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Abstract

Some areas in Western Europe indicate hiatuses in human occupations, which cannot be systematically attributed to taphonomic factors and poor site preservation. The site of la Noira in the center of France records two occupation phases with a significant time gap. The older one is dated to around 700 ka (stratum a) with an Acheulean assemblage, among the earliest in Western Europe, and the upper phase of the sequence (stratum c) is dated to ca 450 ka. Humans left the area at around 670 ka at the beginning of the MIS 16 glacial stage when cold conditions became too severe. No sites between 650 and 450 ka have yet been discovered in the Centre region despite systematic surveys over the past three decades. The archeological evidence indicates that populations returned to the area, at the end of MIS 12 or the beginning of the long interglacial MIS 11. Here we use technological behaviors common to the two levels of la Noira—strata a and c—to evaluate their differences. Compared to other key European sequences, this site can be used to address the evolution of the behavioral strategies in Europe between MIS 17 and 11. We formulate two hypotheses concerning the human settlement of this area: (1) local behavioral evolution over time of populations occasionally occupying the region when the climate was favorable or (2) dispersal and arrival of new populations from other areas. The results focus on (1) changes in land-use patterns with the extension of the territory used by hominins in the upper level, (2) the introduction of new core technologies, including some evidence of early Levallois debitage, and (3) more intensive shaping of bifaces and bifacial tools. Results attest that the la Noira archaeological assemblages record similar regional behavioral evolution as observed at a larger scale in Europe.

Keywords:

MIS 17; MIS 11; Western Europe; Middle Pleistocene; Evolution; Innovation; Land use patterns; Core technologies; Biface production

1. Introduction

The question of whether the earliest human occupations during the Middle Pleistocene in Europe were continuous or discontinuous remains open to debate. It is generally believed that occupations in the south were continuous from 1.4 Ma onwards while hominins came sporadically to the northwest when climatic conditions were favorable (Carrión et al., 2011; MacDonald et al., 2012). From 700 ka onwards, when the evidence for biface production is clear, the area of settlement dispersal seems to have covered the whole of Western Europe when the climate was favorable (Parfitt et al., 2005, 2010; Ashton et al., 2011; Voinchet et al., 2015), despite rare evidence during transitional climatic phases (Early Glacial) as at the French site of Moulin Quignon in the Somme Valley with Acheulean occupation at 670 ka (Antoine et al., 2019).

Some areas in the middle or south of Western Europe indicate hiatuses in human occupations, which cannot be entirely explained by taphonomic processes and/or the destruction of archeological evidence. We must then consider the possibility that hominins disappeared from some regions. For example, in Atapuerca (Spain) a hiatus in occupation is observed between 800 and 500 ka, from TD6 and TD10 levels (Rodríguez et al., 2011; Mosquera et al., 2013; Ollé et al., 2013, 2016). In addition, in the Centre Region of France, two gaps are identified, spanning 1 Ma to 700 ka, and 700 to 450 ka (Despriée et al., 2011).

These possible breaks in occupations would seem to support a hypothesis of multiple waves of dispersal and/or re-occupation before 450 ka. Some of those breaks could be explained by climatic factors, with hominins leaving certain areas when they became too cold, as in the Centre Region of France. Nevertheless, in Spain, climate does not seem to be able to account for why hominins deserted Atapuerca (Rodríguez et al., 2011; Mosquera et al., 2013). In other parts of Western Europe, sites indicate that human occupation could have persisted between the end of MIS 17–beginning of MIS 16 and the end of MIS 12: for instance, Isernia-la-Pineta (590 ka, Italy), Bytham River sites (UK, MIS 15–13), Boxgrove (UK, MIS 13), Caune de l'Arago (MIS 14–12, France) or Cagny-la-Garenne I-II (end of MIS 13, France).

With regard to the technological behaviors preceding and following these breaks in occupation, tracking innovations and/or persistent strategies at two levels separated in time could be a useful way to discuss in the wider European context if we observe similar evolution. Following Renfrew (1978), invention is the act of creation, rarely visible archaeologically, and innovation is where the invention becomes widely established, which is what we can see archaeologically. Innovations could mark the arrivals or dispersals of new populations or an abrupt introduction of new behaviors in affiliated populations in response to external pressures, such as changes in climate and environment, and associated shifts in population. Alternatively, innovation could be through internal behavioral evolution that might be due to climatic, social or environmental pressures, or simply through reaching a new cognitive level. Innovation depends on local circumstances that allow the adoption of the new process, perhaps for solving a problem. Here we evaluate the following two hypotheses using lithic assemblages during the period from MIS 17 to MIS 11: (1) early Middle Pleistocene groups (Acheulean or otherwise) were able to technologically develop late Middle Pleistocene behaviors with a diversity of subsistence strategies, activities, raw material use and traditions of manufacture; or (2) new technologies and behaviors were introduced by external populations after MIS 12, occupying previously abandoned areas during favorable climate with a break in regional development. In both cases, we can assume that these populations had more complex behaviors and were able to adapt to areas abandoned by previous populations, particularly if the reasons for departure were linked to climatic factors (i.e., Schreve et al., 2015). We aim to describe two crucial phases of hominin settlement in Western Europe, before and after the harsh glacial event of MIS 12, and to identify technological behaviors common to both levels, as well as changes.

The site of la Noira records two phases of occupation. The oldest is dated to around 700 ka (stratum a) and the upper phase of the sequence is dated to 449 ± 45 ka (stratum c; Iovita et al., 2017). These two phases yield both heavy-duty tools including bifaces and evidence of core technology (cores and flakes), both being broadly described as 'Acheulean'. Humans seem to have left the area during the early part of the glacial of MIS 16 at around 670–650 ka when cold conditions became too rigorous to allow them to survive (Moncel et al., 2013, 2020c). They do not appear to have returned before ca 450 ka since no archaeological levels or sites with an age ranging between these two dates has yet been discovered; this is despite systematic surveys over the past three decades to find archaeological evidence through regular monitoring of active quarries and geological test pits. We thus suggest that populations returned to the area under favorable climatic conditions at the transition between the MIS 12 glacial and beginning of the MIS 11 interglacial, but whether this was from neighboring areas or externally is the question under investigation. This period of MIS 11 seems marked by a demographic expansion of populations in Europe, as shown by the increase in the number of sites from MIS 11 (and MIS 10) onwards.

It is obviously difficult to identify between new behaviors which originated from within a local region as innovations and those which were introduced from outside via cultural transmission. Periods with an increase in the number of sites, as was the case from MIS 11 onwards, likely suggest hominin dispersals carrying their own traditions to be adapted to the new landscapes, establishing new relations with other groups, and forming new local or regional identities in these new landscapes. La Noira in the Centre Region of France is a site that can contribute to this question by providing new data to address the two hypotheses. By contrasting the technological strategies carried out in the two levels at la Noira, persistent practices and innovations can be identified within the same location, and then compared to the wider European context and at a continental scale with sites between MIS 17 to MIS 11.

Chronologically, the lower level of la Noira (stratum a) is consistent with recent discoveries in Italy, Spain and France, which enhance our vision of the first Acheulean colonization of the southern and northern parts of Europe, and attest to the onset of biface technology before 500 ka: Barranc de la Boella (1–0.9 Ma) and Cueva Negra del Estrecho del Río Quípar (900–700 ka) in Spain, Moulin Quignon (670 ka) in the North of France, Notarchirico (670–610 ka) in Italy and Arago P and Q (older than 550 ka) in the South of France (Piperno, 1999; Barsky and de Lumley, 2010; Barsky, 2013; Moncel et al., 2013, 2020a,b,c; Vallverdu et al., 2014; Pereira et al., 2015; Antoine et al., 2019; Walker et al., 2020). Our specific period of interest is the end of the Middle Pleistocene revolution after the Brunhes-Matuyama shift at 780 ka, when cyclical climate changes and vegetation and faunal turnovers could have led to the successive depopulation or extinction of small groups of hominins, and the subsequent recolonization, before and between the MIS 16 and MIS 12 cold events (Guthrie, 1984; Manzi, 2004; Muttoni et al., 2010, 2018; Rodriguez et al., 2011; Abbate and Sagri, 2012; MacDonald et al., 2012; Pereira et al., 2016, 2017; Carrión and Walker, 2019).

Subsequently, MIS 12 seems coeval with a new shift in occupation, characterized by a harsh glacial event followed by a long interglacial stage (MIS 11), marking the beginnings of the Neandertal world (Moncel et al., 2016a). In terms of hominin evolution, MIS 11 (together with MIS 10 in some places) stands out in Europe, with archeological remains highlighting this interglacial as a threshold period (Blain et al., 2021). Current genetic data and anthropological analyses show that Neandertal features emerged in populations between 600 and 400 ka from *Homo heidelbergensis* and Middle Pleistocene hominins (Hublin and Pääbo, 2005; Hublin, 2009; Meyer et al., 2014). After the severe MIS 12 glaciation, considered as a major crisis for hominins, archeological records show increased occupation, evidence of new subsistence behaviors and technical innovations (core technologies, increase in light-duty tools), and evidence of an early regionalization of traditions (Moncel et al., 2016a, b; Rodríguez-Hidalgo et al., 2017). Population increase (regardless of taphonomic reasons and better site preservation) can be conducive to early regional networks of sites and the diffusion of innovations. MIS 11 is an exceptionally long interglacial, with MIS 11c being more than 25 ka, compared to a typical interglacial duration of ~10 ka (Candy et al., 2014). After a harsh glacial, the period would have been beneficial to vegetation and hominin occupation in Europe (see in Spain, Yustos and Diez-Martín, 2015; Blain et al., 2021). European vegetation is key to human settlement, as it drives biomass availability for large herbivores and affects the mobility of human groups and probably underlies demographic expansion (McManus et al., 2003; Preece et al., 2006; Penkman et al., 2007; Helmke et al., 2008; Roe et al., 2009; Koutsodendris et al., 2010; Limondin-Lozouet et al., 2010, 2015; Wagner et al., 2010; Dabkowski et al., 2012; Raymo and Mitrovica, 2012; Stringer, 2012; Bazin et al., 2013; Kleinen et al., 2014; Combourieu-Nebout et al., 2015; Oliveira et al., 2016; Regattieri et al., 2016; Kaboth et al., 2017; Kousis et al., 2018; Moncel et al., 2018b; Rivals and Ziegler, 2018). These behavioral changes suggest increased cognition with new skills and social interactions (Moncel et al., 2015, 2018a, b; Peretto et al., 2016). Finally, early fire control could have contributed to new hominin abilities to expand territories and modify their behavior accordingly (i.e., Monnier et al., 1994; Preece et al., 2006). This threshold period in Western Europe, corresponding to the end of the Lower Paleolithic (and Acheulean) and the beginning of the Middle Paleolithic world, is at present under-investigated, in particular as to why and how innovations appeared and were transmitted among populations.

1.1. The site of la Noira

The site of la Noira is located in the Middle Loire Basin (Centre Region, France), in the Berry area, 20 km upstream of Vierzon, on the western slope of the Cher River. In this area, the river flows along tectonic fault troughs (grabens) and the fluvial system is composed of nine stepped fossil alluvial formations deposited during the Early and Middle Pleistocene. The site of la Noira is associated with one of these, named the les Fougères Formation (Formation D) at Brinay (Despriée et al., 2007, 2011; Fig. 1).

Four successive strata (a, b, c, d) were observed (from bottom to top) during quarrying of the les Fougères Formation (Fig. 2): a coarse slope deposit or diamicton (stratum a), covered by two sequences of sandy alluvial layers (stratum b), then a rubble level (stratum c) and a sandy-silty soil (stratum d). The oldest archeological level in the current study (or 'lower level') is located in stratum a, and the younger ‘upper level’ is located at the top of stratum c.

The basal layer (stratum a) was deposited on the limestone bedrock at the beginning of a glacial stage after river incision. It is a coarse deposit moved down-slope from the plateau and contains numerous weathered blocks or pebbles of endogenous rocks, sedimentary rocks in a brown rubified clayey matrix (sub-strata a1 and a2). These slope deposits also contained lacustrine millstone slabs, some of which were selected by hominins for knapping and shaping.

