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RESEARCH

The Uluzzian and Châtelperronian: No Technological Affinity in a Shared Chronological Framework

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Abstract

The Châtelperronian and Uluzzian techno-complexes are identified in western Europe in the same stratigraphic position, between the late Middle Palaeolithic and other Upper Palaeolithic assemblages. Both industries include retouched artefacts with abrupt retouch and arched backs, and radiometric dating indicates that these two technocomplexes belong to the same window of time. Here, we provide a detailed, qualitative technological comparison of two Châtelperronian and two Uluzzian lithic assemblages based on a collaborative, first-hand examination of these collections. This study results from a one-week workshop designed to bring relevant researchers together to conduct an in-person investigation of these lithic industries. Our analysis highlights significant technological divergences between these industries. In short, the Châtelperronian is a blade industry with a minor bladelet component produced by freehand direct percussion, whereas the Uluzzian is a flake-bladelet industry with massive use of bipolar percussion and a minor component produced by freehand, direct percussion. Our results suggest that there are no, or very little, technological affinities between the Châtelperronian and the Uluzzian — despite occupying the same window of time. As an extension, this suggests that there was little to no relationship/contact between the groups producing these industries during the Middle to Upper Palaeolithic transition. The distinctiveness of the Châtelperronian and Uluzzian highlights that technological behaviours in western Europe during the 45–40 ka can be very diverse and that general labels such as 'transitional industries' are unsatisfactory in describing this diversity.

Keywords Uluzzian · Châtelperronian · Transitional industries · Lithic technology · MP-UP transition

Giulia Marciani, Leonardo Carmignani, and Igor Djakovic equally contributed to the work.

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Introduction

The Châtelperronian and Uluzzian industries are among the most well-known and well-documented technocomplexes in Europe during the Middle to Upper Palaeolithic transition (60–40 ka), a period marked by biocultural changes at least partly related to multiple waves of *Homo sapiens* dispersal throughout Eurasia (e.g. Benazzi et al., 2011; Demidenko & Škrdla, 2023; Djakovic et al., 2024; Hajdinjak et al., 2021; Moroni et al., 2013; Mylopotamitaki et al., 2024; Slimak, 2023; Slimak et al., 2022) and instances of interbreeding between different groups (Green et al., 2010; Prüfer et al., 2014, 2017; Slon et al., 2018; Vallini et al., 2022, 2024). Since the discovery of the Uluzzian in the 1960s (Palma di Cesnola, 1963), similarities have been noted between the Châtelperronian and Uluzzian due to their comparable chronology, stratigraphic position, and the presence of curved backed retouched tools in both sets of assemblages. When discovering the first lunate at Grotta del Cavallo on 10 July 1963, Palma di Cesnola wrote in his field book: '*salta fuori una Chatelperron*!' which translates to 'a Châtelperron jumps out!' (Fig. 1).

In the first publications defining the Uluzzian, a parallel is drawn between the curved-edged tools used in the Châtelperronian and the Uluzzian (Palma di Cesnola, 1963, 1964, 1965a, b, 1966a, 1993). Stratigraphically, both the Châtelperronian and the Uluzzian are consistently found directly above Mousterian deposits and are succeeded by other Upper Palaeolithic technocomplexes (e.g. Protoaurignacian, Epigravettian — Hublin, 2015; Marciani et al., 2020; Soressi & Roussel, 2014). Radiometric ages obtained for Châtelperronian and Uluzzian assemblages indicate that both are situated within a timeframe between approximately 44 and 40 ka cal. BP (Djakovic et al., 2022; Douka et al., 2014; Higham et al., 2024). Additionally, the Uluzzian is identified as preceding the Campanian Ignimbrite eruption (39.85 ± 0.14 ka BP — Moroni et al., 2013, 2018; Giaccio et al., 2017).

Both the Uluzzian and the Châtelperronian have traditionally been categorised as 'transitional' industries. Originally, this term was used to indicate the presence of a mixture of Middle and Upper Palaeolithic typo-technological features (see Hublin, 2015). In the case of the Châtelperronian, it has been shown that post-depositional perturbations led to the artificial mixing of scrapers, denticulate tools, and Châtelperronian points in several sites (Rigaud, 1996). Descriptions of Châtelperronian assemblages conducted in the past two decades have re-characterized this industry as fully Upper Palaeolithic, lacking evidence of sophisticated flake production characteristic of the Middle Palaeolithic (e.g. Bachellerie, 2011; Bodu et al., 2017; Bordes & Teyssandier, 2011; Connet, 2002; Pelegrin, 1995; Rios-Garaizar et al., 2022; Roussel, 2011). Meanwhile, analyses of the Uluzzian have revealed that there are no techno-typological characteristics in the lithic assemblage resembling the Mousterian, and the abundance of flakes in this technocomplex is not associated with Middle Palaeolithic-like flake production but rather with specific manufacturing processes involving the extensive use of bipolar-on-anvil percussion (Collina et al., 2020; Moroni et al., 2018; Rossini et al., 2022).

Despite the geographical distance and the void of intermediate sites, a possible relationship between the two technocomplexes has been, in the past, proposed based on similar typological traits (mainly convex-backed tools and short end-scrapers) as well as the manufacture of bone artefacts and ornaments within both technocomplexes. Gioia (1988) reinforced this supposed connection by comparing the overall structure of these industries using the Bordes method. A reliance on typology (e.g. Bordes, 1961; Laplace, 1964a, b), however, likely artificially inflates the similarity between the two industries. Even Palma di Cesnola, after his initial impression, highlighted the techno-typological distance between the Châtelperronian and the Uluzzian in his reply to Gioia (1988) (Palma di Cesnola, 1993, p. 112). Since the technological turn of the 1980s, it is well known that analysing the manufacturing processes provides a more appropriate perspective for identifying potential knowledge and know-how transfer amongst individuals while also avoiding the risk of equifinality when solely examining final forms (e.g. Soressi & Geneste, 2011). The technology of Châtelperronian or Uluzzian assemblages has been described in several studies (e.g. Arrighi et al., 2020a; Collina et al., 2020; Moroni et al., 2013, 2018; Rossini et al., 2022; Roussel et al., 2016). However, each industry has always been studied independently — by different researchers who never had the opportunity to see the two industries (that are curated in

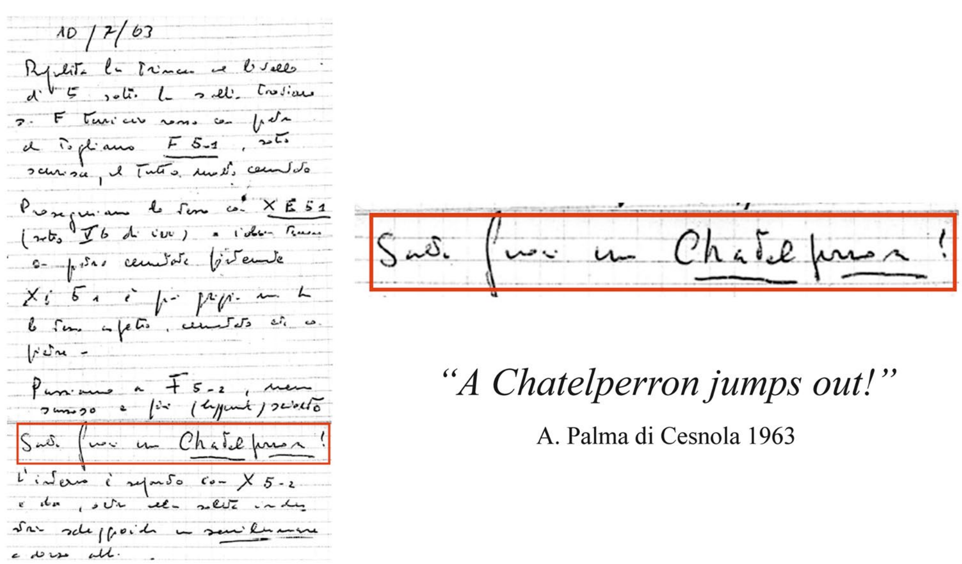

Fig. 1 Excerpt from Palma di Cesnola's excavation field notes, Grotta del Cavallo dated 10 July 1963, documenting the discovery of the first lunate. The exact words are: '*salta fuori una Chatelperron*!' ('a Chatelperron jumps out!')

different countries) side-by-side. The vocabulary and concepts used to describe these industries are different, and it remains difficult — based on the published literature — to identify the key differences and similarities of these industries at each step of their respective *chaine opératoires.*

In 2022, the Research Unit of Prehistory and Anthropology of the University of Siena and Human Origins research unit of the University of Leiden organized a workshop titled 'The Uluzzian and Châtelperronian on Stage!' during which the authors of this paper (with the exception of M. Roussel) collectively examined a sample of the lithic collections from two Châtelperronian sites (Quinçay and Les Cottés) and two Uluzzian sites (Grotta di Castelcivita and Grotta del Cavallo). This in-person examination and handling of representative samples allowed us to refine the vocabulary used to describe the two industries and led to an in-depth agreement on the similarities and differences between the lithic technologies.

This paper presents the results of this direct, qualitative comparison, conducted using a shared terminology. Following a brief overview of the geographic distributions of these industries, associated bone tools and ornaments, and their current hominin associations, we present the selection of artefacts that we physically examined during the workshop as well as the vocabulary that we developed and used here. Since the chronological distribution of these industries has not yet been directly compared using the most recent radiocarbon calibration curve (IntCal20), we also constructed a kernel density estimation model of previously published and modernly produced radiocarbon ages for assemblages corresponding to both industries. The aim of this model is to compare, at a general level, the inferred time window for these industries based on available high-quality dates. The core of our paper consists of a step-by-step qualitative comparison of the Châtelperronian and the Uluzzian lithic technologies with abundant visual documentation from four sites, two from central west France — Les Cottés and Quinçay — and two from the south of Italy — Cavallo and Castelcivita.

Background

Geographic Distribution of Châtelperronian and Uluzzian Assemblages

Châtelperronian sites (approximately 40) have been identified in France and northern Spain within an area spanning approximately 300 km, generally aligning with the western half of the Massif Central (Ruebens et al., 2015; Soressi & Roussel, 2014). This distribution extends from Burgundy in north-central France, through south-west France to Cantabria in the west, with the south-eastern limit marked by the Oriental Pyrenees. As it stands, no Châtelperronian assemblages have been identified east of the Rhone valley — and its northern limit has recently been extended to the site of Ormesson in the Paris basin (Bodu et al., 2017) (Fig. 2; Table 1). Some key sites include Grotte du Renne (Julien et al., 2019), Les Cottés (Soressi & Roussel, 2014), Quinçay (Roussel et al., 2016), Saint-Césaire (Gravina et al., 2018), Canaule II (Bachellerie, 2011), Ormesson (Bodu et al., 2017) and Aranbaltza II (Rios-Garaizar et al., 2022).

Uluzzian sites (14 sites with dated stratigraphic sequences) have been recognized in Italy and Greece (Higham et al., 2024; Marciani et al., 2020). In Italy, their geographic distribution consists of one main cluster which is located within a few kilometers span of the Puglia region, in the southern extremity of Italy: Grotta del Cavallo (Moroni et al., 2018; Palma di Cesnola, 1993), Grotta di Serra Cicora A (Palma di Cesnola, 1993; Spennato, 1981), Grotta Mario Bernardini (Borzatti von Löwenstern, 1970), Grotta di Uluzzo (Borzatti von Löwenstern, 1963, 1964), Grotta-Riparo di Uluzzo C (Borzatti von Löwenstern, 1965; Spinapolice et al., 2022; Silvestrini et al., 2022; Seghi et al., 2024) and Grotta delle Veneri (Palma di Cesnola, 1993). The other sites are located on the Tyrrhenian side of Italy (from south to center): Grotta della Cala (Benini et al., 1997), Grotta di Castelcivita (Arrighi et al., 2020a; Gambassini, 1997; Rossini et al., 2022), Grotta Roccia San Sebastiano (Collina et al., 2020; Oxilia et al., 2022) in Campania, the open-air site of Colle Rotondo (Villa et al., 2018) in Lazio and Grotta La Fabbrica in Tuscany (Dini & Tozzi, 2012; Pitti et al., 1976; Villa et al., 2018). Finally, only two sites were found in the northeast of Italy: Riparo del Broion and Grotta di Fumane (Peresani et al., 2016, 2019). Outside of Italy, the Uluzzian has been reported only in the Peloponnese region, in Greece, at the cave sites of Klissoura (Kaczanowska et al., 2011, Koumouzelis et al., 2001; Marciani et al., 2024) and Kephalari (briefly reported in Hahn, 1984, no detailed study on this industry is currently published) (Fig. 2; Table 1).

Bone Tools and Ornaments

The Uluzzian and Châtelperronian technocomplexes both present evidence for the manufacture of bone artefacts, ornaments, and use of pigments — sharing a tendency towards the exploration and manipulation of diverse materials for both practical and symbolic purposes (Arrighi et al., 2020b, 2020c; D'Errico et al., 1998; Dayet et al., 2014; Julien et al., 2019; Salomon, 2019; Vanhaeren et al., 2019). In the Uluzzian, bone tools are predominantly awls and cylindrical or conical elements and manufactured using straightforward processes. The production of these formal tools involves the use of specific animal species, namely deer and horse, which are exclusively represented by specific anatomical parts: deer metapodials (*Cervus elaphus*), horse fibulae and metapodials (*Equus ferus*) (Arrighi et al., 2020b). When it

