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# Innovations in Acheulean biface production at la Noira (France) during Middle Pleistocene in Western Europe

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## Abstract

The archaeological sequence of la Noira (Centre region, France) yielded two phases of occupation: ca 700 ka (stratum a) and ca 450 ka (stratum c). No site between these two dates has yet been discovered in the area, and this chronological period has thus been interpreted as a gap in settlement from MIS 16 to MIS 12, two crucial phases of occupation in Western Europe. The record before the long glacial event MIS 12 has been traditionally associated with the onset of the Acheulean in Europe. From MIS 12, the record represents the earliest evidence of innovations, a clear shift in human evolution. Here, we compare these two levels (stratum a and c), tracking the technological innovations during this time, and combining technological analysis with geometric morphometrics with the use of 3D models comparison of the Large Cutting Tools (LCTs). Stratum a yielded an Early Acheulean, one of the few evidences in Europe presents tools with mainly short shaping sequences on local millstone slabs, with special attention to tips, but with clear management of tool volume. Stratum c, dated to the MIS 11, differs in that both local millstone and flints from distant sources show longer shaping sequences, the use of soft hammers for several series of removals on tools, combined with final regularizing retouch on entire edges. The morphometric approach shows a morphological transition from oval to teardrop shapes for the thinnest tools. Our data suggest a clear technological filiation between strata a and c and in la Noira populations from MIS 16 and MIS 12, as suggested for innovations of core technologies and land-use patterns, and raise question on local human behavioural evolution over the Middle Pleistocene in Western Europe.

**Keywords:** Acheulean, technology, geometric morphometrics, handaxes, shaping strategies

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The three authors contributed to this work. M.H.M. and J.D. directed the excavation work. P.G. and M.H.M. analysed the materials and wrote the paper. P.G.M took all pictures and 3D models. All authors reviewed the manuscript.

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## 1. Introduction

At the end of the Middle Pleistocene Transition (MPT) in Western Europe, after the Brunhes-Matuyama reversal (780 ka), climatic cycles changed, leading to significant variations in resources. These cycles must have affected the extinction/relocation of small groups of hominins, and subsequent recolonisations, between the two long MIS 16 and MIS 12 cold events (Manzi, 2004; Clark et al. 2010; Muttoni et al. 2010; Almogi-Labin 2011; Rodríguez et al. 2011; MacDonald et al. 2012; Cuenca-Bescós et al. 2011; Bar-Yosef and Belmaker 2011; Pereira et al. 2015; Carrión and Walker 2019). MIS 12 was followed by a long interglacial stage (MIS 11) which marks the beginning of new behaviours and the advent of the Neanderthal technical world (Moncel et al. 2020a). After the MIS 12 glaciation, considered as a major crisis for hominins, archaeological records show a high quantity and variety of occupations, new subsistence behaviours and technical innovations (e.g., Levallois technology, increase in light-duty tools and use of fire), and evidence of an early regionalization of traditions (Moncel et al. 2016, 2020a, 2021; Rodríguez-Hidalgo et al. 2017). Recent data suggest that some technological innovations could be rooted in the past suggesting local evolution (Moncel et al. 2021a). These behavioural changes suggest increased cognition with new skills and social interactions among European populations (Moncel et al. 2015, 2018a, b, Peretto et al. 2016). During the Early to Middle Pleistocene transition, between 1.2 and 0.5 Ma, the increasing duration and severity of cold climatic phases have had deep effects on the landscape and thus available territories for hominin occupations (MacDonald et al. 2012). During the coldest phases, temperate-adapted animal and plant species survived in some glacial refugia in southern Europe. The period after 0.9 Ma was increasingly controlled by 100 ka periodicity, with longer and relatively stable climatic events, progressive temperature decline and increasing aridity, marked oscillations between highly contrasting landscapes, greater seasonality, and increasingly specialized mammal communities (Kahlke et al., 2011). These changes became especially marked after c. 500 ka (Berger and Loutre, 1991; Lisiecki and Raymo, 2005). Perhaps critically from the perspective of hominin distribution and dispersal, these changes were accompanied by regional shifts in characteristic habitat types. After 725-650 ka, the duration of climatic cycles increased to approximately 100,000 years, during which time temperatures fell rapidly at the onset of a glacial cycle. In northern Europe, MIS 16 (621-659 ka), MIS14 (528-568 ka) and especially MIS12 (427-478 ka) were particularly severe (MacDonald et al. 2012).

Among other kinds of behavioural innovations, the Acheulean has been traditionally defined by the emergence of a new tool with bifacial management of volume: the handaxe (Roche, 2005; Gowlett 2006), which has been considered as evidence of new skills and changes in human cognition (Wynn 2002; Stout 2011). Due to the effectiveness and the versatility of this type of instrument, handaxes persisted for more than 1 Ma over a vast geographical area (Moncel et al. 2018c). This tool first appeared in East Africa around 1.75 Ma, but is not present in Western Europe before 900 ka and especially present from 700 ka onwards. In spite of apparent technological stability, this kind of instrument encompasses huge variability in terms of production, as well as in terms of the morphological outcome of shaping processes. Strata a and c of the la Noira site, located in the centre of France, and the large corpus of handaxes are appropriate case studies for tracking technological behaviours common to both levels and identifying innovations over time. We aim to discuss two crucial phases of hominin settlement in Western Europe but also to contribute to hypotheses positing either a filiation between European populations over time or arrivals of new populations introducing new skills after MIS 12. Renfrew (1978) distinguished between innovation and invention, whereby the latter is the creative act that is usually invisible in the archaeological record, whereas innovation is the long-term establishment of the creative act. Sudden innovation normally indicates external introduction, while smaller increments of change suggest internal implementation through technological development, cognitive evolution or acculturation (Moncel et al. 2021). Common features between the two phases of occupation and existence of innovations rooted in the past would point to a possible filiation over time of populations between the MIS 16 and MIS 12 glacial periods and would imply that these populations were able to return to abandoned areas

when the climate was favourable, aided perhaps by more complex behaviours due to internal evolution and increase of skills (Schreve 2015).

There are significant differences in terms of research tradition that hinder any comparative study. Indeed, the research in Great Britain generally used the typology of Wymer (1968), the morphometry of Roe (1968) and the reduction sequences of Newcomer (1971) and Wenban-Smith (1989). Over the same period, French researchers adopted the typology developed by Bordes (1961), which was largely replaced by the more complex concept of the “chaîne opératoire” (Boëda et al. 1990). “Chaîne opératoire” was also used in Spain, together with the Logical Analytic System (Carbonell et al. 1995). The different criteria used for analysing and categorising the results have made it almost impossible to compare data from the different countries. Until now, there were only partial comparisons between the major sites in Western Europe (Moncel et al. 2015, Nicoud et al. 2013a, b). By this reason, it was necessary to develop an unified and simple system of analysis in order to describe and quantify critical features in lithic assemblages, exceeding the local particularities and reaching a regional interpretation of the Middle Pleistocene hominin occupation of Western Europe (García-Medrano et al. 2020).

In recent decades, new dating and excavations have been conducted to identify gaps in human occupations in Western Europe (Moncel et al. 2020a). These possible breaks in occupations support the hypothesis of multiple waves of dispersal and/or re-occupation before 450 ka and the transition MIS12/MIS 11 (Moncel et al. 2021b). Some of those breaks are long and could be possibly explained by climatic factors with unfavorable areas for hominin occupations during long period of time, such as the Centre region of France, one of the areas where two gaps have been documented, one between 1 Ma and 700 ka and a second one between 700 and 450 ka (Despriée et al. 2011). Hominins would have left the area when too cold and never came back despite cooler events. Nevertheless, in southern areas (e.g. Spain), climate does not seem to be the main reason to explain lack of presence of hominins, for instance at Atapuerca (Rodríguez et al. 2011; Mosquera et al. 2013). In different parts of Western Europe, sites indicate that human occupation persisted between the end of MIS17-16 and the end of MIS12 with sometimes short breaks: Italy: Isernia-la-Pineta (590 ka); UK: Bytham River sites (MIS 15-13), Boxgrove (MIS13); France: Caune de l’Arago (MIS14-12), or Cagny-la-Garenne I-II (end MIS13-MIS12).

In Western Europe, few sites can be used to investigate such gaps in human occupation. La Noira is one such example (Moncel et al. 2013, 2020a). The technological analysis of all the lithic material from stratum a at la Noira has already enabled us to explore (Moncel et al. 2013, 2016, 2020a) the onset of the Acheulean at 700 ka in Western Europe and the technological skills of these hominins. A specific morphometric analysis of handaxe symmetry in strata a and c (Iovita et al. 2017) has shown that human groups mastered tool symmetry from 700 ka onwards, despite lower shaping intensity at that time. In order to continue to track the technological drift between ca 700 and ca 450 ka, we applied the WEAP method (García-Medrano et al. 2020) on the whole corpus of handaxes of this site (García-Medrano 2020), combining for the first time a technological analysis with a broader morphometric approach using AGMT3-D software (Herzlinger and Grosman 2018; Herzlinger and Goren-Inbar 2020).

## **2. The archaeological site of la Noira**

The site of la Noira is located in the Middle Loire Basin (Centre region, France), on the western slope of the Cher River Valley (Despriée et al. 2012) (Fig. 1) La Noira belongs to the very little group of sites yielding evidence on the early presence of Acheulean from 700 ka (stratum a) in Western Europe. In the European context, Notarchirico (Italy) and Moulin Quignon (France) are only the two other sites with the same record and their distribution both in the North-West and South allows discussing mode of dispersal of these early Acheulean groups and abilities to occupy areas under various climates. Five successive sediments strata can be observed at

the site (from bottom to top): a coarse slope deposit (stratum a with Early European Acheulean), covered by two sequences of sandy alluvial layers (stratum b), diamictons of pebbles with frost shattered debris and coarse colluvial (stratum c) and the a washed sandy-silty soil (stratum d). This paper focuses on the comparison between the oldest archaeological level (located in stratum a) and the younger upper level (located at the top of stratum c).

