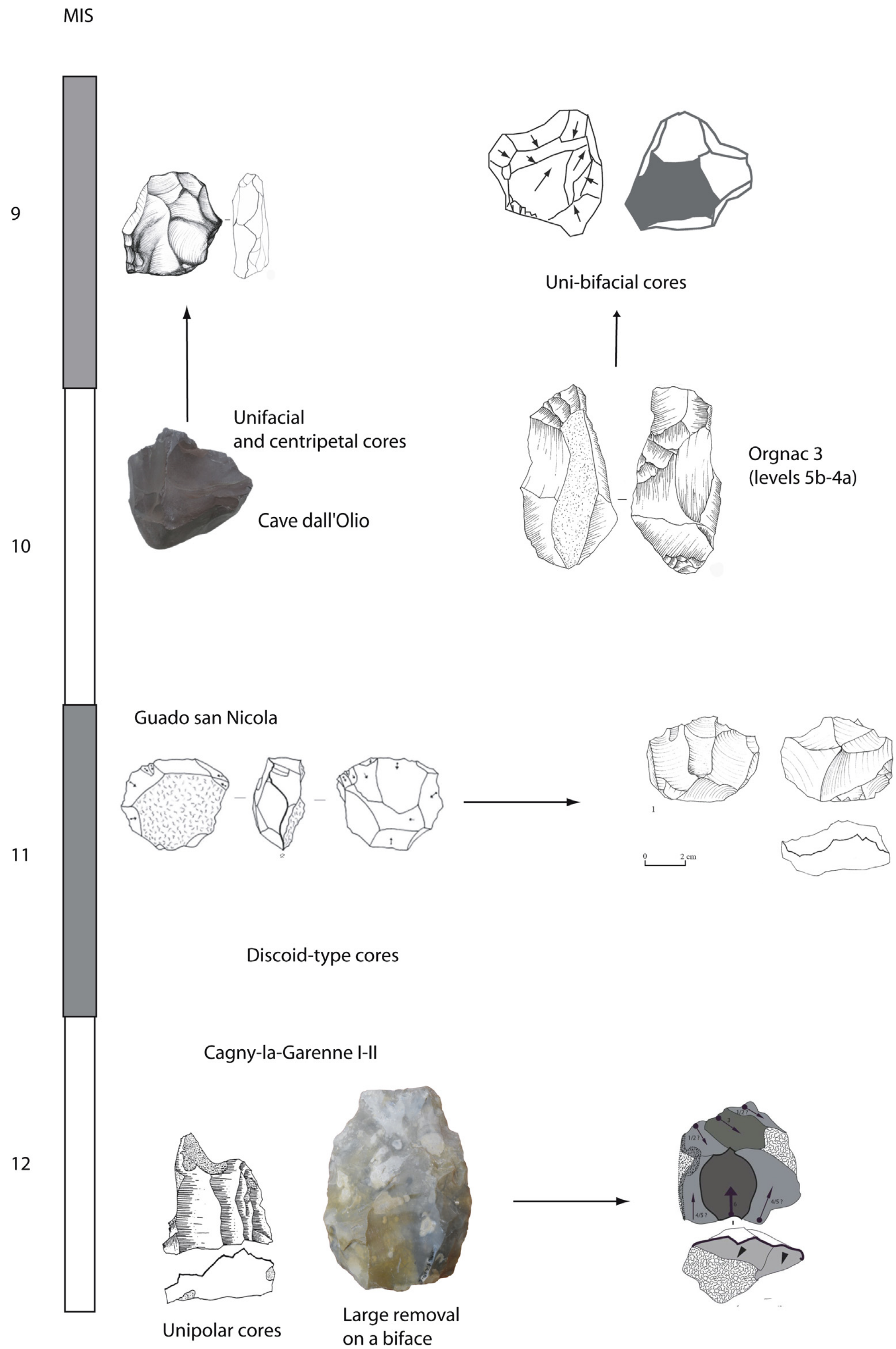

Figure 13. Local innovations of an Early Levallois core technology over time in Europe.

standardized end-products (Malinsky-Buller, 2016a, 2016b; Hérisson et al., 2016b; Soriano and Villa, 2017).