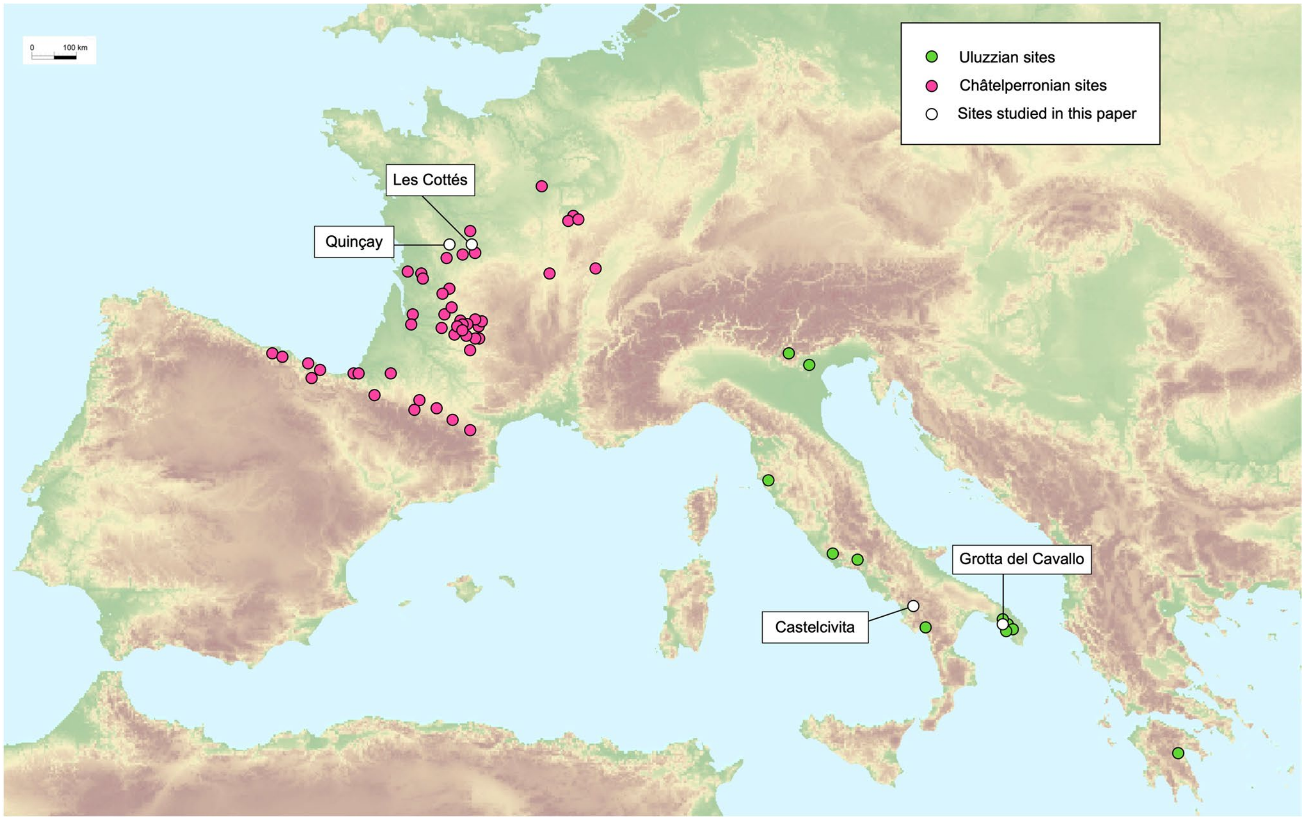

Fig. 2 Map illustrating the distribution of Uluzzian and Châtelperronian sites, with those used in this paper highlighted in white. Châtelperronian sites are compiled from Pelegrin and Soressi (2007) and Soressi and Roussel (2014) modified. Uluzzian sites are compiled after Marciani et al. (2020) and Douka et al. (2014) modified. The map background is *GNU Free Documentation License*

comes to Uluzzian ornaments, Gastropods (*Tritia neritea, Homalopoma sanguineum*) and bivalves (*Glycymeris nummaria — syn. G. insubrica*) were frequently intentionally perforated. However, the use of Scaphopods (*Antalis sp.*) is the true distinctive feature of the Uluzzian culture. These shells were sporadically used in their natural, unmodified state — taking advantage of their hollowness — but mainly were intentionally broken into smaller pieces (Arrighi et al., 2020b, 2020c). Grotta del Cavallo has provided the largest collection of such ornaments to date, with several hundred objects discovered throughout the Uluzzian sequence (Arrighi et al., 2020c) (Table 1).

Bone tools have been reported for seven Châtelperronian sites (see Ruebens et al., 2015), but the most significant and well-published collection corresponds to the Grotte du Renne — including byproducts from their manufacture (Caron et al., 2011; Crevecoeur et al., 2024; D'Errico et al., 1998, 2003; Julien et al., 2019). Awls and points appear to be the most common type of objects — with some occurrences of rods and *lissoirs* (D'Errico et al., 1998, 2003) (Table 1). Personal ornaments have, as it stands, mainly been recovered from two Châtelperronian sites: Grotte du Renne and Quinçay. At Grotte du Renne, ~ 47 artefacts interpreted as ornaments were recovered from the Châtelperronian layers (layers X- VII) (Caron et al., 2011; D'Errico et al., 1998; Vanhaeren et al., 2019). These include examples of perforated and/or grooved mammal teeth, bone fragments and a fossil. Six pierced teeth were also recovered from the Châtelperronian levels at La-Grande-Roche-de-la-Plematrie, Quinçay during the excavations campaign run by F. Lévêque between 1968 and the early 1990s (Granger & Lévêque, 1997). More recently, a collection of perforated shells has been reported in association with Châtelperronian lithic artefacts at Saint-Césaire but remains to be published (Crevecoeur et al., 2024).

Hominin Associations

Originally, upon its discovery, the Châtelperronian was attributed to *Homo sapiens* (see discussion in Soressi & Roussel, 2014 for example). Following the finding of an almost complete Neanderthal skeleton at Saint-Césaire (Lévêque & Vandermeersch, 1980), it progressively came to be seen as an industry produced by local late Neanderthals. Subsequently, a temporal bone and over 30 isolated teeth from at least 6 individuals were identified, displaying traits aligned closely with

Table 1 Comparative table of characteristics for Châtelperronian and Uluzzian assemblages

Aspect	Châtelperronian	Uluzzian
Geographic distribution	France and northern Spain (Aubry et al., 2012, 2014; Bachellerie, 2011; Baillet et al., 2014; Bodu et al., 2017; Boëda, 1991; Bordes, 2003; Bordes & Teyssandier, 2011; Bricker & Laville, 1977; Connet, 2002; Discamps et al., 2019; Grigoletto et al., 2008; Guilbaud, 1993; Harrold, 2000; Pelegrin, 1995; Rios-Garaizar et al., 2022; Roussel, 2011; Roussel et al., 2016; Soressi, 2011)	Italy (Puglia region, Tyrrhenian side, northeast), Greece (Peloponnese) (Arrighi et al., 2020a; Benini et al., 1997; Collina et al., 2020; Gambassini, 1997; Hahn, 1984; Kaczanowska et al., 2011; Koumouzelis et al., 2001; Marciani et al., 2020; Moroni et al., 2013, 2018; Oxilia et al., 2022; Palma di Cesnola, 1993; Peresani et al., 2019; Rossini et al., 2022; Silvestrini et al., 2022; Spinapolice et al., 2022; Villa et al., 2018)
Chronology	Approx. 44,000 to 40,000 years ago	Approx. 44,000 to 40,000 years ago
Stratigraphic position	Above Mousterian layers, below Upper Palaeolithic layers (always Protoaurignacian when in the same sequence)	Above Mousterian layers, below Upper Palaeolithic layers (e.g. Protoaurignacian, Aurignacian, Epigravettian)
Ornaments	Grooved and/or perforated mammal teeth, bone fragments, fossil — all modified (Caron et al., 2011; D'Errico et al., 1998; Vanhaeren et al., 2019). Largest collection at Grotte du Renne (D'Errico et al., 1998)	Gastropods (*Tritia neritea, Homalopoma sanguineum*), bivalves (*Glycymeris nummaria*), Scaphopods (*Antalis* sp.) used both naturally and modified; largest collection at Grotta del Cavallo (Arrighi et al., 2020b, 2020c)
Pigments	Presence of pigments and pigment lumps at several sites — including Grotte du Renne, Les Cottés, Roc-de-Combe, Bidart, Les Tambourets, Labeko Koba, Le Basté (see Dayet et al., 2014 for a detailed review)	Lumps of ochre and limonite have been found at Grotta del Cavallo, Grotta Mario Bernardini (Palma di Cesnola, 1989), and Castelcivita (Gambassini, 1997). Oxidized glomeruli were discovered at Grotta della Cala (Ronchitelli et al., 2009). Traces of red pigments have been detected on several tusks at Grotta del Cavallo (Arrighi et al., 2020c); on two tusk beads found at Riparo Broion (Peresani et al., 2019), as well as on numerous stone artefacts at Grotta del Cavallo (Moroni et al., 2018) (for a review see Arrighi et al., 2020b)
Bone tools	Awls and points the most common type of objects — with comparatively fewer occurrences of rods, lissoirs, and tools related to burnishing and digging activities (D'Errico et al., 1998, 2003)	Predominantly awls and cylindrical/conical elements made from deer metapodials and horse fibulae/metapodials (Arrighi et al., 2020b)
Hominin fossils	Neanderthal remains at Grotte du Renne (Bailey & Hublin, 2006; Henrion et al., 2023) and Saint-Cesaire (Lévêque & Vandermeersch, 1980). The association between the Neanderthal remains and Chatelperronian artefacts at Saint-Cesaire has been demonstrated however as likely being unreliable Recent identification of a juvenile *Homo sapiens* pelvic fragment at Grotte du Renne (Gicqeau et al., 2023)	*Homo sapiens* deciduous teeth at Grotta del Cavallo (Benazzi et al., 2011), though association debated (Zilhao et al., 2015); recent revisions and excavations confirmed stratigraphic integrity of Grotta del Cavallo (Higham et al., 2024; Moroni et al., 2018)

Neanderthal reference specimens rather than *Homo sapiens* (Bailey & Hublin, 2006; Henrion et al., 2023). Additionally, cranial and postcranial remains of an individual with mtDNA indicative of Neanderthal ancestry were reported (Welker et al., 2016). Importantly, a recent re-evaluation of the stratigraphic context at Saint-Césaire has cast substantial doubt on the evidence supporting a Neanderthal-Châtelperronian association at this site (Gravina et al., 2018). Moreover, the recent discovery of a fragmentary ilium of a neonate within the Châtelperronian layers of Grotte du Renne, whose morphology suggests it belongs to a *Homo sapiens* lineage (Gicqueau et al., 2023), has further complicated the unilateral attribution of the Châtelperronian to late Neanderthals (Table 1).

Following the discoveries of Neanderthal remains in the Châtelperronian, the Uluzzian was also postulated to be a product of Neanderthals although the human teeth retrieved at Cavallo were identified one as Neanderthal and the other as *Homo sapiens* based on their morphological characteristics (Churchill & Smith, 2000; Palma di Cesnola & Messeri, 1967). More recently, morphometric analysis showed that the two deciduous teeth found in secure context (Messeri & Palma di Cesnola, 1967; Moroni et al., 2018) at Grotta del Cavallo belong to *Homo sapiens* (Benazzi et al., 2011). However, doubts were raised about their association with the Uluzzian (Zilhao et al., 2015), and criticism regarding the stratigraphic integrity of Cavallo deposits continues to persist to the present day (Table 1). To address these concerns, a careful revision of Palma di Cesnola's and Gambassini's fieldwork documentations of Grotta del Cavallo was conducted in 2018 (Moroni et al., 2018). Subsequently, in 2019, a test trench was excavated within the in situ deposits of Grotta del Cavallo. This operation allowed the excavators to confirm the integrity of the deposit described by Palma di Cesnola (Higham et al., 2024). Interest in the Uluzzian also prompted the reopening of excavations at Cala in 2014 and Castelcivita in 2015. At these three sites, the new excavations focused on collecting samples for new radiocarbon dating (Higham et al., 2024), sedimentological analyses (Martini et al., 2018 — Cala), and the collection of samples for sedimentary DNA analysis.

At the site of Grotta di Roccia San Sebastiano, a *Homo sapiens* tooth associated with the Uluzzian layer was found (Oxilia et al., 2022), but it should be noted that this Uluzzian layer also contains intrusive materials from the upper Gravettian layer (Collina et al., 2020).

Materials and Methods

Selected Châtelperronian and Uluzzian Assemblages

A representative sample of artefacts coming from the Châtelperronian layers of Les Cottés and Quinçay was selected to be brought to the Department of Physical, Earth, and Environmental Sciences, at the University of Siena in Italy. Artefacts from these two sites could be transported outside of France for 3 days and collections from these two sites are well-documented, numerically large, and were excavated relatively recently. Les Cottés, in particular, benefits from recent and modern excavations by M. Soressi from 2006 to 2018. Quinçay, excavated between the 1960s and 1990s and currently undergoing renewed excavations is notable for its rich Châtelperronian deposits — especially the lowermost layer (En) used for this study (see Roussel et al., 2016 for a description of the sequence). Both sites contain large quantities of artefacts made from high-quality, abundant cryptocrystalline materials that have been extensively studied, making them ideal for our comparative study.

Cavallo and Castelcivita initially studied in the 1960s and in the 1990s, respectively, have been the subject of in-depth re-examination in recent years and are stored at the University of Siena, Italy, where we convened. These contexts were chosen as representative sites for the Uluzzian due to their comprehensive re-examinations and the presence of several layers of Uluzzian material, including thousands of lithic artefacts, ornaments, and bone tools. Both sites are notable for the quality and quantity of materials. Grotta del Cavallo, where Uluzzian assemblage was first defined, unearthed the richest assemblages of lunates in the Italian peninsula, making this site ideal for the comparison of the retouched components. Below, we provide a brief description of each site — with more extensive details available in the SI3 and stand-alone publications.

Quinçay

The Grande-Roche-de-la-Plématrie at Quinçay, Vienne, France (hereafter Quinçay), is a limestone cave site in west-central France known for its long sequence of Châtelperronian (Lévêque & Miskovski, 1983). Located 15 km west of Poitiers, the cave is a ~ 20 m deep and ~ 13 m wide karstic chamber which was excavated over a 22-year period by F. Lévêque from 1968 to 1990. The Lévêque excavations covered up to 20 square meters and identified a ~ 1-m-thick stratigraphy of several layers attributed to the Châtelperronian. The lithic collections have been extensively described in Roussel (2011) and Roussel et al. (2016). Here, we focused on layer En (the lower Châtelperronian layer excavated in the entrance of the cave).

Les Cottés

Les Cottés (Saint-Pierre-de-Maillé, Vienne, France) is one of the few sites where Châtelperronian occupations have been recently excavated. It is a limestone cave located on the corridor between the Parisian basin and the Aquitaine basin in west-central France, 80 km east of Quinçay. Excavations were resumed in 2006, lasting until 2018, and revealed a long sequence of Mousterian, Châtelperronian, Protoaurignacian and Early Aurignacian occupations (Rendu et al., 2019; Roussel & Soressi, 2013). More than 6000 lithics bigger than 15 mm were piece plotted during the excavation in one stratigraphic unit preserving Châtelperronian cultural material (US 6). This layer has been dated by AMS using two AMS facilities and two different preparation protocols (collagen and graphite) (Talamo et al., 2012) and by single grain quartz OSL and feldspar MET-pIRIR (Jacobs et al., 2015). Obtained ages show the Châtelperronian occupations belong to circa 43 kya cal BP.

Grotta di Castelcivita

The cave of Castelcivita (Salerno, Campania, Southern Italy) opens at the foot of the Alburni massif, close to the right bank of the Calore River, at 94 m a.s.l. (Lat. 40°29″ N; Long. 15°12″ E). Systematic excavations have been carried out since 1975 by Prof. Gambassini and the Research Unit of Prehistory and Anthropology of the University of Siena and are now conducted by two of the authors (AM and AR). Investigations focused on the cave's entrance where a rich archaeological deposit of ~ 2.60 m has been identified. The sedimentary succession of Castelcivita preserves evidence of an important cultural sequence, encompassing the Late Mousterian, the Uluzzian — layers upper rsi, pie, rpi, and rsa'' — the Protoaurignacian and the Early Aurignacian (Arrighi et al., 2020c; Falcucci et al., 2024; Gambassini, 1997; Mariotti Lippi et al., 2023; Rossini et al., 2022). The Bayesian modelling for the range of the Mousterian is between 47,800–44,000 years cal. BP and 43,850–43,070 years cal. BP (all ranges are given at 95% probability). The onset of the Uluzzian is estimated to start at 43,540–42,840 cal BP and ends a posteriori range of 40,400–39,850 cal BP (Higham et al., 2024). The whole series is sealed by a multilayered flowstone with embedded thin layers of the Campanian Ignimbrite tephra (Y5) (39.85 ± 0.14 ka BP, Giaccio et al., 2017) (see SI3 for more information). In the paper, we considered the recently re-studied materials of layers rpi (Rossini et al., 2022) and rsa" (currently being studied by two of us S.A. and G.M.).

