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The earliest European Acheulean: new insights into the large shaped tools from the late Early Pleistocene site of Barranc de la Boella (Tarragona, Spain)

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Since the oldest known Acheulean lithic techno-typological features in Europe were reported at the site of Barranc de la Boella (Tarragona, Spain), continuous fieldwork has been conducted there in archeological deposits of the late Early Pleistocene age (0.99–0.78 Ma). As a result, excavations in two of the three open-air localities have significantly expanded the collection of lithic and faunal remains, allowing us to make progress in the interpretation of the hominin behaviors in an open-air fluvial-deltaic sedimentary environment. This includes examples of cumulative palimpsests, such as those found at the locality of La Mina, in which hominins only had a minimal role as modifying agents, as well as the extraordinary mammoth butchery site recorded at the Pit 1 locality. The aim of this paper is to present a comprehensive update of the collection of large shaped tools and to assess its significance in the framework of the earliest occurrence of the Acheulean in Europe. This cultural entity is increasingly well-documented for the early Middle Pleistocene, but very little is known about its presence in Europe before the Brunhes–Matuyama boundary. Large shaped tools appear in the three localities explored in the Unit II of Barranc de la Boella, including choppers (unifacial and bifacial) and standard Acheulean forms, such as picks, knives, and cleaver-like forms. Techno-typological and morphometrical analyses revealed a basic heavy-duty component obtained through simple shaping sequences coupled with significantly more elaborate tools produced on various large blanks (cobbles, slabs, or flakes). The complete bifacial and bilateral shapings have yet to be documented, but the present specific tool assemblage attests to the Early Acheulean technological threshold. Hence, the archaeological data from

Barranc de la Boella provide insights into the first appearance of the Acheulean technology in Europe and add critical information to the debate on the technological variability of the Early Pleistocene hominin occupation of the continent. The results of this study revealed a technological assemblage unique in the known late Early Pleistocene archeological record from Europe, different from the rest of ancient Acheulean sites in this continent, which are dated at the Middle Pleistocene. This lends support to the hypothesis that Barranc de la Boella may represent a previously unrecognized Early Acheulean dispersion out of Africa connected to its first evidence at the gates of Eurasia, potentially moving over the northern Mediterranean coastal road to reach Western Europe.

KEYWORDS

Early Acheulean, large shaped tool, trihedral pick, early Europeans, Barranc de la Boella

1 Introduction

Much is known about the appearance of the Acheulean in Africa around 1.75 Ma ago, or even ~1.98 Ma according to estimation models (Key et al., 2021), and about its quick expansion throughout the continent (Lepre et al., 2011; Beyene et al., 2013; de la Torre, 2016; de la Torre et al., 2018a; Kuman, 2019, and references therein). There is general agreement about its significance in terms of technological complexity and its related behavioral and cognitive implications for the genus *Homo*. It has been considered the most significant technological development in the Early Stone Age and a threshold in technological, behavioral, and cognitive evolution (e.g., Sharon, 2007; Lycett and Gowlett, 2008; de la Torre and Mora, 2014; Carbonell et al., 2016; de la Torre, 2016; Wynn and Gowlett, 2017; Gowlett, 2020).

The Acheulean is reflected in the archaeological record as a set of widely accepted defining technological features (and further defining "Mode 2" technology; Clark, 1968). These include the advent of the so-called large cutting tools (LCT), which involve large blank production, progress in raw material management, shape standardization, and distinctive and recognizable tool types (handaxes, cleavers, picks, knives, etc.) that appear to have occasionally served as mobile toolkit elements. These characteristic Acheulean tools are accompanied by improved core reduction (i.e., knapping strategies) for medium and small products (e.g., Keeley, 1993; Clark, 1994; de la Torre, 2011; de la Torre, 2016).

However, there is more uncertainty about Early Acheulean occurrences outside of Africa. The currently accepted scenario is that it presented around 1.5/1.4 Ma ago in the Levant ('Ubeidiya; Bar-Yosef and Goren-Inbar, 1993) and India (Attirampakkam; Pappu et al., 2011). Surprisingly, there is a lack of such early evidence in Western Europe, and no conclusive explanations for this absence are currently available. This could simply reflect a research gap, but it is also proposed that possible environmental or paleoecological barriers prevented the Early Acheulean from spreading to a part of the European continent where communities practicing Mode 1 technology were quite well-established (Carbonell et al., 2008; Carbonell et al., 2010; Moncel, 2010; Parfitt et al., 2010; MacDonald and Roebroeks, 2012; Mosquera et al., 2013; Barsky et al., 2016; Despriée et al., 2018, and references therein).

The earliest Acheulean occurrence in Europe has been the subject of extensive inquiry in recent years, based on both new archaeological sites and updates on previously recognized locations. An Acheulean presence earlier than the formerly accepted dates for its first appearances from MIS 13 (Moncel et al., 2015; Moncel et al., 2018, Moncel and Ashton, 2018) has been documented at early Middle Pleistocene sites such as Bois de Riquet (US4) (Bourguignon et al., 2016; Viallet et al., 2022), La Noira (Moncel et al., 2013; Moncel et al., 2021; García-Medrano et al., 2022), Moulin Quignon (Antoine et al., 2019; Moncel et al., 2022) in France, Notarchirico in Italy (Piperno, 1999; Moncel et al., 2020b), and Brandon Fields and Fordwich in the United Kingdom (Davis et al., 2021; Key et al., 2022).

In 2014, we published the first findings from the late Early Pleistocene open-air site of Barranc de la Boella (Tarragona, Spain; Vallverdú et al., 2014a). We presented geological, faunal, and lithic data from the same stratigraphic Unit II at three different excavated localities. The evidence, dated to 0.99–0.78 Ma, included traces of hominin activity in a rich fluvial-deltaic ecosystem, including a single butchery event of one mammoth (*Mammuthus meridionalis*) carcass (Pit 1), as well as more sparse associations of stone tools and anthropogenic bone breakage at other localities (La Mina and El Forn). Among the stone tool collection dominated by cores and flakes, we reported isolated large cutting tools (a pick and a cleaver-like tool) that, combined with some features of the knapping methods, lead us to support an Acheulean designation (Vallverdú et al., 2014b; Mosquera et al., 2015).

Furthermore, the set of technological features observed in the Barranc de la Boella Unit II collection prompted our claim for the existence of Early Acheulean technology in Europe (Mosquera et al., 2016). By that time, Bose and other Chinese (Hou et al., 2000; Li et al., 2014) sites had demonstrated that Acheulean tool forms (because of either dispersal or convergence phenomena) were present in East Asia by the late Early Pleistocene, and the new dating of Attirampakkam in India (Pappu et al., 2011) showed that they appeared in South Asia much earlier than previously thought. In this context, the evidence at Barranc de la Boella could well be mirroring the situation in Western Europe, where the uncontested Acheulean presence was fully accepted only for the Middle Pleistocene.

Our hypothesis about the presence of the Acheulean in Western Europe during the late Early Pleistocene was initially supported by qualitatively significant but quantitatively scarce evidence, which led to unequal acceptance among colleagues and a general requirement for more diagnostic elements (Moncel et al., 2015; Moncel et al., 2020a; Moncel et al., 2020b; Méndez-Quintas et al., 2018). To address this challenge, based on the proven richness of Unit II at Barranc de la Boella in three discrete localities, we decided in 2016 to significantly enlarge the excavated surface area at two of them: Pit 1 and La Mina. Even though the excavation work has only partially reached the targeted layers, and detailed study of the excavated materials is still in progress, the time is ripe for a first update on the current collection of large shaped tools recovered so far.

In this article, we provide new data on a sample of artifacts that help us to technologically characterize the assemblage. These are the large shaped tools, including the groups of heavy-duty tools and large cutting tools (*sensu* Isaac, 1977), as well as a few but characteristic large flakes (>100 mm). These data allow us to back up our previous interpretations and support our original claim of Early Acheulean evidence in Western Europe around 1 Ma ago.

We are aware that such evidence is so far scarce for that time period and geographical area, as other supposedly Iberian examples of this early presence of the Acheulean techno-complex are based on still limited information and debatable interpretations (Scott and Gibert, 2009; Walker et al., 2020). Consequently, the uniqueness of Barranc de la Boella justifies the need for this update. In the current scenario involving a small number of sites that represent little more than isolated snapshots of hominin occupation (Moncel et al., 2018), any robust input can be crucial for valuable reconstructions (Key and Ashton, 2022).

Thus, Barranc de la Boella contributes relevant data for reconstructing the first phases of hominin settlement in Western Europe. In technological terms, it could shed light on the apparent technological gap between the earliest (Mode 1) and later Acheulean hominin populations, as well as provide clues to addressing wider technological questions, such as the origin of the Acheulean in Europe in terms of local evolution (innovation), out-of-Africa dispersal events, and convergence phenomena.

2 The site of Barranc de la Boella

The Barranc de la Boella (La Canonja, Spain) is located 7 km northwest of the city of Tarragona, on the north-eastern Iberian Peninsula. Geomorphological and paleoenvironmental interpretations have suggested the site was situated within a fluvial-deltaic environment, with braided-channel and pool deposits, associated with the terrace T + 60 m of the lower Francolí River basin, c. 50 m above the Mediterranean Sea level. Its 9-m-thick stratigraphic succession was formed from the late Early to the Upper Pleistocene. The deposit is quite continuous along the explored area and is currently dissected by a modern seasonal ravine.

Despite being known since c.1930, Barranc de la Boella was only published as a paleontological site in 1973 (Vilaseca, 1973), and the first systematic excavations were only conducted in 2007 (Saladié et al., 2009; Vallverdú et al., 2009). The results derived from the first field seasons have been internationally known since 2014 when general works (Vallverdú et al., 2014a; Vallverdú et al., 2014b), as well as specific studies on biochronology (Lozano-Fernández et al., 2013; Lozano-Fernández et al., 2014) and on taphonomy and zooarchaeology (Pineda et al., 2015, Pineda et al., 2017a; Pineda et al., 2017b; Rosas et al., 2015), were published. Paleomagnetic, cosmogenic, and biochronological data provided in these studies situated the richest basal strata, grouped in Unit II, in the late Early Pleistocene (from 0.99 to 0.78 Ma).

Research carried out during the first few years in Unit II revealed a rich archaeological landscape scattered with witnesses of hominin and animal activity, which were identified in several stratigraphic profiles, in isolated surface and stratified findings, and in three excavated localities: Pit 1 (or Cala 1), La Mina (Pit 2), and El Forn (Pit 3) (Figure 1). These testimonies included evidence of co-occurrence between the hominins and other carnivores in a context of high competition between the different predators' paleo guilds (Pineda et al., 2017b).

At Pit 1, a surface of 12 m^2 was excavated in 2007. In the uppermost fertile layer of Unit II (level 2), we described a single animal butchery site (according to Isaac, 1978), including a partial carcass of a prime adult *M. meridionalis* with possible cut marks on ribs as well as abundant notches and bone fractures produced by other mammoths trampling. Such fossil remains were associated with a rich scatter of stone tools around them. The lithic assemblage primarily consisted of local chert that had been knapped, used, and discarded *in situ*, as evidenced by many refitting groups and butchery use-wear traces, aside from some percussive material made of other raw materials. Relevantly, there was a well-shaped schist trihedral pick with that assemblage, whose blank was probably a split cobble (Mosquera et al., 2015).

At La Mina, excavations conducted since 2010 have extended the former 6 m^2 pit, opened in 2008, to a 35 m^2 area. This locality turned out to be the richest in the Barranc de la Boella in terms of faunal remains, both in the number of specimens and in taxonomic diversity, especially for level 2 of Unit II (Pineda et al., 2017b). Although anthropogenic fracturing has been identified, no cut marks have been found to date. This is likely due to the poor preservation of the surface of the bones because of the erosion caused by the sandy sediment. The abundance of signals from large carnivores is coupled with the presence of coprolites throughout the whole deposit (Pineda et al., 2015; Pineda et al., 2017a; Pineda et al., 2017b). The enclave is interpreted as a loitering location for hominins and carnivores to acquire resources, likely because of the area's high concentration of prey. The formerly published lithic assemblage for Unit II consisted of only 80 artifacts, including varied percussive material on different raw materials, some cores and small products of chert, and a small but significant group of choppers, but an absence of LCTs (Mosquera et al., 2016).

Finally, only 15 m opposite Pit 1, there is the El Forn locality, where the 40 m^2 pit excavated between 2008 and 2013 brought to light three archaeological levels inside the geological Unit II. This locality has the lowest density and the greatest dispersion of remains, as only levels 2 and 3 present a significant scatter of materials. The lithic assemblage at El Forn has similarities to the one found at La Mina, with the exception of the presence of a second LCT of schist, which was a cleaver-like tool (Mosquera et al., 2016).

The presence of certain large shaped tools (the pick and the cleaver) led us to tentatively identify Barranc de la Boella as the earliest evidence of the Acheulean technology in Western Europe (Vallverdú et al., 2014a) and fostered the first comprehensive study of the stone tool collection recovered up to the 2013 season (Mosquera et al., 2016).