**Figure 1. A)** Simplified geological map of the Berry Region. **B)** Schematic stratigraphic section of the upper part of the western section of La Noira quarry: Sandy beds and erosional surface of stratum b, superposition of strata c and d with location of Acheulean artefacts and ESR samples (Moncel et al. 2020a)

The lower layer (stratum a) was deposited on the limestone bedrock at the beginning of a glacial stage after river incision. The slope deposits contained local lacustrine millstone slabs, some of which were selected by hominins for knapping and shaping. Occupations were located on the river bank. The age of fluvial formation was determined using the ESR method applied to optically bleached sedimentary quartz grains. The mean ESR age value obtained for the sandy formations of stratum b is  $655 \pm 55$  ka. Tests with cosmogenic nuclide dating provide a similar value of  $730 \pm 210$  ka, but with an excessively high margin of error (Shen et al. 2012). The average age of the human occupation is thus around 700 ka (39). The hominin occupation occurred between the end of river incision and the fluvial deposits, suggesting that hominins were present during the beginning of the MIS 16 glacial stage, just before the pleniglacial fluvial depositions. They left the area during the early glacial MIS 16 at around 670-650 ka, when cold conditions became too rigorous (Moncel et al. 2013, 2020a).

The petrographic composition of the sediments of stratum c (composed of three sub-levels) is identical to that of the lower stratum a, composed of sands and quartz gravels with endogenous pebbles (granite and quartz) and sedimentary siliceous rocks. The ESR date of  $449 \pm 45$  ka indicates that diamictons of stratum c could have been deposited at the end of the MIS 12 glacial (frozen cracks soil and frost debris) and mainly during the MIS 11 interglacial (eroded soil and deep channels). The remarkable preservation of the artefacts could indicate that they were not affected by frost as they were overlain by thick colluvial deposits (Dépont 1984; Despriée et al. 2017a, b; Iovita et al. 2017). While local millstone was the only raw material used during the early occupations, the stratum c assemblage is composed of 30% of flint and silicifications transported from long-distance Jurassic and Cretaceous outcrops, between 50 and 100 km from the site (Despriée et al. 2017c).

Taphonomical and post-depositional approaches on the stratum a (Despriée et al. 2016) indicate low energy context for covering the archaeological layer and few disturbance of the material. Spatial distribution also indicates that large artefacts (tools and broken slabs) have moved on the site due to hominin activities and reveals spots of activities on a 100 m<sup>2</sup> excavated areas. For the stratum c, geological studies indicate recurrent occupations along channels (Moncel et al. 2021b). Most of pieces show fresh edges without traces of crushing or micro-denticulations indicating any displacement due to natural post-depositional processes. Some broken slabs were found joined at stratum a (Despriée et al. 2016). Only chemical superficial processes were observed on the tool surfaces. The two phases yield large lithic assemblages with complete debitage reduction processes, from selection of raw materials to flaking and shaping processes and retouches (Table 1) (Moncel et al. 2021b). While hominins selected only in situ material for the 700 ka stratum a, the occupations of stratum c indicate changes in land-use patterns, with introduction of stones (as nodules, slabs and possible crudely-flaked cores) from a perimeter of 50-100 km around. Moreover, the core technology of stratum c indicates the introduction of some Levallois evidence (cores) with continuity of previous methods observed in stratum a (discoid-type cores and others). Analyses of residues and use-wear traces on the lithic material on stratum a indicate various domestic activities (Hardy et al. 2018) suggesting that the site was not only workshops. La Noira is thus a key-site to question the process of innovations, in particular on the Large Cutting Tools in Western Europe from MIS 16 to MIS 11 and in an area located on this mid-part of Europe considered as less favourable than the South.

### 3. Materials and Methods

The analysis of the whole sample of the 78 handaxes and cleaver-like tools from stratum a and stratum c of la Noira were done through a detailed technological and morphometric study aiming to analyse final tool variability. The applied WEAP method was developed in the context of a Marie Skłodowska Curie IF-EF-ST Fellowship (IP: 748316). It is an unified method of analysis, drawing together a selection of criteria considered significant from previous research methodologies applied to the Western Acheulean record, including typological, technological and processual issues, together with new proposals on morphometrics (García-Medrano et al. 2020). As we have briefly explored, different systems of analysis applied in different countries have made it almost impossible to properly compare the data from different sites, their being only occasional comparisons between the main Acheulean assemblages in Western Europe (e.g. Moncel et al. 2015; Moncel et al. 2018c). WEAP's method is based on three main premises: 1) standardizing and simplifying terminology; 2) avoiding the classification of tools before analysis; 3) analysing each tool in two different ways: a) As a single unit, including aspects such as raw material type, blank type, facial shaping, cortex presence, edge delineation, profile symmetry, number of scars); b) as the sum of the different parts, each of which are analysed independently, defining the type of hammer used, number of removal series, depth of scars on edges, invasiveness of each removal series, and type of shaping (Table 2). Combining all these features, a Multivariate Analysis (PCA) identifies the differences and similarities of bifaces from both levels, comparing raw materials and types of blank. A detailed description of the Method is recorded in the Part 1 of the Supplementary Information.

By Large Cutting Tool (LCT), we refer to both large unifacial and bifacial Acheulean tools, conventionally larger than 10 cm. The term LCT is generically used to refer to the more standardized forms such as handaxes, cleavers, knives, etc., together with less standardized heavy-duty tools as picks, *trièdres*, and choppers (Sharon, 2007). By 'handaxe', we refer to the tool-type defined by Kleindienst (1962). The other key-Acheulean tool-type is the cleaver, particularly documented in Africa, Levant, India and southern Europe. One of the earliest definitions made by Tixier (1956) is a minimalist description of tools made exclusively on large flakes, with an unretouched transversal cutting edge. Nevertheless, in the Iberian context, we see a wider technological variety of this tool-type, with cleavers made on cobbles and tools with a retouched transverse edge (García-Medrano et al., 2014, 2015). Besides, some British and French researchers consider 'cleavers' as any bifacially knapped tool with a transverse cutting edge (i.e., bifacial cleavers of Bordes, 1961). To avoid confusion and to help unifying the terminology, we have adopted the original minimalist definition of Tixier (1956), calling 'cleavers' tools made on flakes, with an unretouched transverse cutting edge. The other cases (on cobbles or with retouched distal ends) are considered as 'cleaver-like' tools, specifying their particular features.

As a single unit, a LCT could be defined by a combination of features that make it unique: raw material and blank type, facial working, edge delineation, bifacial and bilateral symmetry and number of scars. The division of each tool into three parts is based on the metrical distinction of distal part at 1/5 in length and the proximal part, at 4/5 in length (Roe 1968). Therefore, each technological analysis is undertaken three times. The technological features considered are type of hammer, number of removal series, depth of scars on edge, invasiveness of scars on tool's surface, type of shaping and any patina variation (all details recorded in SI Part 1).

Together with the technological descriptions (Bordes 1961), measurements were the basis of the handaxe morphological types (*triangulaires*, *subtriangulaires*, *cordiformes*, *discoïd*, *ovate* and *limandes*) according to three main criteria: length against width, thickness against width, and Bordes' edge shape. However, the boundaries between the categories were sometimes not fully precise, as intermediate shapes exist. Roe (1968) included three new measures: distal width (B1), proximal width (B2) and distal thickness (T1), to distinguish three shapes: pointed,

oval and cleaver-type tools. For our method, we retain all these measures to describe the tools (SI Table 1), and compare the results with the morphological and technical features such as reduction intensity. The measurements have also been used to produce ratios to enhance handaxe description (Roe 1968; 1994; Bordes 1961). Elongation is given as length/width with values  $> 1.5$  described as elongated. Refinement is measured by width/thickness with refined handaxes having values  $> 2.35$ . In addition to the basic measurements and ratios, we have measured six angles along one edge (the most continuous and regular one) according to the division of these tools in five parts: A1 (midpoint of tip), A2 (1/5 of the length), A3 (2/5), A4 (3/5), A5 (4/5) and A6 (midpoint of butt). Where there is cortex, the angle has not been recorded.

To complete the technological analysis, we also applied the Geometric Morphometric analysis to describe tool shape with 3D models. All the tools were scanned using a laser scan (DLP projector) and Flexscan software (LMI technologies), transferred from the Fragmented Heritage Project (University of Bradford). All models are available for scientific and academic purposes at ZENODO (García-Medrano et al. 2020). The 3D models were processed using the AGMT3-D software v.3.1 (Herzlinger and Grosman 2018; Herzlinger and Goren-Inbar 2020). This consists of a data-acquisition procedure for automatically positioning 3D models in space and fitting them with grids of 3D semi-landmarks. In fact, each point of the grid consists of two semi-landmarks, one placed on each face of the artefact, so that a 50x50 grid provides 5,000 landmarks (Fig. 2A). The top and bottom latitudes capture the exact 3D outline of the artefact's distal and proximal ends. Therefore, this protocol provides a list of landmarks that accurately express the artefact's volumetric configuration. It also provides a number of analytical tools and procedures that enable data processing and statistical analysis (Herzlinger and Goren-Inbar 2020). For this paper, data obtained with 3D models are presented.

The multivariate outline data were projected into two dimensions so that the underlying shape variables could be qualitatively examined and compared. In order to interpret the Principal Component Analysis (PCA) results from a morphological perspective, Procrustes superimposed shape data were examined using thin-plate splines to facilitate the visualization of shape changes from the group mean along relative warp (i.e., principal component) axes (Hammer and Harper, 2006; Costa 2010). By examining the morphological deformations and XY plots of specimens from the PCA scatters, it was possible to interpret shape variation by itself, without the size effect, and compare the different tools within a site or between different sites. In addition, the derived principal component scores also allowed for the application of other quantitative tests of multivariate equality of means between the groups (Herzlinger and Grosman 2018; Herzlinger and Goren-Inbar 2020).

**Figure 2.** **A)** 5,000 points defining outlines and tool surfaces; **B)** Edge curvature: visualization of deviation from perfect bilateral symmetry (in green), and from perfect bifacial symmetry (in yellow). **C)** Edge irregularity.

