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RESEARCH

Use-Wear Analysis Shows Changing Handaxe Grip and Use Across Time at la Noira (France)

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Abstract
Handaxes — sub-oval bifacially flaked stone tools — were produced for over a million years across Africa, Europe, and Asia during the Lower Palaeolithic. Their relatively uniform shape across varied environments and over a million years raises the question of whether or not their function and purposes were also uniform. Previous studies suggested that handaxe shape might be related to patterns in use and maintenance, but the level of analysis may have been too coarse to tease out specific uses. This study investigates the function of handaxes from two successive Acheulean occupations at the la Noira site (France), separated by ca. 200 ka. This research aimed to find out how hominins generally used handaxes through microscopic use wear analysis. Specifically, we documented macro-wear characteristics such as type (micro-scars, edge crushing, striations, edge rounding, polish), and their relative position and distribution. We used a Geographic Information System (GIS) to translate these observations into wear location heatmaps — visual representations highlighting areas of intense or repeated use — and compared these across different occupation periods. The analysis revealed that similar handaxes were likely held in different ways and used for different tasks during the two phases of occupation at la Noira, at 700 ka and respectively 450 ka. These findings suggest a more complex scenario of handaxe use than previously understood, including changes in tool use modalities over time that reflect changes in handaxe function and hominin technical behaviors.

Keywords Lower Palaeolithic · Acheulean technology · Handaxes · Use-wear analysis · GIS · Ergonomics

Introduction

The latter half of the Lower Palaeolithic (ca. 1.7 Ma–300 ka) period was marked by the widespread dispersal of hominins from Africa to diverse environments across Africa, Europe, and Asia (Antón, 2003; Bermúdez de Castro & Martinón-Torres, 2019; Carbonell et al., 2008; Hershkovitz et al., 2018; Parfitt et al., 2010; Prat, 2018; Stringer, 2012; Wagner et al., 2011). During this period, hominins adapted to a variety of habitats, ranging from tropical forests to Mediterranean climates, then temperate regions beyond 45°N latitude. This period also saw the emergence and widespread use of "Acheulean" handaxes, tools used by hominins from approximately 1.7 million to 200,000 years ago (Carbonell et al., 1999; Parfitt et al., 2010; Schick & Toth, 1994; Shea, 2017).

Handaxes are thought to be indicative of complex cognitive processes and cultural practices among early hominins (Hodgson, 2015; Leakey & Roe, 1995; Roe, 2003; Shipton et al., 2019; Shipton & Clarkson, 2015; Shipton & White, 2020; Wynn, 1995). They represent a technological shift from simple flake production to techniques that directly shape a stone nodule, implying the imposition of a pre-determined shape onto the material (Roche, 2005; Stout, 2011; Toth & Schick, 2009). High degrees of symmetry in some handaxes have led some to argue that the ability to produce (and possibly copy) symmetrical handaxes suggests advanced cognitive capabilities among

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hominins (Goren-Inbar, 2011; Gowlett, 1986; Wenban-Smith et al., 2000; Wynn, 2002). However, despite their simple form, there is significant variation in the design of handaxes across regions and time, challenging the notion of an unchanging tool (Delson et al., 2004; Klein, 1989; Phillipson, 1997; Renfrew & Morley, 2009; Wynn & Tierson, 1990). Complicating the matter, handaxes are made from a wide range of materials, including flint, quartzite, basalt, obsidian and even bone (e.g., Caruana & Herries, 2020; Chelidonio, 2019; Goren-Inbar & Sharon, 2024; Mussi et al., 2023; Rosenberg et al., 2015; Sano et al., 2020; Wei et al., 2017). This diversity in raw materials further challenges the idea of handaxes as uniform tools, as different materials influence both their design and affordances. Some have interpreted this variability as a result of different cultural norms (Finkel & Barkai 2018; Shipton & White, 2020) or simple drift (Lycett, 2008; Lycett & von Cramon-Taubadel, 2008), while others attributed it to raw material quality (Costa, 2010; De La Torre, 2011; Eren et al., 2014; Sharon, 2010; White, 1998) and degree of resharpening (McPherron, 2016; McPherron, 1999, 2006; Clark et al., 2024; Shipton & Clarkson, 2015).

At the same time, handaxes appear for almost a million years in assemblages as far apart as Spain and China, and the mechanisms behind this long-term persistence of the handaxe form are still hotly debated. Some scholars have proposed that its widespread recurrence across time and space may stem from a genetically canalized behavioral predisposition (Corbey et al., 2016). In this view, the production of handaxes may not have required social transmission in all cases but could reflect an evolved cognitive template for bifacial shaping. These perspectives challenge the assumption that technological traditions like the Acheulean were solely maintained through intergenerational learning. In contrast, (McNabb, 2020) defends a culturally based explanation, contending that key archaeological features of handaxes—including their variability and contextual use—are best explained through socially learned behaviors.

Thus, handaxe shape is both variable and constant. The lengths of time involved in these debates require an explanation for both, and yet these tools' function and especially the relationship between use and form has received comparatively little attention. So far, two ideas have been proposed: 1) that handaxe morphology is an intended design feature, facilitating better grip, handling, and efficiency in cutting tasks; and 2) that handaxe morphology is a result of repeated resharpening of the active edges. Regarding the first hypothesis, several studies have suggested that handaxes were intentionally shaped to optimize ergonomic features (Aldien et al., 2005; Gowlett, 2006, 2009; Simão, 2002; Toth & Schick, 2009). The proximal (butt) portion of handaxes, for instance, is frequently more obtuse than the distal end, leading some researchers to propose that this feature was deliberately produced to facilitate gripping and increase control during use (Key & Lycett, 2017a, b; Mitchell, 1995; Posnansky, 1959). Experimental research has shown that handaxes with moderately obtuse edge angles in the proximal region allow for greater applied force, improving cutting efficiency without compromising effectiveness (Key et al., 2016). However, when angles exceed approximately 70 degrees, cutting efficiency decreases, suggesting that hominins may have actively controlled edge morphology to balance functional performance and ergonomic comfort (Key et al., 2016; Machin et al., 2007; McCall, 2005). Additionally, the weight distribution of handaxes has been linked to ease of handling, with research indicating that placing the highest point of mass centrally within the grip improves usability (Gowlett, 2006, 2009).

To the contrary, the resharpening hypothesis (Iovita & McPherron, 2011; McPherron, 2006) directly ties shape to some aspect of tool function, proposing that repeated use and resharpening of some parts (especially the tips) over others cause most of the variation.

There are issues with both proposals. Ergonomic approaches based on efficiency assessments in experimental tasks can insert too much of the archaeologists' own sensibilities and imagination into past. For instance, several studies have explored the ergonomics of handaxe use experimentally (Fedato & Bruner, 2023; Fedato et al., 2020; Key & Lycett, 2017a, b; Key et al., 2016), but a crucial first step toward testing the experimental results is to establish where wear traces are actually found on these tools. On the other hand, resharpening is a secondary (and blunt) measure of actual use (in the sense of either tool operation or designer-intended function) (Iovita, 2024). Moreover, some recent studies have challenged the utility of resharpening for understanding handaxe shape variation (Clark et al., 2024).