Levallois technology clearly becomes persistent in Europe between MIS 8 and 6 over a vast territory extending from northwestern Europe to the Near East, including central Europe (Tuffreau, 1987; Rigaud et al., 1988; Lamotte and Tuffreau, 2001; White and Ashton, 2003; Brenet et al., 2006; Wiśniewski, 2014; Sánchez-Romero et al., 2016; Soriano and Villa, 2017). Some sites show Levallois schemes, often accompanied by a trend towards the production of elongated blanks (Révillon, 1995; Moncel, 2003; Kozłowski, 2014). Levallois was not the only means of standardizing debitage, with for example unipolar and centripetal débitage at Cueva del Bolomor in MIS 10–9 (Blasco and Peris, 2012), the centripetal exploitation strategies seen in layer TD11 at Gran Dolina

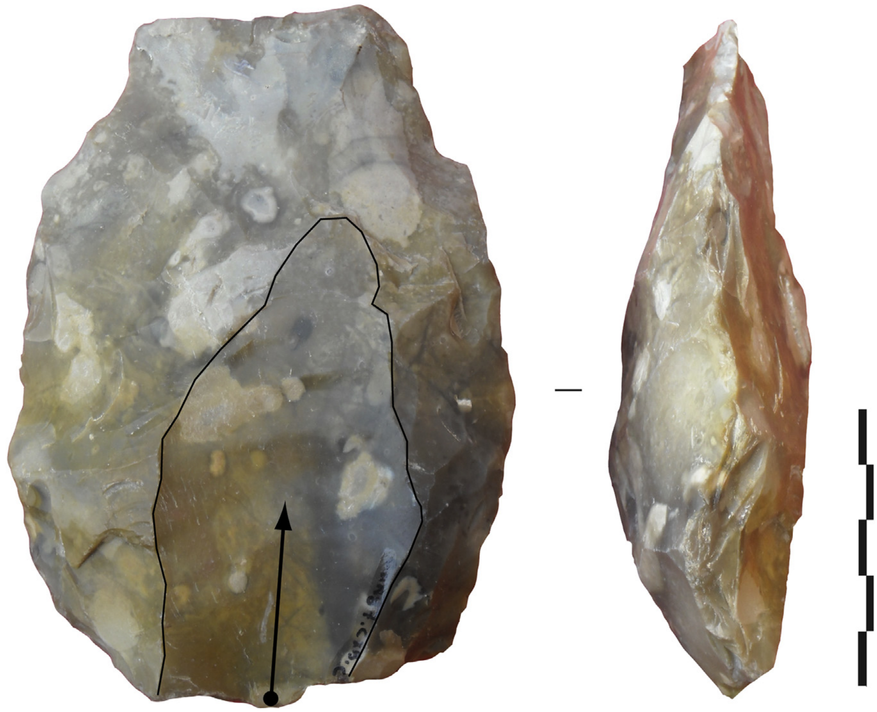

Figure 14. Cagny-la-Garenne I—level CXB: invasive removal on a biface. Photo A. Lamotte.

(Atapuerca) in MIS 10 (García-Medrano et al., 2015) or the laminar method at Cave dall'Olio (Fontana et al., 2013).