Grotta del Cavallo

The cave of Cavallo (Nardó, Lecce, Apulia, Southern Italy) opens into the rocky coast of the Uluzzo bay, around 15 m a.s.l. (Lat. 40°15″ N; Long. 17°96″ E). In this cave, the Uluzzian was firstly discovered and described in the 1960s by Prof. Palma di Cesnola of the University of Siena and the term 'Uluzzian' derives from the Bay of Uluzzo — which was named after the dialectal name for the plant asphodel (U'luzzo). Excavations in the Uluzzian layers of Cavallo were continued by Prof. Gambassini until 1986, and a test trench was recently carried out in 2019. Grotta del Cavallo contains a key stratigraphic sequence, including a thick Mousterian deposit (layers N-F), the Uluzzian (layers E-D) sealed by a volcanic horizon (layer C), the Romanellian (layer B) and Holocene occupations (layer A). The Uluzzian layers are sandwiched between two tephra deposits, the layers Fa (at the base) corresponding to the green tuff of Pantelleria (Y6 tephra) dated to 45.5 ± 1.0 ka, and CII (at the top) attributed to the Campanian Ignimbrite (Y5 tephra) dated to 39.85 ± 0.14 ka (Giaccio et al., 2017; Zanchetta et al., 2018) (See SI3 for more information). Bayesian modelling indicates the earliest Uluzzian is at least 42,650–42,150 cal. BP (Higham et al., 2024). In this paper, we consider the material from layer EIII, which has been revisited and described by Moroni and colleagues in 2018. However, to complete the Uluzzian picture, further data are taken from Palma di Cesnola's publications on Cavallo (Palma di Cesnola, 1965a, b, 1966a, b) and from an updated study, not yet concluded, carried out, together with other colleagues, by two of the authors (A. Moroni and M. Rossini) on layer D.

Artefacts Selected for Our Study

A representative sample of each assemblage, particularly of the French assemblages that could not be transported in their totality for security reasons, was put side-by-side in Siena and studied. Prior to our study, each collection was organised according to technological types which facilitated our selection to reflect the overall diversity within each assemblage. In each category, we preferentially selected complete artefacts (Table 2), artefacts showing frequently occurring procedures, and also artefacts showing uncommon/rare procedures. For the retouched tools, we selected not only lunates and Châtelperronian points but also end-scrapers that, contrary to the former, are present in both industries.

Technological Analysis: Framework and Terminology

We used a qualitative methodological approach that intended to investigate eight technological aspects: raw material selection, percussion technique, initialisation and configuration procedures, striking platform management, core maintenance, blank production, and retouched tools. Our analysis combined two complementary approaches: *chaine opératoire* analysis and qualitative attribute analysis (Boëda et al., 1990; Inizan et al., 1992; Soressi & Geneste, 2011; Tostevin, 2012). Diacritic analyses were conducted to reconstruct the chronology, direction of removals, production stages on discarded cores, and removal sequences

Table 2 Number of lithics examined during the workshop selected among those known and studied previously (in brackets) by artefact category, site, and layer

	Layer	Châtelperronian		Uluzzian					
		Quinçay	Les Cottés	Castelcivita		Cavallo			
		En	US06	rsa''	rpi	EIII	EII-I	E-D	D
Cores	Blade cores	24 (245)	12 (25)	6 (6)	0	0	0	0	0
	Bladelet cores	7 (13)	5 (9)	0	0	0	0	0	0
	Bipolar cores	0	0	121 (121)	76 (76)	0	0	0	0
	Flake cores (direct percussion)	0 (2)	0	43 (43)	26 (26)	0	0	0	0
Blanks	Blades	112 (834)	73 (1462)	6 (9)	37 (37)	0	0	0	0
	Bladelets	29 (69)	26 (82)	12 (23)	5 (5)	0	0	0	0
	Flakes (direct percussion)	12 (52)	27 (187)	107 (179)	2 (94)	0	0	0	0
	Bipolar (bladelets)	0	0	34 (51)	30 (30)	0	0	0	0
	Bipolar (flakes)	0	0	345 (539)	12 (319)	0	0	0	0
Retouched tools	Lunates	0	0	1 (1)	8 (8)	34 (34)	60 (60)	30 (30)	22 (22)
	Châtelperronian Points	31 (77)	7 (34)	0	0	0	0	0	0
	End-scrapers	12 (100)	2 (5)	18 (18)	3 (3)	159 (159)	21 (21)	3 (3)	14 (14)
Anvils		0	0	3 (3)	3 (3)	0	0	0	0

on blanks (Dauvois, 1976). For blade reduction systems, the percussion techniques were identified according to the criteria derived from experimental studies (Pelegrin, 1988, 2000). For bipolar-on-anvil knapping, we relied on recent archaeological and experimental references (e.g. De la Peña, 2011; Delpiano et al., 2024; Morgan et al., 2015; Moroni et al., 2018; Pargeter & Duke, 2015; Pargeter & de la Peña, 2017; Rossini et al., 2022; Soriano et al., 2010; Yeşilova et al., 2024).

To compare the assemblages, it was essential to adjust and agree on the vocabulary used for the definition of blades and bladelets. For the Uluzzian, due to the proliferation of bipolar-on-anvil knapping, we used metric definitions to define flakes, flakelets, blades and bladelets: flakes (pieces whose length/width ratio is between 0 and 1.5), flakelets (if the item is a flake < 12 mm max dimension) (Moroni et al., 2018), elongated flakes (ratio length/width > 1.5 to 2), blades (ratio length/width > 2), and bladelets (if the item is a blade < 12 mm in width). The length of complete artefacts was measured according to technological axis. Conversely, when dealing with the evolved-final Uluzzian of Cavallo, the terms blade/bladelet are used both typometrically and sensu stricto (see below), due to the emergence in this phase of true laminar volumetric debitage and the decrease of the bipolar-on-anvil technique.

In the Châtelperronian, blades and bladelets are defined not only on the basis of a strict dimensional threshold, but also grounded in a technological definition of the entire production. Namely, blades and bladelets not only are pieces that are twice as long as they are wide but also show technological features that can embed them within a discrete reduction process — e.g. unidirectional or bidirectional dorsal scar negatives, parallel or semi parallel edges, presence of maintenance, and initialisation products (crested elements, core tablets, etc.).

The meaning of blades and bladelets is thus contingent on the definition that is given to these words in each context. In order to compare the production of the Châtelperronian with the Uluzzian, in this paper, we consider blades and bladelets sensu stricto. Conversely, pieces that are twice as long as they are wide, but do not exhibit evidence of unidirectional or bidirectional methods and cannot be clearly correlated with a predetermined blade reduction strategy are classified as blade-like and bladelet-like products.

Updated Chronological Summaries

We constructed kernel density estimation (KDE) models summarising the chronological data for each industry using published C14 determinations calibrated using the IntCal20 calibration curve. The dataset consists of 28 modernly produced radiocarbon determinations from seven high-quality Châtelperronian contexts and 45 radiocarbon determinations from three Uluzzian contexts (see SI1). The KDE model for the Uluzzian is replicated following Higham et al. (2024), with the exception of OSL determinations and the inclusion of a single radiocarbon date from Riparo Broion. The KDE model for the Châtelperronian is replicated following Djakovic et al. (2022). The aim of this approach is not to provide occupational durations for any given site, but to compare at a general level, the inferred time window for these complexes based on available, high-quality dates. A summary of all individual dates used in this analysis, as well as the script used to produce these models, is available in the Supplementary Information (SI1 and SI2, respectively).

Results

Châtelperronian and Uluzzian IntCal20 Radiocarbon Chronology

The KDE models for the Châtelperronian and Uluzzian are visualised below (Fig. 3). Both sets of chronological data share a high degree of overlap and effectively identical peaks within their respective probability distributions. Both datasets show a skewed distribution — with dates between ~43 and ~41.5 ka cal BP showing higher probability densities. Given the substantial error ranges inherent to radiocarbon dating in this period, this may be indicative that some of the older and/or younger dates are less reliable. In sum, the aggregated chronological data for these industries is suggestive that these assemblages were likely deposited within the same two to four thousand-year time window.

Raw Material Selection

Châtelperronian

At both Quinçay and Les Cottés, local raw materials (available within a few kilometres of the site) dominate the assemblages. The introduction of exogenous raw materials is limited and is most clearly expressed in a small number of retouched tools (e.g. Châtelperronian points) which were produced on non-local materials and likely introduced to the site in their finished form. Slabs, blocks, and large flakes are the predominant blank types chosen for blade and bladelet production. A tendency toward raw material morphologies which allow for the unproblematic installation of at least a wide and flat flaking surface is noted — an observation which is evident in the morphology and reduction progression of discarded cores in various stages of reduction.

Uluzzian

Although a detailed petrographic study dedicated to raw material acquisition is currently ongoing, it appears that in Uluzzian contexts raw material acquisition is generally limited to local sources, even when the raw material available near the sites are not of very good quality (Moroni et al., 2018; Rossini et al., 2022). In the lowermost layers of Cavallo, the use of local siliceous limestone thin slabs can be noted, especially for the manufacturing of common tools (side and end scrapers — Moroni et al., 2018). At Castelcivita, the natural blocks collected from secondary sources in the surrounding riverbeds were broken in several angular fragments (Rossini et al., 2022), among which those displaying several flat surfaces and acute corners were selected to be flaked. In the Uluzzian as a whole, the production takes full advantage of technical qualities (shape, size, presence of internal fractures, natural guiding ribs) exhibited by raw blocks (including flakes) as it is possible to control the size of the outputs by choosing the dimensional modules of the initial blanks: e.g. small pebbles and fragments are chosen to obtain flakes, whereas the edge of a flake is usually used to obtain bladelets and spalls (as noted in the layers rsa'' and EIII). At Cavallo, there is a decrease in the use of local raw materials and conversely an increase in the allochthonous

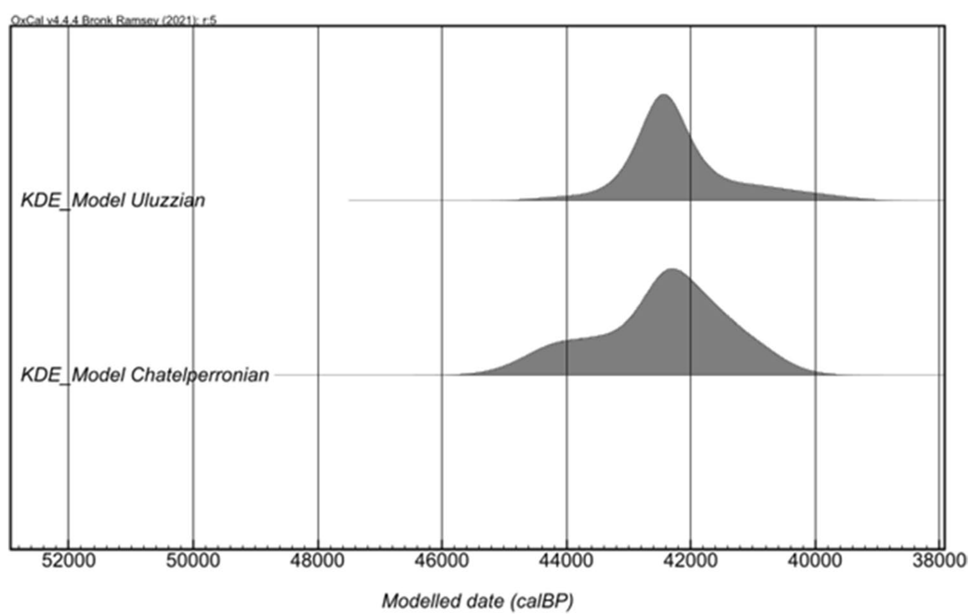

Fig. 3 Kernel density estimation models summarising the chronological data for the Châtelperronian and Uluzzian based on high-quality modernly produced and calibrated radiocarbon ages. The scripts used for this analysis and a summary of all individual dates are available in SI 1 and SI 2

ones as one proceeds from lower to higher levels (Palma di Cesnola, 1965a, b, 1966a, b).

Percussion Techniques

Châtelperronian

At both Quinçay and Les Cottés, striking platforms of laminar artefacts are generally thin, between approximately 2 and 5 mm, and often show signs of soft abrasion. Exterior platform angles (EPA) near-exclusively fall between 75 and 90°. These characteristics, along with a common occurrence of bulbar scars and weakly pronounced bulbs of percussion, are considered consistent with a direct, marginal striking gesture utilizing a soft-stone hammer (Pelegrin, 1995, 2000, 2012; Roussel et al., 2009; Valentin, 2000). However, hard-hammer internal percussion is clearly observed in some stages of reduction — with particular relevance to initialisation procedures, maintenance interventions, and during late-stage reduction. This is evident in the thickness of the platforms and robustness of these products, as well as the pronounced bulbs of percussion and clear ring cracks. This may indicate a strategy of hammer alternation throughout the reduction stages of cores.

Uluzzian

The bipolar-on-anvil technique is very commonly used in the Uluzzian sites, also employed together with direct freehand percussion in the same reduction sequence; thus, both on products and cores, there can be mixed stigmata relating to the two techniques (Collina et al., 2020; Rossini et al., 2022). The debitage products made by bipolar technique are typically characterised by rectilinear longitudinal profiles, similar ventral and dorsal faces, and pronounced ripple marks on the ventral face. Platforms are crushed, punctiform, linear, or cracked. Impact points are diffuse, the bulbs of percussion are sheared (Fig. 10: 5a), absent, or hinged — and the presence of parasitical scars is common. Debitage products typically exhibit splintering on the distal (Fig. 10: 8a) and/or proximal areas, with frequent Siret and transversal fractures. (Moroni et al., 2018; Rossini et al., 2022 and references therein). Cores resulting from bipolar technique show edge battering due to recurrent knapping — and both the striking platform and the lower portion of the core present scars and splintering (from contact with the anvil). On the surface of cores, it is common to find step, hinged, and overshot terminations and bidirectional removals (Moroni et al., 2018; Rossini et al., 2022 and reference therein). A decrease in the use of bipolar technique is observed in layer D of Cavallo.

