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Were Hominins Specifically Adapted to North-Western European Territories Between 700 and 600 ka? New Insight Into the Acheulean Site of Moulin Quignon (France, Somme Valley)

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Current data seem to suggest that the earliest hominins only occupied the Northwest of Europe during favourable climatic periods, and left the area when the climate was too cold and dry, in the same way as Neandertal and even *Homo sapiens*. However, several sites in England and the North of France indicate that the earliest hominins, possibly *Homo antecessor* and/or *Homo heidelbergensis*, could adapt to cool environments and open grasslands without the use of fire. Recent discoveries of Acheulean lithic assemblages in early glacial fluvial deposits at Moulin Quignon in the Somme Valley in the Northwest of France reveal new knowledge on the earliest occupations in north-western territories and indicate hominins' capacity to live above the c. 45th N. under a cold climate. The site shows evidence of occupations at the beginning of MIS 16 at around 650–670 ka. These findings bring to the forefront the possible ability, flexibility and resilience of Acheulean hominins at around 700 ka to extend to northern territories during transitional climatic periods (interglacial/glacial events), even if the climate was not fully favourable. Recent fieldwork has changed our interpretation of the timing and characteristics of the earliest Acheulean techno-complexes in Western Europe over a large geographical area, from Northwest Europe to the Mediterranean coast. In Western Europe, the earliest evidence, Moulin Quignon, is now dated to a narrow timeframe, between 700–650 ka, and is the northernmost evidence of biface production. This latter is earlier than British Acheulean records. Based on new findings at Moulin Quignon, we explore whether Acheulean traditions and associated new technological abilities could have facilitated the dispersal of hominins in Western Europe over large territories, regardless of climatic conditions. Changes in behavioural flexibility, and not only phenotypic changes in *Homo* groups, have to be investigated. Here, we examine the behavioural and technological abilities of hominins in north-western Europe in light of the available environmental data and compare them to those in southern areas between 700 and 600 ka. This event occurred at the end of the “Middle Pleistocene Transition” (MPT), a period marked by cyclical climate changes and vegetation and faunal turnovers (less competition with big carnivores). The extension of the grassland habitat into higher latitudes could have led to the opening and/or closing of migration corridors in these regions, probably favouring hominin expansion depending on tolerance to climate variability.

Keywords: Acheulean, behaviours, Northwest France, environmental conditions, hominin adaptation

INTRODUCTION

Current data seem to suggest that the earliest hominins occupied the Northwest of Europe during favourable and temperate climatic periods and left the area when the climate was too cold and dry (Ashton and Davis, 2021; Moncel et al., 2021a), as in some areas of the South of Europe from the Early Middle Pleistocene onwards (Blain et al., 2021) and the Northwest of Europe for Neandertal (Hublin and Roebroeks, 2009; Locht et al., 2019). There is rare evidence of arid climatic contexts, such as for the sites of Orce (Altolaguirre et al., 2021).

Above the c. 45th N., some sites in France and the Southern England attest to climatic conditions conducive to hominin presence (**Figure 1**). They include Pont-de-Lavaud in the centre of France, dated to 1.055 ± 0.055 Ma, with a forested environment (Marquer et al., 2011; Despriée et al., 2018). If we consider the earliest evidence of occupations in Germany, hominins would also have been present during interglacial periods (Fielder et al., 2019). However, the British sites of Happisburgh 3 (Marine Isotopic Stage (MIS) 21, 866–814 ka, or MIS 25, 970–936 ka) and Pakefield (MIS 19 or MIS 17, about 750–680 ka) show that the climate was rather continental and cool for occupations dated between MIS 25 to 17 (Parfitt et al., 2005; Parfitt et al., 2010; Farjon et al., 2020). At la Noira, in the center of France, Acheulean groups were present at the end of MIS 17 and the beginning of MIS 16 and disappeared from the area when the climate was too cold (Despriée et al., 2011; Moncel et al., 2020a). These different sites, with or without biface production, indicate the capacity of the earliest hominins, possibly *Homo antecessor* and *Homo heidelbergensis*, to adapt to more or less open environments without the use of fire (Hosfield and Cole, 2018). Evidence of the use of fire is not clearly documented before MIS 11, either in the Northwest or the South of Europe (i.e., sites of Barnham, Beeches Pit, La Celle and Terra Amata, Limondin-Lozouet et al., 2010; Schreve et al., 2002; Rosell and Blasco, 2019).

Recent discoveries of Acheulean lithic assemblages at Moulin Quignon in the Somme Valley in the Northwest of France (**Figure 1**) transform our knowledge of the earliest occupations in north-western territories and suggest that hominins were capable of surviving under a cold climate. The site provides evidence of occupations at the beginning of MIS 16 at 650–670 ka (Antoine et al., 2019). Before that, the Acheulean was recorded in the Somme Valley at the beginning of MIS 12 at Cagny-La-Garenne (Antoine et al., 2007) and some artefacts found at the site of Rue du Manège dated to ca. 550 ka, at the

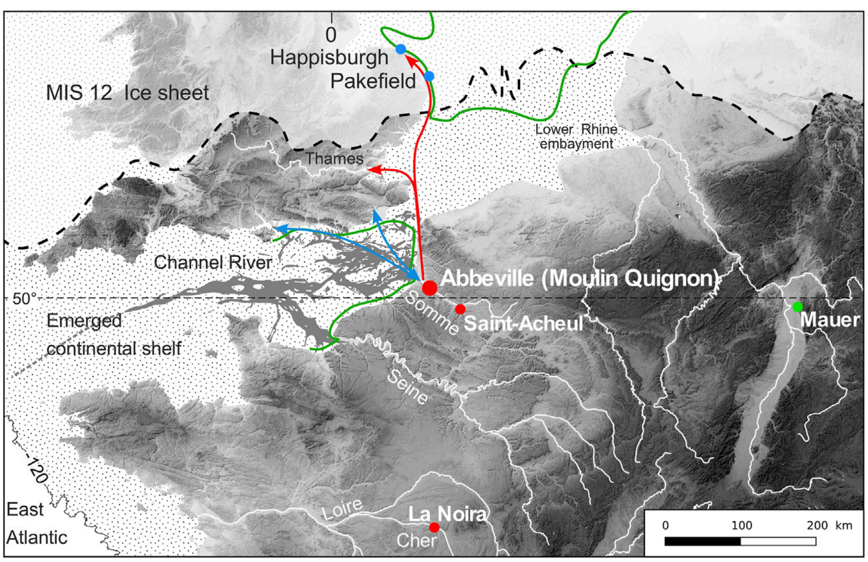

FIGURE 1 | Location of Abbeville-Moulin Quignon and of some Mode 1 sites in Southern England (blue dots), Acheulian sites (red dots), and of the Homo heidelbergensis type-site (Mauer) in Europe. Marine Isotopic Stage 12 ice sheet is located according to Ehlers et al., 2011, Cromerian shoreline (green) to Hijma et al., 2012. Arrows: possible communication routes during interglacial (red), and glacial (blue) periods (modified from Antoine et al., 2019).

MIS 14 - MIS 13 transition, indicated that the Somme Valley was occupied earlier than anticipated (Lamotte and Tuffreau, 2001; Antoine et al., 2003; Antoine et al., 2016).

Finally, recent discoveries at Abbeville following the re-discovery of the former Moulin Quignon site in the sands and gravels of the High terrace of the Somme River indicate that hominins occupied Moulin Quignon above the c. 45th N under a cold climate at the beginning of MIS 16, ca 670–650 ka ago. These findings point to the ability, flexibility and resilience of Acheulean hominins around 700 ka to extend to northern territories.

Current Data on the Early Acheulean

Recent fieldwork and the revision of lithic collections over the past decade have renewed our interpretation of the timing and characteristics of the earliest Acheulean techno-complexes in Western Europe over a large geographical area, extending from Northwest Europe to the Mediterranean coast (i.e., Moncel et al., 2015; ; Schreve et al., 2015; Voinchet et al., 2015; Abruzzese et al., 2016; Ollé et al., 2013; Ollé et al., 2016; Moncel and Ashton, 2018). Core-and-flake or Mode 1 assemblages are recorded as early as 1.4 Ma, particularly in Southern Europe, attesting to sporadic occupations mainly under warm and humid conditions, mostly during glacial/interglacial transition phases (Arzarello et al., 2006; Blain et al., 2021). Biface shaping appears in Western Europe between 1 Ma and 600 ka, associated with some innovations in core technologies in some sites and the production of large flakes (Ashton et al., 2011; Moncel et al., 2013; Vallverdú et al., 2014; Voinchet et al., 2015; Moncel et al., 2021b). These innovations also take place in assemblages without bifaces suggesting various activities or traditions into the Lower Paleolithic and Mode 2. This is considerably later than in East Africa, the Levant and India (between 1.75 and 1.5–1.2 Ma) (Bar-Yosef and Goren-Inbar, 1993; Goren-Inbar et al., 2018; Lepre et al., 2011; Pappu et al., 2011; Beyene et al., 2013).

The earliest evidence of Acheulean complexes (lithic series with biface production) in Europe is found in southern Europe and comes from the site of Barranc de la Boella, Spain with some crudely made Large Cutting Tools (LCTs) dated to 1 Ma–900 ka (Mosquera et al., 2015). The site of Bois-Riquet has also yielded some bifacial tools dated to around 800 ka (Bourguignon et al., 2016). These discoveries, and some other localized cases (see details in Moncel et al., 2016), indicate the early arrival of this technology or local attempts at bifacial manufacture under more diversified climatic conditions (Vallverdú et al., 2014; Mosquera et al., 2015; Bourguignon et al., 2016). The sites of Cueva Negra and Solana del Zamborino seem considerably younger than initially anticipated, and cannot be considered today as early evidence of LCTs (Scott and Gibert, 2009; Jiménez-Arenas et al., 2011; Álvarez-Posada et al., 2017). In Western Europe, the earliest evidence of elaborate bifacial shaping with completely-shaped bifaces is now dated to a narrow timeframe, between 700–650 ka. For this key period, the three major sites are located under diverse latitudes: 1) the Italian site of Notarchirico in the south (Piperno ed., 1999; Lefèvre et al., 2010; Pereira et al., 2015; Moncel et al., 2019), recently dated by $^{40}Ar/^{39}Ar$ between 695.2 ± 6.2 ka and 614 ± 12, 2) the French site of la Noira, in the centre of France, where the lower level (stratum a1) is dated by ESR to more than 665 ± 55 ka (Despriée et al., 2011; Shen et al., 2012; Moncel et al., 2013, Moncel et al., 2015; Moncel et al., 2020a; Despriée et al., 2017b; Despriée et al., 2017c) and 3) the French sites of Moulin Quignon in the Somme Valley dated to 672 ± 54 ka (Antoine et al., 2019). Moulin Quignon is the northernmost site with biface production, and is earlier than the Acheulean British records dated by ESR and ESR/U-series to MIS 15/14 or MIS 13 for microfauna (Candy et al., 2015; Voinchet et al., 2015; Antoine et al., 2019; Lewis et al., 2021). Three hypotheses are currently advanced for the origin of these new behaviours in Western Europe, which led to the settlement of larger territories, the *in situ* evolution or an introduction by new groups or an influx of new ideas that soon reached a large part of Western Europe (i.e., Moncel et al., 2013; Martínez et al., 2014; Moncel et al., 2015; Mosquera et al., 2018; Méndez-Quintas et al., 2018; Moncel et al., 2018a; Moncel et al., 2018b). In sum, studies either describe a chronological and behavioural shift at 700 ka or gradual evolutionary trends with arrivals of new populations or at least new ideas, in relation to *Homo heidelbergensis* or other unknown hominins (McPherron, 2006; Stringer, 2011; Stringer, 2012; Mounier et al., 2009; Wagner et al., 2010; Dennell et al., 2011; Martinón-Torrès et al., 2007; Martinón-Torres et al., 2011; Sharon et al., 2011; MacDonald et al., 2012; Bermúdez de Castro et al., 2013; Bermúdez de Castro et al., 2013; Moncel et al., 2018a; Moncel et al., 2018b, Moncel et al., 2020b). The scarcity of archaeological sites over such a long period either points to poor preservation due to taphonomic processes or short-lived dispersal events with phases of depopulation and recolonization of the continent by small groups of pioneers.

The new findings at Moulin Quignon (Antoine et al., 2019) tend to suggest that Acheulean traditions (Mode 2) and new technological abilities could have helped the dispersal of hominins in Western Europe over larger territories, regardless of climatic conditions. Changes in behavioural plasticity and not only phenotypic changes in *Homo heidelbergensis* groups (or other hominins) have to be explored. We investigate the behavioural and technological abilities of hominins living in North-western Europe and compare them to those from southern areas between 900 and 700–650 ka, when the earliest evidence of biface shaping emerges in Europe; associated sometimes with innovations in core technologies. Moulin Quignon site is not only an emblematic site, rooted in the history of prehistoric sciences, but also a site where occupations point to hominin adaptions to northern territories, to harsher environmental conditions and climates, without the use of fire. The site also suggests the enhanced flexibility of *Homo heidelbergensis* compared to *Homo antecessor*.

This event occurred at the end of the Middle Pleistocene Transition (MPT), a period marked by cyclical climate changes and vegetation and faunal turnovers (less competition with big carnivores). It could have led to the successive depopulation or extinction of small groups of hominins in Western Europe (North and South), and to subsequent recolonization, before and between the MIS 16 and 12 cold events (Guthrie, 1984; Turner, 1992; Belmaker, 2009; Dennell et al., 2011; Muttoni et al., 2015; Cuenca-Bescos et al., 2011; Manzi et al., 2011;

