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The WEAP Method: a New Age in the Analysis of the Acheulean Handaxes

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Abstract
This paper presents a unified methodology to describe critical features in lithic assemblages, in order to better interpret the Middle Pleistocene hominin occupation of western Europe, in the context of the Western European Acheulean Project (WEAP). This project aims to characterise the Acheulean technology of the western side of Europe by the analysis of 10 key assemblages in this area, to generate an in depth regional comparison in particular of the large cutting tools (LCTs). Nevertheless, to go beyond the local perspective and gain a regional point of view requires a deep understanding of the underlying technology to identify the differences or similarities in processes and traditions of manufacture. The different criteria to analyse and to categorise the results make it difficult to compare data from different research traditions (British, French and Spanish). Nevertheless, after decades of intense work on technological analysis and although many technological approaches have been developed, there are still differences in methods between the different countries. It was necessary to develop a unified, yet flexible, protocol to characterise the LCTs that could be adapted to the technological characteristics of each area or site. It also had to be a system that could describe tool technology and morphology, combined with a proper statistical treatment, to summarise all of the data and to compare the results. In addition, due to the recent development of innovative technologies, it is timely to move research forward to make more detailed comparisons between sites. In this paper, we test the WEAP method with three very different European sites, Galería and Gran Dolina-subunit TD10.1 (both in Atapuerca, Spain) and Boxgrove (Sussex, UK).

Keywords Middle Pleistocene · Acheulean · Handaxes · Typology · Chaîne opératoire · Geometric Morphometrics

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Introduction

The Western European Acheulean Project (WEAP, Marie Skłodowska Curie IF-EF-ST Fellowship, Project ID: 748316) aims to characterise the diversity of techno-complexes in Europe during the Middle Pleistocene through analysis of Acheulean technology, usually characterised by the production of handaxes and cleavers and other large cutting tools (LCTs). Over the last decade, new data indicate that the earliest human dispersals into north-west Europe occurred from c. 1 Ma from the Iberian Peninsula to southern and north-west France, and to Britain (Parfitt et al. 2010; Ashton and Lewis 2012; Mosquera et al. 2013). The sequences of cold and temperate events over the last million years suggest repeated phases of colonisation and decolonisation between south-west and north-west Europe (MacDonald et al. 2012) that responded to changes in climate.

Within the Acheulean techno-complex, handaxes have been significant for identifying cultural regions from their mode of shaping and morphological end forms (Roche 2005; Gowlett 2006) and are considered as a significant marker of human cognition and skills (Wynn 2002; Stout 2011). The effectiveness and apparent versatility of these tools were crucial on the persistence of those instruments over more than 1.5 million years and over a vast geographical area (Clark 1994; Moncel et al. 2018). However, despite the apparent stability of the Acheulean shown by the persistent presence of handaxes, understanding the variability of this techno-complex continues to be a major research challenge. Taking into consideration the geographic framework of this study there are significant differences in terms of research tradition that hinder any comparative study. Indeed, the research in Britain has 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 concepts of the *chaîne opératoire* (Boëda et al. 1990). C*haîne opératoire* was also used in Spain, together with the Logical Analytic System (Carbonell et al. 1995a). 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 2013a, b).

WEAP is an ambitious research project whose first step is to devise a unified and common methodology and to describe critical features in lithic assemblages, in order to better interpret the Middle Pleistocene hominin occupation of western Europe. This will be achieved through the combination of (1) the development of a common methodological approach to the study of handaxes from several sites and countries, and (2) the application of innovative technologies (3D records and statistics). Digitisation and 3D analyses clearly provide a new tool to measure shape considering plan and profile shapes at the same time and combined with the thickness of tools. In addition, using 3D models, we can also measure shape in terms of the internal variability of assemblages, or distance significance between groups, or even explore and compare the mean shapes of each group. Finally, 3D models have become a very exciting data for dissemination to both the scientific community and the general public, helping us to move research forward and make more accurate comparisons between sites for a regional understanding of the occupation of western Europe.

Previous Systems of Analysis

From the beginning of prehistoric studies to the middle decades of the twentieth century, typology was the most common form of analysis, often using type fossils and resulting in cultural-historical frameworks with a perceived evolution of stone tools through time (Breuil and Kelley 1954; Cahen et al. 1981). From the second half of the twentieth century, new approaches appeared, aiming to highlight the cultural implications of lithic technology and the processes of manufacture of lithic tools, often drawing from the implications of knapping experiments (Crabtree 1975; Tixier 1991). Although some of the early experiments lacked scientific rigour (Johnson 1978), it was still a valuable tool for research. François Bordes (1961) was the first to combine a typological approach with statistical methods, with the aim of classifying industries according to morphological, functional and technological criteria. Variability in the composition of assemblages, particularly in tool types, led to the classification of a range of cultural groups (Bordes 1961). Even though typology continued to be used, Bordes was the first to include experiments and consider the value of technology in interpreting the archaeological record.

Between the late 1960s and early 1970s, in response to the empirical typological tradition, the analytical and structural typology of Georges Laplace appeared (Laplace 1972, 1974). His classificatory system hoped to break down the morphotechnical structures of lithic implements into a series of significant attributes, on the basis of which a typology could be established. Subjectivity in classification was reduced and an open typology was created, in opposition to that of Bordes (1961). However, despite the new theoretical approach, Laplace retained old concepts from the most traditional descriptive archaeology, as well as the typological approach and cultural perspective. This promising approach was not widely adopted due to the increased use of more traditional empirical typologies, such as that of Bordes.

One of the most important developments in Palaeolithic research was made by André Leroi-Gourhan (1964), who introduced the concept of the *chaîne opératoire*, borrowed from ethnology and social anthropology (Mauss 1947; Pelegrin et al. 1988). Due to the limitations of traditional typologies, from the 1980s there has been an emphasis on production processes. The *chaîne opératoire* approach, as applied to lithic industries, implied the recognition of spatial-temporal relationships through phases of production. The use of this concept was quickly adopted in France during the 1980s and led to a new, dynamic field of research on technology, and, in fact, continues being intensively revisited (Delage 2017; Monnier and Missal 2014; Soressi and Geneste 2011).

The emphasis on reduction processes has given a qualitative improvement to research and contributed to surpassing traditional typology. Nevertheless, the main handicap has been similar: the strong dependency of the categories on empirical typologies, as well as the difficulty of moving beyond traditional cultural interpretative frameworks. In many cases, technological analysis has only justified the typological descriptions, simply complementing the information (Carbonell et al. 2006).

The logical analytical system (LAS) appeared at the beginning of the 1980s, which derived from Laplace's approach and preserved his analytical structure, but eliminated the strong typological emphasis (Carbonell et al. 1983). From a theoretical point of view, there were three inspirational sources (Rodríguez 2004): the analytical typology of Laplace (1972), the analytical archaeology of Clarke (1968) and the historical logic of Thompson (1981). Initially, the LAS classified basic lithic industries, in particular pebble tools (Carbonell et al. 1983), after which the system was slightly adapted to provide a qualitative interpretation (Carbonell et al. 1992, 1995b). The system refers to a systematic and processual reading of the lithic record by an association of characters. These characters are the result of three interrelated components. The morphotechnical component corresponds to a group of technical characteristics generated during the production process, which are observed in the final morphology of the artefact. The morphopotential component provides information regarding the theoretical potential capacity of action on a certain lithic morphology (Airvaux 1987), while the morphofunctional component refers to the actual way in which the artefact was used. More recent works slightly modified the LAS fundamentals, trying to establish bridges with more widely accepted methodological approaches, and strongly reduced its initial theoretical issues. The general concepts of mobility matrices and diacritical shaping analysis were first revised by Carbonell et al. (1995c). It was then necessary to incorporate a deep diachronical analysis, trying to remove some of the original theoretical concepts and making the first attempt to standardise concepts (Ollé et al. 2013; García-Medrano et al. 2014; Mosquera et al. 2018) to get a flexible version of the LAS, completely adapted to the particularities of each record and adding new complementary methods such as morphometry (García-Medrano et al. 2019, 2020).

All these approaches from the historical systems can be formulated from two main perspectives:

- The techno-economic approach, which attempts to analyse the technical hominin behaviour from an economical perspective, starting with raw material sources as a means of understanding the mobility of human groups, use of landscapes and different stages of production with a spatial view of the *chaîne opératoire* (e.g. Collina-Girard 1975; Geneste 1985; Tavoso 1984; Perles 1991; Turq 1992; Jaubert 1995).
- The techno-psychological approach, which aims to determine the knowledge required to manufacture artefacts, focusing on the cognitive and psycho-motor actions as part of the technical processes (e.g. Roche 1980; Boëda 2013; Boëda et al. 1990; Pelegrin 1986; Guilbaud 1987, 1996; Texier 1985).

Although most of the technical systems and *chaînes opératoires* still continue to use traditional, empirical and descriptive typologies, the majority of studies strongly emphasise technological aspects, analysing both the whole knapping sequence and the object itself (Delage 2017; Soressi and Geneste 2011; Tostevin 2011; Van Peer and Wurz 2006).

Handaxes and Other Large Cutting Tools

Handaxes are the best known and iconic Acheulean artefact and have been analysed more than any other tool. They were made starting more than 1.5 Ma, distributed through Africa, Asia and Europe (Wynn 2002; Wynn and Gowlett 2018), and classified according to shape, shaping strategies and style (Sharon 2007). Traditionally, they have been recognised as just one of several large tools that characterise the Acheulean, to which the more general term large cutting tool (LCTs) has been given (Isaac 1977).

Definitions

The debate regarding the term to refer to large Acheulean tool types has been intense, and researchers have been divided between the use of the terms "biface" or "handaxe", and even between the use of "biface" or "large cutting tool" to refer to more than one tool-type (e.g. de Mortillet 1873; Kleindienst 1962; Isaac 1968; Leakey 1971; Isaac 1977; 1997; Harris 1978; Roe 1981; Debénath and Dibble 1994;; Deacon and Deacon 1999; Noll 2000; Ambrose 2001; Sharon 2007). In any case, it seems to be generally accepted that biface is a generic term to refer to a bifacial piece and handaxe is mainly used as a specific type. Nevertheless, de la Torre (2006:2) pointed out that: "While the term biface is probably the most widely used in recent literature to encompass all typical Acheulean forms (i.e. picks, knives, cleavers and bifacial handaxes), it is here advocated that 'handaxe' would be more accurate as a generic term, for in many Acheulean assemblages (particularly in the early African sites), LCTs are often unifacial (rather than bifacial) tools".

So, this discussion is completely open. In this case, we propose to use LCT to refer to both unifacial and bifacial Acheulean tools, conventionally larger than 10 cm and shaped in a standardised way. Actually, the term LCT is generically used to refer the more standardised forms (handaxes, cleavers, knives, etc.), appearing together with less standardised heavy-duty tools (picks, trièdres, choppers, etc.) (Isaac 1977; Sharon 2007).

And we propose the use of term *handaxe* to refer to this specific tool-type. The definition given by Kleindienst (1962: 85) fits well with what we are trying to record. According to this author the handaxes are characterised by: "… a cutting edge around the entire circumference of the tool, or more rarely around the entire circumference with the exception of the butt. The emphasis in the manufacture, if distinguishable, seems to have been upon the point and both edges. Usually bilaterally symmetrical, and more or less biconvex in major and minor sections (i.e., along the major and minor axes) … There is a large variation in size, degree and quality of the workmanship, and plan-view, primarily according to the curvature of the edges, the length: width ratio, and the placement of the greatest width relative to the length of the tool".