The latest version of this software also offers different quantitative approaches to the analysis of specific variations in shape. Firstly, we will use the surface analysis ( $\text{in}^2$ ) and volume ( $\text{in}^3$ ) data apply a quantitative approach to reduction intensity. The Scar Density Index (SDI, Clarkson, 2013; Shipton and Clarkson, 2015a, b) has been defined as the number of flake scars (greater than 10 mm in maximum dimension) divided by the surface area. As García-Medrano and colleagues noted (2019), a loss of information during the knapping process, contrasting this value with volume information, could establish a useful relationship between the number of scars and tool size. Lastly, the landmark data were used to calculate the degree of deviation from perfect bilateral (Fig. 2B) and bifacial symmetries (Fig. 2C), as well as the edge section regularity (Fig. 2D) of each item in the sample. For bilateral symmetry, this was conducted by measuring the mean 3D Euclidean distance between a mirror reflection of the landmarks placed on one lateral half of each object and the corresponding landmarks on the other half. The same procedure was performed for bifacial symmetry, but on the two opposing faces. In a perfect bilaterally or bifacially symmetrical object, the value of these indices will be



0, with increasing values indicating less symmetrical objects. The mean edge section regularity is calculated as the sum of 2D distances on the ZY plain between landmarks on the extremities and their position as predicted by a linear function fitted onto them. These processes are made automatically by the AGMT3-D V3.0 software.

## 4. Results

The studied corpus is composed of 31 handaxes for stratum a and 47 handaxes and cleaver-like tools (bifacial tool with a round or transverse extremity) for stratum c (number of tools recovered until 2017). They were collected *in situ*, and come from recent excavations and systematic surveys carried out for the three last decades in the quarry. All the handaxes from the lower level (stratum a) are made on local millstone slabs, and in nearly 65% of cases, slabs are only used for shaping. In the upper level (stratum c), our corpus of tools is shaped on comparable proportions of millstone slabs (48.94%) and flint nodules (51.06%, Table 3). For 34% of the series, it was impossible to identify the type of blank, due to invasive shaping.

The combination of the technological features (Table 2, Supplem. Inform. Tables 2-5) in a multivariate approach (Principal Component Analysis) indicates that technological differences exist between the two levels (Fig. 1). This PCA accounts for more than 66% of the variability of the series. PC1 (43.11%) divides the samples according to level, whatever the raw material (millstone or flint) or type of blank (slab, flake or nodule).

### 4.1. Stratum a

All the handaxes are made with hard hammers (58.06%) or with a combination of hard and soft (32.26%) hammers, especially on tool extremities (Fig. 4). In the left 10% of cases, it has been impossible to identify the type of hammer used. The tips appear much more worked and retouched than the cortical butts (more than 83%). Tool edges are mainly sinuous (48.39%) and the profile is non-symmetric (80.65%). The high variability of the corpus is mainly due to the type of *façonnage* of the tips. For more than 50% of tools, we observe one or two face by face or alternate series of removals. Less than 50% bear final retouch, and retouch is absent from lateral and proximal cutting edges. Removals affect the edges either marginally (51.61%), producing regular edges, or more intensely (48.39%), generating more denticulate and irregular plan-shape profiles. When only one series of removal exists, it is non-invasive over the tool surface. When there are several series of removals, shaping is more invasive, and can extend up to the midpart of the tool surface. In nearly 40% of cases, there is a combination of an invasive first series of removals and a second series along the tool edges. Butts retain 40-90% of the original cortex for more than 45% of tools. When removals are present, they are concentrated on butt edges. Finally, the corpus of Large Cutting Tools (LCTs) from stratum a presents high shaping variability with a significant difference in the management of tips and butts. Tips present more careful treatment, sometimes with final retouch while butts remain mainly cortical (Suppl. Inform., Fig. 3).

The only exception to this high variability concerns pieces on unknown blanks (13% of tools). The PCA shows how this category of tools is clearly affected by the PC2 (23.14%) (Suppl. Inform. Fig. 4). They differ in that they are characterized by longer operative chains with two series of removals, the first one invasive and the second one short on both the tip and the upper part of the tool, followed by final retouch only on the tip. In both cases, hard and soft hammers are used. The butt is less cortical (40%) and shaped by only one invasive series of removals by hard hammer percussion.

**Figure 3.** Handaxes from la Noira, stratum a (A, BFN III 146; B, BFN III 39; C, BFLN E1 d2 2; D, BFLN 0C5 d1 1) and stratum c (E, BFN SN; F, BFN VI 62; G, BFN VIb 178; H, BFN VIc 45).

### 4.2. Stratum c

The corpus from stratum c includes handaxes and some 'cleaver-like' handaxes (handaxes with wider convexity on tips, generating a sort of transverse end). The tools mainly show higher standardization with longer operative chains and significant blank reduction (Fig. 5). Shaping extensively affects the entire tools with evidence of the use of hard and soft hammers on the whole piece. In more than a 89% of cases, tips has no cortex patches or some residues mainly concentrated on butts and proximal parts. 23% of tools bear no cortex. The tools present mainly non-symmetric profiles with rectilinear edges in a 54% of tools. The use of soft hammers (around 60%) is clearly visible on all the sectors of the tools (tip, mid and butts). For 49%, dense final retouch obliterates the last removals. For 27.66% of the tools, the tip is shaped by two series of removals, combining invasive and non-invasive scars. Final retouch can extend to the midpart of the tool surface or can be limited to the edges. Finally, for 17% of cases, we also documented a *coup de tranchet* removal with a non-retouched distal edge.

**Figure 4.** Technological characteristics of handaxes from stratum a of la Noira (A, BFLN 0C5 d1 1; B, BFN III 156; C, BFN III 148).

The midpart of tools is above all worked by two series of alternate removals (63.87%) with final retouch and without cortex (28%). Like in stratum a, this type of shaping profoundly modifies edges. Nevertheless, for this level, we observe a change in shaping strategies mainly for tools on millstone slabs. The edges are more regular, with a combination of a first invasive series of removals, followed by a non-invasive second series and finally, marginal retouch confined to the edges. Butts are non-cortical or with small patches of cortex. In 92% of cases, there is only one series of removals and marginal use of a soft hammer, mainly on tools shaped on flakes.

**Figure 5.** Technological characteristics of handaxes from stratum c of la Noira (A, BFN VI 62; B, BFN Vb 179; C, BFN VI 22; D, BFN Vic 45; E, BFN VIb 304).

### 4.3. Stratum a vs stratum c LCTs

The Principal Component Analysis defines the existence of two clear groups of tools: strata a and c (Fig. 6). The differences are independent of the type of raw material (millstone and flint) and the type of blank used for shaping (slabs, flakes or nodules). The distance between strata a and c shows rather a technological origin, possibly related to a change in shaping strategies. The first main difference between these groups is that sequences are more diversified and shorter for stratum a tools, and longer and more standardized for stratum c tools. In addition, out of the whole set of technological features considered here, the presence of original cortex (Fig. 6A) and the different combinations of series of removals (Fig. 6B) have a major effect on the distance between these two assemblages (Suppl. Inform. Fig. 3 and Fig. 4), which is also visible by Cluster analysis (Fig. 6C). Handaxes in stratum a present cortex on 50% of tools (butt and mid parts), and sometimes covers the most of the instrument. In stratum c, there is an increase in the ratio of non-cortical tools, as well as in the use of final retouch, independently of the type of blank used. PCA also points to a clear differentiation of tools from stratum a, which present longer shaping sequences and unknown or indeterminate blanks (Unknown). They are clearly apart on the PCA graph and are represented as an independent branch of the Cluster. Tools from stratum c show a different pattern, reflecting a certain association between raw material and blank type. Millstone is mainly associated with what slabs, and flint types present the same technological features as handaxes made on unknown blanks. Flakes appear as an independent group, regardless of raw materials.

**Figure 6.** Principal Component Analysis of the technological features considered for the analysis of handaxes and cleaver-like tools: Handaxe as a single unit (A); Handaxes as three different parts (Tip, B; Midpart, C; Butt, D). The distribution represents the sample divided into stratum a (L) and stratum c (U) levels, the type of blank (Slab, Flake and Unknown, blank dot) and type of raw material (Millstone and Flint red squares). **Graphic A**, distribution of corticality between strata a and c and the type of blank identified (CO\_Butt: Cortex localised on butts; CO\_All, cortex in the whole piece; CO\_Butt+Mid: cortex on butt and mid parts); **Graphic B**, Removal series combinations in strata a and c and blank type (1: one removal series; 2: two removal series; 1+FR: one removal series and final retouch);

2+FR: two removal series and final retouch); **Graphic C**, Cluster analysis and distances between the groups represented in PCA.

The results of the geometric morphometric analyses of tools from strata a and c of la Noira indicate the extent of intra-group shape variability, expressed as the mean multidimensional Euclidean distance of all items of a group from its group centroid. Overall, the groups considered are fairly similar (Fig. 7) but tools from stratum a present higher variability. The most homogeneous group is composed of millstone tools from stratum c. The distribution of the total standardized coefficients across the three dimensions X, Y and Z shows differences in relative width, length and thickness respectively (Table 4). In the archaeological assemblages, most of the variability corresponds to differences in relative thickness, mainly in stratum c and specifically for millstone tools. On the other hand, the tools from stratum a show higher variability in width and length.

**Figure 7.** Principal component scatter plots of handaxes from La Noira, by strata and raw materials: millstone stratum a (black dots), millstone stratum c (blue triangles) and flint stratum c (red crosses). The geometric morphometric analysis was applied to 3D models, consisting of 5,000 semi-landmarks. It also includes **convex hulls** on each group to facilitate scatter plot visualization, and the **warps' tool**, representing morphology. Colour coding represents the most variable landmarks in shape trend described on positive and negatives scores of PC1 and PC2. Lower right-hand side; **Cluster analysis and distances** between the groups represented in PCA.

Figure 7 displays a PCA scatter plot of the first two PC, showing 32.50% of the entire shape variability of the whole sample, including 95% confident ellipses and centroids (corresponding to mean shapes). PC1 (22.13%) indicates the difference between oval vs pointed shapes. PC2 (10.13%) shows the difference between the localization of the main thickness of the tool and the convexity of the butt (mid-upper part or mid-lower part). Shape distribution is fairly homogeneous but some differences are visible. Tools from stratum a present a trend towards oval shapes, with maximum thickness located on the midpart of tools. On the other hand, tools from stratum c present a tendency towards pointed shapes, with maximum thickness on the mid-proximal part of the pieces and a significant reduction in distal width and thickness.