Instead, microscopic wear traces found on the handaxe edges offer a more direct, forensic indicator of past use. To some extent, the few existing use-wear analyses of handaxes already suggest they were used in a variety of ways, such as in cutting animal tissue and wood, and percussive tasks on semi-soft materials (Binneman & Beaumont, 1992; Claud, 2008, 2012; Dominguez- Rodrigo et al., 2001; Hardy et al., 2018; Hérisson et al., 2012; Keeley, 1980; Mitchell, 2016; Moncel, 1995; Murray, 2017; Ollé & Vergès, 2014; Ollé et al., 2015; Rots & Van Peer, 2006; Solodenko et al., 2015; Viallet, 2016; Wenban-Smith et al., 2000; White, 1998; Zupancich et al., 2021). Additionally, some studies have suggested that, beyond their cutting edges, handaxes may have been used in ways that involved the inner faces or broader surfaces of the tool (Mitchell, 1995; Toth & Schick, 2009). Despite these findings, there has been limited systematic research on where wear traces are *generally* found on handaxes and how these relate to their form, thus enabling conclusions about design and ergonomics in a diachronic context.

La Noira, situated in the Cher River Valley and discovered in the 1970s, provides an ideal case study for examining potential changes in handaxe use over time because of its two occupational phases, recent excavation and modern curation practices, and because its collections were already investigated using high-power microscopic use wear and residue analysis (Hardy et al., 2018), as well as geometric morphometrics (Iovita et al., 2017). It preserves a well-defined stratigraphic sequence spanning the Early and Middle Pleistocene periods. The Acheulean layers, located specifically on terrace D, date back approximately 700 ka, determined through electron spin resonance (ESR), extended-range OSL (TT-OSL) and paleomagnetism (Despriee et al., 2016; Despriée et al., 2007, 2010, 2011, 2017; Duval et al., 2020; Shen et al., 2012; Voinchet et al., 2010). The site comprises two occupation layers, with the early phase dating to around 700 ka and the later phase approximately 450 ka. These phases correspond to the early MIS 16 glacial stage and the end of MIS 12 and beginning of MIS 11, respectively, as supported by ESR dating and geological markers (García-Medrano et al., 2022; Moncel et al., 2013).

Even the oldest handaxes at la Noira are remarkably symmetric (Iovita et al., 2017). Symmetry increases slightly for the later, upper level, and raw materials are imported from farther away, but overall, the differences compared with the older handaxes are small. The first use-wear analyses at la Noira hinted at various activities involving animal and plant matter preserved as residues, supporting their use on a variety of materials (Hardy et al., 2018). Beyond the handaxes themselves, changes observed in the broader lithic assemblage across the main occupation phases at la Noira suggest evolving strategies in raw material procurement and tool production (García-Medrano et al., 2022; Moncel et al., 2021). Yet, despite these technological changes, handaxe morphology remains remarkably stable through time — characterized by a conservation of form, high symmetry, regular access to raw materials, and limited innovation in shaping techniques.

The primary objective of this study is to analyze the distribution of microscopic use-wear on handaxes from both phases to determine whether identifiable wear patterns exist and, if so, whether they remain consistent or show variation between occupations. This approach allows us to assess potential shifts in tool use and ergonomics through time.

Method

Sampling Method and Analysis Strategy

This study investigates the functional use of handaxes, examining wear on the tip, edges, butt, and inner surfaces. While previous studies have primarily focused on the tip's role in active tasks, suggesting its shape and orientation affect its use in cutting or percussive activities (Bello et al., 2009; Hardy et al., 2018; Jones, 1980; Machin et al., 2007; Ollé et al., 2013), the butt has also been considered for tasks like butchering due to its thickness and position as the tool's center of gravity (Gowlett, 2014; Keeley, 1980; Machin et al., 2007; Murray, 2017; Ollé & Vergès, 2014; Preece et al., 2006; Wynn & Coolidge, 2017). Moreover, the handaxe's edges and inner surfaces are recognized for cutting, and recent findings suggest uses in percussive activities and fire-starting, highlighting a wider range of purposes (Dominguez- Rodrigo et al., 2001; Gowlett, 2015; Key & Lycett, 2017b; Sorensen et al., 2018). This study seeks to assess wear patterns on the entire handaxe to determine the active employment of the butt and inner parts, in addition to the traditionally examined edges and tip. To this end, thirty (30) handaxes from the collection, twenty (20) out of the total 31 handaxes from layer A and ten (10) out of the total 47 handaxes and cleaver-like tools from layer C, were randomly selected for analysis. The difference in the number of handaxes analyzed from each layer reflects a practical limitation in the scope of the study, designed to balance depth of analysis with available resources and time constraints. While twenty (20) handaxes were selected from Layer A to provide a robust dataset, the sample size for Layer C was adjusted to ten (10) to ensure the study remained manageable within the timeframe while still yielding meaningful comparative insights. All handaxes included in this study were randomly selected from the curated assemblage, without excluding specimens on the basis of completeness or morphological regularity. To ensure an unbiased sample, all available handaxes were laid out and individually numbered, after which a set of random numbers was generated using Excel to select the final sample. This inclusive approach aimed to avoid introducing a selection bias that might favor only well-preserved or “ideal” handaxes, which could distort interpretations of actual use. While a few of the selected handaxes exhibited damage such as broken or missing tips, these artifacts were nonetheless retained in the sample, as they still offered valuable wear data. Given that previous research has often prioritized shape-based classifications, our study instead focused on functional patterns, and thus required a representative cross-section of the assemblage, including irregular and fragmentary tools. A detailed presentation of the technological characteristics of the la Noira assemblage—including raw material use, shaping strategies, and reduction sequences—can be found in previous studies (García-Medrano et al., 2022; Moncel et al., 2013, 2020, 2021).

Wear Observation and Types

Each handaxe was cleaned in an ultrasonic bath with neutral soap for 10 min before high-resolution photographs were taken from every side for detailed examination. As a first step, macro-wear observations were documented with a digital optical microscope (Dino-Lite AM73915MZT). The study focused on macro-wear (micro-scars, striations, edge rounding, pitting, crushing) for several reasons (Fig. 1). First, experiments and blind testing have proved that micro-scars provide information on the modality of use of stone tools, such as the type of motion (pressure or percussion) as well as the direction of the motion (longitudinal or transverse) (Odell-Vereecken & Odell, 1980; Tringham et al., 1974). Additionally, micro-traces are less affected by post-depositional processes in contrast to micro-traces such as polish which can be altered by patina layers (Beyries, 1990). However, the presence of polishes was also documented when possible. Rounding was recorded only when it could be confidently attributed to use. When the overall edges and ridges appeared uniformly rounded, the alteration was interpreted as taphonomic.

Micro-scars Micro-scarring is the result of interaction between the tool and external forces such as pressure, friction, or percussion (Bertouille, 1991; Prost, 1989); their presence is observed for abrasive activity on the edges of stone tools. Differentiating between wear scars and technological scars on bifacial tools such as handaxes can be challenging, particularly in cases where shaping or resharpening overlaps with areas of use. However, several diagnostic features help in distinguishing the two. Technological scars—those resulting from shaping, thinning, or resharpening—tend to occur in clusters of stepped or hinged removals. These scars are generally larger, and irregularly spread across the edge. In contrast, use-wear scars are typically smaller, more localized, and regularly spaced along the working edge (Odell, 1981; Odell-Vereecken & Odell, 1980; Tringham et al., 1974). Their distribution tends to follow patterns consistent with repetitive contact against specific materials, and they often occur in association with other wear features such as rounding, striations, or polish. When such stepped, irregular scars consistent with shaping or resharpening were observed, they were not categorized as use-wear in this study. While the distinction is not always clear-cut, these criteria provided a reliable framework for separating functional wear from manufacturing traces in the current analysis.

Striations Striations are assumed to be due to particles present between the worked material and the tool or within the worked material and that produces linear traces on the tool. They give information on the direction of the motion (Kamminga, 1979; Keeley, 1980; Mansur-Franchomme, 1986a; Semenov, 1964).

Crushing and Pitting The term crushing describes small and overlapping removals due to pressures applied on the cutting edge (Hayden, 1979; Kamminga, 1979). Pitting and crushing of the stone tool edges are observed mainly for percussive activities (Caricola et al., 2018; Haslam et al., 2013).