The other key Acheulean tool-type is the cleaver. They have been documented particularly in southern Europe, Africa, the Levant and India, and are sometimes as numerous as handaxes. However, there are problems of definition (Mourre 2003). In the French literature, there is a minimalist definition for cleavers (or *hachereau*x) as being exclusively made on flakes, with an unretouched transverse cutting edge (Tixier 1956). In North Africa seven such cleaver types (0 to 6) have been defined (Tixier 1956; Roche and Texier 1995, 162). Problems of definition have arisen in Europe, where in Spain for example, large cobbles were often shaped to produce a straight transversal, distal edge, which was sometimes retouched (García-Medrano et al. 2014, 2015). In Britain and France, cleavers include all bifacially knapped tools with a transverse cutting edge (i.e. bifacial cleavers of Bordes, 1961). This can include square-ended handaxes, which Roe (1994, 151–153) suggested should have a transverse or oblique edge greater than half the width of the tool. In this case, we prefer the original definition of Tixier (1956), and the other cases (on cobbles or with retouched distal ends) will be considered as handaxe “cleaver-type”, specifying the particular features of those tools.

Typology *and chaîne opératoire* on LCT Characterisation

The typology of Bordes (1961) has been the most inclusive and influential system for studying LCTs, having been widely used in the Lower and Middle Palaeolithic of Europe and the Levant (Debénath and Dibble 1994). It is based on measurements and indices that provide shape descriptions and classification, combined with some technological features, but since its introduction has been criticised (McPherron 2006). Kleindienst (1962) suggested a less formal typology for African LCTs and did not include measurements and ratios. In contrast, in Britain Roe (1968, 2006) developed a metrical system, which was not strictly typological, but through simple ratios provided a graphical means of plotting and comparing assemblages.

LCTs have also been analysed to understand the complete manufacturing process. The life cycle of LCTs begins with raw material collection, sometimes from outcrops or sources some distance from the site. The knapping proceeds, sometimes in different locations, through to use, potentially re-sharpening and reuse before final discard. Boxgrove, Q1B, provides a rare example where all these stages can be recognised on the same site (Roberts and Parfitt 1999; Pope and Roberts 2005; García-Medrano et al. 2019).

For Britain, reduction has often been described as three stages, with roughing-out, shaping, and finishing phases (Newcomer 1971; Wenban-Smith 1989; Wenban-Smith and Ashton 1998). The roughing-out consists of the initial shaping of the nodule by large alternate sequences of removals by direct percussion with a hard-hammer. The attributes of the original blank can often be identified. The second stage uses a soft hammer to thin and shape the piece to create the main morphology of the final tool. The third stage, finishing, consists of final shaping to produce sharp, straight edges and give a final symmetry to the piece.

The Traditional Interpretation of the LCT Variability

Handaxes are considered to be one of the two main innovations of the Acheulean, alongside the production of large flakes (Isaac 1969, 1986), and have important cognitive implications. Manufacture entails planning, with a hierarchical organisation of activities that may be fragmented and therefore show an understanding of space and time (Wynn 1989; Toth 1991). In addition, handaxe shaping implies demands on the x, y, and z functions of working memory (Stout 2015). All the inferred technical requirements of Acheulean flaking (e.g. Sharon 2009) are consistent with the marked increase in brain size observed in early *Homo erectus* (Antón 2003). The morphological variability documented within Middle Pleistocene LCTs has been widely discussed and variously interpreted by different researchers.

a) Some authors have argued that lithic raw material qualities and the way they were adapted to the knapping strategies were the main determining factors in handaxe morphology and that in Britain pointed forms were often produced on elongated nodules (Ashton and McNabb 1994; White 1995; White 1998a, b; Ashton and White 2003). Although other authors have argued that raw material constraints did not significantly affect either the blank production process or LCT shape and size variability (Sharon 2008).

b) Other researchers have proposed that an important determinant of shape and size variation is the degree of reduction (McPherron 1999; White 2006; Ashton 2008; Emery 2010; Iovita and McPherron 2011). One such model suggested that the initial morphology of handaxes was dominated by pointed, thick forms that through resharpening became thinner and more ovate in form (McPherron 1999). Therefore, differences in handaxe morphology were a by-product of reduction and re-use.

c) There are long-standing proposals that cultural tradition was the prime influence with the final morphology of handaxes reflecting the mental templates of knappers (Roe 1968; Wenban-Smith et al. 2000; Wenban-Smith 2004). In a more nuanced interpretation, it has been suggested that raw material may have been selected according to the desired end-form and was not a limiting factor. Furthermore, it could be demonstrated that there were intensively reduced and finely-made pointed forms of handaxe, which countered both the raw material and resharpening hypotheses (Wenban-Smith et al. 2000). More recently, weight has been added to the cultural interpretation through an improved dating framework for Britain, where distinct handaxe forms characterise different interglacial stages (Bridgland and White 2015; White et al. 2019).

d) The debate concerning morphology also considered functional hypotheses (Crompton and Gowlett 1993; Gowlett and Crompton 1994; Gowlett 2006). Through study of the relative breadth and length of handaxes from Africa and Europe, Gowlett (2011) concluded that there was a preference for handaxes of greater length, but similar shape, implying a sense of proportion among the Acheulean knappers, derived from a long period of social transmission for technological success.

e) The social role of handaxes has also been emphasised; skill has an effect on refinement and symmetry with finished forms influencing individual relationships (Gamble 1999; Stout 2002; Petraglia 2006). Kohn and Mithen (1999) and Mithen (2005) argued that this could play a role in sexual relationships, although this interpretation has been widely debated (Nowell and Lee Chang 2009; Spikins 2012).

Archaeological Context

WEAP aims to characterise the occupational pattern of western Europe during the Middle Pleistocene, from 700Ka (MIS17) to 250Ka (MIS8-7), through the study of Acheulean LCTs from 10 archaeological sites in Britain, France and Spain. These tools and their persistence over time are a perfect marker for probable cultural relationships and could be the base for reconstructing potential dispersals into Europe given their variability over time and space. The chronological range includes two major glaciations that may have led to depopulation of Europe during MIS 16 and 12 (Ashton and Lewis

2012; Moncel et al. 2015; Hosfield 2016). For this paper, we focus on three sites as examples of the application of the WEAP method: from Atapuerca (Spain), the Galería sequence, and Gran Dolina-subunit TD10.1, and from Boxgrove (UK), the assemblage from Quarry 1B (Fig. 1). To show the full technological variability, we have also used

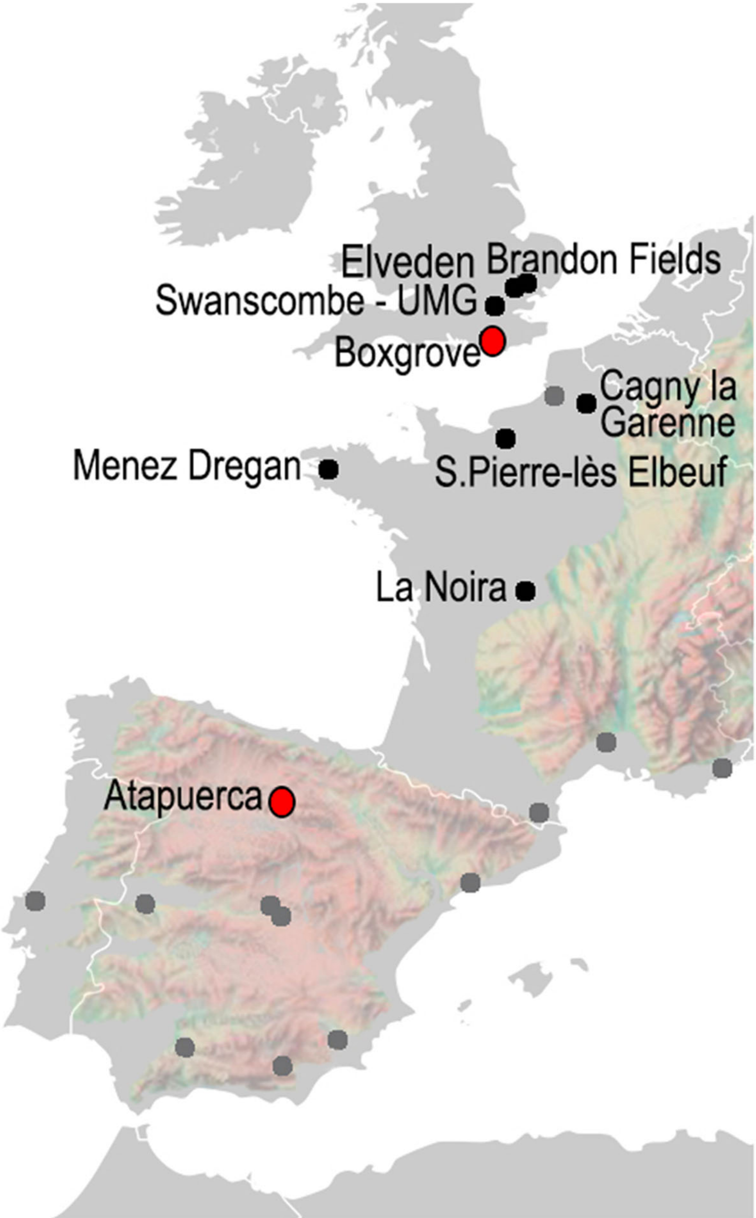

Fig. 1 Location of some Middle Pleistocene sites in western Europe. In black, those sites included in WEAP. In grey, other sites of the same period, not included in WEAP. In red, the sites used in this paper to test the WEAP method

artefacts from the other studied sites when illustrating the attributes measured and categories established.

The *Galería complex* is located on the western side of the Sierra de Atapuerca. Five main infilling phases (GI to GV) and a palaeosol (GVI) have been distinguished (Ollé and Huguet 1999; Pérez-González et al. 1999, 2001; Vallverdú 2002). Only units GII and GIII are archeo-paleontological deposits. Unit GII is divided into two subunits, separated by a continuous organic layer. Several dating methods have been used in Galería, and they have contributed a huge amount of data. Although such a combination of techniques is still offering some incongruence, we can situate the sequence between MIS 11 and 8 (Table 1). Two human fossils were recovered at Galería (TZ area). The first (from unit GII) is an adult mandible fragment with two molars (Bermúdez de Castro and Rosas 1992) and the second, from the base of GIII, is a neurocranial fragment of an adult (Arsuaga et al. 1999). Both remains display common features with the fossils from the Sima de los Huesos site (Arsuaga et al. 1997), located less than 2 km from Galería, and have been attributed to the same clade.

The taphonomy suggests waterlogged ground conditions and semi-darkness in the cave, which may explain the limited domestic activity shown by the lithics. The preferred interpretation is that hominins made sporadic, but repeated, short-term visits for retrieving, in competition with carnivores, animal carcasses that had fallen through a natural shaft into the cave (Díez and Moreno 1994; Huguet et al. 2001; Ollé et al. 2005; Cáceres et al. 2010). A gradual reduction in meat supply could explain decreasing use of the cave by both humans and carnivores. According to this model, Galería would have been a 'complementary settlement area' in the complex karst network of Atapuerca where hominins made occasional, planned visits (Carbonell et al. 1995a,b; Ollé et al. 2013; García-Medrano et al. 2014, 2017). All 54 handaxes and cleavers from the Galería sequence recovered up to the 2016 fieldwork season have been included in this paper.