Geometric morphometric shape analyses quantify these differences using a single value, representing the multidimensional Euclidean distance between the means of each group. Together with the results of the Wilcoxon Rank-sum test on the inter-point distances between the means of each group and the items in the opposite group, it shows that differences between the two strata are statistically significant ( $n_1=32$ ,  $n_2=39$ , ranksum=4128,  $p<0.01$ ), even for the same raw material (millstone  $n_1=32$ ,  $n_2=18$ , ranksum=2086,  $p<0.01$ ). If we compare raw materials in stratum c (millstone and flint), differences are not significant ( $n_1=18$ ,  $n_2=21$ , ranksum=1454,  $p=0.39$ ). The same results are obtained applying the MANOVA test on the first 10 PC (Table 5). The greatest differences emerge from comparisons between the two phases of occupation, as stated by Wilks' lambda Test=0.40;  $df_1=20$ ;  $df_2=118$ ;  $F=3.44$ ;  $p<0.001$ , and the most similar groups are millstone and flint tools of stratum c.

**Figure 8. A)** Ternary plot between Base Length (a), Distal Length (L-a) and Distal width (B1), from strata a and c. **B)** Angle distribution along the edges of tools from stratum a and stratum c of la Noira.

Tool size and thickness decrease from stratum a to stratum c (Suppl. Inform, Table 6). Millstone and flint tools from stratum c present nearly the same values, indicating common strategies, regardless of the stones and their natural geometry. In addition, we must point out significant variation in distal vs base length. In stratum a, proximal length is higher, while in stratum c, distal length is higher (Fig. 8A). This is consistent with the geometric morphometric analysis and the contrast between oval shapes in stratum a, with longer bases, and more pointed shapes, with longer distal parts in stratum c.

Through the analysis of six angles measured along each edge, we document more acute angles on the mid-distal part, and wider angles on the mid-proximal part, in both strata (Figure 8B, Table 6). However, in stratum a, due to the lesser degree of edge shaping standardization,

most of the angles are between 45° and 80° along the whole edge, and only some tips extend beyond this range. In stratum c, where a predominant use of soft hammers is associated with longer sequences, we observe a significant change in angles. The angles of the cutting edges are more acute, homogeneous and differ between the distal and the proximal sectors of the tool. Tip angles are between 30° and 45°, mid part edge angles between 40° and 70° and butt angles between 60° and 80°.

The Scar Density Index (SDI) in relation to tool volume is coherent with the technological and morphometric analysis (Table 7). This ratio is higher for tools from stratum c, as well as for tools made on an unknown blank in stratum a. Therefore, the longer the shaping process, the higher the ratio between SDI and volume. But this also implies that the higher variability and lower standardization of the handaxes from stratum a has a clear effect on this result (Table 2). For raw materials, we can see the same pattern, between flint tools, which present the highest ratio, and millstone handaxes with the lowest ratios.

The statistical analysis of the degree of symmetry of tools shows that the main differences are between millstone handaxes from stratum a and stratum c. We note an increase in bilateral symmetry with an average of 25% (Table 8). Wilcoxon rank sum tests confirm that this difference is statistically significant ( $n_1=32$ ,  $n_2=18$ ,  $\text{ranksum}=916$ ,  $p=0.04$ ). In terms of bifacial symmetry, there is an increase of nearly 35% throughout the sequence, which is statistically significant ( $n_1=32$ ,  $n_2=18$ ,  $\text{ranksum}=968$ ,  $p<0.01$ ). The edge irregularity test shows that, in all cases, both edges of the same tool are always different. Nevertheless, as bilateral and bifacial symmetry show higher diversity for millstone tools from stratum a, flint tools present more regular edges. As mentioned previously, the main difference between the tools from the two strata is the combination of several series of removals (duration of shaping processes). In the case of flint, there is often a third series, and final non-invasive retouch on the cutting edges (Fig. 5D). This has a clear impact on the regularity of the edges (profile symmetry). Nevertheless, the main difference between the millstone handaxes in the two strata is the massive use of at least two series of removals on the midparts and butts of the tools from stratum c, which dramatically reduces tool thickness. Bilateral and bifacial symmetry (plan shape symmetry) is thus affected.

## 5. Discussion.

The Early Pleistocene is marked by climate cycles of 41 ka, leading to temperate and more open conditions during glacial to interglacial transitions (Almogi-Labin 2011; Rodríguez, 2011; MacDonald 2012, Guthrie 1984; Ashton et al. 2011; Candy et al. 2011; Carrión et al. 2011; Messenger et al. 2011; Abbate 2012; Elderfield 2012; Orain 2013). More open environments were favourable to human colonization. During the Middle Pleistocene, the shift to c.100 ka climatic cycles, designated as the Middle Pleistocene Transition (MPT) (Clark 2006; Muttoni 2010, 2018, Manzi 2004; Ashton and Lewis 2012), led to more extreme conditions which could have profoundly impacted human populations and dispersions, and may explain possible successive depopulations or extinctions of small groups of hominins during cold events in the north, necessitating re-colonization from the south during warmer events (Dennell et al. 2011). The second climatic transition (Mid-Brunhes Event-MBE) between MIS 13 and 11, with more marked glacial–interglacial cycles might explain in part the wider diffusion of the Acheulean and Lower Paleolithic traditions through Western Europe during warmer interglacials and the extension of the mammoth steppe in the northwest from 500 ka (Jozuel et al. 2007; Paillard 2015). For north-western Europe, evidence suggests occasional dispersals, which would account for the diversity of strategies due to regular introductions of new behaviours and populations. Gaps are also recorded in southern Europe. At Atapuerca, for example, an occupation hiatus is observed between 800 and 500 ka (Rodríguez et al. 2011; Mosquera et al. 2013), with exception of one quartz flake from TD7 (Ollé et al. 2013), ongoing fieldwork recently added just three artefacts for unit TD8 (P.G.M., unpublished data). A recent study (Blain et al. 2021) suggest that the scarcity of forested areas could be a probable cause of this

punctuated presence in this part of Western Europe. In fact, from a strictly paleoclimatic point of view, neither TD7 nor TD8 shows climatic envelopes that are entirely incompatible with a human presence, but TD8 presents a lower forested cover. A similar hiatus occurs in the centre of France, between 1 Ma and 700 ka and 700 to 500 ka (Moncel et al. 2018c). La Noira (Center of France) and above all Moulin Quignon (Somme Valley, North-West France) suggest a punctual expansion of the Acheulean culture northwards the 45<sup>th</sup> parallel, during MIS17 for la Noira and MIS 16 for Moulin Quignon. Hominins disappeared at la Noira when too cold (beginning of MIS 16) while at Moulin Quignon, they possibly occupied the area under cold or fresh conditions (Antoine 2019). At Notarchirico (Italy), in Southern Europe, recent fieldworks indicate Acheulean occupations between 610 and 695 ka during both the MIS 17 and MIS 16 under moderate climatic conditions (Moncel et al. 2020b).

In Early Acheulean African assemblages, for example, Olduvai, Bed II (1.5 Ma), Gadeb (1.7–1.5 Ma to 0.8 Ma) or Peninj (1.6–1.5 Ma), in East Africa, tools are mainly pick-like with flat or triangular cross-sections and little overall volume management. These tools are associated with minimally shaped LCTs on cobbles and flakes, unifaces and a large diversity of other types of heavy-duty tools (Leakey 1971; McPherron 2006; de la Torre et al. 2008; Semaw et al. 2018). A technological shift is then recorded at c. 1 Ma with the development of the use of soft hammers, together with a higher ratio of more standardized handaxes (Texier 2001, 2018; Roche 2005; Roche et al. 2003). Whatever the origin of Acheulean behaviours in Europe, similar technological and morphometric changes are also recorded over time in the assemblages. Stratum a of la Noira attests to the mastery of biface production, with the management of volume and tool symmetry, assisted in some cases by the use of soft hammers, mainly on distal parts (Moncel et al. 2020a). These features justify the hypothesis of a well-established Acheulean tradition at c. 700 ka in Western Europe (Moncel et al. 2013, 2016, 2020a). Coupled with a geometric morphometric analysis using 3D models, this technological study of the bifaces tracks for the first time innovations v. common features and the degree of filiation between strata a and c for the LCT component. Our method enables us to determine a large set of similar and different tool features related to shaping modes and final morphometry.

Data clearly distinguish the two different technological assemblages (stratum a and stratum c), regardless of raw material or blank types. In stratum a (Moncel et al. 2013, 2016, 2020a), a single local raw material is used, millstone slabs. Handaxe shaping retains large cortical surfaces and exploits stone geometry with one or two series of removals, mainly with hard hammers. This behaviour generates few standardized forms. Nevertheless, technological control of the tips is also observed, using both hard and soft hammer percussion. We can also mention evidence of longer shaping chains on some tools (group of unknown blanks). On the other hand, stratum c is characterized by the use of diverse stones and the introduction of raw materials from long-distance areas. The use of local stones in stratum c indicates an increase in the size of the procurement zone, suggesting higher mobility for hominin groups at the end of MIS 12 and the beginning of MIS 11. The large majority of tools in this level present long reduction sequences, with at least two series of removals and final retouch, thinner tools, a widespread use of soft hammers on the whole tool, and less extensive cortical zones.

The tools made on indeterminate blanks in stratum a, with longer operative chains, are key to point to a possible filiation between the two levels. What was original and occasional in stratum a became generalized in stratum c. These new features also include the generalization of the use of soft hammer percussion and the widespread use of final retouch. Finally, an intensification of the technological features documented in the lower level is only observed on some pieces and a local raw material. This results in higher heterogeneity in tool cutting edge angles in stratum a, while in stratum c, more careful management of tool thickness and edges leads to increased homogeneity and more acute angles. In addition, the values of the angles between tips (30–45°) and butts (60–80°) are differentiated.

**Figure 9.** Mean shapes of LCTs from la Noira, stratum a and stratum c and the different raw materials (millstone and flint). Colour-coding represents the relative degree of variability of each individual semi-landmark reflecting the spatial distribution of variability in tools.