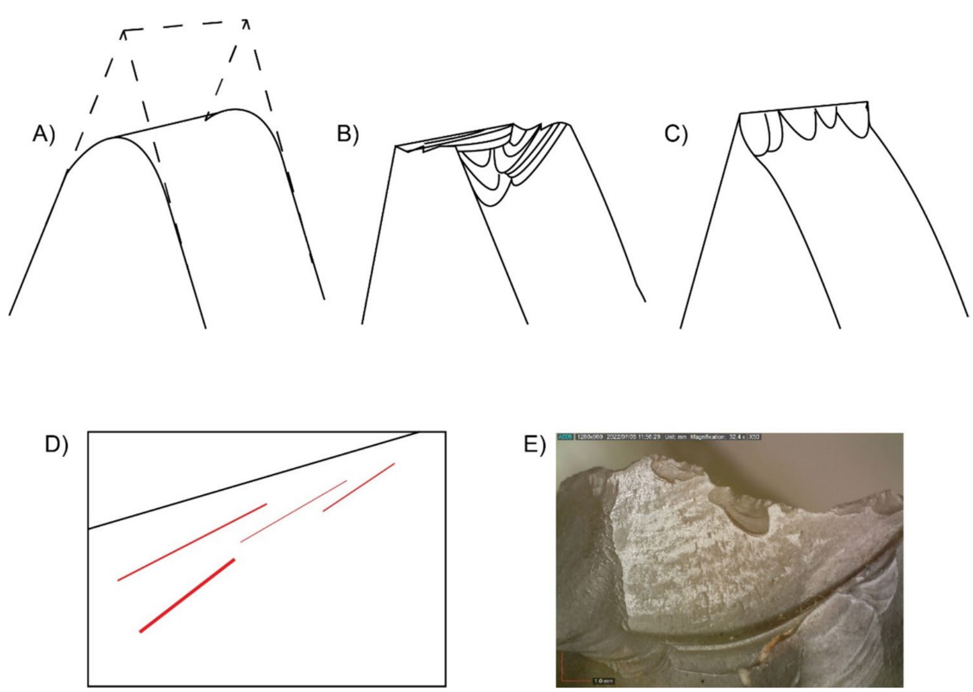


Fig. 1 Representation of the different types of wear on a section of edge used during the study. **A** Edge rounding; **B** Edge crushing; **C** Micro-scars; **D** Striations; **E** Polish observed with the Dino-Lite (AM73915MZT) X50µ)

Edge Rounding The term rounding is used to describe an edge portion that became round/blunt due to abrasion (Roebroeks et al., 1988; Unrath et al., 1984; Van Gijn, 1986). The position of the rounding on the edge can give information on the type of motion. If the rounding appears equally on both sides of the edge, the motion is likely longitudinal; if it is present predominantly on one side, the motion is likely transversal (Anderson-Gerfaud, 1981; Keeley & Toth, 1981; Mansur-Franchomme, 1986b; Vaughan, 1981).

Polish Even if some studies on handaxes have described some polish (Binneman & Beaumont, 1992; Keeley, 1980; White, 1998), polish preservation depends on how patinated the handaxe surfaces are.

The faces were named according to the following strategy: if plano-convex, face A is always the convex face, and face B is always the flat face; if bi-convex, face A is always the face with the highest point in relation to the plane formed by the cutting edges. When it was not possible to identify a more protuberant face, faces were randomly assigned the names Face 1/Face 2.

The Dino-Lite microscope accommodates the entire surface of a handaxe and offers a magnification range of 20 × to 240 ×, allowing for the documentation of both micro- and macro-wear traces. Equipped with light filters that replicate co-axial illumination, it enables the identification and characterization of polish when present (see Fig. 1E). To visualize the use-wear patterns on each tool, a standardized handaxe template was used to digitize the distinct types of use-wear, their specific locations, and their extent on the tool's surface in Illustrator (Fig. 2). The thickness of the lines in these diagrams reflects the invasiveness of the traces, with thicker lines representing more extensive or pronounced modifications. To enhance clarity and provide a tangible representation of these wear patterns, microscopic images alongside the mapped observations were incorporated (Supp 2). This approach offers a broad insight into the wear characteristics of each handaxe. Blind tests on active areas show 87.5% accuracy in identifying the active area at high magnification (Keeley & Newcomer, 1977), and 80% accuracy at low magnification (Odell-Vereecken & Odell, 1980). Along with wear traces, any other important information such as breakage or post-depositional phenomena were also described.

Post-Depositional Processes

It is important to take into account the post-depositional processes that could have impacted the tools. Taphonomic studies conducted during and after the excavations at la Noira have provided crucial insights into site formation processes, artifact distribution, and post-depositional dynamics. Detailed documentation and analysis of 6,495 lithic objects — including their physical characteristics, orientation, and alterations — revealed the combined effects of natural processes and human activities on the archaeological record. These studies highlight, in particular, the presence of anthropogenically modified millstone fragments and the overall good preservation of cutting edges in stratum C, suggesting limited post-depositional disturbance. The patterns observed indicate that artifact distribution and wear have been primarily shaped by human behavior rather than by natural site formation processes (see Supp. 1 for detailed taphonomic and geoarchaeological analyses). The distribution and intensity of use-wear on a stone artifact is markedly different from the traces that post-depositional agents leave (Plisson & Van Gijn, 1989). Sediment compaction and slumping, chemical weathering, fluvial transport, and freeze–thaw cycles should produce damage present over the whole surface of the tool, such as an overall abrasion of the tool, a global rounding of the ridges, or patina. Trampling, however, can produce edge damage similar to micro-scars. Yet, studies suggest that edge damage from trampling presents no strong location preference (Burroni et al., 2002; Eren et al., 2011; McBrearty et al., 1998; Pryor, 1988; Shea & Klenck, 1993; Tringham et al., 1974). In our study, we recorded observations regarding post-depositional traces such as extensive rounding, abrasions, or thick patina and their spatial distribution on the artifacts.

Wear Distribution Maps

Following the use-wear documentation, handaxe templates were exported as shapefiles in ArcGIS to create maps of the most used areas depending on wear types. Although developed for landscape-scale data, GIS methods can be useful for quantifying the spatial distribution of traces on stone tools (Benito-Calvo et al., 2015; Benito-Calvo et al., 2018; Bird et al., 2007; De La Torre, 2011; Schoville, 2010) and bones (Abe et al., 2002; Marean et al., 2001; Parkinson et al., 2014, 2015, 2022). Most relevant to our study, Murray (2017) applied the edge damage distribution method developed by Bird et al. (2007) and Schoville (2010) to handaxes from the Lower to Middle Palaeolithic site of Shishan Marsh 1 (Jordan). By combining experimental archaeology, low-powered microscopy, and GIS spatial analysis, Murray demonstrated the method's potential for identifying activity patterns and functional variability in biface use at the assemblage scale. Similarly, De la Torre et al. (2011), and Benito-Calvo et al. (2015, 2018) applied GIS and 3D morphometrics to experimentally and archaeologically analyze pounding tools, producing surface roughness and wear distribution maps.