Above stratum a, stratum b, about 5-m thick, records successive depositional phases of fluvial coarse sands (Despriée et al., 2017a, b). The age of stratum b was determined using electron spin resonance (ESR) dating applied to optically bleached sedimentary quartz grains. The results are very coherent with good reproducibility and the mean ESR age value obtained for the fluvial sands is 655 ±

55 ka. Tests with cosmogenic nuclide dating provide a similar value of 730 ± 210 ka for the fluvial sands but with excessively high error margins (Shen et al., 2012). The average age of the human occupation of stratum a is thus around 700-670 ka (Despriée et al., 2011). With the regional dating program les Fougères Formation is attributed to the MIS 17/16 glacial cycle. The hominin presence occurred between the end of river incision and the alluvial deposition, which corresponds to the beginning of the glacial stage, just before the pleniglacial phase and before subsequent fluvial deposition. Collectively the ESR results suggest hominin occupation during the climatic transition between the end of MIS 17 and the beginning of MIS 16 at around 700-670 ka (Moncel et al., 2013, 2020a).

The top of stratum b corresponds to an erosional surface dipping with the ground surface slope. This surface is incised, with channels 40 to 90 cm deep, truncated by erosion. Stratum c overlying this eroded surface includes three sub-strata called LA, LB and LC (Macaire, in Dépont, 1984; SOM S1, SOM Fig. S1 for details). Sub-stratum LA corresponds to the successive infillings of the channel that incised the top of stratum b. Artifacts are located on the pebbly interfaces, with most found on the erosional surface of the top of stratum b (Fig. 2). They are in fresh condition with unweathered surfaces and cutting edges. Sub-stratum LB is 5 to 30 cm thick on the western edge of the quarry, composed of gravels with sandy lenses, quartz pebbles and cobbles, fragments of millstone slabs and rare blocks of granite. Sub-stratum LC consists of sandy beds with thicknesses of between 20 cm and 50 cm, but thickening to 2.50 m down slope, indicating gravitational deposition. A few artifacts were found associated with the cobble interfaces of the sub-strata. Hominins were present on the top of les Fougères terrace during the formation of stratum c. The ESR date of 449 ± 45 ka obtained for sub-stratum LB indicates that the sediments of stratum c could have been deposited at the end of MIS 12 or in the first part of MIS 11. Stratum d, about 30 cm thick in the western section, is an eolian loamy sand, overlain by colluvium.

The petrographic and granulometric composition of the sediments of strata c and d of la Noira are identical to those of the lower stratum a, composed of sands and quartz gravels with little or no clay, endogenous pebbles (granite and quartz) and sedimentary siliceous rocks (limestone and millstone). The occupation at the transition between MIS 12 and MIS 11 is a stage characterized by open landscapes where slope solifluction deposition was frequent before the gradual development of forested areas (Limondin-Lozouet et al., 2015). The deep frost crack network affecting sub-strata LB and LC could have occurred during the following cold event of MIS 10, after hominin occupation (Despriée et al., 2017b, c; Iovita et al., 2017). The remarkable preservation of the artifacts indicates they were unaffected by the frost as they were overlain by thick colluvial deposits, which were then partially or totally eroded, as shown by the frost-shattered soil. This erosional surface is probably recent and is overlain by the present-day soil.

For the three substrata of stratum c, millstone slabs could have been collected from beds close to the occupation, on the slope above the site. The Jurassic silicifications ('chailles') could also have been collected from sediments covering the interfluve. Only flint was collected from long-distance Cretaceous outcrops, around 30 to 100 km away. The choice of the large surface of the les Fougères terrace, 2 km long and about 10 m above the river, provided a sweeping view of the graben after its extension (Despriée et al., 2017 a; see details on raw materials in SOM S1).

2. Material and methods

2.1. Material

The material of stratum a comes from a large excavation (100 m²) between 2010 and 2018, whereas that of stratum c comes from over three decades of systematic surveys requested by the Regional Archeology Department, French Ministry of Culture. These surveys aimed to collect material found in situ during the exploitation of vast surfaces of the quarry to access the coarse sands at the bottom of the sequence. In both levels, the assemblage is composed mainly of flakes, from the debitage of small and large cores, and a diverse heavy-duty component. The archeological corpus from stratum a totals 915 pieces, including 2.1% bifaces, bifacial tools and cleavers (or 7.4% if we include the entire heavy-duty component; Table 1). There are only eight bifaces associated with bifacial tools, cleaver-like tools, cleavers on flakes and crudely made heavy-duty tools. The assemblage for the upper level totals 537 pieces and includes a higher percentage of bifaces and bifacial tools (13.2%; Table 1).

2.2. Methods

For testing hypotheses of local evolution or introduction of new behaviors between the two levels at la Noira, we used both a petrological analysis of the raw materials to investigate the land-use patterns and a technological approach on the artifacts.

The petrographic nature of the raw materials used by hominins was characterized during field research and geoarcheological studies of Lower Paleolithic sites excavated in the Berry region (France). The methodology applied to la Noira is similar to that used in previous work (Despriée et al., 2016, 2017a, b, c). Knapped or broken lithic artifacts were first macroscopically observed with the naked eye and then with a magnifying glass x 12 diopters. Cortical remains, siliceous matrix and elements visible on non-patinated knapped surfaces were described. The rocks were compared with samples in local and regional geological deposits, following the recommendations of Malissen (1977) and Rue (2000). The sampled silicifications were observed on fresh broken surfaces, then on slides in the laboratory of the Faculty of Science and Technics, Tours University, and at the Musée de l'Homme, Paris. Three types of raw materials are observed (see SOM Table S1 for petrographic descriptions): (1) Lacustrine silicifications (called millstone), (2) Jurassic silicifications (called 'chailles') and (3) Cretaceous silicifications (flint).

For the technological study, we aimed to identify all the c*haînes opératoires* performed in the lithic assemblages (i.e., Boëda et al., 1990, Geneste, 1991; Boëda, 1993; Texier and Roche, 1995; Roche, 2005) through the succession of gestures and technical choices for the manufacture and the techno-economic processes (complete or partial reduction processes on site), in order to describe the cognitive skills (Stout, 2011, 2015; Stout et al., 2014). Core analysis enabled us to identify knapping methods and techniques through the observation of the hierarchy of flaking surfaces and the interpretation of removal sequences (bipolar or freehand technology; de Lombera-Hermida et al., 2016). Each artifact was attributed first to a general technological category, distinguishing artifacts resulting from core debitage to the heavy-duty component. Technological groups of flakes were distinguished based on their place in the reduction process. They are classified (1) according to their position on the slab, i.e., flaking on cortical surfaces or from edges, and (2) from the first phases to 'full débitage'. Since the slabs present planar surfaces, unlike blanks with convex surfaces, the first phases involved the preparation or use of the most suitable angles for initiating platform preparation or knapping with the use of slab edges. Large flakes are distinguished from small flakes when they present lengths >10 cm (i.e., Kleindienst, 1961; Sharon, 2007, 2008; de la Torre, 2016). For the heavy-duty component, the definitions of bifaces, cleavers and other heavy-duty tools follow, among others, those given by Kleindienst (1961), de la Torre (2016) and Barsky et al. (2018). The bifaces, bifacial tools and cleavers belong to the category of LCTs. A biface is determined by a bifacial management of the whole volume, rather than a bifacial tool made by partial shaping of two convergent edges. A cleaver is a tool with a transverse edge. The rest of the heavy-duty component is composed of various, crudely-made tools such as thick scrapers ('rabot').

We identified the volumetric processes, sizes, relation to stone geometry and morphological results for the LCTs according to Bordes, 1961; Roe, 1964, 1981; Goren-Inbar and Sharon, 2006; McPherron, 2006; Key et al., 2016; Herzlinger et al., 2017). Measurements on the heavy-duty tools, in particular bifaces, used the methodology of Bordes (1961)**.** The shaping method was analyzed to describe the number and location of series of removals, the final retouch and its location, the symmetry in cross section and the general volumetric process. There was also a specific focus on the tip and basal shaping of the bifaces. For cleavers, the blank of flake or slab was recorded, together with the areas of tool management. For the other heavy-duty tools, the location and type of removals were noted in relation to the type and blank form.

3. Results

The results investigate the differences in the 'chaînes opératoires' between strata a and c, in order to address the hypotheses of local filiation, or external innovation. There are five main categories of raw materials, core technology, debitage, retouched debitage and biface technology.

3.1. Raw material types and origin

Stratum a Despite the presence of other rock types, the in situ knapping in the lower level only used millstone slabs and fragments*,* found in large quantities on the river-bank adjacent to the site, and it involved breakage by percussion of the natural slabs for shaping and flaking (Despriée et al., 2016; Moncel et al., 2020c; Table 2). Selection of better-quality millstone was not systematic, but frost shattered slabs were avoided. Cores and bifaces were always on good quality stone, unlike more basic heavy-duty tools, suggesting that selection of quality and thickness was based on production aims, indicating hominin flexibility and adaptability to the range of available slabs.

Stratum c Detailed petrographic determinations were carried out on 526 artifacts, including 83 heavy-duty tools and 395 flakes (some being indeterminate due to poor preservation), with characterizations given in Table 2 and SOM Table S1**.** The analysis determined that in the three archeological levels of stratum c, the siliceous rocks were Eocene-Oligocene millstone (72%), Jurassic oolitic or encrinic silicifications ('chailles'; 18%), and Cretaceous flint (8%). The use of quartzite and quartz is very rare.

For lacustrine millstone, two facies are observed: (1) white millstone with microcracking, solution pits, cavities with terrigenous filling sediments and root pipes; (2) millstone with a fine-grained and more homogeneous groundmass, brown-orange colored, some of which was lateritized. Of the 537 artifacts in the technological study, millstone totals 55% and is mainly unlateritized (Table 2). Comparison with other siliceous rocks in the region, allows distinction of local millstone from that found in other valleys of the Middle Loire basin (Figs. 2 and 3), with the possibility that some millstone was carried c. 50 km from upstream areas near Saint-Amand-Montrond (SOM S1; Fig. 2).

Nodules of Jurassic 'chailles' were used for 18% of the artefacts. An iron-rust to brown-yellow partial coloration of the groundmass indicates a partial lateritization of 24.7% of this material. Although allochtonous, it was available in local Tertiary detrital remains above the site. Other local material included quartz, quartzite, and sandstone (*n* = 7), which were mainly used for flaking.

Cretaceous flint represents 8% of the assemblage, importantly indicating an extension in raw material territory compared to stratum a. It comes from a perimeter of 30–100 km southeast and west of the site (Fig. 3). The fine-grained groundmass is generally blond or 'honey' colored, sometimes orange or beige (SOM S1; Despriée et al., 2016, 2017a, b; Moncel et al., 2013, 2016b). Similar observations on this source were recorded on the lithic industries from Solutrean and Badegoulian sites in the Berry Region (Aubry, 1991).

The use of a wider range of raw materials, some obtained from 30–100 km, indicates an adaptability to other rock types and important change in land-use patterns, compared to stratum a.

3.2. Core technology

Stratum a There are 246 millstone slabs intentionally broken by locally available hard hammers of used millstone, quartz and granite pebbles, fragments of Jurassic 'chailles' or lateritized millstone (Table 3; Despriée et al., 2016). On 84 slabs or fragments (100–200 mm long), discontinuous or continuous scars were seen on the surface, or along one edge on thick pieces, with no evidence of slab preparation (Moncel et al., 2016b, 2020c).

There are 47 structured cores with organized flaking (50–120 mm long; Fig. 4), with or without platform preparation, variable numbers of removals, and either utilizing the slab shape or flaking independently of slab morphology. Debitage was only by direct percussion with a hard hammer. All the cores were on slabs, other than two nodules and two flakes. Slab thickness for these cores is mainly 30–40 mm, which is thinner than the large slabs with few removals, described above (SOM Figs. S1–S5).

Cores have been categorized according to the number of flaking surfaces and the organization of removals (Table 3). Transitional types indicate the flexibility of core technology and probable adaptation to slab shape. The main category consists of bifacial cores with two secant surfaces, some with a hierarchical reduction, and with a total or partial core edge. Unifacial cores are the second category, with removals across natural slab planes with limited preparation. For both types, debitage was mainly centripetal, with partially convergent, invasive removals. With more invasive bifacial flaking, the previous scars acted as striking platforms for the following removals, and blank shape no longer affected core management. There were generally only a small number of removals, and usually a single series for each surface. Bifacial cores are often asymmetrical, with a plane face opposing one with steep removals. In some cases, they attained a pyramidal form, but with final removals across the plane surface, they gradually became multidirectional. The frequent dissymmetry of core cross-sections suggests that one face was considered as a striking platform from the beginning or part way through debitage. In some cases, a third flaking surface, orthogonal to the two secant surfaces, was created by breakage of the core side or by using the preserved natural back of the fragment. Debitage became orthogonal, independent of previous bifacial flaking, and the final cores are trifacial. Two cores are peripheral or 'semi-tournant' type cores through peripheral removals that exploited the entire slab thickness.