From a morphometric point of view, there is a transition between the two levels from oval (globular) shapes and few standardized tools, with the maximum width of the tool at mid-length, to 'teardrop' shapes in a more homogeneous assemblage, with the maximum width of the tool at the base (Fig. 9). There is also a transition from short distal parts, with wider convex tips, to longer convergent edges with more pointed tips, opposed to wider bases. In addition, intense technological work on the tools of stratum c results in reduced tool thickness. As Iovita stated (2017), Acheulean toolmakers had the technical abilities and skills to produce symmetric tools from 700 ka onwards. Nevertheless, there is an increase in this tool symmetry in stratum c. Iovita and colleagues (2017) concluded that this symmetry was dependent on the degree of reduction and the raw material. The use of 3D models in the geometric morphometric analyses led us to go further and clarify this conclusion. Bilateral and bifacial symmetry increase on average by 25% and 35% respectively. Plan symmetry is mainly affected by the *façonnage* strategy, by more than one series of removals on the whole perimeter of the tool, reducing the thickness and modifying the original geometry of the blank whatever the raw material. Nevertheless, edge regularity depends on final edge retouch.

How should these differences between the two occupation phases be interpreted? Do they stem from local or on a broader scale innovations rooted in the past motivated by external or internal changes or do they represent a shift, as a result of a break in populations with new dispersals? At la Noira, our analysis on the total corpus of bifaces and bifacial tools highlights two main features. First, in stratum a, we do not observe any differences in shaping or in morphological results for different blank types, even if slabs predominate. Only some tools with longer sequences stand out from the rest of the corpus ( $n=4$ , 12.9%) due to more intense shaping, making it impossible to identify the type of blank. The tools present a combination of soft and hard hammer percussion and more intensive final retouch. Consequently, the hominins of stratum a were able to develop complex and versatile operative chains.

Should we consider that this ability at 700 ka is evidence of a technological filiation between populations from MIS 16 to MIS 11? If we look at the results of the geometric morphometric analysis, we do not observe real morphological breaks between the two corpora despite the use of the same local stones and introduction of other types of stones and shapes in the stratum c. Handaxes from stratum a are not homogeneous and short shaping sequences are correlated with greater tool thickness. Morphometrically, the complexity of this biface production at 700 ka is observed in the ability to manage tool plan shape for oval shapes, placing the centre of the mass at the midpart of tools. The stratum c corpus is characterized by a higher standardization of shapes, creating wider bases opposed to thinner and more pointed tips. The use of several series of removals reduces tool thickness as we can observe in some sites in Western Europe (Ashton et al. 2012; Moncel et al. 2021a). We observe total control of volume and edge morphology, which become more regular. A filiation over time between the populations at la Noira (and Western European populations) is thus possible, suggesting that the long interglacial MIS 11 in Western Europe was not really a threshold and enabled local and European populations with internal evolution to re-occupy abandoned areas when the climate became more favourable, facilitating demographic expansion and the implementation of more complex strategies. Understanding shifts in human behavioural evolution is a challenge because illustrating abilities to hominins to evolve over time and increase skills and cognition whatever environmental conditions and without necessary introduction by dispersals of new populations. The anatomical diversity of *Homo heidelbergensis* and other fossils such as Ceprano skull suggests an intra or inter diversity of hominins into Europe and raise question on the behavioural process in parallel to the earliest Neanderthal features (Manzi et al. 2010). La Noira site brings a new step forwards to better

describe this process, possibly finding roots in the past. It also contributes to understand the own rhythms of human evolution both for the behaviours and the anatomical evolution.

## **6. Conclusion**

La Noira (Center of France) suggest a punctual expansion of the Acheulean culture northwards the 45<sup>th</sup> parallel, during MIS17. La Noira data suggest the maintenance of some technological traditions over time and over a wider area, such as southwestern Europe, between populations coming back to the site when conditions were favorable, after the glacial event of MIS 12. Data clearly distinguish the two different technological assemblages (stratum a and stratum c), regardless of raw material or blank types. In stratum a single local raw material is used. Handaxe shaping retains large cortical surfaces and exploits stone geometry with one or two series of removals, mainly with hard hammers.

This behaviour generates a few standardized assemblages. Nevertheless, technological control of the tips is also observed, using both hard and soft hammer percussion. On the other hand, stratum c is characterized by the use of diverse stones and the introduction of raw materials from long-distance areas. The use of local stones in stratum c indicates an increase in the size of the procurement zone, suggesting higher mobility for hominin groups at the end of MIS 12 and the beginning of MIS 11. The large majority of tools in this level present longer reduction sequences, with at least two series of removals and final retouch, thinner tools, a widespread use of soft hammers on the whole tool, and less extensive cortical zones. The tools made on indeterminate blanks in stratum a, with longer operative chains, are key to point to a possible filiation between the two levels. The tools present a combination of soft and hard hammer percussion and more intensive final retouch. Consequently, the hominins of stratum a were able to develop complex and versatile operative chains.

We do not observe real morphological breaks between the two corpuses despite the use of the same local stones and introduction of other types of stones and shapes in the stratum c. There is a transition between the two levels from oval shapes and few standardized tools, with the maximum width of the tool at mid-length, to 'teardrop' shapes in a more homogeneous assemblage, with the maximum width of the tool at the base. There is also a transition from short distal parts, with wider convex tips, to longer convergent edges with more pointed tips, opposed to wider bases. Morphometrically, the complexity of this biface production at 700 ka is observed in the ability to manage tool plan shape for oval shapes, placing the centre of the mass at the midpart of tools.

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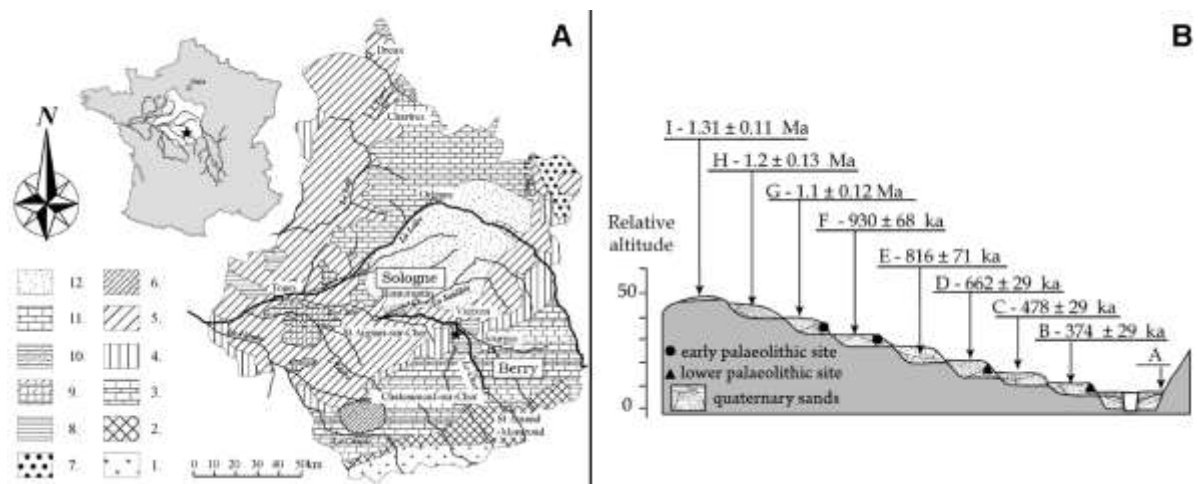
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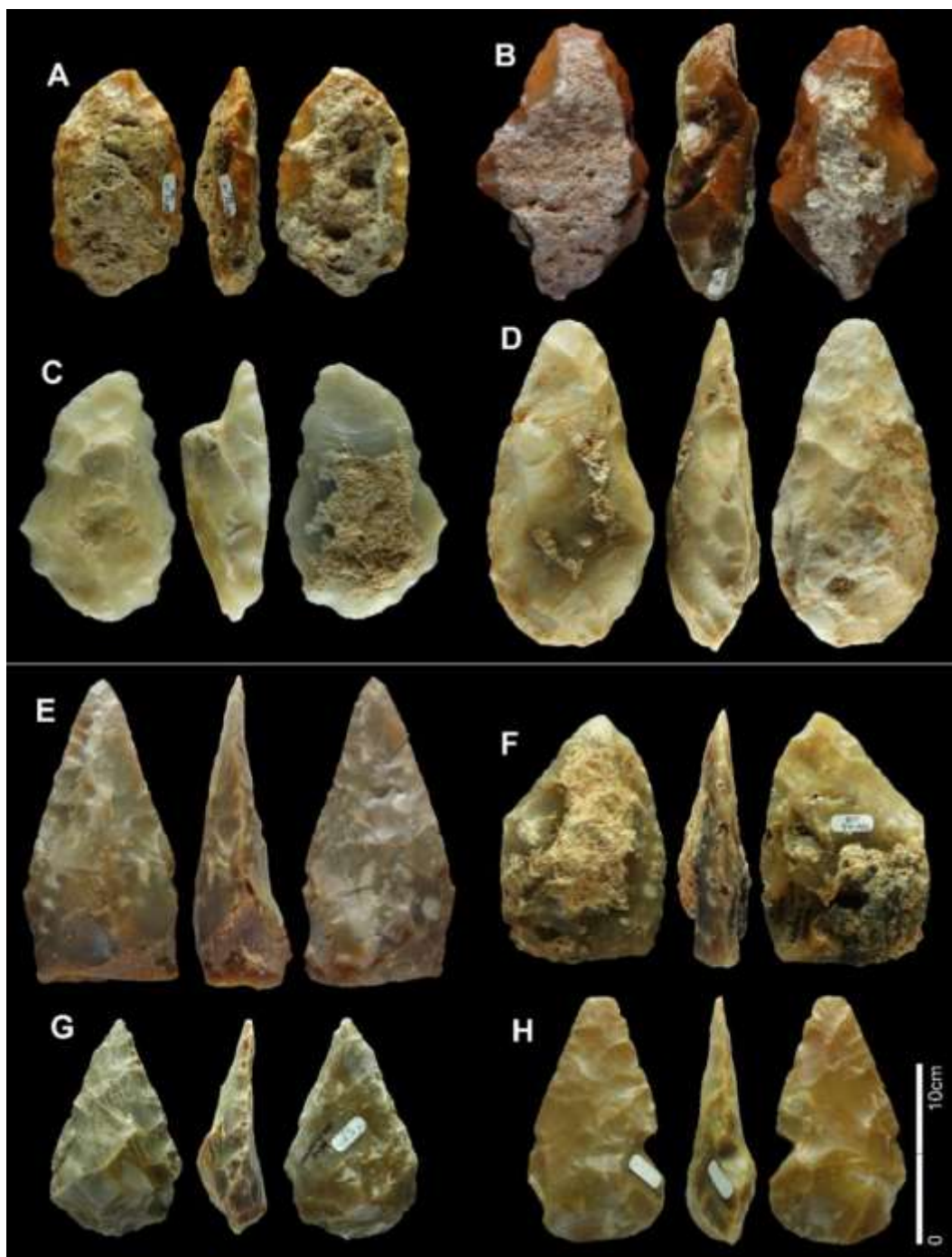


**Figure 1. A)** Simplified geological map of the Berry Region. **B)** Schematic stratigraphic section of the upper part of the western section of La Noira quarry: Sandy beds and erosional surface of stratum b, superposition of strata c and d with location of Acheulean artefacts and ESR samples (14).