This study differs from the above-mentioned work in several methodological ways. Instead of mapping individual micro-polygons of edge damage, as done in Bird and Schoville's

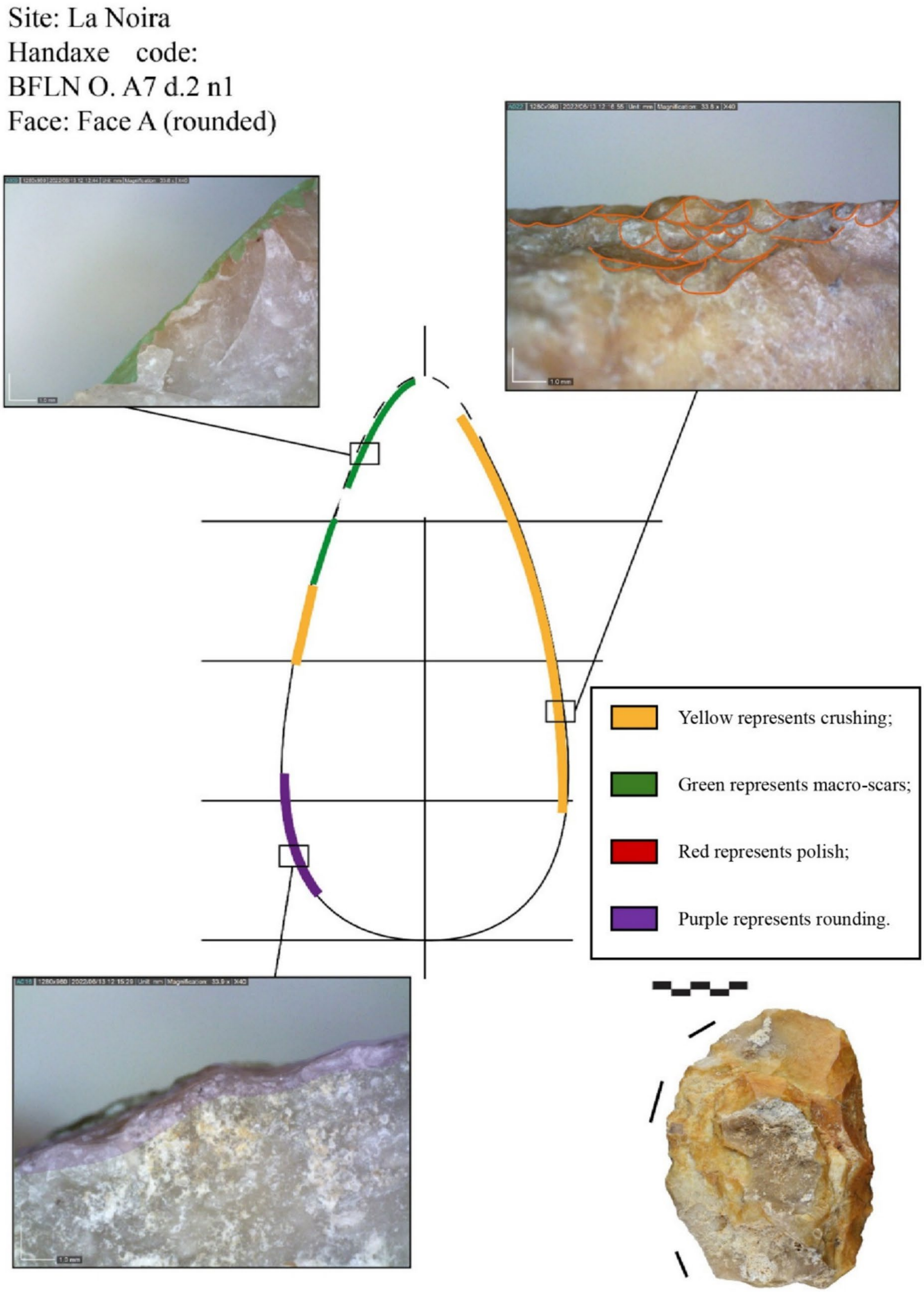


Fig. 2 Template mapping use-wear observation on a handaxe from la Noira. Black lines around the picture of the tool represent previous wear results published in Hardy et al. (2018)

studies, the present approach relies on a standardized handaxe template divided into eight spatially defined zones. Each zone was scored according to the distribution of wear observed under low- and high-power magnification (0–4 scale), drawing inspiration from anatomical mapping techniques used in zooarchaeology for MNE and cut mark frequency (e.g., Abe et al., 2002; Marean et al., 2001). This method allows for a semi-quantitative synthesis of wear distribution without requiring full digitization of scar outlines, making it particularly suitable for the use-wear analysis of bifaces and other large tools with continuous edges. Crucially, unlike the edge damage distribution method (EDDM), which focuses primarily on the spatial frequency of generic edge damage, this approach records distinct use-wear types (e.g., micro-scars, crushing, polish), enabling a more nuanced interpretation of tool function. Differentiating wear types is particularly valuable, as it provides complementary insights into the nature of contact actions (e.g., percussive vs. cutting) and the motions involved in tool use. While not intended to replace EDDM, this method offers a flexible and replicable framework that expands the analytical resolution of distributional studies. Although the handaxes in this study vary in size, shaping intensity, and symmetry, the use of a standardized template was a deliberate choice.

A toolbox was created to process the digitized use wear traces for each type of wear (Fig. 3). All wear observations were imported as unique polygon features into ArcGIS. These features were then converted into raster data using the Polygon to Raster function. Rasters had a value of "1″ in areas with use wear while areas without wear had a value of "0″. CellsRasters were added to the overlain templates to create heat maps visualizing which areas of the tools showed the most wear, with higher values indicating more overlapping wear traces. areas on the handaxes with frequent wear traces. We compare wear patterns across various factors, such as handaxe shape, faces, and archaeological layers to assess changes in the spatial patterns of use wear on handaxes. The heatmaps also help identify potential prehension areas versus active tool edges among the handaxes.

To assess statistical differences in spatial wear patterns between the two archaeological layers at la Noira, each tool's edge was divided into eight sections—four on each lateral edge—using the grid-based template. Sections were scored based on the extent of wear: absent (0), present on ¼ of the Sect. (1), ½ (2), ¾ (3), or the full Sect. (4). Scores were summed separately for the left and right edges of each tool, with the "right edge" defined as the right side when observing the convex face (Face A), and the "left edge" as the left side of the same face. These summed values were then aggregated by layer (Layer A: $n=20$; Layer C: $n=10$) and by edge side. Chi-square tests with Yates' correction were applied to test whether there were significant differences in wear distribution between layers and between lateral edges. When necessary, Monte Carlo simulation with one million permutations was used to refine p-values and account for small, expected frequencies.

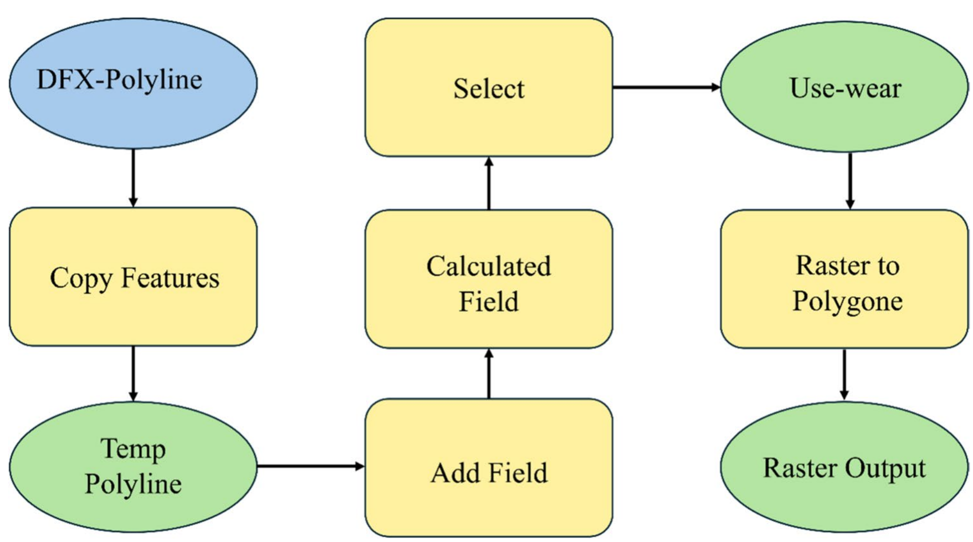
Results

Only the results for micro-scars and crushing are presented in detail in this section because polish and rounding were rarely observed within the analyzed corpus and did not allow for a meaningful analysis.