Among these sites, technological features show early trends toward regionalization of traditions as early as MIS 8 (Picin et al., 2013; Wiśniewski, 2014; Picin, 2017), supporting the hypothesis of multiregional development and local roots. For instance, in southeast France, Orgnac 3 shows from MIS 9 and 8 an emphasis on centripetal Levallois debitage, while in southwest France uni-bipolar is dominant (Moncel et al., 2011). However, in central-eastern Europe, several complexes with Levallois debitage are known from MIS 10 without any evidence of an Acheulean origin, such as Korolevo VI (Koulakovska et al., 2010) and Bechov I (Wiśniewski, 2014). Other central European sites are younger and considered to be evidence of arrivals of new populations during favorable climate with availability of good quality raw materials, such as Rheindahlen, Markkleeberg, and Becoc I and IV (Wiśniewski, 2014; Picin, 2017). Similar hypotheses on the arrivals of new populations have been put forward for the Levant (Malinsky-Buller, 2016a; Shimelmitz and Khün, 2017). The onset of Levallois technology and all the standardized technologies can probably be explained through multiple modes of origin, dependent on area and latitude.

4.4. Explaining Levallois core technology from MIS 12–9 in Western Europe

Flake selection and preference: Levallois end-products vs. other end-products If of local origins, the reasons for the onset of this new core technology remain enigmatic in terms of its selection over other technologies. Levallois core technology is often a minor component of the assemblages, associated with different methods of production, such as discoidal (Bolomor, Ambrona), Kombewa, laminar (Cave dall'Olio), centripetal flaking, and expedient (unifacial cores with some removals, orthogonal cores with two flaking surfaces, and multidirectional cores), which produce a large variety of flakes (Ashton, 1992; Peris et al., 2008; Santonja et al., 2018; Vaquero and Romagnoli, 2018). When discoidal and centripetal methods are used, the flaking surfaces are not hierarchically ordered, and there is no evidence of management of the convexities. The debitage uses the natural forms of the blank and the previous removals for guiding the production. End-products are often thick and the form badly controlled.

Comparison of the size of Levallois-type cores and flakes to other end-products is not consistent. At Guado San Nicola, despite differences in size between preferential and recurrent flakes, Levallois products are similar in size to other end-products. In contrast, at Orgnac 3, Levallois flakes are among the largest end-products of the assemblages (two groups with lengths of 30–50 mm and 65–70 mm for Levallois flakes; Fig. 15). At Purfleet, Levallois cores are slightly smaller (87 mm) than discoidal and simple prepared cores (93–97 mm). The angles and length of cutting edges on Levallois products do not seem to differ between the assemblages.

The morphology of Levallois end-products also varies between sites and regions with different quantities of flakes, elongated flakes, or points. Points dominate some sites in northwest Europe compared with both flakes and points in the south.

Compared with less elaborate core technologies, a better control of the form of Levallois products and a higher productivity of Levallois cores through maintenance of convexities, where all products could be used, seems to be the main focus. This is perhaps linked to an increase in the use of mental templates by populations (Lycett et al., 2016). Villa et al. (2016) suggest that Levallois technology provided thinner products compared with Lower Paleolithic-type methods. These products did not require retouch, the form being predetermined, or the 'one tool, one task' of Douze and Delagnes (2016). The morphological regularity of flakes seems to have led to a reduction in retouched products (Eren and Lycett, 2016). For instance at Orgnac 3, the ratio of flake-tools decreases with the increase in frequency of Levallois core technology (ratio of flake tools of 6% in level 1), whereas the numerous small flakes (10–15 mm long) produced at the end of the Levallois reduction process and from the cores on flakes are never retouched (Moncel