Stratum c Most cores are bifacial and partially discoidal, often with flat flaking-surfaces, with semi-abrupt cross-sections and partial preparation of platforms (Table 3; SOM Fig. S1-S5). As with the lower stratum, the cores vary in size regardless of type, except for the smallest cores which are in flint and Jurassic 'chailles' (SOM Fig. S5). The use of flakes as cores was rare, regardless of raw materials (Table 4) and thin slabs with a thickness of 35–40 mm were also selected. The majority of cores display some cortex on one face, with between 2 and 9 removals.

Most of the unifacial cores have centripetal scars, but an important feature of the assemblage is three unifacial centripetal cores with a flat flaking surface and four cores with a flat flaking surface and one final invasive removal (SOM Figs. S5–S8). These cores are mainly on local millstone but also on Jurassic 'chailles' and flint. The centripetal scars are generally deep, with impact points away from the core edge, although the final scars are often hinged. The platform angles vary between 52–75°.

For four cores, the flaking surface is also flat and the striking platform is still largely cortical, with some abrupt, short removals (SOM Fig. S9) and higher flaking angles than the centripetal cores, of around 68–80°. One of the cores is on Jurassic 'chailles', where the blank might be a flake. The upper face of this core is covered by a preferential flat, invasive removal followed by smaller peripheral, short and deep removals. For the three millstone cores, the upper flat face is covered by a preferential invasive removal, after short, lateral removals (Fig. 5). Some short removals partially cover the last large scar. These four cores clearly combine some typical features of Levallois core technology (SOM Figs. S2a): (1) flaking was organized around a plane of intersection; (2) flaking surfaces show scars that helped maintain convexities; (3) striking platform were partial, but abrupt with angles close to 70–80°; and (4) there was a final invasive removal. Regardless of the centripetal cores, these cores could be interpreted as either early Levallois flaking, or the accidental flaking of an invasive removal on a flat surface of a flake or after the intensive reduction of a slab surface.

Although many of the reduction processes are similar to stratum a, an important difference is the removal of large, invasive flakes from flat surfaces, which appears to an early form of Levallois flaking.

3.3. End products of debitage

Stratum a The series of flakes and knapping fragments comprises 445 pieces (48.6%), mainly on local millstone, except three Jurassic 'chailles' and one quartz piece (Moncel et al., 2020c; Tables 2, 5; SOM Fig. S6a, 6b, 7, 8, 10). Two main size groups were observed for flakes with lengths of 40–50 mm and of 80–100 mm. There are 74 large flakes (>10 cm; see Kleindienst, 1961; 16.6% of assemblage), which are from giant and medium-sized cores (100–200 mm long). Small flakes (<10 cm) have a low ratio of 2.1 to cores with scars less than 10 cm long, and could indicate that flakes were exported. Taphonomic processes cannot explain the lack of very small flakes as the deposits are very low energy. By-products (flakes, 'tranchet' flakes and truncations) from LCT production are rare (*n* = 16) considering the quantity of shaped tools. Five, mainly cortical, flakes from LCT shaping have been identified, based on profile, thin bulb and presence of a lip near a thin platform. There are also 'backed flakes' which indicate the regular use of the core edges for guiding the debitage and avoiding accidents. Despite that, there are numerous broken flakes.

Slab management seems to have conserved the cortical surfaces or slab edges through the process. Striking platforms are sometimes prepared, while butts are cortical or natural (32%), plane (30%), punctiform (21%), dihedral (4%) and facetted (2%). The six facetted butts are from all the flaking phases. Butts vary in thickness and size, with a central or lateral impact point always located near a guiding axis. They sometimes have a crushed area at the edge of the butt, indicating repetitive impacts, possibly due to unsuitable angles. However, the rarity of hinged or overshot products suggests good management of debitage angles. This may explain the range in angle values from 49° to 90° for cortical and plane butts. Facetted butts present angles between 70 and 80°, while dihedral butt angles are between 60 and 80°. The few Kombewa flakes indicate limited debitage of ventral flake surfaces, as observed on cores. The large flakes (>10 cm) are technologically similar but with a higher ratio of cortical products. Of note, the proportion of centripetal and crossed scars on large flakes indicates that the largest cores (giant cores) were turned in the hands to find the most suitable platform.

<u>Stratum c</u> There are 394 flakes (73.3%), with only 13 clearly from biface production. Most flakes are between 20 and 70 cm in length (SOM Fig. S6-8) regardless of the raw materials (SOM Fig. S7). There are a few large flakes (>10 cm). The quantity of broken flakes is lower than for stratum a, possibly suggesting better control of the core surfaces and angles. The ratio of small flakes (<10 cm) to cores is 10, which is high compared to the number of scars on cores. As with stratum a, the stratum c millstone flakes come from the first phases of slab exploitation. The Jurassic 'chailles' and flint reduction processes indicate the same strategies, despite different blank shapes. For both strata, products from complete reduction processes are present, indicating in situ knapping. Regardless of their position in the reduction sequence, flake size generally remains similar, but with a higher diversity for cortical flakes and flakes without cortex.

The range of product types is higher for millstone than for Jurassic 'chailles' and flint (Fig. 6). There is less flake diversity on allochthonous raw material, and with the rarity of cores suggests that some of them may have been produced outside the site. Flaking surface management is unipolar and centripetal. Striking platform preparation is similar to stratum a. Only the ratio of facetted platforms increases (6.6%), mainly on millstone and cortical flint flakes. Jurassic 'chailles' and flint products are smaller. Flint products are thinner and mainly non-cortical or with limited patches. Two Levallois-like flakes in flint and local millstone have unipolar convergent scars (46–53 mm long), and a punctiform or facetted butt (Fig. 6, nos 4, 5 and 6; SOM Tables S2–S5; SOM Figs. S6–S8)**.**

Many of the products from debitage are similar to stratum a, but the increase in facetted butts suggests more core preparation, supported by the presence of two Levallois flakes, while there is some evidence that some allochthonous flakes were brought in, ready-made, to the site, supporting the change in land-use patterns, compared to stratum a.

3.4. Retouched debitage products

Stratum a There are 104 retouched pieces (23.4% of the flakes), of which 71 are small flakes, the remainder being large flakes (Table 6). The majority of tools are flakes with continuous retouch on all or part of the cutting edge ('scrapers'), regardless of flake size. There is no clear choice of particular flake type. Retouch is quite abrupt, rarely denticulate, and can be invasive or inverse, depending on the cross-section. Retouch does not greatly modify the cross-section of the piece. The few 'becs' are on non-cortical flakes and made by notches or a retouched edge associated with other types of tool. Denticulates are made by small retouch and/or by notches. Some convergent scrapers or nosed end scrapers combine a lateral denticulate with inverse or direct retouch. Other tools combine a lateral and distal denticulate with a retouched notch. They are mainly on flakes with cortical patches and sometimes with a back. The isolated notches are mainly retouched forms. Some pieces show some large and thin unifacial or bifacial invasive retouch on one cutting edge. They are fragments of slabs or large non-cortical flakes.

Stratum c The ratio of tools is 15.7%, which is lower than stratum a, with many on Jurassic 'chailles' and Cretaceous flint (43.1%) and only three on large flakes, most being between 35 and 80 mm. The retouched pieces have some bifacial retouch, denticulated, thin or steep/invasive retouch with two Quina types. Direct and inverse retouch relate to the form of the cross-section of the flake, except when there is thinning of the flat face (SOM Table S7). Convergent scrapers and points (tip angle < 70°) are on cortical flakes or 'déjeté' non-cortical flakes, with a range of blank types of variable length and thickness. Most have partial retouch on the tip of marginal, abrupt or standard form, while some have a small retouched tip similar to a nosed end scraper. The composite tools combined continuous retouch, notches and invasive retouch or thin removals, either directly, inversely, or alternately, that resulted in end scrapers, points or peripheral scrapers. Overall, the diversity of retouch types, locations and angles, resulted in a range of tools: simple tools on specific or generic blank types, composite tools, or those with additional modifications. The angles of retouch are similar for all tool types with an increased range for 'scrapers'.

Compared to stratum a, there is a reduction in the use of large flakes, an increase in the use of composite tools, and importantly a selection of Jurassic 'chailles' and Cretaceous flint for their manufacture.

3.5. The shaping processes. Bifaces and other heavy-duty tools

<u>Stratum a</u> There are several groups of modified slab fragments, with both invasive and non-invasive removals. They include 39 diverse, crudely-made heavy-duty tools, where modification was limited to part of the slab, with a variety of sizes, and typological and technological features. The overall blank shape seems of little importance and a partial cutting edge the sole objective. Removals were carefully positioned for optimal blank management. One 'coup de tranchet' and one truncated edge of a bifacial tool are matched by 'tranchet' flakes among the products from shaping.

The 11 bifacial tools were made by peripheral removals to prepare convergent cutting edge, without management of the general volume of the slab (Tables 7 and 8). Forms are varied and just one was on a large flake of 130 mm. Partial shaping retained the natural back on the thinnest slabs. Shaping was face-by-face, producing plano-convex cross-sections and regular cutting edges. The first series of removals was by hard hammer and the final retouch was limited, sometimes with a soft hammer.

The eight bifaces made on the thinnest slabs show volume management, being plano-convex, and symmetrical (Fig. 7). They include cordiform and triangular bifaces, made by various modes of shaping, but without intense reduction (Tables 7 and 8). Most tips and butts are equally shaped and retouched. The lateral and proximal cutting edges are rectilinear with regular angles, but more obtuse than the tips. Heavy hard hammers made the first series of large and medium-sized removals, whereas the final retouch with flat, invasive removals suggest the occasional use of a soft (organic or light stone) hammer to regularize the edges and tip.

There are two cleavers on large millstone flakes, and eight bifacial cleavers ('cleaver-like') with transverse cutting edges made by bifacial shaping of slab fragments (Fig. 8). Removals varied from invasive to simply the lateral or transverse edges, often unifacially. The cross-sections are plano-convex or symmetrical.

Stratum c The 85 LCTs, which includes bifaces (with a pointed tip and oval shape), bifacial 'cleaver'-types, two cleavers on flakes and a range of heavy-duty tools, have a large range of sizes, similar to stratum a (SOM Fig. S11, S12), although flint tools are the smallest (SOM Figs. S2, S3). Most are made from millstone, particularly the heavy-duty tools, followed by Jurassic 'chailles' and flint (Table 2, Figs. 9, 10). Raw materials do not seem to play a role in the final shape, and are represented in all tool types, other than bifacial cleavers, which are only on flint (Table 7).

Blank types vary with raw material, millstone being mainly on slabs with a few on flakes, while flint and Jurassic 'chailles' were on flakes and nodules. The 11 broken bifaces and 6 biface tips were on all material types. Fractures are oblique, with signs of flexion, and some evidence of recycling is visible on two broken bifaces with double patina.

On most bifaces and bifacial tools, removals cover a large part of both faces and all or three-quarters of the periphery (Fig. 9). Flint and Jurassic 'chailles' were more extensively shaped than millstone and most of the LCTs bear no cortex, whatever the raw material. Shaping was mainly alternate, made by several series of removals with one invasive series covering the blank and the following series focused on the cutting edges and tips (Table 8). As scars from initial shaping were removed, evidence of systematic hard hammer-use is not clear. Thin, invasive scars characterize the final series, probably using a soft hammer. When shaping was face by face, cross-sections are generally plano-convex. Cortical or natural backs are preserved on 19 tools, which are mainly lanceolate and oval-shaped. Cutting edge angles vary from 21 to 75°, with greater diversity for lanceolate, oval and plano-convex tools (SOM Tables S7–14; SOM Figs. S11–S16).