Stratum A

Stratum A of la Noira contains the site's oldest layers. Handaxes from this layer show a spread-out pattern of micro-scars across the surface of their edge (Fig. 4). The scars are evenly distributed along both edges, with most of the wear located on the tool's top half.

Fig. 3 ArcGIS workflow to prepare heatmaps from templates for a given wear type



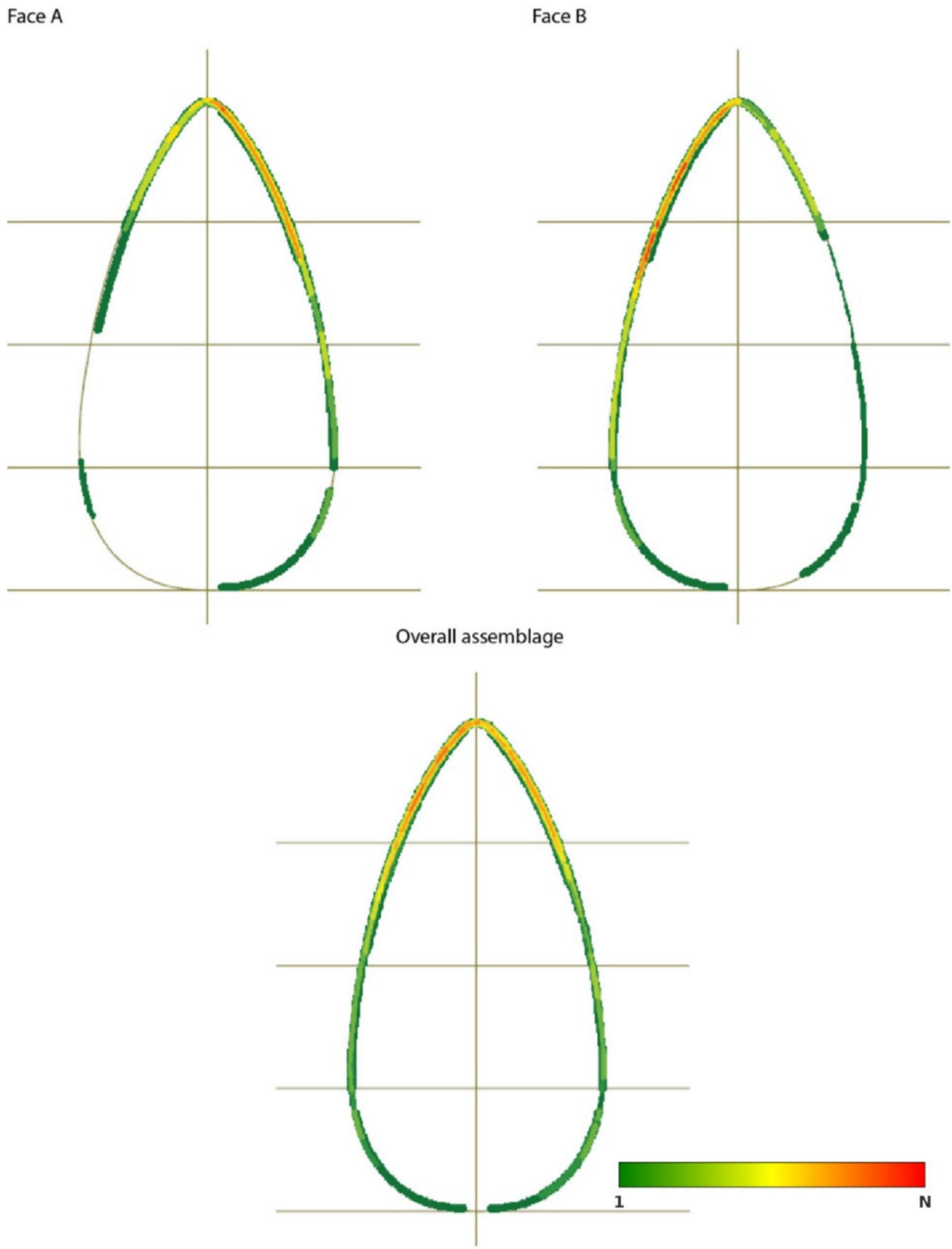


Fig. 4 Micro-scars distribution for the stratum A of la Noira

The crushing damage is located mainly on the top three-quarters of the handaxes (Fig. 5). The tip and butt areas present fewer damages than the other handaxes. One of the two edges (the same edge as stratum C) seems slightly more damaged, particularly for the first and third quarters of the tools. Crushing damage in stratum A predominantly occupies the upper three-quarters of the handaxes. The topmost quarter, specifically the tip, has less crushing damage. The wear pattern on one of the edges is still noticeable but seems slightly less pronounced in this layer. This might suggest a shift in usage or prehension over time.

Micro-scars and crushing present distinct patterns on the handaxes from la Noira. Furthermore, one handaxe from this layer exhibited crushed areas and impacts on its inner surface, suggesting uses beyond merely that of the sharp edges. This indicates that handaxes from this layer could have been utilized not only for their cutting capabilities but also for delivering blunt force.

Stratum C

Stratum C of la Noira contains the site's youngest layers. Most handaxes from this stratum exhibit a concentration of micro-scars on the top half, particularly around the tip area (Fig. 6). In contrast, the butt of the handaxes shows significantly fewer micro-scars, suggesting a less active role in usage. This pattern may indicate that the butt served primarily as a prehensile part, while the tip was employed in tasks requiring precision and sharpness, such as cutting, slicing, or carving.