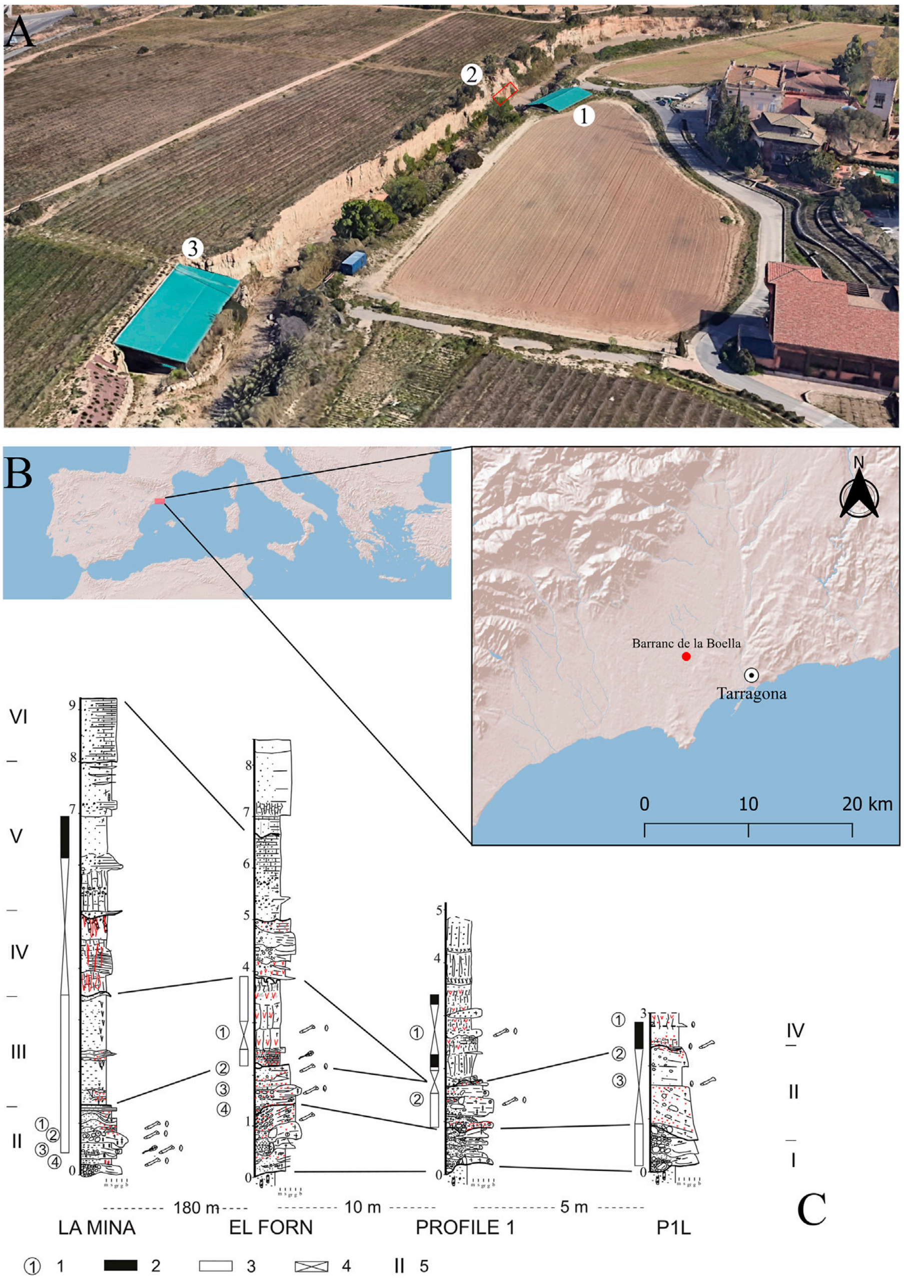

FIGURE 1
Location map and stratigraphy of Barranc de la Boella. **(A)** General view of the sites with the modern ravine cutting the sedimentary succession and the three localities: 1. Pit 1, 2. El Forn, and 3. La Mina; **(B)** Location map of the site in the western Mediterranean basin and in the Camp de Tarragona area; **(C)** Lithostratigraphic logs of the Barranc de la Boella localities: La Mina, El Forn, and Pit 1 (Profile 1 and P1L); (modified from Vallverdú et al., 2014a). Legend: 1. Archaeopaleontological level, 2. Reverse magnetic polarity, 3. Normal magnetic polarity, 4. Undetermined magnetic polarity, and 5. Litostratigraphic units.

As the results of our first period of fieldwork started to be echoed by the scientific community, an unequal acceptance of our claimed Acheulean evidence emerged (Rolland, 2013; Moncel et al., 2015; Moncel et al., 2016; Moncel et al., 2018; Moncel et al., 2020a; Moncel et al., 2020b; Bourguignon et al., 2016; Méndez-Quintas et al., 2018; Muttoni et al., 2018; Rosell and Blasco, 2021; Haynes, 2022; Viallet et al., 2022), demonstrating the importance of the site and, at the same time, that more substantiation was needed to properly assess its significance in the context of Western Europe. Accordingly, the research team decided to actively increase the evidence by excavating extensive areas in some of the known archaeological deposits. These displayed the typical irregularity and discontinuity found in open-air sites in fluvial environments. Therefore, it was considered necessary to excavate broad surfaces in an effort to develop the most comprehensive record possible. In 2016, after conditioning the Pit 1 and La Mina sites with due-protective roofs,

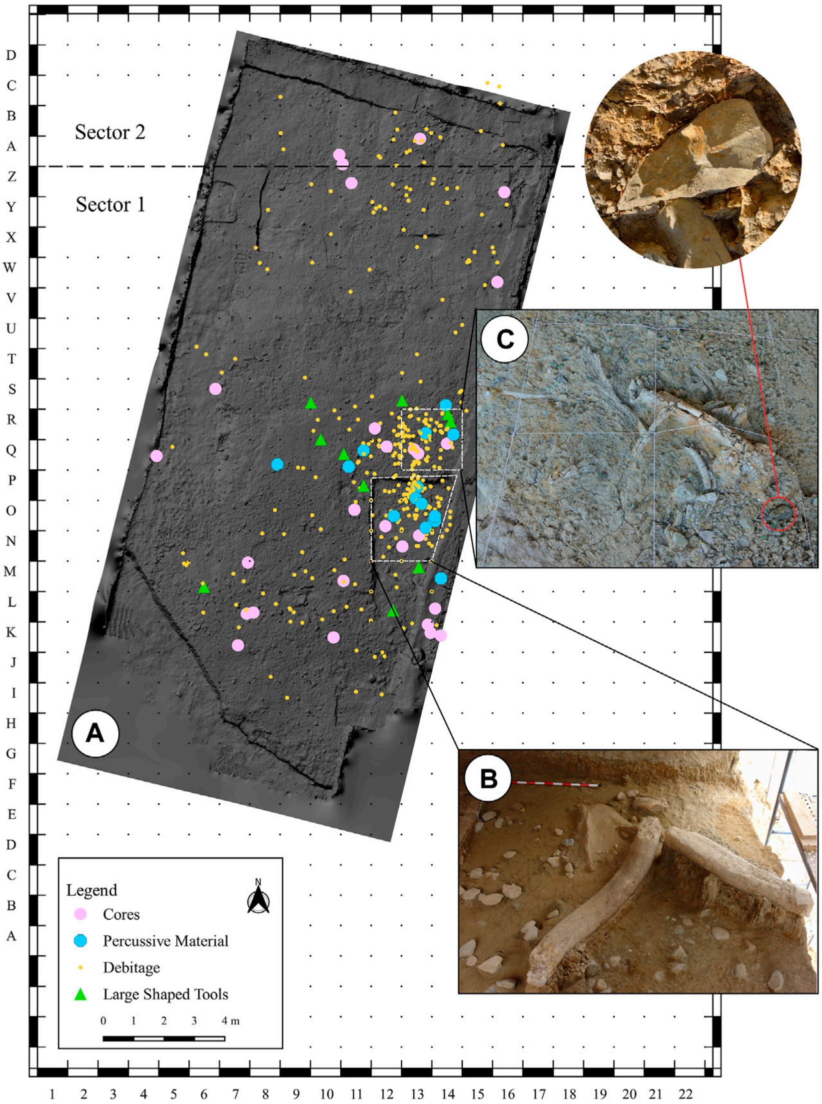

FIGURE 2
(A) Ongoing excavation at Pit 1, with a photogrammetric reconstruction of the excavated surface and the plot of the lithic artifacts recovered up to the 2022 season; **(B)** image of the mammoth remains and associated elements at the 2007 test-pit; and **(C)** image of the mammoth remains and associated elements uncovered in the 2018 season, among which is a schist pick (ref. C1-2018-S1-II-2-R14-9).

two considerable areas were obtained for extension excavation (210 and 250 m^2, respectively) (Supplementary Figures S1, S2).

In 2018 at Pit 1, we reached the layer where we discovered the mammoth carcass in 2007, and since then, we have concentrated on following that paleosurface. Currently, there is a surface of c. 190 m^2 of sediments from Unit II in the process of excavation (Figure 2). Following the mammoth tusks, molars, and scapula from 2007, the newly excavated area has revealed several ribs and a femur from the same individual. Associated with the fauna, there was an exceptional accumulation of chert tools, including cores, flakes, very few retouched flakes (mainly denticulates), and abundant debris. The presence of *in situ* knapping activities was corroborated by representative lithic categories and refitting sets that were directly visible during the excavation process. Significantly, the large-tool component, almost exclusively made of schist, has increased with five picks, one knife, one cleaver, and two choppers. Although the excavation has not completely uncovered the wavy paleo-surface of the archaeological layer across the whole explored area, the plot of the materials recovered so far clearly shows a concentration of materials around the mammoth carcass, and a progressive decrease in density away from it. This distribution also affects the presence of large shaped tools. To the north of the locality, another concentration of remains appears to be drawn; for the moment, it is not possible to establish the possible relationships between them (Figure 2).

At La Mina, the excavation of Unit II is currently covering a surface of approximately 180 m^2. According to the initial survey (4 m^2), Unit II contains at least five archaeological levels, of which only levels 1 to 4 have so far been significantly explored (35 m^2 up to 2016). To date, only level 1 has been fully excavated, and extensive excavation of level 2 has begun. Level 2 is the richest one in terms of faunal and lithic remains. Additionally, Level 3 also stands out from the rest of the succession due to a significant accumulation of hyena coprolites, which could be interpreted as a place these animals used as a latrine (Pineda et al., 2017a). At Unit II of this locality, the original large-tool component was formed by only four choppers (two of them bifacial). New excavations not only quantitatively increased the sample by incorporating three new elements for that group but also contributed qualitatively with a knife and two picks.

In parallel to the enlarged fieldwork, studies have intensively continued, not only regarding specific technological aspects such as the reduction strategies (Lombao, 2021) but especially in terms of paleontological and biochronological research (Lozano-Fernández et al., 2019; Madurell-Malapeira et al., 2019; Fidalgo et al., 2023a; Fidalgo et al., 2023b), as well as in taphonomical and zooarchaeological subjects (Pineda et al., 2014; Pineda et al., 2017b; Pineda et al., 2019; Pineda and Saladié, 2022). In this sense, the paleontological record currently available for Barranc de la Boella Unit II reflects a resource-rich area where competition between carnivores and hominins for prey and utilization of carcasses was at times high. Along with stone tools, abundant and taxonomically varied faunal remains have been recovered; megaherbivores (*M. meridionalis* and *Hippopotamus antiquus*) are the dominant taxa, but the site also yielded other ungulates (*Stephanorhinus hundsheimensis*, *Equus altidens*, *Megacerini* indet., *Cervus elaphus*, *Dama vallonnetensis*, *Capreolus* sp., *Bison schoetensacki*, and *Sus strozzi*), rodents (*Castor fiber*), and carnivores (*Ursus deningeri*, *Canis mosbachensis*, *Panthera* sp. of large size, *Lynx pardinus*, and *Panthera gombaszoegensis*) (Vallverdú et al., 2014a; Pineda et al., 2017b; Madurell-Malapeira et al., 2019; Fidalgo et al., 2023a; Fidalgo et al., 2023b) (Supplementary Table S1). Despite their abundant coprolites, as well as tooth-marked and digested bones, there are as yet no hyena remains (Pineda et al., 2017a).

The specific diversity of these deposits is the reflection of a varied biotope with large bodies of water, in which primary and secondary consumers concurred. In terms of bone surface preservation, leaching effects causing a loss of mass have been identified, especially in some of the Pit 1 remains. At the La Mina locality, a slight abrasion has been documented on the bones in the form of striations caused by trampling within the sandy sediments of the deposit. Weathering is the most frequent modification at El Forn, mainly corresponding to Behrensmeyer's (1978) stage 1 but also higher (Vallverdú et al., 2014a; Mosquera et al., 2015; Pineda et al., 2017b). The anatomical profiles in relation to the bones recovered and their portions (epiphysis vs. diaphysis), such as the complete bones vs. fragmented bones, indicate a high degree of competition for consumption in La Mina (level 2), in which the activity of both hominins (stone tools) and carnivores (tooth marks and other modifications) seems to be high. At El Forn, where the activity of these agents seems to be less intense, levels of competition are low-to-moderate. To sum up, the La Mina and El Forn localities are the outcome of hot spots of activity in open-air ecological systems that tend to give rise to assemblages in which different actors have contributed to their formation without the existence of a dominant agent or process. This is not the case for Pit 1, where a high-resolution event of the butchery exploitation of a large mammoth body has been revealed.

3 Materials and methods

This study analyzes the whole lithic assemblage of Unit II from Barranc de la Boella updated to the 2022 fieldwork season, which amounts to 966 elements. Table 1 compiles aggregate data on assemblage composition by raw materials, technological groups, and localities. However, the numbers provided cannot be taken as definitive because most of the levels of Unit II are still being actively excavated.

For Pit 1, we included the materials from level 2 at Unit II (n = 427), which has a high archaeo-stratigraphic uniformity. Additionally, we have also included a schist cleaver recovered when building the protection structure; it is highly likely that this artifact comes from Unit II.

Excavation in the La Mina locality has so far revealed less dense archaeological concentrations, and some of the five levels distinguished in the previous test pits have not been reached by the ongoing works. For this reason, as in previous studies (Mosquera et al., 2016), we decided to keep all the materials for Unit II together (n = 435).

So far, El Forn is the only locality in which the excavation has concluded. As in Mosquera and colleagues (2016), we have grouped all the materials from Unit II, including levels 2, 3, and 4 (n = 103). The small differences identified during this study with respect to what was published may be due to specific technological or stratigraphical reassessment of some elements.

In all cases, natural elements such as cobbles or pebbles with no trace of anthropic activity were excluded, even for those that were initially recorded and collected. In such a fluvial environment, the recognition of elements as simply manuports is difficult to assess in the absence of any anthropic signal. Also, except for the cleaver mentioned for Pit 1, surface materials were not considered.

To properly frame the group of large shaped tools studied here, Table 1 shows the distribution of the currently available sample at Unit II. The technological categories considered were as follows: elements related to percussive material (cobbles and broken cobbles with fractures and battering traces on their ends), cores, flakes (including the whole ones classified according to size, the broken flakes, and the flake fragments and angular fragments counted together), small shaped tools, and large shaped tools. Although most of the large shaped tools are longer than 100 mm, we include ten artefacts in this group ranging from 70 to 100 mm in length, all of them on cobble blanks, because they represent characteristic macro-tool types such as choppers (unifacial and bifacial). In the same way, we include in the group of small shaped tools five retouched flakes bigger than 70 mm, as they are simple denticulates. The metrical distribution of the different technological categories by localities can be consulted in Supplementary Tables S2–S4.

Despite the variety of raw materials, chert is predominant (87.4% for Pit 1, 78.6% for El Forn, and 87.8% for La Mina). In all cases, this material shows simple core and flake reduction sequences, which are specially complete at Pit 1 regarding technological components and flaking phases. The typological variability of small chert tools is very reduced, with a dominance of denticulates (77.3%) and scrapers (12.2%) over other marginally represented types. Complementary materials are schist (P1: 6.6%, EF: 13.6%, LM: 4.8%), quartz (P1: 3%, EF: 3.9%, LM: 2.7%), and

TABLE 1 Lithic assemblage of Barranc de la Boella Unit II. Distribution of main technological groups by raw materials for the three different localities. (*) One piece without secure stratigraphical context has been included; % (1) considered for the collection of each locality, % (2) considered for the whole assemblage.