Regardless of stone type and form, half the tools are symmetrical in planform and most in cross-section (biconvex, biplane), only 25% being plano-convex. Lanceolates predominate, followed by oval, cordiform and triangular bifaces. Triangular forms are the smallest, like other heavy-duty tools (SOM Figs. S14–S16). The cutting edges are mainly convex or rectilinear with some variation along the two edges. Distal morphology is mainly triangular and trapezoidal, whatever the LCT form (Fig. 10), with oval, trapezoidal and triangular cross-sections. Of the tips, 58 have several removals, and four have a 'coup de tranchet', but followed by further removals in two cases. Proximal shape is oval, or trapezoidal, varying regardless of tool form, while cross-sections are trapezoidal and oval, formed by removals, backs, fractures and cortex. There are two tools with final notches.

Final unifacial or bifacial retouch on the cutting edges varies with combinations of lateral and distal modification, regardless of tool form, and 25% have no retouch. Retouch is mainly short, stepped, and sometimes discontinuous. With symmetrical cross-sections, retouch is mainly bilateral or bilateral-distal, whereas plano-convex cross-sections have unilateral, unifacial retouch without accentuating the asymmetry, although many have no retouch.

LCT length varies between 40 and 160 mm, with the largest on millstone and those on flint being somewhat smaller. Bifacial cleavers are of medium-size and triangular forms are the smallest. The flake cleaver blank is a 10 cm long, thick flake, with a transverse edge. Apart from one flint nodule with percussion marks, the nine heavy duty tools are scrapers—'rabot' types with invasive retouch on flint or millstone. There are also crude tools with just a few removals.

An important difference of stratum c LCTs, compared to stratum a, is the improved tool management, shown by an increase in alternate flaking and the proportion of bifaces. Materials, other than millstone, were also used, particularly Jurassic 'chailles' and Cretaceous flint.

4. Discussion

4.1. Tracking the persistence of technological features and innovations

Quantifying the degree of invention vs. innovation in lithic assemblages raises the question of what one means by these two terms, and consequently how it can contribute to identify technological shifts or filiation over time between techno-complexes. For most authorities, the definitions of invention and innovation differ (i.e., Coward and Grove, 2011; Haidle and Bräuer, 2011; MacDonald, 2011; Rugg, 2011; Rugg and Holland, 2011; Whiten et al 2012; Vaesen and Houkes, 2017). Renfrew (1978, p.89) for instance defines invention as "the discovery or achievement of a new process or form" and innovation as "the widespread acceptance of a new process or form". Invention is an instantaneous event while innovation can take time to be widely adopted, its adoption being impacted by cultural and social factors. Only successful innovations were transmitted from population to population and thus visible in lithic corpuses. To be qualitatively or quantitatively observed, an innovation must be accepted and repeated among populations, and its observation depends on the available data and the frequency of use. The early stages of innovation can rarely be observed in the archaeological record.

Changes in behavior reflect either a stochastic evolution or a deterministic evolution (i.e., Peterson et al., 2011; Derex and Boyd, 2016; Pope et al., 2017; Davis and Ashton, 2019). For Kolodny et al. (2015), the archeological record suggests that cultural traits can accumulate exponentially, with sudden bursts after long periods of stasis and with cultural losses (i.e., Moncel et al., 2012). In a multifaceted process of innovation, certain traits can facilitate the invention of related traits. A fluctuating environment can lead to large-scale cultural losses and select generalist tools that are useful in multiple conditions. After stable environments, knowledge can be lost quickly through rapid climate change. Behavioral changes may be instigated by the environment, population size, cognitive ability which determines the rates of tool invention, changes in the structure of the subgroups in the population, or cultural or genetic change, which affects the rate of transmission and the rate of tool loss (Perreault and Brantingham, 2011; Andersson and Read, 2014; Hosfield and Cole, 2018).

For the two levels at la Noira that are separated by significant time, we observe persistent behaviors combined with the introduction of new behaviors, illustrating a partial ‘shift’ in human practice in the area. The question is how the la Noira hiatus can illustrate what occurred in Western Europe as a whole, or records an original and regional evolution?

Technological filiation between strata a and c Common features are visible in both strata in terms of raw material procurement, core technologies and LCT processes. The main raw material is local millstone collected as slabs and slab fragments. These materials can be found on or close to the site and hominins exploited the same geological resources. The main categories of core are similar with unifacial and bifacial discoid-types. Debitage took advantage of the natural slab morphology for flaking processes and platform preparation. Some discoid-type cores indicate intense debitage, independent of stone shape. Flake types are similar during the different phases of preparation and they show a high ratio of backing through use of slab edges or cortical surfaces. The main flake tools bear continuous retouch on one or several cutting edges (scrapers), sometimes with additional tools on a large diversity of flake types. A large portion of the LCTs are on millstone slabs and are managed in the same way due to the shape of the raw material. The proportion of symmetrical and plano-convex tools is similar, as is the average tool thickness (Iovita et al., 2017). Both hard and soft hammers were used for LCT management and final retouch.

Technological filiation between strata a and c and other MIS 17-12 Western European sequences The comparison of the lithic assemblage of the lower level at la Noira with contemporaneous sites shows shared behavioral traits despite very different geographical locations and mineral environments (Moncel et al., 2015, 2020c). This tends to suggest a common cultural background throughout Western Europe, regardless of climatic conditions (Fig. 11).

Well-dated sites provide a reliable outline of the main features of toolkits and reduction processes between 700–600 ka, and then up to MIS 12: 1) predominant use of local raw materials and no evidence of the debitage of rocks brought to sites from distant outcrops; 2) occasional complex large and small flake production (core technologies); 3) low ratio of bifaces, when present, and association of elaborate bifaces and partial bifacial tools; 4) diversity of shaping modes and forms for bifaces and bifacial tools (i.e., non-standardization), with some evidence of soft percussion; 5) lack of cleavers on flakes in northwestern areas; and 6) rare use of large flakes for making heavy-duty tools or for debitage, with minimal evidence of the fragmentation of reduction processes (Moncel and Ashton, 2018).

If these features are examined more closely, there are some common trends. For example, local raw material procurement may be related to the type of site (e.g., water-edge locations). Flint is mainly used in the north (Bytham sites and Boxgrove in UK, MIS 15–13, or Moulin Quignon in France, MIS 16) whereas various rocks were exploited in the south (Moncel et al., 2015; García-Medrano et al., 2018; Antoine et al., 2019). For instance, in TD6 at Atapuerca Gran Dolina, Spain, or Isernia-la-Pineta, Italy, various local materials were used for flaking, either collected in situ or within 3 km (Mosquera et al., 2018). Only the younger P-Q series from Caune de l'Arago at around 550 ka (MIS 14) documents stone procurement from a wider perimeter of 30 km (Barsky and de Lumley, 2010; Barsky, 2013).

Some tools show bifacial volume management with one or several series of removals to obtain well-balanced surfaces. Some are crudely made by one series of removals for minimal shaping. These pieces are made by different shaping modes on pebbles, nodules, slabs and sometimes large flakes. The resulting morphologies are varied, from oval, cordiform to pointed forms at the Bytham sites, UK (MIS 15-13), or French sites at Moulin Quignon (MIS 16) or levels P-Q (MIS 14) of the Caune de l'Arago (Moncel et al., 2015, 2020b,c; Moncel and Ashton, 2018; Antoine et al., 2019). Bifaces are generally few in number and typically diverse with a lack of standardization. Exceptions are the British MIS 13 sites of Boxgrove and High Lodge (Bed E), where standardization with long shaping processes, were precursors to practices in MIS 11 (García-Medrano et al., 2018).

Core technologies were often opportunistic, with unifacial and multifacial flaking, bipolar flaking, frequently used for flaking quartz (see TD6; Mosquera et al., 2018), or discoidal-type cores that were not always expedient. In most assemblages, there is unifacial and bifacial centripetal debitage, on good-quality stone. Some reduction sequences are more structured and more independent of blank shape and fully managed, again on good-quality material, as shown at la Noira stratum a, and the younger site of Isernia-la-Pineta (590 ka; Peretto et al., 2004; Pereira, 2017). There is also some evidence of prepared striking platforms on some cores and facetted platforms on flakes. Moreover, there are sites such as High Lodge (Bed C), where the quality of retouch is shown by the scrapers and of skilled debitage by alternating flaking of flint cores (Ashton et al., 1992). These innovations occur in assemblages with or without bifacial tools, and could reveal a threshold in skills that dates to the late Lower/early Middle Pleistocene, between 800 and 600 ka. This threshold is connected to the ability to produce large flakes alongside the production of small flakes. The capability to overcome technical problems during longer knapping processes and to manage hierarchical core surfaces could be the first phase towards more complex core technologies, such as 'prepared cores', Levallois cores and discoidal cores (Barsky et al., 2019; Moncel et al., 2020a).

Finally, the impact of site function on the choice of technological strategies and toolkits remains open to discussion. Most of the known sites are open-air, beside rivers, lakes or swamps (e.g. Isernia-La-Pineta, Notarchirico in Italy, la Noira in France; Piperno ed., 1999; Galloti and Peretto, 2015; Moncel et al., 2020a, c). Cut marks and fragmented bones demonstrate meat processing, butchery and scavenging on herbivore carcasses of different size, including megaherbivores. Sites seem to be either multi-activity such as la Noira (Hardy et al., 2018) or specialized sites such as possible scavenging at Barranc de la Boella (Vallverdu et al., 2014) and Isernia-La-Pineta (Longo et al., 1997). At la Noira, flakes and heavy-duty tools were used for similar functions (Hardy et al., 2018). They suggest mobile groups using local resources with little evidence of stone procurement from further afield (Mosquera et al., 2013, 2018; Ollé et al., 2013; Gallotti and Peretto, 2015). Limited mobility is also shown by Strontium isotopes in a human tooth at Isernia-La-Pineta (Lugli et al., 2017).

4.2. New features in stratum c: common evolution in Western Europe from end of MIS 12?

Following MIS 12, the long MIS 11 interglacial (see Fig. 13 for site distribution) is considered in Europe to record evidence of new behaviors with 1) some rooted in the past suggesting local filiation and continuity between populations over time with no clear breaks (before MIS 12), and 2) new behaviors introduced outside the region. Data provided by stratum c compared to stratum a fit well with the current data of the European sites and suggest that the new behaviors observed in stratum c reveal both a local filiation and an evolution on a broader scale. Because of the scarcity of preserved bone remains, we may only focus on the behavior represented by stone tools. In parallel, evidence of new subsistence behaviors demonstrates changes, with for instance an increase in hunting vs. scavenging as early as 400 ka (Moncel et al., 2011, 2012, 2018a,b; García-Medrano et al., 2014, 2015; Scott et al., 2014; Serangeli and Conard, 2015; Rodríguez-Hidalgo et al., 2017). Bone retouchers are rare but occasionally survive (Blasco et al., 2013; Rosell et al., 2015; Moigne et al., 2016; Ollé et al., 2016). Some sites indicate that fire was controlled as early as 400 ka, contributing to new hominin abilities to expand territories and modify their behavior (Monnier et al., 1994; Schreve et al., 2002; Preece et al., 2006; de Lumley, 2009; Wrangham and Carmody, 2010; Roebroeks and Villa, 2011; Stahlschmidt et al., 2015a, b).

Regarding land use patterns, most sites indicate mainly local and semi-local stone procurement, with only rare examples of longer distances, such as 30 km at la Caune de l'Arago (unit D). La Noira stratum c indicates a change in land- use pattern and attests to similar stone procurement to that at la Caune de l'Arago, with evidence of a wide perimeter outlining a minimum territory with additional raw material collection during other activities, or between habitats (Barsky, 2013; Barsky et al., 2019).

In terms of core technology, from MIS 12 onwards some sites in France (i.e. Cagny-la-Garenne I-II, North of France, MIS 12, Saint-Pierre-lès-Elbeuf, West France, MIS 11) and in Italy (i.e. Guado San Nicola, MIS 11-10) yielded some 'Levallois cores' or 'prepared cores', while in Spain (i.e. Atapuerca Gran Dolina TD10, MIS 11-8) there is evidence of more hierarchical and predetermined reduction sequences (Cliquet et al., 2009; Fontana et al., 2013; Ollé et al., 2013; Garciá-Medrano et al., 2015 ; Moncel et al., 2015, 2020b; Peretto et al., 2016; de Lombera-Hermida et al., 2020). La Noira stratum c shares a mixture of features, comprising some early evidence of Levallois-like core technology showing that debitage was independent of stone shape. These cores indicate increased complexity with control of the final shape of products and more intense flaking (Table 9).