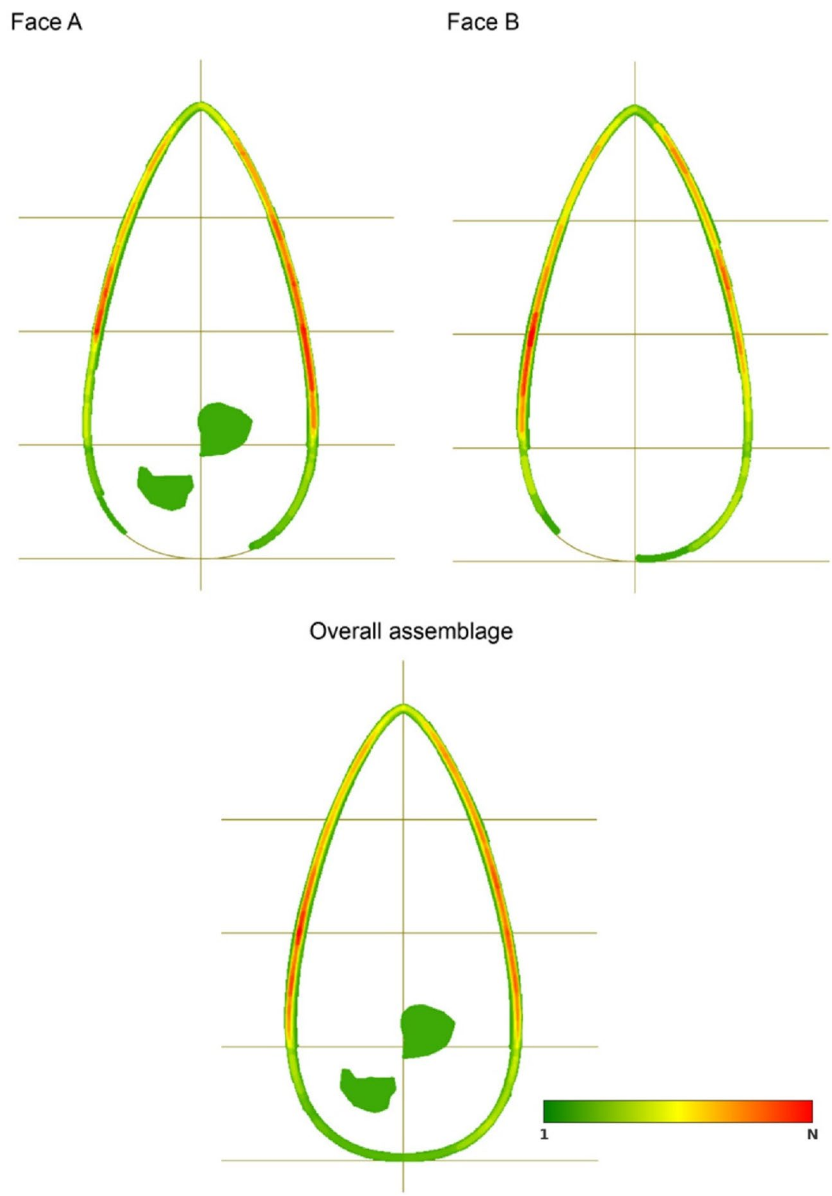


Fig. 5 Crushing distribution for the stratum A of la Noira

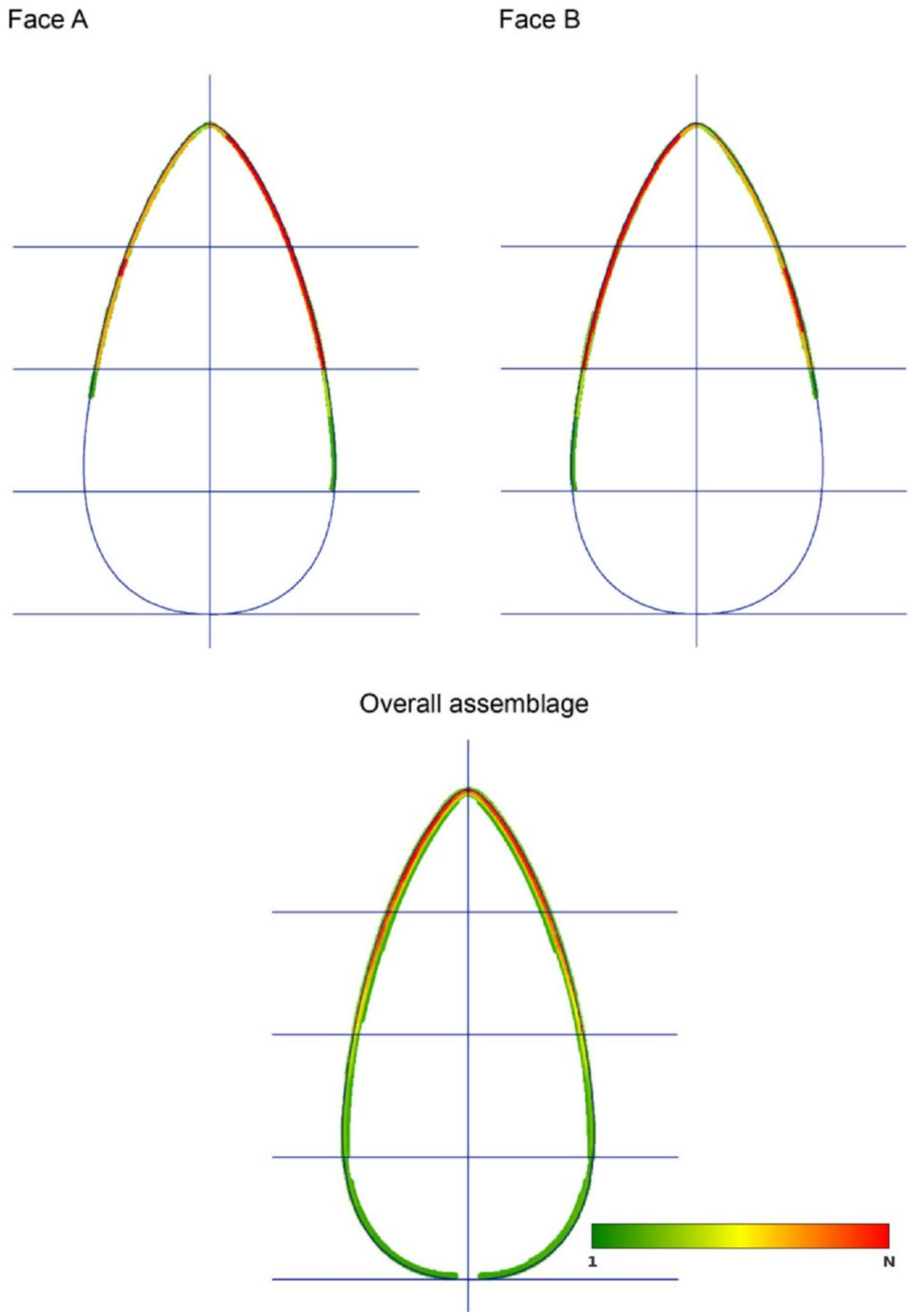


Fig. 6 Micro-scars distribution for the stratum C of la Noira

For handaxes with asymmetrical faces, the micro-scars appear to cluster more heavily on one edge, suggesting preferential use or a dominant cutting side. The overall assemblage image includes additional handaxes not featured in the two-face comparison. Many of these added bifaces are highly symmetrical, making it impossible to distinguish between their faces. This inclusion accounts for the observed discrepancies and ensures that the overall assemblage provides a more comprehensive representation of the collection.

The crushing damage is more prevalent around the center of the handaxe edges (Fig. 7). Specifically, the third quarter of the tool seems to exhibit the most wear. The butt of the handaxes, much like with the micro-scars, shows minimal signs of crushing. This consistent pattern across different types of wear reinforces the interpretation of the butt being less actively utilized. Asymmetrical wear is again noticeable, with one edge of the handaxes presenting more crushing damages, especially along the first and third quarters. In Fig. 7, the upper