LOCALITY/Raw material	Percussive material	Cores	Flakes						Small-shaped	Large-shaped	Total	
			<20 mm	21–60 mm	61–100 mm	>100 mm	Broken	F. F. & frags				% (1)
PIT 1	**15**	**28**	**56**	**122**	**9**	**1**	**67**	**97**	**22**	**11**	**428**	
Schist	4	1		6		1	1	5		10(*)	**28**	*6.54*
Granite	3										**3**	*0.70*
Sandstone	4	1									**5**	*1.17*
Lydite	2										**2**	*0.47*
Quartz			3	2				8			**13**	*3.04*
Quartzite	2			1							**3**	*0.70*
Chert		26	53	113	9		66	84	22	1	**374**	*87.38*
EL FORN	**10**	**8**	**9**	**35**	**2**		**9**	**16**	**7**	**7**	**103**	
Schist	7						1		1	5	**14**	*13.59*
Granite										1	**1**	*0.97*
Sandstone	1										**1**	*0.97*
Quartz	1	1						2			**4**	*3.88*
Quartzite	1									1	**2**	*1.94*
Chert		7	9	35	2		8	14	6		**81**	*78.64*
LA MINA	**20**	**22**	**53**	**103**	**6**	**1**	**51**	**133**	**37**	**10**	**435**	
Limestone				1						1	**2**	*0.46*
Schist	7			2		1	1	2	3	5	**21**	*4.83*
Granite	4	1									**5**	*1.15*
Sandstone	4								1		**5**	*1.15*
Porphyry	1									1	**2**	*0.46*
Quartz	2		1	4				5			**12**	*2.76*
Quartzite	2	1		1			1			1	**6**	*1.38*
Chert		19	52	95	6		49	126	33	2	**382**	*87.82*
TOTAL UII	**45**	**57**	**118**	**260**	**17**	**2**	**127**	**246**	**66**	**28**	**966**	
% (2)	*4.66*	*5.09*	*12.22*	*26.92*	*1.76*	*0.21*	*13.15*	*25.47*	*6.83*	*2.9*		

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TABLE 2 List of large shaped tools and flakes >100 m of Barranc de la Boella Unit II, localities Pit 1, El Forn, and La Mina; (*) marks an artifact without clear stratigraphic correlation with the other pieces at Pit 1.

Reference	Material	Blank	Measure (mm)			Weight (gr)	Volume (cm^3)	Tool type
Pit 1								
C1-2019-S1-II-2-Q11-5	Schist	Cobble	157	83	39	630	226.07	Chopper (distal)
C1-2021-S1-II-2-S13-2	Schist	Cobble	91	62	18	141	54.84	Chopper (distal)
C1-2018-S1-II-2-R14-9	Schist	Cobble	164	73	85	1065	366.28	Pick
C1-2019-S1-II-2-R10-5	Schist	Cobble	164	65	49	655	247.61	Pick
C1-2019-S1-II-2-S10-2	Schist	Cobble	151	115	72	1304	507.72	Pick
C1-2019-S1-II-2-P11-1	Schist	Unknown	136	94	73	740	316.11	Pick
C1-2007-S1-II-2-M13-7	Schist	Flake	161	85	58	682	245.54	Pick (pick-like handaxe)
C1-2020-S1-II-2-M06-2	Chert	Block (slab)	139	86	41	632	243.35	Pick
C1-2018-S1-II-2-R14-12	Schist	Flake	112	92	44	532	216.93	Knife
C1-2013-Surf-1*	Schist	Flake	137	117	36	687	253.25	Cleaver (cleaver-like)
C1-2021-S1-II-2-L12-7	Schist	Cobble	96	96	25	331	124.64	Indeterminate
C1-2019-S1-II-2-T06-2	Schist	Flake	109	191	44	1162	428.64	Large flake (retouched)
El Forn								
EF-2011-II-3-J11-2	Schist	Cobble	214	132	65	2620	972.03	Chopper (lateral)
EF-2013-II-3-C11-1	Schist	Cobble	125	90	39	585	225.34	Chopper (lateral-distal)
EF-2011-II-2-I14-2	Granite	Cobble	95	64	30	234	91.88	Chopper (pointed)
EF-2013-II-2-H13-3	Quartzite	Cobble	85	55	50	309	117.35	Bifacial chopper (distal)
EF-2009-II-2-N14-4	Schist	Flake	153	118	48	960	344.99	Cleaver (cleaver-like)
EF-2012-II-4-H12-1	Schist	Cobble	140	123	25	498	188.99	Indeterminate
EF-2012-II-4-K13-4	Schist	Cobble	141	71	43	560	220.78	Indeterminate
La Mina								
LM-2013-S1-II-2-W13-1	Schist	Cobble	90	78	43	253	106.63	Chopper (pointed)
LM-2019-S1-II-1-V12-3	Schist	Cobble	108	90	55	585	219.54	Chopper (distal)
LM-2010-S1-II-2-Y14-8	Schist	Cobble	95	72	32	276	117.12	Chopper (lateral-distal)
LM-2010-S1-II-1-O15-1	Porphyry	Cobble	145	100	55	966	377.04	Bifacial chopper (lateral-distal)
LM-2013-S1-II-2-U13-1	Quartzite	Cobble	75	73	51	356	136.63	Bifacial chopper (distal)
LM-2021-S2-II-2-B18-1	Limestone	Cobble	72	64	45	272	102.38	Bifacial chopper (distal)
LM-2021-S2-II-2-F14-1	Chert	Cobble	92	58	31	188	76.63	Bifacial chopper (lateral)
LM-2022-S2-II-2-A13-1	Schist	Cobble	220	115	76	2438	888.25	Pick
LM-2022-S2-II-2-A16-4	Chert	Cobble	117	81	78	967	374.66	Pick
LM-2014-S1-II-2-X15-7	Schist	Flake	166	108	40	881	359.78	Knife
LM-2020-S1-II-1-W16-3	Schist	Flake	107	143	51	1255	482.67	Large flake

quartzite (P1: 0.7%, EF: 1.9%, LM: 1.4%). Among these, schist and quartzite stand out, as they were used mainly for production of large shaped tools. Other rocks are represented by very few elements and without any visible selection pattern, such as granite (P1: 0.7%, EF: 1%, LM: 1.1%), sandstone (P1: 1.2%, EF: 1%), lydite (P1: 0.5%), limestone (LM: 0.5%), and porphyry (LM: 0.5%). Given its importance in the assemblage, it is worth noting that the group of schist includes a sandy one, sometimes with marked schistosity plains, and others that are very fine-grained and compact, with the appearance of hornfels. All these varieties of raw materials and the observed blank formats are locally available around the immediate alluvial environment (Mosquera et al., 2016). The Quaternary deposits on which the fluvial-deltaic formation developed worked as secondary outcrops, offering metamorphic (schists and quartzite), igneous (granite and dioritic porphyry), sedimentary materials (chert, limestone, and lydite), and vein quartz, in the form of pebbles and cobbles with a high metrical range, that were more or less rolled and globular depending on the nature and distance of the primary outcrops from which they were derived.

As mentioned previously, this study specifically focuses on the large shaped tool components, made on any type of blank (core tools and retouched large flakes) (n = 28). Additional attention is paid to the large flakes (>100 mm, n = 2). To provide a comprehensive description of this collection, we performed technological analysis using the logic analytic system following other recent papers (e.g., Ollé et al., 2013; de Lombera-Hermida et al., 2020), which was complemented with different techno-typological, volumetric, and geometric morphometrical analyses (Lombao et al., 2020; Lombao et al., 2022; García-Medrano et al., 2022; García-Medrano et al., 2023). Detailed graphic information is provided by means of systematic photography and 3D scanning with diacritic interpretation. All the tools were photographed using a Nikon D600 digital camera (AF-S DX Micro NIKKOR 40 mm lens) and scanned using the Artec Space Spider 3DScan (Artec Studio v15 software) and the Breuckmann smartSCAN3D-HE Scanner with a 250-mm field of view (Breuckmann Optocat 2012 R2-2206 software).

Regarding the functional analysis of the large shaped tools from Barranc de la Boella, a residue and microwear study has been launched following a multi-technique approach that combines reflected light, 3D digital, and scanning electron microscopy (Martín-Viveros and Ollé, 2020). To date, only very preliminary results are available, which come from screening under the digital (Hirox KH-8700) and the scanning electron (ESEM FEI Quanta 600) microscopes to assess the preservation of the materials, to describe some of the observed macrotraces, and to explore the existence of preserved residues.

As a detailed discussion of typological terminology is beyond the scope of this paper, we refer to the large shaped tools (*sensu* Kleindienst, 1962) using commonly accepted terms for Lower Paleolithic simple forms, such as choppers, as well as typical Acheulean forms such as bifacial handaxes, cleavers, picks, or knives (e.g., Bordes, 1961; Kleindienst, 1962; Leakey, 1971; Isaac, 1977; Schick and Toth, 1993; Chavaillon and Piperno, 2004; Sharon, 2007). Regarding the choppers, we adopted terminological proposals that consider them as a whole (e.g., Kleindienst, 1962; Leakey, 1971; Isaac, 1977; Schick and Toth, 1993; Chavaillon and Piperno, 2004), using "bifacial chopper" to refer to tools with two faces flaked, rather than its equivalent "chopping tool" (e.g., Movius, 1948; Bordes, 1961).

Additionally, we applied 3D geometric morphometrics to analyze tool shape variation. The 3D models were processed using AGMT3-D software v.3.1 (Herzlinger and Grosman, 2018; Herzlinger and Goren-Inbar, 2020). This consists of a data-acquisition procedure for automatically positioning 3D models in space and fitting them with grids of 3D semi-landmarks. Each point of the grid consists of two semi-landmarks, one placed on each face of the artifact, so that a 50 × 50 grid provides 5,000 landmarks. The multivariate outline data were projected in two dimensions so that the underlying shape variables could be qualitatively examined and compared. To interpret the principal component analysis (PCA) results from a morphological perspective, Procrustes superimposed shape data were examined using thin-plate splines to facilitate the visualization of shape changes from the group mean along relative warp (i.e., the principal component; PC) axes. By examining the morphological deformations and XY plots of specimens from the PCA scatters, it is possible to interpret shape variation by itself and compare the different tools within a site or between different sites. In addition, the derived principal component scores also allow the application of other quantitative tests of multivariate equality of means between the groups (Costa, 2010; Herzlinger and Grosman, 2018; Herzlinger and Goren-Inbar, 2020). Specific multivariate analysis of variance (MANOVA) of the first 10 PCs helps to evaluate whether there are statistically significant differences between multiple groups. The alpha level for significance was determined as $p < 0.05$.

The landmark data were used to calculate the degree of deviation from perfect bilateral and bifacial symmetries, as well as the edge section regularity of each item in the sample (Herzlinger and Goren-Inbar, 2020). The bilateral symmetry analysis was conducted by measuring the mean 3D Euclidean distance between a mirror reflection of the landmarks placed on one lateral half of each tool and the corresponding landmarks on the other half. The same procedure was performed for bifacial symmetry but on the two opposing faces. In a perfect bilaterally or bifacially symmetrical tool, the value of these indices is 0, with increasing values indicating less symmetrical tools.

4 Results

Table 1 displays the relative weight of the large shaped tools group according to localities and raw materials. Table 2 shows their detailed distribution and summarizes their main technological features. In this section, we pay attention to the techno-typological, metric, volumetric, and morphometrical characteristics recorded at Barranc de la Boella Unit II as a whole, while providing a comprehensive graphic illustration of the more representative artifacts (Figures 3–11). A detailed description of technical attributes and shaping processes piece by piece is provided in Supplementary Table S5, together with additional graphical documentation (Supplementary Figures S3–S10). Because of the reduced sample, the 3D geometric morphometric analysis has been carried out with all the Unit II materials taken together.

4.1 Techno-typological features of the large shaped tool assemblage

The collection at Pit 1 consists of 11 large shaped tools and one large flake, including two choppers, six picks, one cleaver, one knife, and one typologically indeterminate element (Table 2). There is uniformity in raw materials, as all are made of schist, except for one of the picks, which is made of chert. The two choppers are distally shaped. The first was made on an elongated cobble with an apparent oblique fracture (Figure 3B). The second one was made on a flat,

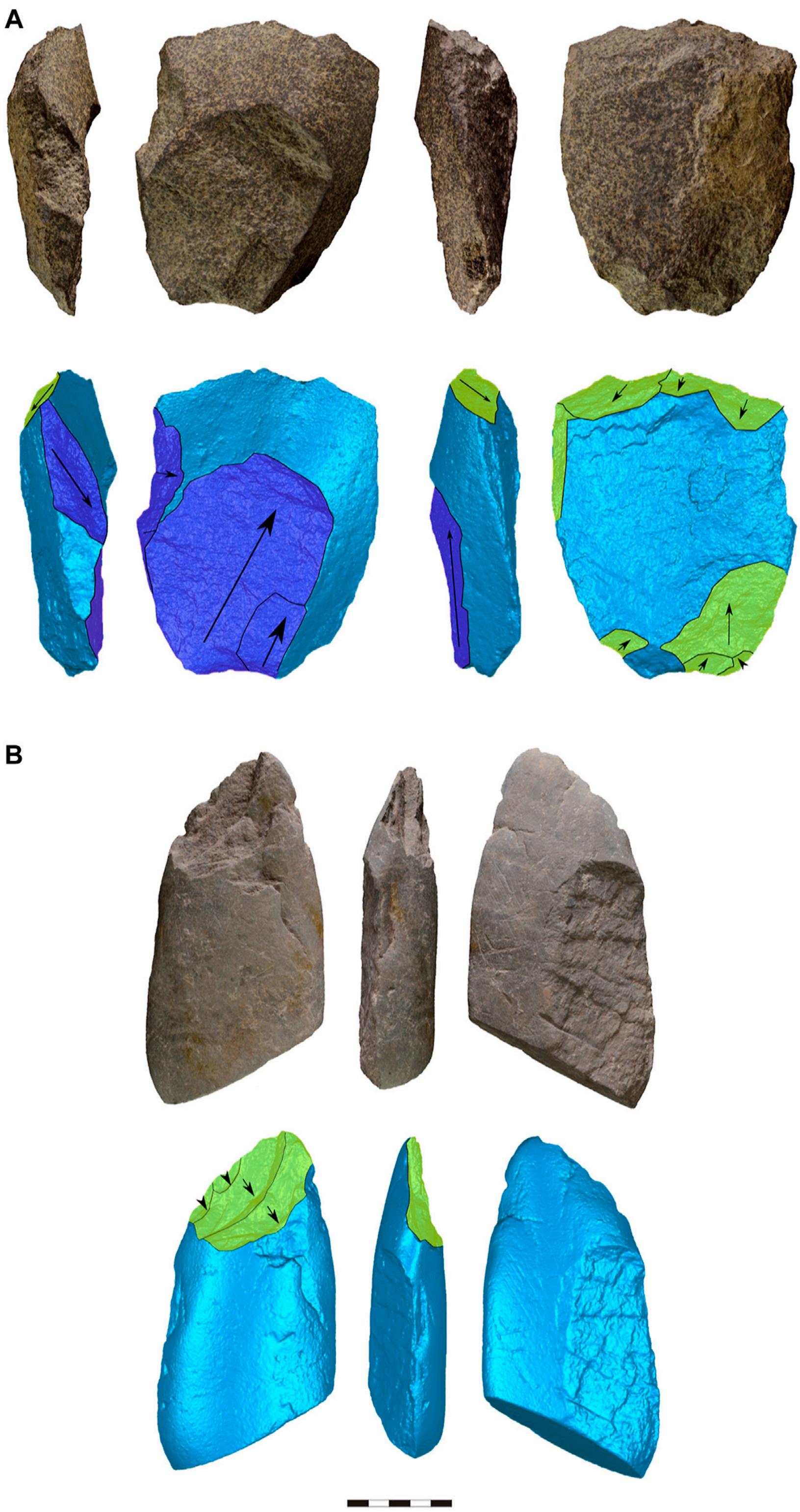

FIGURE 3
Pit 1. **(A)** Schist cleaver (ref. C1-2013-Surf-1) and **(B)** schist distal chopper (ref. C1-2019-S1-II-2-Q11-5); scale bar 5 cm.