At the same time, other sites such as La Grande Vallée (France), dated to 400–450 ka, yielded assemblages with bifacial technology, and persistent unifacial and bifacial core technology (Hérisson et al., 2012).

The lithic corpuses yielding both shaping and core technologies can be attributed to the Acheulean. According to the ratio of bifaces and their modes of shaping, and core technology, they have been named Late Acheulean, Upper Acheulean, evolved Acheulean or Epi-Acheulean (cf. A. Tuffreau's definition; Lamotte and Tuffreau, 2001). The biface production varies, from crudely-made bifaces (Caune de l'Arago, end MIS 12 for unit D and Cagny-la-Garenne I-II, end of MIS 13-beginning of MIS 12 in France) to largely-worked bifaces of the British sites (Ashton et al., 2005, 2008; Moncel et al., 2015, 2020a; Barsky et al., 2019). If we enlarge the comparison to younger sites from MIS 11–10 in northwestern Europe, bifaces and partial bifacial tools, when made, display variable degrees of shaping, thickness and form (ovate or pointed) (Moncel et al., 2015). While at la Noira, bifaces are more intensively worked in stratum c compared to stratum a.

Flake tools are dominated by notches and denticulates and some assemblages only yield a light-duty component with scrapers (Lamotte and Tuffreau, 2001; Ashton et al., 2005, 2006; Leroyer and Cliquet, 2010; Limondin-Lozouet et al., 2010; Scott, 2011; Smith, 2013; Ravon et al., 2016; Malinsky-Buller, 2016). Assemblages without bifaces are penecontemporaneous with 'Acheulean' assemblages, as expressions of different activities or various traditions with similar degree of skill. From the core technology, they cannot all be considered as early expressions of Middle Paleolithic traditions, but show a diversity of Lower Palaeolithic traditions.

In Central Europe and the North Caucasus, Kozarnika, Koudaro I and some levels of Treugolnaya (MIS 9) suggest that this region may be disconnected from Western European traditions

(Doronichev and Golovanova, 2010; Doronichev, 2016; Mgeladze and Moncel, 2016). In Southern Europe, core technology and flake toolkits are diverse and similar to earlier sites, except for some Levallois evidence (Aldène and Pofi-Ceprano basin localities, MIS 11; Rossoni-Notter et al., 2016; Pereira et al., 2018; Biddittu et al., 2019; Moncel et al., 2020d; Table 9). When bifaces are present, they show different shaping modes from site to site, and the selection of blanks with similar configurations to the final morphotypes. We can, however, contrast the crudely-made bifaces on pebbles of metamorphic rock at Galeria II in Spain, and Terra Amata and Menez-Dregan in France, to the bifaces of la Noira stratum c (de Lumley, 2009; Ollé et al., 2013; Garciá-Medrano et al., 2015). Biface ratios vary hugely. They are sometimes made on bones of megaherbivores (Boschian and Saccà, 2015). Microlithic industries continue to exist in possible relation to the exploitation of elephants (i.e. Fontana Ranuccio, MIS 11; Grimaldi et al., 2020) with a connection between blank production on small flint nodules and pebbles, and tool shaping (small pebble tools).

Northern MIS 9 sites indicate clearer changes, associated with the onset of marked regional diversity, with or without bifaces and Levallois cores, dependent at times with site function (i.e., wooden spears at Schöningen; Schreve et al., 2002; Lhomme et al., 2003; White and Ashton, 2003; Ashton et al., 2011; Serangeli and Conard, 2015; Di Modica and Pirson, 2016). Fragmentation of the 'chaînes opératoires' is a key feature of the Middle Paleolithic (Turq et al., 2013). In Central Europe, sites with innovations are dated to MIS 8, with or without Levallois (Wiśniewski, 2014). In Southern Europe, there is a mixture of innovations or inventions in technology and the persistence of earlier behaviors, with toolkits made up of partial bifaces, bifaces with general volume management, bifacial tools (with distinct functional areas) and scrapers, denticulates or notches, with or without Levallois cores (Santonja and Pérez-González, 2010; Brenet et al., 2008, 2014; Bourguignon et al., 2008; Moncel et al., 2011, 2015; García-Medrano et al., 2015; Hérisson et al., 2016; Santucci et al., 2016; Baena et al., 2018; Mathias and Bourguignon, 2019).

4.3. Local human evolution or arrivals of new populations? The paleoanthropological data

Technological and behavioral data do not suggest a clear shift in human strategies before and after MIS 12 despite occasional innovations in reduction sequences for instance that increased over time (from MIS 9). Currently, the first human occupation of Western Europe appears to have occurred during the late Early Pleistocene, but very few fossils are available (Carbonell et al., 2005, 2008; Bermúdez de Castro et al., 2011; Toro- Moyano et al., 2011; Arzarello et al., 2016). It is only from 0.8 Ma that the first human species is identified in Europe (i.e., *Homo antecessor*), represented by the fossils discovered in the Gran Dolina site (Carbonell et al., 1995; Bermúdez de Castro, 1997; Bermúdez-de-Castro et al., 2015).

After sporadic evidence of human presence in Europe, we find the species *Homo heidelbergensis,* with a holotype represented by the mandible of Mauer (Schoetensack, 1908; Rightmire, 1998; Rosas and Bermúdez De Castro, 1998). This species, characterized by high morphological variability, may be of African origin, and its presence in Europe from 600 ka onwards could be the result of migration into Europe from Africa. This hypothesis is based on the identification of similar features in African, Asian and European specimens (Mounier et al., 2009; Manzi et al., 2011). It is important to note that there is a morphological discontinuity between *Homo antecessor* and *Homo heidelbergensis* in Europe, which tends to confirm the allochthonous origin of *Homo heidelbergensis* in Europe (Manzi et al., 2011). Furthermore, an evolution is also observed in Africa between 1 Ma and 600 ka, before the appearance of *Homo heidelbergensis* on the African continent (Manzi et al., 2003; Manzi, 2004). The scarcity of fossils and a gap of nearly 150 ka in the European fossil record during MIS 14/13 makes it difficult to make further inferences about the taxonomic identification and the early evolution of this species in Europe (Rightmire, 2008).

The timespan between MIS 12 and MIS 9, in the history of the peopling of Europe and their evolution, is marked by the appearance of Neandertal-derived features in the hominin population until the first identification of the Neandertal species around 300 ka (Rougier, 2003; Hublin, 2009). Up to now, the available fossil record from this timespan points to a mosaic-type configuration of cranio-facial morphology with a rather plesiomorphic overall morphology of the neurocranium, but a more Neandertal-like maxillofacial complex (Daura et al., 2017; Rosas et al., 2019). The classic and rather unique example of this disparate appearance of Neandertal features is well documented in Caune de l'Arago (450 ka; France; de Lumley and de Lumley, 1971) and Sima de los Huesos (430 ka; Spain; Arsuaga et al., 1997, 2014; Bastir and Rosas, 2004; Martinón-Torres et al., 2012), where numerous human remains were recovered. The Caune de l'Arago fossils are identified as belonging to *Homo heidelbergensis* based on their numerous plesiomorphic features, whereas Atapuerca-SH hominins show a greater degree of 'Neandertalisation' (i.e., number of Neandertal apomorphies) and may belong to the baseline of the Neandertal lineage (Meyer et al., 2016; Rosas et al., 2019). Other important fossils confirm the high morphological variability of the Middle Pleistocene hominin record: Ceprano which, like Arago, presents several plesiomorphic features, and Aroeira 3, which shows more morphological affinities to Atapuerca-SH hominins (Bruner and Manzi, 2007; Manzi et al., 2010, 2011; Daura et al., 2017). It seems that between 450–350 ka in Europe, the population displays a differential degree of 'Neandertalisation', but with insufficient information to highlight chronological or regional patterns (Atapuerca-SH and Caune de l'Arago are chronologically and geographically close). Recent studies on mandibular morphology consider the specimens from Mauer, Arago and Atapuerca-SH as part of the Neandertal lineage, with Mauer and Arago representing an incipient phase of the Neandertal evolutionary process (Rosas et al., 2019). These observations are in line with the Neandertal 'accretion' evolution model (i.e., the gradual appearance of Neandertal features; Dean et al., 1998; Hublin, 1998).

This complex picture of Early European peopling, the delay in the appearance of Neandertal features and the nonlinear trend of the Neandertal evolutionary process has given rise to several hypotheses concerning possible waves of repeated hominin colonization and extinction in Europe, from a 'source population' coming from somewhere in Central Eurasia, following climatic fluctuation: known as the 'source and sink' model (Endicott et al., 2010; Carrión et al., 2011; Dennell et al., 2011; MacDonald et al., 2012; Bermúdez de Castro et al., 2013; Martinón-Torres et al., 2018; Zanolli et al., 2018). These continuous migrations into Europe may furthermore explain the high degree of morphological variability of Middle Pleistocene hominins.

The dispersal of the behavioral innovations and cultural complexity and diversity from MIS 11 onwards must be questioned through group size and density and the role of migration in diffusion (Premo and Hublin, 2008; Premo and Kuhn, 2010; Whiten et al., 2012; Bocquet-Appel and Degioanni, 2013; Derex et al., 2013, 2018; Andersson and Read, 2014; Vaesen et al., 2016; Creanza et al., 2017; Fogarty and Creanza, 2017; Grove, 2016, 2019; Fay et al., 2019). Should we consider the introduction of some innovations from MIS 12 by arrivals of populations in parallel to regional evolution of autochthonous human groups, and thus relationships and/or mixing of populations? This seems to be regionally dependent, because most of the innovations recorded could be due to local evolution of skills with adaptation to local constraints (see for instance Davis and Ashton, 2019 for UK, the early Levallois evidence; Moncel et al., 2020a, or the TD.10 case at Atapuerca; de Lombera-Hermida et al., 2020). In the case of la Noira, comparison of the lithic assemblages of the two phases of occupation and with contemporaneous sites shows common behavioral trends suggesting a similar cultural evolution throughout Western Europe, with specific local adaptations to the geological environment and possibly landscape.

5. Conclusion

Compared to la Noira stratum a, stratum c records a mosaic of new behaviors in terms of land use patterns, core technologies and the intensity of shaping processes. Data suggest the maintenance of some technological traditions over a wider area, such as southern Europe or southwestern Europe, between populations over time that were re-introduced to the site when conditions were favorable, after the glacial event of MIS 12. The industries indicate a similar evolution to that recorded in other key European sequences, despite the time gap between the two levels. Some of the new behaviors, such as Levallois core technology, are indicators of either evidence of innovations or inventions in some populations with dissemination, as a result of demographic expansion, as suggested by the increase in the number of sites from MIS 11. The systematic local origin of some of these new strategies can be questioned, even at la Noira where the core technologies seem to record a clear break with, for instance, the Levallois-like cores. It is also important to note that before MIS 12, most of the sites are open-air sites. This site typology raises questions about site function: were hominins only at the site for food-processing activities or were they living in the area? Part of the answer may lie in the scarcity of hominin remains associated with this site typology and chronological range, which cannot solely be explained by taphonomic factors. Hominin populations may have lived (and consequently died) elsewhere.

The two assemblages from la Noira indicate some behaviors rooted in the past and others that seem to be the result of an abrupt introduction, either through development close to the region, or through external introduction. However, interconnections between these new features are difficult to assess. Regional data on cultural behaviors in Europe indicate a mosaic of changes from MIS 10 to 9 and from MIS 8 to 6 and most of them are rooted in the past. However, thus far, these changes cannot be associated with a morphological regional trend. Nevertheless, across Europe, these two phases are related to the emergence of the Neandertal species, with the first Neandertals defined from MIS 8. The la Noira sequence illustrates the challenge for understanding the shift recorded in Western Europe during MIS 11. Many studies discuss the role of demography in the origin and diffusion of innovations/inventions. The increase in populations characterizes the period following the glacial event of MIS 12 when networks of sites may possibly have formed regional entities.