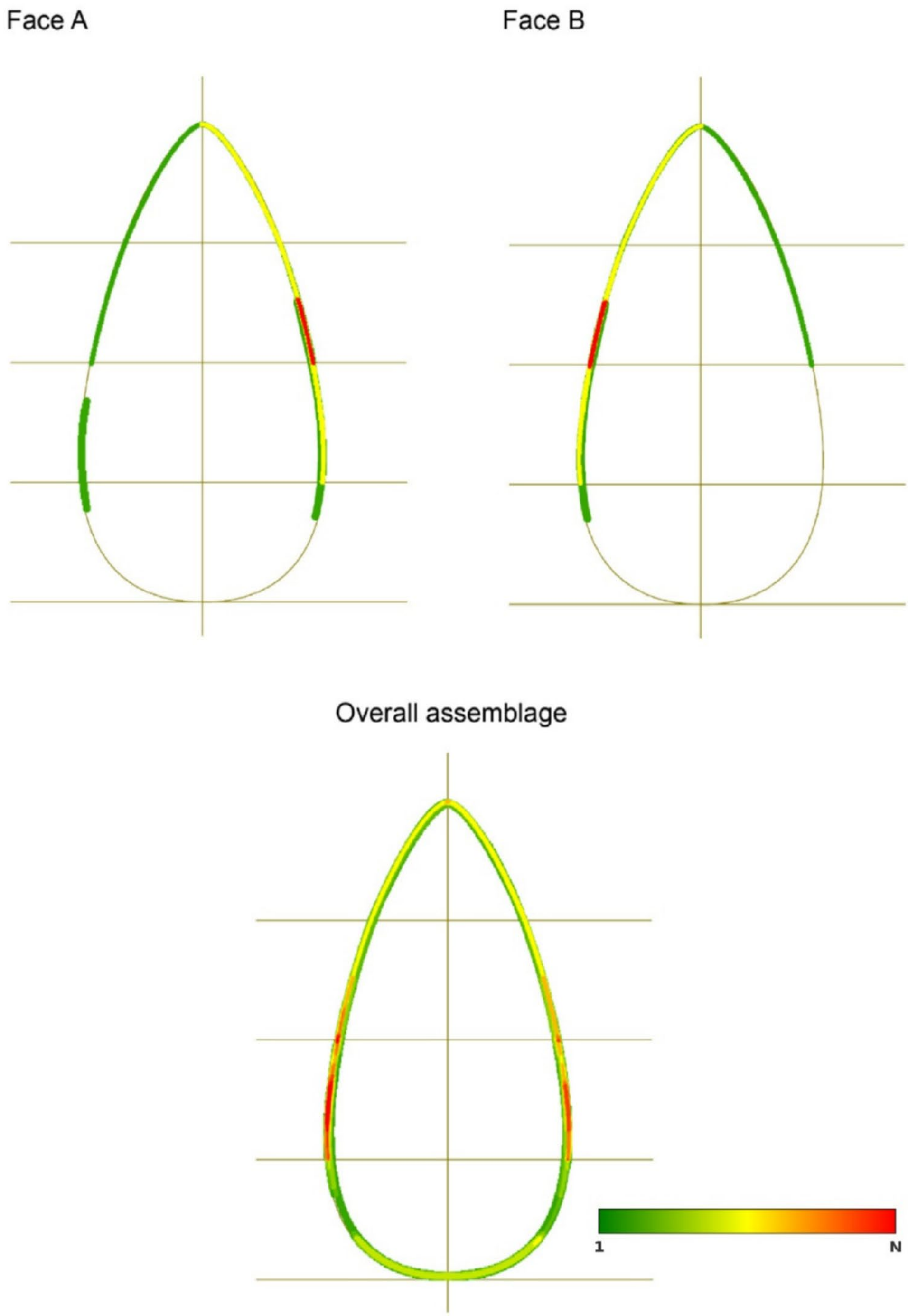


Fig. 7 Crushing distribution for the stratum C of la Noira

diagrams represent only those Layer C handaxes exhibiting a clear asymmetry between a flat and a convex face. This subset was analyzed separately to explore whether this morphological distinction corresponded with lateralized wear suggestive of ergonomic grip preferences. The composite diagram below includes the entire Layer C sample. The additional signals of crushing on the butt in this composite reflect wear patterns from more symmetrical-faced handaxes, suggesting that these morphologies may have allowed or encouraged alternative gripping strategies that involved this area more actively.

We examined the spatial distribution of macro-wear traces (crushing and micro-scars) to test if it differed between the two occupation phases at la Noira. The results highlight a significant variation in crushing wear, but no statistically significant difference for micro-scarring. For crushing wear, a Chi-square test with Yates' correction indicated a statistically significant difference between the left and right edge distributions in Layer A versus Layer C ($\chi^2 = 5.14$, $p = 0.023$; Monte Carlo $p = 0.008$). In Layer A, crushing traces were relatively evenly distributed between the left (176) and right (167) edges. In contrast, Layer C showed an asymmetrical pattern, with more crushing concentrated on the right edge (Left: 43; Right: 69), suggesting a potential behavioral shift in how tools were grasped or used between phases.

For micro-scars, no statistically significant difference was detected in lateral distribution between layers ($\chi^2 = 2.48$, $p = 0.115$; Monte Carlo $p = 0.102$), though a similar directional trend was observed. In Layer A, micro-scars were slightly more frequent on the left edge (52 vs. 43), while in Layer C they appeared more concentrated on the right (58 vs. 76). However, this variation did not reach statistical significance.

These findings refine initial observations from the heatmaps: while both wear types showed some lateral variation, only crushing wear exhibited a statistically significant shift between the two layers. This suggests a change in tool use or handling over time, rather than a uniform pattern across all wear types.

Finally, our results suggest that the handaxes from Stratum C, the younger of the two layers at la Noira, may have been used with a grip that favored one side of the tool (Fig. 8). The overlay of wear concentrations (in red and yellow) and the proposed hand position (purple area) indicate a slightly more lateral or offset grip, particularly in tools with asymmetrical cross-sections. This contrasts with the more balanced and symmetrical distribution of wear observed in Stratum A, which may reflect either a different mode of handling or a wider diversity of functional roles.

Discussion

Overall, for both layers, micro scars predominantly appear on the upper half of the tools, mainly focused around the tip area, but handaxes from stratum A have a more even distribution of micro-scars. Crushing damage is more centered around the midsection, particularly in the third quarter of the handaxe edges. This disparity in distribution suggests that the handaxes underwent different forms of mechanical stresses during their usage. The concentration of micro-scars towards the tip might suggest activities such as cutting, since producing micro-scars requires less force, while the presence of crushing in the mid-section could indicate pounding or heavy-duty tasks. The butt of the handaxes consistently shows less wear in general, possibly indicating a less active role in tool-related tasks.

Both layers exhibit a more pronounced wear on the top half of the handaxes, a pattern that has also been observed at other Acheulian sites. For example, Viallet (2016) noted that at Terra Amata, use-wear and micro-scars on seven handaxes indicated that the working edge was predominantly located on the distal part of the tool. Additionally, two bifaces exhibited use marks on their transversal working edges, suggesting they were used in handheld percussion. These similarities reinforce the idea that the tip of handaxes often played a primary functional role, with variation in wear distribution reflecting different modes of use. Handaxes from stratum C show a stronger concentration of micro-scars toward the tip compared to those from stratum A, where scars are more evenly distributed along the edges. In addition, several asymmetrical handaxes from stratum C display heavier wear on one edge, suggesting that they were consistently used on the same side — either due to their shape or to specific tasks

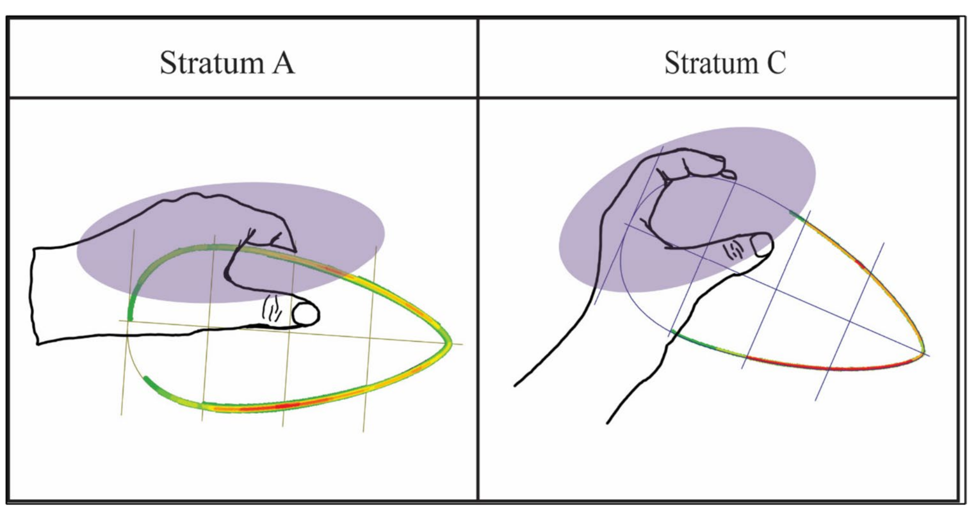


Fig. 8 Proposed hand grip interpretations based on the distribution of wear for each layer at La Noira. The purple area indicates the potential hand position, while the drawn hands illustrate one possible grip configuration