medium-sized cobble (Supplementary Figure S3). Both show non-invasive, step-terminated removals quite constrained by the raw material schistosity plains. Among the picks, three were made on cobble (Figures 4B, 5B, 6A), one on a flake or split cobble (Figure 4A), and one was made on a chert slab (Figure 6B), and in the last case, it was not possible to determine the blank given the

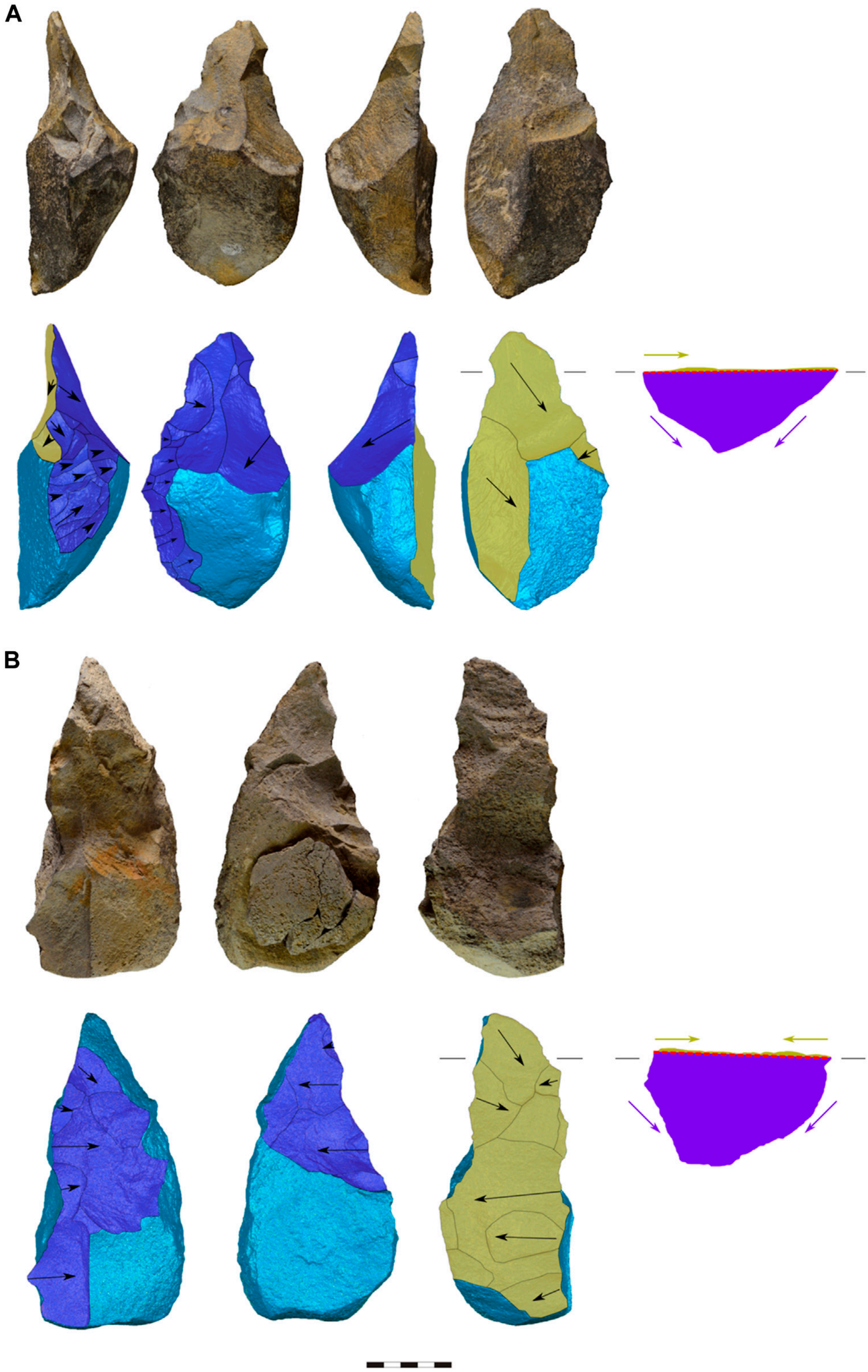

FIGURE 4
Pit 1. **(A)** Schist pick (ref. C1-2007-S1-II-2-M13-7) and **(B)** schist pick (ref. C1-2018-S1-II-2-R14-9); scale bar 5 cm.

intense shaping (Figure 5A). All the picks at Pit 1 show a triangular section and a similar shaping pattern consisting of a few invasive removals, mainly alternate and concentrated in the distal third of the tool, which produce mainly sinuous lateral edges that converge to a robust and pointed tip. Alternating flaking is also present, and even true bifacial shaping occasionally occurs for some portions of the

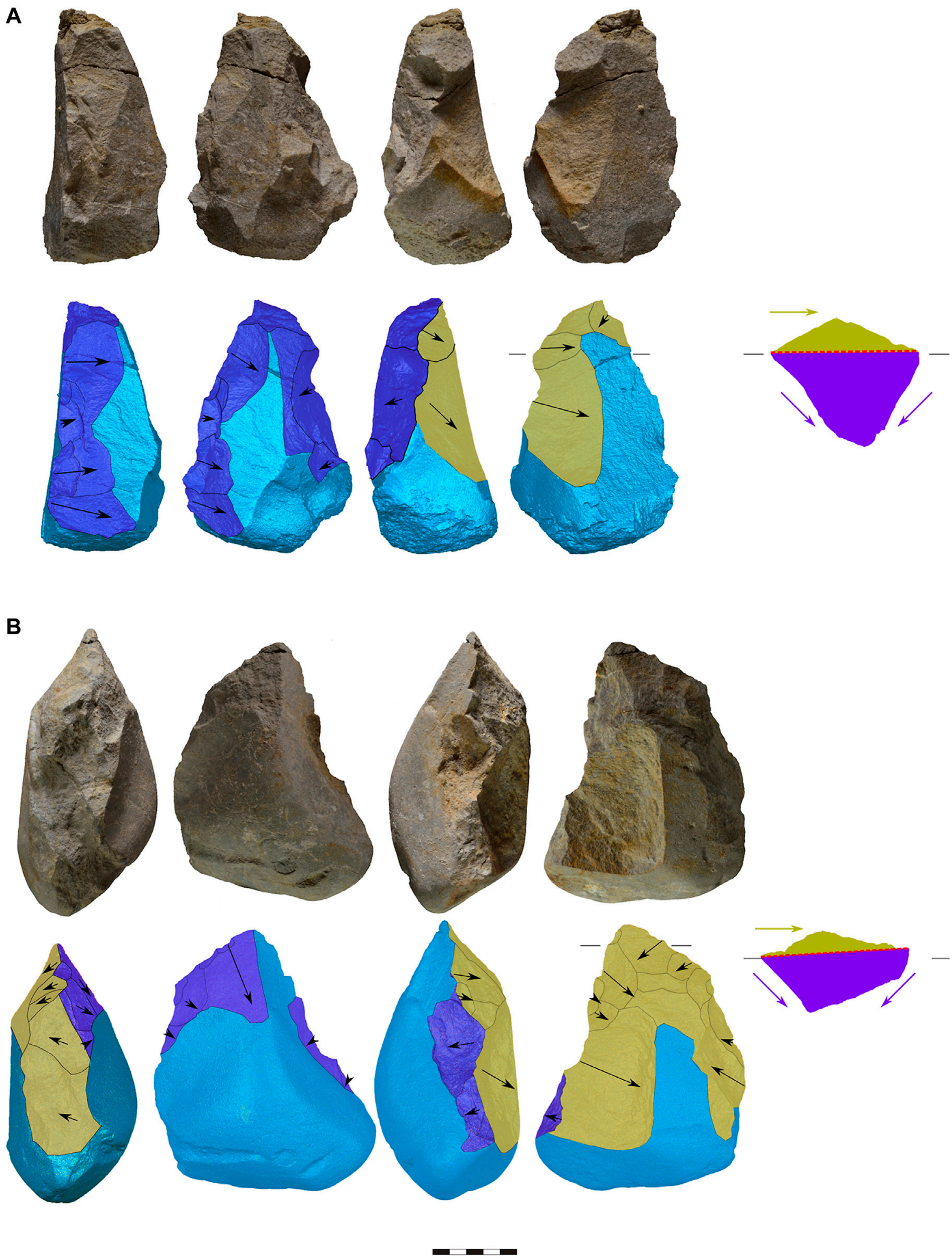

FIGURE 5
Pit1. **(A)** schist pick (ref. C1-2019-S1-II-2-P11-1), **(B)** schist pick (ref. C1-2019-S1-II-2-S10-2); scale bar 5 cm.

edges. Only one of the pieces shows a higher degree of shaping and finishing, with sagittal straight edges and a bilateral symmetry, for which it could be considered a pick-like handaxe (Figure 4A). The only cleaver is on a cortical schist flake, with a convex transversal bit slightly shaped by means of inverse removals [so we can precautionary use the "cleaver-like" term to differentiate it from

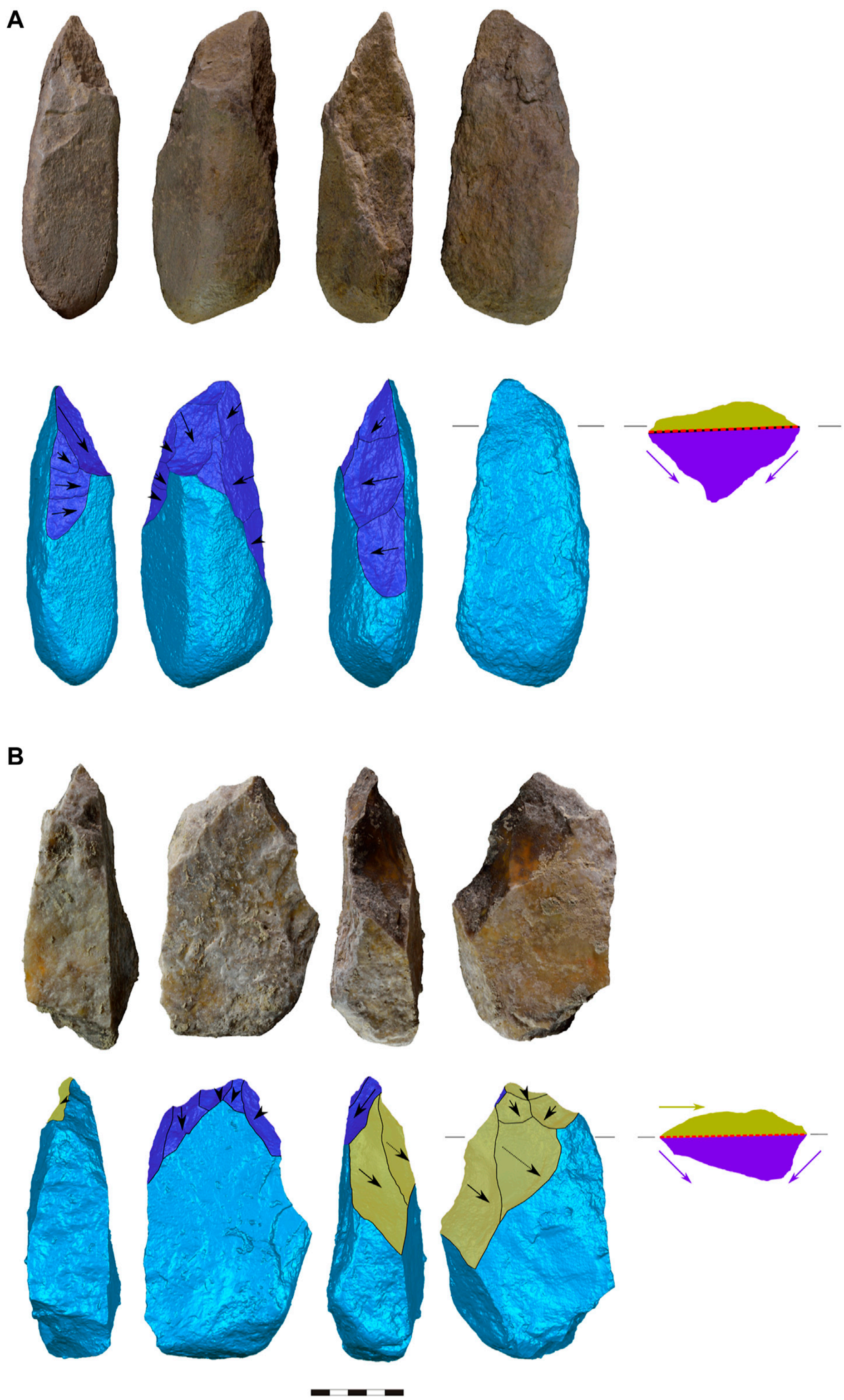

FIGURE 6
Pit1. **(A)** Schist pick (ref. C1-2019-S1-II-2-R10-5) and **(B)** chert pick (ref. C1-2020-S1-II-2-M06-2); scale bar 5 cm.

the "true" ones without a retouch on the bit (Tixier, 1957; Sharon, 2007, and references therein) (Figure 3A)]. The two remaining large shaped tools are a knife made on a quite eroded sandy schist cobble, with a convex edge, sinuous in profile, and a tool for which its heavy alteration hinders it from being properly classified. Finally, the single large flake is a side-struck one, with two previous dorsal removals.

