

# **A critical assessment of the Aurignacian: Insights from Fumane Cave in northern Italy**

**Dissertation**

der Mathematisch-Naturwissenschaftlichen Fakultät  
der Eberhard Karls Universität Tübingen  
zur Erlangung des Grades eines  
Doktors der Naturwissenschaften  
(Dr. rer. nat.)

vorgelegt von

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Tübingen  
2018

Gedruckt mit Genehmigung der Mathematisch-Naturwissenschaftlichen Fakultät der  
Eberhard Karls Universität Tübingen.

Tag der mündlichen Qualifikation:

19.12.2018

Dekan:

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## ACKNOWLEDGMENTS

This PhD thesis is the culmination of almost eight years of study and life experiences that have broadened my horizons and allowed me to live the “European Dream” firsthand, which for many is just a chimera not worth pursuing. A PhD in archaeology is a dangerous hazard and these pages might represent either my definitive farewell to the field or the beginning of an exciting research career. I am, however, convinced that I learned a great deal studying our past. In this section I would like to thank all those people that are part of this microcosm.

First of all, I wish to thank my main supervisor, Nicholas J. Conard, for giving me the opportunity to conduct my doctoral research at the University of Tübingen and supporting this project from the very beginning. Without his help and advice, I would not have accomplished the results I had set myself. I am also very thankful to Michael Bolus, my second supervisor, whose constructive advice and deep knowledge were fundamental in helping me achieve a more critical view of Paleolithic archaeology and lithic technology.

The principle empirical basis of this thesis is provided by the site of Fumane Cave, excavated by the University of Ferrara under the supervision of Marco Peresani. I am thus deeply grateful to him for trusting me and providing me with the opportunity to conduct my research on the Aurignacian assemblages of such an important site since the beginning of my master’s degree in Prehistory and Quaternary Sciences. Without the openness that distinguishes him as a scholar, I would have not been able to conduct my early research and excavation experiences within such an international framework. Furthermore, he was always there when I needed support in writing papers, research projects, and conference papers. Thank you, Prof!

A special thank goes to my bachelor supervisor at the University of Rome II, Mario Federico Rolfo. If I got interested in human prehistory and evolution in the first place, it is mostly because of his passion and outstanding teaching skills.

Furthermore, I would like to express my gratitude to several other people that contributed and supported this PhD project. Thanks to Marie Soressi and Morgan Roussel for providing me with the opportunity to work on the site of Les Cottés and helping me through my first steps in the research environment and peer-reviewing system. Many thanks to Christian Normand for allowing me to

study the Protoaurignacian industry from Isturitz, but also to François Bon and Nicholas Teyssandier for supervising my research during my staying at the University of Toulouse. I wish to thank Fabio Negrino and Julien Riel-Salvatore for supporting me and being an inspiration for my own research, and Maurizio Gatta for the fruitful discussions (but especially for being a good friend).

I am indebted to all my colleagues at the University of Tübingen for being there every time I needed them. Among others, I want to particularly thank Guido Bataille, Andreas Taller, Yvonne Tafelmaier, Christopher Miller, Claudio Tennie, Viola Schmid (who also translated the summary of this thesis in Österreichisches Deutsch), Patrick Cuthbertson, Giulia Toniato, Gregor Bader, Manuel Will, Jens Frick, Andrew Kandell, Keiko Kitagawa, Gillian Wong, Patrick Schmidt, Mima Batalovic, and Harald Floss.

I would also like to express my gratitude to all anonymous reviewers and journal editors that have greatly contributed in improving the quality of the research articles that form this PhD thesis. As recently noted by the editor of *Lithic Technology*, Grant McCall (2018): “We need peer review because it makes the discourse in our field enormously better”.

These lines are dedicated to all those people – that I will not list here – that have crossed my path during this “pilgrimage” and left a piece of themselves in my memory. Also, I have been lucky enough to meet good friends here in Tübingen. Thanks particularly to Tommaso Mori and Fotios A. Karakostis for the great time we spent together.

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I DEDICATE THIS THESIS TO MY FAMILY. THANKS FOR ACCEPTING MY DISTANCE AND FOR PROVIDING ME WITH YOUR UNCONDITIONAL LOVE AND TRUST. I WILL NEVER BE ABLE TO REPAY YOU FOR THAT. AND TO MY GIRLFRIEND, ELENA, WHO SUPPLIED THE NECESSARY LOVE FOR THE LONG TREK AND STIMULATED ME TO OVERCOME THE RATHER PESSIMISTIC VIEW OF LIFE I HAVE AND THAT, IN SOME CASES, STEMS MY AMBITIONS.

## SUMMARY

The Early Upper Paleolithic marks a turning point in the history of human evolution. The cultural modifications that are observable in the European archaeological record are linked to a complex interaction of behavioral, environmental, and biological components that lead to the definitive colonization of Europe by modern humans, and the extinction and/or assimilation of autochthonous Neanderthal populations. Among the techno-complexes that characterize this period, the Aurignacian has received most of the attention because its development marks the consolidation of a set of cultural traits, such as long-distance mobility patterns, production of standardized lithic implements, variate organic artifacts, figurative arts, and personal ornaments made from a wide range of raw materials. However, research conducted in the last few decades has clearly shown that this portrait is more complex than previously thought. The Aurignacian itself, which is frequently described as the first pan-European techno-complex, is characterized by an important synchronic and diachronic variability that has probably been underestimated because of its direct association with the spread of modern humans into Europe.

In this framework, regional studies and accurate re-evaluation of pivotal sites are fundamental in deconstructing the notion of the Aurignacian and achieving a better resolution of information for prehistoric times. The study of lithic industries remains the principle method of investigation for this period, although the growing field of archaeological sciences is enlarging the tools available to scientists to better interpret a distant world that will never be uncovered in all of its facets and details. Stone tools are thus the main focus of this thesis, although attention is also placed on other artifacts, such as ornamental objects and bone and antler tools, and in the stratigraphic reliability of the findings.

Stone artifact assemblages recovered from five Early Upper Paleolithic cultural units at the site of Fumane Cave (Veneto, Italy) represent the main empirical basis of this doctoral thesis. Furthermore, the results are complemented by the analysis of two additional sites, Isturitz (Basque Country, France) and Les Cottés (Vienne, France), and by a systematic review of all sites containing early evidence of Aurignacian occupation. The study of lithic assemblages follows a holistic approach that

aims to integrate and combine methods belonging to different research traditions, such as reduction sequence and attribute analysis.

The main research questions of this thesis can be divided into two main topics that have been addressed in separate research projects, and are here combined to test the validity of the available reconstructions for the beginning and development of the Aurignacian. The first goal was to reassess the technological definition of the Protoaurignacian starting from an extensive analysis of the lithic assemblages recovered in units A2–A1 from Fumane Cave and further investigate the variability of the techno-complex across its geographic extent. Once the concept of the Protoaurignacian had been carefully revised, the second research phase aimed to describe the development of the Aurignacian in northern Italy by analyzing the whole Aurignacian sequence of Fumane Cave. The outcomes of this assessment were compared to the so-called “Aquitaine Model”, formulated in southwestern France, to test its applicability to the whole European extent.

The first major topic evaluates the reliability of the common definition of Protoaurignacian technology. Results of the empirical investigation and the inter-site comparison confirm that the Protoaurignacian is an industry dominated by bladelet implements, although bladelet production is based on a broad range of reduction strategies that are not related to the dwindling core dimensions as blade production progressed. The dissociation of blade and bladelet productions is thus not only restricted to Early Aurignacian assemblages. Although rather homogeneous from a technological standpoint, the variability of retouched bladelets emphasizes the differences that exist between the Protoaurignacian regional groups. They are expected and, prior to drawing any conclusion, they need to be better evaluated in concert with data obtained from multi-disciplinary studies.

The findings of the second research project reject the recurring practice, well-established among Paleolithic archaeologists, to transfer a regional model to geographically distant case studies. At Fumane Cave, the techno-typological features of the Protoaurignacian clearly persists throughout the stratigraphic sequence with some gradual variations that are, however, less distinct if compared to other sequences. Thus, both the “Aquitaine Model” and the idea according to which the Protoaurignacian vanished at the onset of the Heinrich 4 event are invalidated when applied to northern Italy.

In conclusion, this thesis represents an important step towards a more dynamic understanding of the Aurignacian. The re-evaluation of pivotal sites and the definition of particular regional signatures are yielding new insights into the beginning and development of the Upper Paleolithic. The huge

amount of work that needs to be done rests on the willingness of archaeologists to test the validity of the reconstructions proposed so far, starting from accurate reassessments of the available data and the identification of potential sites to be investigated following a holistic approach that the unstoppable development of the *technium* (intended as an interconnected system of technology vibrating around us: Kelly 2010) is more than ever demanding.



## ZUSAMMENFASSUNG

Das frühe Jungpaläolithikum stellt einen Wendepunkt in der Geschichte der menschlichen Evolution dar. Die kulturellen Veränderungen, die sich anhand der archäologischen Hinterlassenschaften an europäischen Fundstellen abzeichnen, hängen mit einem komplexen Zusammenspiel von Verhaltens-, Umwelt- sowie biologischen Komponenten zusammen, die zur endgültigen Durchsetzung des modernen Menschen und zur Ausrottung und/oder Assimilation autochthoner Neandertalerpopulationen führten. Von den Technokomplexen, die diese Periode charakterisieren, wurde dem Aurignacien die meiste Aufmerksamkeit zuteil, weil seine Entwicklung die Verankerung einer Reihe kultureller Eigenschaften, wie die Mobilitätsmuster auf weite Strecken, die Herstellung von standardisierten Steinwerkzeuge, diversen organischen Artefakten, figürlicher Kunst und persönlichen Schmuckgegenständen aus einer Vielzahl von Rohstoffen, kennzeichnet. Die in den letzten Jahrzehnten durchgeführte Forschung hat jedoch deutlich gezeigt, dass dieses Bild komplexer ist als bisher angenommen. Das Aurignacien selbst, das häufig als erster paneuropäischer Technokomplex beschrieben wird, zeichnet sich durch eine wichtige synchrone und diachrone Variabilität aus, die wahrscheinlich wegen ihrer direkten Verbindung mit der Ausbreitung des modernen Menschen nach Europa unterschätzt wurde.

In diesem Rahmen sind regionale Studien und eine akkurate Neubewertung der zentralen Fundorte von grundlegender Bedeutung, um die Auffassung über das Aurignacien auseinanderzunehmen und eine bessere Auflösung prähistorischer Zeiten zu schaffen. Die Erforschung lithischer Inventare verbleibt die Hauptuntersuchungsmethode für diese historische Phase, obwohl durch den wachsenden Bereich der archäologischen Wissenschaften den Forschern erweiterte analytische Werkzeuge zur Verfügung gestellt werden, um eine ferne Welt besser zu interpretieren, die niemals in all ihren Facetten und Details aufgedeckt werden wird. Steinwerkzeuge stehen daher im Mittelpunkt dieser Arbeit, wobei auch andere Artefakte, wie Schmuckstücke und Knochen- sowie Geweihwerkzeuge, und die stratigraphische Verlässlichkeit der Funde berücksichtigt werden.

Die Steinartefaktinventare aus fünf frühjungpaläolithischen Kulturschichten der Fundstelle Fumane-Höhle (Veneto, Italien) stellen die wichtigsten empirischen Grundlagen dieser Doktorarbeit dar. Darüber hinaus werden die Ergebnisse durch die Analyse von zwei weiteren Fundstellen, Isturitz (Baskenland, Frankreich) und Les Cottés (Vienne, Frankreich), und durch eine systematische

Begutachtung aller Fundstellen, die frühe Hinweise auf Aurignacien-Besiedlungen umfassen, vervollständigt. Die Untersuchung von Steinartefaktinventaren folgt einem ganzheitlichen Ansatz, der darauf abzielt Methoden unterschiedlicher Forschungstraditionen, wie die *chaîne opératoire*-Methode und die Attributanalyse, zu integrieren und zu kombinieren.

Die zentralen Forschungsfragen dieser Arbeit lassen sich in zwei Hauptthemen aufteilen, die in unterschiedlichen Forschungsprojekten behandelt wurden und hier zusammengefasst werden, um die Gültigkeit der verfügbaren Rekonstruktionen für den Beginn und die Entwicklung des Aurignacien zu testen. Das erste Forschungsziel verfolgte ausgehend von einer umfassenden Analyse der Steinartefaktinventare der Schichten A2-A1 aus Fumane die Definition des Proto-Aurignacien von einem technologischen Standpunkt neu zu bewerten und des Weiteren die Variabilität des Technokomplexes über sein geographisches Ausdehnungsgebiet hinweg zu untersuchen. Nachdem das Konzept des Proto-Aurignacien sorgfältig überarbeitet worden war, zielte die zweite Forschungsphase darauf ab, die Entwicklung des Aurignacien in Norditalien durch die Analyse der gesamten Aurignacien-Abfolge von Fumane zu beschreiben. Die Ergebnisse dieser Auswertung wurden mit dem so genannten "Aquitaine-Modell", das in Südwestfrankreich ausgearbeitet wurde, verglichen, um seine Anwendbarkeit auf den gesamten europäischen Erstreckungsbereich zu testen.

Das erste Hauptthema bewertet somit die Beständigkeit der gemeinsamen Definition des Proto-Aurignacien-Technokomplexes. Die Ergebnisse der empirischen Untersuchung und der Vergleich von verschiedenen Fundstellen bestätigen, dass das Proto-Aurignacien eine Steinartefaktindustrie darstellt, die von Lamellen dominiert wird, wobei die Herstellung der Lamellen auf einem breiten Spektrum an Abbaustrategien beruht, die nicht mit verringerten Kerndimensionen fortgeschrittener Klingenproduktion in Zusammenhang stehen. Die Abgrenzung von Klingen- und Lamellenherstellung beschränkt sich somit nicht nur auf *Aurignacien ancien*-Inventare. Obwohl die beiden Technokomplexe von einem technologischen Standpunkt aus gesehen relativ homogen sind, unterstreicht die Variabilität der retuschierten Lamellen die Unterschiede, die zwischen den regionalen Gruppen des Proto-Aurignacien existieren. Diese treten erwartungsgemäß auf und müssen vor dem Ziehen voreiliger Schlüsse im Einklang mit den Daten aus multidisziplinären Studien besser eingeschätzt werden.

Die Ergebnisse des zweiten Forschungsprojekts weisen die stark bei Archäologen aus der Altsteinzeitforschung etablierte Routine ab, ein regionales Modell auf geographisch weit entfernte

Fallstudien zu übertragen. In Fumane bestehen die techno-typologischen Merkmale des Proto-Aurignacien eindeutig die gesamte stratigraphische Abfolge hindurch mit einigen graduellen Schwankungen, die jedoch verglichen mit anderen Sequenzen weniger ausgeprägt sind, fort. Daher besitzen sowohl das "Aquitaine-Modell" als auch die Idee, dass das Proto-Aurignacien zu Beginn des Heinrich 4-Event verschwunden ist, für Norditalien keine Gültigkeit.

Zusammenfassend kann diese Doktorarbeit als ein wichtiger Schritt zu einem dynamischeren Verständnis des Aurignacien gesehen werden. Die Neubewertung von Referenzfundstellen und die Definition von bestimmten regionalen Signaturen liefern neue Einblicke auf den Beginn und die Entwicklung des Jungpaläolithikums. Die große Menge an Arbeit, die noch getan werden muss, liegt an der Bereitschaft der Archäologen, die Gültigkeit der bisher vorgeschlagenen Rekonstruktionen zu testen; ausgehend von akkuraten Neubewertungen der verfügbaren Daten und der Identifizierung potenzieller Fundstellen, die durch einen ganzheitlichen Ansatz analysiert werden können, den die unaufhaltsam Entwicklung des Technium (das als ein miteinander vernetztes, um uns herum pulsierendes Technologiesystem verstanden wird: Kelly 2010, 11f.) mehr als je zuvor beansprucht.

## LIST OF PUBLICATIONS

### i.) ACCEPTED PUBLICATIONS

- a) **Falucci, A.**, Conard, N. J., Peresani, M. (2017) A critical assessment of the Protoaurignacian lithic technology at Fumane Cave and its implications for the definition of the earliest Aurignacian. PLoS ONE 12(12): e0189241. DOI:10.1371/journal.pone.0189241. (APPENDIX i.a).
- b) **Falucci, A.** & Peresani, M. (2018) Protoaurignacian Core Reduction Procedures: Blade and Bladelet Technologies at Fumane Cave. Lithic Technology 43:125-140. DOI:10.1080/01977261.2018.1439681. (APPENDIX i.b).
- c) **Falucci, A.**, Peresani, M., Roussel, M., Normand, C., Soressi, M. (2018) What's the point? Retouched bladelet variability in the Protoaurignacian. Results from Fumane, Isturitz, and Les Cottés. Archaeological and Anthropological Sciences 10:539–554. DOI:10.1007/s12520-016-0365-5. (APPENDIX i.c).
- d) Caricola, I., Zupancich, A., Moscone, D., Mutri, G., **Falucci, A.**, Duches, R., Peresani, M., Cristiani, E. (2018) An Integrated Method for Understanding the Function of Macro-Lithic Tools. Use wear, 3D and Spatial analyses of an Early Upper Palaeolithic assemblage from North Eastern Italy. Manuscript accepted to PLoS ONE. (APPENDIX i.d).

### ii.) SUBMITTED MANUSCRIPTS

- e) **Falucci, A.**, Conard, N. J., Peresani, M. (submitted) Breaking through the Aurignacian frame: A re-evaluation on the significance of regional variants during the Early Upper Paleolithic as seen from a key record in southern Europe. Journal of Anthropological Archaeology. (APPENDIX i.e).

## PERSONAL CONTRIBUTION

Description of the extent and significance of the personal contribution according to § 6,2 PromO of the University of Tübingen. Numbers follow the order in LIST OF PUBLICATIONS.

- a) I was first and corresponding author, as well as the main person responsible for conceiving the study design, conducting the reported research and lead author of writing the manuscript. The co-authors helped in writing the manuscript (Marco Peresani, Nicholas J. Conard), were the principal excavators of the archaeological site (Marco Peresani), and oversaw the study as supervisors (Nicholas J. Conard).
- b) I was first author, as well as the main person responsible for conceiving the study design, conducting the reported research, interpretation of data and writing the manuscript. The co- and corresponding author (Marco Peresani), who is the director of excavations at Fumane Cave, helped in writing the manuscript.
- c) I was first and corresponding author, as well as the main person responsible for conducting the reported research, interpretation of data, and writing the manuscript. The study design was conceived together with Marco Peresani and Marie Soressi, who oversaw the study as supervisors. The co-authors helped in writing the manuscript and were the directors of excavations at the sites of Fumane Cave (Marco Peresani), Isturitz (Christian Normand), and Les Cottés (Marie Soressi and Morgan Roussel).
- d) I was supporting co-author responsible for part of the data collection and analyses, and wrote the manuscript together with the other authors.
- e) I was first and corresponding author, as well as the main person responsible for conceiving the study design, conducting the reported research and lead author of writing the manuscript. The co-authors helped in writing of the manuscript (Marco Peresani, Nicholas J. Conard), were the principal excavators of the archaeological site (Marco Peresani), and oversaw the study as supervisors (Nicholas J. Conard).

# INTRODUCTION

## BACKGROUND OF THE RESEARCH

There are few European techno-complexes that have received the same attention as the Aurignacian. This cultural group represents the best known evidence of the definitive spread of anatomically modern humans (AMHs) across Europe (Conard 2002; Mellars 2006a; Davies 2007; Hublin 2015), to the point that the term Aurignacian is perceived by some as a synonymous of AMHs' peopling. In this regard, it is rare to find a paper on the Aurignacian that avoids chronicling AMHs dispersal in the very first paragraphs. The attention and effort placed by prehistoric archaeologists in disentangling its complex synchronic and diachronic variability would have been surely undermined if this association were not made.

However, some researchers believe that the advent of the Aurignacian might be a second wave of AMHs moving across western Eurasia (Hoffecker 2009). The first wave would be associated with the Bohunician, whose material culture is said to be comparable to the Levantine Initial Upper Paleolithic (Skrdla 2003; Bar-Yosef 2012; Nigst 2012; Tostevin 2013). Similar claims have been made for the Uluzzian after the assignment of two teeth to *Homo sapiens* at Cavallo cave (Benazzi et al. 2011; Moroni et al. 2018). The integrity of the Cavallo stratigraphy has, however, been questioned (Zilhão et al. 2015) and further evidence is needed to assess the makers of the Uluzzian in Italy (Benazzi et al. 2014; Peresani et al. 2016; Villa et al. 2018).

To date, the Aurignacian is the sole, undisputed techno-complex associated to AMHs, as suggested by human teeth found in a few stratified sites (Bailey 2006; Bailey et al. 2009; Benazzi et al. 2015). The issue of the supposed link between the Aurignacian and the Ahmarian of the Near East and/or the Baradostian and the Rostamian of Central Asia (e.g. Otte and Kozłowski 2004; Hoffecker 2009; Tsanova et al. 2012; Tsanova 2013; Ghasidian et al. 2017) is still open to debate, given the current available chronology (Kadowaki et al. 2015; Becerra-Valdivia et al. 2017) and the absence of detailed comparisons between techno-complexes.

The oldest appearances of the Aurignacian are dated roughly between 43–42 ky cal BP and are mainly found along the Mediterranean boundaries and the Danube Basin (Conard and Bolus 2008;

Davies and Hedges 2008; Szmidski et al. 2010b; Douka et al. 2012; Higham et al. 2012; Nigst et al. 2014; Wood et al. 2014; Barshay-Szmidski et al. 2018). Criticisms have been raised over the older dates obtained for the Aurignacian of Central Europe (Zilhão and d'Errico 2003; Banks et al. 2013b; Teyssandier and Zilhão 2018), and particular caution is at the moment required when dealing with the site of Willendorf II (described in: Nigst 2012; Nigst and Haesaerts 2012; Nigst et al. 2014).

The Aurignacian was named after the discovery of the eponym site (abri d'Aurignac) in the Haute-Garonne by Édouard Lartet in 1860 (see a research history in: Bon 2006; Le Brun-Ricalens and Bordes 2007). Systematic research started only in the 20<sup>th</sup> Century and it was mainly conducted in the northern Aquitaine Basin, southwestern France (Breuil 1912; Peyrony 1933, 1935; Garrod 1938; de Sonneville-Bordes 1960; Delporte 1964, 1968; Djindjian 1986, 1993). In the last decades, a constantly growing database has permitted researchers to define the main features of the Aurignacian phenomenon and various attempts have been made to understand its variability (Laplace 1966; Hahn 1977; Bon 2002; Le Brun-Ricalens 2005b; Bar-Yosef and Zilhão 2006; Bon et al. 2006). However, given that most of the research has been conducted in the Aquitaine Basin, a region that had a prominent role in the construction of Paleolithic research itself (Groenen 1994), a slightly biased narrative has been constructed (Anderson et al. 2018).

The Aurignacian was initially defined by the association of stone and organic tools discovered in few Aquitaine reference sequences, which led to the identification of four successive stages (Peyrony 1933, 1935; de Sonneville-Bordes 1960; Demars 1992; Demars and Laurent 1992; Bordes 2006). A further stage, the "Aurignacian 0", was used by Delporte (1968) to label industries prior to the Peyrony's Aurignacian I. The most important study on these assemblages was conducted by Laplace (1966). It was him who introduced the term "Protoaurignacian" after the analysis of several sites distributed in the French Pyrenees and the Mediterranean regions of Spain and Italy. Typological definitions of the different Aurignacian stages were only subsequently complemented by technological studies (Le Brun-Ricalens 1993; Bon 2002; Bon and Bodu 2002; Bordes 2002; Chiotti 2005; Le Brun-Ricalens 2005b; Bon et al. 2010).

Research has primarily focused on the earliest phases, which are known as Early Aurignacian (EA) and Protoaurignacian (PA; Bon et al. 2010; Teyssandier et al. 2010). According to some, these two variants have developed in distinct geographic domains and have spread across Europe along different routes. The Danube Basin represented a preferential corridor for the diffusion of EA industries, while the Mediterranean coastline was followed by makers of PA industries (Conard and

Bolus 2003; Mellars 2004, 2006b; Bertola et al. 2013; Hublin 2015). To others, they are instead successive technical traditions reflecting different AMHs' settlement dynamics (Bon 2005; Anderson et al. 2015). In western Europe, the PA is stratigraphically placed below the EA when both industries are documented (Arrizabalaga and Altuna 2000; Bon 2002; Bordes 2006; Normand et al. 2007; Arrizabalaga et al. 2009). In this regard, a recent study has concluded that the adaptive shift that marked the beginning of the EA and the disappearance of the PA over the extension of the European subcontinent was triggered by the deterioration of the environment at the onset of Heinrich Event 4 (H4; Banks et al. 2013b; Banks et al. 2013a; contra: Higham et al. 2013; Ronchitelli et al. 2014). Several scientists have raised criticisms on the validity of this scenario both because of the discard of inconvenient data when running the Bayesian modeling, but also for the strict cultural separation between the two facies (Higham et al. 2013; Ronchitelli et al. 2014; Falcucci et al. 2017). A growing chronological database attests to the beginning of the EA well before the cut-off of ca. 39.9–39.2 ky cal BP and thus a statistical overlap between PA and EA in western Europe (Wood et al. 2014). This is for instance the case of Isturitz (Barshay-Szmidt et al. 2018) and Pataud (Higham et al. 2011).

The previous considerations raise important questions about how these two apparent sister groups relate and if the assumptions that were made are consistent with the available archaeological data (Conard and Bolus 2015). According to the most used reconstructions, PA and EA assemblages can be easily divided according to some technological features that will be briefly summarized. The PA signature is said to lie in the production of blades and bladelets within a single and continuous stone knapping sequence (Bon et al. 2010). Both products are thus obtained from the same core as the result of its progressive reduction (Bon and Bodu 2002). Blades are selected to manufacture endscrapers, burins, and laterally retouched tools. Slender blades, representing the intermediate products between blades and bladelets, are frequently left unretouched. Bladelets are the dominant intention of the lithic production and are described as large, with rectilinear profiles, and are transformed into Dufour sub-type Dufour (Demars and Laurent 1992). The EA is instead characterized by a clear distinction between laminar and lamellar productions as result of a stronger anticipation and planning of different needs (Teyssandier 2008; Anderson et al. 2015). Blades are obtained from unidirectional prismatic cores, while curved bladelets are produced from carinated cores, frequently called "carinated endscrapers" (see a research history in Le Brun-Ricalens 2005a). The latter are said to be scarcely found, or even absent, in PA assemblages (Bordes 2006). Blades are robust, have frequently faceted platforms, and are transformed into laterally retouched tools, strangled blades, and thick endscrapers. These common tools are often modified by the so-called



Aurignacian retouch (de Sonneville-Bordes 1960), which is scalar and invasive due to several re-sharpening stages that occur during repeated use and transport over long distances (Bon 2005). Bladelets are instead produced on-site, as needed, and only few were transformed into small sub-type Dufour by mostly applying an inverse retouch (Le Brun-Ricalens et al. 2009).

Aside from stone tools, historically, the split-based point (SBP) has always been considered a type fossil of the EA (Peyrony 1933, 1935; de Sonneville-Bordes 1960), replaced by other types in successive stages of the Aurignacian (but see: Moreau et al. 2015). This type of organic artifact remains important to the definition of the EA today (Teyssandier 2007; Banks et al. 2013a, b; Teyssandier and Zilhão 2018), although Zilhão (2006) emphasized that bone tools, ornaments, and art should not be included in the basic definition of the Aurignacian, which should be based exclusively on lithic artifacts. Only a small percentage of Aurignacian sites contain SBPs and more generally organic points (Liolios 2006; Doyon 2017). Outside of the Aquitaine and the Swabian Jura, finds are scattered (Tafelmaier 2017). Nevertheless, it is not rare that archaeologists ascribe a cultural unit to the EA based solely on the presence of a SBP (de Sonneville-Bordes 1960; Hahn 1977; Banks et al. 2013a; Tejero and Grimaldi 2015; Teyssandier and Zilhão 2018). Recently, the exclusive association of SBPs with EA assemblages has been questioned and its presence in an archaeological horizon does not in and of itself clarify the cultural attribution (Moreau et al. 2015; Tafelmaier 2017). At Geißenklösterle, for instance, SBPs appear only in the upper Aurignacian horizon (Conard and Bolus 2003; Teyssandier 2007), while at Trou de la Mère Clochette (Szmidt et al. 2010a) and Arbreda (Maroto et al. 1996) SBPs were found in association with lithic assemblages with PA affinities.