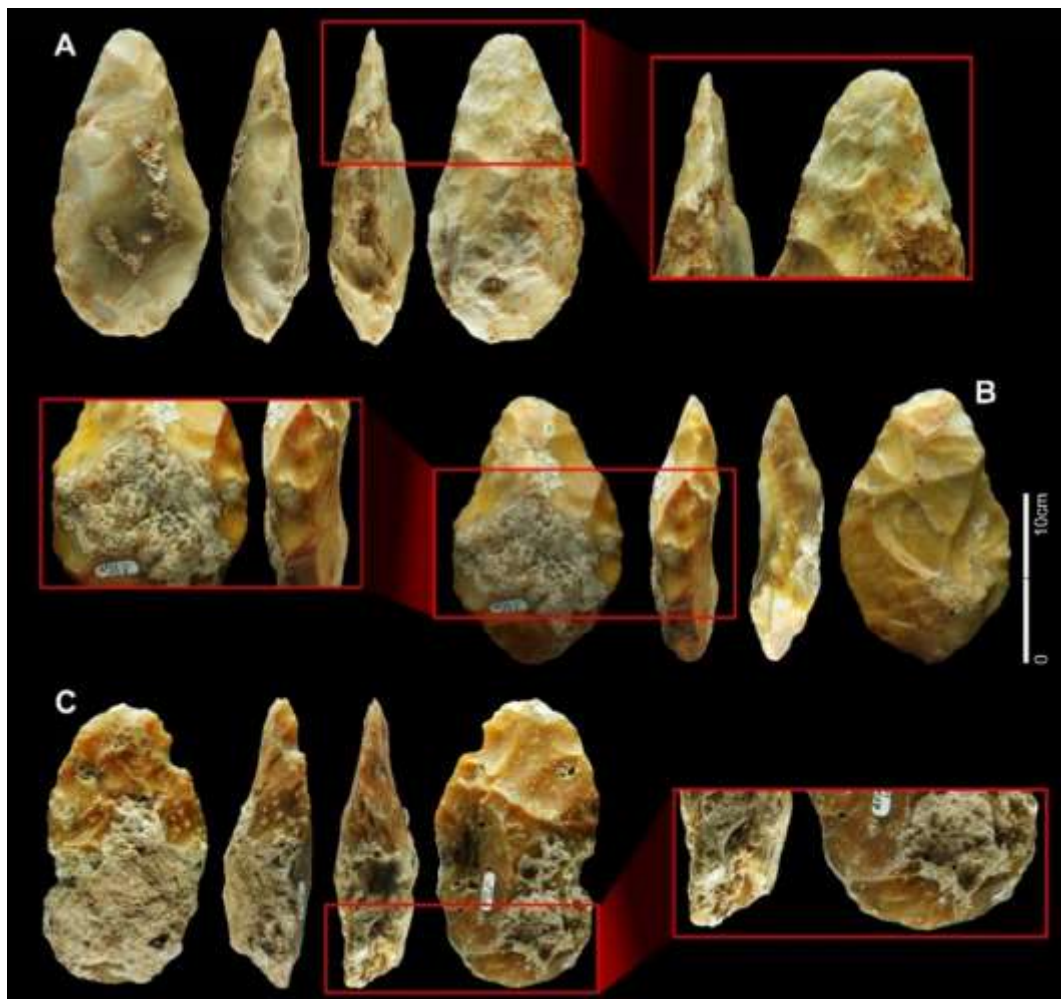
	Stratum a								Stratum c							
	Slab		Flake		Unknown		TOTAL		Slab		Flake		Unknown		TOTAL	
	(N)	%	(N)	%	(N)	%	(N)	%	(N)	%	(N)	%	(N)	%	(N)	%
Millstone	20	64.52	7	22.58	4	12.90	31	100.00	11	47.83	5	21.74	7	30.43	23	48.94
Flint & silicific.	-	-	-	-	-	-	-	-	7	29.17	8	33.33	9	37.50	24	51.06
<b>TOTAL</b>	<b>20</b>	<b>64.52</b>	<b>7</b>	<b>22.58</b>	<b>4</b>	<b>12.90</b>	<b>31</b>		<b>18</b>	<b>38.30</b>	<b>13</b>	<b>27.66</b>	<b>16</b>	<b>34.04</b>	<b>47</b>	

**Table 1.** Number (N) of LCTs and frequencies (%) in stratum a and stratum c, raw material type and type of blank.



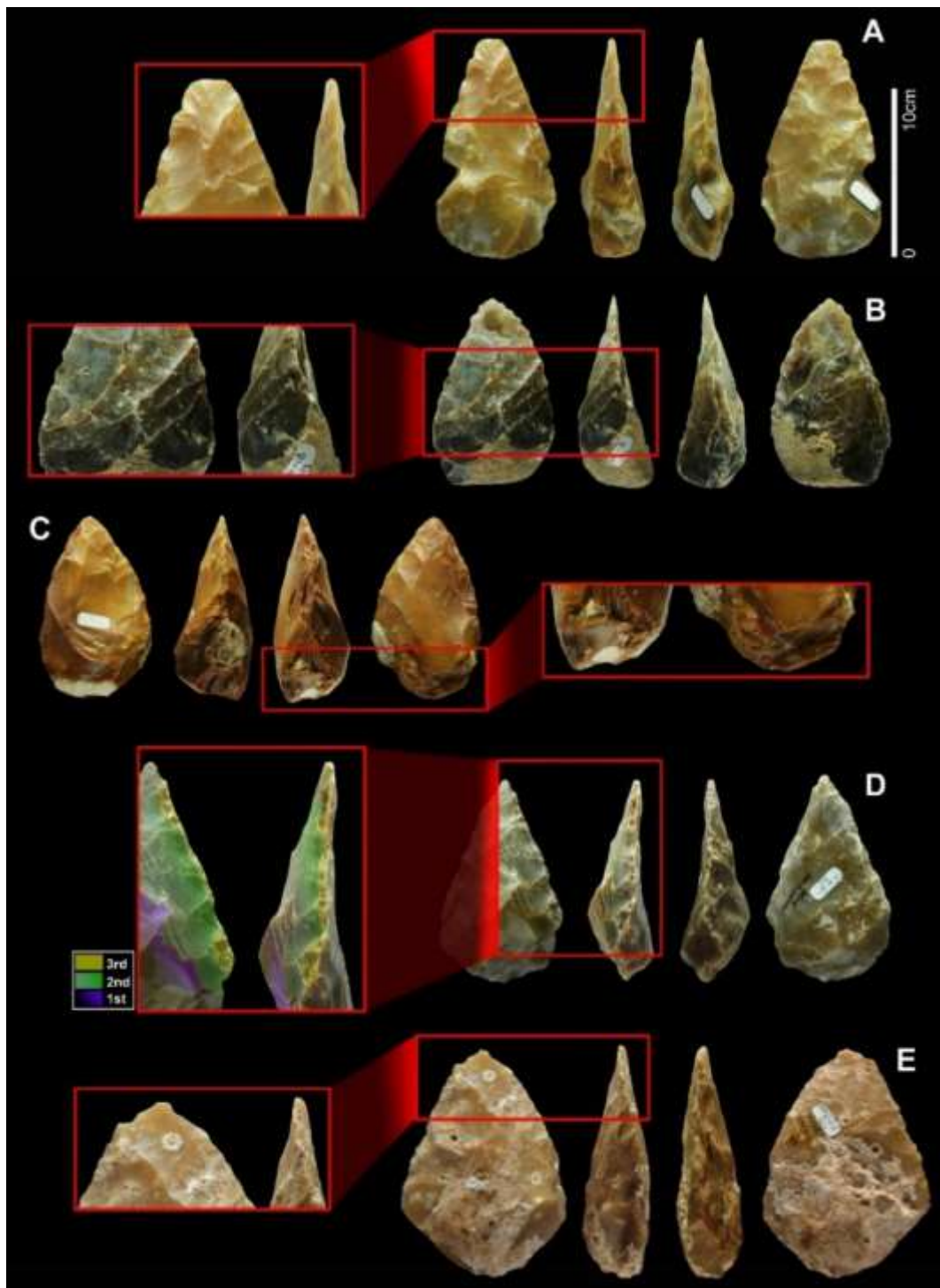


**Figure 2.** Handaxes from la Noira, stratum a (**A**, BFN III 146; **B**, BFN III 39; **C**, BFLN E1 d2 2; **D**, BFLN 0C5 d1 1) and stratum c (**E**, BFN SN; **F**, BFN VI 62; **G**, BFN VIb 178; **H**, BFN VIc 45).