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Figure Legends

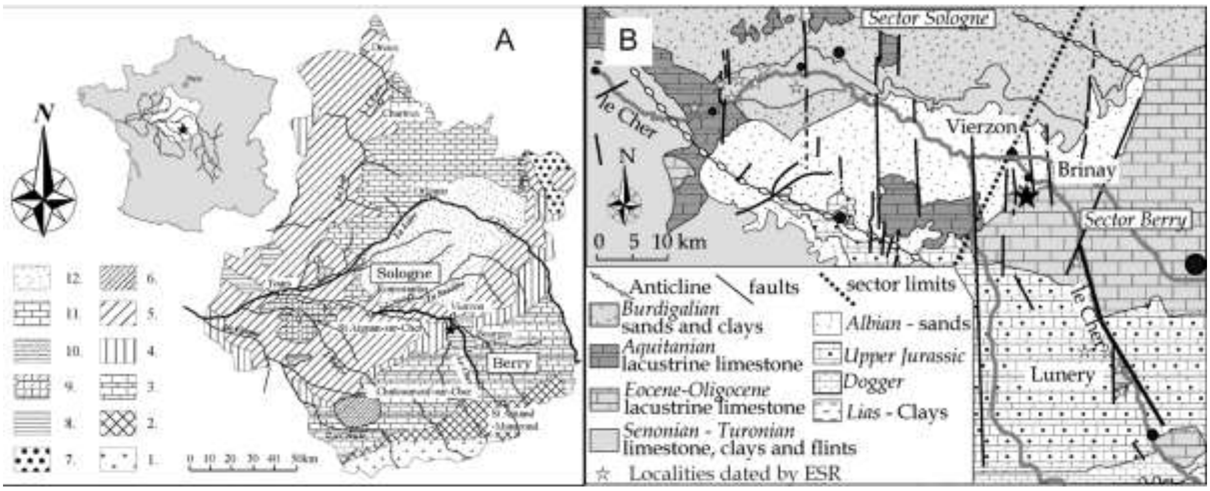

Figure 1. Simplified geological map of the Berry Region in the center of France at two scales (A and B) and location of the site of la Noira (after Despriée et al., 2016).

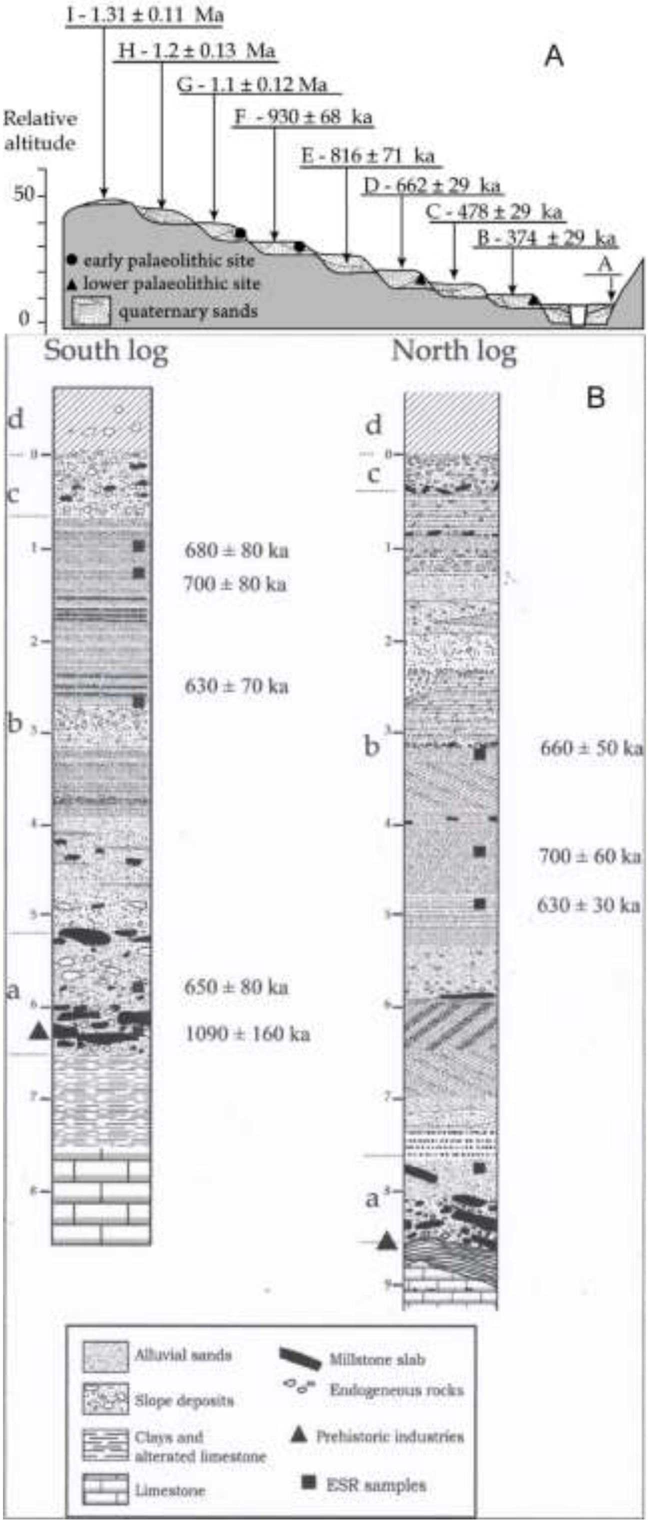

Figure 2. Schematic stratigraphic section of the alluvial formations of A) the Cher Valley and B) South and North sections of the western section of la Noira quarry. Sandy beds and erosional surface of Stratum b, superposition of strata c and d with location of the Acheulean artifacts (triangles) and ESR samples (squares). South log: 0. Surface loamy-sandy soil; 1-2. Colluvium of eolian sands; 3. Gravelly deposits; 4. Ferruginous sands; 5-6. Coarse-grained sands. 7. Clay. 8. Substratum. North log: 0. Actual loamy-sandy soil; 1-2. Colluvium of eolian sands; 3. Gravely deposits; 4. Ferruginous sands; 5-8. Coarse-grained sands. 9. Substratum

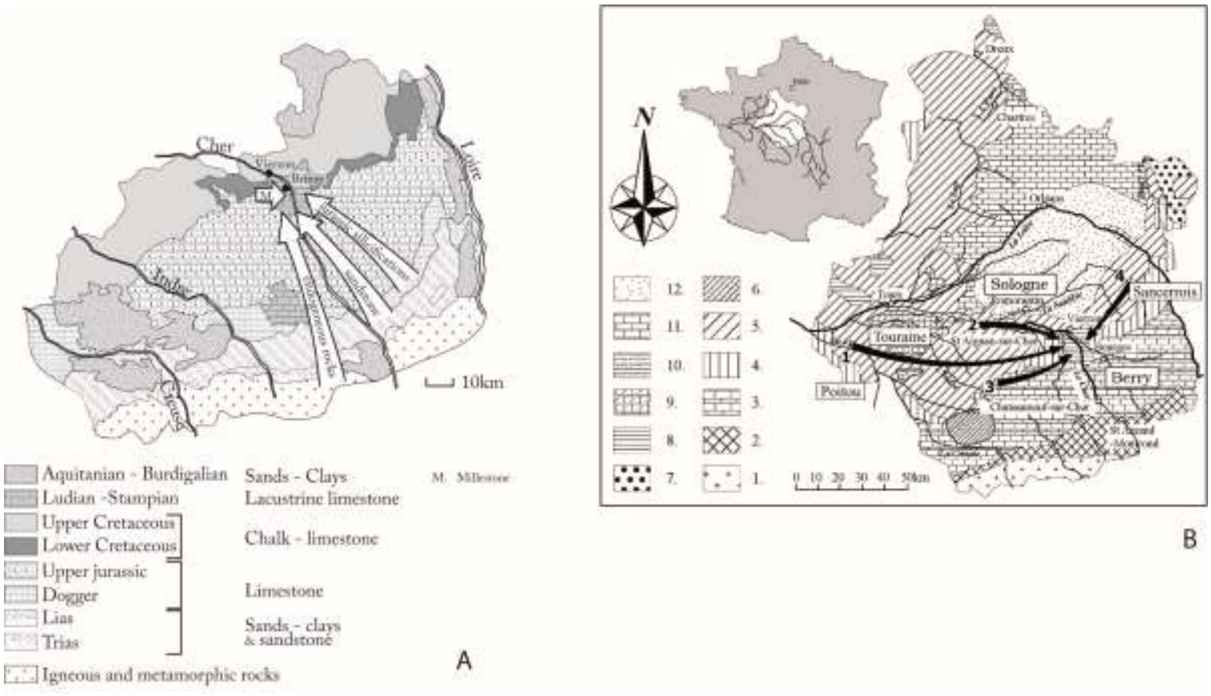

Figure 3. Simplified geological map of the Centre-Val de Loire Region (France) and location of the Cher valley. A) White arrows indicate the South-East and North-West movements of the siliceous materials coming by fluvial transport in wadis during the Paleocene on the plateau of the Champagne berrichonne, then moved down the slopes of the Cher Valley at the Pleistocene (after Despriée et al., 2016). B) Black arrows indicate the estimated carrying of Cretaceous flints by hominins from Turonian Cretaceous sandy chalks of Touraine Region (1), from Cretaceous cliffs of the Middle Cher Valley (2), from Levroux Cretaceous cuesta (3), and of the Jurassic and Eocene lacustrine silicifications from the Saint-Amand-Montrond cuesta (4). 1. Magmatic and metamorphic rocks with quartz; 2. Trias-Lias sands and sandstones ; 3. Jurassic marine limestones; 4. Lower Cretaceous sands and clays; 5. Middle and Upper Cretaceous, chalks and clays with flint; 6. Eocene, 'Formation de Brenne' , sand, clays and quartz; 7. Ludian, 'Cailloutis à chaille' and flint ; 8. Ludian-Stampian, 'Calcaires du Berry' with millstone; 9. Oligocene, 'Calcaires de Touraine', with millstone; 10. Oligocene, sands and sandstone; 11. Aquitanian, 'Calcaires de Beauce' limestone with millstone; 12. Burdigalian, 'Sables et Argiles de Sologne'sands and clays.

Figure 4. Millstone cores from stratum a of la Noira. A. Unifacial and bifacial cores. 1) Unifacial core with unipolar removals; 2) Unifacial partial core; 3) Centripetal bifacial partial core; (4) Asymmetrical discoid-type core; 5) Centripetal bifacial core. B. Other cores. 1) 'semi-tournant' core; 2, 4) Trifacial cores; 3) Orthogonal core on the slab edge (photos by M.-H. Moncel).