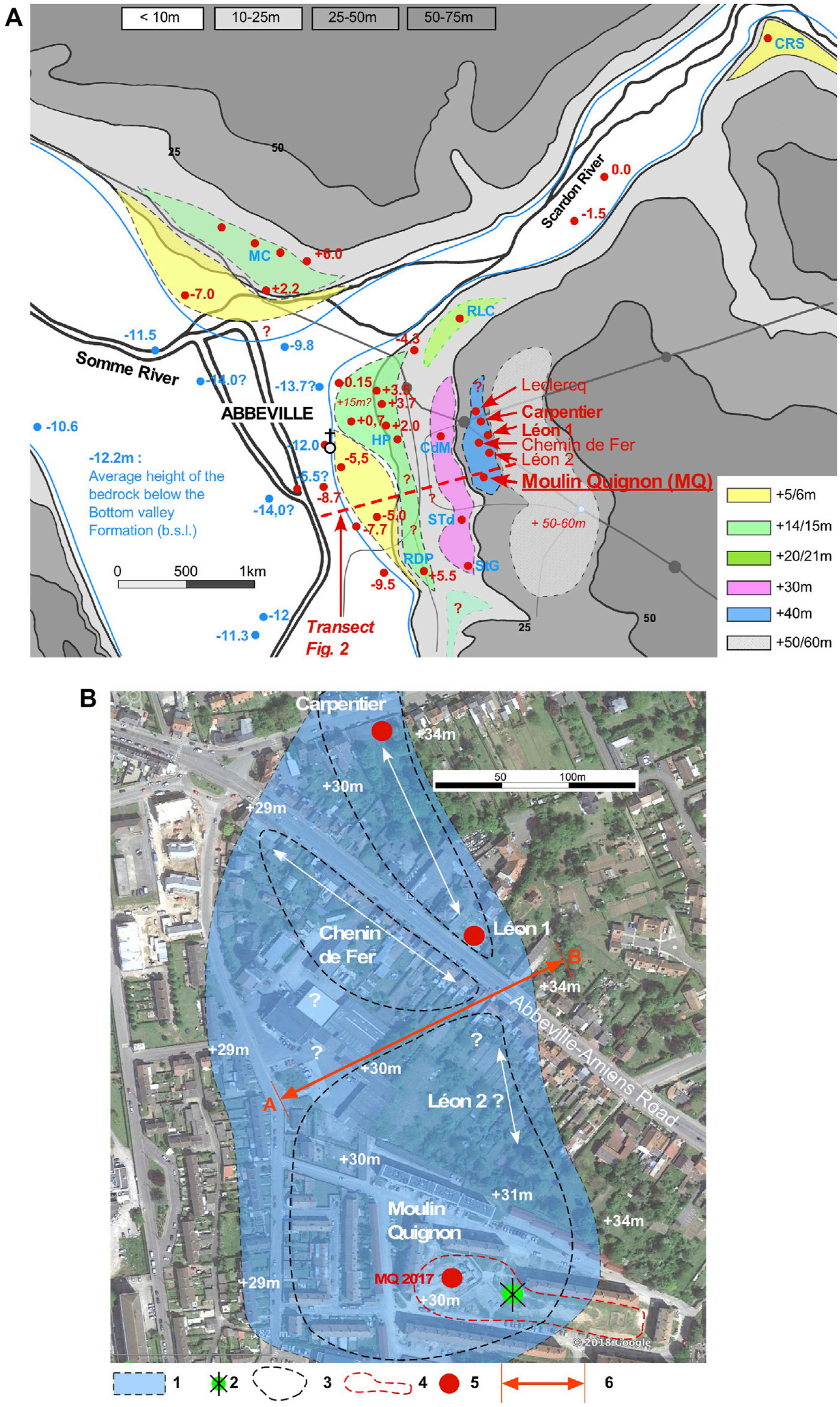

FIGURE 2 | (A) Location of the Moulin Quignon, Carpentier and Leon sites on a map of the Quaternary alluvial formations of the Abbeville area according to (Antoine et al., 2016 modified). Transect of figure 3: red dotted line. Other sites: MT-CB: Mautort-Cambron, RdP: Rue de Paris, Std: Abbeville-Stade, CdM: Abbeville Champ de Mars, HP: Abbeville Hôpital, MC: Abbeville-Menchecourt, RLC: Abbeville-Rue du Lieutenant Caron, CRS: Caours. **(B)** Detailed map of the Carpentier Alluvial Formation (+40 m) between Carpentier and Moulin Quignon, with location of all the sites mentioned in this study according to Antoine et al., 2019. 1) Reconstructed extension of Alluvial Formation VII: (Carpentier Formation, + 40 m). 2) Location of the Moulin Quignon windmill at the end of the 19th Century. 3) Attempted reconstruction of the contour of the quarries at the end of the 19th Century. 4) Area explored during the test-pit campaign in 2016 (17 test-pits) 5) Location of the recently described sequences (2012–2017). 6) **(A,B)**: Transect of **Figure 3**.

Rodriguez et al., 2011; Abbate and Sagri, 2012; MacDonald et al., 2012; Garcia et al., 2013; Carrión et al., 2011; Palombo, 2014; Palombo, 2017; Chauhan et al., 2017). The MPT is also considered to have been conducive to the extension of grasslands to higher latitudes, thereby opening and/or closing migration corridors in these regions. This change in vegetation probably favoured hominin expansion according to tolerance to climate variability, and faunal turnovers (Guthrie, 1984; Turner, 1992; Almogi-Labin, 2011; Bar-Yosef and Belmaker, 2011; Cuenca-Bescos et al., 2011; Leroyer et al., 2011; Rodríguez et al., 2011; Abbate and Sagri, 2012; Martínez et al., 2014). As indicated by sites earlier than 1 Ma, hominin occupations would only have been possible at the transition from glacial to interglacial periods during the Early Pleistocene. However, the lack of records for cold periods may also be due to taphonomic constraints and not only to the absence of occupations.

The Site of Moulin Quignon at Abbeville, Somme

History of Research

The Moulin Quignon site in the suburbs of Abbeville was discovered by Boucher de Perthes during the XIXth century. This sand and gravel quarry is located in the High Terrace on the right bank of the Somme River close to its confluence with the little Scardon River (**Figure 2**). The site yielded fossil bones of large mammals and flint "axes," but it quickly became a subject of controversy with the exhumation in 1863 of an "ante-diluvian" human mandible, found in a stratigraphic context analogous to the aforementioned 'axes' (Abbeville, 1866; Boucher de Perthes, 1847; Quatrefages, 1863a; Quatrefages, 1863b; Boucher de Perthes, 1864a; Boucher de Perthes, 1864b; Milne, 1864). (see **Supplementary Material** for details).

The gradual disappearance of quarries and urbanization in the second half of the nineteenth century in Abbeville made it even more difficult to correlate Moulin Quignon with other sequences from the Carpentier and Léon sites and arbitrary comparisons were sometimes advanced (D'Ault du Mesnil, 1889; D'Ault du Mesnil, 1896; Commont, 1909). (Breuil, 1939; Breuil et al., 1939; Hurel et al., 2016a; Hurel et al., 2016b).

The collections of Abbeville Moulin Quignon were thus forgotten for almost 150 years. Research resumed in 2012 as part of a programme dedicated to the earliest settlements and to the Acheulean, in particular in the Somme valley (Hurel, 2014; Antoine et al., 2016; Moncel et al., 2016).

The geological context of the discoveries was re-examined through the testimonies left by Boucher de Perthes, then by the geologists and archaeologists who subsequently worked on the fossil alluvium from the Somme to Abbeville (Bahain et al., 2016). This critical approach was supplemented by new studies and in particular by the results of work carried out at Carrière Carpentier, as well as by a process of mapping alluvial formations in the Abbeville sector (Antoine et al., 2015; Antoine et al., 2016) (**Figures 2A,B**). The main results confirmed the fluvial nature of the archaeological layers of Moulin Quignon, which are embedded in sands and gravels of the high terrace of the Somme (Antoine et al., 2019). The terrace lies on an incision step in the chalk bedrock located about 40 m above the maximum incision of the Somme valley in Abbeville. The dating carried out at Moulin Quignon using ESR-quartz from fluvial quartz grains provides an age ranging between 709 ± 55 ka and 650 ± 37 ka to the glacial fluvial deposits. The study of the malacofauna collected at the Carrière Carpentier, as well as the mammal fauna collected since the end of the nineteenth century in the Marne Blanche, place these alluvial deposits in an interglacial during the second half of the Cromerian (Cr. III), or to marine isotopic stage (MIS) 15 (Voinchet et al., 2015; Antoine et al., 2016; Bahain et al., 2016) ESR-quartz ages and ESR-U/Th on mammal teeth attributes an age of 584 ± 48 ka to these interglacial fluvial deposits of the Marne Blanche. This is perfectly in line with the position of the Carpentier quarry fluvial formation in the Somme terrace system (Antoine et al., 2007; Antoine et al., 2016) (**Figure 2**).

In addition to geological data, archaeological material (bone remains, lithic tools) from the old quarries of Moulin Quignon, deposited by Boucher de Perthes at the Museum National d'Histoire Naturelle, has been re-examined, in particular the carefully annotated bifaces. Their stratigraphic location is sometimes indicated by labels written by the hand of Boucher de Perthes. However, we cannot distinguish the pieces found by Boucher de Perthes from those brought by workers and given to Boucher de Perthes. Some could come from other sites. The revision of this material provided the first proof of the authenticity of the site, even though it is still impossible to specify the stratigraphic position of these pieces (Moncel et al., 2016). The few malacofaunal remains collected by Boucher de Perthes at Moulin Quignon, and curated in the collections of the MNHN, include Cromerian species confirming such antiquity (Bahain et al., 2016).

New Discoveries at Abbeville Moulin Quignon

Abbeville Moulin Quignon in the Context of the Somme River Quaternary Terrace System

During glacial periods, the palaeo-Somme valley was one of the main tributaries of the Channel River, flowing into the Atlantic, and was a likely major route for human migrations between continental Europe and southern England (Ehlers et al., 2011) (**Figure 1**). The Somme River exhibits a stepped Quaternary fluvial terrace system incised into Upper Cretaceous chalk and composed of 10 stepped alluvial formations spread between +5/6 m and +55 m above the maximal incision of the present-day valley in the Cretaceous chalk bedrock (Antoine et al., 2007) (**Figure 2A**). The relative height of the contact between the successive alluvial sequences and their respective bedrock steps can be used to securely associate archaeological layers such as Moulin Quignon with the Somme River system. In addition, in the Somme valley, each alluvial formation corresponds to the morpho-sedimentary glacial-interglacial cycle.

The terrace series can be summarized by the following phases (**Figures 2A,B–4**):

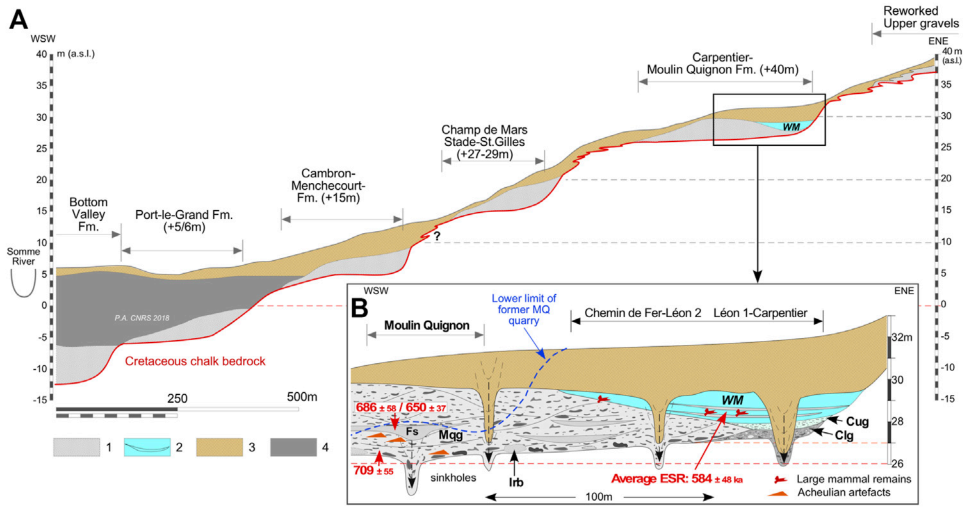

FIGURE 3 | Cross-section of the terrace system of the right bank of the Somme River at Abbeville (see **Figure 2B**). **(A)** General profile. **(B)** Detailed stratigraphic relations between Moulin Quignon and Carpentier sites on the +40 m alluvial formation and ESR-quartz dating results (according to Antoine et al., 2019). 1) Periglacial fluvial gravels, sands and sandy silts (main unit of the various terrace bodies). 2) Carpentier Marne blanche/White marl (WM) complex: interglacial calcareous silts and sandy silts with oncolith sand layers and large mammal remains (Cromerian III/MIS 15). 3) Undifferentiated slope deposits: reworked gravels and palaeosols. 4) Fluvial organic silts, peat and estuarine sands (Holocene infilling). WM: White marl. Cug: Carpentier Upper gravels: well-sorted medium flint gravels with calcareous sandy matrix, interstratified calcareous silt lenses and large mammal remains. Clg: Carpentier Lower Gravels: poorly sorted and heterometric flint gravels including numerous unrolled flint nodules and chalk blocks packed in a calcareous sandy matrix. Mqg: Non-calcareous, coarse, poorly stratified sandy gravels with iron and manganese oxide coatings at the base. Irb: large rounded blocks of reworked Tertiary sandstone (ice-rafted). Fs: Lens of laminated non-calcareous fluvial sands.

(1) Early glacial: heterogeneous coarse sediments made up of slightly reworked large chalk blocks and flint nodules embedded in a calcareous sandy matrix, including some thin lenses of fluvial calcareous silts (slope deposits slightly reworked by fluvial processes). These deposits (between 3 and 4 m thick) are only preserved in the outcrops located very close to the former slope of the valley, as in the Cagny-La Garenne or Carpentier quarry sequences. Overall, they are attributed to continental temperate conditions.
(2) Full glacial: thick body of well-sorted flint gravels including a few sand lenses (braided river system) forming the main sedimentary body of the sequence (3–4 m in thickness). The base of this unit frequently exhibits large Tertiary sandstone blocks reworked by periglacial processes from the slopes to the alluvial plain (very cold conditions, open landscape and periglacial environment, full glacial).
(3) Late glacial to early interglacial: calcareous sandy silts, more or less laminated (0.5–1.5 m thick), characterised by temperate faunas (molluscs, mammals) at the top. This unit, covering the alluvial sequence, is frequently overlain by thin organic grey marshy soil horizons (≈0.1 m).
(4) Interglacial optimum: in a few sequences, calcareous tufa beds (0.5–3.5 m thick), characterised by fully temperate bio-indicators, and especially mollusc assemblages, record the interglacial optimum, as in Caours for MIS 5e, Saint-Acheul for MIS 11, or Abbeville Carpentier for MIS15).

New fieldwork was recently conducted at the Carpentier, Léon and Moulin Quignon quarries, all located on the same +40 m alluvial formation of the Somme system (Antoine et al., 2016; Antoine et al., 2016). The stratigraphic sequence of the Carpentier quarry (average altimetry of the top of the sequence +31 m a.s.l.) is used as a reference to describe the whole sequence of this alluvial formation. It consists of a succession of fluvial gravels covered by whitish fluvial calcareous sandy silts with calcareous nodules ("Marnes Blanches" = White Marl) (Antoine et al., 2016). The fluvial succession is then covered by a slope sequence composed of hillwashed sands and thick clayey soliflucted gravel beds locally trapped in deep sinkholes. During the new fieldwork performed from 2010 to 2014 at this site, no unquestionable artefacts were discovered in the White Marl or in the underlying gravel layer, in keeping with Victor Commont's assertions, while several faunal remains were recovered in the White Marl. Moreover, no clear evidence of human intervention can be shown on the bones although the long bones systematically show helicoidal fractures generally thought to be typical of human intervention (marrow extraction) (Antoine et al., 2016). The rare potentially flaked flints were considered to be geofacts due to post-depositional effects (shocks and pressure flaking between the largest flint blocks during deposition). Two Acheulean bifaces were discovered at the base of the slope deposits directly overlying the fluvial sequence, i.e., at the same stratigraphic location as the pieces recovered by Commont, (1909). Similar types of oval-shaped bifaces were even described and related to the "Acheulean" pieces found in the gravels of the Fréville Formation in Amiens (Commont, 1909) and at the Moulin Quignon site in Abbeville (Aufrère, 1937, Aufrère, 1950; Breuil, 1939). Based on our observations and analyses, the artefacts of

FIGURE 4 | (A) Moulin Quignon 2017: stratigraphic sequence exposed during the excavation (height: 4 m) (according to Antoine et al., 2019). From the top below the reworked sandy gravels from the former Moulin Quignon quarry: Sa-br: Brown-red compact clayey sands preserved in deep dissolution sinkholes. Grs-br: brownish to reddish sandy heterometric clayey rounded gravels with small (reworked) tertiary pebbles. Fs: Yellow fine to medium laminated sands with thick (2–5 cm) red to orange oxidized bands. At its base, in places this unit shows a layer of laminated greyish clayey silts with thin oxidized orange (Fe) and black (FeMn) bands. Grs-j: Heterometric rounded sandy flint gravels with abundant yellow sandy matrix and irregular reddish to orange oxidation (Fe) bands and with (reworked) tertiary pebbles (1–4 cm). Gr-n: Strongly heterometric rounded flint gravels, without any matrix, (mainly 2–4 cm but including irregular elongated nodules up to 30 cm) and scattered (reworked) tertiary pebbles (1–4 cm). This facies is characterized by strong weathering indicated by the occurrence of brownish to blackish Fe-Mn coatings on all the flint nodules and pebbles. All the units described above are free of $CaCO_3$ due to dissolution and weathering processes that affected the whole sequence after its deposition by the river. Chalk: weathered (soft) Upper Cretaceous chalk bedrock including numerous irregular large elongated flint nodules (20–40 cm in length). **(B)** Photo of the fieldworks (P. Antoine 2017).