The *Gran Dolina site* (TD) is a cave, located ca. 50 m north of Galería. The sequence, up to 18 m thick, was initially divided into 11 units (TD1 to TD11 Fig. 2)

Table 1 Different dating methods applied in the Galería site (Atapuerca) and their results by subunits (from base to top: GIIa, GIIb, GIIIa, GIIIb) (Aguirre 2001; Berger et al. 2008; Falguères et al. 2001, 2013; Demuro et al. 2014; Arnold and Demuro 2015)

	Uth	ESR	TL-IRSL	TT-OSL	$pIR\text{-}IR_{225}$ $pIR\text{-}IR_{290}$
GIIIb			224-285 ka	225 ± 18 ka	241 ± 13 ka
		221–269 ka			288 ± 18 ka
			255 ± 26 ka	260 ± 20 ka	236 ± 12 ka
					301 ± 22 ka
GIIIa			466 ± 39 ka	231 ± 18 ka	244 ± 16 ka
GIIb		237–269 ka			
GIIa	> 350 ka	350–363 ka	422 ± 55 ka	231 ± 20 ka	242 ± 17 ka
				284 ± 17 ka	284 ± 17 ka
			503 ± 95 ka	335 ± 17 ka	335 ± 17 ka

(Gil et al. 1987) with later small revisions (Parés and Pérez-González 1999; Pérez-González et al. 2001; Rodríguez et al. 2011). Most of the archaeological record is from unit TD10, which is divided into four lithostratigraphic subunits (from the base TD10.4 to TD10.1). A series of ESR/UTh dates give an age of 430 ± 59 ka for subunit TD10.3. However, a slightly discordant TL date gives an age of 244 ± 26 ka for the bottom of unit TD10.2. The stratigraphic succession finishes with the archaeologically sterile unit TD11, dated to between 240 ± 44 and 55 ± 14 ka (Falguères et al. 1999, 2013; Berger et al. 2008; Rodríguez et al. 2011).

TD10.1 is one the richest levels at Atapuerca, yielding 48,000 faunal remains and more than 20,000 artefacts (Ollé et al. 2013). The archaeological assemblage has been interpreted as a base-camp, with high intensity occupations and successive short-term occupations (Carbonell et al. 2001; López-Ortega et al. 2011; Márquez et al. 2001; Rodríguez 2004; Blasco et al. 2013a, b; Rodríguez-Hidalgo et al. 2015; Ollé et al. 2016). High intensity occupation is shown by abundant remains from faunal processing and domestic activities (Blasco et al. 2013a, b; Pedergnana and Ollé in press), as well as

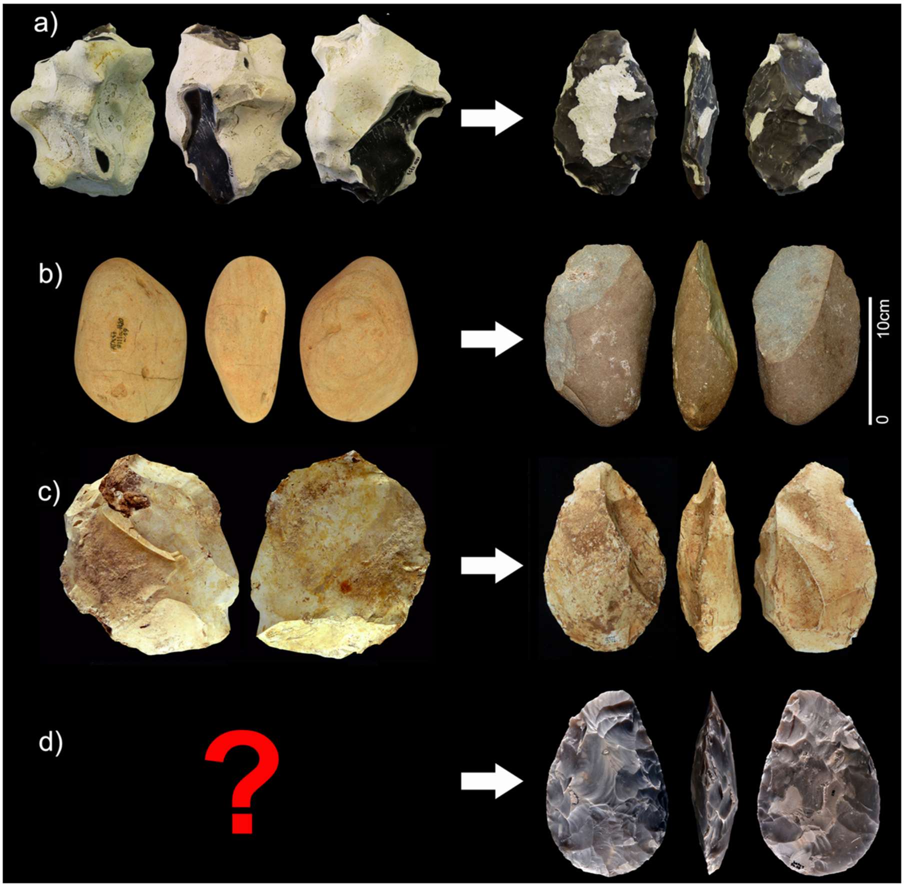

Fig. 2 Type of blanks: **a** nodule (Boxgrove_Q1B_1753); **b** cobble (Galería, Ata17_GIIIa_H20_19); **c** flake (Galería, ATA95_TN2B_E27_1); **d** unknown blank. Final tools, from top to bottom: Boxgrove_Q1B_7097; Galería, ATA94_TN2B_F27_2; Galería, ATA96_TZ_GIIc_L2_48; Boxgrove_Q1B_5162

in the complete lithic knapping sequences (Carbonell et al. 2001; Márquez et al. 2001; Rodríguez 2004; García-Medrano et al. 2015). The faunal assemblages, characterised by elements with high nutritional values, suggest that hominins had primary access to animals and that they transported the richest anatomical parts of the carcasses into the cave. A total of 28 handaxes and cleavers has been analysed for this paper.

Boxgrove Q1B The site consists of a sequence of Middle Pleistocene marine, freshwater and terrestrial sediments exposed in the former Eartham Quarry at Boxgrove. Archaeological and faunal remains occur in all the main sedimentary units but are best preserved in situ within an intertidal deposit, the Slindon Silt Member (Units 4a–c). The units were formed within a semi-enclosed marine embayment at the onset of a marine regression (Roberts and Pope 2009, 2018). Artefact concentrations are visible on the surface of these intertidal silts in a soil horizon—Unit 4c—and in rare freshwater pond and overflow deposits that derive from springs at the base of the Chalk cliff—Units 3c, 3/4, 4u, 4 (Holmes et al. 2010). Known as the waterhole, the pond deposits are correlated with the soil horizon. The site has been attributed through mammalian biostratigraphy to the last temperate stage of the Cromerian Complex, MIS 13 (524–478 ka). Cold stage sediments overlying the temperate sequence and transitional mammalian faunas suggest that the main archaeological horizons date to the final part of the interglacial just before the ensuing Anglian Cold Stage (MIS 12) (Roberts and Parfitt 1999; Roberts and Pope 2018).

The lithic collection is exceptional in terms of the density of knapping, including complete reduction sequences with more than 350 handaxes from Q1B (García-Medrano et al. 2019). Typologically, refined ovate handaxes predominate with regular and sharp edges (Roberts and Parfitt 1999). Previous analyses of the flakes indicated that soft hammers were used (Wenban-Smith 1989), confirmed by the recovery of 41 bone hammers and 3 antler hammers from the Q1B (Roberts and Parfitt 1999; Stout et al. 2014). For this paper, 50 handaxes from the Q1B Unit 4 have been analysed.

The WEAP Method

Technological Analysis

WEAP proposes a single 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.

As we have 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, 2018). The project has developed a common methodological approach, selecting the most significant technological and metrical features from the classical approaches. WEAP's method is based on three main premises: (1) standardising and simplifying terminology; (2) avoiding the classification of tools before analysis; (3) analysing each tool in two different ways: as a complete unit, from a morphotechnical point of view, and as the sum of three different parts (distal, middle and proximal areas). Due to the recent development of innovative technologies, it is timely to move research forward to make more detailed comparisons between sites. In total, 400 handaxes and cleavers, made on several raw material types, have been included in WEAP, of which 132 have been included as examples of the method in this paper (Table 2).

For Britain, all handaxes are made on either flint cobbles (e.g. Brandon Fields and Swanscombe) or on large flint nodules (e.g. Boxgrove). The French assemblages have greater variety of raw materials, although most tools are made on flint nodules and cobbles (St. Pierre and Cagny la Garenne) and millstone slabs (La Noira), the latter also having a few handaxes made on flint cobbles. In levels 8 and 7 of Menez Dregan, the use of quartzite and quartz cobbles for shaping bifaces and cleavers is documented, as well as sandstone. Atapuerca has the highest diversity of raw materials, from chert to limestone from the sequence of Galería and Gran Dolina-subunit TD10.1. The most common rock is flint or chert, followed by a group generically labelled in Atapuerca as sandstone, that actually includes sandy schists and metasandstone, and then by quartz and quartzite. Our method will be used here to compare the LCTs from Boxgrove and Atapuerca (Galería and TD10.1).

The Tool as a Single Unit: Technological Features and Linear Measures

A LCT can be viewed as a single unit that can be defined by features that make it unique: raw material and blank type, facial working, edge form, bifacial and bilateral symmetry, number of scars, linear measurements and weight (Table 3).

– Blank type is a key feature. Shaping can start on blocks (broken from bedrock), nodules (eroded from bedrock, Fig. 2a), cobbles (from river gravels, Fig. 2b) and large flakes (Fig. 2c). The use of flakes implies two stages with the production of the flake (*débitage*) and its shaping (*façonnage*). When shaping is intensive, blank type cannot be identified and is designated as unknown (Fig. 2d).

Table 2 Boxgrove Q1B and Atapuerca (Galería and Gran Dolina-subunit TD10.1) assemblages: MIS, number of tools, type of tools (handaxes and cleavers) and raw materials, considering 4 categories (chert and flint, including all the siliceous chemical sedimentary rocks, with micro or cryptocrystalline grains); quartz and quartzite (including filonian quartz, and the whole set of metamorphic rocks with high content of quartz); Other metamorphic rocks (schist, sandstone, metasandstone); limestone

Sites	MIS	(N)	Handaxe	Cleaver	Chert /flint	Quartz /quartzite	Other metamorph. rocks	Limestone
Boxgrove-Q1B	MIS 13	50	50	–	50	–	–	–
Galería-GIIa	MIS 12-11	13	9	4	3	7	3	–
Galería-GIIb	MIS 8-7	17	9	8	6	5	5	1
Galería-GIIIa	MIS 8-7	13	11	2	2	4	7	–
Galería-GIIIb	MIS 8-7	11	11	–	4	3	4	–
Gran Dolina-TD10.1	MIS 10-8	28	23	5	11	7	10	–
132			113	19	76	26	29	1

Table 3 Technological features and linear measurements considered to analyse LCT according to the WEAP Method

WEAP method: technological features		
LCTas one sole unit		
Variable	Categories	Description
Raw material	Type	Flint, chert, quartzite, quartz, limestone and other metamorphic rocks
Blank type	Blocks	Broken from bedrocks
	Nodules	Eroded from bedrocks
	Cobbles	From river gravels
	Flakes	Detached from cobbles/nodules
Number of faces	Unifacial	Only one shaped face
	Bifacial	Two shaped faces
	Trifacial	Three shaped faced
Cortex localisation	Tip	Cortex only on tip
	Mid	Cortex on mid part
	Butt	Cortex on butt part
	All	Cortex along the whole piece
Edge delineation	Straight	In profile view
	Sinuous	
	Curved	
Symmetry	SIM	Symmetric profile
	NSIM	Non-symmetric profile
Number of scars	(N)	Counted per face
LCTfor each morpho-functional part (tip, mid and butt)		
Variable	Categories	Description
Hammer used	Hard	
	Soft	
	Combined	
Presence of cortex	%	
Removal series *Add as many as needed	1	One removal series
	2	Two removal series
	3 …	Three removal series (or more)
	Final retouch	Could be a removal series by itself
	Combined	The combination of these series
Depth scars on edge	Deep	Generating denticulate edges
	Marginal	Creating continuous edges
Invasiveness (scars on tool's surface) *analyse each series of removals	Non-invasive	Removals close to the edge
	Invasive	Removals affecting ≥ 50% of piece
Final retouch	Non-invasive	Removals close to the edge
	Invasive	Removals affecting ≥50% of piece
	Specific types	e.g. *Tranchet*, Shallow retouch
Type of shaping	General	According to the rest of tool's shaping strategy