Additionally, the EA has produced three-dimensionally formed personal ornaments, figurative representations, occasional finds of mythical imagery, and musical instruments, whereas the PA typically has a more limited range of figurative representations and symbolic artifacts, mostly made from marine shells and teeth (Taborin 1993; Kuhn and Stiner 1998; Conard 2002; Vanhaeren and d'Errico 2006; Zilhão 2007; Broglio et al. 2009; Conard 2009; Higham et al. 2012; White and Normand 2015; Dutkiewicz et al. 2018).

Research outside of southwestern France has often focused on extending the so-called “Aquitaine Model” (Bordes 2006) and its related clear-cut definitions, rather than focusing on achieving refined regional signatures (e.g. Laplace 1966; Hahn 1977; Zilhão and d'Errico 1999; Broglio 2000; Kozłowski and Otte 2000; Otte and Derevianko 2001; Demidenko et al. 2012). However, the growing number of multi-disciplinary analyses and the re-evaluation of some sites are highlighting a greater

technological variability across Europe and revealing several deficiencies in the commonly used chrono-cultural reconstruction (Conard and Bolus 2006; Sitlivy et al. 2012; Bataille 2013; Conard and Bolus 2015; Falcucci et al. 2017; Tafelmaier 2017; Bataille and Conard 2018; Bataille et al. 2018). The main goal of this PhD is therefore to contribute to the understanding of the first stages of the Aurignacian by focusing on a pivotal site in northeastern Italy: Fumane Cave (Bartolomei et al. 1992a). In agreement with Bon (2002), I believe in fact that the definition of high-resolution regional signatures will be beneficial in achieving a better understanding of the development of the Aurignacian and, more generally, of the beginning of the Upper Paleolithic with its related anthropological questions.

The Aurignacian in the southern Alpine range and the Italian Peninsula is known from several stratified and open-air sites and surface collections. They are distributed in different environmental settings, close to the modern coastlines and up to Alpine and Apennine regions (Palma di Cesnola 2001; Mussi 2002). The Italian research tradition was strongly influenced by the so-called *typologie analytique* developed by G. Laplace in the late sixties and seventies (Laplace 1966, 1977; Plutniak and Tarantini 2016) and detailed technological assessments have been conducted only in a few cases (e.g. D'Angelo and Mussi 2005; Dini et al. 2010; Dini et al. 2012; Bertola et al. 2013). Among those, Fumane Cave is the site that has received the attention, although research has mostly focused on the earliest manifestations of the PA (Broglio et al. 2005; De Stefani et al. 2012; Bertola et al. 2013). The potential of its long stratigraphic sequence, with evidence of human occupations that both pre- and postdate the occurrence of H4, is far from being exhausted. Besides Fumane Cave, evidence of Aurignacian sites in the Venetian region is poor and difficult to evaluate. At Tagliente Rockshelter, located in the western Monti Lessini, an Aurignacian assemblage was found within a stratigraphic unit that was partially mixed with Mousterian and Epigravettian implements (Bartolomei et al. 1982). At Paina, in the Colli Berici, few Aurignacian lithic implements were found together with a fragmented organic point (Bartolomei et al. 1988).

Generally, it seems that the PA persisted longer in Italy than in other regions (Palma di Cesnola 2001; Mussi 2002; Bon et al. 2010; Anderson et al. 2015). For this reason, Palma di Cesnola (2001) and Mussi (2002) proposed the prefix Proto- be abolished because it gives the impression that assemblages included in this group have an absolute chrono-stratigraphic significance with respect to others, as for instance is the case in western Europe (Bordes 2006; Bon et al. 2010). Fewer “typical” Aurignacian assemblages exist and have been sorted mainly by the presence of SBPs and

other organic artifacts (Blanc and Segre 1953; Laplace 1977; Palma di Cesnola 2001; Mussi et al. 2006; Tejero and Grimaldi 2015), although some authors suggested that the two variants be grouped together, given the high resemblance of their main typological features (Gheser et al. 1986). Careful reassessments recently conducted at Bombrini in northwestern Italy (Riel-Salvatore and Negrino 2018a, b) suggest that the PA was a resilient technological system that survived well beyond the H4 and the roughly contemporaneous Campanian Ignimbrite volcanic eruption (see references in: Giaccio et al. 2017). Similar conclusions, even if at a preliminary level, were reached by A. Broglio and the research team of Ferrara University at Fumane Cave (Broglio 1997; Higham et al. 2009).

In this doctoral thesis, a detailed analysis of the lithic technology from five cultural units (A2, A1, D3base, D3*alpha*, and D3ab) of Fumane Cave and a reassessment of organic artifacts therein recovered are presented. Fumane Cave has always been considered a key site for understanding the Middle–Upper Paleolithic transition and the complex processes that led to the demise and final extinction of Neanderthal populations and the spread of AMHs across Europe. The systematic and modern excavations conducted for decades, the presence of a high resolution stratigraphic sequence, and the discovery of modern human remains associated with the earliest PA (Benazzi et al. 2015), allow to shed new light on the cultural dynamics that characterized the Aurignacian in the North-Adriatic region and its relationship with contemporaneous industries on a supra-regional scale.

Specifically, I first focus on the lowermost assemblages A2–A1 to test the current technological definition of the PA. An extensive investigation is conducted by using two combined approaches: reduction sequence and attribute analyses. The variability of the PA is then critically discussed across its geographic extent comparing our results with the available scientific literature and the empirical data on retouched bladelets obtained by the author at the sites of Isturitz, in the Pyrenean region, and Les Cottés, in northern France. The second main goal of this PhD is to investigate the diachronic variability of the Aurignacian at Fumane Cave by comparing A2–A1 to the youngest cultural units D3base, D3*alpha*, and D3ab. Evidence of cultural change and/or stability is used to support or reject the “Aquitaine Model” and, particularly, to test if the PA is followed by assemblages that can be attributed to the EA. Finally, an alternative scenario on the beginning and development of the Aurignacian is discussed in the larger framework of the European subcontinent.

## THE SITE OF FUMANE CAVE AND THE AURIGNACIAN SEQUENCE

Fumane Cave is one of the best known Paleolithic sites of Europe. Besides its undeniable scientific relevance, it is one of the few sites in course of excavations that is accessible to visitors of the Lessinia Park and is part of “Ice Age Europe”; a network of the most important prehistoric heritage sites (<https://www.ice-age-europe.eu/home.html>). This site is a cave complex excavated in dolomitic limestone located along the Vajo di Roncomerlo in the Fumane valley, at the foot of the western Monti Lessini, 350 m. asl. The Monti Lessini are limestone hills on the southern edge of the Venetian Pre-Alps that rise gradually just north of Verona. Their higher regions form a range of broad plateaus at about 1,600 m. asl.

Although the site was first reported in 1884 and part of the stratigraphic section was exposed in 1964, systematic excavations began only in 1988 under the direction of the University of Ferrara and the University of Milan (Bartolomei et al. 1992a). Excavations have been carried out at different times and at variable extension beyond the present-day drip-line and in the cave entrance, an area where Middle and Upper Paleolithic levels with well-preserved Mousterian and PA living-floors have been brought to light in a good state of preservation. Nowadays, the site is still in course of excavation on a regular basis under the direction of Prof. Marco Peresani, from the University of Ferrara.

The current morphology of the site is a result of the combined action of huge collapses, which during the Late Pleistocene affected the massive rock banks and the dismantling phases mostly caused by freezing and thawing. Details about the stratigraphic sequence, paleoclimatic significance, as well as its paleontological and cultural content, are available in numerous publications (Bartolomei et al. 1992a; Cassoli and Tagliacozzo 1994; Broglio et al. 2003; Broglio et al. 2005; Broglio and Dalmeri 2005; Higham et al. 2009; Peresani 2012; Benazzi et al. 2015; López-García et al. 2015; Peresani et al. 2016; Falcucci et al. 2017). A main cave and two associated tunnels preserve a finely-layered sedimentary succession spanning the late Middle Paleolithic and the Early Upper Paleolithic (Figure 1), with features and dense scatters of remains in units A11, A10, A9, and A6–A5 (Mousterian: Peresani 2012; Peresani et al. 2013), A4 and A3 (Uluzzian: Peresani et al. 2016), A2–A1 (Protoaurignacian: Broglio et al. 2005; Bertola et al. 2013; Cavallo et al. 2017; Falcucci et al. 2017; Falcucci and Peresani 2018; Falcucci et al. 2018), D6, D3, and D1c (Aurignacian lato sensu: Broglio

and Dalmeri 2005), and D1d (Gravettian: Bartolomei et al. 1992b). Currently, layers have been extensively excavated at the entrance of the cave and partly excavated in the cave mouth.



**Figure 1.** The stratigraphic sequence of Fumane Cave at the entrance of tunnel A with evidence of late Mousterian (A6–A5), Uluzzian (A4–A3) and (Proto)Aurignacian layers (A2–D3). Photo: A. Léone.

In layers A4 and A3, the Uluzzian occupations date to later than 43.6–43.0 ky cal BP (Higham et al. 2009). The transition from the final Mousterian took place in a relatively short time, as the beginning of the Uluzzian is chronologically indistinguishable from the final Mousterian (Douka et al. 2014). The Uluzzian lithic technology is primarily oriented towards flake production. Technological innovations are rooted in a clear Mousterian cultural context (Peresani et al. 2016). In layer A4, flakes are obtained from centripetal cores, following Levallois concepts. Scrapers of varied morphologies are the prevailing tool type. Layer A3 marks the definitive separation of the Uluzzian from the Mousterian. In this layer, flakes are produced through several methods and bladelet production increases slightly. The main tool types are scrapers, splintered pieces, and backed flakes.

Unit A2 dates the appearance of the Aurignacian to 41.2–40.4 ky cal BP (Higham et al. 2009; Higham 2011). Its boundary with layer A3 is clearly marked by a dispersion of ocher over a large area (Cavallo et al. 2017; Cavallo et al. 2018) and by a considerable change in the content of anthropogenic material (Broglia et al. 2009). In the cave entrance, unit A2 is covered by A1, a thin anthropic level with horizontal bedding which makes it indistinguishable from A2 in the cave mouth. A2 thus extends throughout the whole cave.

Post-depositional processes, due to frost activity, affected layers A3 and A2 in the easternmost part of the cave entrance and allowed PA materials (lithics, bones, and pierced shells) to infiltrate into A3 (Peresani et al. 2016). Stratigraphic deformations have been reported in the inner eastern side of the cave mouth, where layer A2 was tilted and compressed towards the cave wall, forming a pronounced fold. Despite this deformation, during the excavation layer A2 appeared to be a clearly discernible sedimentary body preserved with variable thickness from a few centimeters to 10 centimeters, due to its dark-brownish color, its texture and its high charcoal, bone and stone implement density, as well as the occurrence of features (i.e. hearths, post-holes, and toss-zones) mostly located at the cave entrance (Peretto et al. 2004; Broglia et al. 2006a; Broglia et al. 2006b). Some of these hearths were located within shallow basins excavated at the edges of the Uluzzian (Peresani et al. 2016) and final Mousterian layers below, thus producing possible dispersion of a few flaked stones in the A2 and A1 assemblage.

In the front part of the cave, a series of layers from the stratigraphic complex D3 correspond to the youngest Aurignacian phase. From a sedimentological point of view, the macro-unit D is mostly formed of very coarse materials (boulders and stones) collapsed from the cave walls that progressively sealed the cave entrance. These events correspond to a long period of climatic deterioration (Broglia et al. 2003; López-García et al. 2015), where the traces of human presence become less dense than in A2 and A1. Archaeological materials were, however, found in layers embedded in macro-unit D. Due to differences in the composition of the sediments and excavation history, the stratigraphy of the D complex in the cave mouth is different than that of the cave entrance. At the entrance, D3 was divided into several units. At the base of the sequence, D3base was a thin layer that marked the transition with A1. Above D3base, two layers were recognized and then considered as a single accumulation event. They are D3d and D3*alpha* and, in this paper, they will be grouped together and referred to as D3*alpha*. Here, human activity is the most evident. D3d stands for *Dallage* and was initially restricted to a deliberate human feature composed of a

series of angular, small sized (ca. 10 cm) blocks sub-horizontally arranged to form a regular pavement with a diameter of ca. 120 cm bounded by boulders. In D3*balpha*, a combustion feature was uncovered together with an accumulation of several lithic artifacts and a split-based bone point (Broglia et al. 2006a). A radiocarbon date produced from a sample taken from the combustion feature suggests that this event took place at about 38.9–37.7 ky cal BP (95,4% of reliability), thus after the H4 (Higham et al. 2009). The top of the D3 complex is divided into two spits: D3a and D3b. These are the most extended deposits, although the archaeological materials are less numerous compared to the lower units. During excavation, D3a was considered almost sterile. Sediments were quickly removed and sieved only for samples from a few square meters. The number of small lithics, such as bladelets, may therefore be slightly underestimated. Here, D3a and D3b are considered as a single unit named D3ab. The consistency of the assemblages is secured by the lack of any evidence supporting massive percolation of stone implements from and to the D3 complex. Clear boundaries between stratigraphic layers, as well as the lack of significant deformations in a large part of the excavated area, suggest that perturbations between the Aurignacian occupations should be excluded.

In the cave mouth the situation looks very different and correlation to the previously described units is problematic. They are therefore excluded from this study. In this area, due to post-depositional processes that are under examination, the eastern part of the upper sequence appears to be different than that of the western portion. Above a loose stony layer (D6), a thick layer named D3+D6 was described. In the western side, layer D6 was instead covered by a sequence comprising a thin level named D3a+b and the stratigraphic complex D1. The latter was divided in different units, among which D1c was described as Aurignacian, D1d as Gravettian (Bartolomei et al. 1992b; Broglia 1997), and D1e as sterile.

Macro- and micro-faunal remains shed light on the Aurignacian ecological context. They show an association between forest fauna and cold and open habitat species typical of the alpine grassland steppe above the tree line (Cassoli and Tagliacozzo 1994; Broglia et al. 2003; Gurioli et al. 2005). This context reflects a clear climatic cooling with relative decreases in woodland formations. Two main phases were detected: the first (A2–A1) was a cold and dry phase probably related with H4 event, while the second (D3 complex) was a cold and humid phase. The formation of D1d is instead characterized by a warm period. Finally, Heinrich event 3 was identified in D1e (López-García et al. 2015).

## OBJECTIVES AND EXPECTED OUTPUT OF THE DOCTORAL RESEARCH

The principal objective of this doctoral research is to assess the variability in lithic technology and behavior during the first manifestations of the Aurignacian. The empirical basis is given by lithic assemblages from the site of Fumane Cave (Veneto, Italy), which contains evidence of several human occupations during the time span of the European Aurignacian (Broglia et al. 2003; Higham et al. 2009).

Although the available synthesis of the Aurignacian diachronic development (e.g. Bon et al. 2010) is widely accepted and used in a pan-European perspective, some authors question the clear-cut definitions of its earliest manifestations (Proto- and Early Aurignacian) and, more generally, the validity of the “Aquitaine Model” (e.g. Bordes 2006) outside of southwestern France (e.g. Davies 2001; Conard and Bolus 2006; Sitlivy et al. 2014a; Tafelmaier 2017; Bataille and Conard 2018; Bataille et al. 2018). In this regard, the site of Fumane Cave provides a rare opportunity to test the applicability of this model, and the validity of the claims against it, starting from a high-resolution and reliable stratigraphic sequence that contains rich and well-preserved lithic assemblages and organic artifacts. As pointed out by Conard and Bolus (2015): “The fieldwork at Fumane is one of the flagship excavations in the European Paleolithic”.

Previous studies on the lithic assemblages (Bertola 2001; De Stefani 2003; Broglia et al. 2005; De Stefani et al. 2012; Bertola et al. 2013) have the merits of having described the variability of bladelet productions in the PA even if additional quantitative research was needed to discuss in detail the procedures and the objectives of the stone knapping, but also the diachronic development of the Aurignacian throughout the stratigraphic sequence. The goals and expected output of this thesis can be summarized as follows:

- i.) To give a more comprehensive definition of the PA;
- ii.) To address the techno-typological variability of the PA across its geographic extent;
- iii.) To study the development of the Aurignacian at Fumane Cave and more generally in northern Italy;
- iv.) To investigate the relationships that exist between the PA and its apparent sister group, the EA, and thus test the applicability of the Aquitaine reference model over the extension of the European subcontinent.



## MATERIALS

The empirical basis of this dissertation and the published papers is mainly provided by lithic assemblages of five cultural units from the site of Fumane Cave, northeastern Italy. The study on the variability of retouched bladelets across the PA geographic extent was complemented by retouched bladelet datasets from two French sites: Isturitz in the Basque Country (Normand 2006) and Les Cottés in the Vienne region (Roussel and Soressi 2013). General descriptions of these latter assemblages, as well as stratigraphic context and dating can be found in Falcucci et al. (2018). Concerning Fumane Cave, two different sampling strategies have been used to tackle the research questions of this doctoral research.

### THE SAMPLE USED IN THE STUDY OF THE EARLIEST CULTURAL UNITS A2–A1

The purpose of the first research project was to address critically the techno-typological traits of the PA, since its internal variability is frequently neglected in the scientific literature. The empirical base was given by the lithic assemblages recovered in units A2 and A1 at Fumane Cave. Early in the study it became clear that these units did not show significant differences on typological and technological grounds. Thus, given the purpose of the work and the fact that they appear to be chronologically indistinguishable (Higham et al. 2009), I decided to consider them as a single analytical unit.

In order to conduct an extensive technological analysis, all lithic artifacts greater than 1.5 cm in maximal dimension were counted (A2=22,212; A1=4,153 items) and divided according to several technological classes and the sub-square of provenience. The minimal number of flaked products (MNFP), which was calculated by taking into account only blanks with preserved butts, permitted a better estimation of the amount of lithics. This step was judged necessary because no previous quantitative analysis of the lithic assemblage had been undertaken. The data gained during this first phase was used to evaluate the frequency of technological categories and the amount of cortex on artifacts. The sampling procedure was based on the dispersion of lithic materials in the squares and an evaluation of the stratigraphic context, as described in the excavation notebooks. Only the innermost part of the cave, affected by a stratigraphic deformation (see above), was excluded from

the analysis. Seven square meters were selected. They are located in different sectors of the cave and are close to the main combustion features. Two adjacent square meters were analyzed in those sectors with the highest concentration of lithics.

A2–A1 is an assemblage dominated by blades and bladelets. For this reason, all blades and bladelets greater than 1.5 cm in maximal dimension, regardless of the degree of fragmentation, were analyzed, while only flakes with preserved butts greater than 2.0 cm in maximal dimension were fully analyzed. Furthermore, the extent of the cave was sampled in order to isolate and include in the database all cores, tools and tool fragments, all complete and almost complete blades and bladelets, and all by-products deemed to have had a significant role in the reduction process. This strategy was considered effective to avoid potential biases in the reconstruction of the knapping system. Therefore, I analyzed a total of 7,866 artifacts.

## THE SAMPLE USED TO INVESTIGATE THE DIACHRONIC VARIABILITY OF THE STRATIGRAPHIC SEQUENCE

In this case, the studied sample has been restricted to all materials recovered in the front part of the cave, where the stratigraphy is fine grained and the D3 complex is divided into several units. The cave mouth was excluded given that correlations between the D3 units and the layers described in this area are still under revision. The Aurignacian deposits in the external part of the cave have been excavated since the beginning of fieldwork at the site. Most of the studied materials were recovered from 1988 to 2006 under the supervision of A. Broglio and M. Peresani. I consider five cultural units in this study: A2, A1, D3base, D3*alpha*, and D3ab. The number of lithic artifacts recovered in the lowermost layers is much higher than that available for the upper layers (Table 1). During the formation of A2 and A1 the occupation of the site was more intense, while the D complex accumulated during a period in which the cave started to collapse, which resulted in a faster formation of the deposit. However, cores, blanks, tools, and by-products of the reduction sequences are available for all units, which allows for an accurate technological comparison. Given that the aim of this study was a diachronic comparison between the different assemblages, units A2 and A1 have been considered here as two different analytical units.

For A2 and A1, the sampling procedure and recorded data was based on our previous study, but all artifacts belonging to the back of the cave were excluded. Several square meters were selected, most of them located in the vicinity of the combustion features identified during the excavations. Given the smaller sample sizes available for the uppermost units (D3base, D3*alpha*, and D3ab), the whole extension of the cave entrance was sampled and all recovered artifacts greater than 1.5 cm in maximal dimension were fully analyzed.

**Table 1.** Overview of the studied assemblages used for the second research project divided according to the main lithic classes. Percentages are given in brackets.

	Blank	Tool	Core	Angular Debris	Tested nodules	Total
D3ab	382 (73.0%)	70 (13.4%)	17 (3.3%)	54 (10.3%)	-	523
D3 <i>alpha</i>	561 (78.2%)	106 (14.8%)	12 (1.7%)	38 (5.3%)	-	717
D3base	830 (79.5%)	144 (13.8%)	5 (0.5%)	65 (6.2%)	-	1044
A1	3235 (78.2%)	648 (15.7%)	34 (0.8%)	219 (5.3%)	1 (-)	4137
A2	8055 (77.2%)	1458 (14.0%)	34 (0.3%)	883 (8.5%)	4 (-)	10434
Total	13063	2426	102	1259	5	16855

Furthermore, a reassessment of the organic tools, painted rocks, and ornamental objects was conducted. This was possible by using the published literature and the datasets compiled by other researchers and made available by the director of the excavations (Marco Peresani). By doing so, it was possible to quantify the number of artifacts within each of the studied unit, locate them in the square and sub-square of provenience, and finally evaluate the stratigraphic reliability of the findings with the support of the observations recorded on the excavation notebooks.

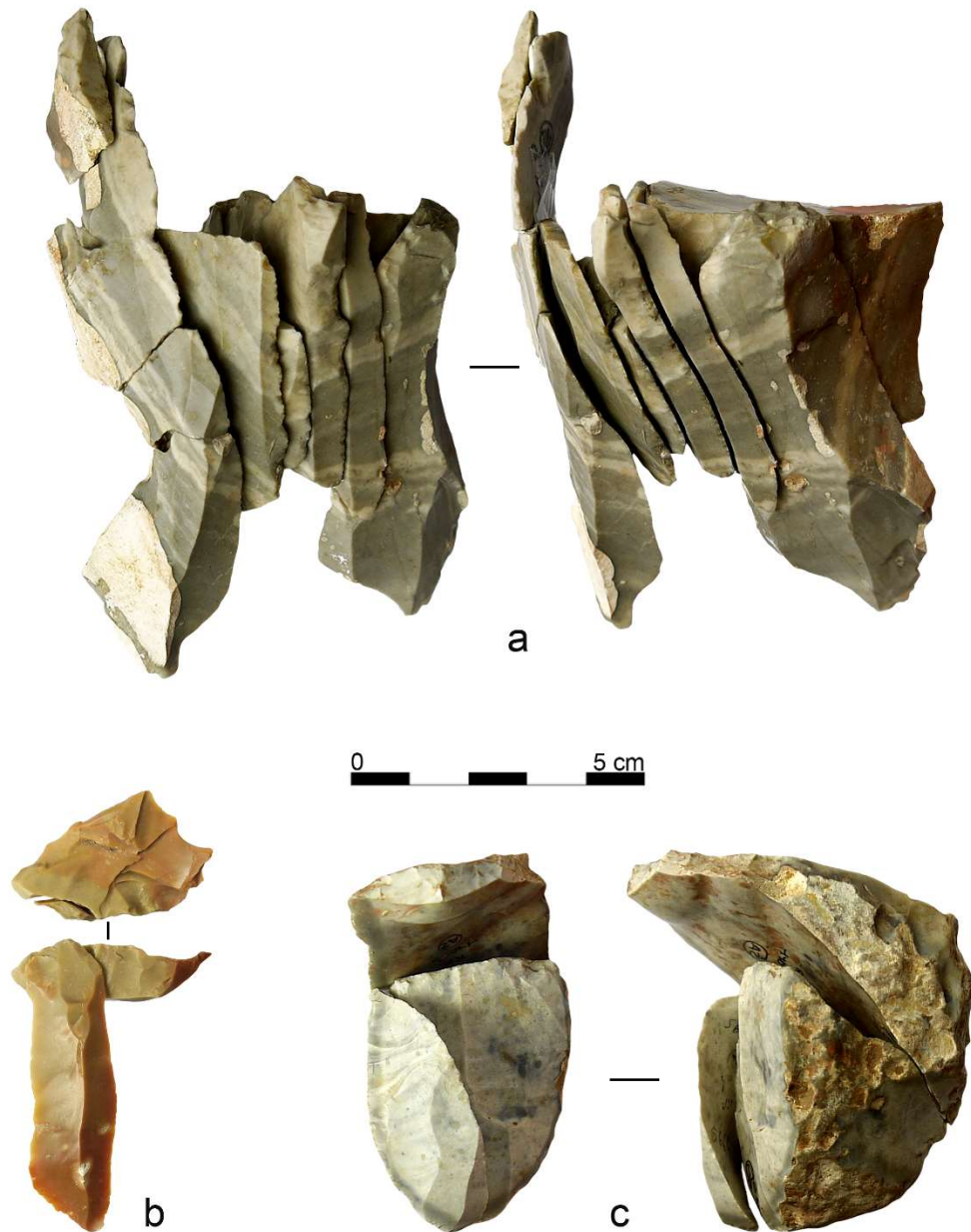
## METHODS

The holistic approach to lithic analyses used in this PhD thesis aimed to integrate methods belonging to different research traditions, mainly the French and the north American, often considered as two opposed methodological approaches. Instead, when combined, they demonstrate to be a powerful tool to characterize the technological system of a given lithic assemblage (e.g. Zwyns 2012a; Conard and Will 2015). These methods are described in detail in the published articles, while a brief summary is presented in the following paragraphs.

The reduction sequence approach (Boëda et al. 1990; Inizan et al. 1995; Conard and Adler 1997; Shott 2003; Soressi and Geneste 2011) identifies the methods of core reduction and the stages of knapping, use, and discard of stone artifacts. The attribute analysis (Andrefsky 1998; Odell 2004; Tostevin 2013) instead provides quantitative data on the numerous discrete and metric features that can be recorded on individual artifacts. The attributes recorded in the database are based on recent studies that have been shown to be valuable for understanding laminar technologies at the onset of the Upper Paleolithic (e.g. Nigst 2012; Zwyns 2012a). Non-extensive refitting analyses (Inizan et al. 1995) were also conducted throughout the study (Figure 2). They have proven to be particularly valuable to test hypotheses formulated during the analytical process.

Diacritic analyses (Dauvois 1976; Boëda 2001; Roussel 2011; Pastoors et al. 2015) were performed to reconstruct the chronology, the direction of removals, the stages of production on exhausted and initial cores, and short sequences of removals on blanks. By doing this, the detailed biography of artifacts was carefully reconstructed to identify the main reduction processes used by knappers. Details on this method and information about the graphic criteria used to produce schematic drawings of cores and blanks can be found in Falcucci and Peresani (2018).

I use the unified taxonomy by Conard et al. (2004) in order to give a general overview of core categories. Platform cores have been further divided into several reduction strategies according to criteria such as: orientation of the flaking surface, knapping progression, and number of platforms and faces exploited. Carinated cores have been sorted in three sub-categories: core-like, endscrapers, and burin forms.



**Figure 2.** Example of refitted artifacts from unit A2. Refitted semi-circumferential blade core (a), small blade refitted to a core tablet (b), and narrow-sided bladelet core with refitted core tablet and plunging technical flake (c). Photo: A. Falcucci.

The typological classification of retouched tools is based on the most used European Upper Paleolithic typologies (de Sonneville-Bordes 1960; Demars and Laurent 1992), that were, however, revised and simplified. This typological approach is particularly valuable in the case of Aurignacian assemblages because provides comparable data across sites when accurate technological studies are lacking.

In order to assess the curvature of blanks, dorsal scars, and shape, I took into account only complete and almost complete specimens. This is beneficial in that it avoids biases due to the high degree of fragmentation of the assemblage. I quantified profile curvature using the categories defined by Bon (2002). I excluded retouched tools from the analysis of morphology and distal ends due to the modification of the shape via retouching. The maximum dimensions of each artifact were recorded using a digital caliper. The metric boundary between blades and bladelets was placed at 12.0 mm (Tixier 1963), in agreement with most of the studies conducted on Aurignacian assemblages (Le Brun-Ricalens 2005b) and according to our case study.