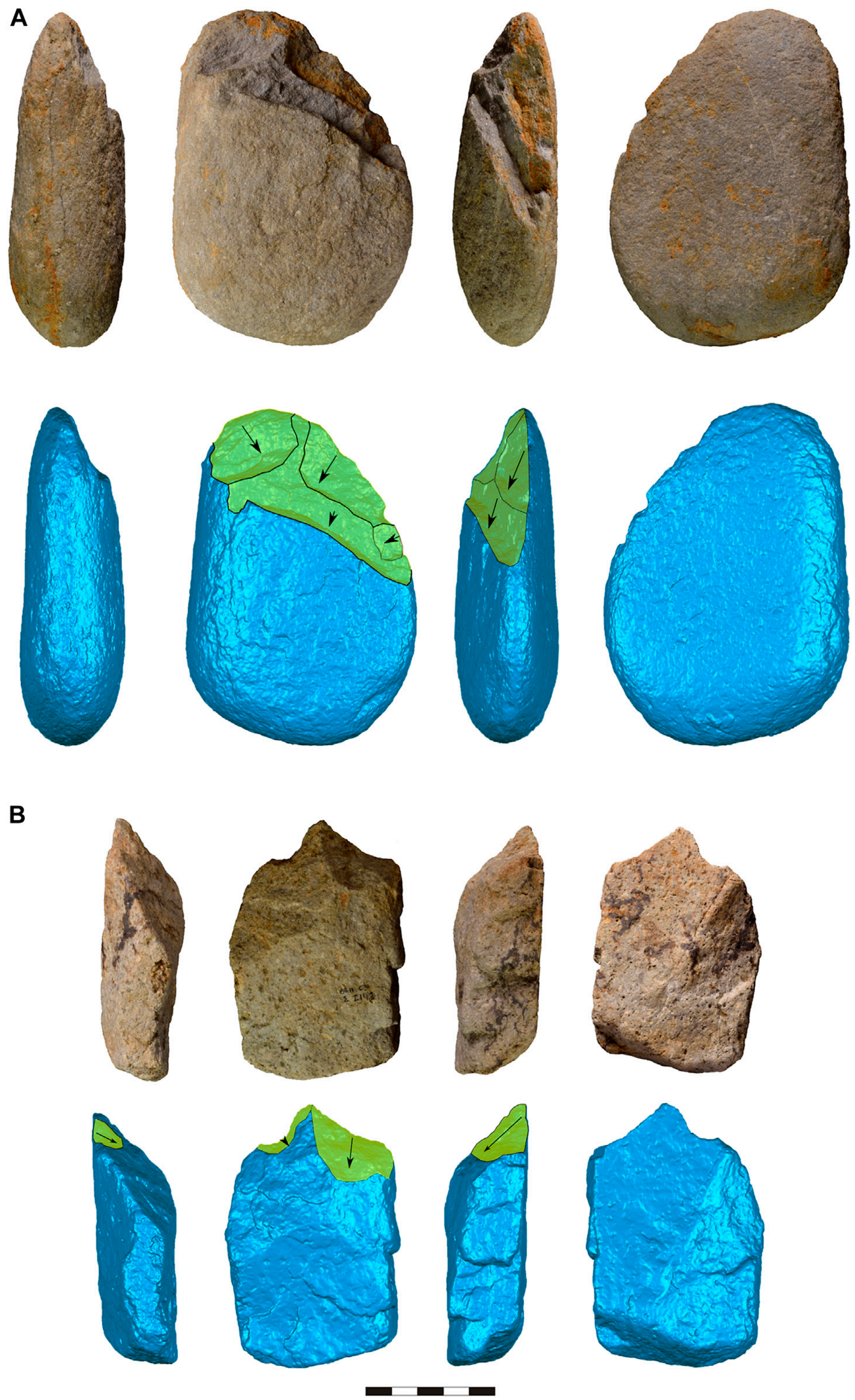

FIGURE 7
El Forn. **(A)** Schist lateral-distal chopper (ref. EF-2013-II-3-C11-1) and **(B)** granite pointed chopper (ref. EF-2011-II-2-I14-2); scale bar 5 cm.

Some opposed scars on its ventral face could be caused by the bipolar technique, and it shows a possible shaping trial on its right proximal end (Supplementary Figure S4).

The assemblage from the El Forn locality consists of seven large shaped tools, mostly on cobble. There are three choppers, one bifacial chopper, two indeterminate artifacts, and one cleaver.

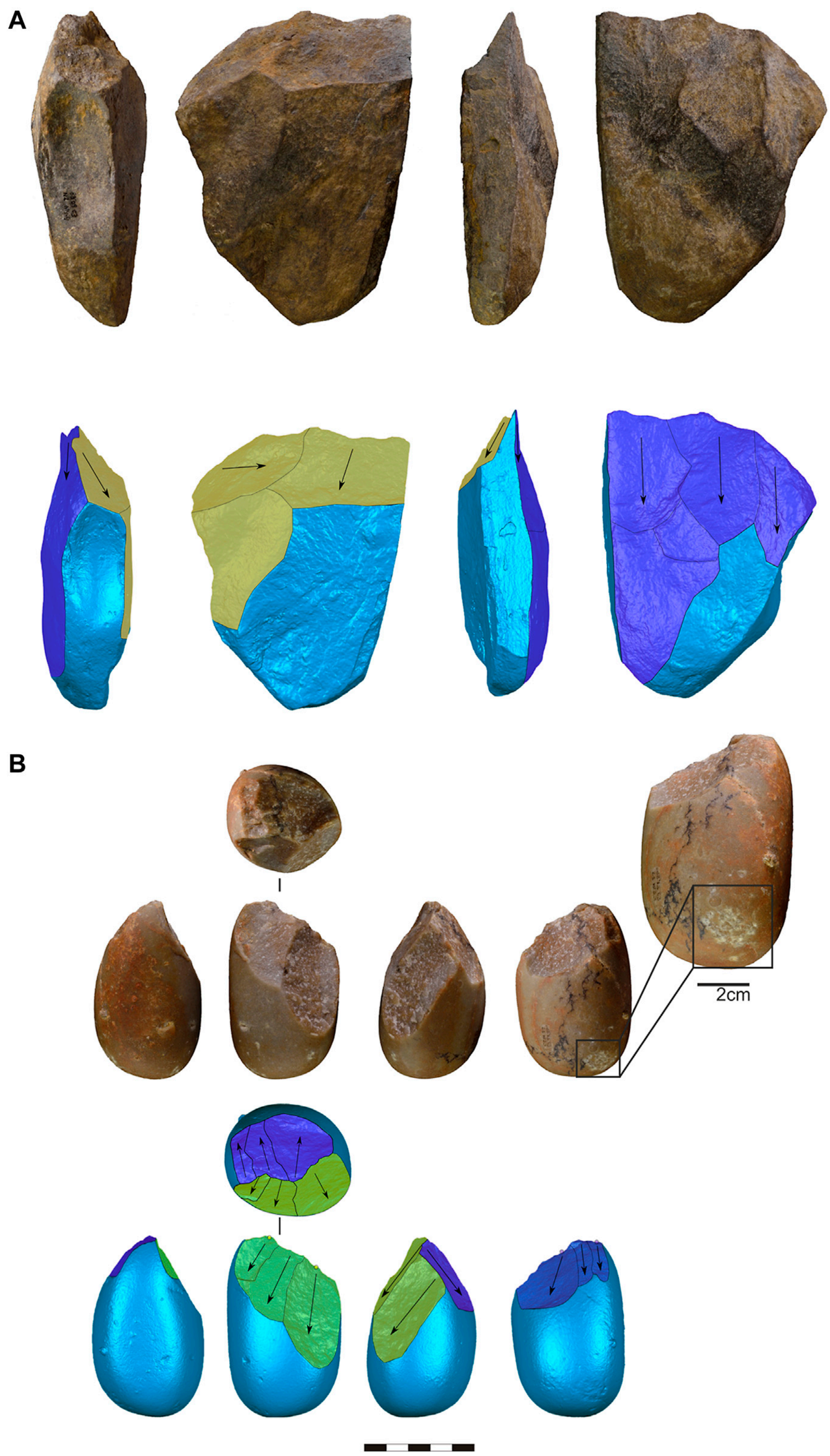

FIGURE 8
El Forn. **(A)** Schist cleaver (ref. EF-2009-II-2-N14-4) and **(B)** quartzite bifacial chopper (ref. EF-2013-II-2-H13-3); scale bar 5 cm.

The choppers show a certain typological and metric variability, with a large side-shaped form with a convex edge opposed to a thick natural back (Supplementary Figure S5), a side-distal form made on a medium-sized flat cobble (Figure 7A), and a pointed form (awl), which was made on a granite cobble (Figure 7B). The bifacial chopper was produced on a high-quality, ovate quartzite cobble,

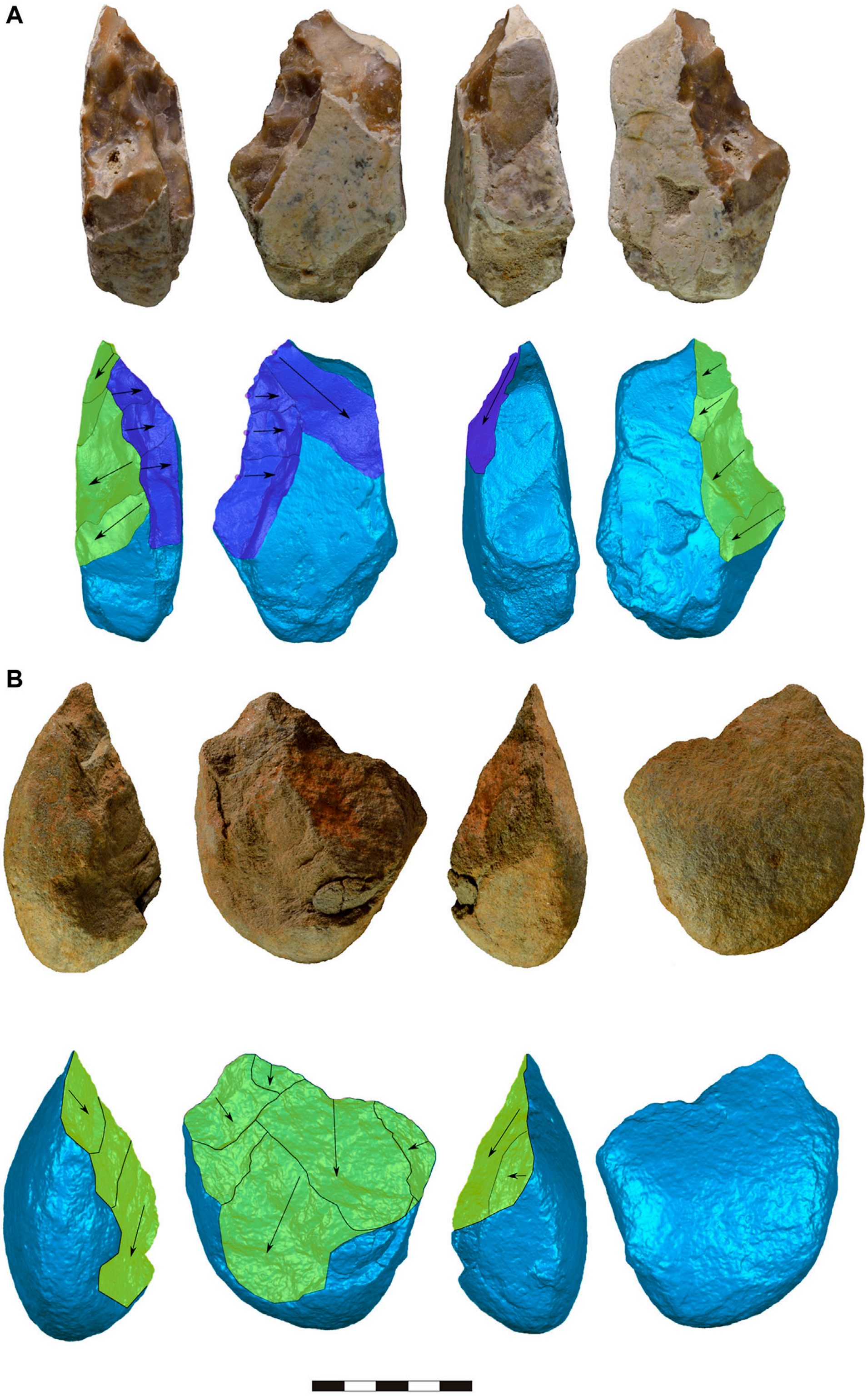

FIGURE 9
La Mina. **(A)** Chert bifacial chopper (ref. LM-2021-S2-II-2-F14-1) and **(B)** schist distal chopper (ref. LM-2013-S1-II-2-W13-1); scale bar 5 cm.

which was shaped through bifacially alternating removals. This artifact shows percussion marks on its proximal end, likely deriving from its use as a hammer in lithic knapping activities (Figure 8B). The two pieces considered typologically indeterminate are flat cobbles with some shaping, bifacial in one case, for which a bad preservation of the material prevents a correct assessment of

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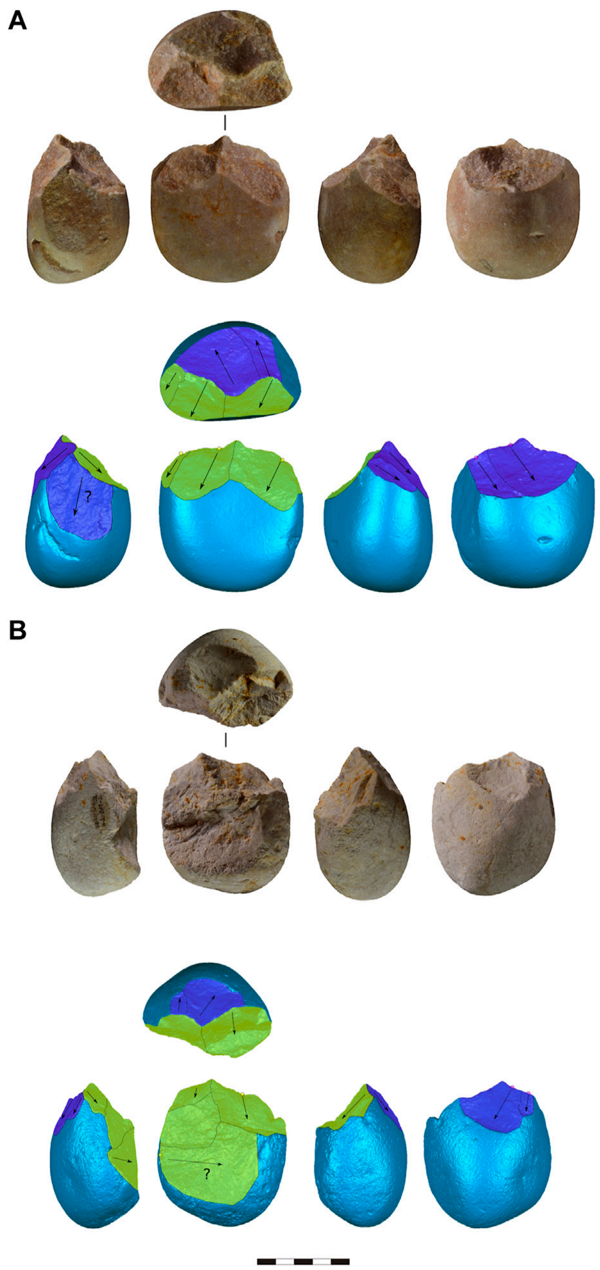

FIGURE 10
La Mina. **(A)** Quartzite bifacial chopper (ref. LM-2013-S1-II-2-U13-1) and **(B)** limestone bifacial chopper (ref. LM-2021-S2-II-2-B18-1); scale bar 5 cm.

their anthropic origin. The only Acheulean form is a cleaver (or cleaver-like tool) made on a large schist flake, probably a split cobble, with the transversal edge finely shaped through bifacial, low-angled invasive removals (Figure 8A).