In addition to the massive amount of both debitage and cores presenting these typical features of bipolar percussion, anvils are also identified at Castelcivita and Cavallo (Arrighi et al., 2020a; Palma di Cesnola, 1965a, 1966b). The detailed study carried out on the six specimens from Castelcivita highlight the occurrence on their surfaces of clear traces related to their use in the bipolar technique. These traces are mostly linear impacts with deep sub-rectangular hollows (Fig. 4: 1, 2, 3) (Arrighi et al., 2020a). Interestingly, the raw materials used for the anvils of Castelcivita are compact elastic rocks, probably intentionally chosen for their physical properties of returning the force produced by the hammerstone instead of absorbing it (Arrighi et al., 2020a). Moreover, some of the Castelcivita anvils are modified (shaped) by flaking on their lower surface, which may serve to create a morphology facilitating their insertion into a support (Fig. 4: 1, 3, 4, 5).

Initialisation and Configuration Procedures

Châtelperronian

Blade production usually begins with the installation of a one-sided crest on a narrow face of a block or slab, with transverse removals extending onto an adjacent broader surface (Djakovic et al., 2024; Roussel et al., 2016). This procedure often results in initialised cores, and also starting crests, which display an asymmetric cross-section (Fig. 5: 1). The other surfaces of the core are often left unmodified at the initialisation stage, although some shaping of the broader volume to realise an appropriate morphology can be evident — particularly on discarded, initialised cores. Cores relating to bladelet production can show analogous initialisation procedures, and most commonly utilise small blocks or flakes and blades as core-blanks. Crested bladelets are identified at Les Cottés and Quinçay. However, bladelet cores in some Châtelperronian assemblages show very limited, or absent, preparation procedures — indicating that there is substantial variability in this procedure within the industry (e.g. Bodu et al., 2017).

Uluzzian

In most Uluzzian contexts, including Castelcivita, a real phase of initialisation and configuration of the raw block is missing or, rather, the beginning of the reduction sequence coincides with the selection of the appropriate block to be flaked (Collina et al., 2020; Moroni et al., 2018; Rossini et al., 2022). The lack of management of the striking platform, as well as the convexities of the debitage surface, are balanced by the selection of an appropriate blank on which the bipolar technique is applied (Collina et al., 2020; Moroni et al., 2018; Rossini et al., 2022). The production takes advantage of the qualities afforded by the raw block (e.g. angles, natural guide ribs, fissure plan), and initialisation/configuration procedures aimed at controlling the

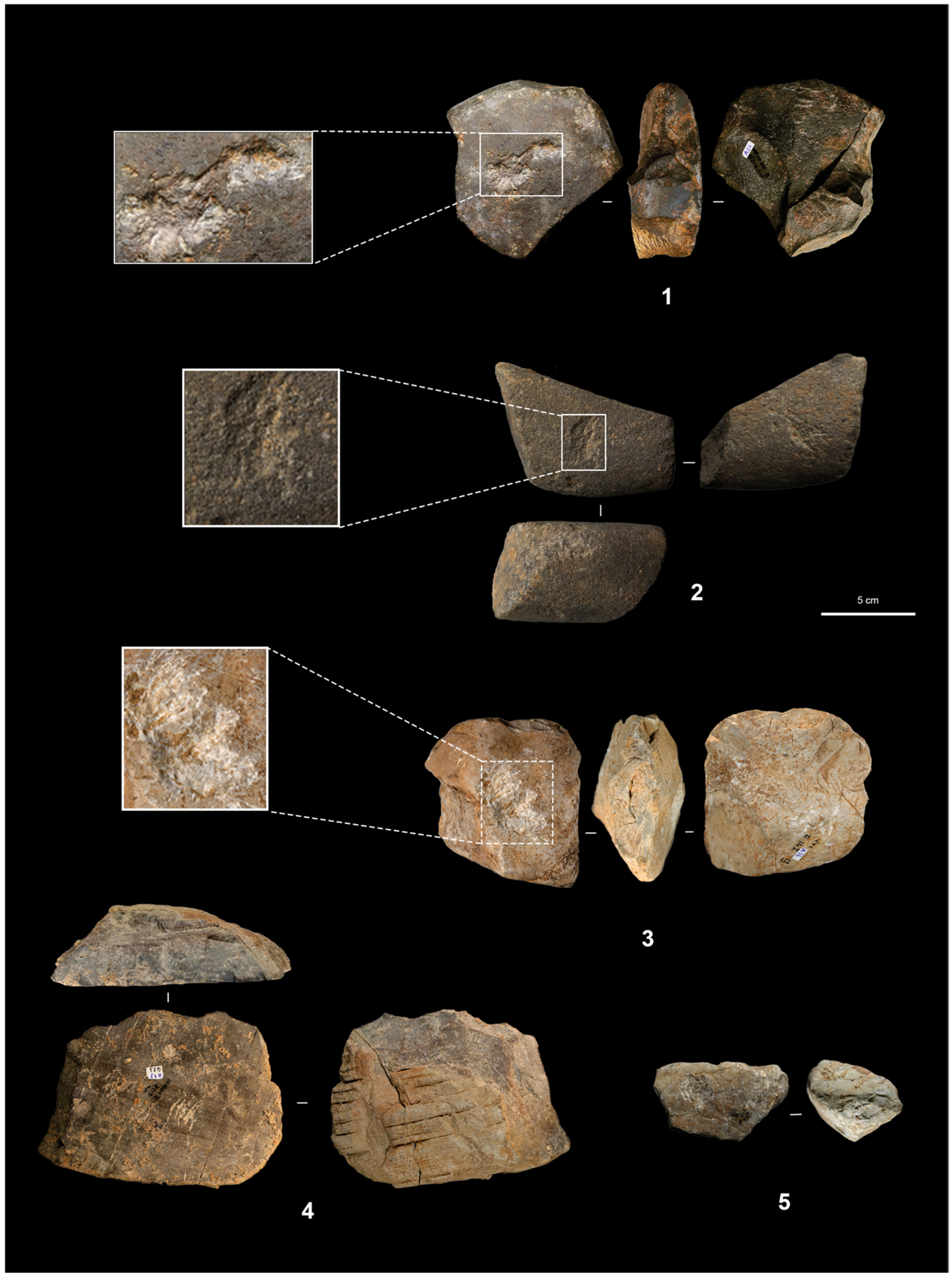

Fig. 4 Anvils used for the bipolar technique on anvil from Castelcivita. (1, 3, 4, 5) Modified anvils, their lower portion was shaped through flaking. (2) Bi-flat anvil. Note the close-up of the principal utilised area showing sub-rectangular hollows and linear impacts (modified from Arrighi et al., 2020a)

techno-morphological characteristics of the debitage are effectively absent or low. What has been said so far is only partially applicable to Cavallo D, where a phase of initial selection is also present followed by management of the convexities through the creation of one-sided crests.

Management of Striking Platform(s)

Châtelperronian

Blade cores at the abandonment stage can display two opposing platforms — though not necessarily in-axis but slightly off-set (Fig. 6: 4–5). These platforms do not necessarily function simultaneously; instead, they likely operate sequentially, with one following the other (see details on the chronology of core removals in Roussel, 2011: 200, 220, 237, 259–260 and multiple detailed core schemes with direction and chronology). Most cores, however, clearly show the use of only a single striking platform (Fig. 6: 1–3). Striking platforms are generally left plain, with faceting being extremely rare, although a soft abrasion of the EPA can be a common occurrence — possibly linked to the use of a soft-stone hammer. The use of two opposed platforms is made evident by robust, overshot

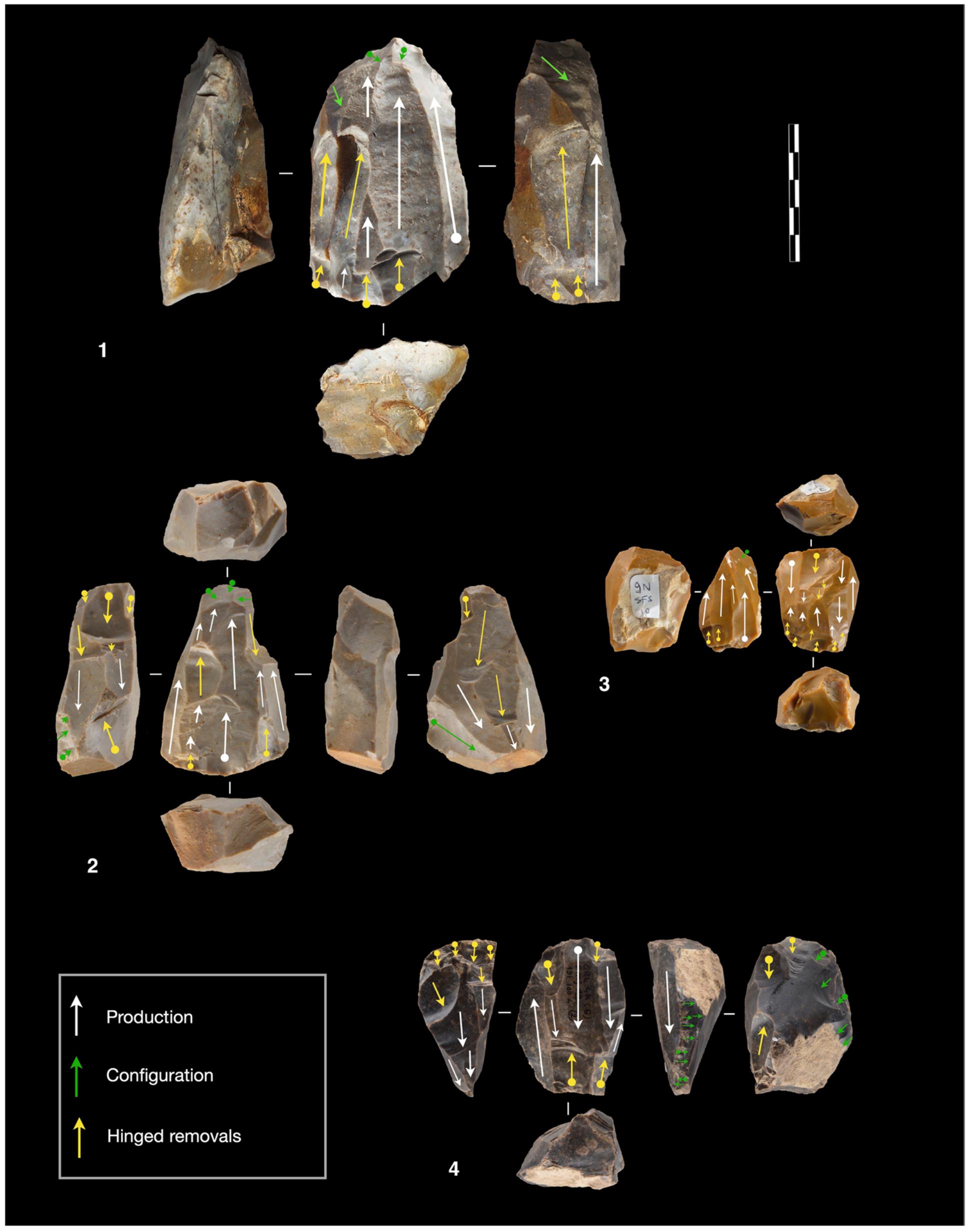

Fig. 5 Cores from the Châtelperronian of Quinçay (En). (1) Asymmetrically-reduced blade core showing production of blades from wide and narrow flaking surfaces. Note the postero-lateral crest installed on the left edge of the core. (2) Blade core reduced from opposed and separated striking platforms. (3) Bladelet core reduced on wide and narrow flaking surfaces, with the last series of removals originating from an opposed platform. (4) Small blade core

products preserving an opposed and often off-set striking platform at their distal end. Platforms are later revived — as reduction progresses — through the removal of often multiple partial or total core tablets, which allows control of the desired angle between the striking platform(s) and the flaking surface(s) of the core. This angle is most commonly kept between 75 and 90°.

Uluzzian

The striking platforms are usually left unprepared, utilizing flat cortical or cleavage planes. Occasionally, the blocks are opened with one or more removals. The debitage surface and striking platforms are typically hierarchical, without alternating between them. However, after an initial series of removals, the core may be rotated to enable a new unidirectional sequence of removals (Rossini et al., 2022) (Fig. 7).

Maintenance Interventions and Typical Products

Châtelperronian

Cores are maintained through the use of well-known 'Upper Palaeolithic' maintenance interventions, including neo-crested blades (Fig. 8: 3), debordant blades, core tablets, and laminar rejuvenation flakes. The installation and detachment of neo-crested blades is a very frequent

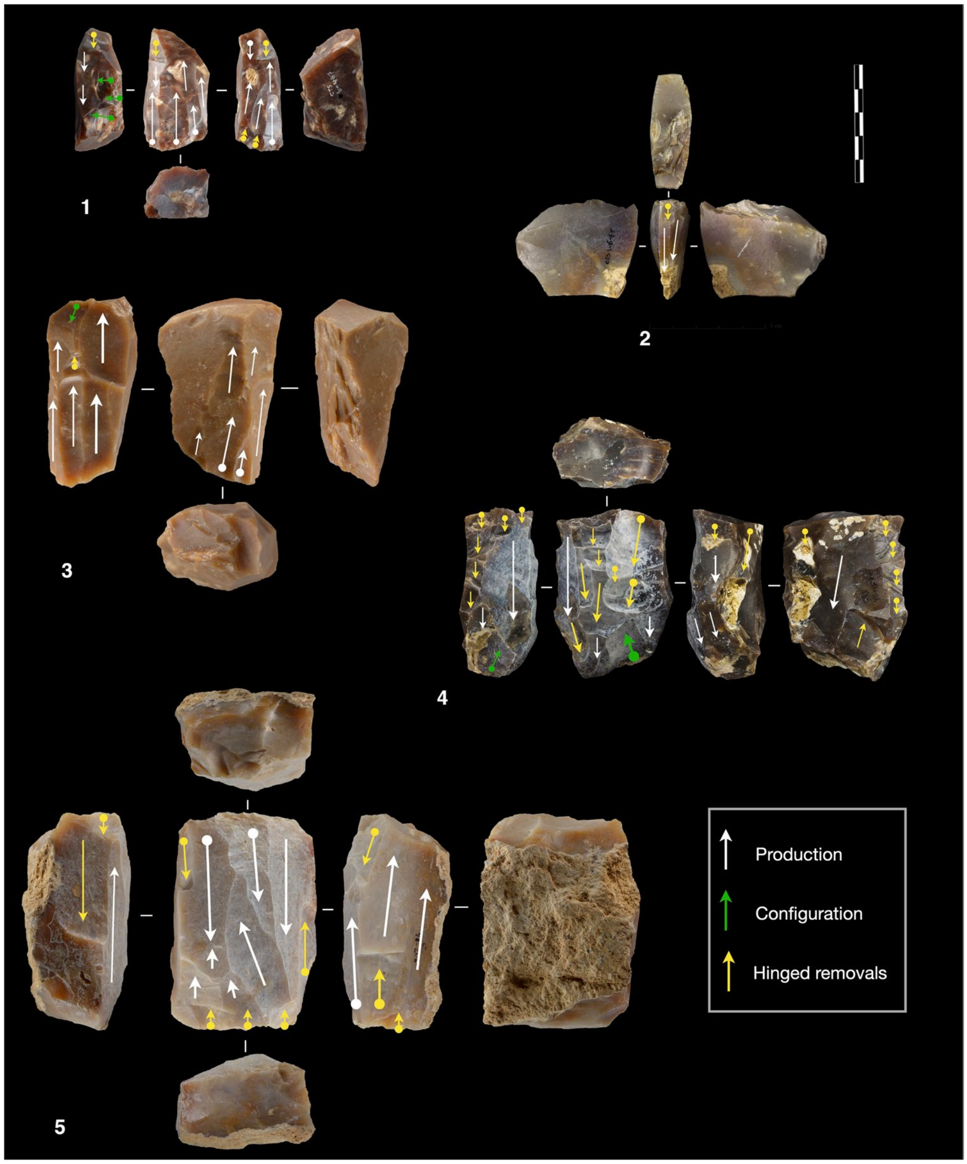

Fig. 6 Cores from the Châtelperronian of Les Cottés (US6). (1) Asymmetrically-reduced unidirectional bladelet core showing production of bladelets from wide and narrow flaking surfaces. Note the postero-lateral crest installed on the left edge of the core. (2) Unidirectional bladelet core produced on the edge of a core tablet (*débitage sur tranche*). (3) Unidirectional blade core reduced on wide and narrow flaking surfaces, note the postero-lateral crest installed on the back of the core. (4) 'Rectangular' blade core reduced on three distinct surfaces (two narrow, one wide). (5) Bidirectional 'Rectangular' blade core with a natural (cortical) back