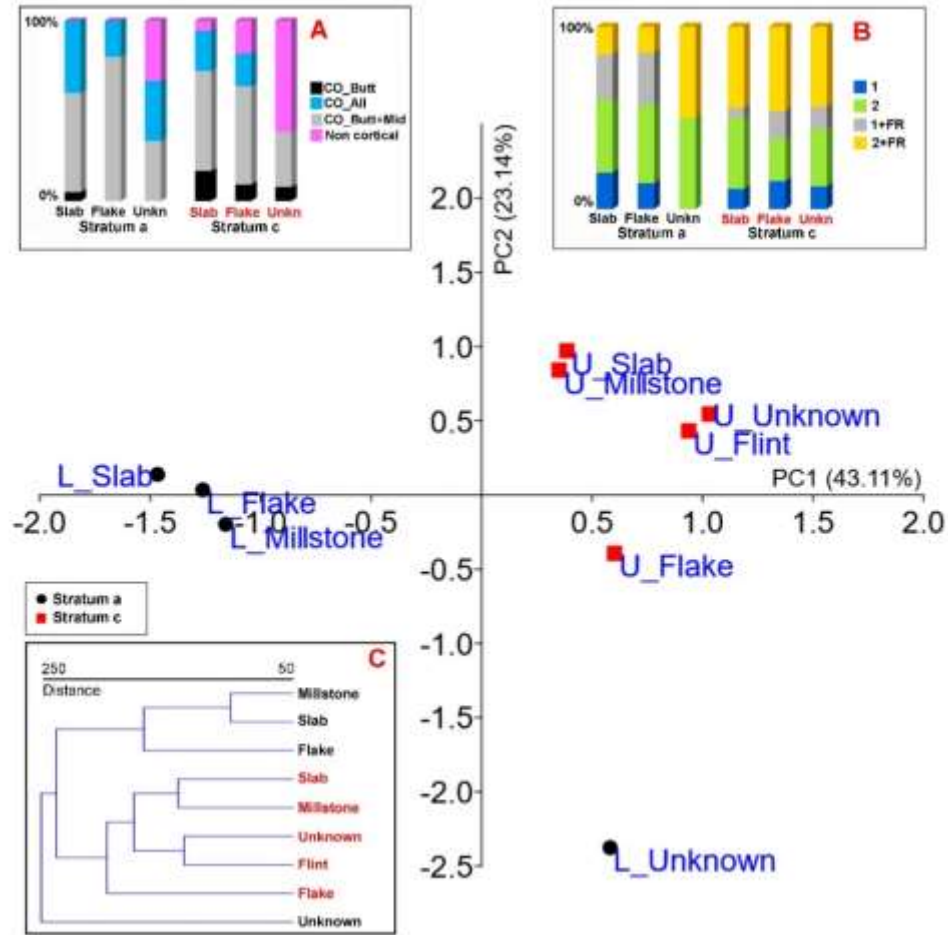


**Figure 3.** Technological characteristics of handaxes from stratum a of la Noira (**A**, BFLN 0C5 d1 1; **B**, BFN III 156; **C**, BFN III 148).





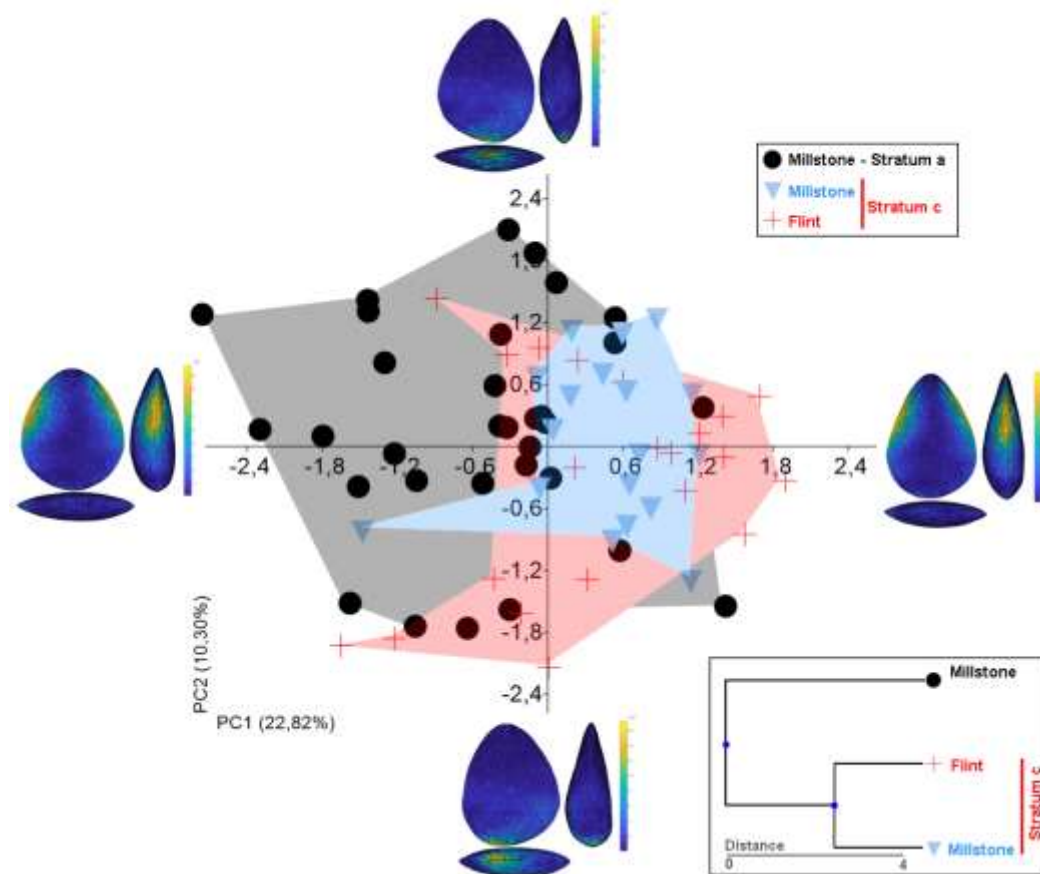
**Figure 4.** Technological characteristics of handaxes from stratum c of la Noira (A, BFN VI 62; B, BFN Vb 179; C, BFN VI 22; D, BFN Vic 45; E, BFN VIb 304).



**Figure 5.** Principal Component Analysis of the technological features considered for the analysis of handaxes and cleaver-like tools: Handaxe as a single unit (A); Handaxes as three different parts (Tip, B; Midpart, C; Butt, D). The distribution represents the sample divided into stratum a (L) and stratum c (U) levels, the type of blank (Slab, Flake and Unknown, blank dot) and type of raw material (Millstone and Flint red squares). **Graphic A**, distribution of Corticality between strata a and c and the type of blank identified; **Graphic B**, Removal series combinations in strata a and c and blank type; **Graphic C**, Cluster analysis and distances between the groups represented in PCA.

	(N)	Shape variability	variability (%) caused by		
			x (width)	y (length)	z (thickness)
Stratum a	31	348.42	47.73	5.97	46.30
Stratum c	47	321.2	38.85	4.84	56.31
Millstone_a	31	348.42	47.73	5.97	46.30
Millstone_c	23	308.90	37.60	3.52	58.88
Flint_c	24	325.75	40.36	5.89	53.74

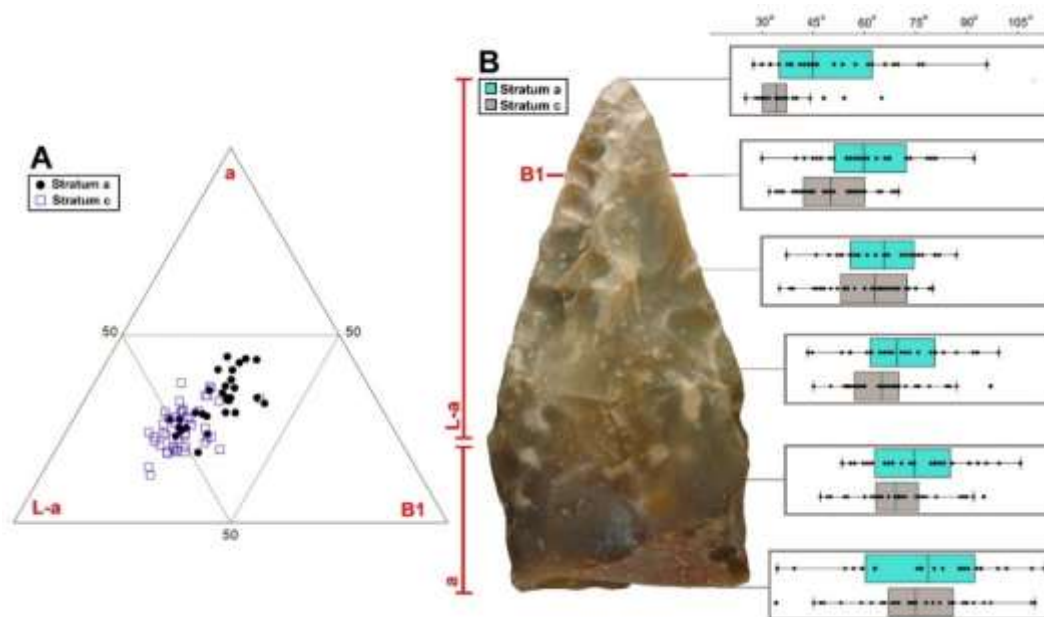
**Table 2.** Intra-assemblage shape variability (measured as the mean multidimensional Euclidean distance of all artefacts from its centroid) and distribution of relative shape variability across dimensions (calculated as the proportion of variability in each homologous semi-landmark coordinate for each specific dimension).



**Figure 6.** Principal component scatter plots of handaxes from La Noira, by strata and raw materials: millstone stratum a (black dots), millstone stratum c (blue triangles) and flint stratum c (red crosses). The geometric morphometric analysis was applied to 3D models, consisting of 5,000 semi-landmarks. It also includes **convex hulls** on each group to facilitate scatter plot visualization, and the **warps' tool**, representing morphology. Colour coding represents the most variable landmarks in shape trend described on positive and negatives scores of PC1 and PC2. Lower right-hand side; **Cluster analysis and distances** between the groups represented in PCA.

	Stratum a Millstone	Stratum c Flint	Stratum c Millstone
Stratum a Millstone		0.0001069	0.0002223
Stratum c Flint	0.0001069		0.6544600
Stratum c Millstone	0.0002223	0.6544600	

**Table 3.** MANOVA analysis on first 10 PC scores (74% of variance) from Figure 7, between stratum a and stratum c from la Noira and raw materials.



**Figure 7. A)** Ternary plot between Base Length (a), Distal Length (L-a) and Distal width (B1), from strata a and c. **B)** Angle distribution along the edges of tools from stratum a and stratum c of la Noira.

		Distal	1/5	2/5	3/5	4/5	Proximal
Str. a	Mean	46.87	59.29	66.7	71	75.38	74.4
	SD	13.69	11.22	9.82	11.18	11.2	16.11
	CV	0.29	0.18	0.14	0.15	0.14	0.21
Str. c	Mean	34.22	50.00	60.26	64.94	68.28	73.74
	SD	7.38	10.86	12.74	11.05	12.01	16.09
	CV	0.21	0.21	0.21	0.17	0.17	0.21

**Table 4.** Descriptive statistics (mean and standard deviation, SD) and coefficients of variation (CV) for the six edge angles considered, for strata a and c of la Noira.