The intra- and inter-assemblage differences were statistically tested in IBM SPSS Statistics 24 by using both discrete and metric attributes. Pearson's chi-squared tests were performed to assess the significance of discrete variables while metric differences were assessed by using non-parametric tests (Mann-Whitney and Kruskal-Wallis), given that our samples were not normally distributed according to Shapiro-Wilk and Kolmogorov-Smirnov tests. Finally, I used the Holm-Bonferroni sequential correction test to reduce the probability of performing a type 1 error (Holm 1979).

## RESULTS AND DISCUSSION

This chapter summarizes the principle findings of the research articles that form this PhD thesis – listed in LIST OF PUBLICATIONS and attached in the APPENDIX – and discusses the results within the larger framework of the Aurignacian studies. The chapter is structured into four main sections that follow the objectives of the doctoral research listed in OBJECTIVES AND EXPECTED OUTPUT OF THE DOCTORAL RESEARCH. Papers are combined and summarized in order to address the research questions in a discursive way.

### THE PROTOAURIGNACIAN LITHIC TECHNOLOGY AT FUMANE CAVE

The aim of this research project was to reassess the lithic technology of units A2–A1 from Fumane Cave and critically discuss the definition of the PA summarized in Bon et al. (2010). Results presented in this section are discussed in detail in Falcucci et al. (2017), Falcucci and Peresani (2018), and Caricola et al. (accepted).

The most relevant features of the PA at Fumane Cave are the systematic and variable bladelet production and the dominance of retouched bladelets among tools (ca. 78%). The quantitative analysis of the knapped assemblage shows that most of the artifacts discarded at the site belong indeed to bladelets and by-products of lamellar reduction strategies. The presence and degree of cortical surfaces among blanks suggest that raw material decortication and core initialization resulted mostly in the production of flakes and blades of variable sizes. Instead, bladelets display cortical surfaces only rarely.

The investigation of core technology permitted to identify three main core reduction methods: platform, multidirectional, and parallel. Multidirectional and parallel methods played a secondary role and were used to produce flakes of varied morphologies. Multidirectional cores seem to be rather opportunistic and display removals from several faces without well-developed striking platforms. Parallel cores are instead characterized by a removal surface with centripetal negatives that originated from the intersection with the underside. However, this reduction method might be the outcome of marginal post-depositional processes, given the strong resemblance to the

centripetal flake cores recovered in the Uluzzian units A4–A3 (Peresani et al. 2016). Knappers employed platform methods to exclusively obtain blades and bladelets. Platform cores have been divided according to five reduction strategies and the main production objectives (Table 2). Blade and bladelet cores represent a relatively homogeneous group. All the identified types share a certain degree of technological overlap; a consequence of a volumetric and unidirectional approach to the knapping. The detailed reduction procedures of each strategy have been described in Falcucci and Peresani (2018). Here, results are combined with the blank analysis to give an overall summary of the technological system.

**Table 2.** Distribution of platform cores in A2–A1 according to the identified reduction strategy and the objective of the blank production.

<b>Core Classification</b>	<b>Blade</b>	<b>Bladelet</b>	<b>Blade– Bladelet</b>	<b>Blade– Flake</b>	<b>Undet.</b>	<b>Total</b>
Narrow-sided	-	23	-	-	-	23 (26%)
Semi-circumferential	4	15	1	-	-	20 (22%)
Wide-faced flat	2	9	1	-	1	13 (15%)
Carinated	-	10	-	-	-	10 (11%)
Multi-platform	-	19	3	1	-	23 (26%)
<b>Total</b>	<b>6 (7%)</b>	<b>76 (85%)</b>	<b>5 (6%)</b>	<b>1 (1%)</b>	<b>1 (1%)</b>	<b>89 (100%)</b>

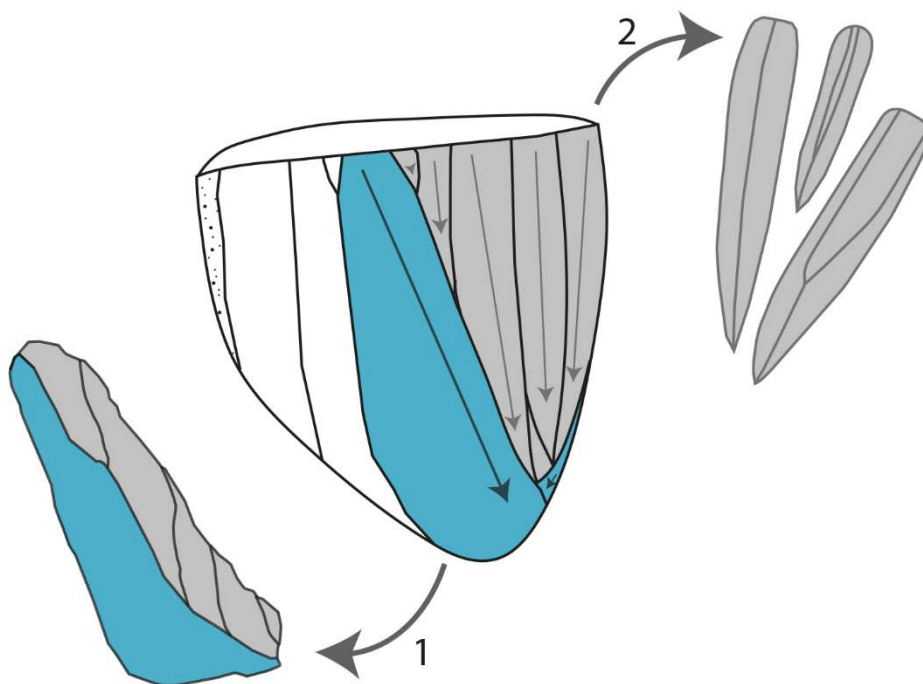
Note that multi-platform blade–bladelet cores have produced bladelets in independent phases (n=2) or simultaneously with blades, followed by an independent reduction phase (n=1). Initial platform cores (n=26) are not listed. Rounded percentages are given in brackets.

Bladelet production is characterized by a relatively broad range of core reduction strategies. Intact nodules and fragments were brought to the site where the future cores were prepared using simple shaping processes. The orientation of the flaking surface in relation to a flat striking platform depended on the initial volume of the blank and on the intended production goal. A laminar blank, usually cortical, took advantage of a natural steep angle. Non-invasive crests were applied only when the morphology of the blank did not permit the direct extraction of laminar products. According to the volume of the selected raw material nodule, bladelet core initialization could sometimes result in a first series of blade removals. In some cases, the most robust blanks produced in this initial reduction stage were selected to manufacture tools as endscrapers, burins, and laterally-retouched blades and flakes.

The optimal production phase took place on cores that were almost completely deprived of cortex and targeted bladelets of variable sizes. Blanks were extracted with direct marginal percussion after an accurate abrasion of the platform edge. According to the wear-traces identified on the macro-



tool category (Caricola et al. accepted) and the relatively high frequency of bulbar scars associated to fine ripples in the first millimeters of the ventral face of blanks (Falcucci et al. 2017), it can be said that soft stone cobbles were likely to be used as hammers during the optimal production and maintenance phases. The frequent application of convergent and secondly sub-parallel reduction patterns resulted in the production of bladelets with pointed outlines, as well as bladelets with sub-parallel edges. In the case of convergent patterns, the use of an original procedure permitted narrow and convergent surfaces to be isolated, independently from the location of the flaking surface, during discontinuous reduction phases (Figure 3). Each phase allowed the production of a short series of regular bladelets with pointed distal ends following an alternated convergent knapping progression (Falcucci and Peresani 2018). A common operation to isolate the flaking surface consisted of the removal of lateral comma-like blanks at the intersection of core faces and along the longitudinal axis of the core. Lateral comma-like blanks had usually the size of small blades, well recognizable because of the presence of multiple lamellar negatives on their dorsal side. The protracted alternation of primary blanks and by-products required the exploitation of most of the available surfaces by means of a semi-circumferential core progression.



**Figure 3.** Schematic drawing of an alternated knapping progression conducted on a semi-circumferential bladelet core. A lateral blade is detached at the intersection of core faces (1) to isolate a narrow and convergent surface where a set of pointed bladelets (2) is removed. Drawing: A. Falcucci.

Narrow-sided cores had a major importance and were exclusively used to produce bladelets, usually slender and rather straight in profile view. The production usually began with crested bladelets, well-represented in our studied assemblage, detached at the junction of the ventral face of the core blank. The extraction of regular bladelets was then achieved by lateral removals that converged towards the center of the flaking surface. Core recycling was also a frequent strategy used to increase production efficiency. Multi-platform cores and technical blanks related to different operations of re-orientation are in fact numerous. In some cases, bladelet production took advantage of discarded blade cores.

As shown, the flaking surface of bladelet cores was oriented, in most cases, according to the longitudinal axis of the blank, which represents one of the main technological features of the PA. Carinated technology is thus generally less represented if compared to EA industries (Bon 2002). The technological organization of PA carinated cores from Fumane Cave, however, does not differ from the EA (as described in Le Brun-Ricalens 2005c). Furthermore, it shares several features with the semi-circumferential reduction strategy such as the use of lateral removals to isolate the flaking surface and the discontinuous knapping pattern.

Blades represented the second goal of the PA lithic production system, and their frequency is always lower than that of bladelets. Blades were obtained from independent and, to a lesser extent, simultaneous reduction sequences. The flaked surface of blade cores was framed by at least one perpendicular flank; a feature that permitted the extraction of naturally backed blades and the use of neo-crests to shape the core convexities. Blades were extracted with direct marginal percussion and the striking platform usually remained flat. Faceted platforms are instead rare. The operational concept used to produce blades was based on the exploitation of a broad area during a linear and consecutive knapping progression that followed a sub-parallel reduction pattern (Falcucci and Peresani 2018). Blades have variable morpho-metric attributes, but among retouched tools a selection of the bigger blanks, independent of their regularity and the presence of cortical remains, is verified.

Flake production has been observed less often among PA industries and has generally received less attention. At Fumane Cave, this production appears to be marginal and carried out in most cases on informal cores (see above). Most of the flakes recovered were the outcomes of initialization and maintenance operations of blade and bladelet cores. For this reason, flake-tools were mostly made from by-products of the laminar reduction sequences.

Overall, this reassessment shows that the PA is a bladelet-dominated industry. Bladelet production dictates the general organization of stone knapping and is based on a broad range of independent reduction strategies, among which the preference towards the exploitation of the core longitudinal axis stands out. The role of the so-called single and continuous reduction sequence (Bon et al. 2010; Teyssandier et al. 2010) has been instead over-emphasized, given that bladelet production is in most cases not related to the reduction of larger blade cores. Blade and bladelet productions are, however, not strictly separated due to the presence of simultaneous reduction sequences, the recycling of some blade cores into bladelet cores, the selection of by-products of the bladelet production as blanks to manufacture common tools, as well as the production of a short sequence of blades on some initial bladelet cores prior to the optimal production phase.

## THE VARIABILITY OF THE PROTOAURIGNACIAN ACROSS ITS GEOGRAPHIC EXTENT

In order to investigate the variability of the PA across its geographic extent, I conducted an extensive inter-site comparison using the available and pertinent literature (Falcucci et al. 2017). The sites that have been carefully compared are Castelvita (Gambassini 1997), La Fabbrica (Dini et al. 2012), Bombrini (Bietti and Negrino 2008; Bertola et al. 2013), Mochi (Kuhn and Stiner 1998; Grimaldi et al. 2014), Observatoire (Porraz et al. 2010), Esquicho-Grapaou (Sicard 1994; Bazile 2005), Louza (Sicard 1995; Bazile 2005), Mandrin (Slimak et al. 2006a, b), Arbreda (Ortega Cobos et al. 2005; Tafelmaier 2017; Bataille et al. 2018), Morin (Maillo-Fernandez 2003, 2005, 2006), El Castillo (Maillo-Fernandez and de Quiros 2010), La Viña (Santamaría 2012), Labeko Koba (Arrizabalaga and Altuna 2000; Tafelmaier 2017; Bataille et al. 2018), Isturitz (Normand and Turq 2005; Normand 2006; Normand et al. 2007; Normand et al. 2008), Piage (Bordes 2002, 2006), Les Cottés (Roussel and Soressi 2013), Arcy (Bon and Bodu 2002; Paris 2005), Tincova (Sitlivy et al. 2014a; Sitlivy et al. 2014b), Romanești (Sitlivy et al. 2012), Kozarnika (Tsanova 2008), and Siuren I (Demidenko et al. 2012; Zwyns 2012b; Bataille 2013, 2017; Bataille et al. 2018). Additionally, retouched bladelets from two sites, Isturitz and Les Cottés, were analyzed and compared to Fumane Cave with the aim to address the typological variability in the PA (Falcucci et al. 2018).

The systematic review of lithic assemblages suggests that the PA is technologically consistent across its geographic extent. First of all, it can be emphasized that independent and variable bladelet reduction strategies are the rule, rather than the exception. Although it is not categorically excluded

that, in favorable cases, a blade reduction sequence was followed by a bladelet production without going through a substantial re-organization of the core structure, the systematic use of this concept would have not responded to the need of immediate production and consumption of bladelet implements that is the defining features of the PA. Similar conclusions were reached by Tafelmaier (2017) in the course of a reassessment of the lithic technology of Labeko Koba – layer VII and Bataille (2013) during the analysis of the PA assemblage from Siuren I – units G and H. A detailed critique and revision to the main arguments used by some authors to identify the continuous reduction sequence in PA lithic assemblages can be found in Falcucci et al. (2017).

One of the main features of the PA is the selection of the longitudinal axis of the core to obtain regular and slender bladelets. In many cases, the production was based on the exploitation of narrow flaking surfaces following a convergent reduction pattern to better control the width of the end products. The dichotomy between blade or blade–bladelet productions based on broad surfaces and bladelet productions based on narrow surfaces has been well described at Observatoire (Porraz et al. 2010). The technological strategies used to exploit narrow flaking surfaces in the framework of bladelet production is evident at several PA sites. At Louza, most of the operations conducted on bladelet cores aim to isolate narrow surfaces (Sicard 1995), while at Esquicho-Grapaou the production is sometimes based on a knapping progression that alternates removals at the center of the flaking surface with maintenance products that invade the core flanks (Sicard 1994). At Mandrin, narrow and convergent flaking surfaces are instead isolated by sets of transverse removals detached from an adjacent core face (Slimak et al. 2006b). The use of highly diagnostic lateral maintenance products, such as lateral comma-like blanks has been identified in many PA assemblages (Sicard 1994; Bon and Bodu 2002; Normand and Turq 2005; Tsanova 2008; Bataille 2017; Tafelmaier 2017) and seems to be related to semi-circumferential cores with convex flaking surfaces that are progressively invaded by the progression of knapping. Narrow-sided cores are also numerous. At Arbreda, they have served to produce small blades (Ortega Cobos et al. 2005), while in other sites they are always described as bladelet cores. The initialization and maintenance operations carried out on narrow-sided cores at Observatoire (Porraz et al. 2010) and Arcy (Paris 2005) are comparable to Fumane. Multi-platform cores are frequent at Mochi (40% of cores; Kuhn and Stiner 1998) and are reported at Arcy (Paris 2005), Isturitz (Normand et al. 2008), Arbreda (Ortega Cobos et al. 2005), and Siuren I (Bataille 2017). Carinated cores are represented in most of the PA assemblages. They are rare in Liguria and in southeast France (Bazile 2005; Porraz et al. 2010; Douka et al. 2012; Bertola et al. 2013), are the dominant bladelet production strategy at Arbreda

(Ortega Cobos et al. 2005), and are well-represented in northern Spain (Maillo-Fernandez 2005; Santamaría 2012), Pyrenean region (Normand et al. 2008; Barshay-Szmidt et al. 2013; Tafelmaier 2017), and eastern Europe (Sitlivy et al. 2012; Bataille 2013; Sitlivy et al. 2014a).

The emphasized variety of lamellar reduction strategies may be a result of the need to manufacture different end-products. Bladelets were used for multiple activities and some studies have proposed a correlation between size and function (Normand et al. 2008; Porraz et al. 2010; Rios Garaizar 2012), although methodological prudence is required (Anderson et al. 2015). By comparison to the EA, PA bladelets are said to be large and straight (Teyssandier 2007; Le Brun-Ricalens et al. 2009). In the literature and at Fumane, however, large and rather straight bladelets are described along with small and curved bladelets.

The major differences between PA assemblages appear to be more typological in nature. Typological differences are expected and are usually the outcome of factors such as uneven sample sizes, stochastic variation, and possible differences in the function and use of the different sites. The PA seems to be characterized by a slightly higher frequency and variability of burins compared to endscrapers. Laterally retouched tools are frequent and, as expected, have in most cases the size of bladelets. The frequency of retouched bladelets, often typed Dufour bladelets (Demars and Laurent 1992), is the most important typological feature when it comes to identify a PA assemblage. The share of these tools is very high in the PA, although its frequency varies across space and time. At Fumane the richest retouched bladelet assemblage was found, while in other sites percentages can be lower. For instance, PA sites in southern Italy account fewer retouched bladelets compared to northern Italian assemblages (Accorsi et al. 1979; Gambassini 1997; Palma di Cesnola 2004; Riel-Salvatore 2010).

With the aim to study the variability of retouched bladelets in the PA, I analyzed the assemblages of Isturitz and Les Cottés and compared the results obtained to Fumane Cave (Falcucci et al. 2018). This direct reassessment was beneficial because a unique database was used to record specific and well distinguishable attributes that are in most cases difficult to identify when looking at published papers. They are often based on highly variable typological approaches and make frequently use of loose terminology. To overcome this problem, I decided to use a simplified and unified classification of retouched bladelets for comparing behavior in between groups distant in space. Two macro-groups were identified: bladelets with convergent retouch and bladelets with lateral retouch. Each group can be further sorted according to the retouch positions (alternate, direct, and inverse). The

first group includes all of the bladelets retouched up the apex, with the clear intention to modify and rectify the main tool attribute. The second group includes the rest of the bladelets that, even if naturally convergent in their distal part, are modified only on the lateral edge(s).

Results show several differences between the analyzed bladelet assemblages, even though the selection of elongated blanks with regular edges and slightly curved or straight profiles support the existence of very similar technological concepts and production objectives. First, retouched bladelets at Fumane Cave are often pointed by retouch (59%), while bladelets with convergent retouch are less common at Isturitz (33%) and missing at Les Cottés. Second, differences were found in the incidence of alternate, inverse, and direct retouching. While at Les Cottés most of the bladelets are modified by inverse retouch, at Isturitz the alternate retouch has the same importance of inverse retouch. At Fumane, instead, alternate retouch is the most frequent, followed by direct retouch. Third, an evident link was found between retouch position and the retouching of the distal tip. At Fumane, bladelets with convergent retouch were mostly modified by direct retouch, while at Isturitz the same target was obtained by applying, in most cases, alternate retouch. Our results were compared with the available literature on retouched bladelets. Overall, the main differences can be found in the presence, proportion, and relative retouch position of bladelets with convergent retouch. Bladelets with convergent retouch did not play a significant role in the toolkit of PA foragers settled in northern France. It also seems that the proportion of this tool type decreases in frequency moving from Fumane Cave to the west, as also noticed by Bon et al. (2010). However, we concluded that it is not possible yet to be confident in the limited role, or even absence, of bladelets with convergent retouch in western PA assemblages, because of the approach employed in the study of retouched tools and the inclusion of most of the retouched bladelets in the Dufour family without further characterization.

This assessment proves that the PA fits well within the broad taxonomic group of the Aurignacian. Despite the obvious, and expected, technological overlaps with its sister group, the EA, assemblages assigned to the PA in southern and western Europe can be further divided according to a number of techno-typological features that are undeniable. On a typological ground, the high frequency of retouched bladelets is the most relevant feature, as already noticed five decades ago by Laplace (1966). On a technological ground, it can be now underlined that PA technology is more variable than previously thought and bladelet production is not simply the result of dwindling core dimensions as blade production progresses. As for the terminology to be used, I suggest that it is

not advisable to abolish the term PA at this stage of the research, although I agree that the use of the prefix Proto- might be awkward, and its original definition has a problematic research history (Conard and Bolus 2015). Research has however advanced and the accurate analyses conducted at numerous sites have better described the signature of assemblages assigned to the PA. That being said, archaeologists should not passively embrace the use of the term to underestimate the geographic and chronological (see below) variability that characterizes the earliest manifestations of the Aurignacian in this part of the European subcontinent. The present study has the merit of having built additional and high-resolution information for a more dynamic understanding of the Aurignacian, and Fumane Cave should be used as a major site for a more accurate definition of the PA itself, and the identification of inter-regional variability. In this perspective, the use of new cultural taxonomic terms borrowed from single case-studies, such as Fumanian or Mochian (as suggested in Conard and Bolus 2006), would only result in an over-fragmentation of cultural entities without solving the unanswered questions raised by the scientific community. We can instead discuss variability *within* the PA and talk about particular local features *across* different regions and environmental settings.

## THE CHRONO-CULTURAL NARRATIVE OF THE AURIGNACIAN AT FUMANE CAVE

In this section, the comparison of five cultural units (A2, A1, D3base, D3*alpha*, D3ab) from Fumane Cave is presented and discussed. Lithic assemblage variability and organic artifacts will be investigated to detect evidence of cultural modifications throughout the stratigraphic sequence. Detailed information on this assessment can be found in (Falcucci et al. submitted).

The studied sequence shows little diachronic changes and no major discontinuities in lithic technology. All assemblages are characterized by variable and systematic bladelet productions and the dominance of retouched bladelets among tools. Blade blanks and cores are less common, while evidence of simultaneous blade–bladelet production is more evident in A2–A1 and D3ab. Bladelets were the first goal of lithic production and the reduction strategies identified in oldest cultural units were never abandoned. Cores with bladelet scars are the most common type of core, with frequencies that vary from 86% in A2 to 70% in D3ab. In A2–A1 major emphasis was placed in the selection of the longitudinal axis of the core blank to carry out semi-circumferential and narrow-sided reduction sequences. In D3base–D3ab, instead, carinated technology gradually increases in

frequency but is never the sole reduction strategy used. Carinated burins were only recovered in A2–D3base, while in D3*beta*–D3ab carinated technology was exclusively based on core-like and endscraper forms. The reduction procedures conducted on carinated cores are very similar across the studied units. Multi-platform cores were not found in D3base–D3*beta*, while they are common in the D3ab. The strong similarities in the different bladelet productions are also clear when studying the morpho-metric attributes of lamellar blanks. Bladelets with convergent outlines of varied sizes represented the main production objective. Twisted blanks, that are often said to be obtained from the sides of carinated cores (Le Brun-Ricalens 2005c), are instead represented in low frequencies throughout the sequence.

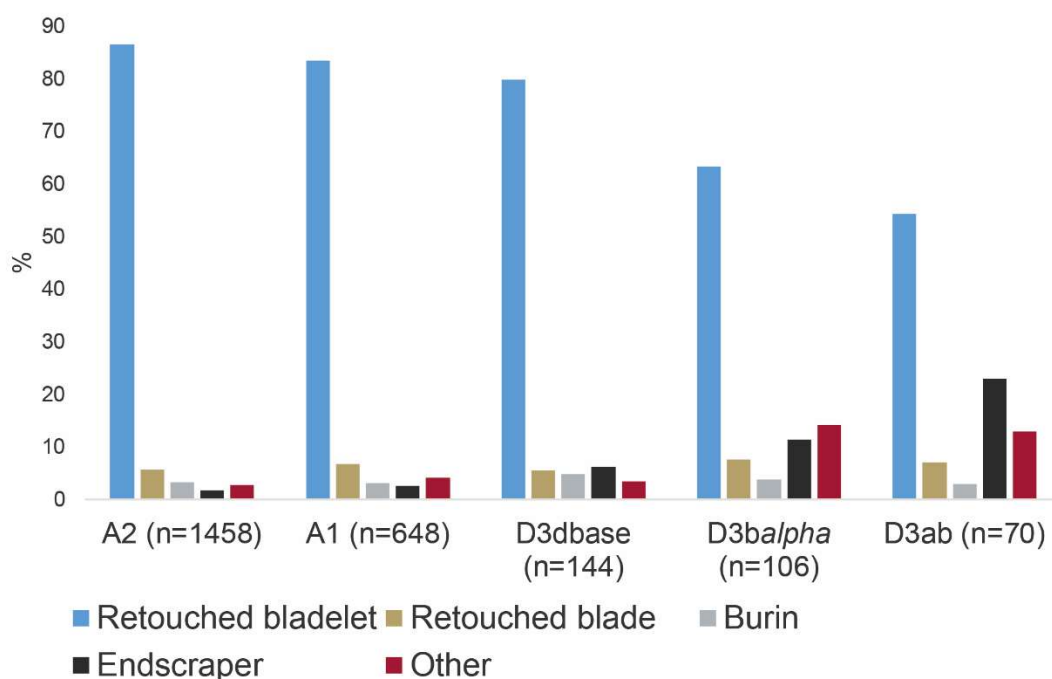
No significant changes were found in the organization of blade production. Blades were obtained from unidirectional semi-circumferential and wide-faced flat cores by means of linear and consecutive knapping progressions, and only exceptionally from narrow-sided cores. In most cases, striking platforms were flat, while faceted platforms are rare both among cores and blanks. Blanks with sub-parallel edges and similar metrical attributes were the objectives of production. The interdependence between blades and bladelets that characterizes A2–A1 (Falcucci et al. 2017) is still represented in the youngest assemblages. Blades could either be simultaneously produced with bladelets or detached during maintenance operations conducted on bladelet cores. However, blade cores were not systematically reduced into bladelet cores.

The youngest assemblages show a major emphasis in the production of flakes. Flakes increase in frequency in the youngest units (D3base–D3ab), where flake production has in some cases a higher degree of predetermination. Parallel cores and the related by-products were not found in D3base–D3ab, while multidirectional cores are still represented. In D3*beta*–D3ab, flakes were also obtained from platform cores. These cores are made from nodules and thick cortical flakes and have flat striking platforms and straight flaked surfaces. Flaking direction is unidirectional and the reduction pattern sub-parallel. Last negatives are frequently hinged. Flakes with unidirectional hinged scars and plain butts are common among blanks and are likely to be the result of this reduction strategy.

The main differences between assemblages can be seen in the typological composition of tools (Figure 4). Retouched bladelets, although always the most common tool type, gradually decrease in frequency towards the top of the sequence. They are comparable from a morpho-metric standpoint, although smaller tools were found in D3*beta*. There is little variability in the application of



alternate, inverse, and direct retouching. Bladelet with convergent retouch are frequent across all the assemblages and usually are modified by direct and alternate retouch. As for the common tool's category, the lowermost assemblages are characterized by a higher frequency of laterally retouched blades and a major typological variability in burins. Endscrapers instead, and among those carinated forms, gradually increase in frequency starting from D3base and represent the main type of tool in D3*alpha*–D3ab. Aurignacian retouch is rare and no Aurignacian blades were found in D3base and D3*alpha*. Finally, in A2–A1 common tools are in most cases made on blades, while in D3base–D3ab tools on flakes are more frequent, in agreement with the general incidence in the number of flakes in the youngest units.



**Figure 4.** Bar-charts comparing the frequencies of the main tool types identified throughout cultural units A2–D3ab. See the color legend to identify the tool types.

In addition to the lithic artifacts at the site, all the studied units are characterized by ornamental objects manufactured on marine shell. Only one grooved deer incisor was recovered at the top of unit A1. Osseous industry is characterized by a series of common tools such as awls and perforators made from long bone diaphysis, but also by antler points. In few cases, the proximal part is still preserved, allowing to further classify some of them as SBPs. Two SBPs were recovered in the D3 complex, while artifacts confidently attributable to this type were not found in the oldest units, although an antler point lacking of its proximal part was found at the top of A1.