Boucher de Perthes are most likely coeval with the end of MIS 15 or with an early stage of MIS 14, between 550 and 500 ka (Antoine et al., 2016).

Rediscovery, Dating and Rehabilitation of the Moulin Quignon Palaeolithic Site

In this context, new investigations were undertaken in 2016–2017 at Moulin Quignon (50°06′18″N/1°50′89″E, **Figures 3**, **4**), as a result of the redevelopment of the suburb of Abbeville, leading to the rediscovery of this emblematic Palaeolithic site 170 years later (Antoine et al., 2019). In 2016, seventeen 4-to-5-m-deep test pits were excavated, resulting in the discovery of undisturbed fluvial gravels and sands, well preserved below thick layers of reworked sandy gravels (from the former quarry) and modern dump deposits. The average bedrock altitude measured at Moulin Quignon (26.5 m a.s.l.) in test pits and in the archaeological excavation is very close to the altitudes obtained for the Léon 1 and Carpentier quarries, located 200 and 400 m northwards respectively (relative height: 39–40 m). This approach demonstrates that the three alluvial remnants are located on the same bedrock step and correspond to the same alluvial formation.

The relative elevation of this Moulin Quignon alluvial formation above the altitude of the maximum incision of the chalk below the present-day valley (+40 m) correlates it with Alluvial Formation VII of the Somme system (Antoine et al., 2007).

In addition, we compiled all the available stratigraphic information for this alluvial formation from the area located between Carpentier Quarry and Moulin Quignon, taking into account our recent observations at Carpentier, Léon 1 and Moulin Quignon quarries between 2012 and 2017, as well as the former data published by D'Ault-du-Mesnil, Commont and Breuil (D'Ault du Mesnil, 1889; D'Ault du Mesnil, 1896; Breuil, 1939).

This approach was completed by a new test pit campaign during spring 2019 over an abandoned area further to the north (140–180 m) of the Moulin Quignon 2017 excavation, closer to Carpentier Quarry (**Figures 3**, **4**). During this extensive survey (17 test pits on 2,600 m^2), *in situ* remnants of fluvial gravels and sands were discovered (thickness about 1 m), overlying the same chalk bedrock step as in Carpentier Quarry and Moulin Quignon 2017.

These results strongly support the direct stratigraphic correlation between the fluvial sequences from Moulin Quignon and Carpentier Quarry, despite their distance.

The facies and stratigraphic succession observed in the new Moulin Quignon excavation are very similar to descriptions published in the nineteenth century by Boucher de Perthes and Prestwich, in terms of overall thickness of the sequences and sedimentary facies. Boucher de Perthes described a sequence composed of gravel beds and sand layers, with a thickness of about 4.5 m. This is perfectly compatible with the difference between the average altitude of the bedrock step measured at the base of the sands and gravels during the new excavations and test pits (26.5 m) and that of the surface of the topsoil (30.5–31 m). Moreover, at the very base of the fluvial sequence, we also found only at Moulin Quignon a 0.4–0.5 m-thick layer of gravels strongly coloured by iron and manganese oxides, which was formerly described by Boucher de Perthes

("Couche noire") and Prestwich (the Black band) in the same stratigraphic position, and in which we also discovered Palaeolithic artefacts.

The stratigraphic synthesis shows that the Carpentier interglacial deposit, the "White marl," extends to the south towards the area corresponding to the Chemin de Fer and Léon 2 quarries located at less than 100 m from the area explored at Moulin Quignon in 2016–2017 and that they overlie the coarse gravels and sands from the Moulin Quignon Formation.

The interglacial calcareous facies of the "White marl" is thus only preserved in sequences located in the external part of the alluvial formation. This configuration results from the occurrence of a lateral channel close to the right bank of the Palaeo-Somme valley, whereas interglacial deposits are not preserved towards the central part of the former river valley, showing a markedly thicker lower gravel unit (3–3.5 m), like in the Moulin Quignon area. Thus, combining the new observations and former data, we can demonstrate:

Given the stratigraphic information exposed above, the geochronological data from the deposits of the Carpentier quarry, and especially the ESR and ESR/U-series dates from the interglacial deposits of the White marl, can be used to reliably infer the age of the Moulin Quignon findings. Besides, three samples of sandy sediments were extracted during the 2017 archaeological excavation from the main stratigraphic units and *in situ* gamma-ray measurements were performed in each sampling hole. The results obtained for the three samples from Moulin Quignon, using the aluminium (Al) and lithium titanium (Ti-Li) centres of quartz, are consistent with each other (overlapping of uncertainty domains at 2 σ). An average age of 672 ± 54 ka was obtained for the whole fluvial sands and gravels formation of Moulin Quignon, confirming the antiquity of the site.

Although the average age of the Moulin Quignon fluvial deposits corresponds to the early phases of MIS 16 (Glacial b of the Cromerian Complex), and thus to clearly cold and markedly different conditions compared to the "Marne Blanche" deposits, no accurate palaeoenvironmental reconstruction can be attempted due to the absence of bio-indicators in the Moulin Quignon gravel formation (fully decalcified deposits).

The interpretation that the Moulin Quignon gravels and sands were deposited in a periglacial environment is based on the occurrence of some very large rounded Tertiary sandstone blocks (up to 0.5–0.8 m in length), at the base and in the fluvial gravels, reworked during episodes of periglacial mudflows from the slopes of the valley towards the alluvial plain. Indeed, in the alluvial formations of the Somme River, as in numerous rivers of Northwest Europe, these large ice-rafted blocks are described within or at the very base of Quaternary alluvial formations. The reworking of these sometime huge rounded blocks (>1 ton) from the slopes to the alluvial plains, and their subsequent transport by fluvial systems, imply that major episodes of solifluction occurred on the slopes and that extremely strong river dynamics transported large ice-rafted blocks and heavy loads of coarse and poorly sorted material (flint nodules and chalk blocks) during spring break-ups and floods.

These processes characterise full glacial conditions and are typical of braided river systems in Quaternary periglacial and present-day northern tundra environments. The deposition of the Moulin Quignon sequence during periglacial conditions is also shown (**Figures 3**, **4**) by 1) the occurrence of well-sorted flint gravel layers including a main stratified sand lens deposited in a shallow channel structure (at least 5–6 m wide) typical of braided river systems (Gr-n, Grs-j, Grs-br and Fs), 2) a very low proportion of sandy matrix as well as iron oxide and manganese coatings on the gravels (Sa-br), that are both typical of the basal units of the fluvial sequences of the other Somme terraces and, 3) the occurrence of numerous large and poorly rolled flint blocks (20–40 cm in length at the base of Gr-n), as generally found at the base of the gravel bars and islands in braided river systems (lag deposits).

Finer facies (grey silty sands, yellow laminated sands) observed in Moulin Quignon sections that could have reflected different climatic conditions, but no bio-indicators, are preserved due to post-depositional weathering processes. The thin layers of clayey-silty sands occurring at the base of the main sandy lens have been tested for pollen without success. These fine-grained sediments were probably deposited in the same braided river environment in an abandoned shallow channel between gravel bars at the end of a flood episode.

The homogeneous character of the physical characteristics (abrasion and patina) of the archaeological pieces from Moulin Quignon excludes reworking from an older terrace formation and no traces of occupation have ever been described in the older alluvial sequences of the Somme system despite more than 150 years of intensive research.

The archaeological excavation showed that the artefacts are not regularly distributed in the fluvial deposit but are rather localized in spatially discrete concentrations separated by archaeologically sterile zones.

The Acheulean artefacts discovered at Moulin Quignon thus probably represent human occupations during a cold period, located in the former alluvial plain of the Somme River on a gravel bar close to the right bank of the valley, at the margins of the valley. In this position the site was regularly flooded during spring floods and the flint artefacts were probably displaced over short distances (a few metres), before being buried in the sandy-gravelly material.

However, it is highly likely that human occupations from this period only correspond to short incursions of human groups during the summer season. Taking into account the wide dating error bars, it is also possible that the Moulin Quignon human occupation took place during a short interstadial period (≤1–2 ka) characterised by a milder climate (especially during summer season), as is the case for example for Upper Palaeolithic hunters during the Last glacial period in the area (Renancourt: Paris et al., 2016; Moine et al., 2021), or for the Acheulean occupation at Cagny-la-Garenne during the Early MIS 12 glacial period (Tuffreau and Lamotte, 2010; Lamotte and Tuffreau, 2016).

At that time, Acheulean "pioneers" probably followed the tracks made by the Somme valley and river banks along a straightforward trajectory. In this context, the occurrence of a confluence between the Somme and the Scardon River valleys, as is the case in Moulin Quignon, was a particularly good marker in the landscape. This configuration is also auspicious for large mammals, and was particularly attractive for the first Acheulean "pioneers" in the Somme Valley.

MATERIALS AND METHODS

Materials

Lithic Collections of Boucher-de-Perthes

The lithic material attributed to Moulin Quignon is abundant in museum collections; at the Musée de l'Homme and the Institut de Paléontologie Humaine (Paris), or in other French museums, despite partial destruction during the two world wars. However, for most of the pieces, no precise geographic or stratigraphic location is indicated. These series are undoubtedly from surface collections and not from archaeological excavations or quarries.

In 1860, Jacques Boucher de Perthes gave the Museum National d'Histoire Naturelle Paris a sample of the archaeological material that he collected in Abbeville and its region, consisting of several hundred pieces (Hurel, 2014). The collection of these pieces began in 1840 and the last entry in the inventory is in 1859. There is no doubt about the authenticity of the pieces that make up this corpus (with some very rare exceptions). Twenty-two of them bear various indications and are recorded in the inventory. There are, in particular, bifaces from Moulin Quignon with indications written by the hand of Boucher de Perthes between 1845 and 1863.

Our goal was to identify the pieces with clear stratigraphic attributions handwritten on labels stuck directly on the piece or on the box. These annotations have been systematically checked in the inventory.

To date, only fourteen pieces of often very patinated flint can be attributed to a layer or a "depth" in the sequence of Moulin Quignon (3, 4 and 5 m deep). According to the inscriptions, which indicate a clear stratigraphic attribution, these lithic pieces were discovered by workers in the presence of Quatrefages or collected by Boucher de Perthes himself. The two Quatrefages bifaces, extracted in April 1863 from the same layer as the "mandible", are now curated with the collection donated by Boucher de Perthes in 1860, in the reserves of the Musée de l'Homme (Nos. 2977 and 2978).

In addition, there are two bifaces (Nos. 2157-31 and 2837/27) without a precise stratigraphic position, but inventoried as coming from the sequence. They are described separately.

Finally, two other pieces (Nos. 2155-29 and 1931-27), a small ball in flint and a gelifract (discovered in 1866), with no stratigraphic position but inventoried, were considered as natural and eliminated from the study.

Our study focused above all on the technological characteristics of the lithic pieces.

Lithic Corpus From the New Excavations (2016–2019)

A total of 254 flakes, 15 cores, 5 bifaces and 4 shaped tools were discovered *in situ* at the base of the deposits in several stratigraphic groups (Gr-n, Grs-j and Grs-j) during the recent test pits (2016–2019) and excavation (2017) (Antoine et al., 2019) (**Table 1**). The material is made on flint collected from the local Middle Coniacian C4b (flint with green cortex), from secondary flint reworked in the Tertiary formations or from the Pleistocene gravels. Only eight pieces show traces of crushing and 19 are clearly flake-tools. The vast majority are fresh. The geological features of the sequence and the taphonomy of the artefacts indicate that they were moved little by natural processes (≤1 m). As there are no significant differences between the sub-layers, the corpus is studied as a whole.

Methods

The technological analysis of the lithic corpus was performed using the "chaîne opératoire" (i.e., Boëda et al., 1990; Geneste, 1991; Texier and Roche, 1995; Baena et al., 2018), in order to understand the production systems and technical objectives through the analysis and description of each object. The characteristics of LCTs were analysed by general morphology, raw material and blank (if recognizable), size, number and characteristics of removals, symmetry (bifacial and bilateral), processing sequence for the general volume and the tip, presence of cortical residue and retouch. Core technologies are identified on cores and flakes by studying the reduction processes: size of cores and end-products, type of cores (discoid, unifacial, bifacial, orthogonal and polyhedral), organization of removals on cores and flakes, extension of cortex, platform and retouch. The analysis of the retouched items focused on broad categories of tools (scrapers, denticulates and notches): size, location, extension, type and continuity of retouch, and final tool morphology.

Correlations with the current environmental and archaeological data in South and Northwest Europe are made through direct studies of material from recent research and literature.

RESULTS: TECHNOLOGICAL STRATEGIES AT THE SITE OF MOULIN QUIGNON IN NORTHWEST EUROPE

Revision of the Artefacts Found by Boucher de Perthes (Musée de l'Homme Nineteenth Century Collection)

A small series has been identified in the Boucher de Perthes collection with clear data on the origin of the finds and above all their stratigraphic depth written in Boucher de Perthes' handwriting (**Figure 5**). The material from known stratigraphic locations is mainly composed of bifaces from depths of 3, 4 and 5 m, some of which were collected near the human mandible.

TABLE 1 | Lithic corpus by layer (from the youngest to the earliest) at Moulin Quignon (fieldworks 2016–2019)—in number.