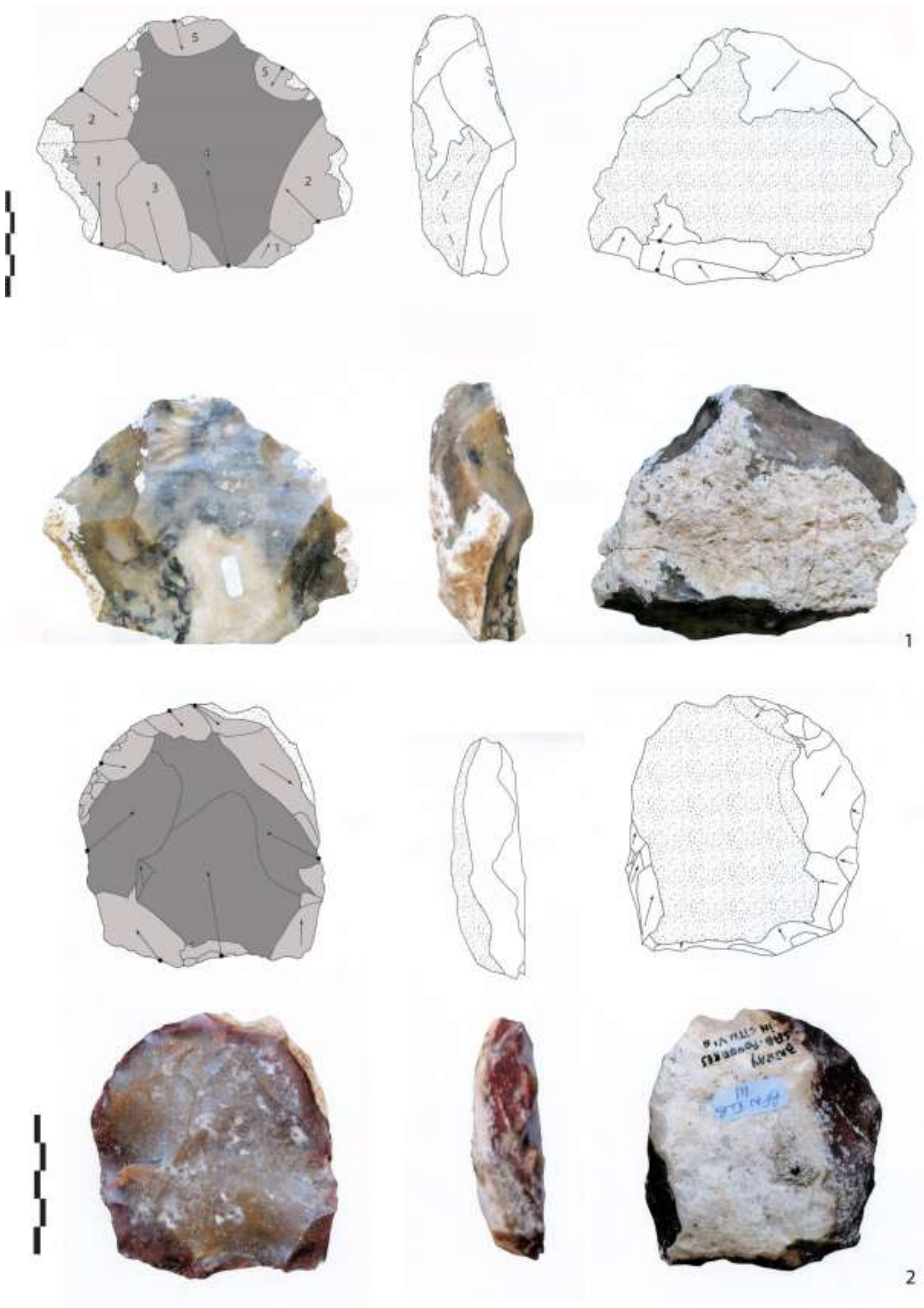

Figure 5. Levallois-like cores in millstone from stratum c of la Noira (photos by M.-H. Moncel, drawings by A. Theodoropoulou)

Figure 6. Cretaceous flint and Jurassic 'chailles' flakes from stratum c of la Noira. Nos. 1–8) Flakes without cortex; No. 9) Backed flake. Nos. 2, 4, 6, 8–9) Retouched flakes; No. 7) Convergent scraper with inverse thinning of the proximal part.

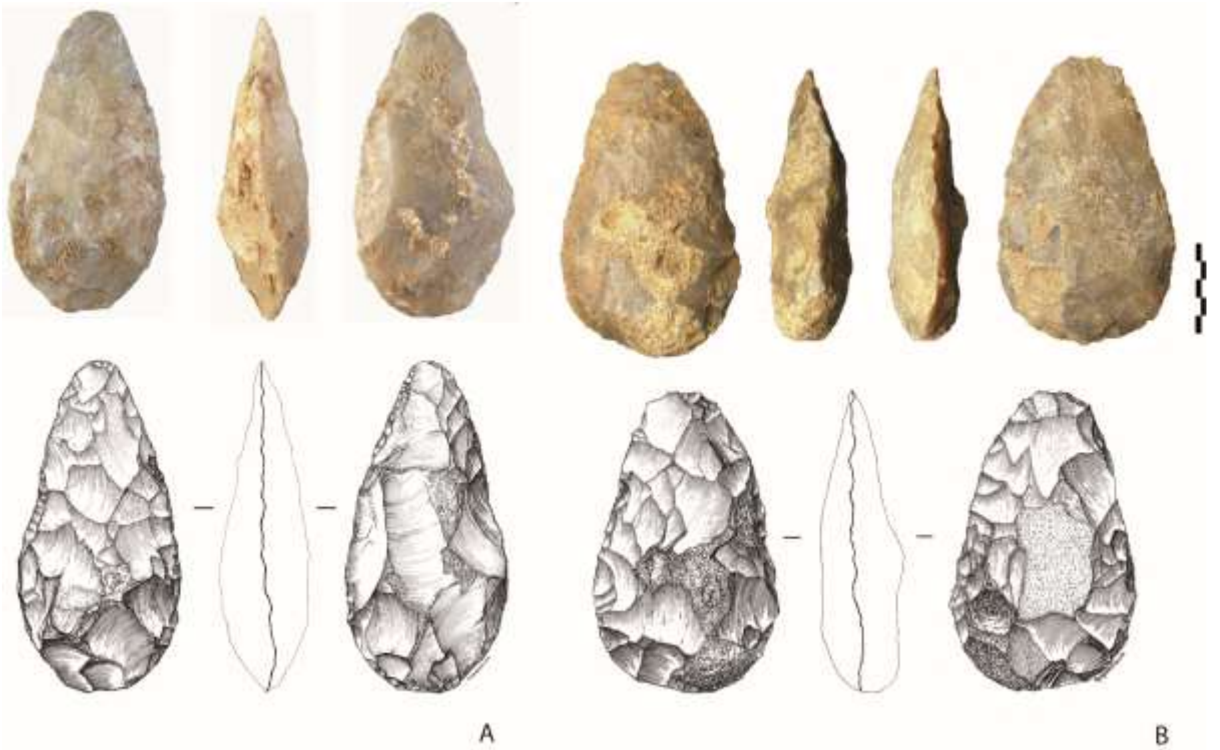

Figure 7. Millstone bifaces with a total volume management from stratum a of la Noira. No 1 elongated cordiform biface, no 2) cordiform biface (photos M-H. Moncel, drawings A. Theodoropoulou)

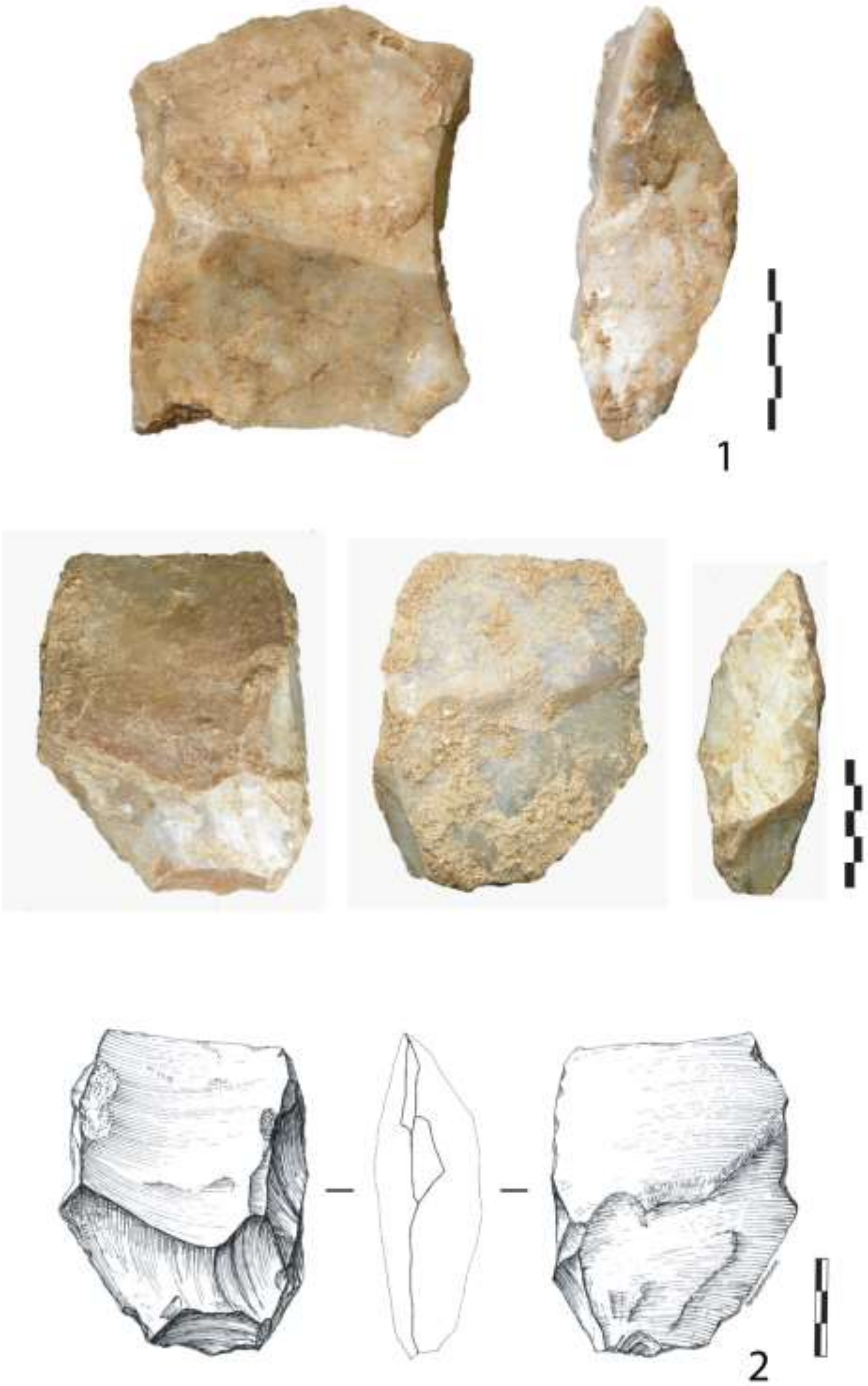

Figure 8. Millstone cleaver on flake from stratum a. They are made for no 1 on a backed and non-cortical flake and no 2, on a cortical flake. (photos n°1, 2 M-H. Moncel, drawings n°2 A. Theodoropoulou)

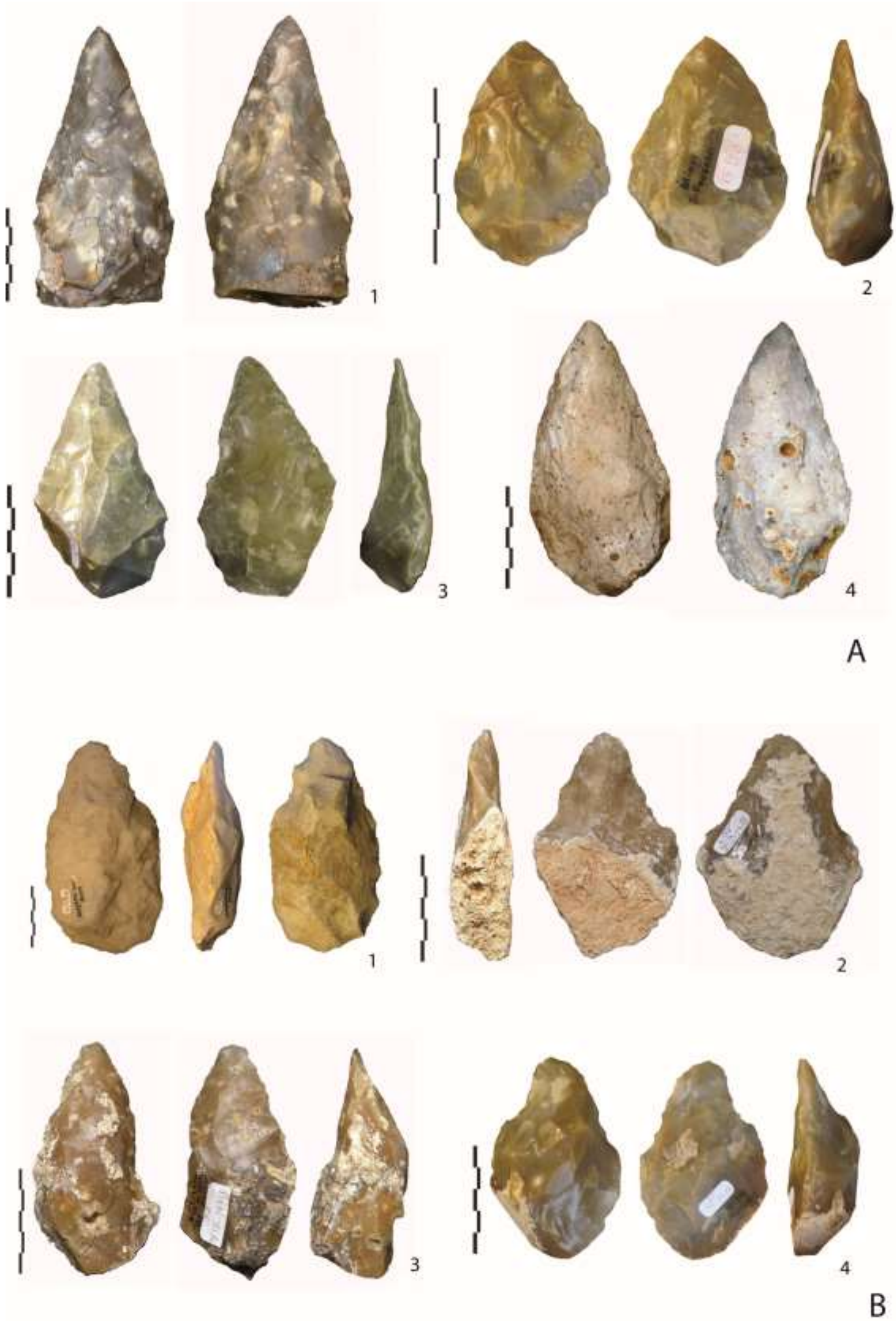

Figure 9. Bifaces from stratum c of la Noira. A. Pointed and largely managed. Nos. 1, 3, 4 Millstone; No. 2 Cretaceous flint and Jurassic ‘chailles’. B. Partially-made bifaces and bifacial tools. Nos. 1, 2, 3 Millstone. No. 4 Cretaceous flint and Jurassic ‘chailles’ (photos by M.-H. Moncel, drawings by A. Theodoropoulou)