This study permits to identify three main phases within the studied sequence of Fumane Cave: A2–A1, D3base, and D3*alpha*–D3ab (Figure 5). The main differences were found in the youngest phase, while the few variations that characterize D3base might be explained both as a supporting evidence for a gradual modification of the PA technological system or as possible mixing between A1 and D3*alpha*. D3base was in fact described as being in direct contact with the under- and overlying units. We might refer to phase D3*alpha*–D3ab as the *late* PA to emphasize the continuity and the changes in the lithic technological system that occur throughout the stratigraphic sequence, but also to underline the chrono-stratigraphic position of the youngest assemblages. In this framework, the prefix Proto- loses its literal meaning and is only used to refer to assemblages with similar set of attributes and behavioral features, regardless of their stratigraphic position. We should avoid using archaeological taxonomies in static and dogmatic ways. Taxonomic terms only have meaning in terms of questions that researchers aim to answer, and should be used as conceptual tools to describe and interpret the archaeological record (Brew 1946). The use of the term PA is the most appropriate way to describe the youngest assemblages according to the research objective pursued here, and it additionally helps to criticize the validity of the Aquitaine Model itself. In fact, the signature of the *late* PA provides a signal that is in contrast to the four stages model developed in the Aquitaine region. In other words, the youngest phase of Fumane Cave cannot be assigned to the EA. If the main features of D3*alpha*–D3ab are compared to the EA as commonly described (de Sonneville-Bordes 1960; Bon 2002; Chiotti 2005; Bordes 2006; Bon et al. 2010; Teyssandier et al. 2010), several differences can be highlighted.

In the *late* PA, blades are not more robust and platforms are almost never faceted. Laterally retouched blades only rarely display the so-called Aurignacian retouch (de Sonneville-Bordes 1960). This type of modification, which is said to be virtually absent in the PA and common in the EA (Bordes 2006), is represented in unit A2 and never increases in frequency in the upper sequence. Although the independence of bladelet production is not a viable characteristic with which to define EA (Ortega Cobos et al. 2005; Slimak et al. 2006b; Normand et al. 2007; Porraz et al. 2010; Bataille 2017; Falcucci et al. 2017; Tafelmaier 2017; Bataille et al. 2018; Falcucci and Peresani 2018; Riel-Salvatore and Negrino 2018b), carinated cores are said to be the almost exclusive strategy used to obtain bladelets in the EA. Instead, carinated technology is never the sole reduction strategy responsible for the production of bladelets in the *late* PA, though carinated pieces are more numerous if compared to the lowermost assemblages. Bladelets in EA assemblages are seldom retouched. Contrarily to that, retouched bladelets are the most common tool type in D3*alpha*–D3ab. Finally,

the simultaneous production of blades and bladelets has been only rarely described in the EA (Chiotti 2005; Teyssandier 2007; Tafelmaier 2017), whereas at Fumane Cave it is a common feature.



**Figure 5.** Selection of cores and tools from the youngest cultural phase D3balpha–D3ab. Wide-faced flat blade core (a), Semi-circumferential bladelet core (b), multi-platform bladelet core with evidence of both carinated and narrow-sided reduction strategies (c), partially refitted initial semi-circumferential blade core (d), unidirectional platform flake core (e), carinated end-scraper (f), laterally-retouched blade (g), Aurignacian blade (h), endscrapers on flake (i–j), endscraper on blade (k), bladelets with lateral retouch (l–o), and bladelets with convergent retouch (p–q). D3balpha = d, g, j, l, o–q; D3ab = a–c, e–f, h–i, k, m–n. Photo: A. Falcucci.

## TOWARDS A MORE DYNAMIC INTERPRETATION OF THE AURIGNACIAN PHENOMENON

Our study challenges the tendency among Paleolithic archaeologists to transfer a regional sequence, although well-defined, to geographically and in some cases chronologically distant case-studies. It derives in fact a clear inconsistency between the archaeological data and the interpretative model. For instance, the PA adaptive system cannot be seen as simply a pioneering, short-term phase of modern human dispersal into Europe, as recently suggested (Anderson et al. 2015). Our results are part of the increasing evidence suggesting that the PA was an efficient technological and behavioral adaptation that lasted for several millennia under changing climatic and environmental conditions. Recent studies conducted in northwestern Italy, where long PA sequences are also well represented, are important. At Bombrini, the PA units A2 and A1 accumulated during a period of about five millennia, from ca. 40,710 to ca. 35,640 ka cal BP (Benazzi et al. 2015). The cold phase associated to the onset of H4 took place in the lower unit A2 and did not result in the alteration of its defining characteristics, proving that these foragers had the capacity to adapt to shifting conditions (Riel-Salvatore and Negrino 2018a, b). At Mochi, the recent identification of two PA occupations (Grimaldi et al. 2014) that precede the well-known PA assemblage from unit G (Laplace 1977; Kuhn and Stiner 1998; Bietti and Negrino 2008) and the long chronological span that characterizes the latter (Douka et al. 2012) point towards similar conclusions.

The persistence of the PA in Italy, and thus the contemporaneity with the EA on a supra-regional scale, was considered possible by Bon (2002, 2006). However, it is now clear that technological continuity does not imply cultural isolation. This study has permitted to identify an internal variability within the sequence of Fumane Cave. The gradual changes that occur attest to common chrono-cultural trends that link Fumane Cave to other southern and western European regions, where a clear cultural break between PA and EA is difficult to detect. Correspondences with the Aquitaine reference sequence is never one-to-one and differences with the classic EA definition, as well as resilience of PA traits, are frequently emphasized. In the Pyrenean region the recently excavated site of Isturitz contains several layers that have been attributed to PA and EA occupations (Normand and Turq 2005). The EA from units C 4b1 and C 4b2 is characterized by the presence of SBPs (Normand et al. 2007), bovine teeth, and basket-shaped beads used as personal ornaments (White and Normand 2015). In terms of the lithic assemblages, the increase in the number of endscrapers and carinated cores, and the presence of Aurignacian blades are considered supporting

evidence for a shift to an EA phase. However, the researchers also emphasize there are several differences compared to the classic definition, such as the high proportion of retouched bladelets (ca. 23% in C 4b1) and the interdependence of blade and bladelet reduction systems (Normand 2006; Normand et al. 2007; Barshay-Szmidt et al. 2018). The cultural unit C 4c4 is described as a transitional phase, suggesting a regional development of the EA (Normand 2006; Szmidt et al. 2010b). In Cantabria, the PA unit VII and EA units VI–V of Labeko Koba (Arrizabalaga and Altuna 2000) were recently re-analyzed by Tafelmaier (2017). Tafelmaier shows the strong technological affinities that exist between PA and EA technological systems in terms of bladelet production. As in the previous case, carinated reduction strategies increase in frequency in the EA, while from a typological standpoint retouched bladelets are less common (from ca. 50% to ca. 10%) and endscrapers are more common. It is also interesting to note that flakes are numerous in the EA units, similar to the late PA of Fumane. In northern France, the site of Les Cottés contains PA (US 04inf.) and EA (US 04sup.) units that are chronologically undistinguishable (Talamo et al. 2012). US 04sup. consists of techno-typological traits that are also well represented in the underlying PA (Roussel and Soressi 2013). Research conducted some decades ago in southeastern France shows that sites such as Pêcheurs (Lhomme 1976), Esquicho Grapaou units B.R. 1 and C.C. 1 (Bazile 1974), Rainaude (Onoratini 1986), and Observatoire unit E (Onoratini et al. 1999), assigned to the EA based on the presence of SBPs and carinated cores, present several features that diverge from the classic definition. For this reason, Slimak et al. (2006a) have observed that the use of two static groups such as PA and EA does not allow us to well appreciate the development of the Aurignacian in the Rhone Basin. The authors conclude that a Mediterranean variant of the EA with several PA features is very likely. The duality that seems to exist between the Atlantic and Mediterranean Aurignacian has also been emphasized by other researchers, who have called for new regional assessments to better identify the defining features of the latter variant (Le Brun-Ricalens and Bordes 2007; Anderson et al. 2018).

If we broaden our focus to cover Central Europe, the scenario becomes more complex. In the Swabian Jura, for instance, the Aurignacian seems to begin with assemblages that differ greatly from the PA identified in southern and western Europe and that are rich in carinated cores and almost completely devoid of retouched bladelets (Hahn 1977; Conard and Bolus 2006; Teyssandier 2007). The lithic industries at Geißenklösterle have been described by Teyssandier (2007) as being close to the EA of the Aquitaine Basin, but Conard and Bolus (2006) have also stressed the strong regional signal of the Aurignacian sequence. Distinct chrono-cultural phases have not been identified, but

Teyssandier (2008) has suggested a possible change in the organization of the lithic system within the sequence of Geißenklösterle that may not be solely related to the functional variability of the site. Additionally, new data from the ongoing excavations at Hohle Fels suggest that the technological features of the Aurignacian of the Swabian Jura are more diverse than previously thought (Bataille and Conard 2018). The analyses of the assemblages recovered in oldest horizons will surely better define these components and the development of the Aurignacian in the region.

It is clear that the data and examples presented above demand a new step in research on the genesis and development of the Aurignacian. Archaeologists should be less stuck in terminological and taxonomic problems and more involved in researching the reasons behind the dichotomy between heterogeneity and commonalities that are evident when one focuses on a regional framework. A pertinent example can be considered from Arbreda. In a recent paper, Wood et al. (2014) wrote that the PA unit H may contain EA implements, such as carinated endscrapers and SBPs. Although Zilhão and d'Errico (1999) have claimed that post-depositional processes have caused this, their arguments have been denied on both stratigraphic (Soler Subils et al. 2008) and archaeological (Ortega Cobos et al. 2005; Tafelmaier 2017) grounds. Wood et al.'s study reveals that an alternative scenario needs to be defined in order to clarify the relationships that existed between the two sister groups. In this regard, we remind that both us and other authors have pointed out that the PA shares a common technological background in the scope of lithic technology with the EA and that no features are restricted to one of the two variants (Sitlivy et al. 2012; Sitlivy et al. 2014a; Falcucci et al. 2017; Tafelmaier 2017; Bataille et al. 2018). Although post-depositional and taphonomic processes may distort the archaeological record, mixing cannot be considered the sole explanation for interpreting this cultural variability. As previously shown, variability in the Aurignacian is the rule, rather than the exception.

A thought-provoking reconstruction proposed by Tafelmaier (2017) interprets the PA and EA as two *adaptive facies*. They are distinguishable on the basis of quantitative differences, although being rooted in the same technological repertoire, which is seen as the basal adaptation of an *early stage Aurignacian* that subsumes both variants. Differences would thus be merely functional with no cultural meaning, while specific regional adaptation mechanisms would be reflected in the inter-assemblage variability that can be seen across its geographic extent. In this scenario, PA and EA would not represent two strictly distinct technical traditions, as suggested by Teyssandier et al. (2010). My data partially agree with this interpretation and suggest that the Aurignacian be

considered a complex phenomenon where PA and EA represent conceptual tools to help describe a non-linear process with multiple poles of variability (regional, chronological, functional, etc.), and no strict, mutually-excluding features. Nevertheless, if only western and southern Europe are considered, it must be also underlined that assemblages with strong PA affinities are always stratigraphically below assemblages with EA affinities. The common trends towards the decrease of retouched bladelets and the major use of carinated technology to produce bladelets are undeniable. Differences would thus not be exclusively functional and quantitative variations seem to have a chronological meaning in some regions. They cannot be neglected, otherwise all Aurignacian assemblages would fall in the same macro-group, with little or no possibility to follow processes of temporal development and geographic variability. According to our results, as well as the previous observations on western and southern European assemblages, two main stages can be distinguished. The first coincides with the beginning of the Aurignacian in many stratigraphic sequences. This *early* PA stage has been supposed by us as being technological homogeneous (Falcucci et al. 2017), although variability on a typological ground is expected (Falcucci et al. 2018). During the second stage, gradual modifications and the consolidation of regional components can be detected. They are evident when studying the variability of personal ornaments and technological behaviors. *Late* PA assemblages in northern Italy appear to be contemporaneous with assemblages grouped in the EA. However, I have shown that assemblages that express a high degree of internal variability are frequently classified under this variant, and future research should focus on better isolating particular regional trajectories.

The isolation of general trends in lithic technology that link Fumane Cave to other Aurignacian regions demonstrate the possibility of cultural interactions between foragers. A supporting evidence for this hypothesis is the appearance of SBPs at several sites across Europe (Liolios 2006; Doyon 2017). The manufacture of a SBP requires a highly standardized procedure (Tartar and White 2013) that seems unlikely to have been reinvented in multiple regions without any technological transfer. Its presence in the *late* PA of Fumane Cave thus suggests inter-regional contacts between movable foragers that allowed technological innovations to spread over large areas. For instance, the circulation of marine shells of both Mediterranean and Atlantic origins across Europe testifies of extensive exchange networks from the beginning of the Aurignacian (Taborin 1993; Vanhaeren and d'Errico 2006).

As for the timing of its appearance, the debate is still open. It is often said that when SBPs are found within a clear stratigraphic framework, they are never associated to the lowermost cultural unit (Hahn 1977; Doyon 2017). Also, a chronological comparison of directly or indirectly dated SBPs across Europe suggests that this artifact type does not date to the earliest manifestations of the Aurignacian (Tafelmaier 2017). The ongoing excavations at Hohle Fels attest, however, to the presence of SBPs in the lowermost Aurignacian horizons (Conard and Malina 2008). More data is thus needed to answer to this question. In this regard, new findings from some eastern European regions seem promising (Hopkins et al. 2016; Hopkins et al. 2018), although they still need to be accurately described.

In Europe there were not insurmountable natural barriers at the time of the Aurignacian. In the specific case of Italy, the Ligurian corridor and the exposed land that is today under the northern Adriatic Sea allowed people to move both westwards and eastwards. In this type of favorable situations, the circulation and diffusion of new ideas related to the fabrication of innovative tools is well documented in the ethnographic literature (Kroeber 1940; Murdock 1960; Mulvaney 1976; Wiessner 1983, 1984; Kelly 2013; Tostevin 2013). For instance, research shows that sub-contemporary foragers can be affected by material culture diffusing as far as 1200 km away from the source (Mulvaney 1976). In this framework, multi-lineal and reciprocal transfer of ideas are to be expected (Bataille 2013). The nature of the spread and assimilation of new technologies depends on the degree of social intimacy that occur between foragers, which is triggered by similarities in their respective material culture (Tostevin 2007, 2013). Social intimacy was likely to be very high between groups of PA and EA foragers that, as discussed in this thesis, shared a common technological background. Human groups that manifest similar cultural traits are in fact open to and likely to exchange information (Eerkens and Lipo 2007). For these reasons, the presence of SBPs, if not studied in combination with other aspects of an archaeological assemblage, should not be used to infer cultural attributions. In fact, the data from Fumane Cave demonstrate that SBPs are not exclusively related to the EA-like assemblages, as frequently emphasized (Teyssandier 2007; Banks et al. 2013a; Teyssandier and Zilhão 2018). The development and assimilation of organic tools may have followed different paths compared to lithics that require further investigation.



## CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This cumulative PhD thesis pursued two principle topics, following the questions that were formalized and revised during the research process. First, a reassessment of the PA to better understand its techno-typological signature and assess its affiliation to the Aurignacian. Second, a detailed diachronic study of the Aurignacian sequence at Fumane Cave in order to examine the development of the Aurignacian in northern Italy. To meet these objectives, I have conducted a detailed analysis of the lithic assemblages and I have carefully re-evaluated the presence and the stratigraphic reliability of the organic artifacts (pierced shells, teeth, painted fragments, bone tools, and SBPs) recovered in five cultural units (A2, A1, D3base, D3*alpha*, and D3ab). The outcomes of these research projects were thus combined and compared with other studies to test the veracity of the available models for the development of the Aurignacian.

The choice to focus principally on Fumane Cave is explained by the importance of the site in the context of the Middle–Upper Paleolithic transition and the studies related to the spread of modern humans into Europe. The PA assemblages of Fumane Cave have always received major attention from the research community. Furthermore, excavations have been conducted with modern techniques and have thus the merits of having provided a reliable and detailed stratigraphic sequence. These are important prerequisites for any assessment of the archaeological record that aims to be as meticulous as possible.

The investigation of the lithic technology from units A2–A1, and careful inter-site comparison across Europe, confirms that the PA is part of the broad taxonomic group of the Aurignacian. PA assemblages can be further grouped, because they have in common the need to produce and retouch regular and standardized bladelet implements. This study demonstrates that bladelet production is based on a broad range of reduction strategies that are, in most cases, not related to the reduction of larger blade cores, as previously suggested by Bon et al. (2010). The PA appears to be technologically homogeneous across its geographic extent, although regional signatures are noticeable in the typological variability of retouched bladelets and in the importance given to certain platform reduction strategies, among which the preference towards the exploitation of the core longitudinal axis stands out. The fact that lithic assemblages included in this variant (also named Aurignacian 0 and Archaic Aurignacian; see a research history in Bon, 2006) share a set of qualitative

*and* quantitative features points towards the utility of retaining the term PA at this stage of research, as long as archaeologists critically address its historical definition and emphasize its geographic and chronological variability.

The second research project aimed to define a chrono-cultural narrative of the Aurignacian at Fumane Cave, and to identify possible cultural breaks in the archaeological records of the studied cultural units. Results show that the techno-typological features of units A2–A1 clearly persist throughout the stratigraphic sequence, with few gradual variations that are less marked if compared to other regional sequences. PA assemblages are thus not related to a certain time span and the occurrence of H4 does not coincide with a shift to an EA adaptive system across all of Europe. This study challenges the generalization of the Aquitaine reference sequence and supports the doubts over the eco-cultural niche modeling that builds on it (Banks et al. 2013a). Furthermore, my data strongly discourage the use of the so-called *fossils directeurs* to infer cultural attributions if information on these artifacts is not combined with the general organization of a given assemblage. For instance, SBPs cannot be used to identify an EA cultural unit. At best, the appearance of SBPs across a large geographic extent suggests the presence of extensive networks that allowed technological innovations to spread across hundreds of kilometers. The identification of a source region for this tool type seems unlikely given that forager territories frequently overlap and the accuracy of our dating methods still leave these issues open to debate.

The Aurignacian can be seen as a landscape of spatial and temporal variability with multiple poles and end points that are difficult to describe if terminological issues prevail over more consciously dynamic research questions. Such research questions will surely be easier to formulate and address when additional regional studies are conducted. The development of the Aurignacian seems in fact to be characterized by a high heterogeneity that cannot be reduced to a static model in which technical traditions and/or adaptive systems are divided by straightforward temporal hiatuses and/or geographic domains. PA and EA should be thus considered as conceptual tools for a preliminary sorting of a given lithic assemblage in the course of the analysis, and not as two clear-cut groups connected by a linear and abrupt change.

The research conducted in this doctoral thesis has identified an internal variability within the stratigraphic sequence of Fumane Cave that is framed in several chronological trends that are recognizable in south and west European sites. These trends in lithic technology permit us to define two main stages within the early manifestations of the Aurignacian in this part of the subcontinent.

The first corresponds to the *early* PA, which appears to be rather homogeneous across its extent, as shown in the first research project. The second refers to a period of gradual modification and consolidation of regional signatures. At Fumane, and more generally in northern Italy, this phase seems to be in strong cultural continuity with the underlying units, and can be tentatively referred to as *late* PA. The main differences in stone artifacts are the increased proportion of carinated endscrapers and the decrease of retouched bladelets.

When additional evidence in the North-Adriatic region will be produced, there might be the possibility to discuss the use of Fumane Cave as a type site for regional variability and the definition of a new variant of the Aurignacian phenomenon, in agreement with evidence from the northern Tyrrhenian coastal belt. In this thesis, the use of the existing terminology has helped to critically address the validity of the available pan-European reconstructions. While the definition and concept of the PA have been directly verified with empirical data, the critique of the EA rests exclusively on comparison with published data. Having said that, new taxonomical systems, if retained as necessary, should be discussed by the scientific community involved in Aurignacian studies. These debates would give a necessarily more accurate description of the ever more complex scenario being generated by the increasing number of sites available for comparison and the data obtained from multi-disciplinary studies. This is not the task of one author but the goal of a cooperative research community. This issue therefore remains necessarily open for debate and development within the diverse traditions of the discipline of Paleolithic archaeology.

The present thesis represents only the first step towards a more solid definition of the PA at Fumane Cave. Although this technological assessment provides an indispensable prerequisite for any work that interpret human behavior using assemblage variability, future research needs to address questions related to the use of the site through time, and to consider the mobility strategies adopted by foragers. This further research will be important to investigate the impact of functional variables in the formation of the lithic assemblages.

This PhD is an important step towards a more dynamic understanding of the Aurignacian. The re-evaluation of pivotal sites and the definition of regional signatures are shedding new light on the beginning and development of the Upper Paleolithic in Europe. Several exciting research questions came to mind when finalizing this thesis. For instance, it became clear that a great amount of work needs to be done to better understand the Aurignacian south of the Alpine range and the Italian Peninsula. Several sites are waiting for a careful analysis of the lithic assemblages and organic

artifacts. One of the main issues here concerns the variability between the northern and the southern Peninsula. Data from the south have a great potential but are still incomplete, sometimes derived from old excavations and surface collections. Further evidence is needed to test the hypothesis of an abrupt end of the PA, triggered by the Campanian Ignimbrite volcanic eruption. Furthermore, research should focus on the possible cultural interactions between the makers of Aurignacian and Uluzzian techno-complexes, and their related bio-cultural consequences. In this framework, the chronological and archaeological differences that exist between the northern and southern records might be the outcomes of complex adaptation mechanisms but also of transfer of ideas between human groups that were settled in adjacent regions. This is an exciting research question that might contribute to support or reject the hypothesis according to which an early wave of AMHs was responsible for the appearance of the Uluzzian in Italy and Greece.

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## APPENDIX

The ensuing accepted publications (i.a–d) and the submitted manuscript (ii.e) are listed in this appendix following the order in LIST OF PUBLICATIONS.

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<http://www.tandfonline.com/10.1080/01977261.2018.1439681>.

APPENDIX **i.c** is an Accepted Manuscript of an article published by Springer-Verlag Berlin Heidelberg in Archaeological and Anthropological Sciences on 12/09/2016, available online:

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RESEARCH ARTICLE

# A critical assessment of the Protoaurignacian lithic technology at Fumane Cave and its implications for the definition of the earliest Aurignacian

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**OPEN ACCESS**

**Citation:** Falcucci A, Conard NJ, Peresani M (2017) A critical assessment of the Protoaurignacian lithic technology at Fumane Cave and its implications for the definition of the earliest Aurignacian. PLoS ONE 12(12): e0189241. <https://doi.org/10.1371/journal.pone.0189241>

**Editor:** Michael D. Petraglia, Max Planck Institute for the Science of Human History, GERMANY

**Received:** September 18, 2017

**Accepted:** November 24, 2017

**Published:** December 7, 2017

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**Data Availability Statement:** All relevant data underlying the findings described in this paper are within the paper and its Supporting Information files (see S1 File for a list of individual artifacts with catalogue number and discrete and metric attributes recorded during the technological analysis). The Protoaurignacian lithic assemblage from Fumane Cave is permanently stored at the University of Ferrara, Dipartimento di Studi Umanistici, Sezione di Scienze Preistoriche e Antropologiche, Corso Ercole I d'Este, 32, I-44100 Ferrara, Italy. Lithics had not individual numbers,

## Abstract

In the scenario of the spread of the anatomically modern humans (AMHs) into Europe, the techno-complex known as Protoaurignacian is defined by the production of blades and bladelets within a single and continuous stone knapping sequence from the same core as the result of its progressive reduction. However, the growing re-evaluation of some assemblages is revealing that bladelets are frequently obtained from independent reduction sequences, hence discouraging the direct application of the model developed in southwestern France. High-resolution regional signatures are thus needed to reconstruct a more accurate portrait of the AMH colonization dynamic. Northeastern Italy, with the key site of Fumane Cave, is one among the regions of Mediterranean Europe worthy of consideration for reconstructing this colonization process and its cultural dynamics. Within the framework of a critical discussion of the technological definition of the Protoaurignacian and its relationship with contemporaneous industries on a regional and supra-regional scale, we present the results of a detailed analysis of the lithic technology from units A2-A1 based on reduction sequence and attribute analyses. Results show that bladelets are the first goal of production and they do not originate from reduced blade cores but from a broad range of independent and simultaneous core reduction strategies. One implication is that the most commonly used technological trait that is said to define the Protoaurignacian has been over-emphasized and that the Protoaurignacian is technologically consistent across its geographical extent. Additional data based on carinated core technology imply that this techno-complex shares a common technological background with the Early Aurignacian and that no features are restricted to one of the two facies. Furthermore, the major difference between the Protoaurignacian and Early Aurignacian appears to be more typological in nature, with retouched bladelets being less common in the Early Aurignacian.

but were labeled according to the site of provenience (RF, that stands for Riparo di Fumane), square, sub-square, and archaeological layer (A1 and A2). We then assigned to artifacts individual catalogue number in sequential numerical order preceded by the label "AF". AF stands for Armando Falcucci.

**Funding:** Research at Fumane is coordinated by the Ferrara University in the framework of a project supported by the Ministry of Culture - Veneto Archaeological Superintendency, public institutions (Lessinia Mountain Community - Regional Natural Park, Fumane Municipality), Foundations (Leakey Foundation, Spring 2015 Grant), and private associations and companies. The doctoral studies of Armando Falcucci are founded by the state of Baden-Württemberg and the University of Tübingen. The authors acknowledge support by the Deutsche Forschungsgemeinschaft and Open Access Publishing Fund of Tuebingen University. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

**Competing interests:** The authors have declared that no competing interests exist.

## Introduction

The Aurignacian is considered the result of the spread of anatomically modern humans (AMHs) across Europe [1–4]. To trace this migration route, the techno-complexes which are said to represent the precursors of the classic Aurignacian, like the Mediterranean Protoaurignacian and the Kozarnikian, have at times been assigned to the Early Ahmarian [5, 6]. The issue is however open to debate because of currently available chronology in the Near East [7], and the absence of a detailed comparison between techno-complexes. According to some researchers, the appearance of the Aurignacian *sensu lato* might represent a second wave of AMHs moving across Western Eurasia [5]. The first wave would be associated with the Bohunian in Europe, whose material culture is comparable to the Levantine Initial Upper Paleolithic [8–11]. Similar claims have been made for the Uluzzian after the assignment of two teeth to *Homo sapiens* at Cavallo cave [12]. The integrity of the Cavallo stratigraphy has, however, been questioned [13] and further evidence is needed to assess the makers of the Uluzzian industry [14, 15].

To date, the Aurignacian is the sole, undisputed techno-complex associated to AMHs [3, 16, 17]. The appearance of the Aurignacian at Willendorf II, Geißenklösterle, and Peskó dates back to about 43 ka cal BP [18–22]. Slightly later dates (c. 42 ka cal BP) exist at Isturitz [23], Mochi [24], and Arbrede [25]. The Aurignacian thus seems to overlap for few millennia with the transitional industries and late Mousterian techno-complexes [25–27]; but see Davies et al. [21].

The earliest phases are known as Protoaurignacian and Early Aurignacian (see a background history in [28, 29–35]). The Protoaurignacian was first described by Laplace [33] along the Mediterranean boundaries and in the French Pyrenees. In these regions, the Protoaurignacian is stratigraphically placed below the Early Aurignacian when both industries are documented [35–38]. According to this evidence and with the support of a series of radiocarbon dates, Banks, d'Errico and Zilhao [39] have concluded that the changes in the Early Aurignacian material culture represent the response of AMHs to the deterioration of the environment at the onset of the Heinrich event 4 (contra [40, 41]). On a supra-regional scale, however, this theory is questioned by the manifestation of the Early Aurignacian prior to HE4 in Central Europe [18–21]. Some have proposed that the two Aurignacian varieties have developed in different geographical domains and have spread across Europe along two different routes [3, 42]. The Danube represented a preferential corridor for the diffusion of Early Aurignacian industries [20], while the Mediterranean coastline was followed by makers of Protoaurignacian industries [43, 44]. These considerations raise questions about how these two apparent sister groups relate and if the assumptions that were made are consistent with the available archaeological data [45].