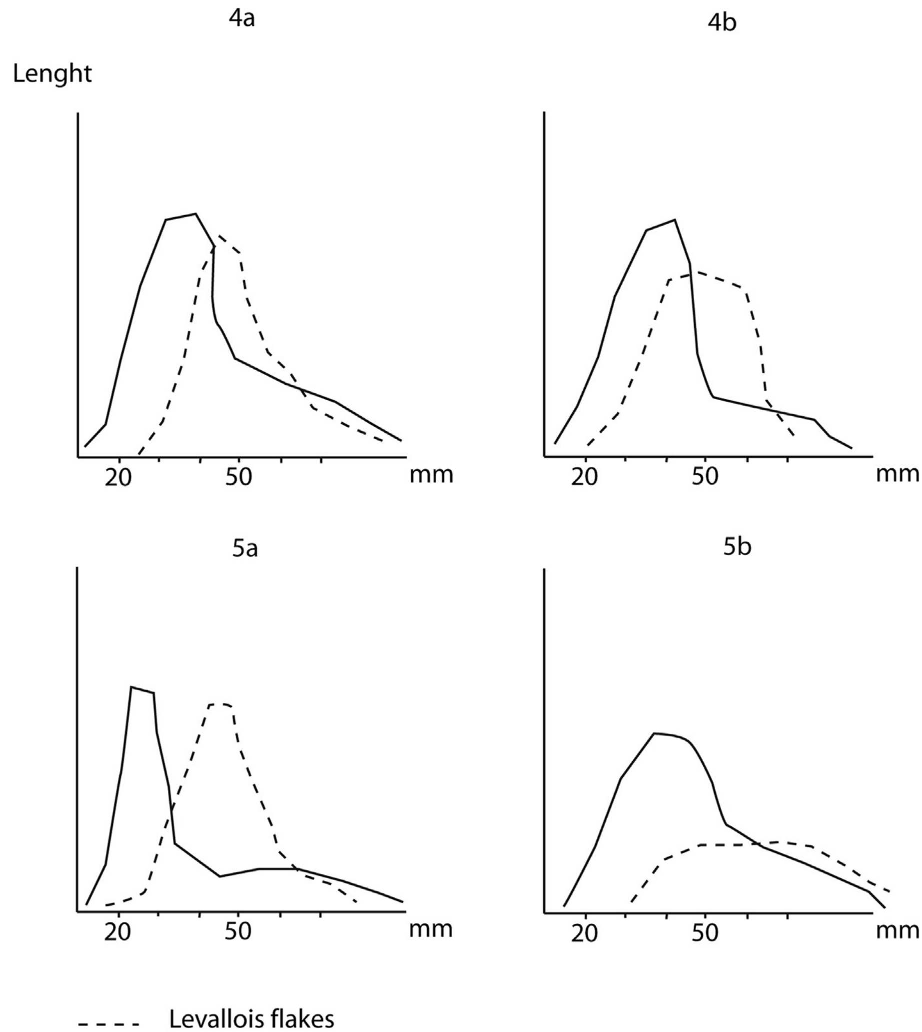

Figure 15. Comparison of length of Levallois flakes and the other flakes for the levels 4a to 5b at Orgnac 3.

et al., 2011). At Guado San Nicola, retouched Levallois flakes are extremely rare, with just a few scrapers (Peretto et al., 2015). This decrease in flake modification could have been a cost-benefit in energy. The selection of good quality raw materials (for instance at Orgnac 3) also suggests that attention was paid to this type of debitage.

Functional reasons: For hunting and hafting? In parallel to the increase of hunting in subsistence strategies and some changes in land use patterns (e.g., Moncel et al., 2011), the onset of Levallois is sometimes explained by the appearance of hafting of stone points and the use of points as projectiles (Villa et al., 2009; Hardy et al., 2013; Rots, 2013; Iovita and Katsuhiro, 2016). Stone points are often considered as light penetrative tools (Knecht, 1997) and more effective than wooden spears (see Schöningen, MIS 9; Böhner et al., 2015). The early evidence of hafting at Kathu Pan (South Africa), dated to 500 ka, shows points with modification near the base and damage from hafting (Wilkins et al., 2012). The emergence of the Middle Stone Age tradition in East Africa is related to convergent tool technology (Douze and Delagnes, 2016). Modification on small flakes at Gesher Benot Yakov also argued to be evidence of hafting as early as 900 ka (Alperson-Afil and Goren-Inbar, 2016). However, the development of Levallois technology is only associated with the more dominant production of points in northwest Europe, rather than southern Europe. The lithic assemblages of Cagny-La-Garenne I and II and the other sites during MIS 12 clearly do not indicate an emphasis on triangular flake production, but far more oval and rectangular removals. Moreover, microwear analyses indicate that Levallois products were not systematically single purpose tools and also show that form does not necessarily indicate function. Despite little hafting evidence clearly recorded in the European Levallois (Ben-Dor et al., 2011; Rots et al., 2011; Rots, 2013; Iovita and Katsuhiro, 2016; Villa et al., 2016), some patterns show however that Neanderthals were able to haft stone tools and use glues (Mazza et al., 2006; Kozowyk et al., 2017), indicating common capabilities to modern humans characterized by abstraction and planning ability (Villa and Roebroeks, 2014; Soressi, 2016).