maintenance intervention — and, as evidenced by their size variability, is likely a recurrent procedure which can occur multiple times throughout core reduction. The detachment of debordant blades from the intersection between two flaking surfaces, or a flaking surface and the back of the core, is also a frequent procedure. Both of these interventions are likely linked to the maintenance and restoration of lateral convexities, with debordant blades also being sought-after for the production of backed points (Châtelperronian points). The removal of a large, elongated flake from the flaking surface (referred to here as a laminar rejuvenation flake), commonly with a more internal striking gesture, appears to reflect a maintenance intervention linked with correcting the over-flattening of a flaking surface during reduction. These products, due to their morphology, are commonly converted into end-scrapers (Fig. 12: 1–2). Following their detachment, the core can either be discarded or production is re-started following the extraction of an asymmetrical blade from an appropriate intersection (Fig. 8: 1, 6). Finally, partial or complete core tablet removals are a very frequent procedure applied in order to rejuvenate the striking platform(s), as well as to control the desired EPA.

Uluzzian

Cores in the Uluzzian do not exhibit a specific strategy for configuration and maintenance. Whether using bipolar or direct percussion, the series of removals are short, taking advantage of the natural convexities of the block and the recurrence of previous removals (Collina et al., 2020; Moroni et al., 2018; Rossini et al., 2022).

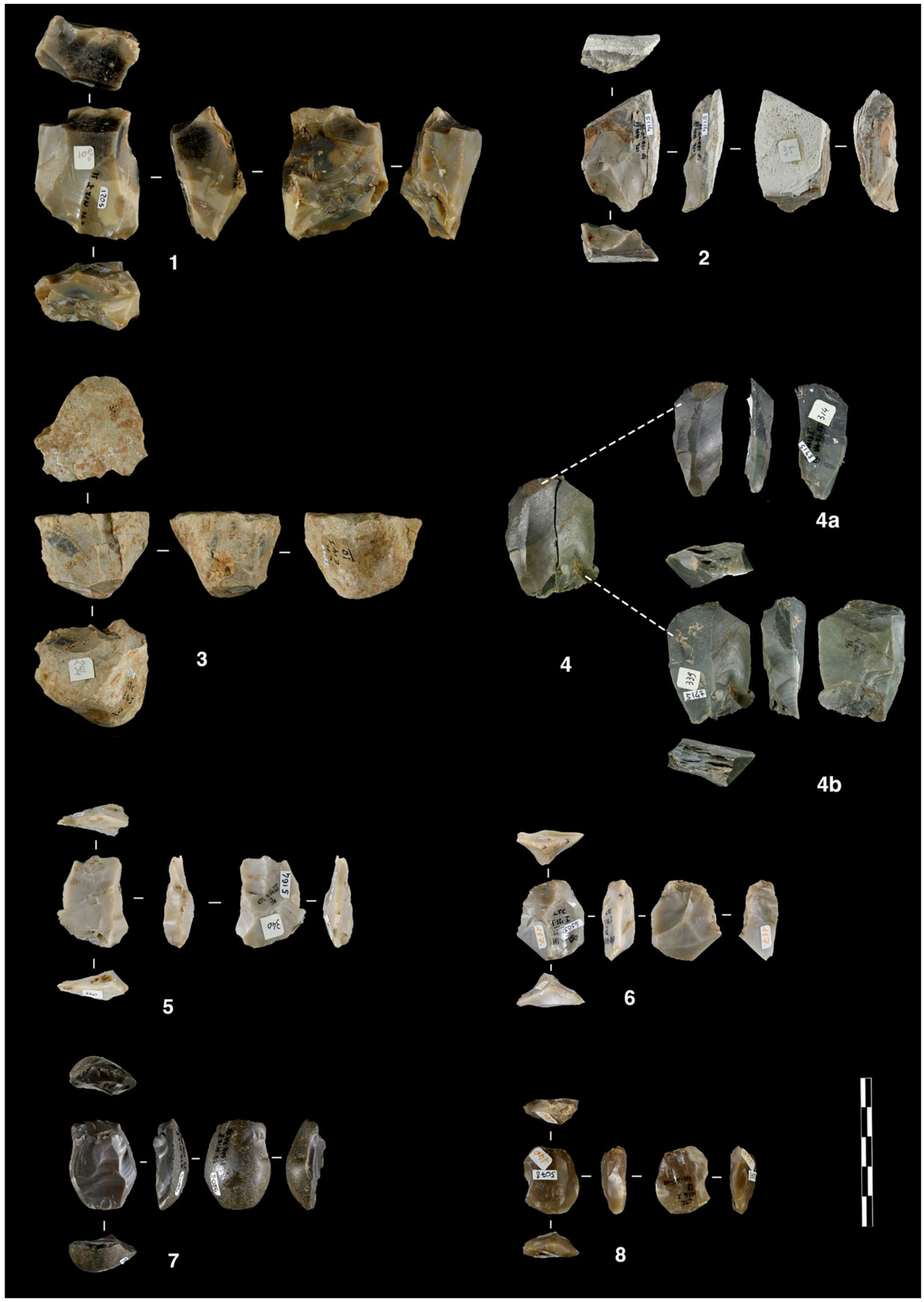

Fig. 7 Cores from the Uluzzian layer rsa'' of Castelcivita. (1) Core exploited by orthogonal planes. (2, 7) single-face cores with parallel detachments. (3) Semi-tournant core. (4) Refitting set of a core with two adjacent faces with parallel detachments (modified from Higham et al., 2024). (4a) blade-like. (4b) Core. (5, 6) Cores with three adjacent faces with parallel detachments. (7, 8) Core with two opposing faces with parallel detachments

Blank Production

Châtelperronian

Blades are detached in series generally following a sub-parallel reduction pattern. Reduction often progresses via a short set of parallel removals from one platform before a switch to an opposing and/or offset platform and another set of removals. This is evident in the co-occurrence of blanks with both unidirectional and bidirectional dorsal scar negatives (Fig. 8) — which occur in lower frequency for the latter (see details in Roussel, 2011: 259–260). The largest quantity of primary production products is likely removed from the wide flaking surface of a core, although reduction can alternate with the narrow surface either from the same platform, or from an opposed and

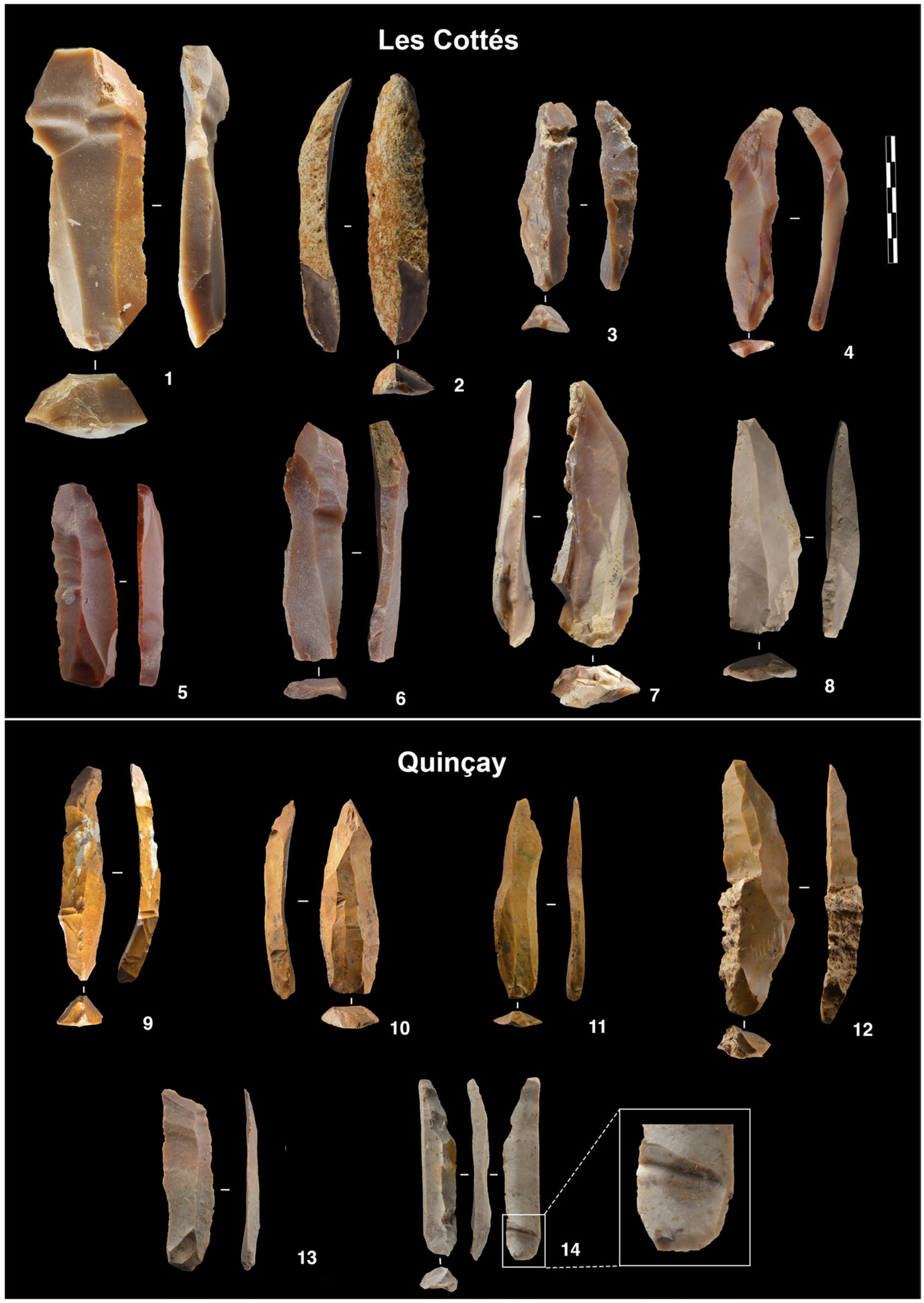

Fig. 8 Blade debitage from the Châtelperronian of Les Cottés (US6) and Quinçay (En). (1, 6) Large debordant blade. (2) Cortical blade from initialisation of core. (3) Crested blade. (4, 8, 9, 10, 13) Blades and retouched blade with unidirectional dorsal scar negatives. (5, 7, 11, 12) Blades and retouched blade with bidirectional dorsal scar negatives. (14) Neo-crested blade highlighting direct soft stone percussion features: '*esquillement du bulbe*' (i.e. Pelegrin, 2000)

separated platform (Figs. 5 and 6). Exhausted cores can in fact show the production of blades on three discrete surfaces (e.g. Roussel et al., 2016). The use of an opposed and separated striking platform during blank production is made evident by overshot products preserving an opposed and separated platform at their distal end — which occur in notable numbers at both Quinçay and Les Cottés. The identification of this procedure on exhausted cores, generally in combination with a last series of detachments showing a more internal percussion gesture, may suggest that this procedure is particularly frequent in late stage reduction — shortly preceding the discard of the core.

Bladelet production is identified in at least two modes: prismatic/volumetric bladelet cores, and burin-type cores. Prismatic bladelet cores are generally more productive and show a high degree of conceptual similarity with the schema used for blade production (e.g. the alternation between wide and narrow flaking surfaces, the use of debordant and neo-crested elements for controlling convexities). There appears to be no indication for the production of bladelets via convergent flaking, instead aimed towards the production of straight, parallel bladelets (Fig. 9). Burin-type cores present a simpler reduction scheme and are, as a result, generally less productive than the prismatic counterparts (i.e. producing fewer primary products). The platform of these cores is sometimes prepared through truncation, and residual cresting can be observed on some examples. Reduction is initiated on the edge of the flake or blade (with a crest or spall) and can progress onto ventral surface of the core blank. Unlike for blades and prismatic bladelet cores, burin-type cores are more often reduced utilising a single platform.

Uluzzian

The knappers do not seem to look for a specific techno-type (Moroni et al., 2018; Rossini et al., 2022). On the contrary, the straightforward manufacturing mode allowed the production of several products: not only large quadrangular and elongated flakes (Fig. 10: 5, 9, 10; Fig. 11: 1–7), thick and thin flakes, flakelets (Fig. 10: 1–3), blade-like products (Fig. 10: 11–12), bladelet-like products (Fig. 10: 6–8), but also thick fragments and chunks which were selected to be retouched and used.