The Aurignacian was initially defined by the association of stone and organic tools discovered in southwestern France, with technological features subsequently investigated to isolate two distinct technical traditions [35, 46–48]. The Protoaurignacian technological signature is said to lie in the production of blades and bladelets within a single and continuous stone knapping sequence. Both products are thus obtained from the same core as the result of its progressive reduction [35, 49]. Blades are selected to manufacture end-scrapers, burins, and laterally-retouched tools. Slender blades, representing the intermediate products between blades and bladelets, are frequently left unretouched. Bladelets are the dominant intention of the lithic production and are described as large, with rectilinear profiles, and are transformed into Dufour sub-type Dufour [50]. The Early Aurignacian is instead characterized by a clear distinction between laminar and lamellar productions as result of a stronger anticipation and planning of different needs [51, 52]. Blades are obtained from unidirectional prismatic cores,

while curved bladelets are produced from carinated cores, frequently called “carinated end-scrapers” (see a research history in [53]). The latter are said to be scarcely found, or even absent, in Protoaurignacian assemblages [36]. Blades are robust, have frequently faceted platforms, and are transformed into laterally-retouched tools, strangled blades, and thick end-scrapers. These common tools are often modified by the so-called Aurignacian retouch [31], which is scalar and invasive due to several re-sharpening stages that occur during repeated use and transport over long distances [54]. Bladelets are instead produced on-site, as needed, and only few were transformed into small sub-type Dufour [55].

Aside from stone tools, historically, the most important type-fossil associated with the Early Aurignacian is the split-based bone point [31, 48]. Recently, the exclusive association of split-based bone points with Early Aurignacian assemblages has been questioned and its presence in an archaeological horizon does not in and of itself clarify the cultural attribution [56, 57]. At Geißenklösterle, for instance, split-based bone points appear only in the upper Early Aurignacian horizon [20, 51], while at Trou de la Mère Clochette [58] and Arbreda [59] split-based bone points were found in association with Protoaurignacian lithic implements.

Additionally, the Early Aurignacian has produced three-dimensionally formed personal ornaments, figurative representations, occasional finds of mythical imagery, and musical instruments, whereas the Protoaurignacian typically has a more limited range of symbolic artifacts, made especially on marine shells and animal teeth [60–63].

The growing number of multi-disciplinary analyses and the re-evaluation of some assemblages are highlighting a greater technological variability that is casting serious doubts on the direct application of the model developed in southwestern France. Lithic assemblages with mixed features have been described in the Basque Country, Romania, and Crimea [23, 56, 64, 65]. Also, technological analyses carried out at some Protoaurignacian sites have revealed that bladelets are frequently obtained from independent reduction sequences [46, 56, 66]. As noticed by Bon [35], a further step in the research history is needed in order to build up high-resolution Aurignacian regional signatures and to reconstruct a more accurate portrait of AMHs colonization dynamics.

Here, we present a detailed analysis of the lithic technology of the Protoaurignacian from units A2-A1 of Fumane Cave in northeastern Italy. Fumane has always been considered a key site for understanding the Middle-to-Upper Paleolithic transition and the complex processes that led to the demise and final extinction of Neandertal populations and the spread of AMHs across Europe. The systematic and modern excavations conducted for decades, the presence of a high resolution stratigraphic sequence that includes the Mousterian, the Uluzzian, and the Protoaurignacian, and the discovery of modern human remains associated with the Protoaurignacian [17], allow us to critically discuss the technological definition of this techno-complex and its relationship with contemporaneous industries on a regional and supra-regional scale. Previous studies on the lithic assemblage [43, 67] have the merits of having described the variability of bladelet production, even if additional quantitative research was needed to discuss in detail the procedures and the objectives of the stone knapping. Specifically, we present the results of an extensive investigation on the Protoaurignacian lithic technology by using two combined approaches: reduction sequence and attribute analyses. The information gained during the analytical process will be then compared with the existing literature, in order to address the following research questions:

1. What are the main goals of the Protoaurignacian lithic technology at Fumane Cave and how are they met?
2. Is the continuous reduction sequence theory [48] a viable proxy to define the Protoaurignacian on a technological ground?

3. What are the shared features of Protoaurignacian lithic technology across its geographical extent?
4. How does the Protoaurignacian relate to the Early Aurignacian, and how do the archaeological data fit with the reconstruction proposed by Banks, d’Errico and Zilhao [39]?

### Fumane Cave, the Middle-to-Upper Paleolithic transition, and the Aurignacian

Fumane Cave, excavated since 1988, lies at the foot of the Monti Lessini Plateau (Venetian Pre-alps; Fig 1). Details about the cave’s structure, Late Pleistocene stratigraphic sequence, and paleoclimatic significance, as well as its paleontological and cultural content, are available in numerous publications [15, 17, 67–72]. A main cave and two associated tunnels preserve a finely-layered sedimentary succession spanning the late Middle Paleolithic and the Early Upper Paleolithic, with features and dense scatters of remains in units A11, A10, A9, and A6–A5 (Mousterian [71, 73]), A4 and A3 (Uluzzian [15, 74]), A2 and A1 (Protoaurignacian [43, 67, 75]), D6 and D3 (Aurignacian lato sensu [68]). Currently, layers A9 to A1 have been extensively excavated at the entrance of the cave and partly excavated in the cave mouth.

In layers A4 and A3, the Uluzzian occupations date to later than 43.6–43.0 ky cal BP [69]. The transition from the final Mousterian took place in a relatively short time, as the beginning



**Fig 1. Map showing the localization of Fumane Cave and other Aurignacian sites cited throughout the paper.** 1 = La Viña (Spain), 2 = Morin (Spain), 3 = Labeko Koba (Spain), 4 = Isturitz (France), 5 = Champ-Parel (France), 6 = Barbas III (France), 7 = Hui (France), 8 = Les Cottés (France), 9 = Piage (France); 10 = Tuto-de-Camalhot (France), 11 = Arbreda (Spain), 12 = Esquicho-Grapaou (France), 13 = Louza (France), 14 = Arcy (France), 15 = Mandrin (France), 16 = Trou de la Mère Clochette (France), 17 = Observatoire (France), 18 = Mochi (Italy), 19 = Bombrini (Italy), 20 = Geißenklösterle (Germany), 21 = La Fabbrica (Italy), 22 = Fumane (Italy), 23 = Castelcivita (Italy), 24 = Willendorf II (Austria), 25 = Peskő (Hungary), 26 = Tincova (Romania), 27 = Românești (Romania), 28 = Kozarnika (Bulgaria), 29 = Siuren I (Crimea). Map downloaded from the NASA Earth Observatory (<http://earthobservatory.nasa.gov/>) and processed by K. Di Modica (Scladina Cave Archaeological Center).

<https://doi.org/10.1371/journal.pone.0189241.g001>

of the Uluzzian is chronologically indistinguishable from the final Mousterian [27]. The Uluzzian lithic technology is primarily oriented towards flake production. Technological innovations are rooted in a clear Mousterian cultural context [15]. In layer A4, flakes are obtained from centripetal cores, following Levallois concepts. Scrapers of varied morphologies are the prevailing tool type. Layer A3 marks the definitive separation of the Uluzzian from the Mousterian. In this layer, flakes are produced through several methods and bladelet production slightly increases. The main tool types are scrapers, splintered pieces, and backed flakes.

Unit A2 dates the appearance of the Protoaurignacian to 41.2–40.4 ky cal BP [69]. Its boundary with layer A3 and with the overlying layer D3 is clear and is marked by a dispersion of ocher over a large extent of the area [75, 76] and by a considerable change in the content of anthropogenic material [77]. In the cave entrance, unit A2 is covered by unit A1, a thin anthropic level with horizontal bedding which makes it indistinguishable from A2 in the cave mouth. A2 thus extends throughout the whole cave extent.

Post-depositional processes, due to frost activity, affected layers A3 and A2 in the easternmost part of the cave entrance and produced infiltrations of Protoaurignacian materials (lithics, bones, and shells) into A3 [15]. Stratigraphic deformations have been reported in the inner eastern side of the cave mouth, where layer A2 was tilted and compressed towards the cave wall, forming a pronounced fold. Despite this deformation, during the excavation layer A2 appeared like a clearly discernible sedimentary body preserved with variable thickness from a few to 10 centimeters, due to its dark-brownish color, its texture and its high charcoal, bone and stone implement density, as well as the occurrence of features (i.e. hearths, post-holes, toss-zones) mostly located at the cave entrance [78, 79]. Some of these hearths were located within shallow basins excavated at the expenses of the Uluzzian and final Mousterian layers below, thus producing possible dispersion of few flaked stones in the A2-A1 Protoaurignacian assemblage.

The consistency of A2-A1 assemblages is also secured by the lack of any evidence supporting massive percolation of stone implements from the above D6-D3 stratigraphic complex and related layers at the cave entrance. Clear boundaries between Aurignacian contexts, as well as the lack of deformations, point for excluding a mixing between different Aurignacian occupations. The youngest Aurignacian phase is from the stratigraphic complex D6-D3, which includes several layers embedded in coarse-sandy sediments. Layers D3a and D3b are the most extended, while D6 is a loose stony layer limited to the eastern zone of the cave. The traces of human presence are less dense than in A2-A1, however, hearths and other surface features have been exposed.

Ornamental objects represent a regular cultural component of the Aurignacian layers. They consist of grooved red deer incisors and several hundreds of perforated shell beads belonging to sixty different taxa, most of them marine [68, 80]. The bone and antler industry is composed of a variety of tools [43, 68]. Split-based bone points are not found in units A2-A1; they are only found in units D6 and D3, except one implement found at the interface between D3 and A1 [43]. The same is true of the five rock fragments painted with red ocher [68, 77]. The lithic implements of units D6-D3 do not seem to differ significantly from A2-A1 [67, 69, 81]. New, careful, investigations are being performed by one of us (AF) to test this first hypothesis.

Faunal remains shed lights on the Aurignacian ecological context. They show an association between forest fauna and cold and open habitat species typical of the alpine grassland steppe above the tree line [82]. This context reflects a clear climatic cooling with relative decreases in woodland formations, as also indicated by the micromammal associations [70].

## Materials and methods

Units A2 and A1 do not show significant differences on typo-technological or chronological grounds [69], and were undistinguishable in the cave mouth during the excavations. For these reasons and for the purpose of this study, it was considered more accurate to incorporate both layers into a single analytical unit. The archaeological material was either directly excavated using a 33×33 cm grid or recovered from wet sieving. All artifacts, independently from their size, are available for detailed investigations; except for a small set of cores ( $n = 5$ ) and tools ( $n = 17$ ) that are on display in permanent exhibitions at the Museo Paleontologico e Preistorico di Sant'Anna d'Alfaedo. In order to conduct an extensive technological analysis of the Protoaurignacian lithics, all artifacts greater than 1.5 cm in maximal dimension were counted (A2 = 22,212; A1 = 4,153 items) and divided according to several technological classes and the sub-square of provenience. The minimal number of flaked products (MNFP), which was calculated by taking into account only blanks with preserved butts, permitted a better estimation of the amount of lithics. This step was judged necessary because no previous quantitative analysis of the lithic assemblage had been undertaken. The data gained during this first phase was used to evaluate the frequency of technological categories and the degree of cortex extension on artifacts. The sampling procedure is based on the dispersion of lithic materials in the squares and an evaluation of the stratigraphic context, as described in the excavation notebooks. Seven square meters were selected (S1 Fig). They are located in different sectors of the cave and are close to the main combustion features. Two adjacent square meters were analyzed in those sectors with the highest concentration of lithics. Early on in the study it became clear that A2-A1 is a blade-bladelet dominated industry. For this reason, all blades and bladelets greater than 1.5 cm in maximal dimension, regardless of the degree of fragmentation, were analyzed, while only flakes with preserved butts greater than 2.0 cm in maximal dimension were fully analyzed. Furthermore, the extent of the cave was sampled in order to isolate and include in the database all cores, tools and tool fragments, all complete and almost complete blades and bladelets, and all by-products deemed to have had a significant role in the reduction process. Only the innermost part of the cave, affected by a stratigraphic deformation (see above), was excluded from the analysis. This strategy was considered effective to avoid potential biases in the reconstruction of the blank production system. Therefore, we analyzed a total of 7,866 artifacts.

The Protoaurignacian industries have been made on flint of different carbonatic formations, which, in the western Monti Lessini, range from the Upper Jurassic to Middle Eocene. They were easily collected within 5–15 km from the site. The most widespread types, distinguished on the base of macroscopic features, are from the Maiolica, the Scaglia Rossa, the Scaglia variegata, and the Ooliti di San Virgilio formations. Flint also abounds in loose coarse stream or fluvial gravels, slope-waste deposits, and soils in the immediate surroundings of the cave [83]. Jurassic and Tertiary calcarenites, frequently found in large-sized and homogeneous nodules, were almost exclusively used to produce blades [43].

The lithic analysis approach combines two complementary methods: reduction sequence analysis [84–88] and attribute analysis [10, 89, 90]. The first permits identification of the methods of core reduction and the stages of knapping, and use and discard of stone artifacts enchainned in a temporal trajectory. The second is particularly valuable because it provides quantitative data on the numerous discrete and metric features that can be recorded on individual artifacts. The attributes recorded in the database are based on recent studies and have been shown to be valuable for understanding laminar technologies at the onset of the Upper Paleolithic (e.g. [8, 91]).

Additionally, diacritic analyses [92, 93] were performed to reconstruct the chronology, the direction of removals, the stages of production on discarded cores, and short sequences of removals on blanks. By doing this, the detailed procedures of core reduction were identified [94]. Diacritic investigations have been particularly helpful to contextualize the operations and technical expedients performed to maintain the core structure and to isolate recurrent patterns among the studied assemblage.

Non-extensive refitting analyses were also conducted throughout the study. They have proven to be particularly valuable to test hypotheses formulated during the analytical process.

Supplementary and specific databases were designed to record additional features on particularly informative blank types such as core tablets and technical blanks, and also to discriminate the knapping technique (based on [95, 96]).

The unified taxonomy by Conard et al. [97] was used to give a general overview of core categories. Platform cores have been further divided into several reduction strategies according to criteria such as: orientation of the flaking surface, knapping progression, and number of platforms and faces exploited.

In order to assess the curvature of blanks, dorsal scars, and shape only complete and almost complete specimens have been taken into account. This is beneficial in that it avoids biases due to the high degree of fragmentation of the assemblage. Profile curvature was quantified using the categories defined by Bon [35]. Retouched tools were excluded from the analysis of morphology and distal ends due to the modification of the shape via retouching. The metric boundary between blades and bladelets was placed at 12.0 mm [98], in agreement with most of the studies conducted on Aurignacian assemblages and according to our case study. At Fumane, the inverse and alternate retouch, common among retouched bladelets, is indeed rarely applied on laminar tools wider than 12.0 mm ( $n = 16$ ; 3.9%).

The maximum dimensions of each artifact were recorded using a digital caliper and metric differences were assessed in IBM SPSS Statistics 24. Given that our sample was not normally distributed according to Shapiro–Wilk and Kolmogorov–Smirnov tests, we have performed non-parametric tests (Mann–Whitney and Kruskal–Wallis). Given that multiple tests were conducted, the Holm–Bonferroni sequential correction test was utilized for the purpose of reducing the probability of performing a type 1 error [99].

## Results

### Quantitative analysis of the knapped assemblage

The quantitative analysis of the knapped assemblage (Table 1) shows that blanks dominate, followed by tools, angular debris, and, finally, cores. The paucity of cores is not surprising and may be explained as the result of a high on-site reduction, but also as an off-site transport of non-exhausted cores. Seven raw materials were discarded prior blank production, after at least one removal that aimed to evaluate the quality of the selected piece. Tested raw materials have

**Table 1. Quantification of the knapped assemblage (> 1.5 cm).**

Category	Number	Percentage
Blank	21373	81
Tool	3177	12
Core	155	0.6
Angular debris	1674	6.3
Tested nodule	7	-
Total	26386	100

<https://doi.org/10.1371/journal.pone.0189241.t001>



maximum linear dimensions (MLD [89]) that range from 63.7 to 111.9 mm (mean: 82.5 mm), polygonal morphologies, and are almost completely cortical.

Table 2 summarizes the frequency of the main blank types and gives a detailed technological overview among each class. The frequency of by-products related to maintenance operations may be underestimated due to the degree of fragmentation. Only specimens with a combination of technologically relevant attributes have been typed under specific sub-types. Laminar products dominate the blank assemblage. Taken together, blades and bladelets

**Table 2. Distribution of blank types (> 1.5 cm) according to the whole assemblage and the minimal number of flaked products (MNFP).**

Blank type	Number	MNFP
<b>Flake</b>	<b>8921 (36.3%)</b>	<b>4486 (37.4%)</b>
Flake	6671 (74.8%)	3321 (74.0%)
Semi-cortical flake	1347 (15.1%)	631 (14.1%)
Fully cortical flake	499 (5.6%)	178 (4.0%)
Debordant flake	69 (0.8%)	61 (1.4%)
Crested flake	8 (0.1%)	7 (0.2%)
Two-sided crested flake	2 (-)	2 (-)
Crested secondary flake	1 (-)	1 (-)
Neo-crested flake	6 (0.1%)	4 (0.1%)
Technical flake	149 (1.7%)	120 (2.7%)
Lateral comma-like flake	5 (0.1%)	4 (0.1%)
Core tablet	164 (1.8%)	157 (3.5%)
<b>Blade</b>	<b>5875 (23.9%)</b>	<b>2941 (24.5%)</b>
Blade	4460 (75.9%)	2214 (75.3%)
Semi-cortical blade	913 (15.5%)	410 (13.9%)
Fully cortical blade	99 (1.7%)	43 (1.5%)
Naturally backed blade	68 (1.2%)	49 (1.7%)
Crested blade	35 (0.6%)	16 (0.5%)
Two-sided crested blade	13 (0.2%)	8 (0.3%)
Crested secondary blade	36 (0.6%)	22 (0.7%)
Neo-crested blade	51 (0.9%)	32 (1.1%)
Technical blade	117 (2.0%)	86 (2.9%)
Lateral comma-like blade	83 (1.4%)	61 (2.1%)
<b>Bladelet</b>	<b>9664 (39.4%)</b>	<b>4513 (37.7%)</b>
Bladelet	9009 (93.2%)	4237 (93.9%)
Semi-cortical bladelet	509 (5.3%)	185 (4.1%)
Fully cortical bladelet	11 (0.1%)	3 (0.1%)
Crested bladelet	36 (0.4%)	15 (0.3%)
Two-sided crested bladelet	2 (-)	2 (-)
Crested secondary bladelet	22 (0.2%)	14 (0.3%)
Neo-crested bladelet	17 (0.2%)	8 (0.2%)
Technical bladelet	32 (0.3%)	26 (0.6%)
Lateral comma-like bladelet	26 (0.3%)	23 (0.5%)
<b>Burin Spall</b>	<b>80 (0.3%)</b>	<b>49 (0.4%)</b>
<b>Undetermined</b>	<b>10 (-)</b>	<b>-</b>
<b>Total</b>	<b>24550 (100%)</b>	<b>11989 (100%)</b>

The count includes blank types of tools. Percentages are given in brackets.

<https://doi.org/10.1371/journal.pone.0189241.t002>

amount to 63.3% (MNFP = 62.2%). Flakes are relatively abundant, even if this category is mainly composed of by-products of blade and bladelet reduction strategies (see below). The degree of breakage is high (90.1%), while MNFP amounts to 48.8% of the entire blank assemblage. Cortical surfaces are well-represented among flake (22.2%) and blade (20.2%) categories, while among bladelets, they are rare (5.3%). This evidence suggests that raw material decortication and core initialization resulted mostly in the production of flakes and blades of variable sizes. Among the studied sample, the decortication phase is represented by objects with more than 66% cortex coverage (n = 198). Most of the pieces are flakes (n = 118), followed by blades (n = 66), and rarely bladelets (n = 14). There is no significant difference between size and cortex when the length of complete blanks is compared across specimens with different grades of cortex coverage (S1 Table; Kruskal–Wallis, H = 1,163; p = 0.7).

### Core reduction

Three core reduction methods were identified in layers A2-A1: platform, multidirectional, and parallel. Platform cores represent the most abundant category, with multidirectional and parallel reduction strategies playing a secondary role (Table 3). Core fragments belong mostly to platform cores, even if most of them cannot be further sub-grouped. Knappers employed multidirectional and parallel methods to produce flakes of varied morphologies and used the platform method to obtain blades and bladelets. Some evidence suggests that platform cores were sometimes recycled to produce flakes from two or more core faces, obliterating the previous removal scars. This is the case of a discarded blade core, and of a blade core fragment. In the following paragraphs the three core reduction strategies are described.

**Multidirectional cores.** In the case of Fumane, this group includes cores that have removals from two or more faces without well-developed striking platforms. They have polyhedral morphologies, and display irregular negatives of removals. All of them have produced flakes by rotating the cores according to the exploitable morphology achieved after the former removals. One of these cores exploited a fragment of a blade core, identified thanks to the preservation of a portion of the striking platform and a few related unidirectional scars which were almost completely covered by the flake negatives. Multidirectional cores have produced from three to six flakes prior to discard. The negatives of bulbs suggest that flakes were detached by using direct internal percussion, without any particular kind of preparation prior detachment. To conclude, this core reduction strategy seems to be rather opportunistic and marginal.

**Table 3. Distribution of core categories.**

Core category	Number
Initial platform core	26 (16.8%)
Platform	89 (57.4%)
<i>Narrow-sided</i>	23 (25.8%)
<i>Semi-circumferential</i>	20 (22.5%)
<i>Wide-faced flat</i>	13 (14.6%)
<i>Transverse carinated</i>	10 (11.2%)
<i>Multi-platform</i>	23 (25.8%)
Parallel	5 (3.2%)
Multidirectional	9 (5.8%)
Core fragment	26 (16.8%)
<b>Total</b>	<b>155 (100%)</b>

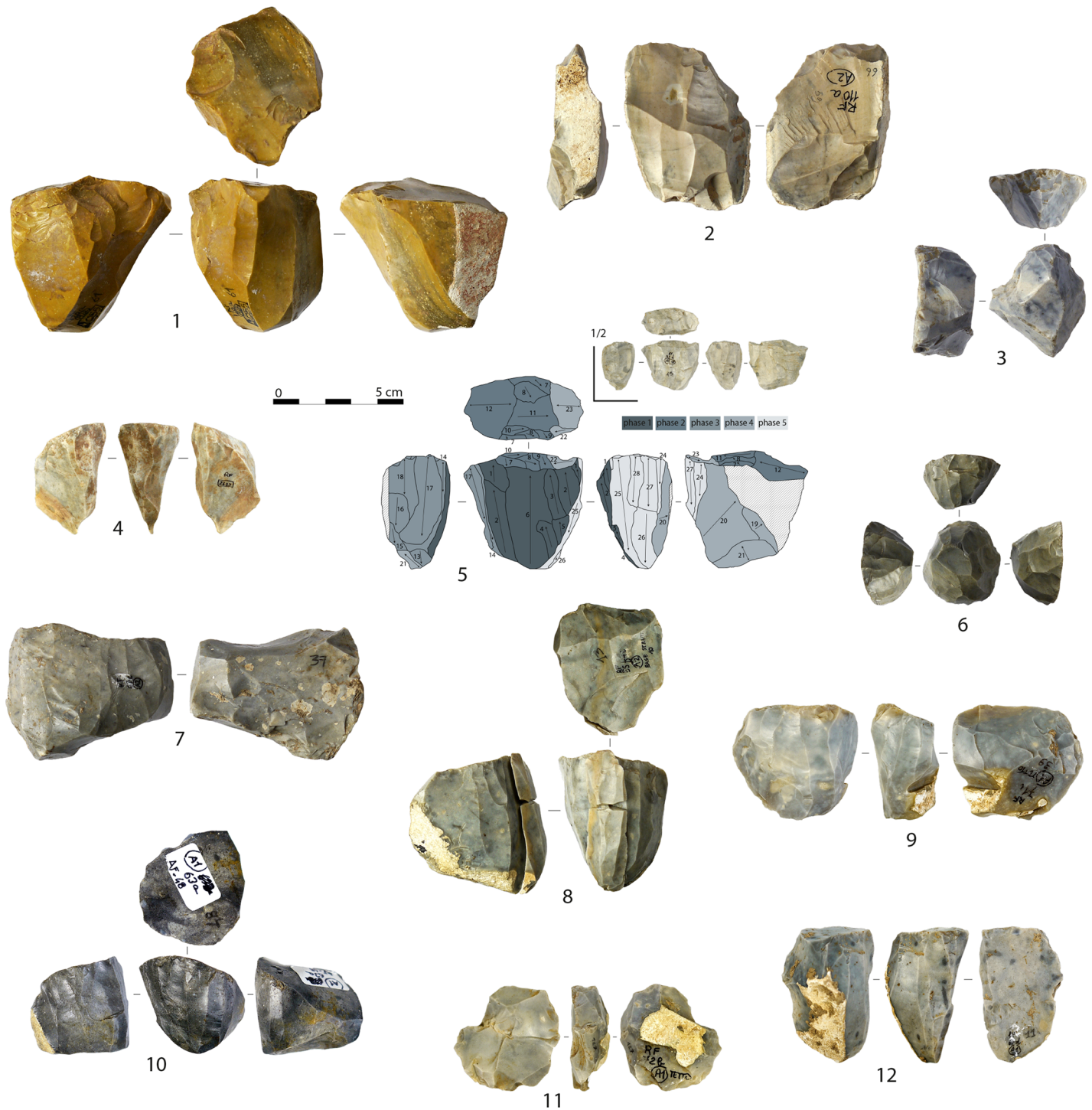
Platform cores are further divided according to the five reduction strategies identified. Percentages are given in brackets.

<https://doi.org/10.1371/journal.pone.0189241.t003>

**Parallel cores.** Parallel cores are characterized by a removal surface with centripetal negatives that originated from the intersection with the underside (Fig 2: 11). This underside presents short platform preparation scars all along its periphery, while its central area is always cortical. In two cases, the striking platform is weakly trimmed. The flaking angle is around 70° to 80° and the pronounced bulbar negatives relate with the application of direct internal percussion. The final size of the cores suggests a high degree of reduction (mean MLD = 39.2 mm). Last removal scars suggest that, through this method, knappers obtained polygonal flakes, some of them characterized by hinged distal terminations. This reduction method must be treated with caution, due to its strong resemblance to the centripetal flake method of the Uluzzian layers A4 and especially A3 [15]. On the other hand, the spatial distribution analysis shows that parallel cores were found in different sectors of the cave, making the attribution to A2–A1 at least plausible.

**Platform cores.** Platform methods were used to manufacture almost exclusively blades and bladelets. Cores have been discarded at different stages of reduction. Exhausted platform cores can be classified as blade cores (n = 6), bladelet cores (n = 76), blade-bladelet cores (n = 5), and blade-flake cores (n = 1) according to the organization of the last visible scars. One core is undetermined. Bladelet cores may display laminar scars wider than 12.0 mm related to maintenance operations. For this reason, they have not been typed as blade-bladelet cores. The latter are characterized by a clear alternation of blade and bladelet removals, or by an independent bladelet production performed on a re-oriented blade core. Finally, initial platform cores were identified. Under this category, all objects displaying only few removal scars have been included. They reflect the initial stages of knapping in which much of the original piece is still unmodified. Initial platform cores represent an important source of information because they allow appreciation of the preliminary flaking and configuration of the selected blanks before their overall morphology is modified and the volume is reduced. The lengths of the flaking surfaces suggest that most of them were intended to be bladelet cores. Only five specimens, ranging from 55.6 to 116.1 mm (mean: 76.5 mm), may have served as blade cores. On the other hand, initial bladelet cores frequently display shaping negatives that belong both to blades and flakes. Five reduction strategies were identified among platform cores [94]. Their main features can be summarized as follows:

1. **Narrow-sided core** This category consists of cores exploited on the narrow face along the longitudinal axis to produce exclusively bladelets (Fig 2: 4,12). They are made from flakes or flat raw material nodules selected according to their thickness and are frequently characterized by posterior crests or dorsal thinning.
2. **Semi-circumferential core** This category corresponds to cores that have been exploited along the longitudinal axis around at least two available sides in continuity, by turning the core during the reduction process (Fig 2: 1,8,10). Semi-circumferential cores can have a rectangular or triangular removal surface. They have produced bladelets (n = 15), blades (n = 4), and blades and bladelets simultaneously (n = 1).
3. **Wide-faced flat core** The third category is composed of cores exploited in one of the broader faces of the blank, along the longitudinal axis (Fig 2: 2,7). They have been discarded in an advanced stage of reduction, given that at least one of the flanks is missing, linking the flaking surface directly to the back of the core. Last removals at discard correspond to blades (n = 2), to a simultaneous blade and bladelet production (n = 1), and especially to bladelets (n = 9). One core is undeterminable due to a technical flake that obliterated the previous removal scars.