The role of Levallois products consequently remains obscure in terms of form and awaits more microwear analyses to clarify the specific uses of these tools. At Guado san Nicola, among the 75% of the studied artifacts, only 2–4.5% show traces ($n = 82$). Some Levallois flakes carry microtraces with one or two different zones of use with the same activity. All show predominantly animal carcass processing and occasionally plant use with mainly longitudinal actions from cutting (Berruti, 2017). Flakes from Levallois, other core technologies and bifaces equally show occasional wood-plant use (Peretto et al., 2015). At Orgnac 3, the development of the use of Levallois core technology is related to changes in landscape use, with seasonal and specialized occupations focused on horse hunting, such as in level 1 (Moncel et al., 2012).

4.5. Increase in the mental templates over time

If control of the core knapping surface was a major initial feature, the innovation of Levallois could have been in parallel with the long process of the acquisition of Neanderthal features (accretion model; Hublin, 2009) and could be compared with similar isolated attempts that are observed in some sites older than 400 ka in Africa (Pope et al., 2017). This process could explain why this technology became dominant in many areas through the Middle Paleolithic and why it did not emerge earlier (e.g., Lycett and Eren, 2013).

For instance, the Oldowan assemblage of Nyabusosi (Uganda) dated to 1.5 Ma shows the hierarchical relationship of core surfaces (Texier, 1995). The Early Acheulean site of Peninj (1.6–1.2 Ma, Tanzania) shows some evidence of the preparation of core convexities, as at Wonderwerk (800–500 ka, South Africa), Gesher Benot Yakov with giant Kombewa and 'Levallois' flakes (900–800 ka, Israel), or la Noira (700 ka, France; Texier and Roche, 1995; De la Torre et al., 2003; Moncel et al., 2013; Chazan, 2015; Leader et al., 2018). In the past, the different Victoria West methods have been considered as para-, proto-, or pre-Levallois evidence, with large, wide asymmetrical flakes removed through planning from the core edge by radial or centripetal flaking (Bordes, 1950; McNabb, 2001; Mourre, 2006; Sharon, 2009). Similarly, the Tabelbala-Tachenghit method or the Kombewa technique used the bulb of the ventral face of a flake and were described as a 'preferential-flake method' (Boëda, 1995). The onset of actual Levallois technology is also observed in East Africa by early modern humans with embedded roots as early as 500 ka with local, gradual changes in the Middle Stone Age (Douze and Delagnes, 2016; Deino et al., 2018; Potts et al., 2018). Meanwhile at Misliya cave (Israël), at around 200 ka, there is full Levallois with modern human remains (Hershkovitz et al., 2018).

4.6. Emergence of Neanderthals or adaptation of hominins to climatic and environmental changes

If we consider the paleoanthropological record in Europe from MIS 13 to 9, data indicate complexity in the acquisition over time of Neanderthal characteristics among *H. heidelbergensis* and Middle Pleistocene populations (Hublin, 2009; Manzi et al., 2010). In western Europe, the anatomical diversity of fossils suggests pre-Neanderthal regional groups, perhaps persistent forms of *H. heidelbergensis* (Ceprano skull dated to 350 ka), as shown by the genetic variability (Rightmire, 2008, 2017; Fabre et al., 2009; Manzi et al., 2010; Walker et al., 2011; Stringer, 2012; Meyer et al., 2016).