Cores vary significantly in shape and size. Unidirectional and bidirectional cores exploit one, two, three or even four surfaces of the block (Fig. 7). These cores are commonly associated with the bipolar technique on an anvil. It is important to note that while bipolar reduction is the predominant technique used in these cores, some removals may also be achieved through internal direct percussion (Collina et al., 2020; Rossini et al., 2022). These cores produce mostly flakes and bladelets both on the wide and narrow sides of the block, also producing thick spall-like bladelets. The reduction sequences are often continued until the complete exhaustion of the raw block. Flakes are mostly produced by orthogonal plane cores, alternating the surface of debitage and striking platform; these cores use direct internal percussion and represent short sequences of removals (Fig. 7: 1). Flakes and blades were also obtained by platform

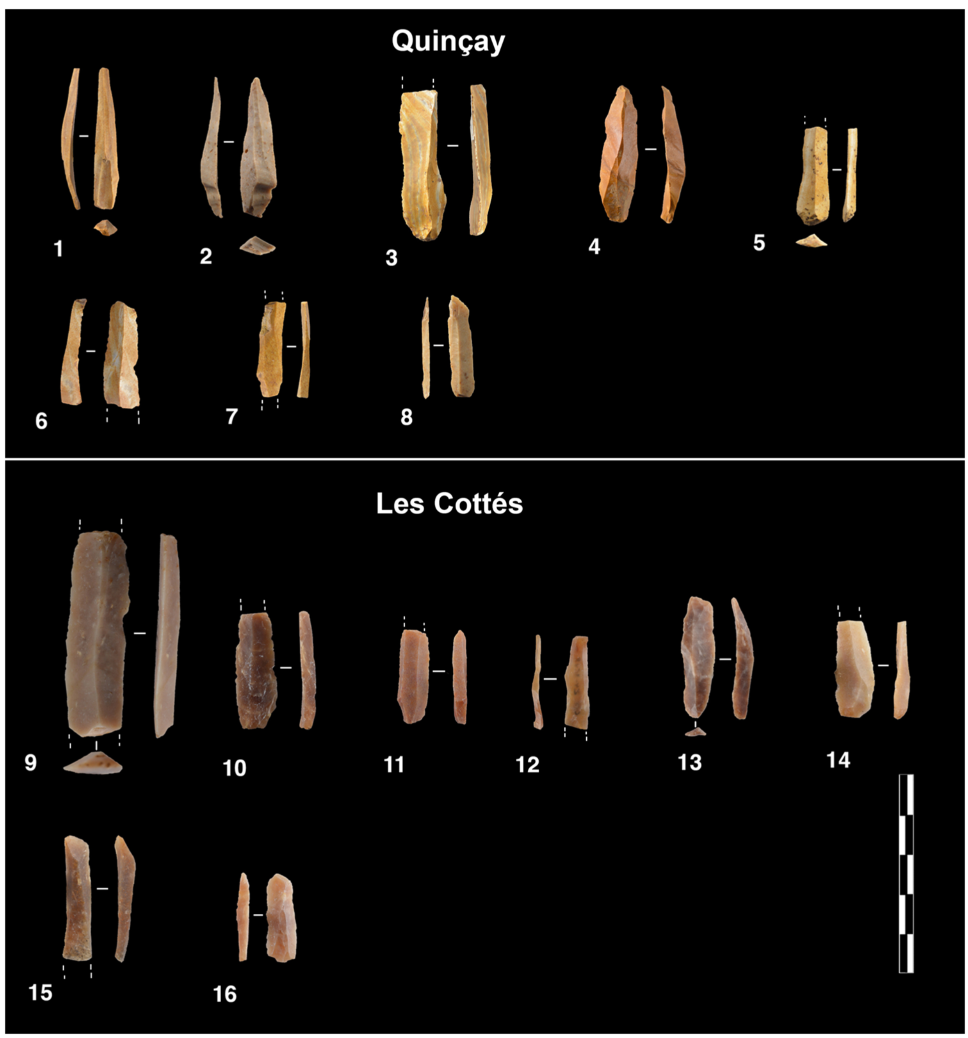

Fig. 9 Bladelet debitage from the Châtelperronian of Les Cottés (US6) and Quinçay (En). Bladelets of various sizes showing range of variation. Some exhibit parallel lateral edges, while some show a more convergent outline morphology. Dorsal scar negatives are unidirectional

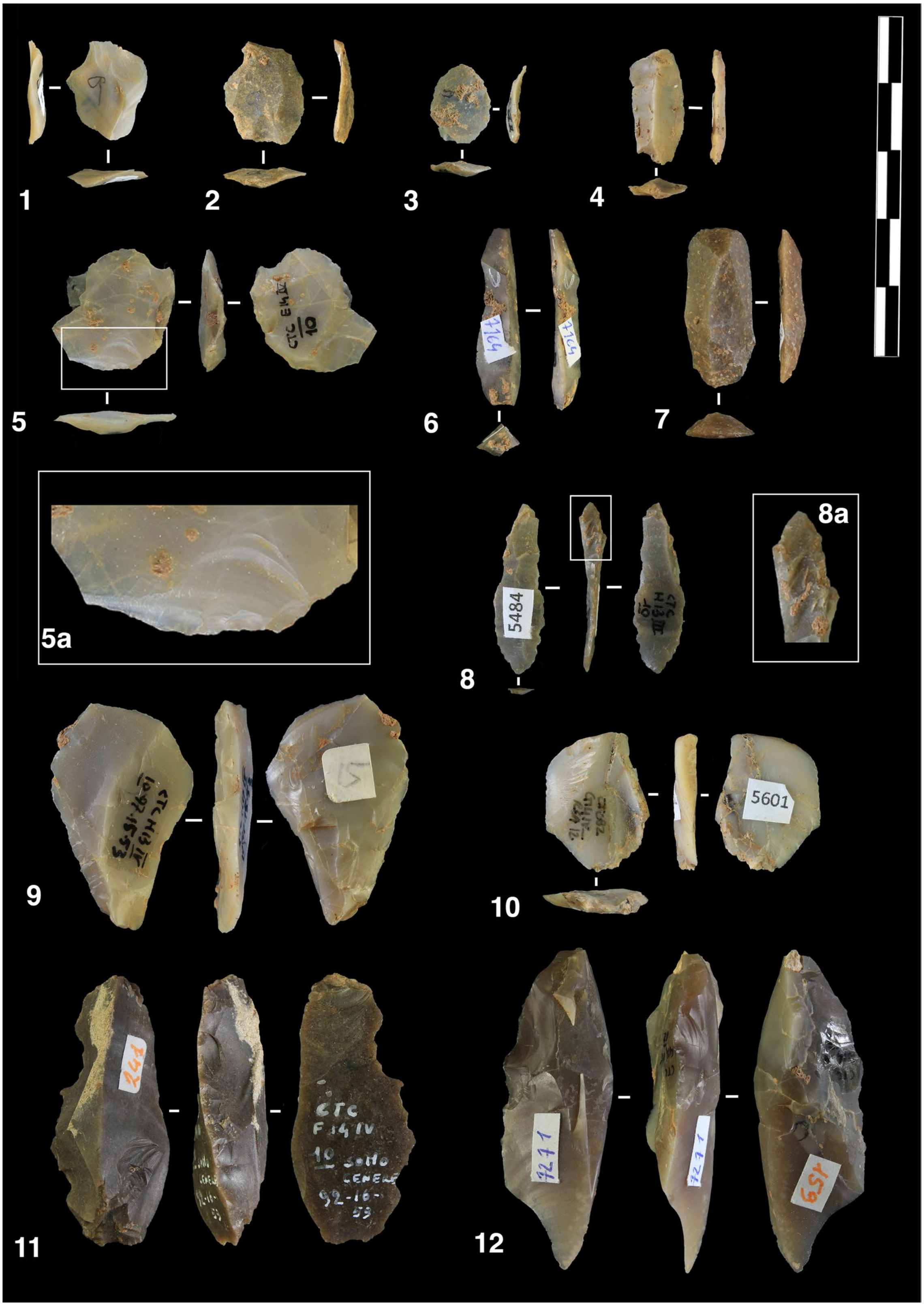

Fig. 10 Blank production by bipolar technique from the Uluzzian layer rsa'' of Castelcivita. Note the wide range of products that the bipolar can produce. (1, 2, 3) Flakelets. (5, 9, 10) Flakes of different morphologies and size. Note the close-up (5a) detail of a sheared bulb of percussion. (11, 12) Thick blade-like product. (6) Bladelet-spall. (7, 8) Bladelets. Note the close-up (8a) detail of distal splintering

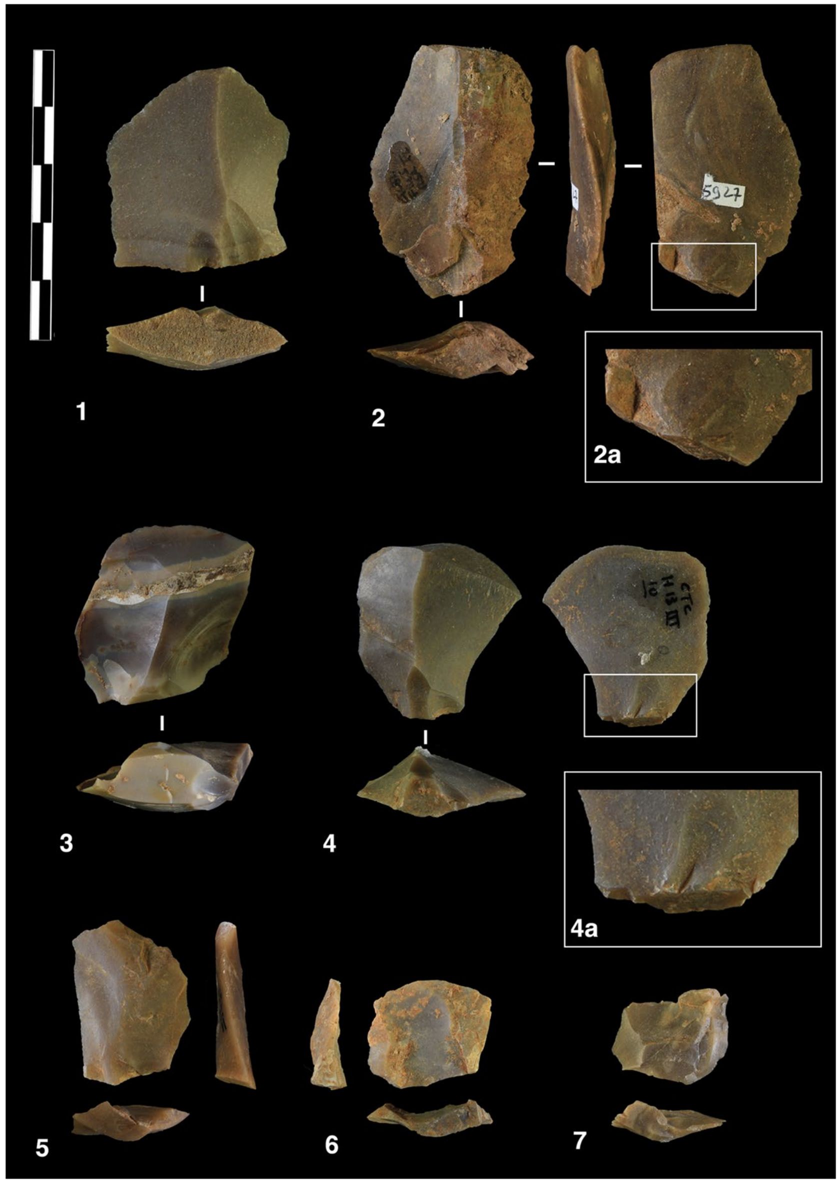

Fig. 11 Blank production of unidirectional debitage produced by direct percussion with an internal gesture from the Uluzzian layer rsa'' of Castelcivita. (1, 3, 4, 5, 6, 7) Flakes with diverse morphologies. (2) Elongated flake. Note the close-up (2a, 4a) thick platforms with very developed bulb of percussion and a parasitical scar

semi-turning cores that employ mostly internal direct percussion (Fig. 7: 3) (Moroni et al., 2018; Rossini et al., 2022), though combinations with bipolar on anvil techniques are observed.

If compared to products of other debitage concepts such as Levallois and volumetric blade reduction, it is clear that the Uluzzian products appear to be unstandardised with high variability in shape, section morphology and dimension. Blades are rare as the laminar component is represented almost exclusively by bladelets, which are well-represented in the most advanced phases of Cavallo (Moroni et al., 2018; Rossini et al., 2022). At this site, bladelets are more regular as they seem to be obtained primarily from lamellar reduction strategies (both on small blocks/slabs and flakes). However, the low quantity of cores prevents a detailed reconstruction of the production procedures.

Retouched Tools

Châtelperronian

Retouched tools are dominated by four formal categories: backed points (Châtelperronian points), simple burins, laterally retouched blades, and wide-fronted end-scrapers. More standardised blades are generally chosen for the manufacture of Châtelperronian points — generally between 12 and 35 mm width, 35–85 mm length, and 4–10 mm thickness (Fig. 12: 3–9, 14–15). However, there is substantial size variability in the manufacture of backed points — with some examples nearing the metric cut-off of bladelets (< 12 mm) after retouching, while others can be quite robust (Fig. 12: 4). Less regular blades are most commonly used for the production of simple burins or laterally-retouched blades, featuring continuous, marginal, and most commonly direct retouch. Burins are either dihedral or produced on an oblique truncation, and generally feature less than three removals. Typical of this industry is the production of wide-fronted end-scrapers produced on robust technical products (e.g. laminar rejuvenation flakes) resulting from laminar reduction (Fig. 12: 1–2, 12), but also suitable flakes resulting from the decortification of a block. Bladelets are most commonly left unretouched. However, oblique truncations occur on some examples from Quinçay and Les Cottés — somewhat analogous to the backing of larger Châtelperronian points — as do examples showing either direct or inverse marginal retouch affecting one lateral edge.

Uluzzian

The blanks selected to be retouched show a pronounced variability: consisting of end-products, chunks, and debris. Usually, unmodified pieces that present specific morphological features (e.g. thick, pointed) (Fig. 13: 2, 4) were selected