**Fig 2. Cores.** Semi-circumferential blade core (1), wide-faced flat blade core with scars of a technical orthogonal flake on the proximal side (2), transverse carinated cores (3, 6), narrow-sided cores (4, 12), multi-platform core, and its schematic drawing (arrows indicate direction of the removals and numbers indicate the order of the removals), exploited for blade (phase 1) and bladelet productions (phases 3 and 5) (5), wide-faced flat core with evidence of a simultaneous production of small blades and big bladelets (7), semi-circumferential bladelet core with a refitted plunging blade (8), multi-platform bladelet core exploited on the narrow face and successively on the wide face in two distinct phases (9), semi-circumferential bladelet cores (10), and parallel flake core (11) (photo and drawing: A. Falucci).

<https://doi.org/10.1371/journal.pone.0189241.g002>

4. **Transverse carinated core** This category groups cores that have been oriented on the transversal axis to exploit the thickness of the available blank (Fig 2: 3,6). They have technological attributes comparable to well-known descriptions (see in [35, 46]) and are distinct from the rest of the categories because the frontal regression of the knapping penetrates orthogonally along the longitudinal axis of the blank. Core thickness corresponds to the length of the former categories. Transverse carinated cores are made almost exclusively from flakes and bladelets are the goal of the production.
5. **Multi-platform core** This core category is the most variable, being composed of cores exploited on one or more faces, starting from two or more platforms during independent reduction stages (Fig 2: 5,9). Last visible scars display bladelet removals most often (n = 19), simultaneous blade and bladelet removals followed by a disjointed bladelet production (n = 1), bladelets with a previous and disjointed blade production (n = 2), and blades followed by flakes (n = 1).

Globally, platform cores represent a relatively homogenous category, where all the identified sub-categories share a certain degree of technological overlap (see core schematic drawings and diacritic analyses in S2 Fig). Two core types, narrow-sided and transverse carinated cores, have been used exclusively to produce bladelets. Blade cores are found in the other categories. Their length at discard does not exceed 66.4 mm. A refitted blade core (Fig 3) provides an example of reduction intensity. Its length at discard is 36.4 mm, while its refitted length is 105.3 mm. Among blade cores, a sub-parallel reduction pattern is exclusive, while a convergent reduction pattern is well attested among to bladelet cores. Overall, the progression of knapping is parallel to the axis of core symmetry and is always unidirectional. Opposed platforms were sometimes used to maintain the core distal convexity (n = 11).

The last complete removals across platform core sub-categories are compared in Fig 4. The dimensions of the last complete negatives are similar for all core sub-categories, with only transverse carinated cores displaying shorter removals and narrow-sided cores targeting slender bladelets.

## Overall blank analysis

**Blades and bladelets.** Morphological and technological attributes of blades and bladelets (Fig 5) are listed in Table 4.

Curved profiles, of different intensity grades, clearly dominate the blade and bladelet samples. Straight profiles are more common among bladelets, while the frequency of intense curved blanks is higher among blades. Twisted specimens are common, especially across blades. Twisting is, in most cases, slightly pronounced for both blades (67.5%) and bladelets (67.3%), and is usually associated with an off-axis orientation of the blank. Twisted specimens are likely to have been produced from the periphery of the core flaking surface, especially for maintenance operations.

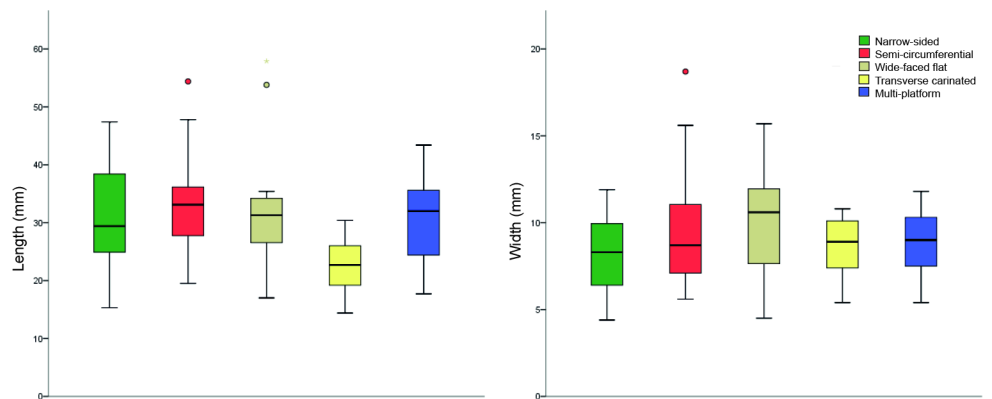
Cross-sections are mainly trapezoidal and triangular in shape. In the bladelet category, however, triangular cross-sections are dominant, indicating that a single ridge was frequently used during knapping. Polyhedral and lateral steeped cross-sections are more common among blades and, in most cases, characterize technical and naturally backed blades. Symmetrical cross-sections dominate both groups, but asymmetrical specimens are more frequent among blades.

Dorsal scar pattern is strictly unidirectional, with few occurrences of bidirectional scars. Blades and bladelets with bidirectional scar patterns indicate the use of opposed platforms to maintain the distal side of the core. In other cases, they characterize the first removals from an



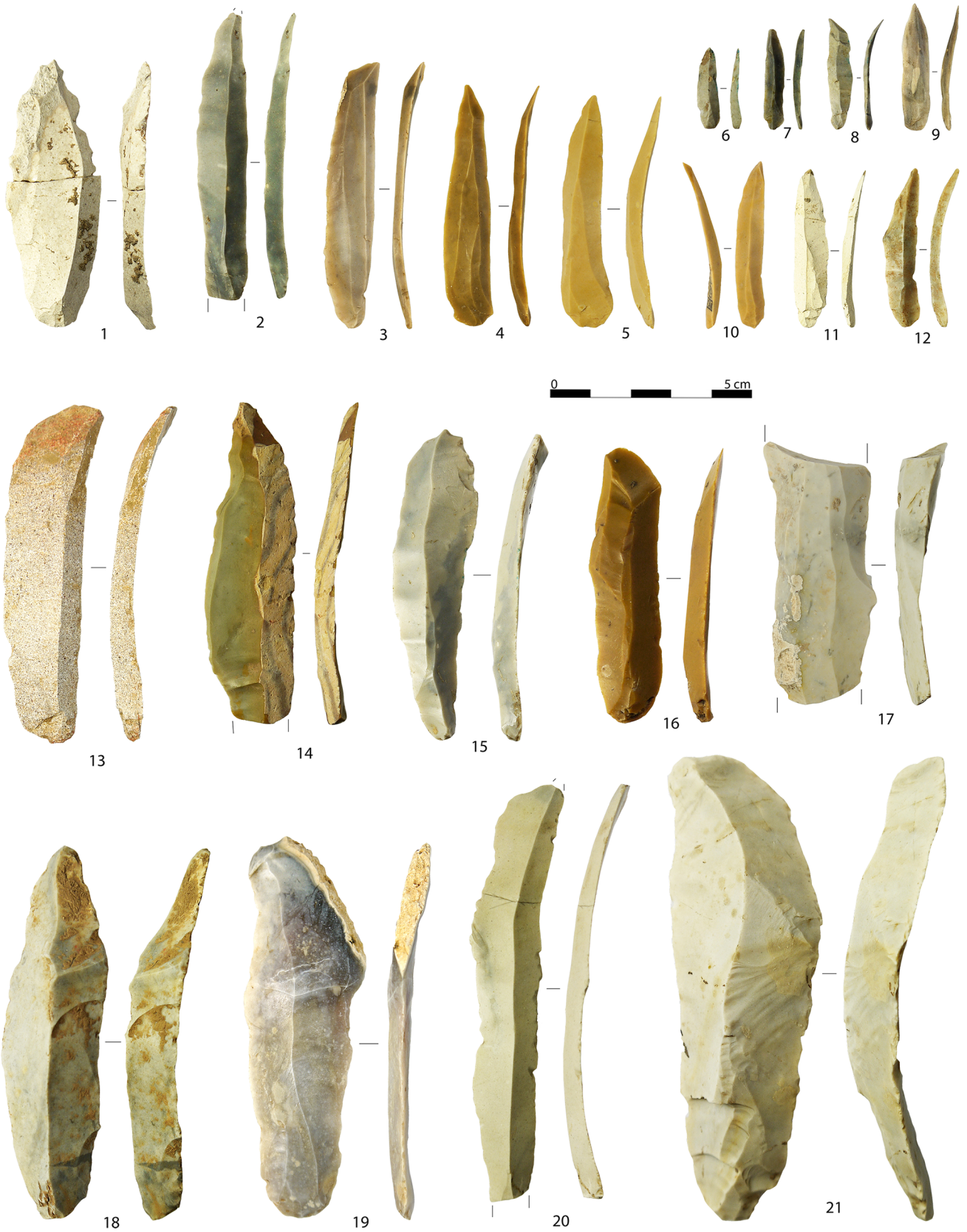
**Fig 3. Refitted semi-circumferential blade core (photo: A. Falcucci).**

<https://doi.org/10.1371/journal.pone.0189241.g003>



**Fig 4. Box-plots of length (left) and width (right) values (in millimeters) of the last complete negatives measured on platform cores divided per reduction strategy. For colors see the legend.**

<https://doi.org/10.1371/journal.pone.0189241.g004>



**Fig 5. A sample of blades (1, 13–21) and bladelets (2–12) of different sizes with unidirectional scar patterns.** Artifacts are oriented with the butt at the bottom of the photo (photo: A. Falcucci).

<https://doi.org/10.1371/journal.pone.0189241.g005>

opposed platform during a new reduction stage, as shown by multi-platform cores. The major difference between categories is the relevance of the unidirectional convergent scar pattern across bladelets. Bladelets with convergent scars have almost the same importance of specimens with sub-parallel scars. The presence of a transverse scar pattern testifies also to slight changes in the direction of blade and bladelet removals on the flaking surface.

Bladelets with a convergent outline morphology starting from the mesio-distal part are numerous. Furthermore, bladelets with pointed distal ends are more common than blades with pointed distal ends. In profile view, the frequency of plunging and stepped distal ends is very low among bladelets, while together they amount to 33.9% of the blades. Even if some of them are linked to striking accidents, this high frequency may be related to maintenance operations carried out from the main striking platform with the aim to remove part of the core base.

A summary of metric attributes of blade and bladelet blanks is given in [Table 5](#).

When considered as a whole, the distribution of width measurements is unimodal ([Fig 6](#)). The median value falls in the bladelet range. Blade and bladelet length ranges overlap extensively ([Fig 7](#)), although the two categories have different medians (Mann–Whitney,  $U = 16691$ ;  $p < 0.01$ ). Considered together, the length of elongated blanks in the seventy fifth percentile is 46.5 mm. Similar to length, blade and bladelet thickness ranges partially overlap ([S3 Fig](#)). Most of the blades are relatively small in sizes, even if the production of large-sized blades is evident by isolating the raw material unit (RMU [100]) of Oolithic flint. This was verified statistically using a series of Mann–Whitney tests comparing between blades made from Oolithic flint and all other blades together ([S2 Table](#)). Blades made from this coarse-grained flint are bigger in length (Mann–Whitney,  $U = 75$ ;  $p < 0.01$ ), width (Mann–Whitney,  $U = 12479$ ;  $p < 0.01$ ), and thickness (Mann–Whitney,  $U = 18519$ ;  $p < 0.01$ ).

Concerning the width to thickness ratio, blade ( $4.3 \pm 1.6$  mm) and bladelet ( $4.2 \pm 1.6$  mm) means are not different (Mann–Whitney,  $U = 1.4E06$ ,  $p = 0.7$ ), indicating a constant robustness across blanks. The elongation ratio (length to width), instead, suggests a production of slender bladelets. The elongation mean for blades is  $3.0 \pm 0.6$  mm, while for bladelets it is  $3.4 \pm 0.9$  mm (Mann–Whitney,  $U = 82941$ ,  $p < 0.01$ ).

**Flakes.** Flake morphological and technological attributes are listed in [Table 4](#). The analysis of core reduction has already shown that flakes were not the main goal of lithic production. Flakes were mostly involved in the initialization and maintenance of blade and bladelet cores. Most of the flakes, however, have undiagnostic features that do not allow them to be placed in an unequivocal stage of the reduction sequence. Straight and slightly curved profiles dominate the assemblage. Certain types of cross-sections, less frequent across blades and bladelets, are common in the flake assemblage. This is especially true of flat and rectangular cross-sections. Dorsal scars attest to the application of unidirectional patterns, usually sub-parallel. The crossed scar pattern is, however, more common than in the previous categories and is frequently associated with semi-cortical flakes involved in the raw material decortication. Outline morphology and distal end attributes demonstrate that regular flakes were not the objective of the knapping. Most of them are, indeed, irregular and have stepped or plunging distal ends.

Finally, it must be mentioned that a small sample of flakes ( $n = 22$ ), sometimes patinated, characterized by a high degree of predetermination and with faceted platforms has been identified. These flakes are technologically comparable to the Levallois unidirectional flakes found in



**Table 4. Morphological and technological attributes of blades, bladelets, and flakes.**

Morphological and technological attributes	Blade	Bladelet	Flake
<b>Profile</b>			
Straight	111 (20.6%)	185 (26%)	208 (40.1%)
Slightly curved	107 (19.9%)	195 (27.4%)	119 (22.9%)
Curved	138 (25.6%)	178 (25%)	108 (20.8%)
Intense curvature	69 (12.8%)	39 (5.5%)	48 (9.2%)
Inverse curvature	-	4 (0.6%)	8 (1.5%)
Twisted	114 (21.5%)	110 (15.5%)	28 (5.4%)
<b>Orientation</b>			
Axial	492 (82.1%)	598 (82.8%)	417 (91.6%)
Off-axis	99 (16.5%)	114 (15.8%)	36 (7.9%)
Undetermined	8 (1.3%)	10 (1.4%)	2 (0.4%)
<b>Cross-section</b>			
Triangular	523 (26.3%)	2030 (47.0%)	175 (13.7%)
Trapezoidal	819 (41.2%)	1756 (40.6%)	294 (23.1%)
Polyhedral	317 (16.0%)	180 (4.2%)	95 (7.5%)
Lateral steeped	254 (12.8%)	261 (6.0%)	230 (18.0%)
Rectangular	13 (0.7%)	12 (0.3%)	204 (16.0%)
Flat	57 (2.9%)	80 (1.9%)	272 (21.3%)
Undetermined	4 (0.2%)	3 (0.1%)	5 (0.4%)
<b>Cross-section symmetry</b>			
Symmetrical	1561 (78.6%)	3930 (90.9%)	928 (72.8%)
Asymmetrical	426 (21.4%)	392 (9.1%)	347 (27.2%)
<b>Dorsal scar pattern</b>			
Unidirectional sub-parallel	292 (54.2%)	340 (47.8%)	222 (42.8%)
Unidirectional convergent	129 (23.9%)	302 (42.5%)	59 (11.4%)
Unidirectional transverse	59 (10.9%)	49 (6.9%)	63 (12.1%)
Bidirectional	32 (5.9%)	14 (2.0%)	31 (6.0%)
Crossed	8 (1.5%)	3 (0.4%)	62 (11.9%)
Other	19 (3.5%)	3 (0.4%)	82 (15.8%)
<b>Outline morphology</b>			
Sub-parallel	229 (52.2%)	249 (44.5%)	143 (34.5%)
Convergent	60 (13.7%)	196 (35.1%)	31 (7.5%)
Irregular	150 (34.2%)	114 (20.4%)	241 (58.1%)
<b>Distal end—dorsal view</b>			
Straight	142 (23.7%)	81 (11.2%)	151 (33.2%)
Pointed	104 (17.4%)	334 (46.3%)	35 (7.7%)
Convex-concav	279 (46.6%)	267 (37%)	160 (35.2%)
Irregular	62 (10.4%)	29 (4.0%)	99 (21.8%)
Undetermined	12 (2.0%)	11 (1.5%)	10 (2.2%)
<b>Distal end—profile view</b>			
Feathered	367 (61.3%)	639 (88.5%)	237 (66.8%)
Stepped	95 (15.9%)	43 (6.0%)	114 (32.1%)
Plunging	108 (18.0%)	22 (3.0%)	65 (18.3%)
Hinged	17 (2.8%)	7 (1.0%)	29 (8.2%)
Undetermined	12 (2.0%)	11 (1.5%)	10 (2.8%)

Note that profile curvature, dorsal scar pattern, and outline morphology attributes take into account only complete and almost complete specimens. Retouched tools are excluded from the analysis of the outline morphology and distal end on dorsal and profile views. Percentages are given in brackets.

<https://doi.org/10.1371/journal.pone.0189241.t004>

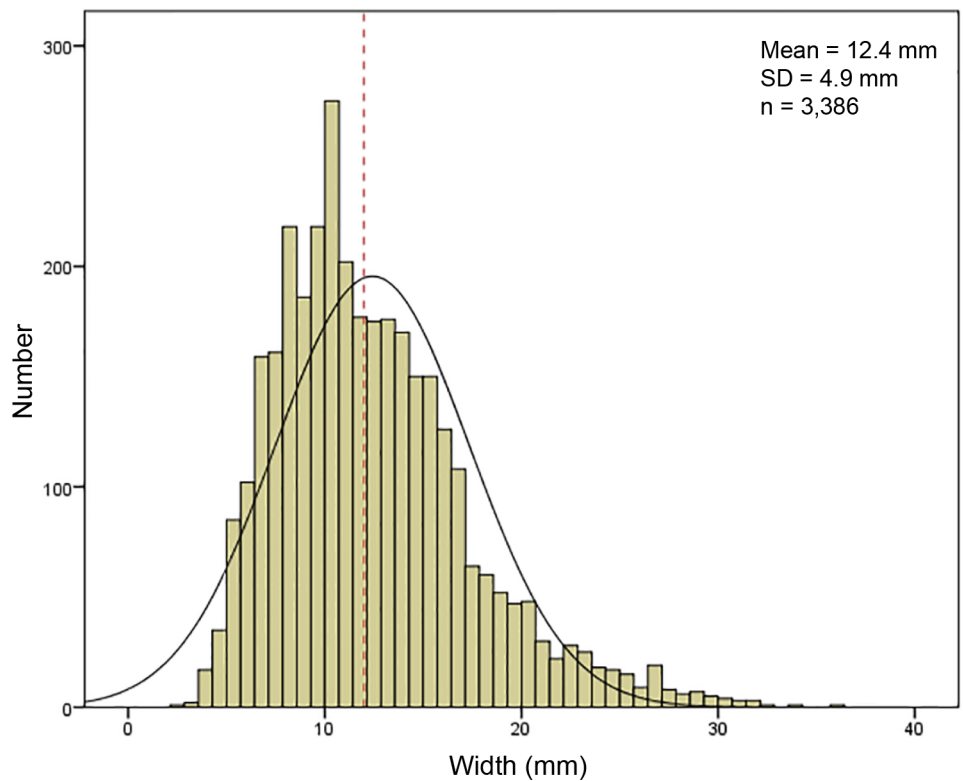
**Table 5. Summary of metric attributes of blades, bladelets, and blades and bladelets considered as a whole.**

	Number	Range	Mean	SE	SD	25 prcntl	Median	75 prcntl
<b>Blade</b>								
Length	420	24.2 to 102.5	49.61	0.65	13.32	39.85	47.5	58.00
Width	1578	12.1 to 35.8	16.53	0.10	4.00	13.6	15.4	18.3
Thickness	1578	1.1 to 21.0	4.47	0.05	2.22	2.9	4.0	5.4
<b>Bladelet</b>								
Length	553	10.8 to 66.7	27.58	0.38	9.11	21.0	26.0	33.25
Width	1808	2.6 to 12.0	8.81	0.04	1.96	7.4	9.0	10.5
Thickness	1808	0.5 to 8.8	2.37	0.02	1.09	1.6	2.2	2.8
<b>Blade and bladelet</b>								
Length	973	10.8 to 102.5	37.1	0.049	15.58	24.85	35.0	46.5
Width	3386	2.6 to 35.8	12.41	0.08	4.93	8.8	11.5	15.0
Thickness	3386	0.5 to 21.0	3.35	0.03	2.01	2.0	2.8	4.1

SE: standard error; SD: standard deviation. Tools are excluded from the analysis.

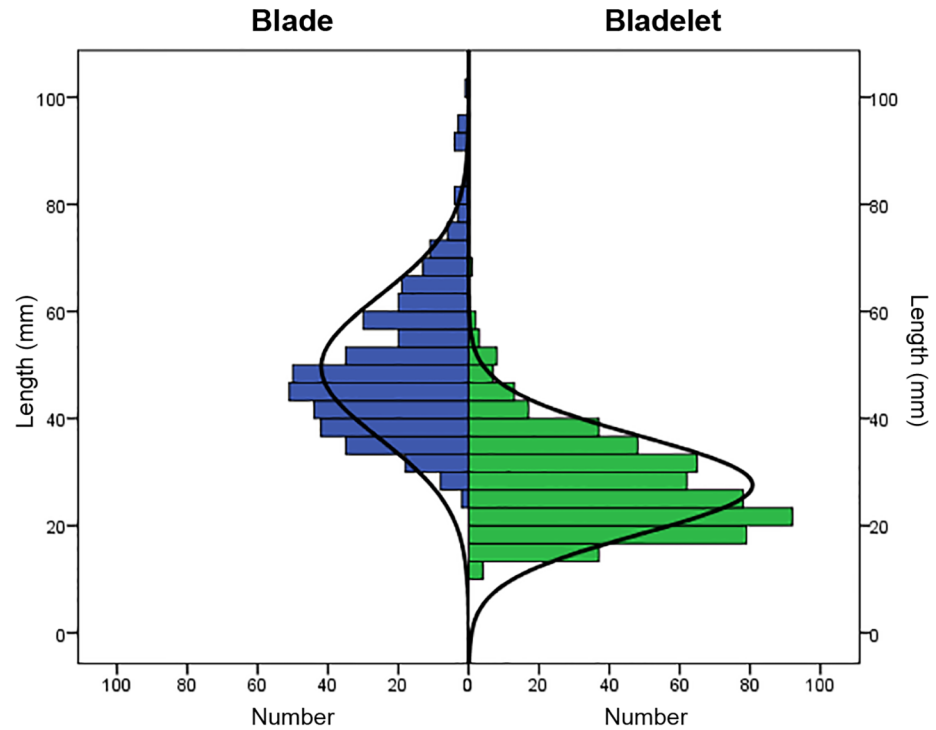
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the Final Mousterian layers [73]. Furthermore, flakes with centripetal scar patterns (n = 45) could be ascribed to the parallel core method previously described. Both groups are likely to represent the results of post-depositional events that marginally affected the integrity of the Protoaurignacian rather than to independent reduction sequences.



**Fig 6. Distribution of blade and bladelet widths (in millimeters) considered as a whole.** The red dashed line represents the arbitrary metric limit (12.0 mm) between blades and bladelets.

<https://doi.org/10.1371/journal.pone.0189241.g006>



**Fig 7. Comparison between the distribution of complete blade lengths (in millimeters; blue) and complete bladelet lengths (in millimeters; green).**

<https://doi.org/10.1371/journal.pone.0189241.g007>

### Core initialization and maintenance interventions

This section aims to isolate and describe blanks that had a key role in the beginning of the reduction sequence of platform cores, but also in its progression. The information gained through the diacritic analyses of the initial and exhausted cores allowed us to identify the functions of certain by-products frequently obtained during the platform reduction methods. The description of these products is therefore closely related and dependent on the core analysis.

**Initialization.** Fully cortical blades with steep triangular cross-sections attest to the frequent use of natural ridges present on the raw material nodules to start the blank production (Fig 8: 7). A favorable angle was usually found at the intersection of two faces. When the core blank was a flake, or was previously decorticated, initial blades bear cortical remains that usually range from 66% to 99%. The length of complete fully cortical blades ( $n = 7$ ) and almost completely cortical blades ( $n = 14$ ) ranges from 31.6 to 85.1 mm (mean: 55.0 mm). Given the small size of some products, these are at times likely to be part of bladelet core initialization (Fig 8: 2). Sometimes prior interventions to design the core volume structure was required. In these cases, the resulting products are both crested blades and two-sided crested blades (Fig 8: 15,16). Two-sided crests are less common and usually have a crested edge more developed than the other. Removals always come from the anterior side of the core, towards the flanks. Complete two-sided crested blade ( $n = 5$ ) length ranges from 59.3 to 102.5 mm (mean: 70.0 mm). Crested blades are more common and were usually applied on smaller nodules. The crest could be produced starting from a cortical edge (Fig 8: 11,13), or at the junction with a perpendicular plain face (Fig 8: 3,14,17). In most cases, crests were performed only after a cortical blade or cortical flake was removed following the longitudinal axis of the flaking surface ( $n = 14$ ; Fig 8: 9). Some of these share certain similarities with neo-crested blades, which are



**Fig 8. Blanks belonging to the decortication and initialization of platform cores.** Fully cortical flakes (1, 12), semi-cortical blade with multiple bladelet scars (2), crested blades (3, 9, 11, 13–14, 17), fully cortical bladelet (4), crested bladelets displaying remains of the ventral face of the core blank (5, 6), fully cortical blade (7), crested flake (8), crested bladelet (10), naturally backed blade with the rest of a two-sided crest in the distal side (15), two-sided crested blade (16). Arrows indicate the direction of removals. Artifacts are oriented with the butt at the bottom of the photo (photo: A. Falcucci).

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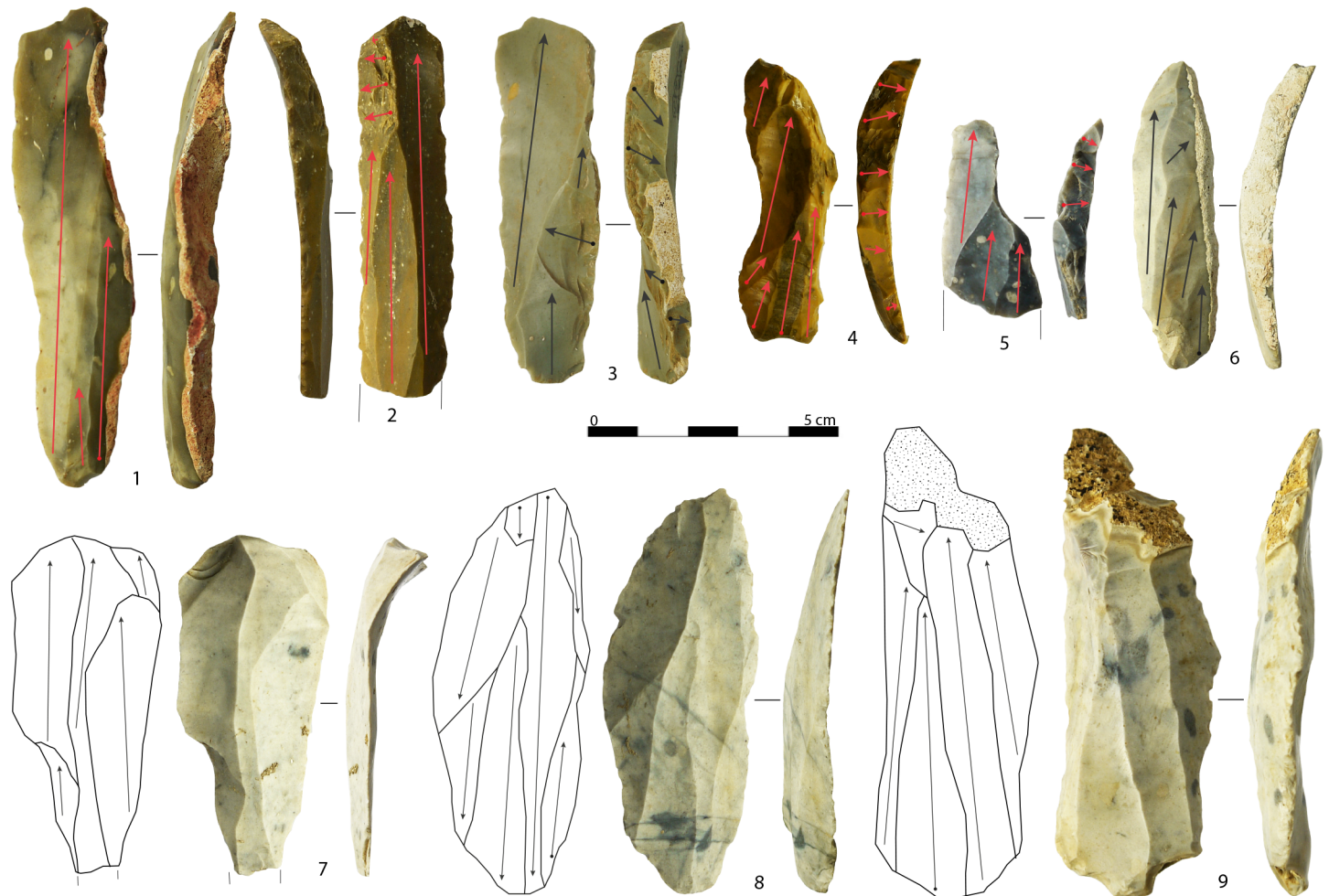
instead removed during the core maintenance operations, and may even be confused with them. Crests are usually continuous, even if removals are more pronounced in the mesio-distal side. Complete crested blade ( $n = 12$ ) length ranges from 35.4 to 87.5 mm (mean: 56.9 mm). Some of these products are also likely to represent the first stage of bladelet core configuration. Secondary crested blades are not frequent, as crest removals were rather short and modified only a limited area of the core.