Finally, the collection from La Mina consists of nine large shaped tools and one large flake. Here the raw material diversity is higher, as, apart from different varieties of schist, chert, and quartzite, dioritic porphyry and limestone were used. There are three schist choppers, pointed, latero-distal, and distal. Although the former two were made on a sandy schist and are partially weathered, they show an intensive and well-organized shaping (Figure 9B and Supplementary Figure S6); the third one shows only two distal invasive removals that create a convex edge with incurvated profile (Supplementary Figure S7). The bifacial chopper group is the best represented at La Mina, with four pieces each made of a different raw material. The one on dioritic porphyry shows an intensive shaping on its side and distal portions by means of a series of alternating removals, which led to a convex edge, very sinuous in profile (Figure11B). The edge irregularity, together with the existence of a possible knapping mishap in the form of a steep fracture opposed to the shaped lateral and the volumetric potential of the cobble, leaves open the idea of viewing the tool as an LCT in the early stages

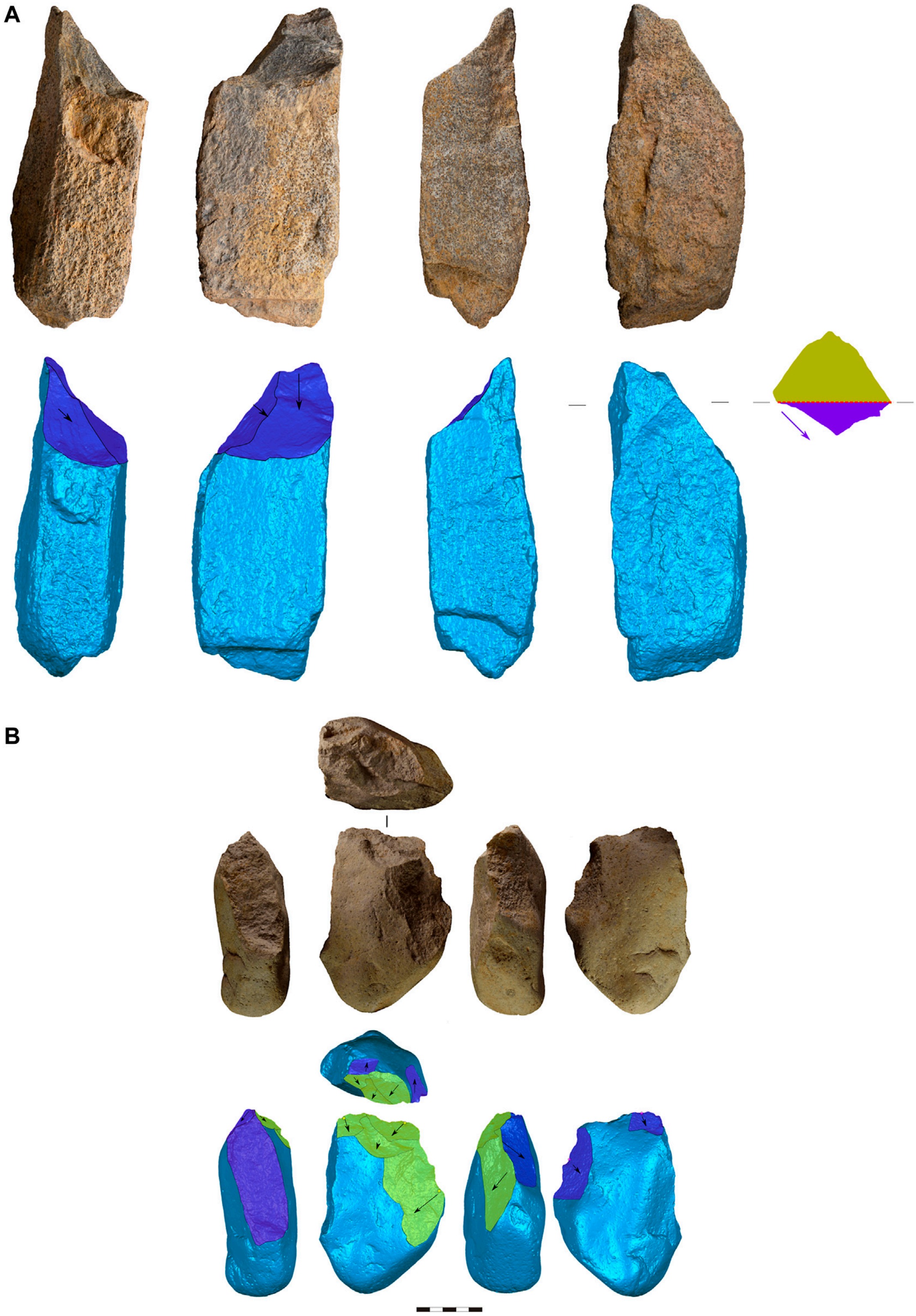

FIGURE 11
La Mina. **(A)** Schist pick (ref. LM-2022-S2-II-2-A13-1) and **(B)** porphyry bifacial chopper (ref. LM-2010-S1-II-1-O15-1); scale bar 5 cm.

of shaping. The quartzite one, like the one at El Forn, was shaped through a series of alternating, unipolar, and invasive removals, which led to a sinuous mid-angled edge (Figure 10A). The bifacial chopper made of limestone shows a similar distal shaping strategy and output, alternating removals, and a sinuous edge, in addition to a large removal on the lateral likely deriving from an earlier

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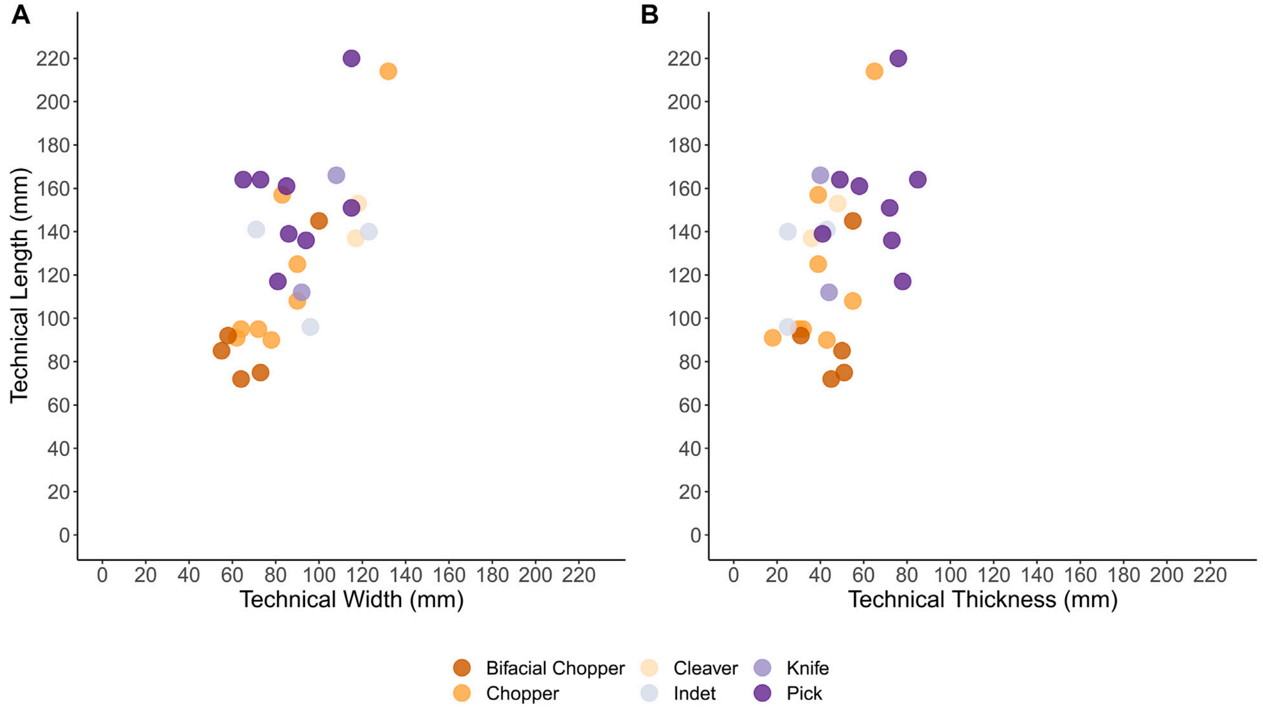

FIGURE 12
Scatter plot comparing **(A)** length and width by category and **(B)** length and thickness by category.

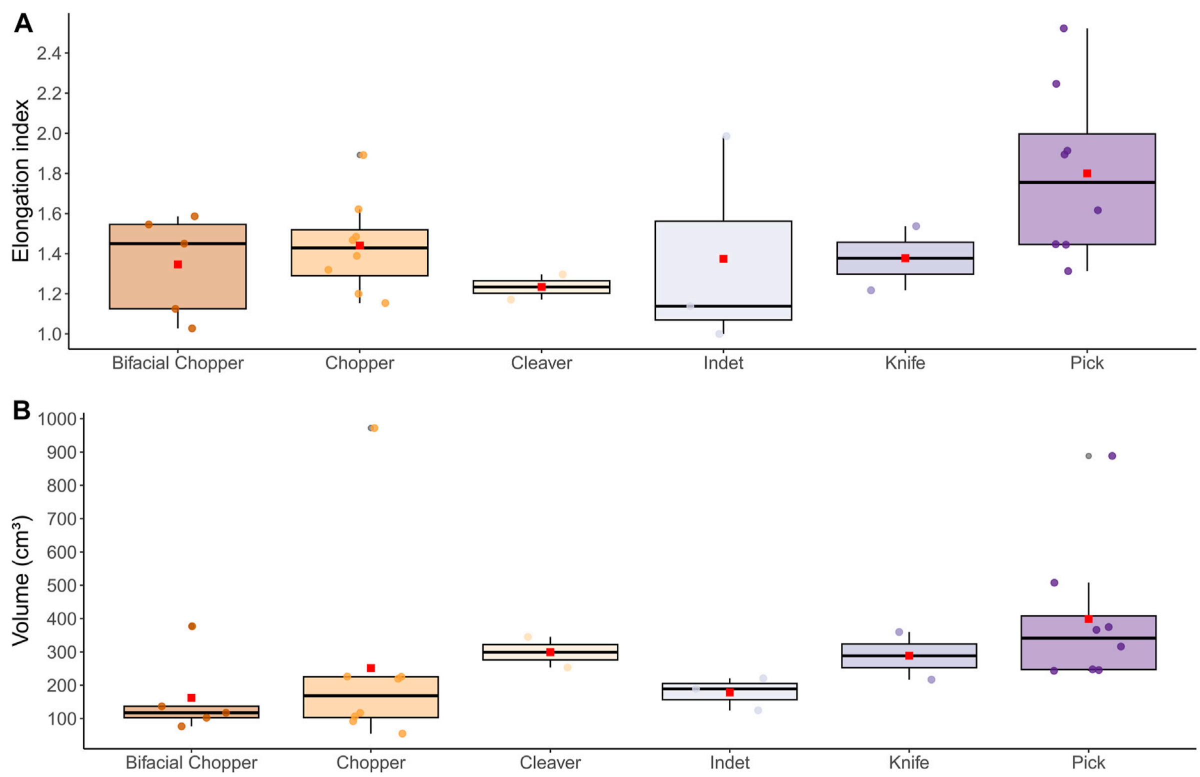

FIGURE 13
Boxplot comparing **(A)** elongation index (Length/Width) and **(B)** volume (cm^3) according to type. The red squares show the mean value for each type.

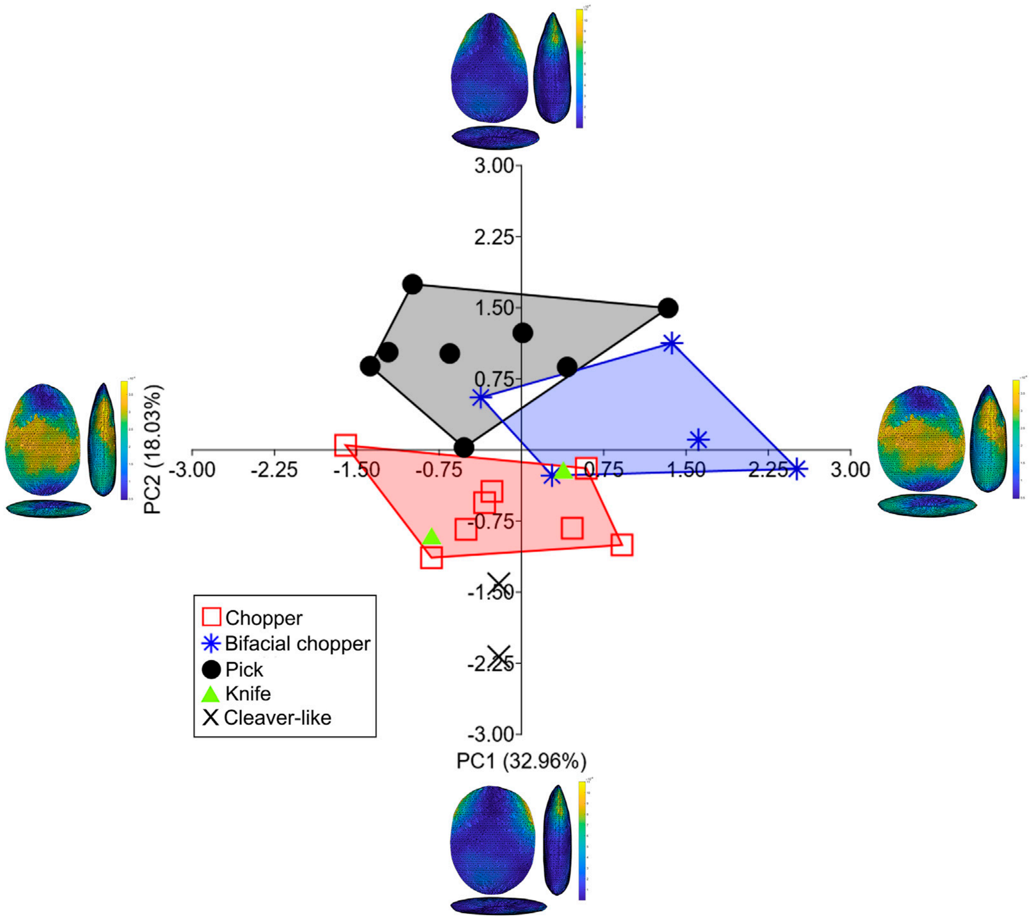

FIGURE 14
Principal component scatter plots of large shaped tools from Barranc de la Boella by type. Color coding represents the most variable landmarks in shape trends described in terms of positive and negative scores of PC1 and PC2.

TABLE 3 Intra-group shape variability analysis (measured as the mean multidimensional Euclidean distance of all artifacts from their centroid) and distribution of relative shape variability across dimensions (we excluded the indeterminate tools, refs. C1-2021-S1-II-2-L12-7, EF-2012-II-4-H12-1, and EF-2012-II-4-K13-4).