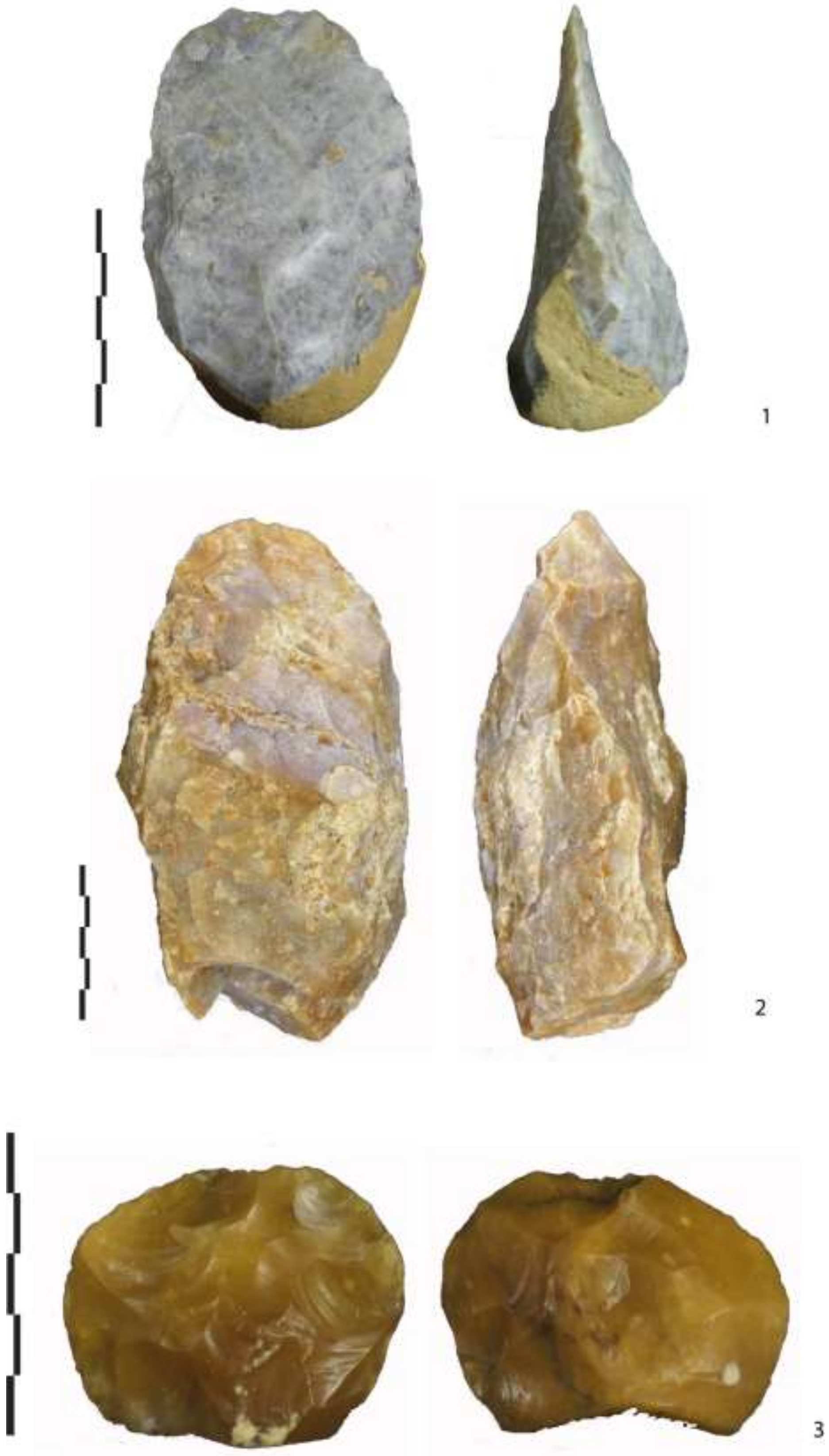

Figure 10. Bifacial tools with a transverse cutting edge from stratum c of la Noira. Nos. 1-3, Cretaceous Flint; No. 2, Millstone. (photos and drawings by M.-H. Moncel)

Figure 11. Early sites with evidence of human occupation before MIS 12. Stars indicate the sites without handaxes (bifaces and bifacial tools). Schematic bifaces indicate the sites with handaxes.

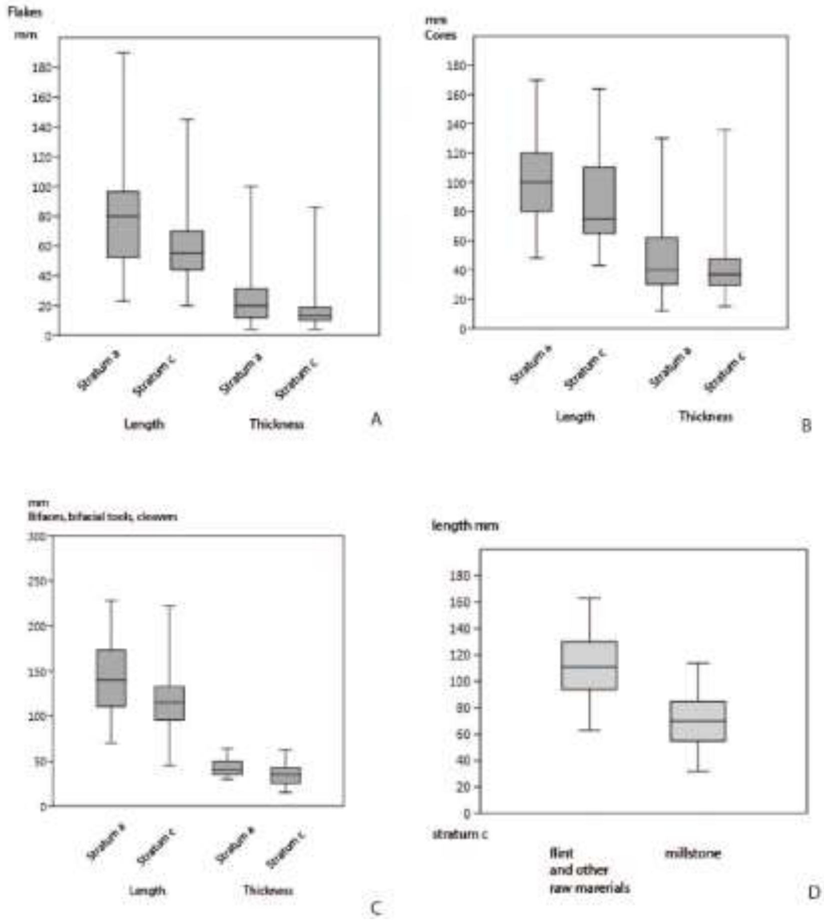

Figure 12. Boxplots comparing length and thickness of A) flakes, B) cores, C) bifaces, bifacial tools and cleavers, and D) bifaces, bifacial tools and cleavers in millstone and flint, from stratum a and stratum c of la Noira.

Figure 13. MIS 12-9 sites in Western Europe (stars).

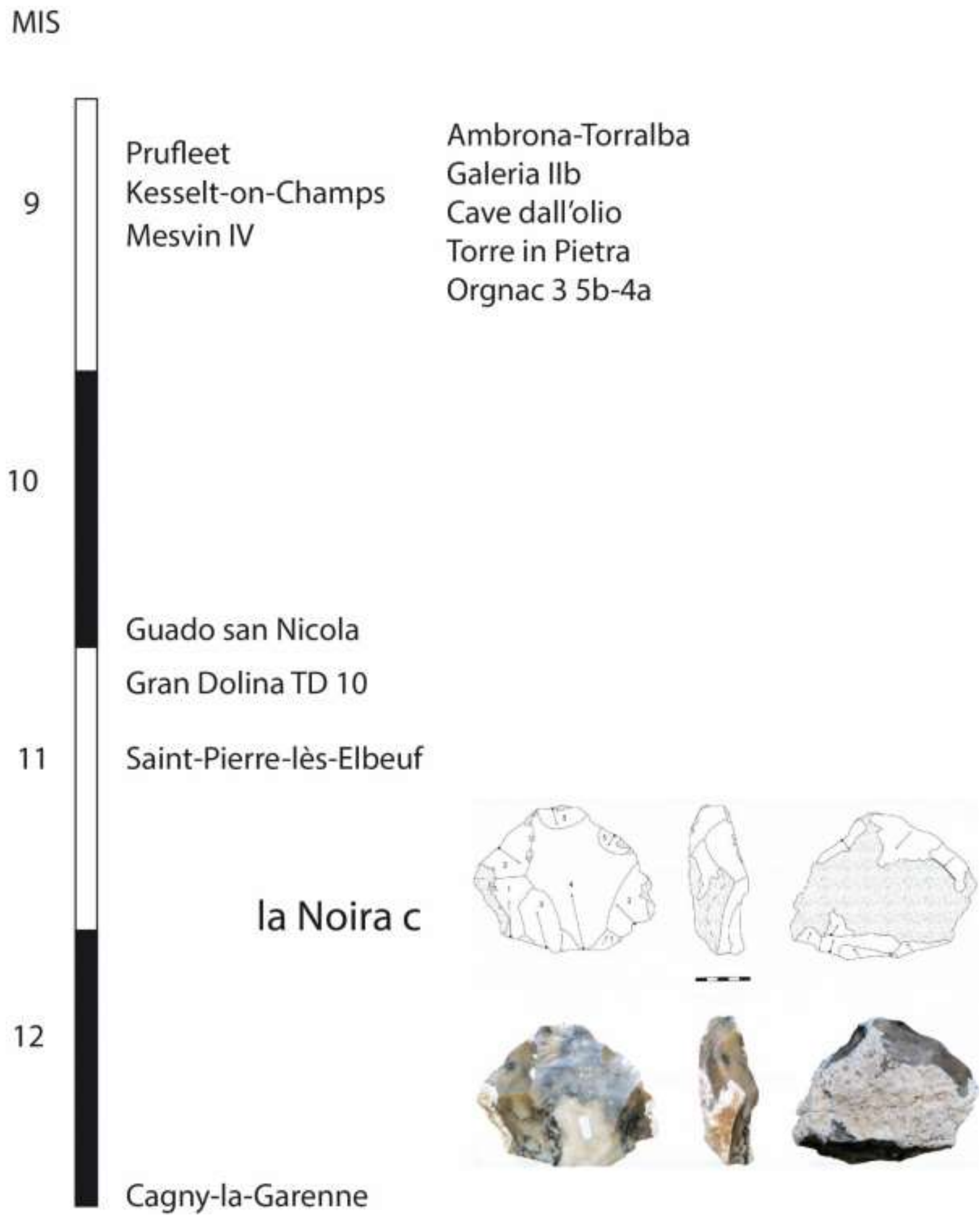

Figure 14. Temporal sequence of the main assemblages with some evidence of Levallois or 'prepared core' technologies in Western Europe.