Fully cortical bladelets (Fig 8: 4) are less common, indicating that bladelet core initialization usually started with the removal of small blades. Crested bladelets are well represented in the assemblage, while two-sided crests are rare. As for blades, crest removals were shaped from the anterior side of the core towards the flanks and were more invasive starting from the medial part. In fourteen cases (38.9%), the opposite side of the crest displays remains of the ventral face of the core blank (Fig 8: 5,6). These artifacts belong to narrow-sided cores made from flake. They indicate that crests were performed at the junction of the ventral face with the dorsal side, along the longitudinal axis. Crested bladelets also attest to the selection of small nodules ( $n = 2$ ) and the recycling of previous cores to pursue the production of lamellar blanks ( $n = 3$ ). In these cases, the perpendicular laminar removals of the previous reduction stage act as crests [101]. Complete crested bladelets ( $n = 8$ ) length ranges from 18.8 to 50.0 mm (mean: 30.4 mm) and, except in the case of the longer specimen, do not exceed 33.0 mm in length. Thus, they were applied on relative small cores.

Flakes were frequently used to partially decorticate the raw material nodules (Fig 8: 12). A frequent operation consisted of the removal of a thick cortical flake to create a flat striking platform (Fig 8: 1). Flakes were also used to allow the first laminar negative to be detached, sometimes opening temporary striking platforms to shape an opposite crest. Crested flakes (Fig 8: 8) are not common and have lengths that range from 25.0 to 95.0 mm (mean: 50.0 mm).

**Maintenance.** Maintenance products are common among blades. Their function was to maintain and re-establish the lateral and longitudinal convexities of the core, but also to rejuvenate part of the flaking surface. The most common operations carried out on blade cores resulted in naturally backed blades (Fig 9: 1, 6) and neo-crested blades (Fig 9: 2–5). Both products are commonly related to a sub-parallel reduction pattern and aimed to control the lateral convexities of the core during a continuous linear progression that alternates detachments at the center of the flaking surface and at the intersection with a perpendicular core side [94]. Naturally backed blades are an expression of the opportunistic exploitation of available edges, while neo-crested blades reveal a major technical investment. Neo-crested blades usually display a backed edge. Neo-crest removals are, in most cases, located on the mesio-distal side of the core and, in only seven cases (13.7%), invade the whole length of the blank.

The technical blade category includes all by-products detached at the center of the flaking surface with the aim to remove critical parts of the core or to accentuate the distal core convexity (Fig 9: 7–9; Fig 10: 1–5, 9). For these reasons, they are characterized by polyhedral cross-sections (65%) and plunging (51%) or stepped (14.6%) distal ends. The most striking feature of technical blades is that they have in eighty-six cases (73.5%) from one to seven bladelet negatives on their dorsal face (Fig 10: 1–5, 9). Even if they correspond to cores characterized by a simultaneous production of small blades and big bladelets in few cases, most of them



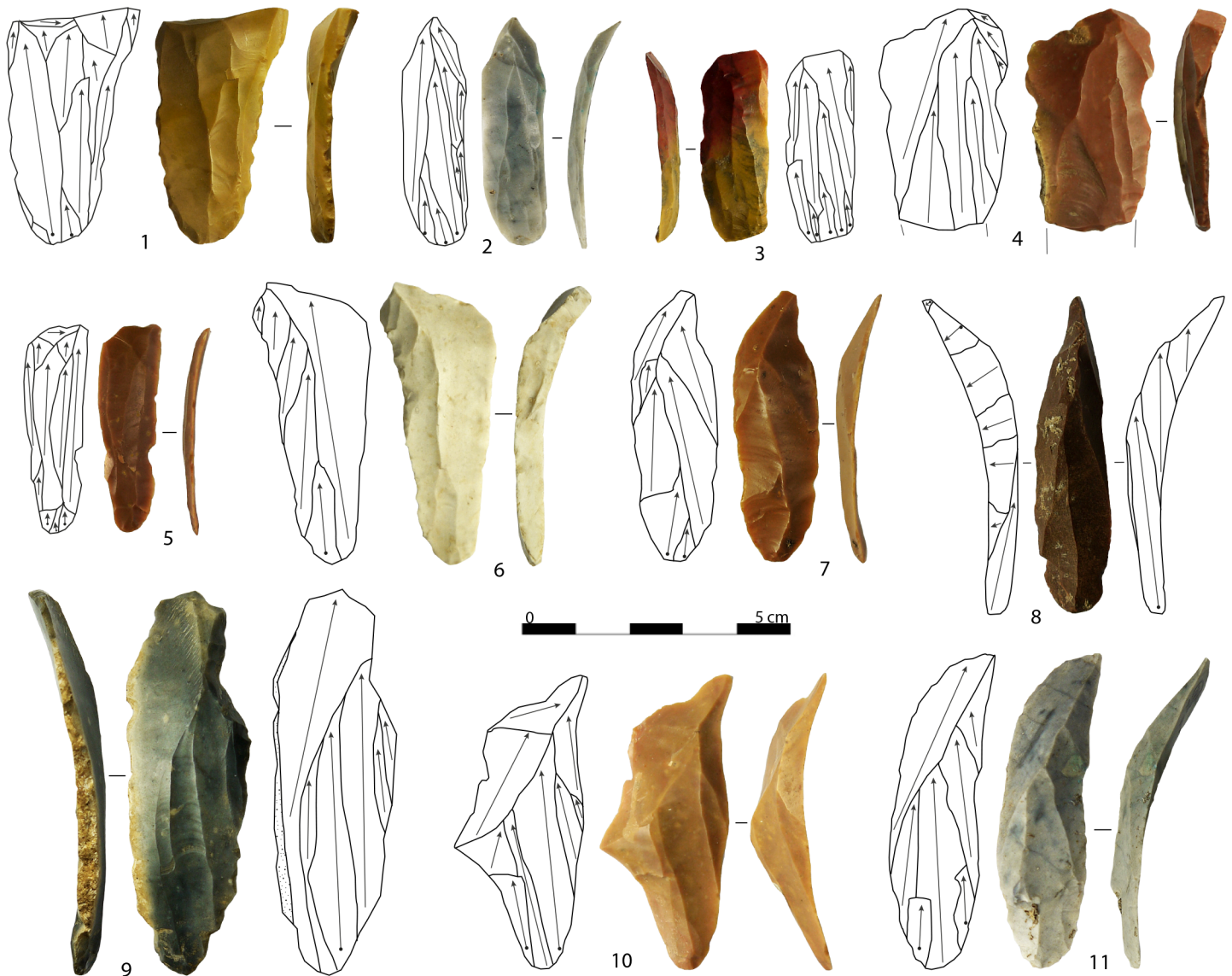
**Fig 9. Maintenance products from blade production.** Naturally backed blades (1, 6), neo-crested blades (2–5), and technical blades with multiple blade scars (7–9). Arrows indicate the direction of removals. Artifacts are oriented with the butt at the bottom of the photo (photo and drawings: A. Falcucci).

<https://doi.org/10.1371/journal.pone.0189241.g009>

correspond to maintenance operations carried out on bladelet cores. A plunging technical blade refitted to a semi-circumferential bladelet core (Fig 2: 8) is a good example of this operation.

The last category of blade maintenance products was named lateral comma-like blade after Porraz et al. [102] (Fig 10: 6–8, 10, 11). Lateral comma-like blades represent the most frequent maintenance operation carried out at the junction of core faces during convergent reduction patterns that target pointed bladelets, but also during the shaping of initial blade or bladelet cores in order to isolate the future flaking surface. Lateral comma-like blades have distal ends with an off-axis orientation and usually have asymmetrical cross sections (55.4%) and a twisted (50.6%) or intense curved (21.7%) profile. Distal ends are usually plunging (57.9%) or stepped (13.2%), as they remove part of the core base. As for technical blades, they usually display lamellar negatives on the dorsal face (54.2%).

The study of blades displaying lamellar negatives was highly informative. The number of these products among the studied sample is considerable ( $n = 265$ , MNFP = 198). The fact that many of those blades have been interpreted as by-products of the lamellar production system suggests that a remarkable amount of blades was not the primary intention of blank production, instead, it was part of elaborate maintenance operations carried out on bladelet cores.



**Fig 10. Maintenance products from bladelet and simultaneous blade-bladelet productions.** Technical blades with multiple bladelet scars (1–5, 9), lateral comma-like blades with multiple bladelet scars (6–8, 10, 11). Arrows indicate the direction of removals. Artifacts are oriented with the butt at the bottom of the photo (photo and drawings: A. Falcucci).

<https://doi.org/10.1371/journal.pone.0189241.g010>

Complete blades with lamellar dorsal negatives ( $n = 121$ ) have lengths ranging from 26.4 to 75.6 mm (mean: 46.4 mm; median: 45.4 mm). They are, indeed, significantly shorter than the rest of the analyzed blades (Mann–Whitney,  $U = 17209$ ;  $p < 0.01$ ).

It has been shown that all range of maintenance operations on bladelet cores were usually performed by blades. For this reason, maintenance products on bladelets are low in frequency. Neo-crested bladelets are not common. They have asymmetrical cross-sections and in most cases a sub-parallel dorsal scars pattern (76.5%). Technical bladelets and lateral comma-like bladelets do not differ from the same products made from blades. Both products display regular lamellar negatives on dorsal sides, usually belonging to short, pointed bladelets.

Partial and total core tablets were frequently used to manage the striking platform. Table 6 lists relevant attributes detected on these by-products.

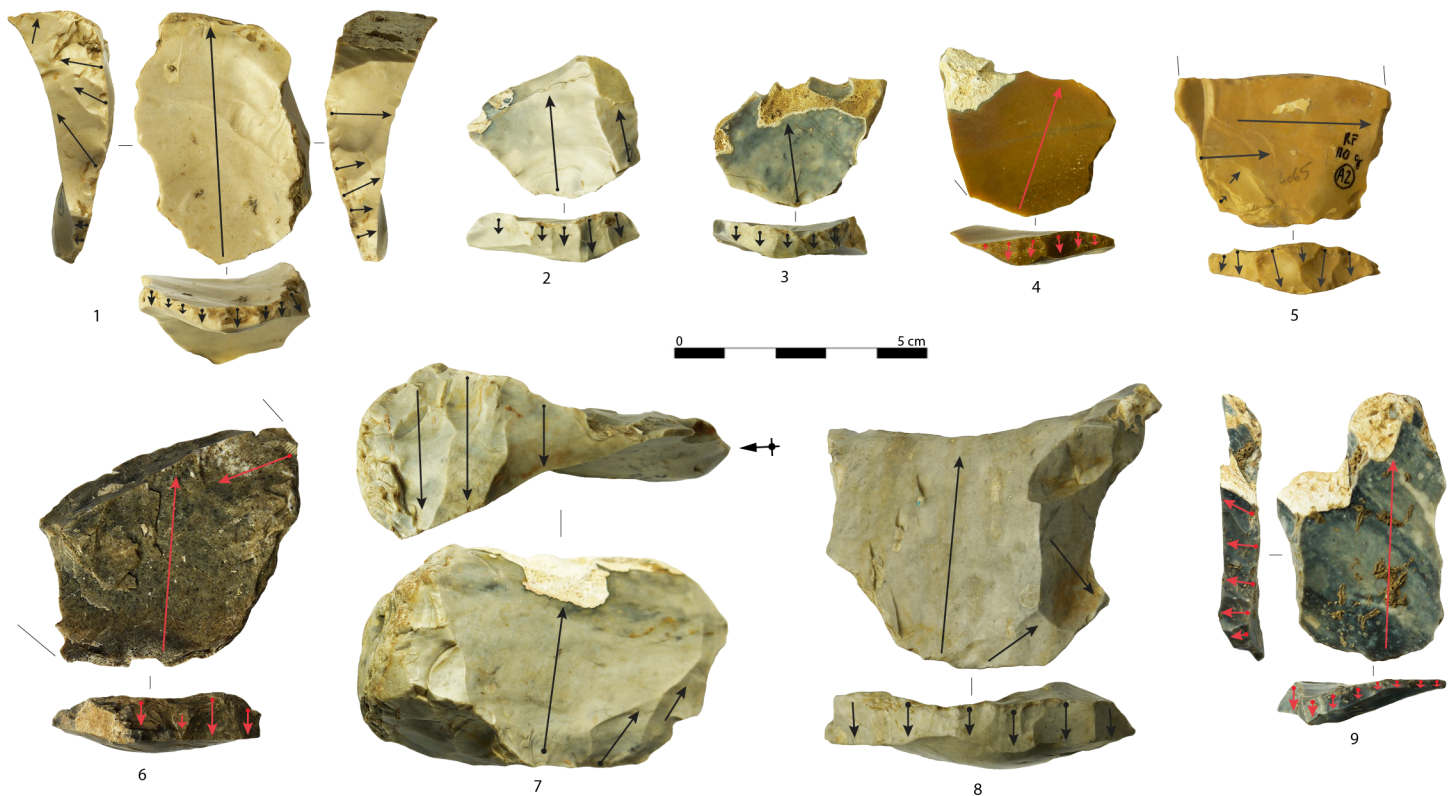
**Table 6. List of relevant attributes recorded on core tablets.**

Core tablet attributes	
Knapping progression	
Frontal, narrow face	33 (20.1%)
Frontal, wide face	21 (12.8%)
Semi-circumferential	90 (54.9%)
Undetermined	20 (12.2%)
Blank production	
Blade	25 (15.2%)
Bladelet	115 (70.1%)
Blade-bladelet	24 (14.6%)
Core flaking surface width	
Blade core	46.7 ± 10.4
Bladelet core	27.3 ± 6.1
Blade-bladelet core	37.0 ± 13.4

Core flaking surface width was measurable only on total core tablets (n = 67). Percentages are given in brackets.

<https://doi.org/10.1371/journal.pone.0189241.t006>

They are clearly linked to the identified core types. As expected, most of them belong to bladelet cores. Total core tablets (n = 67) allow us to measure the width of the related core flaking surface. Blade core tablets (Fig 11: 6–8) display broader flaking surfaces compared to blade-



**Fig 11. Core tablets.** Blade core tablets (6–8) and bladelet core tablets (1–5, 9). Arrows indicate the direction of the blow and of removals (photo: A. Falcucci).

<https://doi.org/10.1371/journal.pone.0189241.g011>



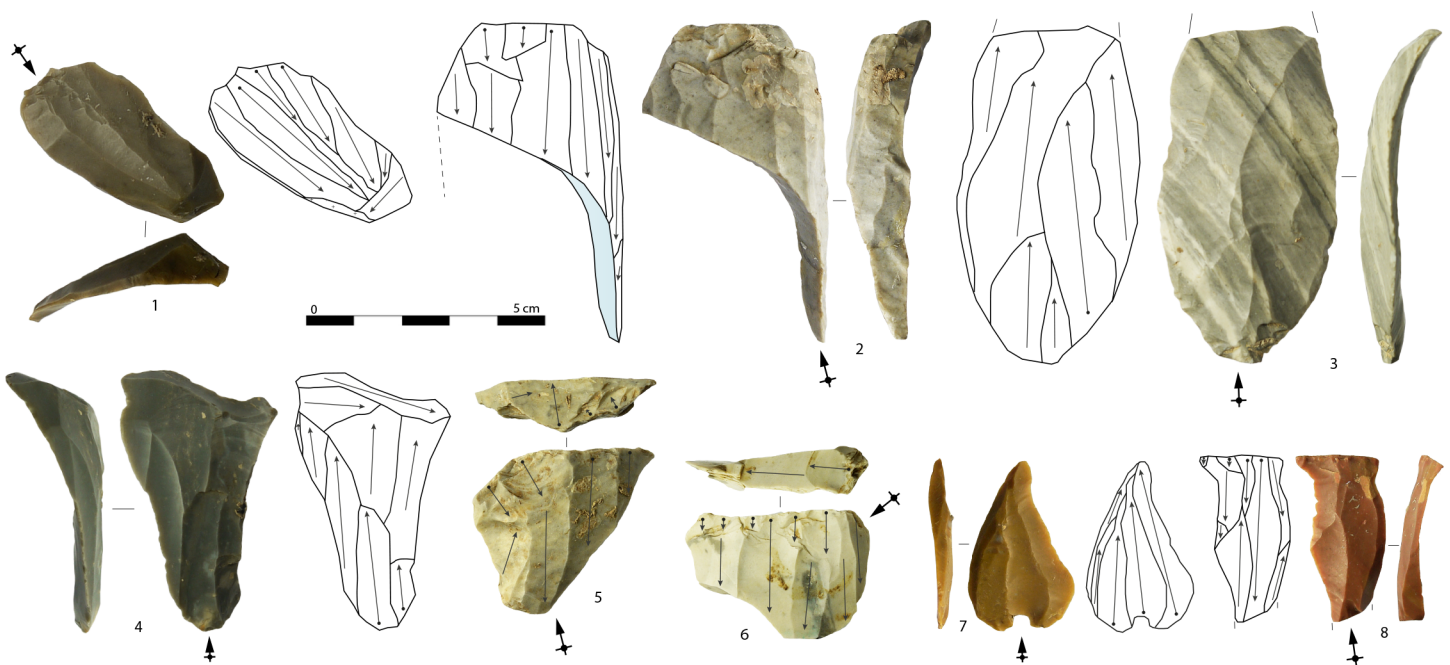
bladelet or bladelet cores (Fig 11: 1–5, 9). Among blade core tablets, large-sized cores were identified. They may have been highly reduced on site or exported. The latter case is exemplified by a core tablet on Oolithic flint (Fig 11: 6) that is associated with several blades and whose discarded core has not been found.

Technical flakes are another important source of information because they display evidence of laminar and lamellar production at different reduction stages (Fig 12). Sometimes technical flakes rejuvenated most of the flaking surface prior, or slightly after, the core rotation (Fig 12: 8). Technical flakes display up to eight blade or bladelet negatives. Last visible negatives allow us to link some of them to a blade production (n = 33, 22.1%), others to a simultaneous blade-bladelet production (n = 15, 10.1%), and finally to a bladelet production (n = 86, 57.7%). The remaining products are unidentifiable (n = 15, 10.1%). The length of complete technical flakes (n = 87) ranges from 10.9 to 116.0 mm (mean: 42.2 mm). Technical flakes with blade scars belong to cores of different sizes and display blades with lengths ranging from 39.0 to 95.2 mm. A Kruskal–Wallis test was run to evaluate the differences among complete technical flakes with laminar, lamellar, and simultaneous negatives (H = 15.63, p < 0.01). Flakes with bladelet negatives are smaller than the others, while flakes with a simultaneous blade-bladelet production are not different from flakes with blade negatives (S3 Table). This evidence indicates that simultaneous blade-bladelet productions were carried out from the initial stages of core exploitation.

Neo-crested flakes and lateral comma-like flakes are less common than in the blade and bladelet categories. In most cases, they manifest a failed attempt to remove a laminar blank.

### Tools

Table 7 gives a general overview of the main tool categories. This section does not aim to describe retouched tools from a typological perspective, but instead seeks to identify signatures relevant for the technological analysis.



**Fig 12. Technical flakes.** Technical flakes removed from bladelet cores (1, 5–8), blade cores (2, 3), and blade-bladelet cores (4). Note that 2 is a spall removed from a technical flake. Arrows indicate the direction of the blow and of removals (photo and drawings: A. Falcucci).

<https://doi.org/10.1371/journal.pone.0189241.g012>

**Table 7. General overview of the main tool categories.**

Tool categories	Number	MNFP
Retouched bladelet	2481 (78.1%)	912 (69.6%)
Retouched blade	239 (7.5%)	130 (9.9%)
Retouched flake	98 (3.1%)	66 (5%)
Retouch, undetermined	4 (0.1%)	-
Burin	104 (3.3%)	63 (4.8%)
Burin + lateral retouch	16 (0.5%)	10 (0.8%)
End-scraper	107 (3.4%)	61 (4.7%)
End-scraper + burin	4 (0.1%)	1 (0.1%)
End-scraper + lateral retouch	18 (0.6%)	13 (1%)
End-scraper + truncation	1 (-)	1 (0.1%)
End-scraper + splintered piece	1 (-)	1 (0,1%)
Truncation	34 (1.1%)	20 (1.5%)
Truncation + lateral retouch	25 (0.8%)	10 (0.8%)
Splintered piece	45 (1.4%)	22 (1.7%)
Total	3177 (100%)	1310 (100%)
<b>Blank types</b>		
Bladelet	2514 (79.1%)	927 (70.8%)
Blade	424 (13.3%)	229 (17.5%)
Flake	222 (7%)	150 (11.5%)
Undetermined	17 (0.5%)	4 (0.3%)

Percentages are given in brackets.

<https://doi.org/10.1371/journal.pone.0189241.t007>

The most striking feature of the assemblage is the dominance of tools made from bladelets. Retouched bladelets represent 26% (MNFP = 20.5%) of the whole bladelet assemblage. This index is very low for blades (7%, MNFP = 7.4%) and especially flakes (2.4%, MNFP = 3.2%). Tools on bladelets represent a rather homogeneous category. They are, in most cases, only modified on the edges by applying a marginal retouch and have been typed as bladelet with lateral retouch (Fig 13: 4–9) and bladelet with convergent retouch (Fig 13: 1–3, 10–13) according to the external blank morphology [103].

Retouched bladelets have regular outline morphologies and almost always lack cortical remains (98.7%). On the contrary, cortical remains are frequently found on tools on blades (29.5%), and especially tools on flakes (49.1%). Bladelet tools have been manufactured from by-products of the core reduction sequence only in two cases. This data is different for blades and flakes, as the selection of by-products is relatively high (Figs 14 and 15).

Among blade tools, fifty-three pieces (12.5%) display lamellar negatives on the dorsal side. This evidence suggests that, along with blanks coming from a proper blade production, some blanks could be selected among the waste of bladelet reduction strategies. Common tools are dominated by laterally-retouched blades (Fig 15: 10–11, 15–19, 24) followed by end-scrapers (Fig 15: 7–9, 12–14, 20–23, 25), and burins (Fig 15: 1–6). Six blades display intense scalar retouching and can be classified as Aurignacian blades (Fig 15: 15–16). They may be correlated to a protracted use and to a possible introduction of formal tools.

Table 8 shows metric comparisons between blanks and tools according to the blank category and the results of multiple Mann–Whitney tests. The bigger blade and flake products were systematically selected. For bladelet tools the opposite can be said; they have inferior width and thickness values, but differences in length are not significant. The relatively high



**Fig 13. Retouched bladelets with convergent (1–3, 6, 10–13) and lateral (4–5, 7–9) retouch (typological definition after Falcucci et al. [103]).** Retouching is direct on 1–3, 6, 10, and 12; alternate on 4–5, 11, and 13; inverse on 7–9 (photo: A. Falcucci).

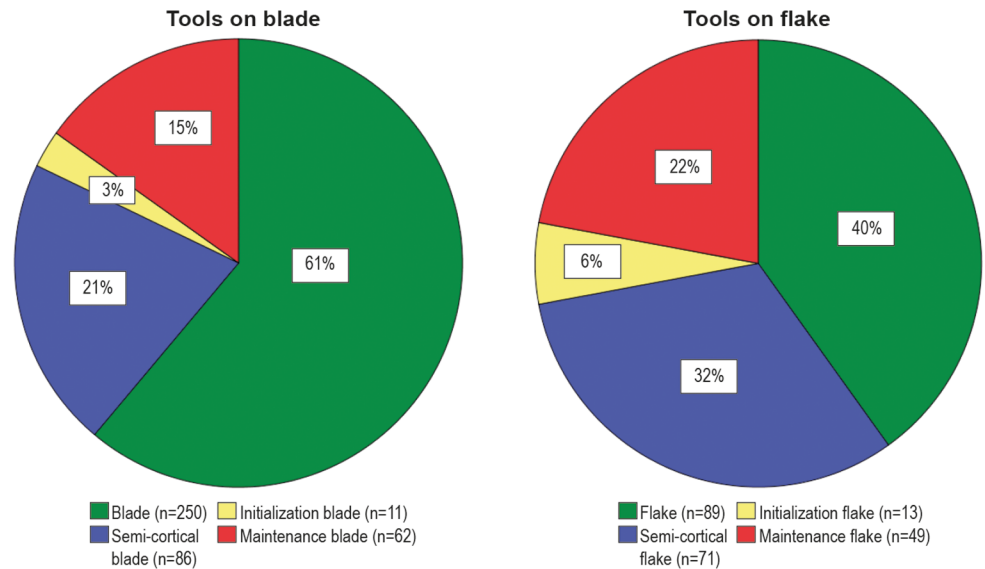
<https://doi.org/10.1371/journal.pone.0189241.g013>

difference in width may be explained in part as a selection of the narrower products, but mostly as a consequence of retouching.

### Knapping technique

Table 9 gives an overview of the criteria that have been used to identify the knapping techniques. All features agree with a direct application of force. Differences can be found in the gesture involved in the detachment of blades, bladelets, and flakes. For blades and bladelets, the high frequency of dorsal thinning to reduce the overhang, the small thickness of platforms, the presence of lips, and the EPA values clearly indicates a marginal percussion. However, some blades were knapped with an internal striking gesture. This was detected by the higher frequency of bulbs and a certain number of thicker platforms, especially among blades involved in core maintenance operations.

Flake platforms are very similar to blade and bladelet platforms, with most of them being plain. However, they are characterized by a combination of features that can be explained as an ambivalence of striking gestures that involved both marginal and internal percussion. Internal percussion is evident in the presence of thick platforms, some of them above the 4 mm



**Fig 14. Pie charts representing the proportion of tools made on blades (left) and flakes (right), grouped according to the main technological categories.** Initialization group includes fully cortical and crested elements; maintenance group includes crested secondary, naturally backed, neo-crested, lateral comma-like, and technical blanks. For colors see the legend.

<https://doi.org/10.1371/journal.pone.0189241.g014>

border suggested by Pelegrin [104]. The lower frequency of dorsal thinning and lips, the higher frequency of pronounced bulbs, and the higher EPA values compared to laminar blanks argue in favor of this hypothesis. It is worth mentioning a small sample of flakes characterized by faceted platforms. As previously said, they are frequently found in flakes that are technologically very different from the rest of the assemblage. Their frequency is, however, very low and does not affect the general reconstruction of knapping techniques across flakes. To conclude, flakes were produced both with internal and marginal percussion at different stages of the reduction sequence.

The type of knapping tool involved in lithic production for this assemblage will not be directly addressed, following recent experimental works that have criticized the unequivocal distinction between the use of hard or soft stone and organic hammers [105–107]. However, it can be noted that there is a relatively high frequency of bulbar scars (esquilletement bulbaire [85]) especially among blades and flakes. Bulbar scars are sometimes associated with fine ripples in the first millimeters of the ventral face. This evidence, together with the frequent association of lips and moderate bulbs, suggests that soft stone hammers were part of the involved knapping tools [95], which should be confirmed from the use-wear traces observed on most of the stone hammers in the course of examination.

## Discussion

### The issue of the continuous reduction sequence

The extensive analysis conducted on the Protoaurignacian of Fumane Cave permits us to carefully address the technological definition of this techno-complex. Before discussing its internal and geographical variability, a critical review of the so-called continuous reduction sequence [35, 47, 48, 51] is needed. Based on the results of this study, it can be underlined that bladelets do not originate from reduced blade cores. Independent and variable reduction strategies are common at Fumane and, more generally, in the Protoaurignacian assemblages of Mochi and



**Fig 15. Examples of tools.** Burins on blade (1–6), end-scrapers on crested blades (7, 21), end-scrapers on flake (8, 13), thick end-scrapers on cortical flakes (9, 14), blades with lateral retouch (10–11, 17–19, 24), end-scraper on a technical flake with blade scars (12), thick blades with Aurignacian retouch (15, 16), end-scraper on a technical blade with bladelet scars (20), end-scraper on blade (22) belonging to the first reduction phase of core number 5 in Fig 2, end-scrapers with lateral scalar retouch on blades (23, 25). Arrows indicate the direction of the blow (photo: A. Falcucci).