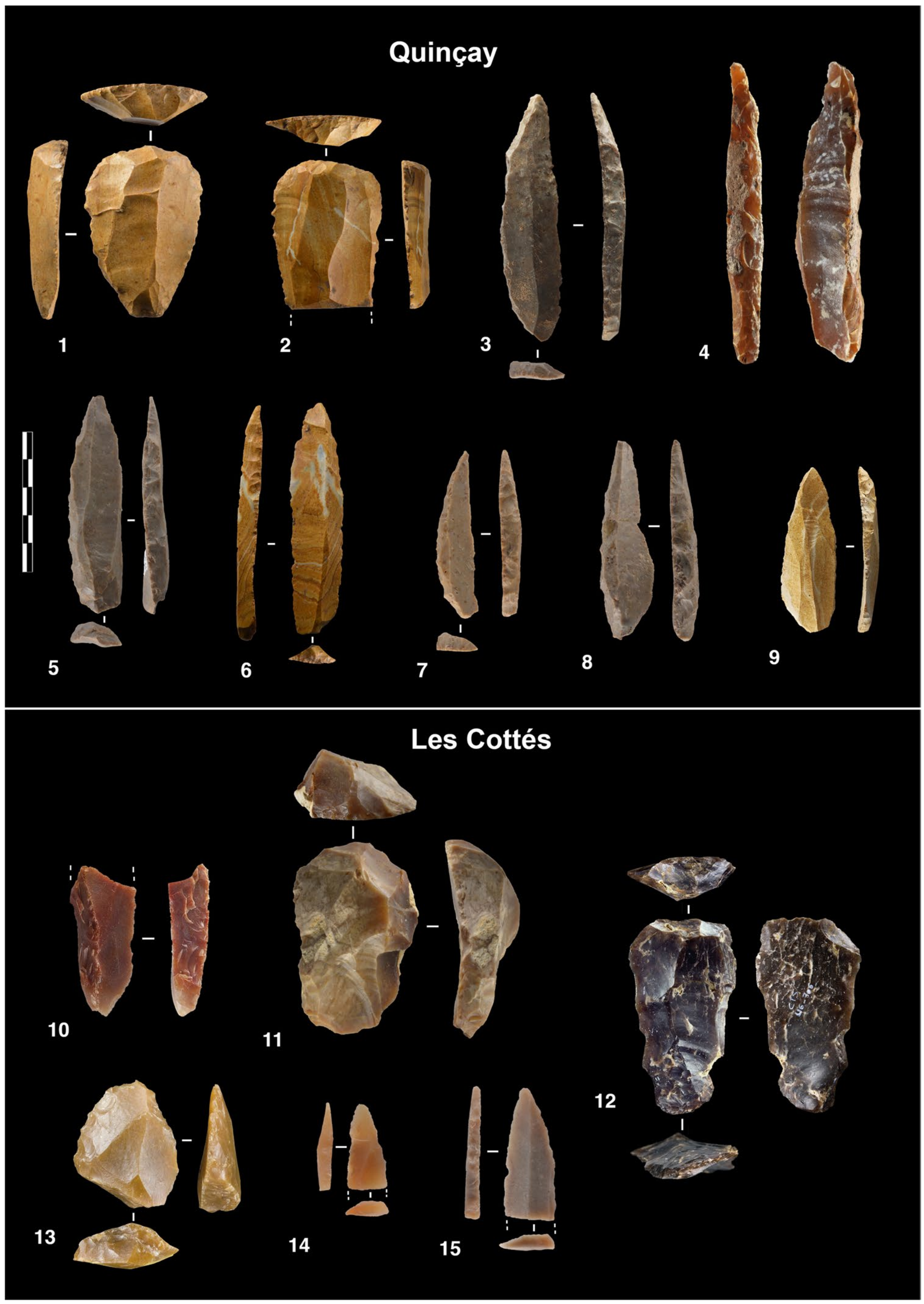

Fig. 12 Retouched tools from the Châtelperronian of Les Cottés (US6) and Quinçay (En). (1, 2, 11, 12) Wide-fronted end-scrapers produced on 'laminar rejuvenation flakes' and wide blades. (3–9, 14, 15) Châtelperronian backed points. (10) Neo-crested blade. (13) Convergent side-scraper. Note the variation in size of the pieces

and adjusted by retouch. The retouch is mostly performed by direct percussion, and, in many cases, only rough adjustments are made to the natural morphology of the blank. Hence, we can state that in many cases retouching is not of primary importance in manufacturing tools. Instead, the emphasis is placed on pieces that already have an ergonomic potential in their unmodified state (Moroni et al., 2018; Rossini et al., 2022).

Conversely, particular attention is dedicated to the categories of lunates and endscrapers, having more specific uses, respectively as insets in projectile weapons (as demonstrated at Cavallo — Sano et al., 2019) and, possibly, hide working (functional studies of the Uluzzian end-scrapers are in progress). For the manufacture of endscrapers, thick flat blanks were selected and then carefully retouched. Besides showing a very accurate procedure of retouching, backed pieces (mostly lunates but also straight backed bladelets) are the only tool category presenting a relative uniformity in size (especially at Cavallo) (Moroni et al., 2018; Rossini et al., 2022). Regarding these tool types, it must be highlighted that those found at Cavallo (Moroni et al., 2018; Palma di Cesnola, 1965a, 1966b) are more curated and much more numerous than those from Castelcivita (Gambassini, 1997; Rossini et al., 2022) and other Uluzzian sites (e.g. Roccia San Sebastiano, Collina et al., 2020) (see Fig. 14 for a comparison of the lunates from Castelcivita and Cavallo). Blanks selected for lunates are flakes and bladelets having the thickness required for the realisation of a deep abrupt retouch (Moroni et al., 2018). At Cavallo, especially in the evolved/final phases, lunates on bladelets are very common. Except for those used in backed implements, both regular and irregular bladelets are usually unmodified. As no use-wear study has been performed on unretouched bladelets so far, we are not able to say whether these items were used or not in their unretouched state.

Technological Divergences Between the Uluzzian and Châtelperronian

The technological comparison between the Uluzzian and Châtelperronian assemblages reveal multiple divergences at different levels: volumetric concepts, methods, percussion techniques, and production targets (Figs. 15 and 16).

In the Châtelperronian, the primary production is characterized by a specific volumetric laminar concept (e.g. Bachellerie, 2011; Bodu et al., 2017; Roussel et al., 2016) (Fig. 15). The percussion techniques employed involve marginal percussion likely utilising a soft-stone hammer, with a lesser degree of internal percussion during particular phases of reduction. It is possible that this alternation also includes the switch to a hard-stone hammer. In contrast, the distinguishing feature of the Uluzzian is the predominant use of the bipolar technique on anvil. This technique is consistently applied regardless of variations in the size, format, and quality of available raw materials

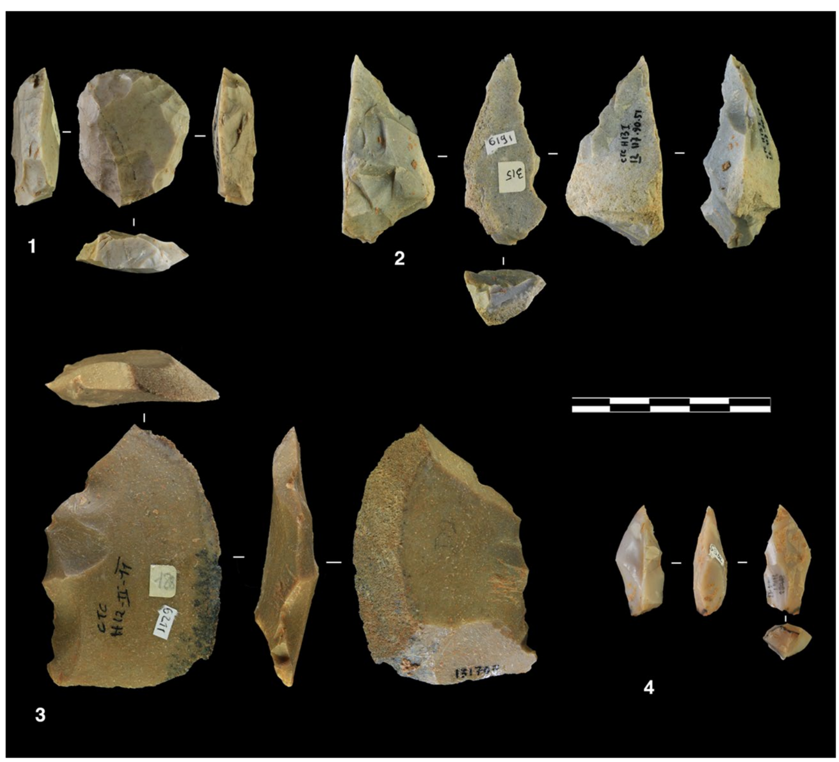

Fig. 13 Retouched tools from the Uluzzian layer rsa'' of Castelcivita. (1) Endscraper on flake. (2) Sidescraper with an adjustment of the distal end. (3) Sidescrapers realised on the ventral side of a big flake. (4) Pointed tool realised by adjusting the distal end of an already pointed fragment

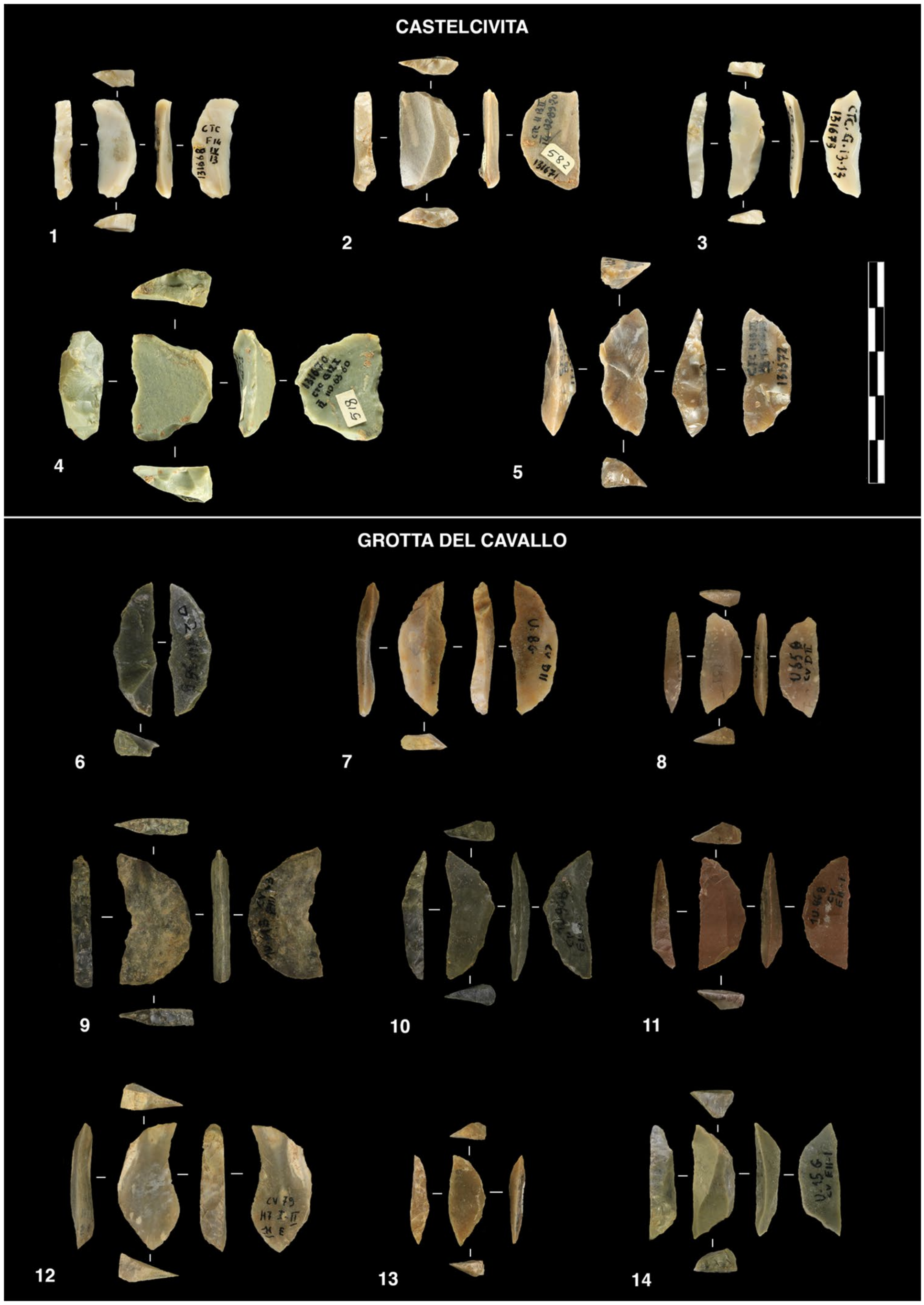

Fig. 14 Uluzzian lunates. (1–5) Lunates from the layer rpi of Castelcivita (modified from Rossini et al., 2022). (6–14) Lunates from Grotta del Cavallo

(Arrighi et al., 2020a; Collina et al., 2020; Marciani et al., 2020; Moroni et al., 2018; Peresani et al., 2019; Rossini et al., 2022; Silvestrini et al., 2022; Villa et al., 2018) (Fig. 15). Evidence suggests that toolmakers deliberately employed bipolar knapping, not only to exploit both low- and high-quality materials but also to achieve specific technological goals such as producing rectilinear profiles, thin flakes, and bladelets (Collina et al., 2020; Moroni et al., 2018; Rossini et al., 2022). The use of the bipolar technique reflects a conscious decision aimed at maximizing efficiency in lithic production, minimizing time and energy expenditure, and maintaining flexibility in product outcomes (Rossini et al., 2022; Delpiano et al., 2024). Partially deviating from this picture is the evolved-final Uluzzian of Grotta del Cavallo in which lamellar reduction strategies are applied to such an extent that they can be regarded as primary productions alongside the bipolar counterparts.

Divergences can also be observed concerning the 'secondary' productions (Fig. 15). The Châtelperronian includes

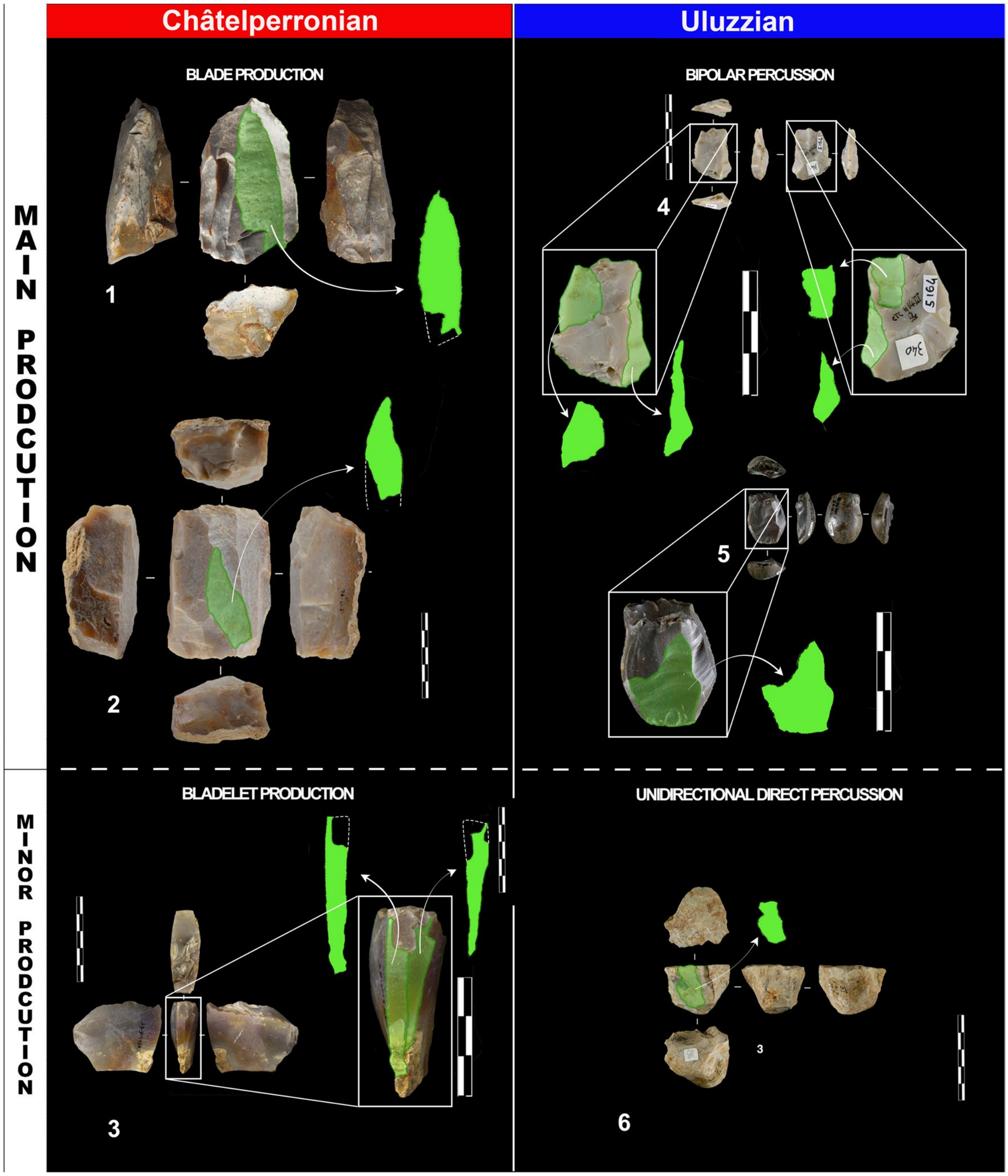

Fig. 15 Technological comparisons between the Uluzzian and Châtelperronian main and minor production modes. (1, 2) Châtelperronian blade cores. (3) Châtelperronian bladelet core. (4, 5) Uluzzian parallel plan cores reduced by bipolar technique. (6) Uluzzian semi-tournant core reduce by direct percussion

bladelet reduction strategies obtained on small blocks or flakes/blades, while in the Uluzzian, a minor proportion of flakes are produced with direct freehand percussion in combination, or not, with the bipolar technique.