Table 3 (continued)

WEAP method: technological features		
	Specific	In a different way (e.g. combination of different series, or with different depth or invasiveness).
	Final retouch	e.g. *tranchet* removals or shallow retouch
LCT linear measurements and indices (see Fig. 5)		
Length (L)		
Maximum width (m)		
Maximum thickness (e)		
Width at middle Length (n)		
Distal width (B1)		
Proximal width (B2)		
Base length (a)		
Distal length (L-a)		
Distal thickness (T1)		
*Elongation index (L/m)		
*Refinement index (m/e)		

- Number of faces. Handaxes and cleavers have one (unifacial, Fig. 3a) or two shaped faces (bifacial, Fig. 3b) and the shaping is face by face or alternate. When shaping is long and flexible, and adapted to the raw material form, sometimes trifacial rough-outs are produced (Fig. 3c; García-Medrano et al. 2019). A trifacial tool is not always the main aim, just a consequence of the shaping process.
- Cortex location is given according to the metrical division of the tool (butt, middle or tip, or in more than one area), without face distinction (Fig. 7).
- The edge is analysed by the delineation (profile), which can be straight (Fig. 4a), sinuous (Fig. 4b) or curved (Fig. 4c). A pronounced form of sinuous edge is a twisted profile, which on some British sites seems to be intentional (White et al. 2019; Fig. 8d).
- Tools are categorised as symmetrical (Fig. 4f) or non-symmetrical (Fig. 4e), and plano-convex, according to their profile (Fig. 4d).
- The number of scars on each face includes all removals larger than 10 mm, according to the technical length of the removal (from the impact point to the most distant point). This attribute has been used to measure reduction intensity. Here we have used the Scar Density Index (SDI), calculated by the number of scars ($\geq$10 mm) per surface area (cm^2) (Shipton and Clarkson 2015a, b). However, recent studies point out the limits of this method and calculate reduction intensity according to the remaining mass and the metrical features of the associated flakes (Lombao et al. 2019a, b) or according to the Flaked Area Index (Li et al. 2015).

For Bordes, measurements were the basis of his handaxe morphological types (*triangulaires*, *subtriangulaires*, *cordiformes*, *discoid*, *ovate* and *limandes*) according to three main criteria: length against width, thickness against width and Bordes' edge

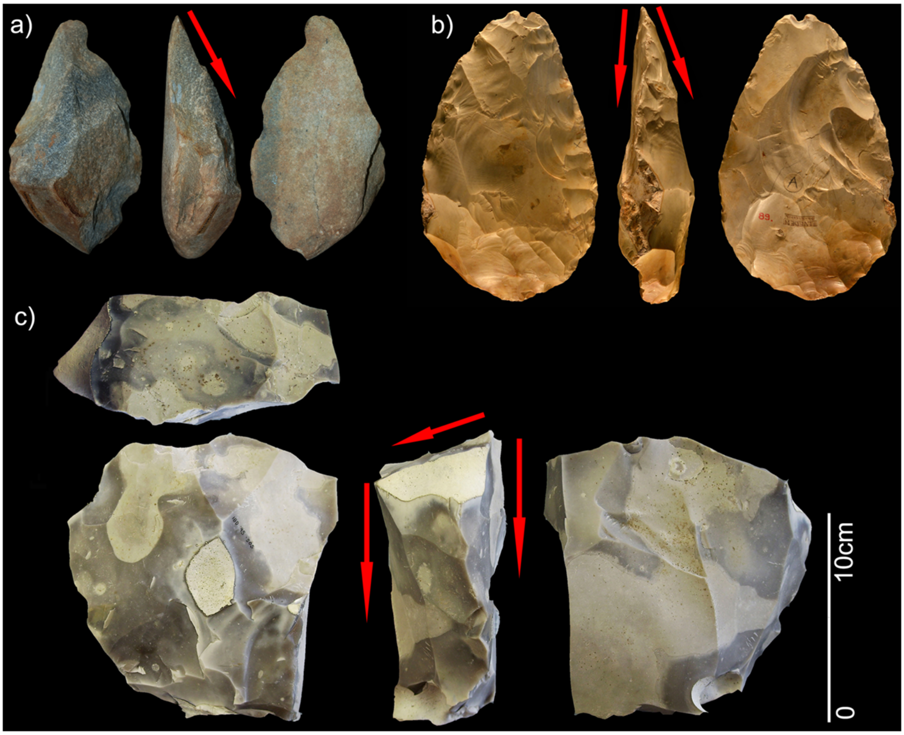

Fig. 3 Faciality: **a** unifacial (Galería, ATA94_TN2B_G22_5, tool on quartzite); **b** bifacial (Elveden, Sturge_89, tool on flint); **c** trifacial (Boxgrove_Q1B_505, rough-out on flint)

shape (Bordes, 1961). However, the boundaries between the categories were sometimes not fully precise, as intermediate shapes exist. Besides, 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 (Table 3, Fig. 5), 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 (Bordes 1961; Roe 1964, 1968). 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.

With all these measurements, it should be acknowledged that there is no consistent way to position an asymmetric and irregular object such as a handaxe; measurement is often subjective, dependent on the analyst, and manual measurements also include errors. In order to minimise these problems, we use 3D models and new computational software.

Software specially designed for this purpose by the Hebrew University of Jerusalem has been used. The Artifact3-D software (Grosman et al. 2008) was developed for

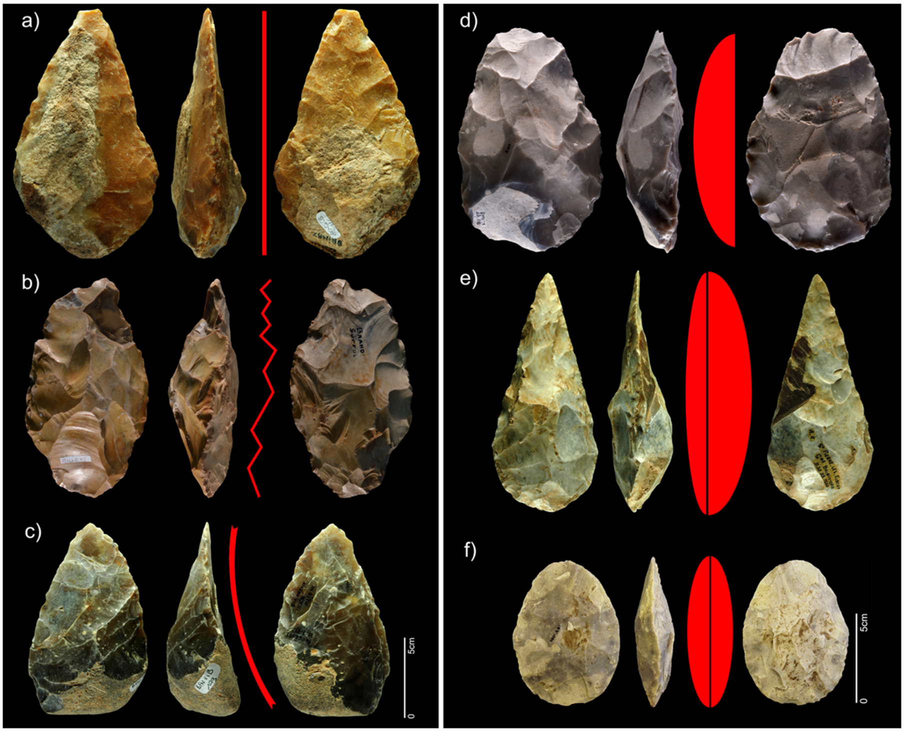

Fig. 4 On the left, *edge delineation*: **a** straight (La Noira_Upper_VIb_116); **b** sinuous (Brandon Fields 15); **c** incurved (La Noira_Upper_179). On the right, *symmetry*: **d** plan-convex (Boxgrove_Q1B_1418); **e** non-symmetric (S.Pierre_D38.23.7540); **f** symmetric (Boxgrove_Q1B_11080)

documenting artefacts that do not show simple shape or surface features (scars, ridges, engravings, etc.). The programme procedures enable the automatic positioning of non-

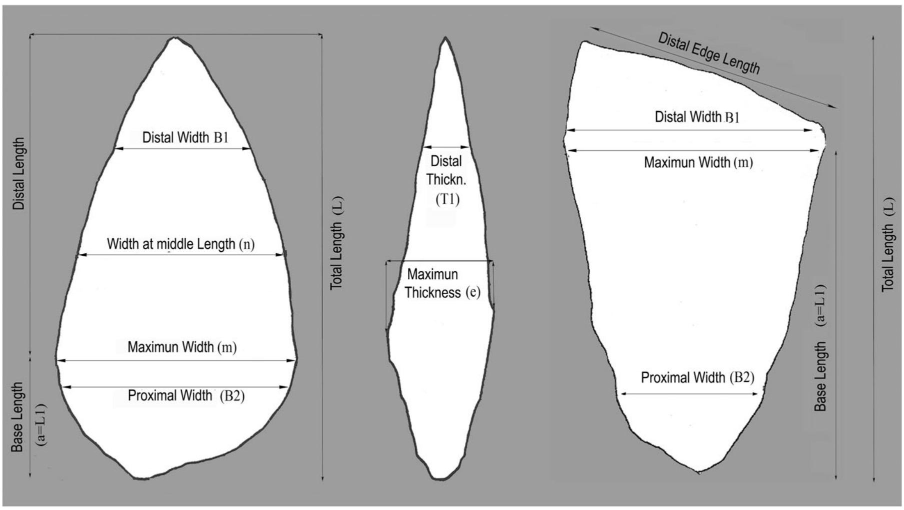

Fig. 5 Metrical features and their localisation on handaxes and cleavers

symmetric objects such as lithic artefacts, bones and stone vessels. The traditional drawing of lithic artefacts depends on how artefacts are positioned and results may vary substantially according to the analyst. Moreover, differences in artefact positioning lead to differences in the simplest metric record. The programme positions the artefact by deducing its intrinsic geometric properties and generates views, dimensions, and sections selected algorithmically without concomitant interpretation according to the centre of mass (Fig. 6) (Grosman et al. 2008). The programme also enables a large repertoire of measurements, the production of sections or the addition of visual aids. In addition to the linear measures, the software calculates quantities that are otherwise difficult to measure, such as volume (cm^3), surface area (cm^2), the location of the centre of mass and the moment of inertia (Grosman 2016).