	(N)	Mean Variability	% of variability caused by x (Width)	% of variability caused by y (Length)	% of variability caused by z (Thickness)
Chopper	8	9.57	57.04	5.23	37.74
Bifacial chopper	5	10.67	31.42	11.84	56.74
Pick	8	10.73	32.77	4.18	63.06
Cleaver	2	5.64	44.98	6.18	48.84
Knife	2	8.91	65.91	3.24	30.84

percussion activity (Figure 10B). The last bifacial chopper was produced on a small tabular chert nodule, on which a series of lateral, bifacially alternating removals created a concave and sagittally straight-to-sinuous edge (Figure 9A). The picks are represented by two pieces. One was made on a large and thick, rounded coarse-grained schist slab, where two invasive removals and some additional lateral shaping define a marked distal trihedron (Figure 11A), while the second is crude, made of chert, with poor shaping that produced a not-prominent tip (Supplementary Figure S8). The remaining large shaped tool is a knife made on a sandy schist overshoot flake; there, although the erosion prevents an accurate reading, a sequence of bifacial removals created a convex and sinuous side working edge (Supplementary Figure S9).

The single flake larger than 100 mm, on schist, shows a previous dorsal removal orthogonally arranged with respect to its technical axis and provides an example of large schist flake production (Supplementary Figure S10).

It is important to note that several of the pieces show macroscopic damage on the edges or surfaces likely produced by their use. The surfaces of the schist and limestone artifacts have poor preservation compared to the excellent surfaces of the chert and quartzite objects. However, apart from the aforementioned percussion marks on two of the bifacial choppers, possible macroscopic use-wear was observed on nine large shaped tools (on two picks and one unifacial chopper from Pit 1; one unifacial chopper and one bifacial chopper from El Forn; and one unifacial chopper, one bifacial chopper, and two picks from La Mina). The preliminary microscopic analysis showed very promising results at least on three tools: the chert pick from Pit 1, with a very pronounced edge rounding only on the tip of the tool (Supplementary Figure S11); the quartzite bifacial chopper from El Forn, with intensive crushing in all the exposed portions of the distal edge (Supplementary Figure S12); and the small chert bifacial chopper from La Mina, where a small portion with intensive and continuous scarring has been documented on a generally fresh edge (Supplementary Figure S13).

4.2 Metrical distribution, volume, and blank selection

From a metrical point of view, there are several notable characteristics in the studied assemblage. There are clear differences in the dimensional measurements according to tool typology. Thus, bifacial choppers are the group with the smallest dimensions (Figure 12, Supplementary Tables S6–S8), both in terms of technical length and width, as well as in terms of volume (Supplementary Table S10). Also, they have a greater thickness compared to most of those tools, apart from the picks (Supplementary Table S9).

On the opposite side, we find the picks and cleavers, with generally larger technical dimensions, with central values (mean and medians) approximately 150 mm in length and 90 and 117 mm in width, respectively (Supplementary Tables S6, S7). The picks present a generally larger remaining volume than the rest of the tools (Figure 13, Supplementary Table S10). These differences are statistically significant in the central values (K-W = 11.18, df = 5, $p = 0.047$), although the p-value is very close to 0.05. However, these differences are also noticeable after calculating the elongation index (EI = technical length/technical width, Supplementary Table S9). Therefore, a very marked allometric pattern can be observed between the picks and the rest of the tools, with the picks being relatively longer than wide (Figure 12A). Meanwhile, the two large flakes present larger dimensions in technical width than in length, which explains the very low EI values, although they present similarities with the picks in terms of size or volume.

Considering the large amount of preserved cortical surface and the generally restricted shaping in specific sectors of the large shaped tools, these morphometric differences provide valuable information about the blank selection strategies of the hominins from Barranc de la Boella. To produce bifacial choppers (chopping tools), blanks with an oval-ellipsoidal morphology were selected. In some cases, these artifacts bore impacts and battered marks, indicating their previous or subsequent use as hammerstones. In addition, a remarkable feature of these chopping tools is that several raw materials are used, generally marginal within the assemblage, such as limestone, quartzite, and porphyry. This is unlike most of the large shaped tools made in different varieties of schist. Considering the toughness, morphology, and size of these materials, managing these blanks volumetrically through knapping is not easy. In this sense, the development of alternate and/or alternating methods demonstrates a great capability on the part of these hominins to overcome the restrictions of the raw material.

The unifacial choppers exhibit great variability in both dimensions and volume, as well as in the EI. No apparent pattern is discernible in terms of morphology and size of the blank.

Conversely, especially in some picks, natural shapes with a trihedral tendency are selected, which require minimal further modification (sometimes only a series of unifacial extractions) to achieve the desired morphology. This selection reduces the intensity of the shaping, restricted to the tip, which can in some cases give rise to similarities from a technological point of view with other typologies such as choppers (Figures 3B, 6A). In other cases, the shaping of the picks is carried out through longer and more complex series, while in still other cases, large flakes are obtained for subsequent shaping. The importance of the selection process within the technical system of these hominins is also evident in the large flakes, both modified (cleavers and knives) and unmodified. Thus, there is a morpho-dimensional homogeneity in the flakes used as cleavers and knives. This homogeneity is visible in all the metric aspects considered here (dimensions and volume), with a major difference in width because cleavers are slightly wider than knives, which translates into a lower EI.

However, when comparing the blanks of these tools with the large flakes without retouching, we observe how the latter are 1) thicker, 2) technically shorter (according to the technical axis of the flake), and 3) larger in volume (Table 2). This suggests a certain criterion when selecting large flakes for further shaping, especially considering that these instruments are already modified when transported to the sites.

4.3 Morphometrical analysis

To assess the intra-group variability in the shape of the large shaped tools, we applied the geometric morphometric techniques to 24 LCT 3D models, excluding fragmented and indeterminate tools that had lost their final shape. The PCA pointed out the high heterogeneity of this assemblage and clear morphometrical distribution of tool types. More than 87% of the variability was explained by the first 10 principal components (Supplementary Table S11). The best morphological characterization of this assemblage resulted from the combination of PC1 (32.96%) and PC2 (18.03%) (Figure 14). PC1 represented the transition from wider and thick shapes on positive values to elongated and thinner tools on negative ones. PC2 gathered variation from pointed distal ends in thicker shapes in positive values to wider convex parts in thinner tools.

According to this analysis, there is a clear distance between the distributions of the three main generic tool types: choppers, bifacial choppers, and picks. The interpoint distances between the mean shapes of these groups are statistically significant (rank sum = 112; $n1 = 8$; $n2 = 5$; $p = <0.01$/rank sum = 168; $n1 = 8$; n2 = 8; $p = <0.01$). Choppers are located on the lower part of the graph. Their morphologies are distributed along PC1, with a clear variation in tool width (Table 3). Nevertheless, they are mainly thin cobbles, and shaping creates widely convex distal parts. In contrast, picks are distributed on the upper part of the graph. They present the highest intra-group variability, with thinner and pointed shapes, and their maximum variability is focused on thickness. Bifacial choppers are distributed on the right side of the graph, presenting their major variation concentrated on tool thickness. They are the thickest tool type, and, as the second major intra-site variability group, their distal morphologies range from convex to more pointed distal ends. Knives are integrated within the scatter group of choppers/bifacial choppers. The two cleavers appear clearly apart from choppers and picks, being the widest and thinnest tools.

A different aspect related to tool morphology is their degree of symmetry (Supplementary Table S12). As we stated in the methodological section, we focus on the deviation from bilateral and bifacial symmetry, the planform and section irregularities. In general terms, choppers, bifacial choppers, and picks present a high coefficient of variation (CV), which indicates a high intra-group variability, which in turn means a low degree of symmetrical standardization. Nevertheless, picks are the least symmetrical tools. They present 52% less bifacial symmetry than choppers, showing clear differences between the upper-middle and lower-middle parts of tools. Section irregularity is higher in picks. Both edges present planform differences in all cases, but knives present the greatest degree of difference, with 56% more irregularity in one of their edges. However, due to the low number of cleavers and knives, we cannot evaluate their statistics.

5 Discussion

The results presented in this study reflect the systematic research program carried out since 2007 in the late Early Pleistocene deposits from the Barranc de la Boella site. Because of the significance of the large shaped tools for the cultural ascription of the site in the frame of the earliest presence of the Acheulean techno-complex in Europe, we have focused on the collection of these elements recovered so far at Unit II (0.99–0.78 Ma). After summarizing the characteristics of these large shaped tools, we will discuss the features that make Barranc de la Boella unique in the known late Early Pleistocene archaeological record from Europe and distinguish it from the rest of known ancient Acheulean sites in this continent, which are all dated at the Middle Pleistocene. The discussion will support the idea of an Early European Acheulean and will lead us to consider aspects of its possible origin in terms of technological transitions, hominin dispersals, and technological convergence phenomena.

Although the two main localities at Barranc de la Boella, Pit 1 and La Mina, are still under excavation in layers containing these assemblages, at this time, we have enough solid data to adequately depict a fluvial-deltaic landscape, to report on its paleoenvironmental features, and to identify the impact that early hominins had on it. Research conducted so far enabled us to document hot spots of activity in that landscape, which vary in spatial and temporal resolution. They include high archaeological (so behavioral) resolution records like Pit 1, together with illustrations of cumulative palimpsests indicating scarce but considerable human activity as an accumulator or a modifying agent (the El Forn and La Mina localities).

At Pit 1, preliminary spatial observations enabled us to distinguish a close relationship between the faunal remains and the scatter of lithics (Figure 2). The percussive material and the large shaped tools seem to be mainly concentrated around the mammoth remains, while the chert cores and flakes exhibit two different concentrations. The denser one surrounded the mammoth remains, and the other one, found towards the north of the excavated surface, was accompanied by more dispersed faunal remains from different taxa. Future spatial studies are needed, among which lithic refitting stands out, to explore the possible temporal connection with these two lithic clusters.

The lithic assemblage from Barranc de la Boella Unit II includes, so far, 966 elements and shows general similarities among the three explored localities. In all cases, the predominant raw material is chert (86.7%), while a group of secondary materials includes schist (6.5%), quartz (3%), quartzite and sandstone (1.1%), and a third group, which represents less than 1% of the total assemblage, includes granite, lydite, porphyry, and limestone. All these raw material types are now accessible in the adjacent alluvial environment, although a comprehensive petrographic study is required to delve further into the internal variability and particular supply strategies.

The distribution of the lithic collection of Barranc de la Boella by technological groups and raw materials (Table 1) shows a good representation of the percussive material (4.7%), the predominance of the core-and-flake group (<90% if we consider the cores, most of the small and medium-sized products, and the knapping angular fragments), and the low weight of the large shaped tools (2.9%). Moreover, we identified a differential selection and management of raw materials in which there is a prevailing use of chert for flake production (91.2% of the cores and a similar weight for the different classes of detached pieces), in contrast to a clear correlation of the rest of the raw materials with percussive elements and large shaped tools.

The previous analysis of the core-and-flake group (Mosquera et al., 2016), as well as the general metric data provided in this study (Supplementary Tables S2–S4), and recent research on the core reduction (Lombao, 2021) revealed exploitation strategies focused on the production of small and medium-sized products neither morphologically nor typometrically standardized. While there is a certain degree of variability in knapping strategies (mainly unifacial unidirectional and bifacial orthogonal), there are some examples of bifacial centripetal cores that show more efficient and organized volumetric management. These imply knapping sequences not strongly constrained by the size or shape of original raw material blanks. A significant proportion of those products were subsequently modified by retouching (6.8% of the whole sample), mainly in the form of denticulates and, to a lesser extent, scrapers. It is worth noting that at Pit 1, the development of the *in situ* chert knapping activities has been attested, thanks to the abundant knapping debris, the spatial distribution of the materials, and the identified refits (Mosquera et al., 2015).

As stated in the introduction, in this study, we used the category of large shaped tools, a term used by Kleindienst (1962) and Isaac (1977), to refer to a "primary class" with all the shaped elements of large size, which, according to these authors, would include "secondary classes" referring to the large cutting tools (LCTs) and the heavy-duty tools. As presented in the results section, the predominant types in the Barranc de la Boella assemblage are choppers and picks, both classed by these authors as heavy-duty tools, while the types they consider as LCTs are scarcer.

Unifacial choppers are present in all Barranc de la Boella localities, mainly made of different varieties of schist and, in one case, of granite. They are made on flat cobbles variable in size and show primarily distal or latero-distal shaping, with only two cases of pointed morphology. The absence of recurrence in their flaking, the absence of products resulting from their knapping, the flatness of most of the blanks, and the preliminary functional data derived from macroscopic observation and primary microscopic screening are proxies that make us assume that these elements are real tools and not cores or the by-product of flake production. In fact, their shaped edges are mainly low angled, with a mean of approximately 55° (P1: 42°, EF: 53°, and LM: 68°).

The bifacial choppers are present only at El Forn and La Mina localities. This is the group with higher variability in terms of raw materials, as they are present in quartzite (two elements), porphyry, limestone, and chert (one element each), but they are absent in schist. As observed in Section 4.2, apart from the porphyry case, these elements were produced on small, globular cobbles—quartzite and limestone—and were shaped through bifacial alternating removals, resulting in mainly lateral and distal convex edges, sinuous in profile. These edges present significantly higher angles than unifacial choppers, with a mean of 70°. Again, the fact that there are no flakes originating from these blanks, together with the preliminary functional observations, allows us to think of them as tools rather than cores. In addition, at least in two cases (the quartzite one from El Forn and the limestone one from La Mina), they were also involved in percussive activities.

Following the choppers, the picks are the best represented and more characteristic large shaped tools at Barranc de la Boella. This tool type has unequally been classed in the literature. While some authors included them in the heavy-duty secondary class (Kleindienst, 1962; Isaac, 1977), they are commonly counted among the LCTs in more recent works (e.g., Sharon, 2007; Kuman, 2019; Herzlinger et al., 2021, to mention but a few). However, there is general agreement on considering them bifacial forms (Leakey, 1971), characteristic of the Acheulean (Isaac et al., 1997; Stout, 2011; de la Torre, 2016, and references therein).

Picks at Barranc de la Boella are mainly made on medium to large-sized schist cobbles, although at Pit 1, there is one made on a large flake probably obtained after a cobble of this material split and another one for which the blank remained undetermined. The two picks of chert are on a slab (Pit 1) and on a possibly fragmented cobble (La Mina). Overall, these pieces represent the biggest and most elongated tools at Barranc de la Boella (Figures 12, 13). They present a certain morpho-technical standardization. On the one hand, they seem to follow a pattern in terms of blank format selection, likely to reduce the necessary further modification. They also share a triangular cross-section and a similar shaping pattern consisting of a few invasive removals concentrated in the distal third of the tool. This shaping is predominantly alternate, although alternating bifacial flaking has been attested. Outcomes show robust thick sections, quite sinuous lateral edges, and scarce bifacial and bilateral symmetry. The one of schist from La Mina, made on a large, rounded slab, stands out for its dimensions and weight as well as for its simplicity, as the shaping was basically limited to two large invasive distal removals and some minor arrangement on the lateral.