	Fs	Grs-j	Gr-n/Grs-j	Gr-sr	Gr-n	Gr-n base	Grs-br (disturbed)	Disturbed	Total
Bifaces		1	3		1	1			5
Shaped tools		1	3						4
Cores		8	4	2	1				15
Products of debitage	5	84	110	10	21	12	2	10	254

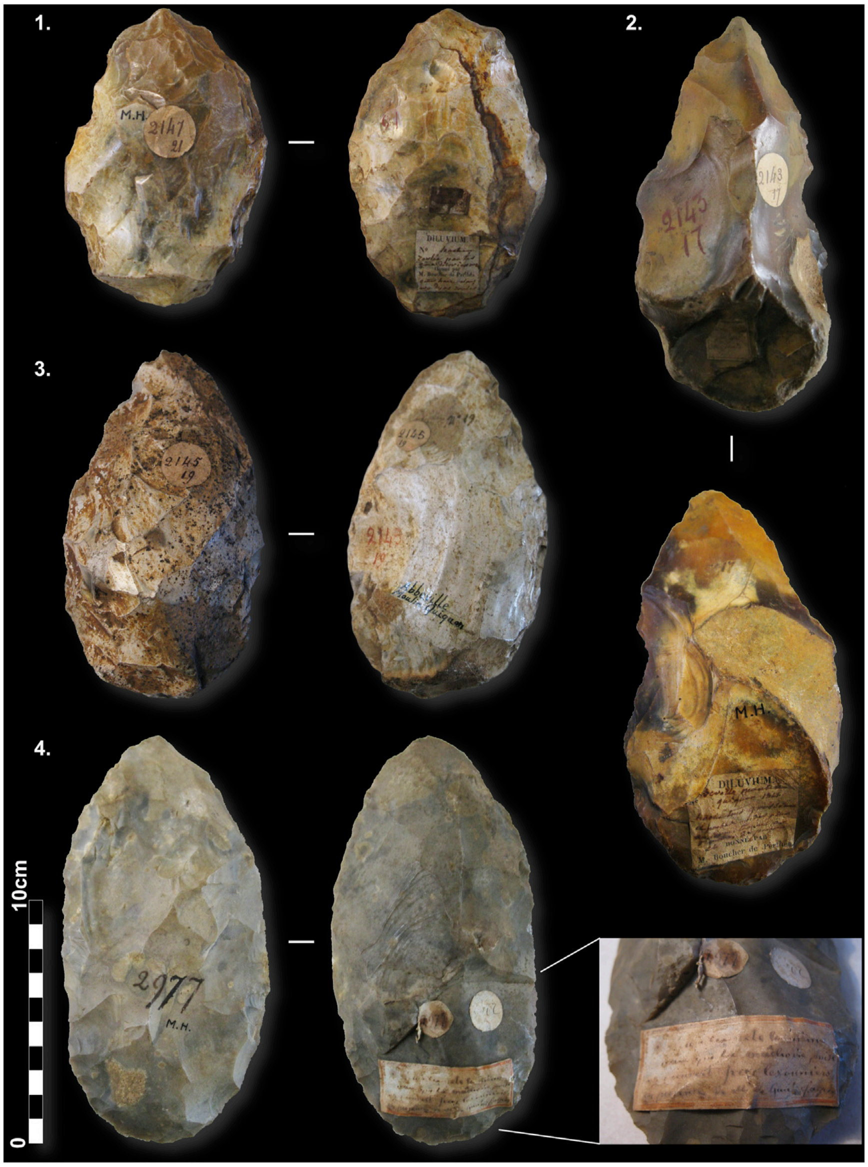

FIGURE 5 | Handaxes coming from J. Boucher de Perthes's collections of the XIXth century exploration of Moulin Quignon quarry, preserved in Musée de l'Homme in Paris. 1–3: handaxes potentially discovered in Gr-n or Grs-j layers, due to the features of the patina and the presence of well-developped ferro-manganic veneers. 4: handaxe probably introduces by workers in the stratigraphy of Moulin Quignon, next to the famous mandible as mentionned in the XIXth century label. The technical proprieties and the patina do not fit with the recently excavated artefacts in Moulin Quignon. Photos: Marie-Hélène Moncel, Rachel Orlaic. CAD: David Hérisson.

TABLE 2 | Lithic corpus by layer (from the youngest to the earliest) and technical types of flakes at Moulin Quignon (fieldworks 2016–2019) - in number.

	Fs	Grs-j	Gr-n/Grs-j	Gr-rs	Gr-n	Gr-n base	Grs-br (remanié)	Remanié	Total
indet. flakes	1	1			1			1	4
First cortical flakes		3	10	1	1	2			17
Flakes with bilateral cortical backs			1						1
Flakes with a lateral cortical back	2	8	16		2	2		2	32
Flakes with distal-lateral cortical backs		1	2						3
Flakes with a distal back					1				1
Flakes with a distal cortical back		2	4		1	1		1	9
Flakes of biface		1		1					2
Flakes of biface?	1	2	1		1				5
Flakes with a cortical butt-back			3			3			6
Flakes with cortex		37	38	3	4	2	2	3	89
Backed flakes with cortical patches		1	5						6
Flakes without cortex		25	22	4	5	1		2	60
Backed flakes without cortex			6		3				9
Kombewa flakes		1	1						2
Fragments of flakes		1		1	1				3
Fragments of elongated flakes						1			1
Elongated flakes (blades)	1		1		1			1	4
Total	5	84	110	10	21	12	2	10	254

TABLE 3 | Technical types of flakes and organization of removals at Moulin Quignon (fieldworks 2016–2019) –when readable- in number.

	Bipolar	Centripetal	Crossed	Transversal	Unipolar	Unipolar convergent
Flakes with bilateral cortical backs			1			
Flakes with a lateral cortical back		2	11	1	14	1
Flakes with distal-lateral cortical backs		1			2	
Flakes with a distal back		1				
Flakes with a distal cortical back					8	1
Flakes of biface			1			
Flakes of biface?		1			1	3
Flakes with cortex	2	6	9	1	57	3
Backed flakes with cortical patches	1		2		3	
Flakes without cortex	2	7	11		22	9
Backed flakes without cortex		3	4		2	
Flakes with a cortical butt-back			2		3	
Cortical flakes		1		2	3	
Fragments of flakes		1			1	
Elongated flakes	1				1	
Total	6	23	41	4	118	17

Two bifaces were collected at a depth of 3 m. The biface extremity is not diagnostic (No. 2149-23). The complete biface (No. 2150-25) measures 10 cm, and is shaped by a few removals, with irregular edges, despite unifacial retouch on one edge.

Five flint pieces come from a depth of 4 m, including two flakes measuring around 10 cm. Two of the three bifaces were found in direct association with the human mandible discovered in 1863. The first one (No. 2977) is a cordiform elongated biface, largely shaped face by face. The section is plano-convex and the form is symmetrical. The second one (No. 2978) is also symmetrical, cordiform and elongated, shaped by several series of invasive removals. Bifacial secondary retouch covers the periphery of the tool. Earth residues are still visible on both sides, trapped in the retouch. A third biface, without a number, is an asymmetrical oval bifacial piece on poor-quality flint. The section is trihedral and it is made by abrupt or flat removals. One side is thinned by a large invasive lateral removal. This piece, described in the inventory as fake, could be considered as a core.

The richest corpus was recovered at a depth of 5 m. The six bifaces are all patinated, sometimes with cracks caused by frost and a black colour, and are considered as anthropogenic. The black colour corresponds to the impregnation of sands and gravels by black ferro-manganese oxides, observed at the bottom of the sequence of the new excavations.

Two of the six bifaces were directly removed from the section where the human mandible was discovered (for instance Nos. 2143, 2144, 2145, 2146, 2148). They are diversified but most of them are largely shaped, often asymmetrical, and with final retouch on the edges for some. They measure around 15 cm long and are cordiform or lanceolate.

TABLE 4 | Technical types of flakes and platforms at Moulin Quignon (fieldworks 2016–2019) –when readable- in number.

	Cortical	Diedhral	Facetted	Flat	Punctiform
flakes				1	
Flakes with a lateral cortical back	1	3	2	21	1
Flakes with distal-lateral cortical backs				1	1
Flakes with a distal back				1	
Flakes with a distal cortical back	1	2	1	3	2
Flakes of biface				2	
Flakes of biface?		2			1
Flakes with cortex	12	12	2	43	8
Backed flakes with cortex			1	4	
Kombewa flakes				1	1
Flakes without cortex	4	7	6	29	9
Backed flakes without cortex		2	3	2	1
Flakes with a cortical butt-back	6				
Cortical flakes	2	3	1	6	2
Elongated flakes				1	1
Total	26	31	16	116	27

The Lithic Corpus From the Recent Excavations

Core Technology

The series is composed of 15 cores made on flint nodules, which is rather a low number compared to the number of flakes (n = 254) (**Tables 2–4**). The core/flake ratio shows a core deficit.

The organization of removals on cores indicates short debitage sequences with unipolar or centripetal removals, on one, two (orthogonal or bifacial secant) or multiple surfaces. Most of the cores, however, are largely cortical with few removals.

The nodules used were of various sizes, often with irregular shapes, and the flint is of medium quality (sometimes presence of inclusions). No particular selection of nodule morphology seems to have been applied.

The scars, as well as the diversified nodule sizes, indicate the production of flakes of disparate shapes and sizes. No core preparation is visible and debitage exploits the natural morphology of the nodule. The relatively low frequency of hinged scars on the core surfaces seems to indicate well-controlled management of knapping angles despite the low proportion of prepared striking platforms.

Most of the cores are unifacial with one (or two) series of unipolar and centripetal removals. The striking platform is cortical or with preparation limited to reducing the angle (around 60°), when necessary. Debitage produces thick flakes with a large and thick butt, and frequently uses the natural cortical convexities of core edges. Sometimes, the lateral convexities of the flaking surface are prepared by hinged removals. The core technology of these cores indicates efficiency with very limited predetermination.

Rare cores show more intensive flaking. They are unifacial, bifacial secant or multifacial, with unipolar, centripetal or crossed removals produced in one or several series. The striking platform is partially prepared with previous removals (**Figure 6**). Bifacial cores indicate flaking on two faces with two or three series of removals. Some small final removals on two cores can be considered as retouch or final debitage attempts. Two cores indicate that flaking can become independent of the natural geometry of the nodule. They show peripheral unipolar removals obtained from a prepared striking surface and could be described as “semi-tournant”-type cores. One other core surface shows additional debitage by invasive and hinged unipolar removals.

The largest core (163 mm × 150 mm × 92 mm) is a piece with three orthogonal surfaces. Two opposite surfaces and the edges of the core were flaked. Invasive centripetal removals on one face are obtained from cortical striking platforms or previous removals. Finally, peripheral and orthogonal removals are produced on part of the core periphery. Then there is alternating flaking of two orthogonal surfaces with some additional removals on the first flaked surface. The lower surface of the core shows some scars extracted from other cortical striking platforms. Traces of strong impacts on the edges, with angles close to 90°, suggest that the core was recycled as a hammerstone.

Most of the products come from on-site debitage. A large proportion of flakes are cortical, from the first phases of flaking (**Figure 7**). They measure between 40 and 80 mm long (**Table 2**). Most of them are “robust” and thick flakes with edge angles of around 70°. Cortical flakes indicate the flaking of oval or irregular nodules. Convergent unipolar or unipolar removals eliminate the cortex by a series of thick flakes. The butts indicate that striking platforms were prepared or cortical. A majority of flakes have a cortical back and some have a cortical butt-back, from the edges of the core or nodule.

Non-cortical flakes show that a longer debitage sequence can continue on the cores by unipolar, centripetal or crossed flaking. The frequency of backs for non-cortical flakes also indicates that flaking continued on core edges. Some more elongated flakes mainly result from the use of the scars and core edges. Flakes are often thick, and some are truncations of a convex or pyramidal flaking surface. Flake sections show abrupt facets and deep scars. Butts are flat, but also punctiform, dihedral and “faceted” (with more than two scars). Few flakes are hinged, confirming control of the striking platform, despite some evidence of hinged scars on

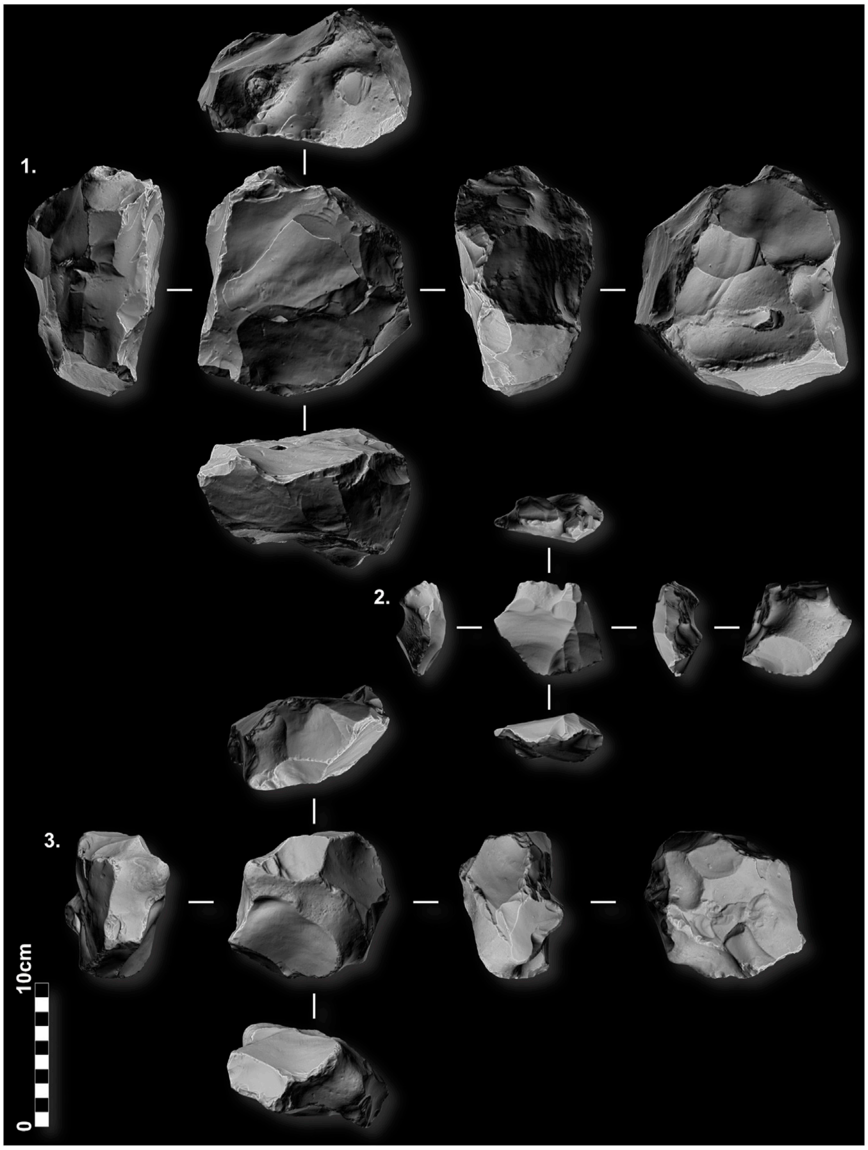

FIGURE 6 | Cores discovered at Moulin Quignon in layers Gr-n in 2019 campaign. Compléter la description en cohérence avec la bdd et le texte. Views come from the 3D models obtained by photogrammetry, reworked by a radiance scaling shader in Meshlab; sections are generated thanks to compute planar section in Meshlab. 3D models and CAD by David Hérisson.

cores. One of the main production characteristics is the presence of wide and thick butts with an acute angle (50–60°). Impact points are positioned far from core edges, as is the case for "Clactonian" type debitage (Ashton et al., 1994). We can mention two Kombewa flakes, resulting from the breakage of a nodule and the knapping of the broken surface.

Less than 31 flakes show retouch (one or more edges with marginal or irregular retouch), but only seven are unquestionably retouched: three convergent scrapers made by irregular retouch and two end scrapers on the largest elongated flake (128 mm) and a cortical flake, with retouch on both lateral edges (**Figure 7**).