Tool as the Sum of Three Different Parts, in a Functional Sense

The division of each tool into three parts is based on the metrical distinction of Roe (1968), with the distal end (1/5 length), the proximal end (4/5 length) and the remaining middle sector. Therefore, each technological analysis is undertaken three times. The technological features considered are (Table 2):

  - Type of hammer. In most cases, the identification of the type of hammer used is not easy. If possible, the assignment depends on the combination of several features, such as the depth of removals on the edge, the invasiveness on the surface, the thickness of removals and the angle of blows. The most traditional assignment suggests that low angles, with high invasiveness ratios and marginal modification on edges could be ascribed to the use of soft hammer. On the contrary, high angle values, with thick removals and deep effect on edges could be related to the use of hard hammer. Nevertheless, the limit between them are sometimes very diffuse. Hard (Fig. 7a, c), soft (Fig. 7b, f) or the combination of both.
- Removal sequence is the number of discrete sequences of flake removals on a sector of a handaxe. The simplest is one series (Fig. 8a), with two series sometimes recognisable and/or with the addition of final retouch. First removal sequence may

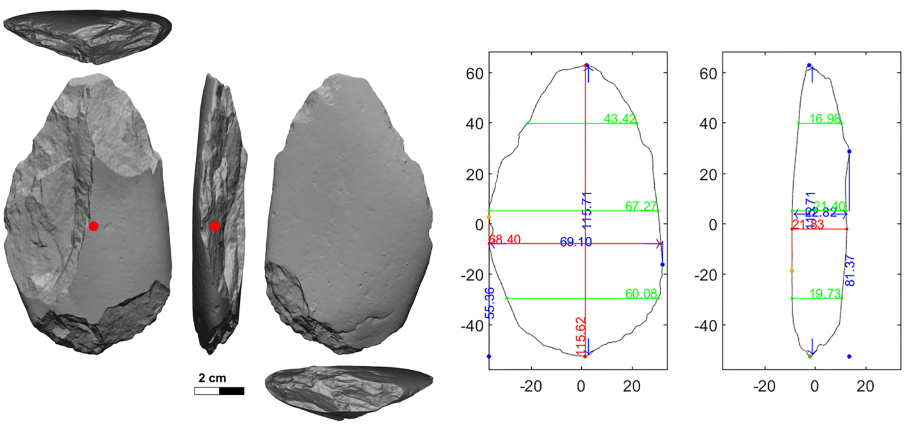

Fig. 6 Plan and profile view of a 3D model of a handaxe with the centre of mass (red point) and the basic measurements marked (Handaxe, Galeria_Ata95_GIIa_TN2B_H23_1)

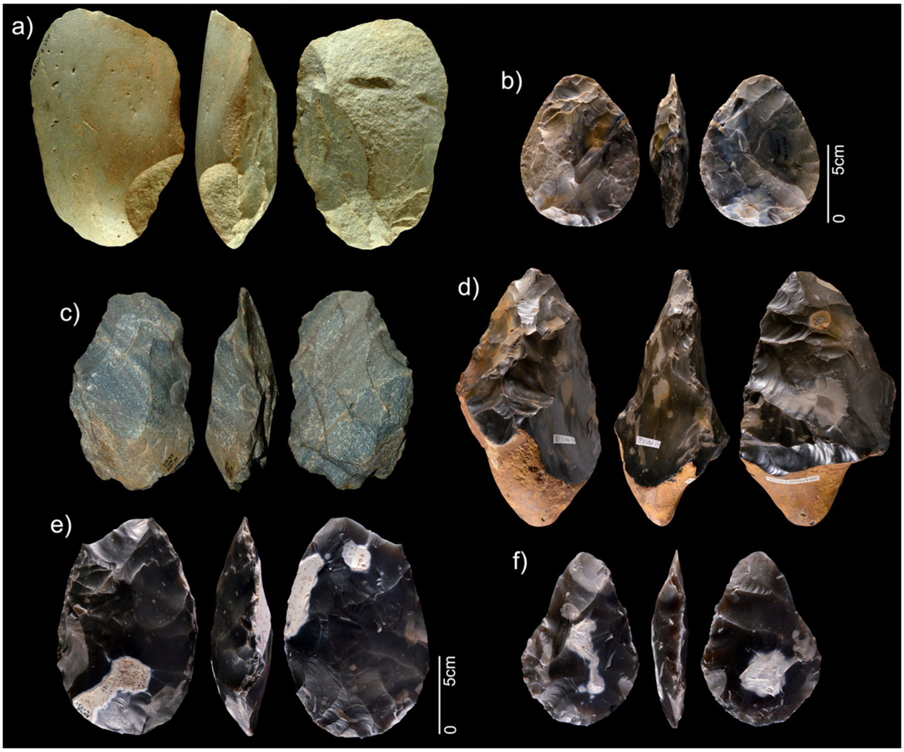

Fig. 7 Localisation of cortex: **a** total cortical (Menez Dregan, MD1_7_115638); **b** noncortical (Boxgrove_Q1B_Unit4_10575; **c** cortical butt (Galeria_Ata93_GIIb_TN5_G25_30); **d** cortex at mid-proximal part (Brandon Fields_Sturge_14); **e**) cortex at mid-distal part (Boxgrove_Q1B_Unit4_1731; **f** cortex at mid part (Boxgrove_Q1B_Unit4_1090). Type of hammer: hard (**a**, **c**) and soft (**b**, **f**)

be partially or completely erased by subsequent series (Fig. 8b), although they might be identified towards the centre of a tool. Secondary sequences are often distributed on a smaller area of the tool, while final retouch can be even more localised such as a tip (e.g. Fig. 8c) or edge. A specific form of retouch is a tranchet removal across the surface of the tip to create a fresh, unretouched edge on one of the faces (Fig. 8c), or shallow retouch, which aims to reduce the thickness of the piece and the irregularities of the surface. Removal series have a direct effect on the edge of the tool, steepness and the surface of each face (invasiveness).

- Depth of removals, refers to the concavity generated by a removal in a tool's frontal planform. Deep scars (Fig. 9a) generate an irregular edge, whereas marginal scars leave the edge largely unchanged and are usually from soft-hammer use (Fig. 9b).
- Invasiveness of the removals can either be non-invasive when the removals are short, concentrated on the edge of the tool (Fig. 9c), or invasive when they affect around the 50% or more of the tool's surface (Fig. 9d). Final retouch should also be defined as invasive and non-invasive, as some forms such as tranchet removal may affect larger areas of a sector (Fig. 8f).
- General type of shaping, as a general description. Once all those features are recorded, we can assess if the different areas of the tool were treated in a similar

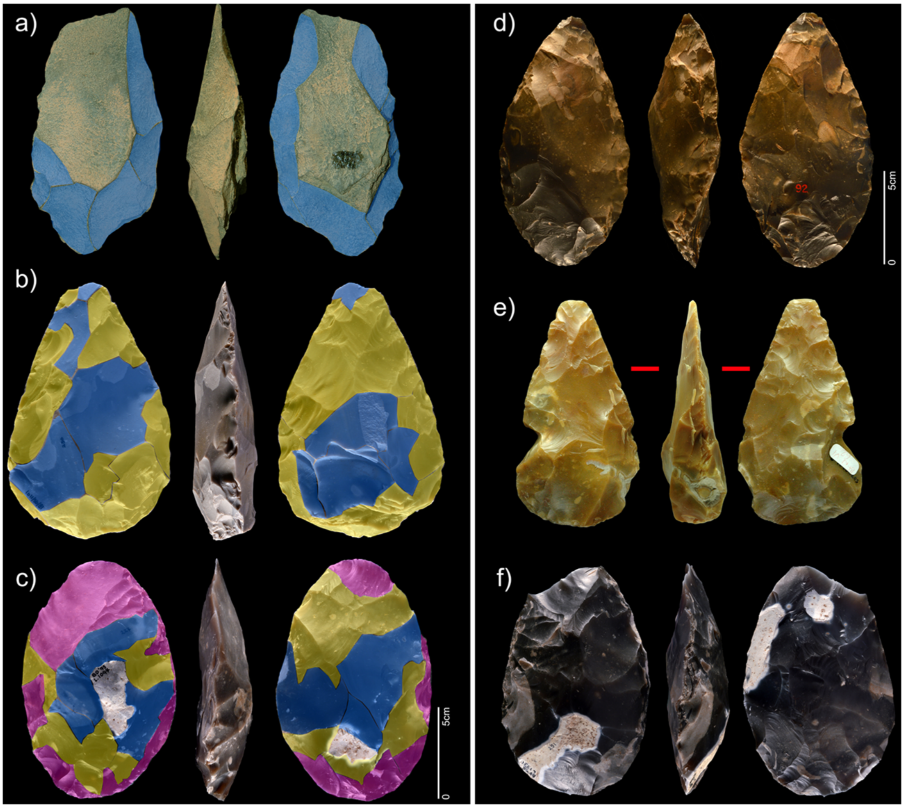

Fig. 8 Number of removal series: **a** one removal sequence (Galería_Ata88_GIIIa_TG10A_G17_83); **b** two removal sequences (Boxgrove_Q1B_Unit4_L1191); **c** two removal sequences plus final retouch concentrated on tip (Boxgrove_Q1B_Unit4_L1097). Shaping strategies on one tool: **d** the same strategy on the whole tool (Elveden_Sturge_92); **e** one area with a specific treatment (La Noira_Upper_BFN_VI_62); **f** final retouch covering the previous sequence of removals (Boxgrove_Q1B_Unit4_L1731)

way (Fig. 8d), or with a different combination of removals (Fig. 8e) or with application of final retouch, covering the rest of the removal series (Fig. 8f).

– Differences in patination and staining can distinguish instances of reuse of tools after protracted lengths of time (Fig. 9e). The number and location of different patinas are counted.

Geometric Morphometrics Analysis on LCTs

While there are several morphometric approaches, landmark-based GM is a powerful tool for the quantitative description of shape variability within and between groups of tools (Lycett and Chauchan 2010). It is a variant of the methods used for the quantitative study of shape between physical objects (Herzlinger and Grosman 2018). This approach has been used by archaeologists, adopted from biology. It is based on a finite number of points—landmarks—placed on the surface of a piece and expressed by two

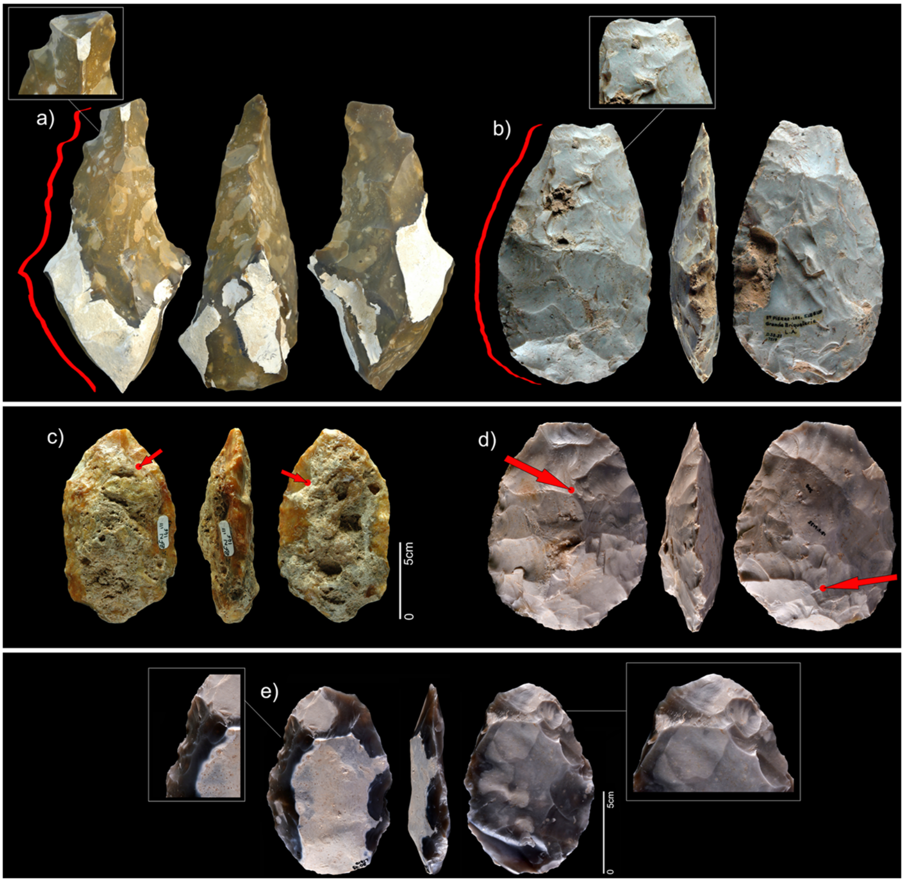

Fig. 9 Depth of scars on edge: **a** deep (Cagny La Garenne_CA_Gar87_CAF); **b** marginal (Saint Pierre_LA_D_38.23.7519). Invasiveness, scars on tool's surface: **c** non-invasive (La Noira_Lower_BFNIII_156); **d** invasive (Boxgrove_Q1B_Unit4_6135). Double patinas on one tool (**e**, Boxgrove_Q1B_Unit4_L141)

or three Cartesian coordinates. These landmarks should have respective points across all specimens in the sample. While in biology, homology can be based on phylogenetic, developmental or functional considerations, readily identifiable homologous landmarks are sometimes missing for cultural objects (Lycett and Chauchan 2010; Okumura and Araujo 2019). Landmarks represent concrete points, which define a shape, and semi-landmarks reproduce shapes but are not homologous points between specimens. For that, the study of archaeological artefacts often makes use of semi-landmarks, which are placed according to a consistent geometric positioning of the tools (Dryden and Mardia 1998; Bookstein 1997).