performed. In contrast, wear patterns in stratum A appear more balanced between edges and along the length of the tool, indicating a potentially different way of handling or using the handaxes over time. Handaxes from stratum A display a greater variability in shape and degree of shaping. These range from fully shaped handaxes, produced through extensive bifacial removals, to more expedient tools with limited shaping along the two convergent edges and the tip. Two specimens even feature a transverse extremity fashioned by bifacial removals. Overall, their forms include heart-shaped (cordiform), oval, or triangular morphologies, with edges typically smoothed by unifacial or bifacial retouch. About half of the handaxes are symmetrical in cross-section. For stratum C, handaxes vary; they may be symmetrical in cross-section or not, displaying extensive shaping through multiple series of removals followed by final retouching. The shaping primarily concentrates on the upper two-thirds of the tool and the tip. The forms are similar (heart-shaped, oval, lanceolate) to those in stratum A, crafted from either local millstone or Cretaceous flint sourced from a distance.

Comparing stratum A to stratum C showed changes in how handaxes are used, as seen in the different wear patterns. This research on the bifaces from la Noira complements the observations made by Hardy et al., 2018. Their study highlighted the flexibility and opportunistic nature of handaxe use, noting that not just the tip or the two convergent edges were utilized. Any part of the periphery could be engaged, whether it had been retouched or not. They also emphasized that the base was not exclusively used for gripping but was often a cutting edge as well. Residues observed in this study further suggested that handaxes at la Noira were used in the processing of a wide variety of materials, including plants, wood, animals, birds, and fish (Hardy et al., 2018). Our findings reinforce these insights and further emphasize the functional versatility and adaptability of bifacial tools at la Noira. Notably, although a few handaxes in our sample lacked complete tips, the results consistently showed that the tip area remains one of the most intensively used zones across the assemblage.

In the discourse surrounding handaxes in human evolution, symmetry has frequently been presented as a proxy for the cognitive advancement in hominins. It is commonly believed that an increase in handaxe symmetry over time mirrors an evolutionary trajectory in brain development and the resulting capacities for refining and shaping natural materials. However, other researchers challenge this idea by suggesting that handaxe symmetry and refinement are not the result of a consistent evolutionary trend but rather reflect localized or situational choices. For example, McNabb and Cole (2015) argue that the archaeological record does not show a gradual or universal increase in handaxe symmetry over time. Instead, they propose a "variable equilibrium" model, in which different levels of refinement coexisted across time and space, depending on functional needs, raw material availability, and cultural preferences.

Regarding the site of la Noira, Iovita et al. (2017) found that comparatively high levels of symmetry were already present in stratum A, concluding that the ability to produce symmetrical handaxes existed since the beginning of the European Acheulian. However, they correlated these trends in handaxe symmetry at la Noira to the degree of reduction, emphasizing the potential influence of raw material availability and discard patterns on observed symmetry values. This view is further supported by Machin et al. (2007), who demonstrated that symmetry plays only a marginal role in the effectiveness of handaxes for butchery, suggesting that other variables might have been more critical in shaping these tools.

This could reflect differences in hand positioning or task-specific actions. Experimental work by Murray (2017) supports the idea that grip can influence the spatial distribution of edge damage. Using Schoville's (2010) Edge Damage Distribution Method, Murray observed that different grips could produce distinct edge damage patterns. Recent studies underscore the role of ergonomics in shaping handaxe morphology and use. Key et al. (2016) demonstrated that edge angles influence both cutting efficiency and hand comfort, suggesting that ergonomic considerations may have guided design choices. Fedato et al. (2020, 2024) extended this perspective through morphometric, biomechanical, and psychophysiological approaches, showing that tool form affects grasping behavior, user comfort, and even attentional engagement. These insights are especially relevant to our observations at la Noira, where the preferential use of one lateral edge in some stratum C handaxes—particularly those with a flatter face opposite a more convex one—may reflect similar ergonomic concerns, with tool morphology guiding gripping behavior. Moreover, it is essential to consider the ergonomic implications of using these tools. For instance, it is impractical to grip a handaxe by its sharp edges for tasks requiring force, as this might lead to injury. To protect oneself, one could use a handle made of wood, plant material, bone, or leather. Such handles for bifacial tools are known from Arctic *ulu* knives used by Inuit women to process skins, and have been proposed for other bifacial tools in the Middle Palaeolithic on the basis of polishes present on the interior surfaces of handaxes (Claud, 2008). Although Neanderthals are now commonly thought to have gripped tools using precision rather than power grips (Karakostis et al., 2018), recent morphometric research on Neanderthal thumb morphology suggests habitual use of extended and adducted thumb postures consistent with transverse power squeeze grips, likely suited for hafted tool use (Bardo et al., 2020). Use wear analysis could be key to understanding how far back into the past these activities reached, since the fossil record for the Lower Palaeolithic is sparser. In the future, replicative experiments with different grips can contribute to clearer hypotheses that can be tested in the archaeological record.

Conclusion

This study on handaxe wear patterns at la Noira aimed to explore persistent use and variability of handaxes across different stages of the Lower Palaeolithic period. Focusing on chert handaxes, we employed digital microscopy and GIS to classify and analyze the distribution of wear along their edges. The findings at la Noira revealed that microscars concentrated on the upper half of the handaxes, indicating primary use for precision activities like cutting or piercing. Crushing damage in the mid-section suggested use in rough tasks, such as cutting associated with pounding. These findings do not contradict the idea that handaxes were multifunctional tools, as shown in previous research (e.g., Hardy et al., 2018). Rather, they suggest that multifunctionality was neither random, nor expressed in a uniform way over time. At la Noira, while handaxes from both occupational phases were used for a variety of tasks, the patterns and locations of wear differ between layers. This points to a shift in how the tools were handled and operated, suggesting that even if handaxes remained versatile, the ways in which they were used may have changed across time.

Such patterns raise doubts that symmetry is only related to aesthetics; rather, it becomes clear that differences in the tool's operation, i.e., how it was held and moved also play an important role (Iovita, 2024; Sigaut, 1991). The evidence thus suggests that handaxe use was shaped by a dynamic interplay of factors, where ergonomic considerations and functional demands interacted with the constraints of raw material quality, knapping skill, and unintended morphological outcomes — all of which likely influenced how these tools were ultimately grasped and operated. Further, we examined the entire surface of each handaxe at la Noira in order to assess whether the butt and inner part were actively used and found that they likely were used occasionally as blunt tools. Our findings underscore the importance of considering the entire tool in use-wear analysis to fully appreciate handaxe use and its implications for early hominin technological capabilities and cultural practices.

Future research should broaden the dataset to include handaxes from a wider geographical and temporal range. Ideally, such research would correlate wear patterns with a detailed morphometric analysis to better understand the relationship between designer-intended function, operation, shape, dimensions, and edge angles on function. This approach could provide a more nuanced view of the adaptive strategies of hominin populations, revealing aspects of technology otherwise masked by the uniformity of stone tool shapes.

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Author Contributions A.R. was responsible for data collection, data analysis, research design, wrote the main manuscript text, and creating the figures. E.C. contributed to the GIS analysis and contributed to the relevant sections. M.-H.M. served as the second supervisor and collection director, contributing to writing, editing, and figure preparation. J.D. wrote the section on taphonomy. B.H. reviewed the manuscript and provided critical feedback. R.I. was the Principal Investigator (PI) of the project, contributed to the research design, and assisted with writing and editing the manuscript. All authors reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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