Shaping of Bifaces and Other Heavy-Duty Tools

The five bifaces recovered during work in 2016–2019 display diversified shapes and shaping modes, resulting from short management strategies (one series of removals), several series of removals and possible resharpening in one case (**Figures 8**, **9**). Some parts are worked by a single series of removals, probably with a hard hammer, leaving cortical areas. Others indicate several series of removals shaping the piece first by direct percussion with a hard hammer (deep and large scars), then probably with a soft hammer or a hard hammer with a tangential

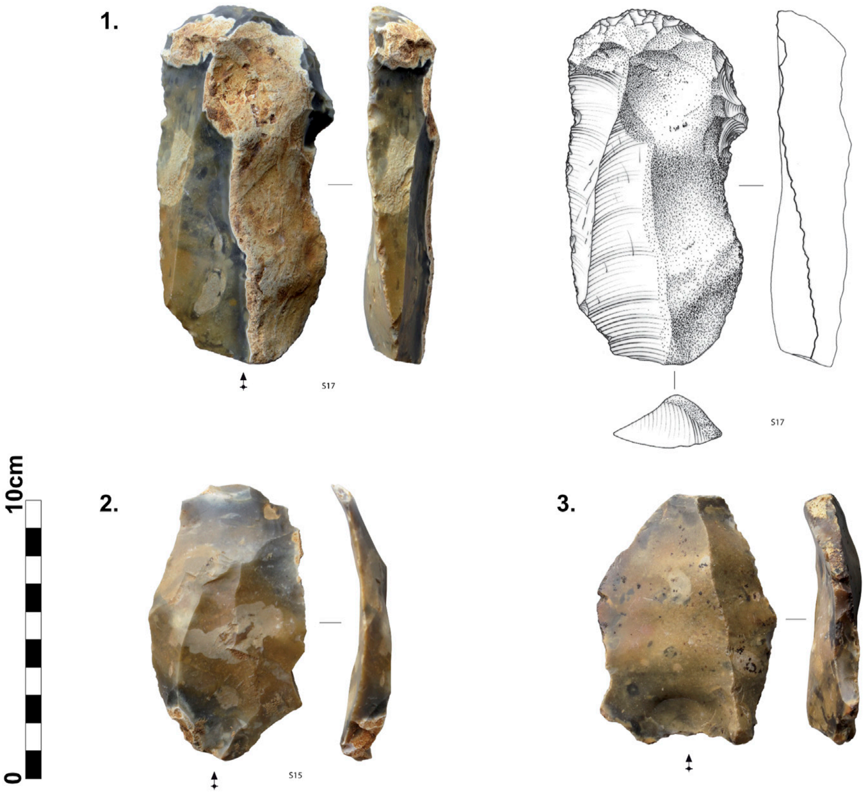

FIGURE 7 | Flakes discovered at Moulin Quignon in layers Gr-n in 2016–2019 campaign. 1: End-scrapper on cortical thick flake. 2: Fine large flake coming from bifacial shaping. 3: Non cortical flake. Photos and drawings by Stéphane Lancelot.

gesture (fine and more or less invasive removals or retouch) for the final shaping phase of the tip and/or distal edges.

- Elongated triangular biface without cortex. It is an asymmetrical piece with a lateral back created by abrupt removals. It is shaped by invasive and flat removals. Special care is taken at the extremity of the tool with small retouch/removals. It is worth mentioning an invasive removal on the base which covers a large part of one of the faces of the tool.
- Triangular and symmetrical biface with a thick, cortical base. Shaping is carried out by alternate invasive and thick removals, which manage the entire volume. Special attention is given to the tip modified by small removals and retouch covers the entire periphery. The edges are sinuous. This tool has been deeply shaped and reduced and must have been considerably longer at the beginning of the shaping process. Hard then soft hammers were used. The final removals/retouch are flat and some abrasion is visible.
- Oval and symmetrical biface with cortical residues on one side and one back. Centripetal removals cover the surfaces and particular care was paid to the extremity, which is thin and rounded. Retouch is visible all around the periphery. Tool size is similar to the size of the nodule.
- Symmetrical and broken biface made by large removals on one side. The point is broken by flexion. Transversal removals remove the base. Thick, bifacial and unifacial retouch covers the edges. Crushing is visible on the edges. The organization of removals and the cortex indicate that biface size was similar to nodule size. Fragmentation occurred during the shaping process or in the use process.
- Crudely-shaped biface by alternate shaping with large and deep removals. The extremity is modified by a small transverse removal (use?). The section is asymmetrical, which does not modify initial blank morphology. Retouch and traces of crushing are visible on the edges.

Flakes that can be related to biface shaping are very rare. They are selected by features such as a lip, reduced butt and the cross-section. This small quantity is due to the geological history of the corpus. There are no refits and no flakes from the bifaces of the series have been identified with certainty in the assemblage.

Four pieces on fragments of nodules were classified as shaped tools. These are two “rabots,” thick scrapers with abrupt retouch/removals, and two crudely-made bifacial pieces.

Comparison Between the Boucher de Perthes Lithic Corpus and the Recent Excavation Corpus

Only some bifaces can be diagnosed in the corpus found by Boucher de Perthes. This series includes a small set of well stratigraphically located pieces with labels written by the hand of Boucher de Perthes.

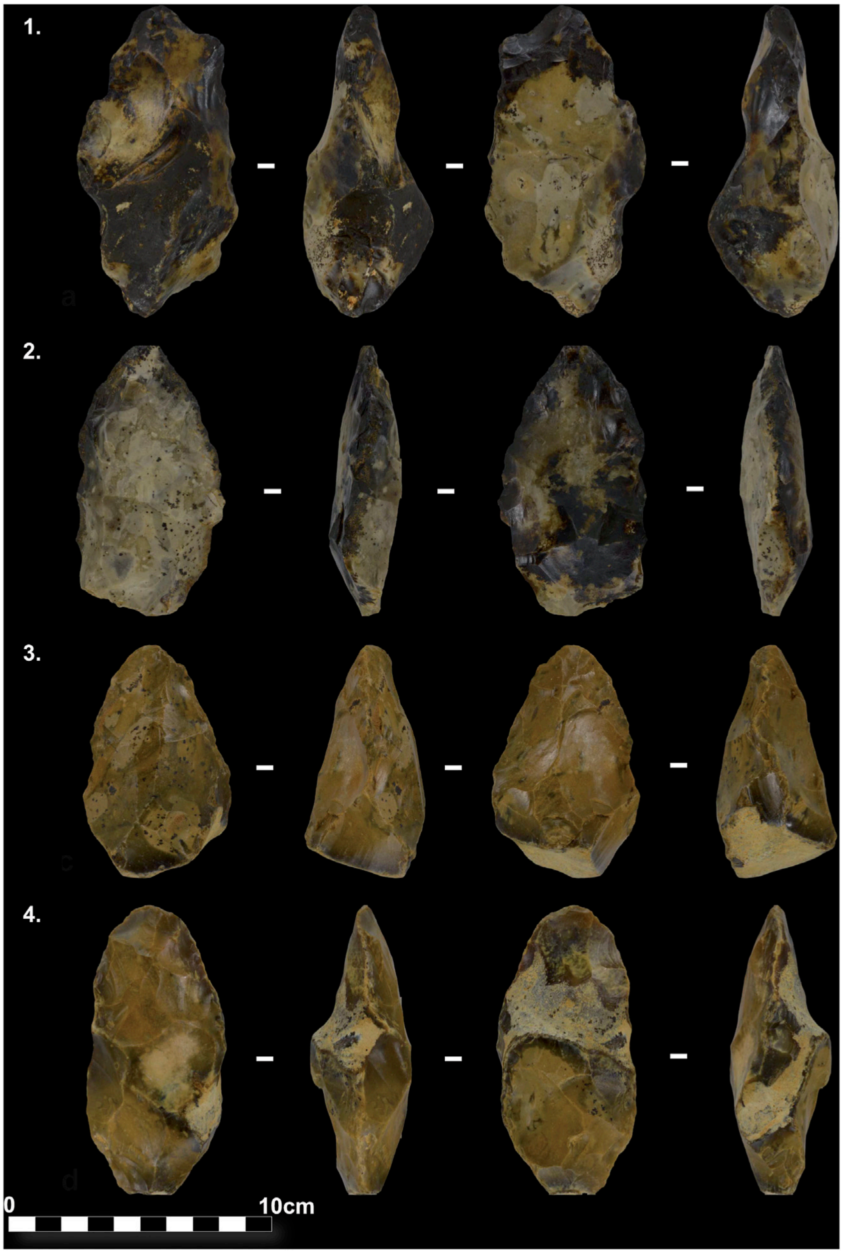

FIGURE 8 | Handaxes discovered at Moulin Quignon in layers Gr-n in 2016–2019 campaign. Views come from the 3D models obtained by photogrammetry, reworked by a radiance scaling shader in Meshlab; sections are generated thanks to compute planar section in Meshlab. 3D models and CAD by David Hérisson.

However, their position, at 4 and 5 m deep *in situ* on this site, cannot confirm their actual position in the sequence. These pieces may have been brought to the quarry by workers. However, similarities between the patina of these tools and the patina of tools from recent excavations can be observed. Biface No. 2978 from a depth of 4 m shows a face with breccia and a dark patina typical of the black layer observed at the bottom of the sequence. This black layer was also observed in the various recent test pits and during the 2017 excavation at the base of the gravels. It corresponds to a very deep impregnation of the sands and gravels by black ferro-manganese oxides forming thick coatings on the flints. No.2143, at a depth of 5 m, is covered by a greenish-yellow patina, similar to pieces from our sandy layers. No. 2144, at a depth of 5 m, is affected by frost cracks. Nos. 2145, 2146 and 2147 are patinated.

The surface aspect validates to some extent the authenticity criteria of what Falconner and his colleagues in 1863 described as an "axe" (presence of patina and polish, and smooth edges). None of them bears traces of iron (fake tools) and the few earthy residues are encrusted in the edges of the scars.

If we consider that the bifaces found by Boucher de Perthes were in place and not introduced by workers from other prehistoric sites, their technical characteristics allow us to

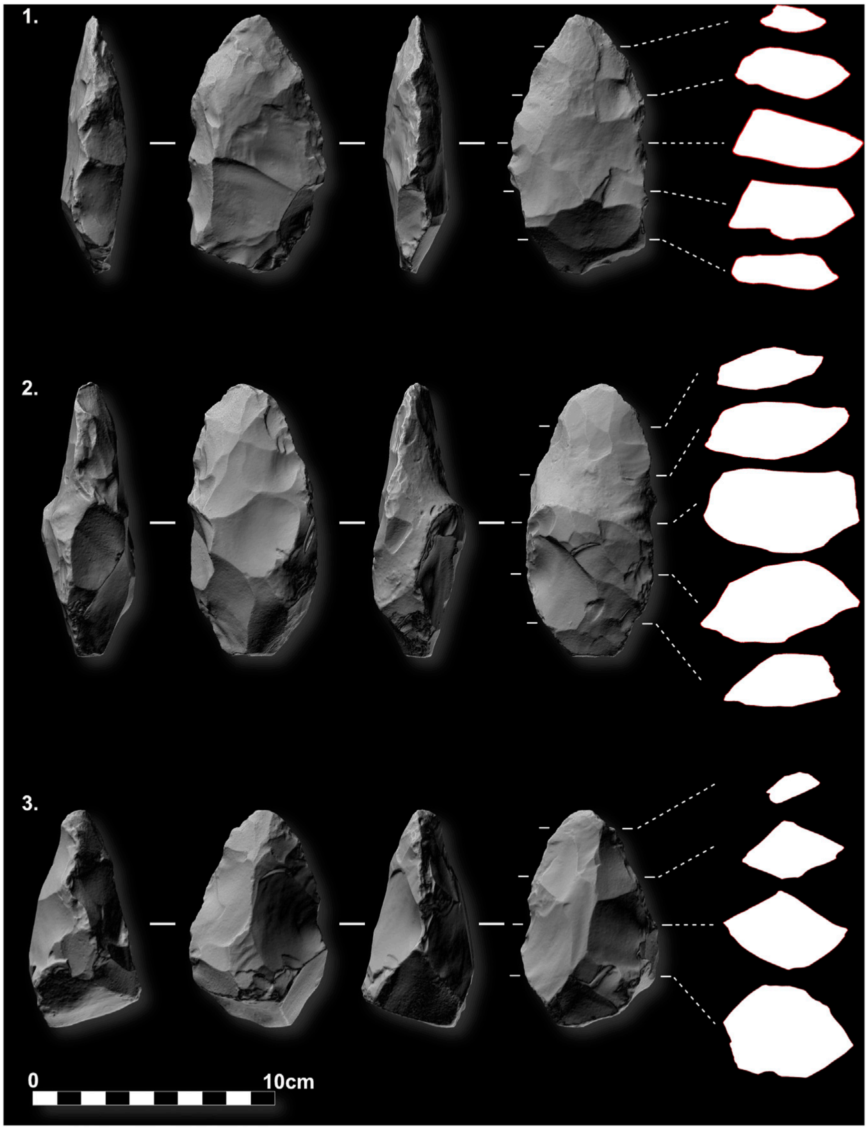

FIGURE 9 | Handaxes discovered at Moulin Quignon in layers Gr-n in 2016–2019 campaign. Views come from the 3D models obtained by photogrammetry. 3D models and CAD by David Hérisson.

observe 1) an association of not very elaborate bifaces and largely-shaped bifaces, 2) oval or cordiform tools, often with a plano-convex cross-section, with a symmetrical or asymmetrical shape, sometimes with retouch to regularize the edges.

The five bifaces found in the recent excavations show similar characteristics and, despite the small number for each series, could indirectly confirm the origin of the old series.

DISCUSSION: NORTH-WESTERN AND SOUTHERN EUROPEAN CONTEXTS FOR HUMAN OCCUPATIONS

The link between global climate variations and regional environments is difficult to establish for the time period before MIS 12. Indeed, global as well as regional palaeoclimatic data (i.e., mainly marine records) are continuous, but palaeoenvironmental data from both northern and southern Europe are still partial. Only a few archaeological sites have been identified over this period. Moreover, the paleoenvironmental proxies found in each archaeological site (e.g., micro and macro fauna, pollen grains) are often scant and of poor quality. Archaeological sites can thus only provide snapshots of local past environmental changes.

If we look at the technological strategies applied by hominins, from the earliest evidence of human occupation (1.4–1.2 Ma) to the long MIS 12 glacial event, over Western Europe, above and south of the c. 45th N., assemblages are composed of cores (including chopper-cores) and flakes or of cores (Mode 1 assemblages), flakes and Large Cutting Tools (LCTs, including bifaces, cleavers,

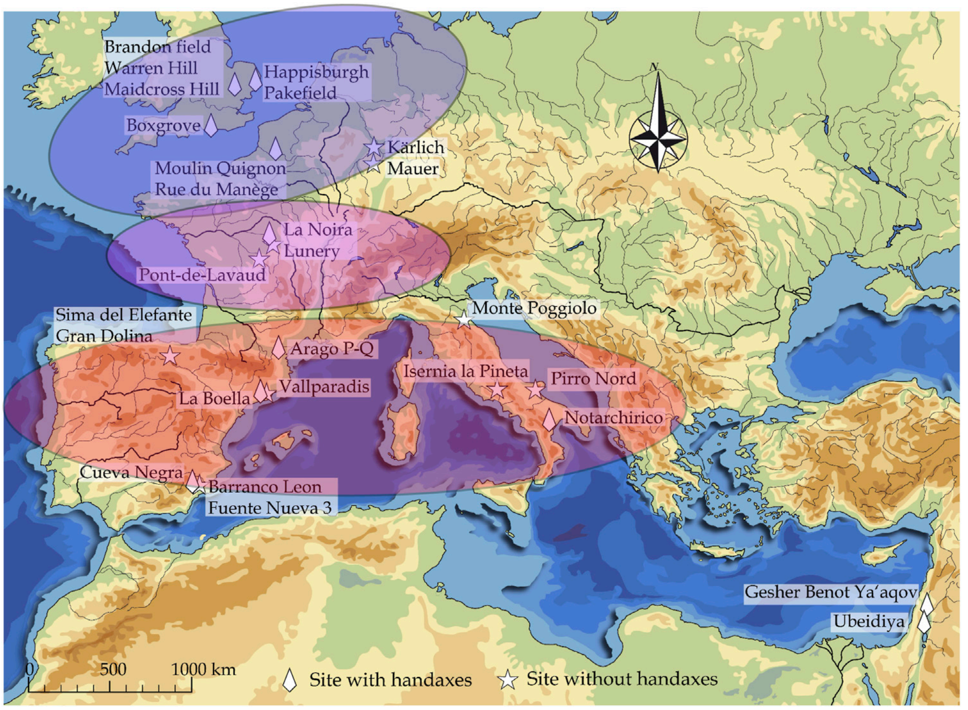

FIGURE 10 | Moulin Quignon in the North of France (North-Western biome) and the main sites in Western Europe, with or without handaxes.

bifacial tools and other shaped tools, Mode 2 and Acheulean). For some, the lack of LCTs associated to some innovations in core technology suggest that the assemblages could be also attributed to Mode 2 or in general to Lower Palaeolithic.