The utilisation of distinct reduction systems in the Châtelperronian and Uluzzian is also evident in completely distinct blank techno-types (Fig. 16). The Châtelperronian is essentially a blade-based toolkit with a minor component of bladelets. Distal pointed blades and blades with a natural back can be considered the hallmark of the Châtelperronian (Fig. 16). The products of the Uluzzian are instead usually unstandardized, with high variability in shape, section, dimension, and angles. However, the employment of the bipolar technique allows the creation of usable products with definite and recurring characteristics such as straight profiles, absence of prominent bulbs, and

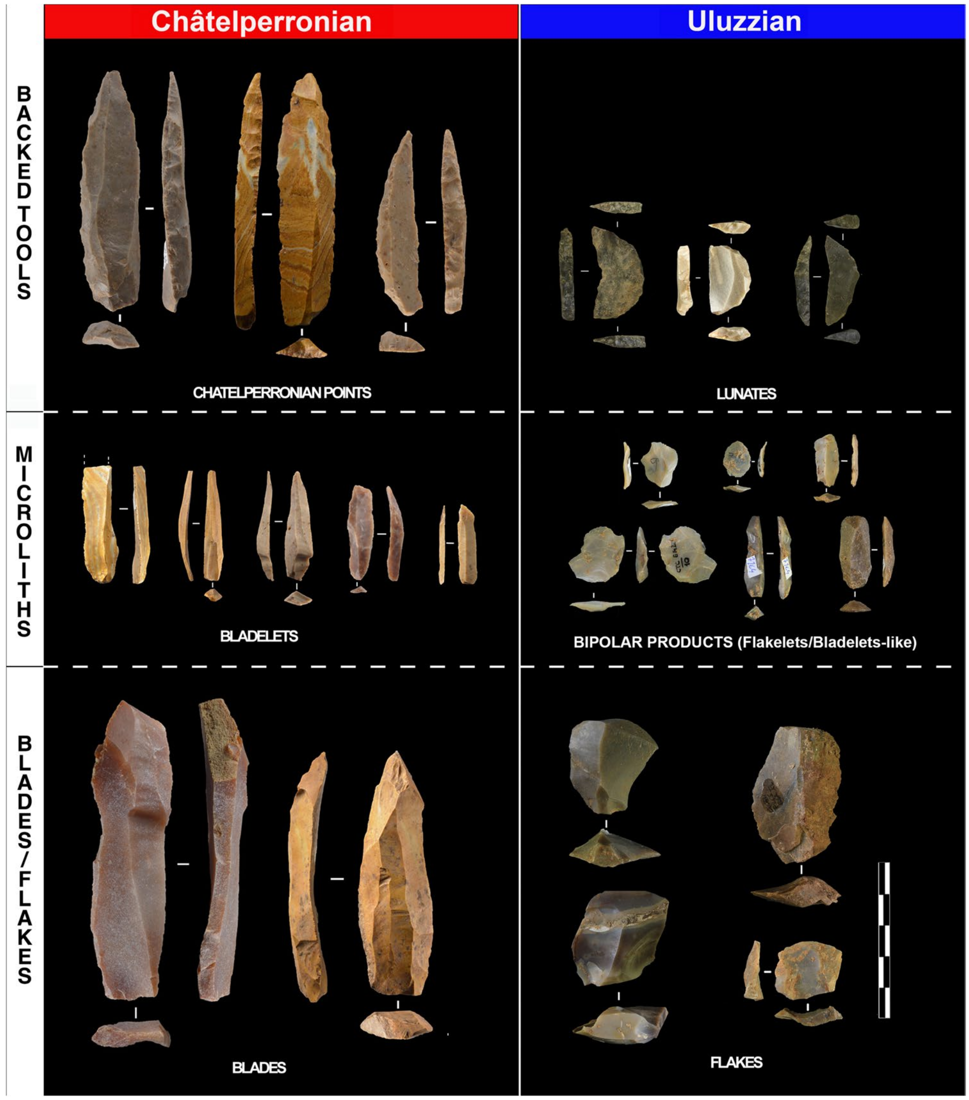

Fig. 16 Visualisation of the technological similarities and differences between the Uluzzian and Châtelperronian debitage products and tool kit (all artefacts to scale)

straight thin cutting edges (Collina et al., 2020; Moroni et al., 2018; Rossini et al., 2022). These traits make the pieces suitable for becoming insets in composite tools (Marciani et al., 2020; Moroni et al., 2018), whose occurrence in Uluzzian contexts is attested to by the study carried out by Sano and colleagues (2019) on the lunates of Cavallo. In the Uluzzian, blades are almost absent while the production of bladelets is always present. At Cavallo, bladelet production appears to increase and becomes more refined over time. In brief, the Uluzzian can be conceptually defined as a flake/bladelet-based industry with a very scarce component of blades.

The only meaningful element of convergence between the Châtelperronian and Uluzzian can be identified in the utilisation of the *abrupt* retouch to produce Châtelperronian points in the case of the Châtelperronian and the 'lunates' in the Uluzzian. Past typological analyses (carried out according to Laplace, 1964a, b) considered this mode (abrupt) and shape (arched) of retouch as evidence for the chrono-cultural correspondence (Palma di Cesnola, 1993) or even possible interactions between the producers of these industries (Gioia, 1990). However, upon closer examination, it becomes evident that the retouching of the back is the only element of similarity between Uluzzian lunates and Châtelperronian points, while the technological systems underlying their production are significantly divergent. Secondly, the manufacturing of the back has a distinct impact on the overall morphology of these tools. In the case of Châtelperronian points, the retouching of the back creates or enhances the tip of the blade. The desired form is essentially an elongated convergent tool with a slightly curved back. In the case of the lunates, the blank is heavily modified on one side and/or on the distal and proximal ends in order to obtain a convex back opposing a straight-cutting edge.

Additionally, the backing method represents a further distinction between Châtelperronian points and Uluzzian lunates. The Châtelperronian points are shaped through a variety of backing methods, including assisted anvil percussion and the application of '*egrisage*' techniques. Retouching on these points can take both direct and '*croisée*' forms, involving the application of retouch from both the ventral and dorsal sides. The thickness of the retouch varies, ranging from relatively thick to quite thin (marginal), depending on the thickness of the blank (Baillet & Maury, 2018). In the case of Uluzzian lunates, backing is sometimes employed to reduce the entire longest edge of the blank (referred to as Type A according to Moroni et al., 2018). However, in other instances, reduction is achieved by retouching only the distal and proximal ends, leaving the mesial portion slightly modified or unaltered (referred to as Type B according to Moroni et al., 2018). Various types of retouching methods are applied, including direct, inverse, as well as '*croisée*' (from both the ventral and dorsal surfaces).

In addition to rare marginally backed bladelets, in the evolved-final Uluzzian phases at Cavallo D and Cala, we have observed the presence of carinated pieces, which bear similarities to Aurignacian forms (Benini et al., 1997; Gambassini, 1997; Palma di Cesnola, 1966a, b). The occurrence of this phenomenon especially in the case of Cavallo, where no Aurignacian occupation has been confirmed, calls for a more thorough examination and in-depth study. It is essential to refrain from oversimplifying the situation, as attributing this solely to potential mixtures between the Uluzzian and subsequent Aurignacian deposits may not provide a complete understanding of the archaeological reality (Teyssandier, 2024).

Both in the Uluzzian and the Châtelperronian, bladelets are most often left unretouched. Interestingly, some marginally backed bladelets are present at Castelcivita, Cavallo (Gambassini, 1997; Moroni et al., 2018), Quinçay (Roussel et al., 2016), and Les Cottés. Finally, a characteristic that both the Uluzzian and Châtelperronian share with later Upper Palaeolithic complexes is the presence in the lithic industry of two clearly functionally distinct components: tools for 'domestic use' (e.g. endscrapers) on the one hand and armatures (backed points, lunates) on the other (Moroni et al., 2018; Tartar et al., 2005). The Uluzzian industries are distinguished by their specific manufacturing processes, that involve the extensive use of bipolar-on-anvil percussion. The Uluzzian sites exhibit notable cultural and technological unity, reflected in ornaments and the manufacture of bone and lithic tools, alongside a reliance on the bipolar technique. This internal coherence indicates a shared cultural expression among the sites (Arrighi et al., 2020b). However, there is evidence of variability within Uluzzian sites over time.

For instance, at sites such as Cavallo, there is a decrease in the use of bipolar reduction and an increase in freehand direct percussion for volumetric debitage (Moroni et al., 2018). A similar trend of increased managed volumetric debitage is also observed at Klissoura, alongside the continued use of bipolar reduction (Marciani et al., 2024).

This chronological shift from a predominant reliance on bipolar reduction to a greater incorporation of volumetric debitage suggests a dynamic and adaptive cultural framework. Additionally, a shared feature of Uluzzian industries is the production related to the use of mechanically delivered weapons (Sano et al., 2019).

The Châtelperronian, characterised by systematic and well-developed blade and bladelet production, should be considered fully 'Upper Palaeolithic'. In terms of internal variability, the Châtelperronian is a remarkably coherent industry across its geographic distribution — with the only pronounced variability observed reflecting an occasional proliferation of bladelet production and associated products at some sites (for example, Aranbaltza II and Ormesson) (Bodu et al., 2017; Rios-Gairazar et al., 2022). Additionally, there is variability in the use of Châtelperronian points — with some likely used as knives (Bodu et al., 2017) and others as tips of spears (Bachellerie et al., 2011; Rios Garaizar, 2008; Rots & Plisson, 2014). As it stands, there is no empirical evidence for their usage in mechanically delivered weapons.

In conclusion, our comparative analysis on lithic techno-typological traits of the Uluzzian and Châtelperronian reveals a significant behavioural gap between these two technocomplexes (Table 3), leaving very little room for any potential techno-cultural connections.

Conclusion

Our techno-typological analysis, using a common vocabulary and framework, and conducted by physically putting the artefacts side-by-side confirms the presence of significant technological divergences between the Châtelperronian and Uluzzian industries. The Châtelperronian is a blade industry with a minor bladelet component all produced by freehand direct percussion, whereas the Uluzzian is a flake-bladelet industry mainly obtained by bipolar-on-anvil percussion — featuring a minor component produced by freehand direct percussion. The direct, first-hand comparison of four assemblages in the same room also settles that using the term 'transitional' to refer to an alleged 'transitional' character of these technologies is not valid nor meaningful — both for the Châtelperronian (as regularly argued since Connet, 2002) and for the Uluzzian (Riel-Salvatore, 2009). The analysis undertaken here has further strengthened the fact that neither of these industries should be called 'transitional' except when referring to the chronological position of these cultural entities, positioned at the transition from the Middle to Upper Palaeolithic.

Table 3 Summary of observed technological differences between the Châtelperronian and Uluzzian at the studied sites

Aspect	Châtelperronian	Uluzzian
Volumetric concepts	Specific volumetric laminar concept, focusing on blade production	Mainly unidirectional debitage
Primary production	Blades (sub-parallel and distal-pointed)	Flakes and flakelets, bladelets, unstandardized products with high variability in shape, section, and dimension, made by bipolar technique
Secondary productions	Bladelet reduction strategies produced on small blocks or flakes/blades	Minor proportion of flakes produced with direct free-hand percussion, sometimes combined with the bipolar technique
Percussion techniques	Marginal percussion with lesser internal percussion, often during certain phases of reduction (e.g. near-discard, maintenance procedures)	Bipolar percussion on anvil as a primary technique
Retouched tools	Châtelperronian points created by abrupt retouch; retouching methods include assisted anvil percussion and 'egrisage' techniques, with retouch from both ventral and dorsal sides	Lunates created by retouching one side and/or the distal and proximal ends; retouching methods include direct, inverse, and retouches from both ventral and dorsal sides
Bladelets	Most often left unretouched; some marginally backed or truncated bladelets	Most often left unretouched; production increases and refines over time, particularly at Cavallo
Functional components	Tools for 'domestic use' (e.g. end-scrapers) and armatures (backed points)	Tools for 'domestic use' and armatures (lunates), with a significant presence of arched backed items

Modelling of the available radiocarbon ages using the latest calibration curve confirms that the Châtelperronian and the Uluzzian likely occupy the same window of time. Despite their likely contemporaneity it seems that there was no techno-cultural connection between the groups producing these industries. An alternative, of course, is that a connection between these groups is instead imperceptible within their material culture. We suggest that the similarity in the usage of stone-tipped weaponry shaped by abrupt retouch is likely the consequence of abrupt retouch being one of the only options available to back a stone point. The shape difference in the morphology of the arched back is likely related to different hafting/delivery systems, with Uluzzian lunates likely being mechanically delivered. Then, the only technological similarities that remain between Châtelperronian and the Uluzzian are the usage of stone-tipped weaponry, the usage of relatively simple bone tools, personal ornaments made of durable materials, and colouring minerals. However, these are characteristics shared by *Homo sapiens* among almost all cultures corresponding to this time period — and covering an enormous geographic distribution.

The absence of technological affinities between the Châtelperronian and Uluzzian suggests that these two technocomplexes reflect groups that were demographically and culturally isolated from each other, despite occupying the same time window, an assumption which is also supported by the geographical distance. We emphasize that what previously seemed like similarities between lunates and Châtelperronian points in fact masks the significant divergences in the technological strategies characterising these industries. The lithic industries are underpinned by two divergent technological trajectories: laminar artefacts derived from direct percussion (Châtelperronian) and unstandardized blanks derived from bipolar-on-anvil percussion (Uluzzian). If there had been contact between the groups, it is reasonable to expect to see some evidence of shared technological tendencies, tool types, and manufacturing techniques in the archaeological record — reflecting an exchange of knowledge and cultural practices. The absence of such shared features and the distinctiveness of each technocomplex underscore the diverse and regionally specific nature of technological behaviours in western Europe between 45 and 40 ka, challenging the utility of broad labels such as 'transitional' industries.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s41982-024-00202-1.

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

Declarations

Conflict of Interest The authors declare no competing interests.

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