Neanderthal characteristics were evolving in Europe as far back as MIS 11 and possibly earlier (Hublin, 2009; Stringer, 2012). An earlier divergence time (>430 ka) between Neanderthals and Denisovans was inferred from the nuclear DNA sequence from Sima de los Huesos, whereas mtDNA places these populations closer to one another (Meyer et al., 2014). During the time span of MIS 12 to MIS 7 (ca. 460–250 ka), Neanderthal populations may have experienced a period of isolation but contact with African lineages postdating the divergence from the Denisovans is also suggested (Arsuaga et al., 2014; Meyer et al., 2016; Hublin et al., 2017; Richter et al., 2017; Bermúdez de Castro et al., 2019).

At the moment, correlations between types of hominin and technological innovations are not evident (see Levallois evidence in the Ceprano basin contemporaneous with the skull; Pereira et al., 2018). Technological convergence could exist in many places with a variety of hominins, such as *H. heidelbergensis*, *Homo neanderthalensis*, and *Homo* sp. (DeBono and Goren-Inbar, 2001; Tryon, 2006; Adler et al., 2014). Neanderthal anatomical features developed in parallel, as with other hominins at this time, with an increase in brain size but also changes in life history, such as an extended childhood and an adolescent phase (Kyriacou and Bruner, 2011). This allowed an increase in the capability to transmit more complex technological behaviors through social learning (Nowell and White, 2010; White et al., 2011). Similar developments in East Africa could explain the onset of Levallois technology among modern human populations. If we consider the low number of 'Levallois' pieces or the eventuality of an event by chance in parallel to some innovations (hierarchical organization on some cores), the phenomenon would indicate (1) a progressive development of the use of mental templates and (2) a technological shift in some areas. This progressive development could have found its roots among *H. heidelbergensis* (and Middle Pleistocene populations), not just after the speciation to Neanderthals.

The numerous paleoclimatic archives show a transition from 1.25 Ma up to 0.7 Ma (Mid-Pleistocene Revolution) with a change of the dominant periodicity of climate cycles from 41 ka to 100 ka. Combining different archives over the last 800 ka, some particularly marked interglacials (MIS 19, 15, 11, 9 and 5) and glacial maxima (MIS 16, 12 and 2) have been identified (Jouzel et al., 2007). Some of the earliest Levallois evidence is during MIS 11 (Schreve, 2001; Geyh and Müller, 2005; Nitychoruk et al., 2006; Roe et al., 2009; Rohling et al., 2010; Blain et al., 2015; Limondin-Lozouet et al., 2015; Picin, 2017). This period of time (post MIS 12, MIS 11) is crucial and characterized by a large biodiversity, large-scale faunal dispersion associated with the regionalization of mammal communities, and hominin morphological variability (Stiner, 2002; Bar-Yosef and Belmaker, 2011; Dennell et al., 2011; Palombo, 2015). Such a long-lasting interglacial (MIS 11) after a harsh glacial (MIS 12) could have favored more sustained vegetational systems and hence more stable hominin occupation and connections between groups in Europe dependent on latitude (Guthrie, 2001; Ashton et al., 2017, 2018). However, climate does not seem to play a great role in the earliest onset of Levallois from MIS 12–9. It appears during both cold and temperate events in various areas. But climate change was certainly important for diffusion and some breaks in occupation in some areas because of climatic constraints and could explain the introduction of this new technology such as the UK during periods of lowered sea levels.