If we focus on some key sites in a narrower timeframe (**Figure 10**; **Table 5**), between 1 Ma and 600 ka where we observe the earliest evidence of a biface shaping in Western Europe, we observe the following strategies:

(1) Above the c.45th N:
  - Only core technologies with core-and-flake series (Mode 1): British sites of Happisburgh 3 (MIS 25–21, around 900 ka) and Pakefield (MIS 19 or 17, around 700 ka), French sites of Lunery and Pont-de-Lavaud (MIS 31, ca 1 Ma).
  - Series with core technologies and Large Cutting Tools (LCTs) (Mode 2): British sites of eastern England such as Brandon Field (MIS 15, 600–550 ka ?), French sites of Moulin Quignon (670 ka, beginning of the MIS 16) and la Noira (700–650 ka, end of MIS 17/beginning of MIS 16).

(2) South of the c. 45th N:
  - Only core technologies with core-and-flake series (Mode 1 and Mode 2): Spanish site of Atapuerca Gran Dolina level TD6 (ca 800 ka, Mode 1), Italian site of Isernia-la-Pineta (590 ka, Mode 2).
  - Series with core technologies and Large Cutting Tools (LCTs) (Mode 2): Spanish site of Barranc la Boella (1 Ma–900 ka), Italian site of Notarchirico (650–610 ka) and French site of the Caune de l'Arago, levels P-Q (532 ± 106 ka).

Available Environmental Data for the Earliest Human Occupations

Above the c. 45th North

Above the c. 45th N., the site of Pont-de-Lavaud in the centre of France yielded pollen grains associated with human occupations related to core-and-flake type assemblages and dated to 1.055 ± 0.055 Ma. Pollen grains indicate a forested environment in a very humid warm temperate climate. Hominids were therefore present during an interglacial temperate climate at this mid-latitude (Marquer et al., 2011; Despriée et al., 2018).

Plant and faunal remains from British sites such as Happisburgh 3 (MIS 21, 866–814 ka, or MIS 25, 970–936 ka) and Pakefield (MIS 19 or MIS 17, about 750–680 ka) attest however that the climate was rather continental and cool for occupations dated between MIS 25 and 17 at this latitude (Parfitt et al., 2005; Parfitt et al., 2010; Farjon et al., 2020). These two sites yielded series of cores and flakes, with no evidence of biface production. At Happisburgh 3, artefacts are associated with *Pinus* and *Picea* pollens and conifer wood and pine cones, indicating regional conifer-dominated forest. Temperature estimations point to mean summer temperatures between 16 and 18°C and mean winter temperatures between 0 and −3°, with similar conifer-dominated woodland to that of present-day southern Scandinavia. Local grassland is indicated by the range of grazers (*Equus suessenbornensis,* Bovidae and *Microtus* spp.) and indirectly, by preserved pollen from hyaena coprolites. Mammals include *Mammuthus* cf. *meridionalis,* Bovidae, *Equus suessenbornensis* and at least two species of *Mimomys*.

TABLE 5 | Synthetic data on Northwestern and Southern sites.

	Raw materials	Main features of the debitage	Independency of the stone shape on cores	Preparation of a striking platform	Flake-tools	Bifaces	Heavy-duty component	Percussion	Envrionmental data	References
Happisburgh 3 (UK) 900 ka	Local flint nodules	Unipolar Centripetal Thick flakes	no	Plain butts	Numerous tools	no	no	Freehand hard hammer	Conifer forest Grassland	Parfitt et al. (2010)
Pakefield (UK) 700 ka	Local good quality black flint nodules	Unipolar Centripetal Multidirectional cores Thick flakes	no	Plain butts	some	no	no	Freehand hard hammer	Broad-Leaf woodland	Parfitt et al. (2005)
Brandon Field (UK) MIS 15/14	Local flint nodules	?	?	?	?	Numerous Crudely-made bifaces Ovate bifaces	?	Freehand hard hammer Soft hammer (LCTs)?	Interglacial?	Moncel et al., 2015
Moulin Quignon (FR) 670 ka	Local flint nodules	Unipolar-bipolar convergent centripetal cores Thick and large flakes	One centripetal and orthogonal core	Plain and cortical butts	Around 10%	N = 5 Crudely-made tools and pointed bifaces	Some on fragments of nodule	Freehand hard hammer Soft hammer (LCTs)?	Cold event	Antoine et al. (2019)
Lunery (FR) 1,1 Ma	Local Jurassic silicifications Cubic blocks	Unipolar Crossed Unipolar convergent cores Small flakes	no	Rare	4%	no	Some on blocks	Freehand hard hammer	?	Despriée et al. (2018)
Pont-de-Lavaud (FR) 1,1 Ma	Local quartz blocks and pebbles	Unipolar Bipolar Multidirectional cores Thick flakes and fragments	no	Rare	Few	no	One bifacial tool	Freehand hard hammer Anvil percussion	Forested Warm humid	Despriée et al. (2018)
La Noira (FR) 700 ka	Local millstone slabs	Unipolar Centripetal cores	Some bifacial centripetal cores	Plain and cortical butts	23.4%	N = 8 bifaces (new fieldworks) Diversity of crudely-made	Numerous and divers tools on slab	Freehand hard hammer Soft hammer (LCTs)	End of interglacial Beginning of a glacial event	Moncel et al. (2020a)

(Continued on following page)

TABLE 5 | (*Continued*) Synthetic data on Northwestern and Southern sites.

	Raw materials	Main features of the debitage	Independency of the stone shape on cores	Preparation of a striking platform	Flake-tools	Bifaces	Heavy-duty component	Percussion	Envrionmental data	References
						tools and bifacial tools				
Stratum a		Unipolar and centripetal cores				Largely-shaped bifaces				
Barranc de la Boella (SP)	Local various stones	Unipolar	no	Rare	Some Denticulates, notches	N = 2	Some pebble-tools	Freehand hard hammer	Temperate	Vallverdú et al. (2014)
1 Ma-900 ka 3 localities		Centripetal cores Large and small flakes				Crudely-made 1 pick 1 cleaver-like on flake	Hammers Chopper-cores			Mosquera et al. (2015)
Sima del Elefante TE7-TE16 (SP) 1.2 Ma	Diversified local stones Chert and others	Rare artefacts				no	no		Warm, humid	De Lombera-Hermida et al. (2015)
Gran Dolina TD6 (SP) 800 ka	Local and semi-local Neogene flint dominant quartz	Unipolar Centripetal cores Large and small flakes	no	No	6%	no	Some crudely-made on blocks	Freehand hard hammer Anvil percussion	Warm, humid Woodland, steppe transition	Ollè et al. (2013)
Notarchirico (IT)	Diversified local stones	Unipolar	no	Plain and cortical butt	Around 10%	Diversity of crudely-made bifaces and largely-shaped bifaces	Pebble-tools (some pointed) on limestone	Freehand hard hammer	Interglacial and glacial events	Moncel et al. (2019), Moncel et al. (2020a)
610–695 ka	Chert and radiolarite nodules, limestone pebbles	Centripetal Multidirectional cores Retouched small nodules Small flakes and backed flakes							Temperate and dry (top)	
Isernia-la-Pineta (IT) Level t.3c 590 ka	Local flint and limestone	Unipolar Centripetal cores Small flakes Retouched fragments	Discoid-type cores	Plain and cortical butts	Around 7%	no	Numerous pebble-tools on limestone	Freehand hard hammer	Woodland steppe	Gallotti and Peretto, (2015)

(Continued on following page)

TABLE 5 | (*Continued*) Synthetic data on Northwestern and Southern sites.

	Raw materials	Main features of the debitage	Independency of the stone shape on cores	Preparation of a striking platform	Flake-tools	Bifaces	Heavy-duty component	Percussion	Envrionmental data	References
Caune de l'Arago	Local to 15–30 km long	Discoid-type cores	no	Plain and cortical butt	8%	Diversified bifaces and cleavers on flake	Pebble-tools on quartz	Freehand hard hammer	Interglacial	Barsky and Lumley, (2010)
Levels P-Q	Quartz, quartzite, flint and others	Unipolar cores								
550 ka		Small flakes								

An assemblage of 78 flint cores, flakes and flake-tools has been excavated according to studies from fluvial gravels and laminated estuarine sands and silts or glaciomarginal fans desposited in a proglacial lake complex (Cromer Forest-bed Formation CF-bF) (Gibbard et al., 2009; Gibbard et al., 2011; Gibbard et al., 2012; Gibbard et al., 2018; Hijma et al. 2012; Parfitt et al., 2010; West, 2019; West et al., 2019; Turner et al., 2020; Gibbard et al., 2021; West and Gibbard, 2021).

At Pakefield, macro remains and fauna from the Cromerian Forest-bed indicate warmer summers and mild winters (between 18 and 23°C for summer) with broad-leaf woodland. Macro-remains (*Trapa natans*, *Salvinia natans* and *Corema album*), beetles (*Cybister lateralimarginalis*, *Oxytelus opacus* and *Valgus hemipterus*) and the presence of *Hippopotamus* indicate warmer summers and mild winters (between 18 and 23° for summer). *Mammuthus trogontherii*, *Stephanorhinus hundsheimensis*, *Megaloceros savini*, *M. dawkinsi*, *Bison cf. schoetensacki*, and carnivores (*Homotherium sp.*, *Panthera leo*, *Canis lupus* and *Crocuta crocuta*) make up the faunal assemblage. Pollen analysis indicates an interglacial with broad-leaf woodland including *Carpinus*. *Mimomys savini* and *M. aff. Pusillus* are both present.

The British sites of Brandon Fields, Maidscross Hill and Warren Hill yielded evidence of bifacial technology on flint. The age of the associated sediments was recently dated by ESR-quartz to 550–600 ka suggesting an age of MIS 15-14 for the earliest bifaces in Great Britain (Voinchet et al., 2015; Lewis et al., 2021). However, microfaunal data are not in keeping with the ESR dates, and place these sites in MIS 13 under a landscape of boreal species and open grassland (Candy et al., 2015).

At la Noira, in the centre of France, hominids were present at the end of MIS 17 and the beginning of MIS 16 and disappeared from the area when it became too cold (Despriée et al., 2011; Moncel et al., 2020c). The site is located along the Cher River, a tributary of the Loire River. The substratum of Tertiary lacustrine limestone (stratum a) is overlain by five strata. A coarse slope deposit (Stratum b) is covered by two sequences of fluvial sediments (Strata c and d). The artefacts are associated with the basal coarse sand of stratum b, the lower part of which consists of an accumulation of local "millstone" in Oligocene lacustrine limestone. The earliest archaeological level is located at the bottom of the sequence. The position of the artefacts between the deposition of slope materials on the limestone bedrock and later phases of gelifluction and cryoturbation, would suggest that hominins were present after the period of river incision at the beginning of a cold climatic stage. ESR dates (mean age of 655 ± 55 ka) place this stage at the beginning of MIS 16 (Moncel et al., 2013; Moncel et al., 2015, Moncel et al., 2020c; Moncel et al., 2021a).

Below the c. 45th North

At the Caune de l'Arago (France), levels P-Q are dated back to 532 ± 106 ka by ESR/U-series (Falguères et al., 2015). Sedimentological analysis shows that the Unit I deposit is essentially composed of sands blown into the cave by strong north-eastern winds during a dry and cold phase of MIS 14. The levels yielded assemblages with bifaces (Barsky and Lumley, 2010;

Barsky, 2013). The faunal spectrum includes *Ursus deningeri*, *Cuon priscus*, *Vulpes vulpes*, *Lynx spelaeus*, *Panthera cf. pardus*, *Equus mosbachensis*, *Stephanorhinus hemitoechus*, *Bison* sp., *Ovis ammon antiqua*, *Hemitragus bonali*, *Rangifer tarandus* and *Cervus elaphus* (Moigne et al., 2006). Horse (28%), reindeer (20%) and bear (28%) are the most abundant taxa indicating an open and steppe landscape. The cave was alternately a bear den or a den for other carnivores and a habitat for short-term human occupations.

In Spain, at Atapuerca, Sima del Elefante and Gran Dolina yielded several archaeological levels from this period. At Sima del Elefante, lower units TE7 to TE16 show reversed polarity magnetization attributed to the Matuyama Chron, confirmed by cosmogenic nucleids with 1.2 Ma to TD9 (Parès et al., 2006; Carbonell et al., 2008; de Lombera-Hermida et al., 2015). The occupations were characterised by a humid and warm climate before a period of cooling recorded at MIS 22 (ca. 900 ka). Pollen shows the presence of *Pinus sylvestris*. Unit TE16 is dated to 804 ± 47 ka and 864 ± 88 ka. The luminiscence ages obtained for TE17 are 724 ± 43 ka and 781 ± 63 ka.

Layer TD6 at Gran Dolina, composed of 2–2.5 m of blocks and gravels in a poor clayey matrix, has been divided into three lithostratigraphical units and yielded hominin remains (Carbonell et al., 2005; Carbonell et al., 2010). TD6 has a pre-Matuyama negative polarity (>0.78 Ma, MIS 21) (Blain et al., 2013; Parès et al., 2013) confirmed by biostratigraphy and radiometric dating by electron spin resonance of optically-bleached quartz and U-series methods (Rodriguez et al., 2011; Duval et al., 2018). Sub-unit TD6-2 is characterised by warm and humid climatic conditions (continental Mediterranean climate) (Rodriguez et al., 2011). The landscape indicates open woodland and steppe. This can be correlated with the transitional phase of forest development during a cold to warm climatic transition (possibly correlated with the MIS 22/21 transition). A moderate increase in the presence of open dry taxa occurs in several samples from sub-unit TD6-3 to TD6-1 and indicates steppe habitats in a mosaic environment.

The site of Barranc de la Boella in Spain is located in a fluvio-deltaic area with an aquatic environment. Six lithostratigraphic units (Units I–VI, from bottom to top) are described (Mosquera et al., 2013; Vallverdú et al., 2014; Mosquera et al., 2015; Mosquera et al., 2016), including one with crude bifacial tools. Fieldwork has been carried out in three different localities, at the same stratigraphic position: Pit 1 (P1), la Mina (LM), and el Forn (EF). Fossils recovered up until now are almost exclusively from Unit II (Vallverdú et al., 2014). The P1 faunal sample is almost entirely composed of mammoth remains, associated with a lithic sample of more than 100 remains, including a pick and a cleaver cited as proof of the early arrival of Acheulean technology in Europe. A solid geochronological age for the lithic assemblages found in BB Unit II could indicate a position in the late Early Pleistocene or late Matuyama Chron (0.96–0.78 Ma). The presence of *Mammuthus meridionalis* and the morphology of *Mimomys savini* molars from the top of Unit II at the three localities support the age of the archaeological deposits. The faunal assemblage of level 2 (Unit II) of the Pit 1 locality is dominated by *Mammuthus meridionalis,* associated with a few *Dama* cf. *vallonetensis* and *Equus* sp. (Pineda et al., 2015; Pineda et al., 2017).