Shape can be analysed either as 2D images or 3D models. Both approaches to the study of tools shape are useful; nevertheless, between them, there are important differences. For 2D images, tool outlines have been created using 60 equally spaced semi-landmarks along the perimeter of the tool (Fig. 10). Those points have been generated automatically with the tpsDig2 software (Rohlf 2009). Once the extraction of

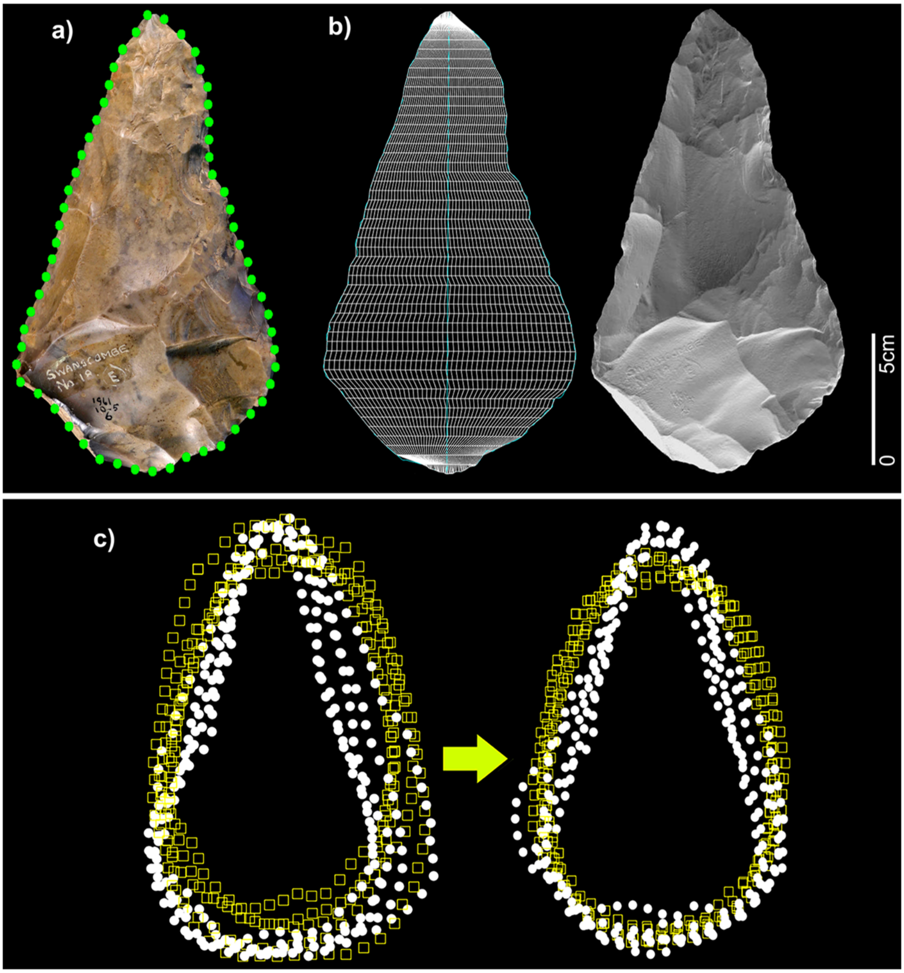

Fig. 10 Two possible morphometrical methods to analyse the tool's shape: **a** 60 equally spaced points, on a 2D image (using tpsDig2 software), and **b** 5000 points defining outlines and tool surfaces, using a 3D model (software AGMT3D). **c** Example of procrustes superimposition process, which removes size, translates and rotates (i.e. orientation) the outlines from the original shape data. Original outline data (left) vs. procrustes aligned data (right)

coordinate data is made, the pieces were oriented according to their maximum length from the tip with the starting point manually digitised. The XY coordinates of the different points per specimen were saved in a .NTS file, and then exported to PAST software (Paleontological Statistics; Hammer et al. 2001). A 2D Procrustes superimposition of the XY outline coordinate data was performed, which scaled, rotated and translated the XY data, bringing all handaxe outlines to a standardised size, orientation, and position before subsequent analysis. In this way, the differences in landmarks can be attributed exclusively to shape differences between different objects. In addition, using 2D images to analyse shape, the analysis of plan and profile shapes must be done separately.

For performing the landmarks-based GM shape analysis on 3D models, open access Artifact GeoMorph Toolbox 3D (AGMT3-D) has been used, a software designed specifically to study archaeological objects. AGMT3-D 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 artefact face, so that a grid of 50 × 50 provides 5000 landmarks (Fig. 3c). 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 expresses the artefact's volumetric configuration. It also provides a number of analytical tools and procedures that allow the processing and statistical analysis of the data (Herzlinger & Grosman 2018). The use of 3D models to analyse shapes lets you to combine plan and profiles shapes and add information regarding size of tools, such as for example thickness of pieces. From our point of view, the shape analysis using 3D models record a wider set of factors which are affecting the morphological variability, obtaining a deeper interpretation of results (García-Medrano et al. 2020).

The multivariate outline data was projected into two dimensions so that the underlying shape variables could be qualitatively examined and compared. In order to interpret the meaning of the principal component analysis (PCA) results from a morphological perspective, Procrustes superimposed shape data were examined utilising thin-plate splines to facilitate visualisation of shape changes from the group mean along relative warp (i.e. principal component) axes (Hammer and Harper 2006). By examining the morphological deformations and XY plots of specimens from the PCA scatters, it was possible to interpret the 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 permitted application of other quantitative tests of multivariate equality of means between the groups (Costa 2010; Herzlinger and Grosman 2018).

The Middle Pleistocene LCT from Atapuerca (Galería and Gran Dolina-Subunit TD10.1) and Boxgrove (Quarry 1B)

All the technological features have been combined using PCA, which allows interpretation of the record according to a reduced number of factors or principal components (PC). Each PC explains a certain percentage of the variance of the assemblage and the weight of each variable, through the location of points in the scatter, can be assessed (Fig. 11). In this case, PC1 explains almost 43% of the variance, and PC2 over 27%, so between them, we can explain more than 70% of the variance of our record. With the first five PCs 100% of the variance can be explained.

Boxgrove, TD10.1 and Galería-GIIa represent clear differences in the handaxes. In an intermediate space, there are the upper levels of Galería (GIIIa and GIIIb) and level GIIb. The technological features have been tested with both the general attributes of the tool, and the three morphofunctional parts: tip, middle and butt. It is clear that the global technological features provide less information than if each part is considered independently. Only the type of blank (marked in yellow) makes a significant

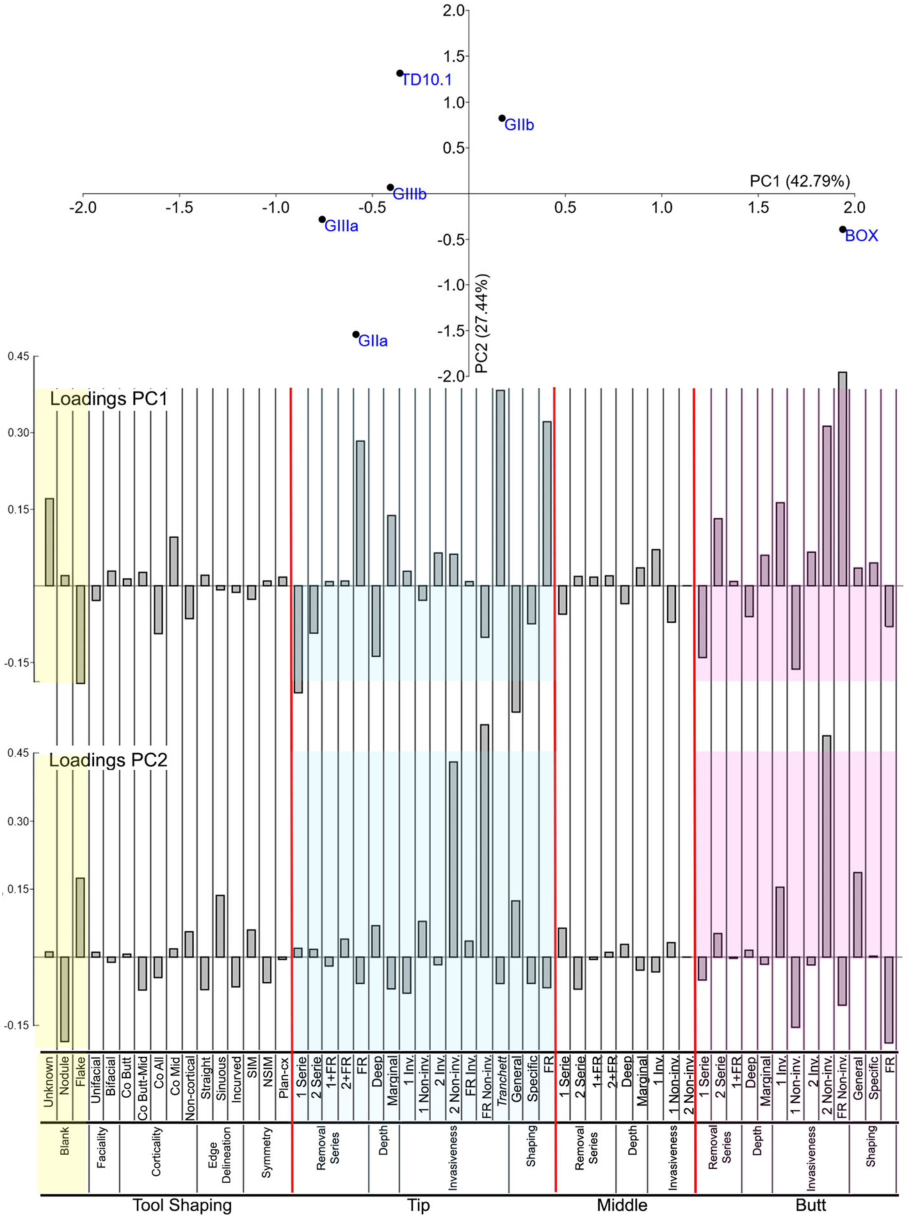

Fig. 11 PCA with all the technological features considered according to the different sites: Galería (GIIa, GIIb, GIIIa, GIIIb), Gran Dolina-subunit TD10.1 and Boxgrove. In the lower part, the effect of each variable in the PC1 and PC2. The tools' parts which differentiate more the samples are marked in blue (tip) and pink (butt). In yellow, the technological feature with more influence on tools (the type of blank)

difference. For example, Boxgrove is characterised by the use of nodules or unknown type of blanks, GIIa by the use of cobbles, and TD10.1 by the large use of flakes. Other parameters also have an influence, but the results are less clear.