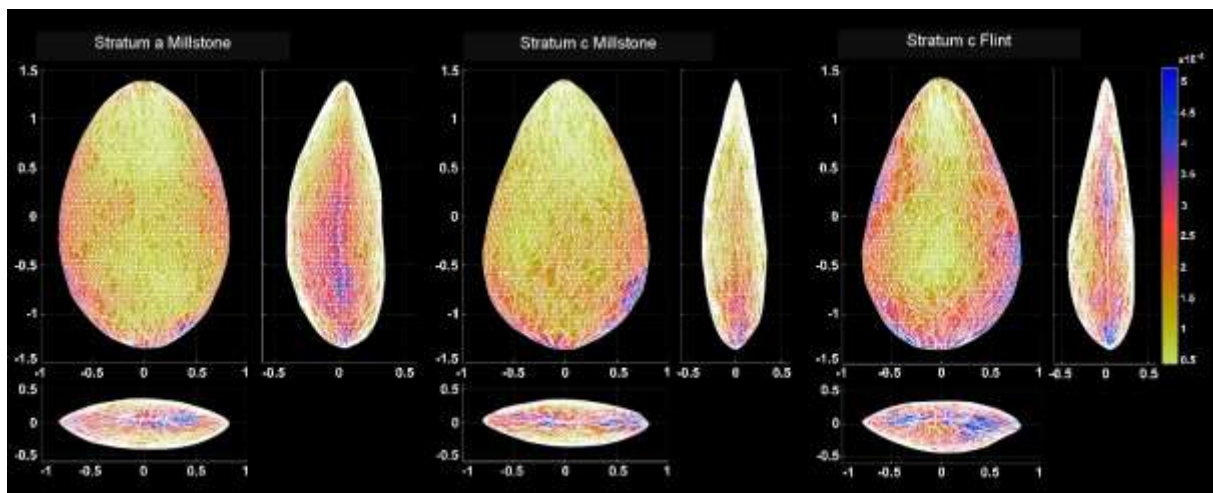
		N	F	p	r <sup>2</sup>
Stratum a	Millstone	31	11.07	<0.01	0.27
	Slab	20	7.03	0.01	0.28
	Flake	7	1.69	0.25	0.25
	Unknown	4	5.34	>0.1	0.72
Stratum c	Millstone	20	6.73	0.01	0.27
	Flint	21	13.85	<0.01	0.42
	Slab	15	3.42	<0.01	0.20
	Flake	11	6.79	>0.01	0.42
	Unknown	15	15.44	<0.01	0.54

**Table 5.** ANOVA statistical test between SDI values and volume according to raw material type and the type of blank between strata a and c of la Noira.

		Stratum a		Stratum c
		Millstone	Flint	Millstone
Deviation from perfect bilateral symmetry	Max	19.82	13.61	9.41
	Median	6.08	5.50	5.07
	Min	2.62	2.36	2.93
	Mean	7.06	5.66	5.17
	Std Dev	3.49	2.72	1.52
Deviation from perfect bifacial symmetry	Max	15.27	11.81	6.58
	Median	6.05	5.13	3.38

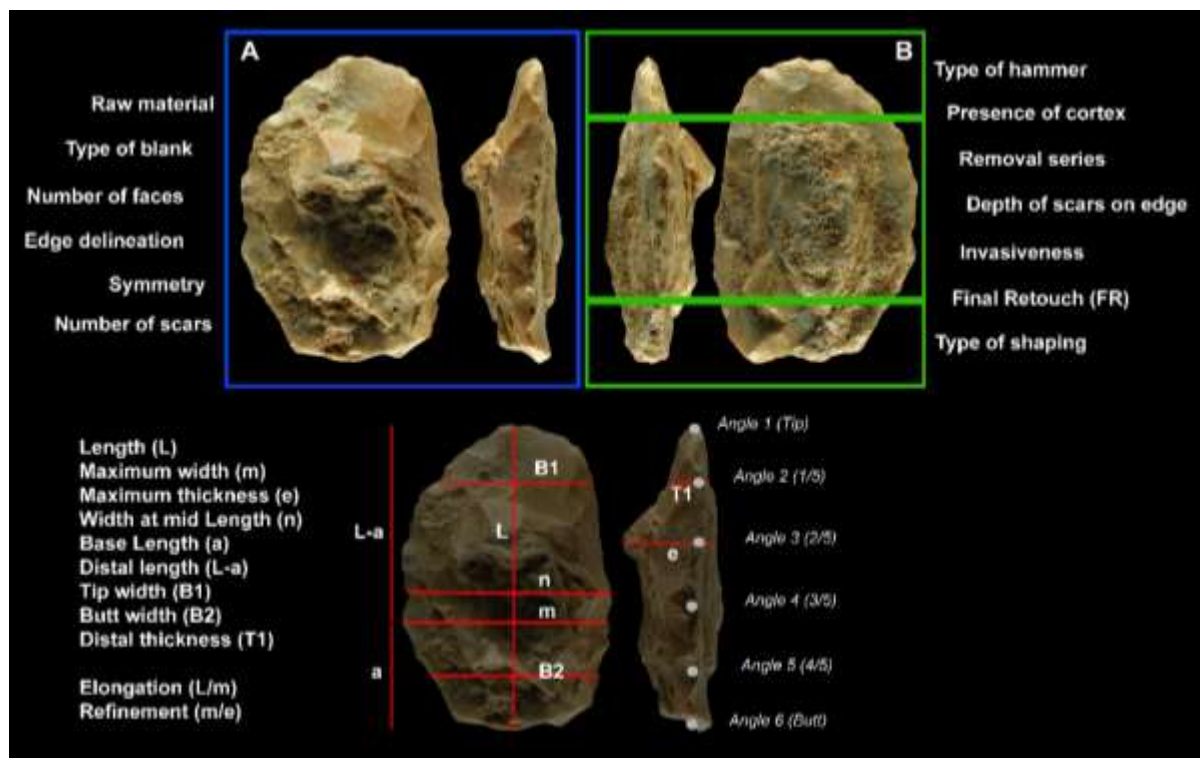
	Min	2.81	2.11	2.48
	<b>Mean</b>	6.18	5.12	3.99
	Std Dev	2.79	2.21	1.28
Left edge irregularity	Max	319.46	188.68	162.02
	Median	109.44	83.80	76.12
	Min	41.31	48.43	39.88
	<b>Mean</b>	124.76	86.16	85.06
	Std Dev	69.16	34.14	35.01
Right edge irregularity	Max	293.25	200.22	229.58
	Median	97.96	89.21	107.79
	Min	51.78	26.54	45.37
	<b>Mean</b>	122.99	90.81	112.68
	Std Dev	64.37	46.50	49.11

**Table 6.** Summary statistics for deviations from perfect bilateral and bifacial symmetry and edge irregularity.

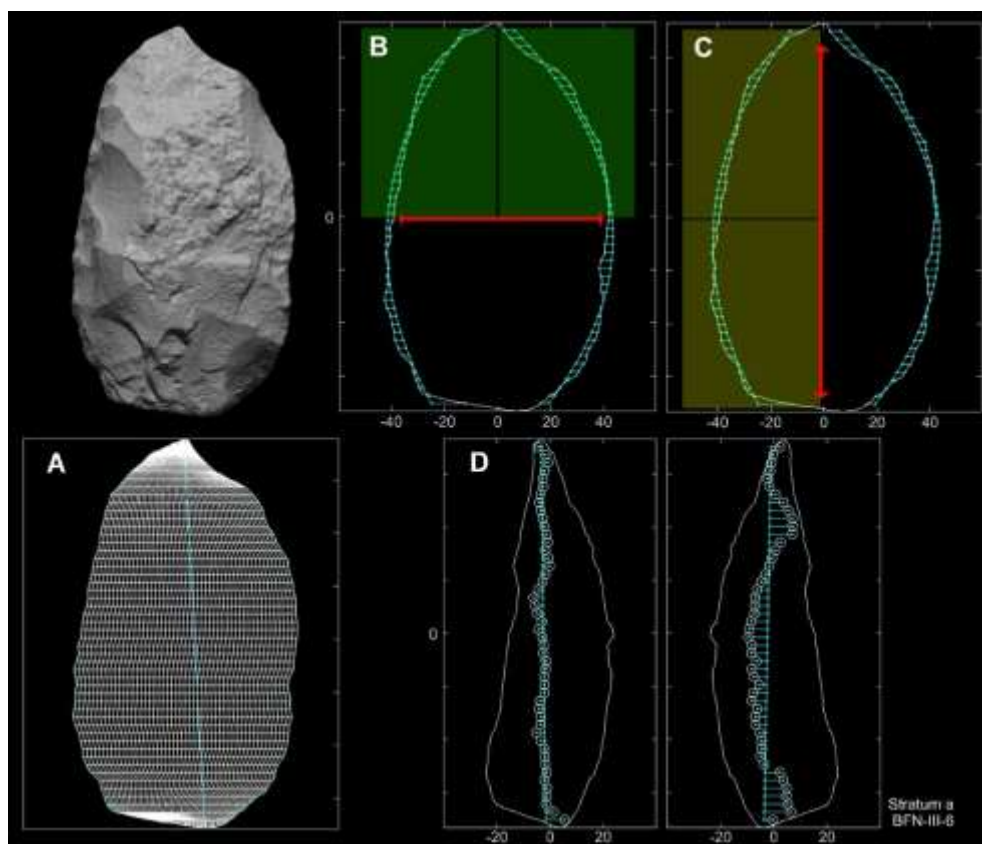


**Figure 8.** Mean shapes of LCTs from la Noira, stratum a and stratum c and the different raw materials (millstone and flint). Colour-coding represents the relative degree of variability of each individual semi-landmark reflecting the spatial distribution of variability in tools.





**Figure 9.** Technological analysis: technological features on each tool (A: considering each tool as one unit, and B: each tool divided into three parts), measurements, indices and angles.



**Figure 10.** A) 5,000 points defining outlines and tool surfaces; B) Edge curvature: visualization of deviation from perfect bilateral symmetry (in green), and from perfect bifacial symmetry (in yellow). C) Edge irregularity.