Notarchirico in Italy is a 10-m-thick fluvial-derived sedimentary sequence rich in volcanic materials from the Monte Vulture stratovolcano (Piperno, 1999; Lefèvre et al., 2010). Hominins circulated regularly along these water channels or lakeshores. Several radio-isotopic methods (ESR and $^{40}Ar/^{39}Ar$) were applied to quartz grains and volcanic minerals (mainly sanidines and clinopyroxenes) in the sediments. The results constrain the period of occupation of this site to between 695 ± 6 ka and 614 ± 12, spanning the entire cold stage MIS 16 and the end of MIS 17 (Pereira et al., 2015; Moncel et al., 2020b). The site thus records one of the earliest known occurrences of bifacial technology in Southern Europe (levels B, D, F, G) (Piperno, 1999; Moncel et al., 2020a; Santagata, et al., 2020). Raw material procurement and core technology are similar throughout the sequence and focus on the production of small flint end-products. The oldest handaxes found at Notarchirico (levels F and G) are now securely dated to more than 670 ± 4 ka and prove that hominid populations lived there as early as at the beginning of MIS 16 and at the end of the MIS 17. The faunal remains found in the lower levels (E/E1, F, and G) are *Elephas antiquus*, *Dama clactoniana*, *Bos primigenius*, and *Bison schoetensacki.* The faunal assemblage of Notarchirico belongs to the "Ponte Galeria" faunal unit. From the microfaunal point of view, micro-mammals indicate a dry climate typical of the Middle Pleistocene glacial period in the Italian peninsula. Results from the top of the sequence show that vegetation was characteristic of open and cold environmental conditions with *Poaceae* meadows (Piperno, 1999).

The stratigraphy of Isernia-la-Pineta (Italy), near Notarchirico, is composed of five units (Gallotti and Peretto, 2015). Unit 3 contains the archaeological deposits and is sub-divided into three sub-units. Unit 3a is the richest level, composed of a high concentration of flint and limestone artefacts (without bifaces). Recent $^{39}Ar/^{40}Ar$ dates of 583–561 ka corresponding to the MIS 15/MIS 14 transition were proposed by Peretto et al. (2015) for this site, based on more than 90 single crystal sanidine dates. The faunal list is composed of *Elephas (Palaeoloxodon) antiquus*, *Hippopotamus* cf. *antiquus*, *Stephanorhinus hundsheimensis*, *Bison schoetensacki*, *Praemegaceros solilhacus*, *Cervus elaphus* cf. *acoronatus*, *Dama* cf. *roberti*, *Capreolus* sp., *Sus scrofa*, *Hemitragus* cf. *bonali*, *Panthera leo fossilis*, *Panthera pardus* and *Homo*. The most abundant carnivore remains are those of *Ursus deningeri* (Thun Hohenstein et al., 2009; Peretto et al., 2015). The large number of herbivores indicates that the Isernia region was an area of open vegetation of woodland steppe, rich in pastures, with bison herds and numerous pachyderms during the MIS 15/MIS 14 period (Thun Hohenstein et al., 2009; Pineda et al., 2020). This kind of environment indicates a climate with a long and arid season coupled with a shorter one with concentrated annual rainfall (Lebreton, 2002; Orain et al., 2013).

Hominin Strategies in North-Western Europe

The technical features of the flint industry identified in the Cromer Forest bed formation at Happisburg 3 and Pakefield (Great-Britain, ~900 and 700 ka) are difficult to evaluate due to the limited number of lithic pieces in local flint (Parfitt et al., 2005; Parfitt et al., 2010). However, it is possible to observe: 1) thick platforms and open angles on flakes, 2) unipolar and centripetal removals on flakes, 3) opportunistic cores on flint nodules. These features are common to the French sites of Lunery and Pont de Lavaud dated around 1 Ma ago (Despriée et al., 2017a; Despriée et al., 2018) (**Table 5**). At Pont-de-Lavaud (de Lombera-Hermida et al., 2016; Despriée et al., 2018), debitage is only on quartz pebbles with short sequences of freehand percussion or anvil percussion (bipolar debitage).

These features are similar to those of the Moulin Quignon corpus of flakes and cores, perhaps due in part to the common use of local flint nodules, except for the quartz series of Pont-de-Lavaud. The flake reduction process consists mainly of knapping large flakes. Cores indicate either crude and opportunistic flaking, using the natural blank shape on one or multiple surfaces. Some cores show no links with nodule shape and thus indicate the limited constraints of blanks and a degree of independence from the raw material.

At the French site la Noira (Centre of France) (stratum a, 700 ka) (Moncel et al., 2013; Moncel et al., 2015, Moncel et al., 2020c), hominins used local millstone slabs, a type of silicification in Oligocene lacustrine limestone, available in huge quantities on the riverbank in deposits covering the valley slopes. Hominins recovered millstone quadrangular slabs *in situ* for flaking or shaping. They focused on this raw material despite the presence of some other materials, in the same way as at Moulin Quignon. Slab shape is conducive to the first phases of debitage and shaping processes with the use of the flat natural surfaces. Cores and bifaces are always on good-quality stone, suggesting that stone selection was linked to production and management aims. The selection of the thickness and the shape of the slab or slab fragment was a priority for bifaces and structured cores. This selection indicates the flexibility and adaptability of hominins to the diversity of available slabs. Core technology is the predominant activity at the site, with two main "chaînes opératoires"; one devoted to the production of small flakes and the other to large flakes.

For LCT technology, the British sites of Brandon Fields, Maidscross Hill and Warren Hill, dated to MIS 15/14 (Voinchet et al., 2015; McNabb et al., 2018; Lewis et al., 2021), yielded flint bifaces made by deep removals and thinner tools (oval, cordiform) made by a series of removals with final working of the cutting edges and the tip. All the assemblages are made on locally available flint nodules from fluvial gravels (Bridgland and White, 2015; Moncel et al., 2015). These series are made up of two groups of bifaces with varying ratios, with crudely fashioned bifaces made with a hard hammer and thin ovates and cordiform bifaces (made with a soft hammer with final retouch, with a symmetrical shape and cross-section, sometimes with a "tranchet flake" removal across the tip).

These features are similar to the bifaces found at Moulin Quignon, with diversified shapes and shaping modes.

At la Noira, stratum a (700 ka), the assemblage combines two groups of artefacts: one with high levels of investment and complexity (bifaces, small flakes), and one showing less complex, opportunistic and expedient behaviour (partial tools, cleavers, heavy-duty tools, large flakes). As at Moulin Quignon, shaping technology produces tools with varied shapes and more or less invasive removals. The material indicates the ability to manage the contour and biconvex symmetry and shows that standardized and structured rules were applied even though the morphological results are diverse. The shape of some final removals may possibly indicate the occasional use of a soft hammer (some thin and invasive removals). Cross-sections are plano-convex or symmetric, regardless of categories and the final morphological result (Garcia-Medrano et al., 2022). They attest to the limited role of slab morphology. The final retouch could represent resharpening in some cases and confirms controlled tool edge management. The use of elongated and thin slabs could explain the longer size of the bifaces compared to Moulin Quignon.

Are North-Western Technological Strategies Similar to Southern Traditions?

The lithic series from level TD6 of Gran Dolina (Atapuerca, Spain, ~0.8 Ma; Falguères et al., 1999; Parés et al., 2013; Duval et al., 2018) are made from all the available suitable raw materials from the surrounding areas. Neogene flint is the most abundant rock type and large blocks were flaked outside the cave (Carbonell et al., 1999; Mosquera et al., 2018). Few of them are large flakes, and they never exceed 10 cm. Core technology is mainly multifacial and orthogonal with no striking platform preparation. Bipolar exploitation on an anvil appears to be reserved for quartz (Ollé et al., 2013). Retouched thick flakes, mostly on flint, total 6% of the artefacts.

At Barranc de la Boella, Spain (Vallverdú et al., 2014; Mosquera et al., 2015), the localities yielded mainly flakes and cores, but also pebbles (hammerstones), pebble tools and chopper-cores on various local stones. Debitage is unipolar or centripetal, adapted to stone shapes with rare preparation. There are, in this case, some crudely-made LCTs, including a pick and a cleaver-like tool on a large flake, indicating sporadic bifacial shaping.

One of the earliest occurrences (levels B, D, F, G) of bifacial technology in Southern Europe is found at Notarchirico, Italy, (Piperno ed, 1999; Moncel et al., 2019; Moncel et al., 2020a). Raw material procurement is local and core technology is similar throughout the sequence, focusing on the production of small flint end-products by the freehand knapping of small flint nodules of chert or limestone pebbles. Raw material shape strongly impacts core technology. Flint end-products and cores (20–40 mm) are small in size. Retouch modifies the initial shape of the small flakes. It is often abrupt, in particular on the small retouched nodules which are directly retouched.

The diversified heavy-duty component displays little standardization and include numerous pointed chopping-tools and rare pseudo-cleavers on limestone pebbles. Hominins used local cobbles/pebbles, available in large quantities along the lakeshore. Some bifaces on quartzite, limestone and flint pebbles or flakes are bifacially shaped by more or less invasive series of deep removals, and then, in some cases, rectified by a second series of small removals on the tip. Cutting edges are irregular and the cross-section of bifaces is asymmetrical. They are rather small in size (on average, 100–120 mm long) compared to Moulin Quignon and la Noira.

The slightly younger assemblages of Isernia-la-Pineta level 3 (585 ± 1 ka; Peretto et al., 2015; Pereira, 2017), did not yield bifaces but contain an abundant heavy-duty component on pebbles and evidence of more complex debitage management (Gallotti and Peretto, 2015; Lugli et al., 2017). The lithic assemblage corresponds to well-established mental templates despite the lack of bifaces. Knappers mainly used a discoid knapping method, regardless of the size and shape of the original blank, for producing medium-sized flakes that could be retouched into tools.

At the Caune de l'Arago (France), in levels P-Q (MIS 14), discoidal working was applied to quartz or siliceous stone cobbles from 15–30 km away. Retouched flakes are abundant and mainly pointed. Bifacial tools on a variety of raw materials include well-worked bifaces of various sizes with overall volume management by a series of invasive bifacial removals and with final retouch. There are also some cleavers on flakes (Barsky and Lumley, 2010; Barsky, 2013).

Common or Variable Traditions Over Western Europe Whatever the Environmental Context?

The comparison of the lithic assemblage of contemporaneous sites shows shared behavioural traits despite very different geographical locations and mineral environments, with only flint and siliceous stones for the northwest and diversified stones for the south. This tends to suggest a common cultural background throughout Western Europe, regardless of climatic conditions, and possibly among a metapopulation.

We observe: 1) the predominant use of local raw materials and no evidence of stones brought to sites from distant outcrops, 2) occasional complex large and small flake production (core technologies), 3) adaptation to stone constraints suggesting flexibility and some evidence of flaking independently of stone geometry, 4) low ratio of bifaces, when present, and association of elaborate bifaces and partial bifacial tools, 5) diversity of shaping modes and forms for bifaces and bifacial tools (non-standardization) with some evidence of soft percussion, 6) lack of cleavers on flakes in north-western territories, and 7) rare use of large flakes for making the heavy-duty component or for knapping (little evidence of fragmentation of the reduction processes).

Location and Type of Site

The available sites are mainly open-air habitats beside rivers, lakes or swamps, except some sites in caves. This may be due to the low number of sites for this long period of time and conservation conditions. However, it may also indicate common patterns of territory and resource management. Regardless, such locations allow for easy access to quantities of local raw materials, as the sites are located on shores with abundant stones, and herbivore carcasses. Faunal remains indicate, when preserved, accumulations of large herbivores, including megaherbivores, along rivers and possibly scavenging and butchery activities in competition or not with carnivores (i.e., Barranc de la Boella, Notarchirico, Isernia-la-Pineta) (Piperno, 1999; Vallverdu et al., 2014; Gallotti and Peretto, 2015; Mosquera et al., 2015; Pineda et al., 2017; Moncel et al., 2020b). When visible, cut marks and fragmented bones demonstrate meat processing, butchery and scavenging on herbivore carcasses of different sizes, including megaherbivores (Pineda et al., 2015; Pineda et al., 2017; Pineda et al., 2020). Sites seem to be either multi-activity sites (la Noira; Hardy et al., 2018) or specialized sites (possibly scavenging sites at Isernia-La-Pineta (Longo et al., 1997; Thun Hohenstein et al., 2009; Pineda et al., 2020). They point either to mobile groups using local raw materials with little evidence of semi-local stone procurement, or less mobile groups with strong ties to a specific place and environment (Gallotti and Peretto, 2015; Mosquera et al., 2015; Ollé et al., 2016). Isotopes of strontium on the human tooth of Isernia-La-Pineta indicate the relatively limited mobility of the corresponding individual (Lugli et al., 2017).

No correlations have been established at la Noira between types of tools and function, and crudely-made bifacial tools appear to have been used in the same way as bifaces (Hardy et al., 2018). This suggests that the lithic assemblage could represent above all a cultural package, and not merely tool kits devoted to specific functions. Sites described as butchery sites for large herbivores of the same age indicate that small flakes were widely used and were possibly as valuable as heavy-duty tools for these activities (for instance Isernia-La-Pineta in Italy, Thun Hohenstein et al., 2009; Pineda et al., 2020).

Raw Materials

Raw material procurement is mainly local and related to the type of site (along water areas and rivers). Hominins used various available stones, such as cubic blocks, slabs, nodules or cobbles/pebbles and selected stone quality or thickness depending on the type of activity (Moncel et al., 2020c; Santagata et al., 2020). Medium or large-size nodules or slabs of local flint are used at Moulin Quignon and millstone slabs at la Noira while small chertlocal nodules were recovered at Notarchirico, mainly for debitage or direct retouch. Limestone pebbles are collected à Notarchirico for pebble tools and LCTs. At Moulin Quignon, all the parts of irregular flint nodules were used, even some rounded extremities. Nodule quality is mainly good. At la Noira, raw material quality seems to have been a criterion for selection, and slabs with no evidence of frost cracking were chosen (Despriée et al., 2016; Moncel et al., 2020a). Three main lithotypes were identified at Notarchirico for the small nodules used for the debitage or direct retouch: silicified calcarenites (flysch chert), nodular chert (carbonate platform) and radiolarite (basin) (Synthem of Palazzo San Gervasio (Eramo et al., in Moncel et al., 2020b). No clear selection of a specific type of chert or radiolarite is observed, whatever the occupation phase. Selection seems to have focused on nodule size and shape, for flaking or direct retouch (thick and flat small nodules for abrupt and denticulate retouch). At Pont-de-Lavaud, quartz was used, perhaps as a result of its abundance near the site (Despriée et al., 2018). The only exception is the Caune de l'Arago with some long-distance stones collected in a perimeter of 15–30 km, especially for debitage and LCTs (Barsky, 2013).

Core Technologies

Flaking comprises long and short sequences of removals, showing a diversity of hominin skills and cognition (unifacial and multifacial, bipolar or discoid-type). However, flaking sequences cannot always be considered as expedient. We observe adaptation to the shape of the blank with common rules, even on quartz. These rules indicate flexibility and a selection of stone shape for the best results. Platforms are prepared if necessary. Some reduction sequences are more structured and more independent of blank shape and fully managed on good-quality stones, as clearly observed at la Noira, Moulin Quignon and the slightly younger site of Isernia-la-Pineta.