If the three sectors of each tool are considered, then much more information can be extracted. First, the tip provides evidence of the largest technological variability between Atapuerca and Boxgrove (marked in blue). The butt also records a slight diversity (marked in pink). The middle part of the tools shows little difference between the sites. Evaluating the distribution of technological features of tips and sites, axis 1 explains 61.71% of the variability and axis 2, 16.46% (Fig. 12). It can be seen how the specific character of Boxgrove is explained by use of invasive secondary retouch on tips, as well as tranchet removals. The whole Atapuerca sites/units retain the same features on axis 1.

Nevertheless, two groups can be distinguished according to axis 2. The first one is the lower part of Galería (GIIa) where the handaxes present mainly one series with non-invasive removals and with a deep impact on the edges. TD10.1 and GIIb are mainly influenced by the use of two series of non-invasive removals. GIIIb is separate due to non-invasive retouch around the tip.

The correspondence analysis (CA) on butts (Fig. 13) explains nearly 80% of the distribution, with Boxgrove and Atapuerca again showing two different knapping strategies. The butts of the LCTs from Boxgrove are characterised by a specific management of two series of removals, and a final retouch with a marginal impact. By contrast, at Atapuerca most of the butts have one series of removals where differences are due to the invasiveness of the removal series. GIIa are characterised by a large number of unworked cortical butts or a single non-invasive series. For TD10.1 and GIIb, the first removal series is invasive, the second one being non-invasive.

The metrical distribution of these LCTs generates a pattern where tool refinement and elongation generate an inverse relationship, where elongation decreases while refinement increases (Fig. 14). In conclusion the Boxgrove handaxes are shorter but their refinement is the highest. The Atapuerca LCTs are longer but have less refined shapes.

Regarding edge angles, Boxgrove handaxes show a range of angles along the perimeter (Fig. 15). The difference in angle between the distal and the middle part of

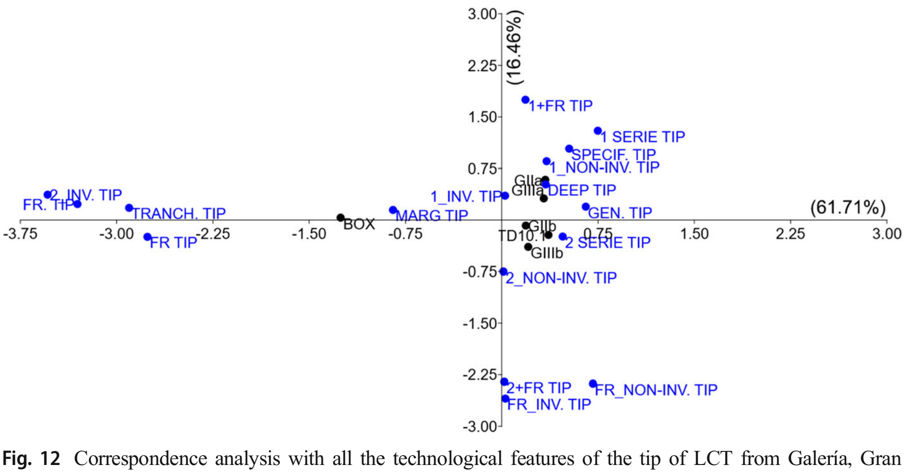

Fig. 12 Correspondence analysis with all the technological features of the tip of LCT from Galería, Gran Dolina-subunit TD10.1 and Boxgrove

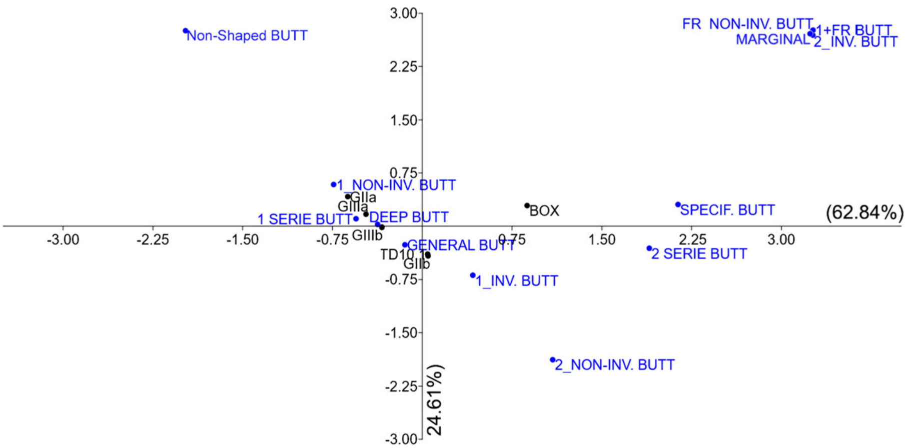

Fig. 13 Correspondence analysis with all the technological features of the butt of LCT from Galería, Gran Dolina-subunit TD10.1 and Boxgrove

the tool is much more pronounced, with angles more acute around the tip and greater intensity of final retouch (25°–35°). In contrast, the middle and proximal parts have similar angles, which result from two series of removals or final retouch being applied to the proximal ends. The Atapuerca assemblages show a different pattern to Boxgrove, with distal angles between 45°-55° and variable values along the perimeter. This could be related to the limited use of secondary removal series or final retouch. Variation is more pronounced on the middle to proximal parts, where larger areas of cortex are preserved.

Combined with the technological analysis, we can make a morphometrical analyses using 3D models with AGMT3D software, using a configuration of 5000 semi-landmarks. A general comparison shows that Boxgrove and Atapuerca share oval shapes (Fig. 16; PC1, 33.95% and PC2, 22.37%). However, Boxgrove tends towards refined 'tear drop' shapes with acute angles. The LCTs from Atapuerca show wider and thicker shapes with higher angles between the faces. These morphological distinctions are significantly different in terms of group inter-point distances (Ranksum = 3904; $p \leq$

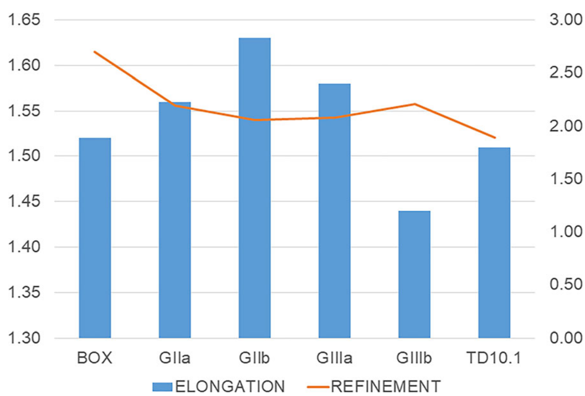

Fig. 14 Graphical distribution of elongation (length/width) and refinement (width/thickness) values along the sites/units considered

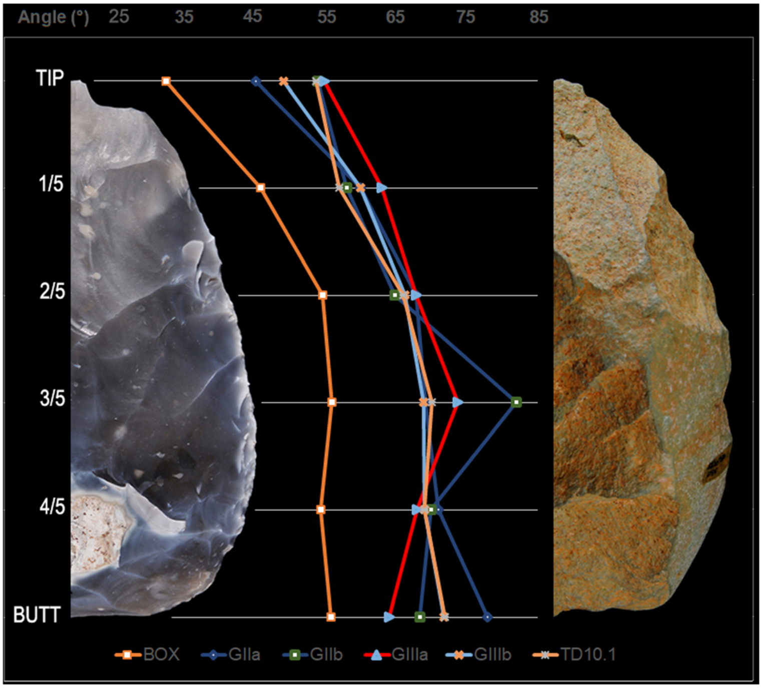

Fig. 15 Set of angles taken along the LCT edge. The points reflect the mean values in each case

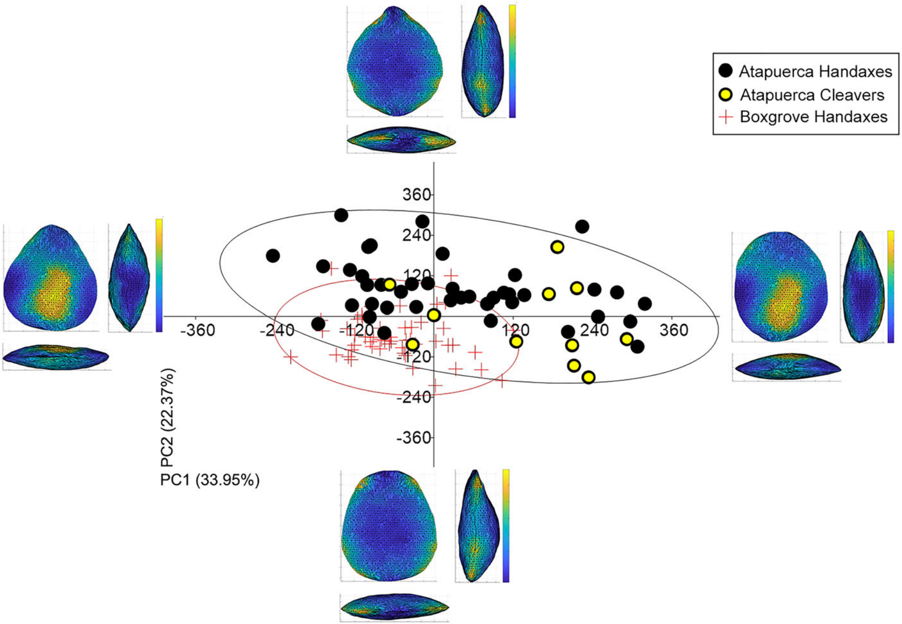

Fig. 16 PCA on Boxgrove and Atapuerca LCT (black dots, Atapuerca handaxes; yellow dots, Atapuerca cleavers; red crosses, Boxgrove handaxes)

0.01) and inter-point distances between group means (Ranksum = 9264; n1 = 53; n2 = 50; $p \leq 0.01$). Euclidean distances enable measurement of shape variability for each group with Boxgrove (203.64) being much more homogenous than Atapuerca (347.93).