The collection also features two schist cleavers that do not correspond with Tixier's classical definition that implies an untrimmed bit (Tixier, 1957). Both blanks indicate skillfulness in large flake production in the form of splitting cobbles (El Forn) or giant core reduction (La Mina). Although present in both cases, the shaping is especially significant for the former, on which the transverse bit shows bifacial invasive flaking.

The two pieces classified as knives (Pit 1 and La Mina) were made of schist, and currently show postdepositional alteration in the form of loss of grain cohesion. Both are on large cortical flakes, with characteristic asymmetry and one steep and blunt side opposed to the shaped edge. Only in one case (La Mina) is this shaping clearly bifacial.

Apart from the cleavers ($n = 2$), the knives ($n = 2$), and one pick, the skill on large schist flake production is attested by two unretouched elements (Pit 1 and La Mina). Both the cobble splitting and the management of giant cores resting on the ground appear to have been applied, perhaps involving some throwing technique (Li et al., 2017). However, such giant cores are absent in the record, and the sample of products is too small ($n = 7$) to raise conclusive observations. We must highlight that classical handaxes, in the sense of symmetrical tools with two lateral convex edges converging in a more or less marked tip, a lenticular cross-section, and shaped all along their perimeter through invasive bifacial removals that cover its whole surface, are, to date, absent in the collection of Barranc de la Boella.

Despite the described crudeness of the shaped tools at Barranc de la Boella, deriving from a limited shaping, a reduced symmetry, and a low degree of finishing, a certain standardization can be observed. This issue is visible in terms of raw materials management, morpho-technical procedures and outputs represented. As commented on in Section 4.2, such standardization can be particularly seen in the selection of suitable raw material formats for the production of some types. Here, the case of the picks stands out. While their shaping is limited to the creation of a pointed tool, the capacity to obtain relatively homogeneous forms through different technical processes is evident. These include quite intensive shaping of a cobble, selection of the more suitable blanks that require only a slight modification, and the production of large flakes for subsequent shaping. These processes can be considered a reflection of a high cognitive flexibility (Sharon, 2009).

It is important to note that at Barranc de la Boella, there is a spatiotemporal fragmented reduction sequence for the whole set of large shaped tools. Although the raw materials were locally available, the manufacture of the large shape tools seems to be allochthonous and independent from the chert flake production that took place at the site. This implies a differential transport of materials, hominin mobility, and, in the end, forecasting and technical planning. Indeed, this pattern has been observed in other European Acheulean assemblages (Bourguignon et al., 2016; Moncel et al., 2019; 2020b; 2021) and specifically reported in Iberian Middle Pleistocene sites, for instance, Galería and TD10.2 in Atapuerca (Ollé et al., 2013; García-Medrano et al., 2017), Áridos in Madrid (Ollé, 2003), or La Cansaladeta (Ollé et al., 2016), in the same Francolí basin as Barranc de la Boella.

In addition, the coexistence of the two *chaînes opératoires* identified at Barranc de la Boella has also been reported in African Early Acheulean sites such as Gadeb (de la Torre, 2011) or Thomas Quarry I (Gallotti et al., 2020), where reduction sequences devoted to small size debitage appear together with an important group of LCTs, in which symmetry and bifacial shaping are only occasionally present. In fact, such a coexistence may well reflect a functional complementarity. At Barranc de la Boella, the preliminary results from the low-power approach microwear analysis of the pieces presented in this study, which indicate traces of forceful activity likely related to the exploitation of the animal carcasses, may supplement the butchery use-wear traces identified by a previous study on a sample of small and medium-size chert flakes from Pit 1 (Mosquera et al., 2015).

Overall, the technological features described in the collection from Barranc de la Boella allow us to support the formerly proposed idea of a European Early Acheulean (Mosquera et al., 2016). This is based on the technological parallels with Early Acheulean African sites, as well as the differences with respect to what is observed in contemporaneous sites European sites, and the significant differences with the technological features recorded at the Acheulean sites dated at the beginning of the Middle Pleistocene.

As summarized elsewhere (Presnyakova et al., 2018), in Africa, the scarcity of bilaterally and bifacially symmetrical large shaped tool forms helps to distinguish Early Acheulean assemblages from later ones. Stout (2011) argued that, in contrast to the complex production process of large shaped tools younger than 1 Ma, those of the Early Acheulean indicate significantly simpler production sequences. Even though the diachronic variability of handaxe morphology is still debated (Caruana, 2020), in Africa, the presence of pick-like pieces with triangular sections and little management of the central volume is commonly presented as a distinctive trait of the Early Acheulean (de la Torre et al., 2018b; Kuman, 2019; Gallotti et al., 2020). To our knowledge, Barranc de la Boella is the only Early Pleistocene site in Europe showing this techno-typological feature.

In Western Europe, the onset of the Acheulean has traditionally been poorly known due to the limited archaeological evidence before 0.7 Ma, as well as the relatively few sites dating from the Early to Middle Pleistocene transition to 0.5 Ma. The latter research gap has considerably disappeared in recent times (Moncel et al., 2013; 2019; 2020a; 2020b; Moncel et al., 2015; Antoine et al., 2019), while the former is still a drawback. In this sense, Barranc de la Boella is, to date, one of the few sites providing data.

The closest known European parallel to Barranc de la Boella is the site of Notarchirico (Southern Italy), whose oldest layers are dated at c. 0.7 Ma (Moncel et al., 2020b). In fact, some of the main technological features described at Notarchirico can be seen on the large shaped tools from Barranc de la Boella. These include a poor bifacial management and bilateral equilibrium (asymmetry), both face-to-face and alternating shaping, often sinuous lateral edges converging on a tip with specific management, absence of evident resharpening, as well as the existence of many pebble tools, including choppers and cleaver-like forms. However, more evident management of the bifacial volume has been reported at Notarchirico than at Barranc de la Boella (Moncel et al., 2019; 2020b; Santagata et al., 2020). Other close parallels could be seen in the French sites of La Noira (c. 0.7 Ma; Moncel et al., 2020a; Moncel et al., 2021) and Moulin Quignon (c. 0.65 Ma; Antoine et al., 2019; Moncel et al., 2022), in which, importantly, handaxe production involving patterned bifacial and bilateral equilibrium is already attested.

Human dispersals and associated cultural transmission phenomena have been widely explored. Thanks to discoveries at new sites such as Barranc de la Boella, some new observations can be made to contribute to this research topic. In a previous article, we commented on several possible scenarios (Mosquera et al., 2016) that have been later summarized with the idea that Barranc de la Boella "*. . .could represent an early attempt of bifacial shaping and local onset of crudely made bifacial tools. . .*," or "*. . .could also represent the arrival of a non-local hominin group and technology*" (Moncel et al., 2020b:12).

So far, there is no evidence of any transitional feature pointing to a local evolution from an older and simpler Mode 1 technology. In the north-east of Iberia, such assemblages are scarce, and the ones with similar chronology, for example, Gran Dolina-TD6 in Atapuerca, show very different characteristics from what is documented at Barranc de la Boella (Mosquera et al., 2018; Lombao et al., 2022). In this sense, future work at the lower levels of Unit II at La Mina could provide interesting clues.

Of course, convergence phenomena can also be possible. This hypothesis would imply the innovation of similar bifacial morphologies in unrelated places and moments instead of being caused by human migrations or cultural diffusion. However, the idea of a single but variable cultural tradition lasting a very long period (Lycett and Gowlett, 2008) seems to gain support from recently published research. Shipton interprets the western Acheulean as a "*coherent cultural entity that seems to have spread from a single source region, and with regionally consistent variations suggesting it was maintained through social transmission*" (Shipton, 2020:13). Based on statistical assessment, Key (2023) perceived the Acheulean as a temporary, cohesive, single cultural tradition with no interruptions in the social transmission of information during either its earlier or later periods. Even studies that attribute coincidences in large core technology to convergent cultural evolution reject this mechanism as being responsible for the similarities in the Acheulean end products such as handaxes and cleavers (Sharon, 2019).

Therefore, the idea of a diffusion/dispersal of the Acheulean into Western Europe earlier than previously known, mirroring the situation in Asia (Pappu et al., 2011), must be considered. Although several possible dispersal routes for such an event have been discussed (O'Regan, 2008, and references therein), research recently being carried out in the Aegean zone (Sakellariou and Galanidou, 2017; Tourloukis and Harvati, 2018) makes us consider the coastal route following the northern Mediterranean basin as very plausible.

As highlighted when commenting on the role played by technology in human expansions through the "Out of Africa Technological Hypothesis" (Carbonell et al., 1999), the oldest examples of Acheulean evidence in Western Europe (at that moment, Notarchirico and Caune de l'Arago) showed evolved techno-typological features of that technology. In this sense, we later draw specific attention to the absence in Europe of a set of "archaic traits" present in sites such as 'Ubeidiya (crude handaxes, pick-forms, and spheroids, along with choppers) (Carbonell et al., 2010:39). Therefore, we supported the idea of a first expansion of Mode 2 in the Near East (represented by 'Ubeidiya at 1.4 Ma), which would not have been strong enough to reach other Eurasian regions. A more successful second expansion would have occurred later, around 0.8 Ma, represented in the Levant by the large flake Acheulean assemblage of Gesher Benot Ya'aqov (Goren-Inbar et al., 1992; Goren-Inbar et al., 2000), and with echoes in eastern Asia in sites as Bose (Hou et al., 2000), and, in its turn, being the origin of the Western Europe Acheulean.

The new evidence presented in this study allows us to make some inferences to build on the cultural relationships between the Levantine and Western European records. The chronology and the described technological features enable us to hypothesize the record of Barranc de la Boella as the reflection of an "out of Africa event" with an Early Acheulean technology unprecedently recorded in Europe. This implies adding an important nuance to the hypothesis on the onset of the European Acheulean proposed by Moncel et al. (2020a) by clearly pointing to the technology represented by 'Ubeidiya as the key referent for what we have recorded c. 1 Ma ago in the eastern coast of Iberia. 'Ubeidiya, in fact, holds the most comprehensive known record of Early Acheulean culture outside Africa (Herzlinger et al., 2021) and shows a set of features that we also described for the Barranc de la Boella assemblage. Similarities can be seen in terms of the management of raw materials that overcomes their constraints, a definite preference for producing specific tools on particular rock types, a technological forecast and certain planning capacities visible from the large-tool technology, and a spatiotemporal fragmented reduction sequence for these elements, with initial production phases located beyond the sites. This goes together with a clear low modification intensity of the flake blanks, a less standardized core reduction than in younger Acheulean occurrences, the presence of two general classes (the handaxe and the non-handaxe groups, the latter including the well-represented picks), and a preferential investment in the design of the final tool given to its tip (Herzlinger et al., 2021). As previously mentioned, Barranc de la Boella is the only Early Pleistocene site in Western Europe to exhibit this particular collection of technological features. To explain how this came about, we suggest that gradual diffusion may have occurred along the north Mediterranean coastal basin from the Levant to Southwestern Europe, where the new technology may have coexisted with a well-established Mode 1.

Finally, the time gap between the onset and dispersal of the Acheulean in Africa and its first appearance in Western Europe is not easy to explain with the current data. Geographical barriers and other paleoenvironmental constraints may be argued, as may climatic variations (glaciations effect, changes in the sea level, etc.), the fact of being located at one end of the continent, hominin paleobiology, and demographic issues (Hosfield and Cole, 2018; 2019, and references therein). In part, as the Barranc de la Boella evidence suggests, it could be the result of a still-deficient record (Key and Ashton, 2022) or a lack of research. In any case, unique findings coming from the interdisciplinary project conducted at Barranc de la Boella gain a particular significance to help understand and even model hominin subsistence and settlement patterns and, in the end, population dynamics during the Early Pleistocene in Western Europe.

6 Conclusion

This article provides detailed information on the large-tool component in Barranc de la Boella, which is highly valuable for any research focusing on the onset of the Acheulean in Europe. Our understanding of how this techno-complex originally dispersed out of Africa and reached Western Europe is dependent on a highly fragmented archaeological and fossil record. In that context, unique sites represent, by definition, isolated evidence. Barranc de la Boella is revealed as a key site in this sense, as it provides the oldest known presence of large shaped tools attributable to the Acheulean in the southwestern end of the continent, in a paleoenvironmentally and archeologically rich context.

The features of the large shaped tools from Barranc de la Boella suggest a technological shift in comparison with the pre-existing Mode 1 type European Early Pleistocene sites, with which this new technology coexists. We documented an initial development of volume management, with a quantitative and qualitative importance of trihedral pick forms, with unifacial and bifacial choppers, cleaver-like forms, and knives as accompanying tool types. These were functional pieces, and it seems clear that there was no need for the makers to produce standardized forms, symmetrical pieces with regular shapes, or full management of bifacial volume. Such systematic bifacial shaping, symmetry, and classic handaxes appear to represent an authentic cultural threshold that develops in more advanced stages of the Acheulean culture. For this reason, Barranc de la Boella must be considered an Early Acheulean site.

Although transitional elements are hard to recognize, as the diagnosis of the Acheulean signature is still strongly based on the presence of certain types of large shaped tools and on a more complex flaking strategy that is sometimes difficult to assess, there is no clear evidence of local evolution that would explain the Barranc de la Boella assemblage. Additionally, it is obvious that site function remains as one of the major drivers of variability in terms of assemblage composition, which hinders the assessment of evolutionary patterns in the fragmented archaeological record for the European late Early Pleistocene.

However, we must seriously consider an Early European Acheulean arriving/developing since that period. In this context, we hypothesize that Barranc de la Boella could reflect a previously unknown dispersal of the Early Acheulean leaving Africa by 1.4 Ma (with the site of 'Ubeidiya as the clearest reference). This would be mirroring the early Acheulean dispersal towards Asia, by means of a spreading through the north Mediterranean coast on the road to Western Europe, at least 1 Ma ago.

Finally, it is worth noting that the ongoing fieldwork and research project at Barranc de la Boella will not only shed light on the dispersal of the Acheulean technology but will also provide valuable paleoenvironmental and behavioral information to make progress in our knowledge of the early human settlement of Europe.

Data availability statement

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

Author contributions

AO, DL, LA, PG-M, AA, JF-M, and GY: conceptualization, methodology, data curation, formal technological analysis, visualization, and writing; DL and PG-M: 3D scanning and morphometrical analyses; DL, LA, and GY; lithic graphic documentation; JF-M and AO: preliminary use-wear analysis; IC, RH, AP, and PS: taphonomical and zooarchaeological analyses; AG-T, DF, and AR: paleontological and paleoenvironmental analyses; LL-P: conservation and preparation of materials; JV: geoarchaeological analyses; PS and JV: fieldwork direction, data curation, supervision and project management, and funding acquisition. All authors conducted field excavation and contributed to the manuscript revision; AO: final revision and edition. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feart.2023.1188663/full#supplementary-material

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