5. Conclusions

Between MIS 12 and 9, elements of Levallois technology, some probably intentional, are found intermittently over a vast area in both northern and southern Europe and are sometimes accompanied by a trend toward the production of elongated blanks. The lithics seem to be evidence of a technological shift in some areas rather than production by chance. Levallois core technology before the end of MIS 9 to the beginning of MIS 8 remains rare (Fig. 1). From MIS 8, it was diffused all over Europe and appears to have been a phase of diversification rather than the initial stage. A discontinuity between the earliest and youngest phases during MIS 7–6 is open to question, as in East Africa with the isolated early appearance of laminar debitage at 500 ka (Roure Johnson and McBrearty, 2010). Is there a progressive phenomenon preceded by a preparation phase, i.e., a protostage ('prepared core technology' and invasive removals on bifaces)? Owing to the small number of sites and their distribution over a large area, we do not know if there is clear evidence of a transition. It is not known whether the isolated evidence of Levallois is due only to innovation (in situ), with multiple convergence or roots in the Acheulean in a variety of environments and geographic situations or also to invention from outside Europe that by its diffusion may have certainly been enhanced by contacts and exchanges of experiences between different groups (Foley and Mirazón Larh, 1997; Hublin, 2009; Stringer, 2012).

The only certainty is the apparent parallel development with the earliest appearance of Levallois core technology and some behavioral changes affecting subsistence, land use, and mobility of populations during and after MIS 12 in Europe as shown by the longer distances for raw material procurement and more specialized hunting. Cultural and technical expertise of these populations allowed integration of strategies for making, using, transporting, and discarding tools and the materials needed for their manufacture and maintenance. However, the development of the Early Middle Paleolithic through Europe is not only related to the innovation of Levallois, which appeared later in some regions, indicating a diversity of trajectories.

To conclude, it is important to note that these isolated onsets of Levallois are associated with an increase of archaeological data and human activity all over Eurasia after the Anglian or Elsterian glaciation (MIS 12), which is considered as a major turning point. The increase in the quantity of sites raises the question of whether this is because of better preservation or reflects larger populations, whereas genetic data indicate a decrease of the population size after 500 ka (Meyer et al., 2014). Cultural complexity in the form of Levallois technology does not necessarily reflect demographic expansion (Vaesen and Collard, 2016), just as an increase in population does not always lead to diffusion of behavioral changes if populations are poorly connected (Premo and Hublin, 2008; Rogers et al., 2017). Data on the Early Middle Paleolithic (MIS 8–6) indicate both a large diversity of technical expertise among groups and some trends of regionalization before a more pronounced regionalization of traditions during the Late Middle Paleolithic (MIS 5–3; Baena et al., 2017; Carmignani et al., 2017). Middle Paleolithic features emerged as a mosaic as early as MIS 12, including a more complex management of local resources and the use of long-distance lithic raw materials in short-term recurrent occupations. This suggests local innovations. The degree of mobility of human groups and connections between different groups is difficult to estimate, depending on topography and climate and estimating the type and size of the European population is open to discussion, ranging from a well-connected metapopulation or to more isolated networks of sites with small populations (Bocquet-Appel and Degioanni, 2013; Collard et al., 2013; Derex and Boyd, 2016; Grove, 2016, 2018; Fogarty and Creanza, 2017; Ríos et al., 2019).

Finally, we have to keep in mind that from at least 500 ka, two technological worlds existed in Eurasia with western Europe standing in contrast to a large area from central Europe to central Asia. In western Europe, the Acheulean and other Lower Paleolithic behaviors are commonly referred to *H. heidelbergensis* and early Neanderthals from 700 ka, whereas in central Europe, the traditions are considered as 'Micro-Mousterian and Pre-Mousterian' without bifacial technology (Kozłowski, 2014; Moncel et al., 2015; Golovanova and Doronichev, 2017). Regional differences persisted in Middle Paleolithic traditions from MIS 6 between these two areas (for instance Micoquian in Central Europe) and perhaps between populations (human colonization from Asia from the Middle Pleistocene?) despite a common technical background in core technologies. This feature is unexplained so far and may be because of at least some late exchanges between populations. The preexisting Lower Paleolithic certainly had a structuring effect on the different adaptive options selected by hominin groups over Europe. The key question now is why Levallois technology became the dominant technological strategy even if other technologies were also used during the Early Middle Paleolithic.

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