Product size is highest at la Noira and Happisburgh (flakes >145 mm), as a result of flaking nodules or slabs, and smallest at Moulin Quignon on medium-sized nodules. At Notarchirico, the use of the small available nodules results in very small flakes (10–20 mm) and very small and thin cubic nodules are sometimes directly retouched. However, there is not always a strict correlation between the natural blank and product size. Small flakes (40 mm long) are also produced at la Noira on millstone cores and large flakes (80–100 mm long) are obtained from large cobbles at Notarchirico (**Supplementary Figures S1–S3**).

Platform angles are acute for plain and thick butts at Moulin Quignon, Happisburgh 3 and Pakefield, and more obtuse (80–90°) on slabs at la Noira and small cubic nodules at Notarchirico. The impact of stone shape alone cannot explain production aims. We observe thicker and more robust flakes in the northwest with acute retouched and unretouched cutting edges. Relationships with activities must be examined.

The ratio of flake-tools differs (mainly unilateral or bilateral retouch and some notches) depending on the site and TD6 and Happisburgh 3 seem to be an exception for Mode 1 series. In most sites, flake-tools bear one or several retouched cutting edges. Angles are mainly dependent on the type of raw material, and are lower for flint with acute unretouched angles. The diversity of the number of retouched edges, creating simple, multiple or an association of simple tools on the same blank, can be correlated to needs. At the Caune de l'Arago, discoidal working was applied to quartz or siliceous stone cobbles from 15–30 km away. Retouched flakes are abundant and mainly pointed.

Bifaces and Large Cutting Tools

The number of bifaces with overall volume management is low for each site and we cannot assess whether or not these tools were more mobile than other tools. Raw materials are local. Despite the small numbers, the series associate various intensities of shaping, with crudely-made tools and very reduced bifaces. The artefacts from la Noira illustrate the diversity of the heavy-duty component, with diverse heavy-duty tools made on irregular fragments of slabs (Iovita et al., 2017; Moncel et al., 2020c).

Series are characterised by the diversity and lack of standardization of bifacial tools and the heavy-duty component, although some are more homogeneous, due to the raw materials. Cutting edge angles vary depending on the sites and stones, as does biface size, which is smaller at Notarchirico, longer at la Noira. However, we have to keep in mind that some bifaces, like at Brandon Field, Moulin Quignon and la Noira, may have undergone resharpening, resulting in decreased tool size. Raw material size could also partly explain the diversity of biface size (**Supplementary Figure S4**). At Caune de l'Arago, bifacial tools on a variety of raw materials include well-worked bifaces of various sizes with overall volume management. There are also some cleavers on flakes.

Strategies and Behavioural Solutions for North-Western Europe?

The limited number of sites and the diversity of contexts hinder comparisons of the specific features of each site and the investigation of adaptation to colder climates and environmental contexts. Stone types do not seem to be associated with specific flaking methods, except for quartz. Debitage modes on siliceous rocks are similar, with adaptation to stone shape (slabs, nodules…). Flaking products differ according to raw material size, ranging from large flint flakes in the northwest of Europe to mainly small flakes in the South of Italy. Observations are similar for LCT management and production. We also observe a wide diversity of cutting edge angles among the light and heavy-duty component, possibly pointing to diverse functional tool kits and cultural packages. The diversity of skills, routines and strategies among populations in Western Europe between 1 Ma and 600 ka seems to have been favourable to adaptation to varied environmental contexts.

In Moncel et al. (2018a), we discussed current data from the archaeological record for which the climatic context cannot be accurately assessed. The link between global climate variations and regional environments is difficult to establish for this period of time. During the main Middle Pleistocene glacial periods such as MIS 16 and MIS 12, the ice sheet probably had an impact on hominin occupations in Eurasia, erasing northern evidence of human sites from previous interglacials. In addition, many sites are not dated accurately enough to be confidently correlated with regional climatic and palaeoenvironmental records. The position of a human occupation cannot always be strictly linked to a glacial or interglacial solely on the basis of age and stratigraphic position. On the other hand, faunal remains and thus biostratigraphy are markers of specific environmental conditions. Furthermore, occupation duration (i.e., seasons, months, years?) in a specific site cannot be directly appraised. The archaeological characteristics of sites are related to hominin occupation and faunal assemblages can be biased by the nature of the site (e.g., butchery site, seasonal settlement) or by the origin of the fauna (selective hunting, opportunistic butchery…).

At northern sites, records indicate that hominin occupations took place either in dry steppic environments or woodland settings. Some sites yield more reliable environmental data based on multiple proxies such as the British sites (Happisburg 3 and Pakefield), while others are less relevant due to the lack of well-preserved remains (Bytham River sites, Somme Valley sites) (Antoine et al., 2007; Gibbard et al., 2009; Candy et al., 2015). For la Noira (Centre France), hominins disappeared when very cold and dry conditions emerged at the beginning of MIS 16, considered as one of the harshest glacial phases since 1 Ma. This would account for the chronological gap in hominin occupations in the Centre of France and in the Somme Valley between 700 and 500 ka ("bottleneck") up until now (Despriée et al., 2011; Moncel et al., 2020a).

In Southern Europe, if we enlarge the chronological span of the study, Spanish sites suggests recurrent humid and warm environments during occupations but steppic environments are also recorded, for instance at Orce dated to around 1.2 Ma (Rodríguez et al., 2011; Huguet et al., 2013; Rodríguez-Gómez et al., 2014; Rodríguez-Gómez et al., 2016; Blain et al., 2021). At Atapuerca, the early sequences of Sima del Elefante, lower units TE7 to TE16 (Parès et al., 2006; de Lombera-Hermida et al., 2015) were characterised by a humid and warm climate before the cooling recorded from MIS 22 onwards (ca. 900 ka) (Cuenca-Bescós et al., 2011; Blain et al., 2013; Parès et al., 2013). Then the landscape indicates open woodland and steppe correlated with the transitional phase of forest development (possibly correlated with the MIS 22/21 transition) (Rodriguez et al., 2011). The site of La Boella (0.96–0.78 Ma) indicates a mixture of temperate environments (Vallverdú et al., 2014; Mosquera et al., 2015; Mosquera et al., 2016). In Italy and the South of France, dry MIS 16 or 14 environments are associated with occupations, such as Notarchirico, in both MIS 17 and 16, without clear differences in fauna and occupation along lakeshores or water channels (Pereira et al., 2015; Moncel et al., 2020b). This suggests less intense glacial phases in the south compared to the north.

The possibility, that Northwest Europe, including Northern France and Southern England, was at the limit of the "Oekoumen" of *Homo heidelbergenis* of hominins leaving in Europe at that time, especially during the severe MIS 16 glacial event (around 650–620 ka), has be discussed by the scarcity of ocupations. Evidence of occupations during interglacial events or at the transition are more common (see for instance Boxgrove, MIS 13, Souther England; Robert and Parfitt, 1999; Pope, 2002; Leroyer, 2016; Pope et al., 2017). However, some traces of occupations show that hominins could tolerate the environmental conditions and especially cold conditions during glacial events as "permanent residents" or "punctual visitors" (cf. Cohen et al., 2012; MacDonald et al., 2012) and outperform their capabilities and not completely depopulate these territories. Southern climatic data suggest that humidity and temperatures were the two main prerequisites for human occupations (Jouzel et al., 2007; Joannin et al., 2011; Combourieu-Nebout et al., 2015). Pakefield climatic data suggest cold winters but some faunal and plant evidence suggests that low temperatures were possibly rare (Parfitt et al., 2005). To settle these north-western territories, with cold and arid climates, with similar technologies, hominins may possibly have developed specific strategies that cannot be seen in the stone tools. Due to the low quantities of human fossils, no discussions or comparisons of the anatomy of hominins living in Northwest Europe can be undertaken. Indeed, the Mauer mandibule found in Germany merely gives us an idea of the robustness of the hominin living at this latitude (Wagner et al., 2010; Wagner et al., 2011; Fiedler et al., 2019), but we have no idea of the anatomical plasticity of hominins such as *Homo heidelbergensis* during long periods of slow climatic changes (Hosfield and Cole, 2018). de León et al. (2021) show that the brain size of *Homo* enabled him to adapt to various scenarios and environments. So far, there is no evidence of the use of fire and taphonomic processes could have destroyed traces of fire if it existed before MIS 11 (i.e., Ashton et al., 2016; Gowlett, 2016). Faunal remains are not preserved at Moulin Quignon or at la Noira for instance. However, at Notarchirico and Isernia-la-Pineta, the bones do not show any evidence of the use of fire and the scant evidence recorded at the Caune de l'Arago could be due to wind or water transport of micro-charcoals (Deldicque et al., 2021). Seasonal mobility and visits of human groups following migrations of herds and big game could explain the sporadic presence of hominins in these northern regions (i.e., Dennell et al., 2011; Fielder et al., 2019). However, we also have to consider the possibility that hominins could permanently occupy these areas and find strategies to survive in more or less harsh or mild episodes.

Despite footprints suggesting bare feet in some situations and family groups moving in swamps to find food (wet sediments at Happisburgh; Ashton et al., 2014), various solutions can be envisaged to survive winter conditions with clothes (animal skins) and increased energy intakes, ingesting the necessary quantity of food and high nutrition (fat) by extracting animal marrow or collecting plants for instance. Ashton and Lewis, 2012, Ashton, 2015; McDonald et al., 2018, Hosfield et al., 2016 and Hosfield and Cole, 2018 have developed detailed accounts of what was required to survive cold conditions in these latitudes. We also have to bear in mind that hominins could have occupied smaller and specific areas with microclimates, such as sunny parts of valleys or slopes protected from cold winds. Summers (as indicated by the mean temperatures estimated at Happisburgh 3 and Pakefield) may have been warmer than winters with sub-zero temperatures, few available plants and short daylight hours. Food storage could have been practised during winter, facilitated by a diversity of tools, combining light-duty and heavy-duty tools such as bifaces with long functional cutting edges. Moreover, the diversity of the landscape and rich environmental resources (i.e., around Happisburgh and Pakefield) could have been favourable to collecting plants (berries, nuts,. . .) for winter, as well as the large river estuary near the coast (marine and terrestrial resources) (Ashton et al., 2014). Preece and Parfitt, (2012) indicate cut marks on bison bones from Happisburgh (series collected in 1870s). Similar situations may have occurred at Moulin Quignon, located along the Somme Valley close to the confluence with the Scardon River (hot spot for large mammals?), with herds of game, or at la Noira along a tributary of the Loire River. Animal carcasses and plant resources could have been collected to prepare winter. The sites of Notarchirico and Isernia-la-Pineta in Italy confirm that hominins sought out banks of water zones for recovering meat on large herbivore carcasses

(Elephants, bison, horses and cervids) or for hunting (Ben-Dor et al., 2011). At Carpentier Quarry (Antoine et al., 2016), new excavations have revealed that abundant fauna lived there during the deposit of the White Marl (MIS 15) with bovids, cervids, proboscideans, rhinoceros, horse, wild boar, indicating grassland and wooded areas. In Northern France, more than 20 taxa have been recorded during such interglacial phases (Auguste, 2009). Hominins at Moulin Quignon at the glacial/interglacial transition, or possibly during a short cooler event (unrecorded in the sequence), could have discovered this diversity of animals before the onset of cold conditions (Antoine et al., 2019). At Cagny-la-Garenne (Somme Valley, beginning of MIS 12, top of gravels), the fauna was composed of elephants, horses and cervids in a steppe-type landscape (Auguste, 1995; Auguste, 2009; Auguste, 2012).

The hypothesis of a strong relationship during the Middle Pleistocene between hominins and megafauna such as elephants is attractive for explaining the ability to occupy diversified territories even in the northwest (i.e., Reshef and Barkai, 2015; Solodenko et al., 2015; Barkai, 2016). Hominins would have taken advantage of the plentiful carcasses available along water areas with easy primary access and residues and micro-wear traces indicate domestic activities (Hardy et al., 2018; Moncel et al., 2020c). The sequence of the Caune de l'Arago illustrates the possible functional link between bifaces (LCTs) and megafaunal remains (i.e., elephant), during cold events (for instance MIS 14), suggesting that these tools could have been efficient and useful for cutting up large herbivore carcasses (Barsky and Lumley, 2010; Barsky, 2013).

CONCLUSION

In Western Europe, from 700 ka onwards, we sporadically observe new behaviours, such as the possible amplified mobility of human groups, increased selection of raw materials, large and small heavy-duty tools, and curated tools destined for diverse functions, along with some innovations in core technologies. Hominins applied similar strategies and similar evidence of innovations emerges, whatever the environments, indicating adaptation to varied geological, climatic and topographic environments.

European Acheulean assemblages point to strategies with shared basic features, perhaps partly imputed to raw material constraints, activities and diverse traditions, as well as multiple scenarios of dispersals and adaptation to local environments in relation to the climate and extension of territories (Schreve et al., 2015).

Can we describe specific modes of hominin adaptation and cognition to cool or cold climates? The technological data from new fieldwork at Moulin Quignon do not identify original features in Northwest Europe, but rather an ability to adapt behaviour to local and available raw materials, flint nodules, like for the British sites.

Did small groups of hominins in the northwest make short incursions during cooler periods or occupied the area at the onset of a glacial event as at la Noira, leaving the northern region when to cold? We have no evidence of this, but it is likely that small mobile and pioneering groups settled in large territories in Europe and northern latitudes Dennell et al., 2010. This would perhaps indicate higher densities of hominins in Western Europe from 700 ka onwards. This mobility and density of human groups in larger territories raise questions about climatic conditions. The Moulin Quignon series shows that technological behaviours and toolkits are preserved, indicating a complex geographical dispersal of possibly fragmented populations of foragers and collectors in northern areas (cf. Bennett and Provan, 2008; Stewart et al., 2010; Perreault and Brantingham, 2011; Derex et al., 2013; Derex et al., 2016; Andersson and Read, 2014; Kolodny et al., 2015; Grove, 2016; Vaesen et al., 2016; Fogarty and Creanza, 2017; Derex et al., 2018; Fay et al., 2019; Grove, 2019). This does not imply changes in strategies over Western Europe, paleoclimatic data suggesting that hominins appaear to have favoured treeless and open environments in preference to closed forests. New environments did not entail changes in behaviour and we cannot suggest that local extinctions of human groups in unfavourable environments led to decreased cultural diversity or changes in the structure of groups, as we observe the same features among different cultural traditions (cf. Premo and Kuhn, 2010; Kolodny et al., 2015). Who occupied Moulin Quignon and made the bifaes at Barranc de la Boella, la Noira and Notarchirico between 900 and 700 ka? Only Notarchirico yielded a fragment of hominin long bone that is under studied. If the earliest bifaces were made everywhere by what we name *Homo heidelbergensis*, this or possibly these hominins seem to have been more resilient and able to adapt to a higher diversity of climatic and environmental conditions than the earliest populations of hominids in Europe, *Homo antecessor?*

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

Article design: M-HM. Initiative of the re-study of the site: AH. Material analyse: M-HM. Writing: M-HM, PA, and J-JB. Editing writing: M-HM, PA, J-JB, DA, and AH. Fieldworks: PA, M-HM, DH, and J-LL. Figures: M-HM, PA, and DH.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feart.2022.882110/full#supplementary-material

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