Comparison of the Atapuerca assemblages show that most LCTs have a similar distribution with oval/global shapes, the biggest difference being shown by TD10.1

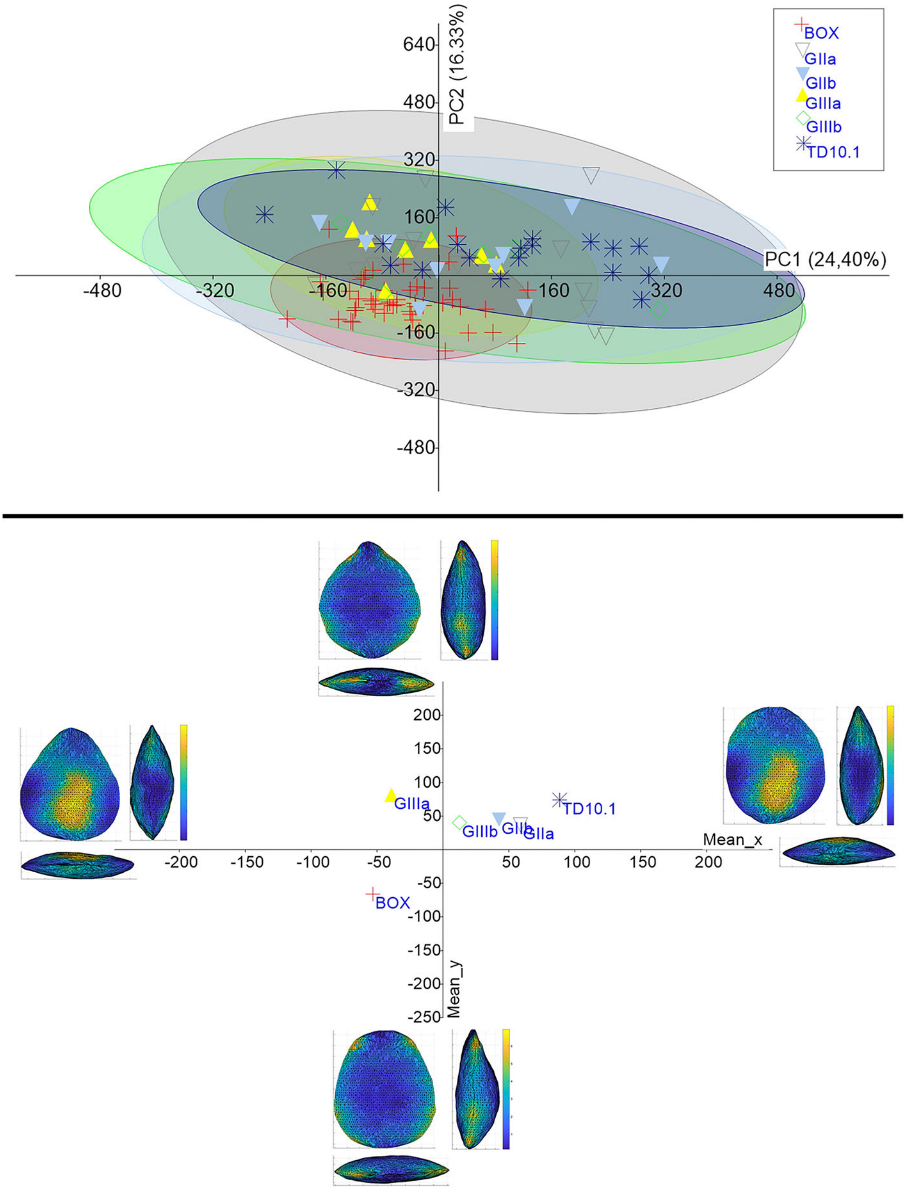

Fig. 17 PCA on Boxgrove and Atapuerca LCT, including all the studied assemblages (GIIa, GIIb, GIIIa, GIIIb, TD10.1). In the upper part is the whole scatter plot and in the lower part is the mean value of each group

(Fig. 17; PC1, 24.40% and PC2, 16,33%). The main differences between sites come from the thickness, represented in the PC1, from globular and thicker pieces at Atapuerca to a more “tear drop” shape with thinner profiles at Boxgrove.

The distribution along PC2 shows differences in tip and butt shapes. In the case of Atapuerca, the extremities are more pointed and the profiles more symmetrical. By contrast, the Boxgrove handaxes are more rounded near the distal ends, with a clear tendency to plano-convex or very asymmetric profiles. This approach is innovative, combining the plan shape with the profile view, allowing the interpretation of the tool’s thickness in relation to the general shape. On this PCA, we can visualise the changes produced to the tip and also the butt, which can be shown in both PC1 and PC2. The handaxes from Atapuerca show more irregular butts and a tendency to thicker pointed tips, whereas Boxgrove LCTs record wider and thinner butts, due to intense shaping in this area.

Discussion and Conclusions

The final goal of WEAP is to compare handaxes from Middle Pleistocene assemblages in western Europe, to generate an in depth regional comparison. After decades of intense work on technological analyses, it was necessary to develop a unified, yet flexible, protocol to characterise the LCTs that could be adapted to the technological characteristics of each area or site. It also had to be a system that could describe tool technology and morphology, combined with a proper statistical treatment, to summarise the data and compare the results. A great effort has been made to find a common, flexible and simplified method, with the combination of the British, French and Spanish schools of research, and with the agreement of three researchers, representing those traditions. Together, we have selected several key technological features key to making comparable several assemblages, with marked differences and with specific characteristics. In addition, this new approach has been combined with other techniques such as the geometric morphometrics, and in this paper, we present as a methodological proposal by providing a first test on LCT assemblages from two key European Acheulean sites: Atapuerca (Galería and Gran Dolina-subunit TD10.1) and Boxgrove, Q1B.

This new approach helps to not only describe and characterise the differences in LCTs between sites but also to observe similarities intrinsic to a single tool type. The generalist term of Acheulean includes a great technological and morphometrical variability that cannot be explained simply by the raw materials, the type of blank or the intensity of reduction. This proposal tries to define an easy way to make comparisons between different assemblages despite their variability, by using a combination of technological features that are key to defining a LCT. The Atapuerca sites from 450 to 250 ka record the use of several raw material types from Neogene and Cretaceous chert, to quartzite, sandstone and limestone, all with different sizes, shapes and knapping properties. Tools from the base of Galería are made mainly on quartzite cobbles, while in GIIb flakes are used for shaping and new raw materials of sandstone and Neogene chert are introduced. Boxgrove LCTs are all made on flint nodules that are variable in size and shape (between 100 and 300 mm, García-Medrano et al. 2019). There are a large number of fractures that presented problems for the knapping process, which often led to adaptation of the *chaîne opératoire*, to maintain the end goal of the knapping, or mental template. Despite of raw material differences, the same end-forms are produced.

The method is based on the idea that a tool is not only a unit but a sum of three different morphofunctional parts (tip, middle and butt). We have taken a general consideration of the tool with the main purpose of the shaping process, adapted to the raw material characteristics, being to produce long functional edges with a distal/useful extremity opposite to a proximal butt.

Each tool can be divided into three main parts—tip, middle and butt—each treated in specific ways, which through analysing each part independently can provide more detailed information. The same technological features have been recorded on the three parts: type of hammer, number of removal series, depth of edge scars and invasiveness (regarding both *façonnage* and final retouch). A complete set of measurements are also recorded, including elongation and refinement indices. The use of the geometric morphometric analysis helped us to define not only the differences between shapes but also to define the form of intermediate shapes. The use of 3D models enables the extraction of data including linear measurements, surface areas, volumes and angles. The models are also the basis for the GM analysis, using a new software (AGMT3D), to combine plan and profile shapes.

The analysis of each tool in three independent parts shows the small role played by the middle part of the tool in distinguishing sites. In most cases, between tip and butt (i.e. the middle sector), the handaxes and cleavers share common technological features. The differences come from the morphology, especially between the localisation of the maximum width and the thickness of the tools. Boxgrove and Atapuerca share the localisation of the maximum width at the mid-point of the piece. With respect to the thickness, it is crucial to use 3D models of the GM approach in combining the plan and the profile shape of tools. The tools from Boxgrove, with a clear "tear-drop" plan shape, are thinner than those from Atapuerca, which is clearly related to the type of shaping. In Boxgrove, several removal series are combined with final retouch. For Atapuerca, in TD10.1 it is due to the use of only one removal series, while for the base of Galería more cortex has been retained.

From a technological point of view, the PCA and the CA allow visualisation and analysis of how the tip and butt are primarily responsible for the variability between sites, where the number of removal series and the use of final retouch are the main criteria. The amount of cortex and the type of shaping also have an effect, depending on the site. The LCTs from Boxgrove indicate several removal series, combined with intense final retouch on the tip, using tranchet removals. The butt area shows a specific management with final retouch. This removal series has a marginal effect on edges, but they are invasive across the tool surfaces. These result in less elongated pieces with a higher refinement index, combined with lower angle values. Morphometrically, Boxgrove handaxes can be characterised as having a clear "tear-drop" shape, with thinner tools, wider tips and lower butt angles.

In contrast, the LCTs from Atapuerca have a larger variability in shape and morphology, which may be expected from a longer chronological range (450 to 250 ka). The removal series has a deep effect producing sinuous edges, and being non-invasive, leaves large cortical patches on the middle to butt areas. At the base of Galería, LCTs are often cortical, associated with a specific manufacture of the tips, with

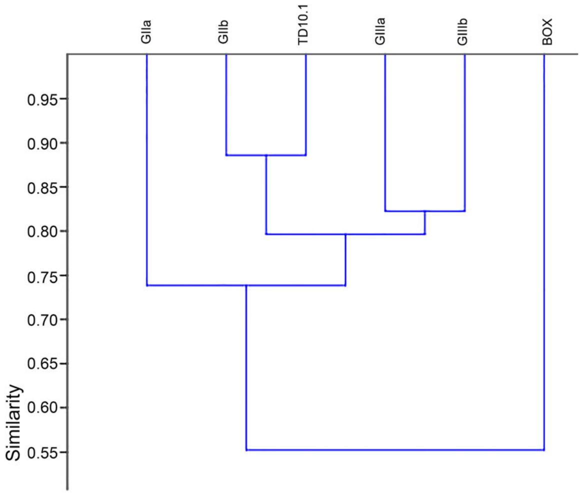

Fig. 18 Cluster analysis between the different levels of Galería, Gran Dolina-subunit TD10.1 and Boxgrove

one removal series and final retouch. In the upper levels of Galería, the tips are shaped by two series of removals and a final retouch, and non-invasive removals on the butt. Morphometrically, the handaxes from Atapuerca are more globular, more elongated and less refined. These measures decrease over time, the tools become less elongated and less refined also.

The cluster analysis is another multivariate technique, which main aim is to group objects (in clusters) based on their characteristics. All the objects included in one cluster are very similar between them, and different from the other clusters. In this case, we have applied a cluster analysis (Fig. 18) combining the whole set of technological features. The base of the cluster analysis is a coefficient correlation matrix (Table 4). Boxgrove presents the lowest correlation with both Galería and TD10.1. By other side, between the Atapuerca's sites, the base of Galería shows slighter correlation with the rest of sub-units. In addition, the cluster analysis shows that between them, GIIa and Boxgrove are nearly opposite entities. In this case, the technological features documented in TD10.1 present stronger correlation with those documented in the mid-upper part of Galería.

Table 4 Coefficient correlation matrix between the sites and sub-units considered, considering all the technological features included in the analysis

	BOX	GIIa	GIIb	GIIIa	GIIIb	TD10.1
BOX	1					
GIIa	0.49	1				
GIIb	0.65	0.70	1			
GIIIa	0.49	0.79	0.75	1		
GIIIb	0.59	0.76	0.80	0.82	1	
TD10.1	0.54	0.68	0.88	0.83	0.81	1

This paper has shown how the use of a unified and flexible method of analysis on a large corpus of LCTs goes beyond the particularities of each site, and combining a short list of technological features with a deep morphological and metrical analysis can enhance understanding of the variability of Acheulean tools over time and space and highlight differences between regions. This is just a first step in our search for a common language, an easy way to apply a unified method considering just significant features, defining them in a simple and clear way, and incorporating new methodologies which complement the definition of technological variability. We consider that this is the best way to make meaningful regional interpretations, adding to the local particularities and descriptions, which in the most cases have already been done.

The main aim is to apply this method in the WEAP project, comparing 10 different archaeological sites, and trying to assess a regional perspective which allows us to interpret the Middle Pleistocene occupational pattern through the technological analysis of LCTs. With a simple description of features and a clear explanation of how to define them, we would like to provide a useful method for other researchers who could apply this method to other assemblages and obtain comparable data. Therefore, we are working on the creation of an open database which will be very useful not only to share information but also to compare and test results.

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Compliance with Ethical Standards

Conflict of Interest is the authors declare that they have no conflict of interest.

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