<https://doi.org/10.1371/journal.pone.0189241.g015>

Bombrini [24, 43, 61], La Fabbrica [108], Castelcivita [109], Observatoire [110], Mandrin [111, 112], Esquicho-Grapaou [113], Arbreda [114], Labeko Koba [56], La Viña [37], Isturitz [66], Arcy [49, 115], Românești and Tincova [65, 116], and Siuren I [117, 118].

Given the absence of extensive refitting analyses, the assumption that bladelets were the result of decreasing core size is supported by three main arguments: the absence of blade cores, the morphological affinity between blades and bladelets, and, finally, the dimensional continuity between them [37, 38, 49, 51, 119–121]. Our results disagree with these points.

First, blade cores have been found at Fumane, Bombrini [43], Românești and Tincova [65, 116], Mandrin [111], Arbreda [114], La Viña [37], Piage [47], and Les Cottés [122]. They are generally reduced, but the last complete negatives correspond to blades. At Les Cottés fifteen blade cores (32% of the core collection) were found; a frequency that is even higher when compared to the upper Early Aurignacian layer [122]. At Fumane and Arbreda [114], blade cores or blade core fragments could be recycled into bladelet cores, which implied a general reorganization of their structure. This is also the case in the Early Aurignacian of Geißenklösterle, Champ-Parel and Hui [51, 123–125]. At Fumane and Labeko Koba [56], non-exhausted blade cores were likely exported, while at Mochi and Bombrini, blades made from high-quality raw material nodules were knapped elsewhere and imported as formal tools [43]. The same has been proposed for some large-sized blades found at Mandrin [112], Arcy [126], and Kozarnika [120]. It is worth mentioning that the techno-economic dissociation of blade and bladelet reduction strategies over a large territory is a feature commonly associated with the Early Aurignacian [54, 127]. This behavior reflects constraints in raw material availability in certain regions. While at Fumane, large-sized nodules could be found within few kilometers from the site [83], at Bombrini and Mochi human groups often had to rely upon extra-local flint coming from the French Provence or the Italian Apennines [128].

Second, blades and bladelets have indeed a certain affinity, noticeable in the preparation of flat striking platforms and in the systematic abrasion of the overhang related to the use of direct marginal percussion. At Fumane, however, bladelets often have a convergent and pointed outline and are produced following a convergent reduction pattern. Blades are instead produced with sub-parallel reduction patterns, following procedures commonly described in Early Aurignacian assemblages [35].

Third, the dimensional overlap between blades and bladelets is not a reliable proxy to detect a continuous stone knapping sequence. This is indeed a pattern originating from the incorporation of products resulting from different temporal events into a unique and, apparently, linear distribution. According to the initial volume of the raw material nodule, the first stage of

**Table 8. Metrical comparison of the mean values (in millimeters) ± standard deviations between tools and blanks according to the main blank types, and results of the multiple Mann–Whitney U-tests (p values) that were conducted.**

	Blade			Bladelet			Flake		
	Blank	Tool	p-value	Blank	Tool	p-value	Blank	Tool	p-value
<b>Length</b>	49.6±13.3	60.5±18.3	p<0.01	27.6±9.11	28.3±8.8	p = 0.25	37.1±13.2	43.8±14.4	p<0.01
<b>Width</b>	16.5±4.0	19.5±5.5	p<0.01	8.8±2.0	6.6±1.8	p<0.01	25.2±9.6	30.3±9.4	p<0.01
<b>Thickness</b>	4.5±2.2	5.9±2.5	p<0.01	2.4±1.1	1.7±0.6	p<0.01	6.8±4.0	10.1±4.4	p<0.01

<https://doi.org/10.1371/journal.pone.0189241.t008>

**Table 9. List of the attributes used to identify the knapping technique.**

Knapping technique	Blade	Bladelet	Flake
Platform measurements			
Width	4.2±2.4	2.4±1.2	8.8±6.2
Thickness	1.6±1.1	0.8±0.5	3.4±2.7
Ratio W/T	3.2±2.5	4.1±4.2	3.3±3.3
EPA			
≤ 45°	83 (6.7%)	59 (2.8%)	63 (6.6%)
≤ 60°	443 (35.5%)	726 (34.2%)	234 (24.5%)
≤ 75°	613 (49.2%)	1271 (60%)	455 (47.7%)
≤ 90°	66 (5.3%)	19 (0.9%)	153 (16%)
Undetermined	42 (3.4%)	45 (2.1%)	49 (5.1%)
Platform type			
Plain	923 (74%)	1299 (61.3%)	596 (62.5%)
Linear	138 (11.1%)	543 (25.6%)	48 (5.0%)
Punctiform	36 (2.9%)	166 (7.8%)	13 (1.3%)
Faceted	21 (1.7%)	1 (.0%)	86 (9.0%)
Other	129 (10.3%)	111 (5.3%)	211 (22.1%)
Dorsal thinning			
Yes	1049 (84.1%)	1931 (91.1%)	398 (41.7%)
No	154 (12.3%)	147 (6.9%)	509 (53.4%)
Undetermined	44 (3.5%)	42 (2%)	47 (4.9%)
Bulb			
Yes, moderate	495 (39.7%)	569 (26.8%)	432 (45.3%)
Yes, pronounced	51 (4.1%)	18 (0.8%)	135 (14.2%)
No	659 (52.8%)	1491 (70.3%)	339 (35.5%)
Undetermined	42 (3.4%)	42 (2%)	48 (5%)
Lip			
Yes, moderate	477 (38.3%)	1074 (50.7%)	208 (21.8%)
Yes, pronounced	642 (51.5%)	921 (43.4%)	336 (35.2%)
No	86 (6.9%)	83 (3.9%)	362 (37.9%)
Undetermined	42 (3.4%)	42 (2%)	48 (5%)
Bulbar scars			
Yes	257 (20.6%)	197 (9.3%)	246 (25.8%)
No	948 (76%)	1881 (88.7%)	660 (69.2%)
Undetermined	42 (3.4%)	42 (2%)	48 (5%)

EPA: external platform angle. Percentages are given in brackets.

<https://doi.org/10.1371/journal.pone.0189241.t009>

bladelet core reduction could sometimes result in the extraction of blade-sized blanks. The fact that the production tended rapidly to bladelets does not allow such evidence to speak for a continuous reduction process that started from large blade cores. In other words, bladelets were the objective of production before that first lamellar blank was detached, as also noticed by Bon [35] in one of the first description of the Protoaurignacian lithic technology. During the optimal phase of production, maintenance products, such as lateral comma-like blades and technical blades, could be intercalated to bladelets. They are shared elements in the Protoaurignacian and have been well described at Arcy [49], Esquicho-Grapaou and Louza [113, 129], Observatoire [110], and Kozarnika [120].

Blade and bladelet productions are not, however, always independent, as a simultaneous production of small blades and big bladelets has been demonstrated at Fumane, Labeko Koba [56], and Siuren I [118]. In all these cases, simultaneous production started from the early stage of core reduction, which is also one of the reasons for the overall dimensional continuity that exists between blades and bladelets.

To conclude, the most commonly used technological trait that is said to define the Protoaurignacian has been over-emphasized, and other features are needed to isolate its lithic technology.

## Protoaurignacian lithic technologies: Fumane in the European context

The most relevant features of the Protoaurignacian industry at Fumane Cave are the systematic and variable bladelet production and the dominance of retouched bladelets among tools. Most of the artifacts discarded at the site indeed belong to bladelets and by-products of lamellar reduction strategies. This is very different from the Uluzzian layers A4 and A3, in which bladelets played a minor role in the lithic system [15].

Bladelet-based industries mark the full consolidation of new technical solutions for the manufacture of small lithic implements, probably intended to be hafted in composite tools, at the beginning of the Eurasian Upper Paleolithic [55]. They are a shared feature of the Protoaurignacian across Europe, as evident at Fumane, Bombrini [43, 130], Mochi [61, 131], Observatoire [110], Esquicho-Grapaou [113, 132], Louza [129, 132], Mandrin [111, 112], Arbreda [114], Morín [119, 133], La Viña [37], Labeko Koba [38, 56], Isturitz [134, 135], Piage [36, 136], Les Cottés [122], Arcy [49, 115], Tincova [116, 137], Românești [65], Kozarnika [120], and Siuren I [64, 117, 138]. In these assemblages, bladelet production is characterized by a relatively broad range of core reduction strategies and is carried out on high quality raw material nodules. At Fumane, intact nodules and fragments were brought to the site where the future cores were roughly prepared. Non-invasive crests were applied only when the morphology of the blank did not permit the direct extraction of laminar products. According to the volume of the selected raw material nodule, bladelet core initialization could sometimes result in a first series of blade removals, as seen also at Observatoire [110]. In some cases, the most robust blanks produced in this initial reduction stage were selected to manufacture tools as end-scrapers, burins, and laterally-retouched blades and flakes. At Isturitz [66, 134] and Arcy [126] the selection of these by-products to manufacture tools is documented.

The optimal production phase took place on cores that were almost completely deprived of cortex and targeted bladelets of variable sizes. The frequent application of convergent and secondly sub-parallel reduction patterns resulted in the production of bladelets with pointed outlines, as well as bladelets with sub-parallel edges. Convergent reduction patterns are common in the entire extent of the Protoaurignacian and are associated with highly diagnostic maintenance operations such as lateral comma-like blades. These operations were usually carried out along the longitudinal axis of the flaked surface and in most cases from the main striking platform. At Fumane, the length of such products is compatible with most of the exhausted cores. Lateral comma-like blanks were detached at the intersection of core faces, isolating rather short surfaces and allowing the production of regular bladelets from early reduction phases [94]. The protracted alternation of primary blanks and by-products required the exploitation of most of the available surfaces by means of a semi-circumferential core progression. Most of these cores are usually classified sub-prismatic and sub-pyramidal cores and are found in all Protoaurignacian industries.

At Fumane, besides semi-circumferential cores, narrow-sided cores had a major importance and were exclusively used to produce bladelets. Narrow-sided cores were made from



flakes and flat raw material nodules and targeted slender and rather straight bladelets. At Arbreda, they have served to produce small blades [114], while in other sites they are always described as bladelet cores. The initialization and maintenance operations carried out on narrow-sided cores at Observatoire [110] and Arcy [115] are comparable to Fumane. The production usually began with crested bladelets, well-represented in our studied assemblage, detached at the junction of the ventral face of the core blank. The extraction of regular bladelets was then achieved by lateral removals that converged towards the center of the flaking surface.

Core re-orientation was also a frequent strategy used to increase production efficiency. Multi-platform cores are frequent at Fumane and Mochi (40% of cores [61]) and are reported at Arcy [115], Isturitz [66], Arbreda [114], and Siuren I [118]. This evidence contradicts the assumption that core re-orientation is rare in the Protoaurignacian [139].

As showed, the flaking surface of bladelet cores was oriented, in most cases, according to the longitudinal axis of the blank, which represents one of the main technological features of the Protoaurignacian. Carinated technology is thus generally less well-represented compared to Early Aurignacian industries [35]. The technological organization of Protoaurignacian carinated cores, however, does not differ from the Early Aurignacian (as described in [35, 125]). Carinated cores are rare in the Ligurian region and in Southeast France [24, 43, 110, 132], but are the dominant bladelet production strategy at Arbreda [114] and are well-represented in northern Spain [37, 119], Pyrenean region [56, 66, 140], and Eastern Europe [65, 116, 118]. At Fumane, carinated cores do not differ much from semi-circumferential bladelet cores. The use of lateral removals to isolate the flaking surface and the discontinuous knapping pattern [94] represent the main shared features.

The emphasized variety of lamellar reduction strategies may be a result of the need to manufacture different end-products. Bladelets were used for multiple activities and some studies have proposed a correlation between size and function [66, 110, 141]. By comparison to the Early Aurignacian, Protoaurignacian bladelets are said to be large and straight [51, 55]. At Fumane, however, bladelets have varied dimensional and morphological attributes and large and rather straight blanks were found along with small and curved bladelets. The same variability has been shown to be characteristic of other industries, such as Mandrin [111], Isturitz [66], and Labeko Koba [56].

Blades represent the second goal of the Protoaurignacian lithic production system, and their frequency is always lower than that of bladelets. The flaked surface of blade cores was framed by at least one perpendicular flank; a feature that permitted the extraction of naturally backed blades and the use of neo-crests to shape the core convexities. Blades were extracted with direct marginal percussion and the striking platform usually remained flat. Faceted platforms, which are well-represented in Early Aurignacian assemblages of southwestern France [35, 142], are rare. Even if faceted platforms are not common outside of southwestern France [37, 51, 143, 144], the differences in the preparation of the core striking platform seem related to the production of more robust blades in Early Aurignacian assemblages [35, 36]. At Fumane, blades have variable morpho-metric attributes, but among retouched tools a selection of the bigger blanks, independent of their regularity and the presence of cortical remains, is verified. Among laterally-retouched blades, Aurignacian blades are present at variable degrees in most of the Protoaurignacian assemblages and are abundant at Arbreda [114] and Tincova [116]. It does thus not seem to be a tool type restricted to Early Aurignacian assemblages, as is frequently argued [48, 145].

Flake production has been observed less often among Protoaurignacian industries and has generally received less attention in the available studies. At Fumane, most of the flakes recovered originated from the initialization and maintenance operations of blade and bladelet cores.

For this reason, flake-tools were made mostly from by-products of the laminar reduction sequences, as demonstrated also at Siuren I [146]. At Arcy, an exclusive flake production has been described [49]. It was usually produced with low-quality raw material nodules or it could take place on exhausted laminar cores. At Morín, flakes were produced from discoid cores, and were used to manufacture side-scrapers and denticulates [147]. Generally, Protoaurignacian flake production appears to be marginal, as in most of the Early Aurignacian assemblages [35, 148].

### Testing models: Future research prospects

The Protoaurignacian is technologically consistent across its geographical extent. Bladelet production dictates the general organization of stone knapping, which is based on variable and, most cases, independent reduction strategies. The re-evaluation of the Protoaurignacian lithic technology has pointed out that this techno-complex shares a common technological background in the scope of lithic production with the Early Aurignacian and that no features are restricted to one of the two varieties. In the Early Aurignacian, bladelets are generally produced from carinated cores, even if the production could be carried out on prismatic and narrow-sided cores, as it is at Tuto-de-Camalhot [35], Barbas III (Ortega Cordellat, 2005), Les Cottés layer US 04 superior [122], Isturitz layers C4b1 and C4b2 [134, 149], Labeko Koba layer V [56], La Viña layer XIII [37], Geißenklösterle AHII [51], and Willendorf II AHIII [8, 19]. The higher frequency of carinated cores is probably a result of the need of different end-products. The major difference between the Protoaurignacian and Early Aurignacian appears to be more typological in nature, with retouched bladelets being less common in the Early Aurignacian.

Although the regional signatures of the Aurignacian techno-complex are far from being established, we argue that the clear-cut subdivision of two temporally consecutive technical traditions is unsustainable. The Swabian Aurignacian, for instance, has been associated with the Early Aurignacian of Aquitaine [51], although Hahn [150] has pointed out that the Aquitaine model does not apply to the region and Conard and Bolus [151] have emphasized the fact that the Aurignacian of the Swabian Jura is characterized by a strong local signature. In northern Italy, the development of the Protoaurignacian is still open to debate. At Mochi, preliminary results suggest that no clear cultural breaks are evident in the realm of the lithic assemblage between the two Aurignacian horizons [24]. Only antler exploitation and the manufacture of split-based bone points permit a differentiation between the upper and lower horizons [152]. Similar results have been reached in previous works at Fumane [67, 69]. The ongoing analyses on the upper (Proto)Aurignacian layers (D6 and D3) will be of primary importance in the understanding of the regional development of the Aurignacian in northeastern Italy.

In light of these observations and due to the narrow archaeological definition of Protoaurignacian and Early Aurignacian, the model proposed by Banks, d'Errico and Zilhao [39] is not applicable to all of Europe and should be viewed with caution. Future research will have to focus on the reasons for the quantitative differences found between Early Aurignacian and Protoaurignacian assemblages, by investigating the development of these techno-complexes on a regional perspective. Indeed, it is not clear whether all the industries described as Early Aurignacian are equivalent or if the earliest assemblages are comparable to the latest [25]. The cultural mosaic of lithic technologies at the beginning of the Upper Paleolithic could be explained in several ways. Among them, the progressive assimilation of the bladelet concept may have played a major role [55]. People's high mobility may have permitted cultural interactions between different regional groups with exchanges of technological knowledge over large territories. In this regard, the association of the Aurignacian techno-complex with the spread

of AMHs requires the design of a large-scale study that incorporates a detailed comparison of Eurasian Early Upper Paleolithic techno-complexes, such as the Baradostian [153–155], the Rostamian [155–157], and the Early Ahmarian [158].

## Conclusions

This extensive investigation of the lithic technology from the Protoaurignacian units A2-A1 at Fumane Cave and careful comparison with other assemblages confirms that the Protoaurignacian is a bladelet-dominated industry. Our study demonstrates that bladelet production is based on a broad range of reduction strategies that are not related to the reduction of larger blade cores, as postulated by Bon, Teyssandier and Bordes [48]. Blade and bladelet productions are, however, not strictly separated due to the presence of simultaneous reduction sequences, the recycling of some blade cores into bladelet cores, the selection of by-products of the bladelet production as blanks to manufacture common tools, and the production of a short sequence of blades on some initial bladelet cores prior to the main production phase. The Protoaurignacian appears to be technologically homogeneous, although regional signatures are noticeable in the typological variability of retouched bladelets [103] and in the importance given to certain platform reduction strategies, among which the preference towards the exploitation of the core longitudinal axis stands out.

In the light of recent radiocarbon dates, it is very likely that the Protoaurignacian and the Early Aurignacian coexisted for few millennia, probably in adjacent regions. This study suggests that no unique technological characteristics are restricted to either of the two techno-complexes. These results question the assumption that the Early Aurignacian evolved out of the Protoaurignacian [39]. Careful investigations carried out on a regional scale are the only way to clarify the relationships between human groups that inhabited Europe at the onset of the Upper Paleolithic. Being that the Protoaurignacian lithic assemblage of Fumane Cave has been extensively investigated and that its technological spectrum encompasses all of the variability that has been verified in all Protoaurignacian assemblages, it should be used as a reference site for the identification of inter-regional variability and for large-scale comparisons among contemporaneous Eurasian techno-complexes.

## Supporting information

**S1 File. List of all lithic artifacts analyzed in this paper.** For each artifact is given A. Falcucci's database number, basic dataclass, technological classification, cortex coverage, breakage class, and all individual measurements. Measurements include: length (only for complete artifacts), width, and thickness of blanks and tools, and width and thickness of preserved platforms.

(XLSX)

**S1 Fig. Plan view of the cave.** Squares colored yellow are square meters where all cores, all tools and tool fragments, all complete and almost complete blades and bladelets, and all by-products deemed to have had a significant role in the reduction process were studied. Additionally, in squares colored brown all blades and bladelets greater than 1.5 cm regardless of the fragmentation index and all flakes with preserved butts greater than 2.0 cm were analyzed.

(PDF)

**S2 Fig. Core diacritic analyses.** Schematic drawings of semi-circumferential blade (a) and bladelet (b, e) cores, wide-faced flat blade-bladelet (c) and blade (h) cores, narrow-sided bladelet cores (d, i), transverse carinated bladelet core (f), and multi-platform bladelet core (g). See individual captions for interpretation of core reduction procedures and the legend for

explanation of the symbols and graphic criteria used to draw cores (drawings: A. Falcucci). (PDF)

**S3 Fig. Comparison between the distribution of blade thickness values (in millimeters; blue) and bladelet thickness values (in millimeters; green).** (PDF)

**S1 Table. Summary of length measurements across complete blanks (flakes, blades, and bladelets together) with different grades of cortex coverage.** SE: standard error; SD: standard deviation. (PDF)

**S2 Table. Summary of metric attributes of blades made from Oolithic flint and blades made from all other raw material types.** SE: standard error; SD: standard deviation. (PDF)

**S3 Table. Summary of length measurements across complete technical flakes with blade, bladelet, and simultaneous blade-bladelet scars.** Complete technical flakes with undetermined scars (n = 6) are excluded. SE: standard error; SD: standard deviation. (PDF)

## Acknowledgments

The authors thank R. Duches and a team of students (A. Aleo, F. Scianò, G. Rigolin, I. Cinti, et al.) for having put in order the A2-A1 lithic collection in 2015. The authors are grateful to Gillian Wong for improving the English text, to Kevin Di Modica for providing the map used in [Fig 1](#), and to two anonymous reviewers for providing contribution to considerably ameliorating the paper.

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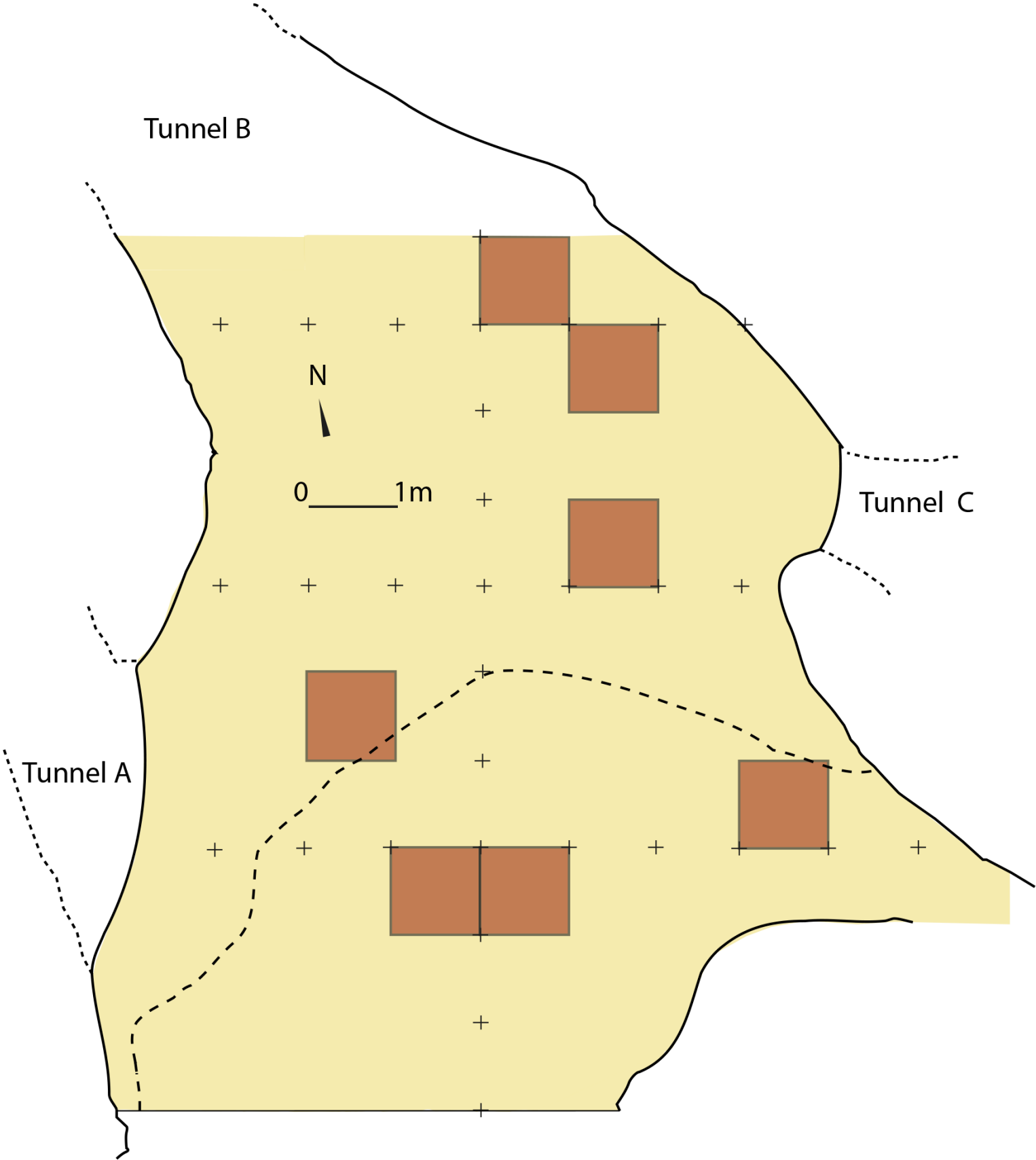
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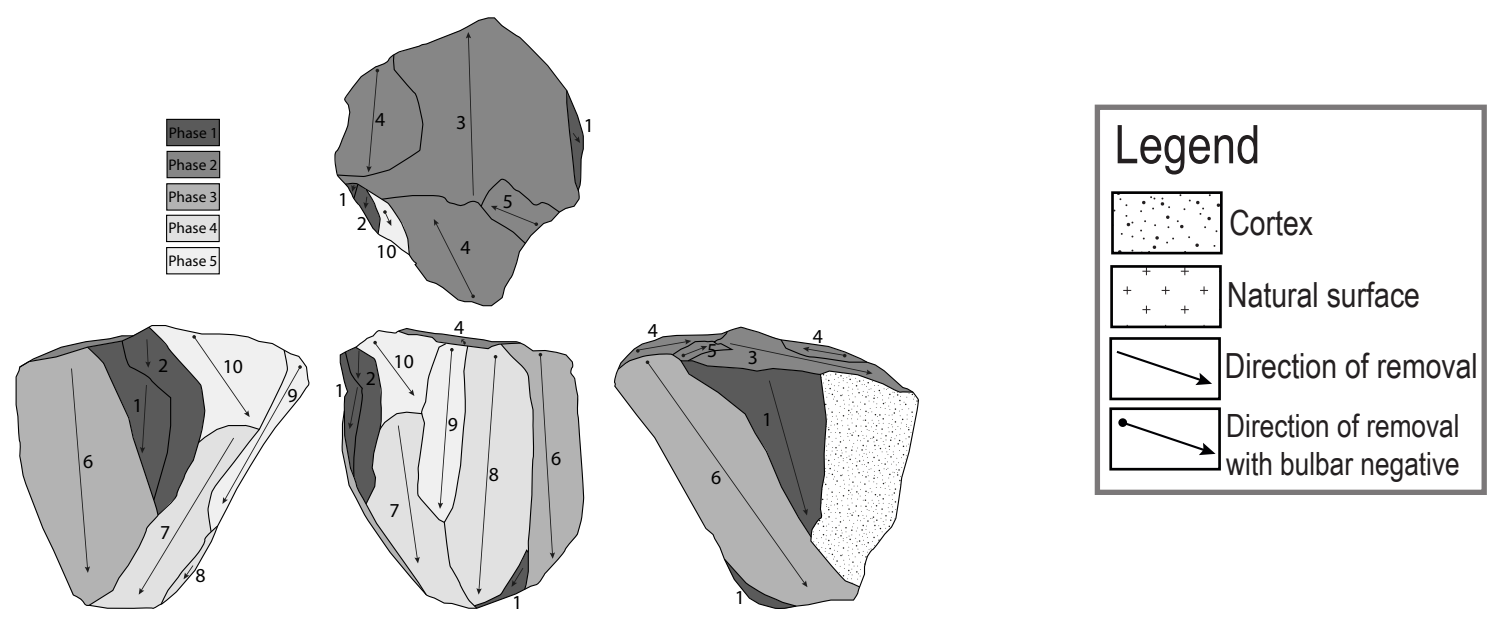
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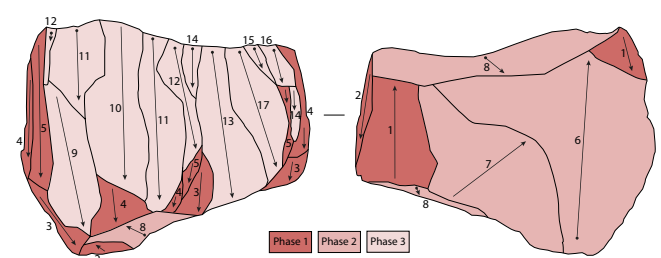
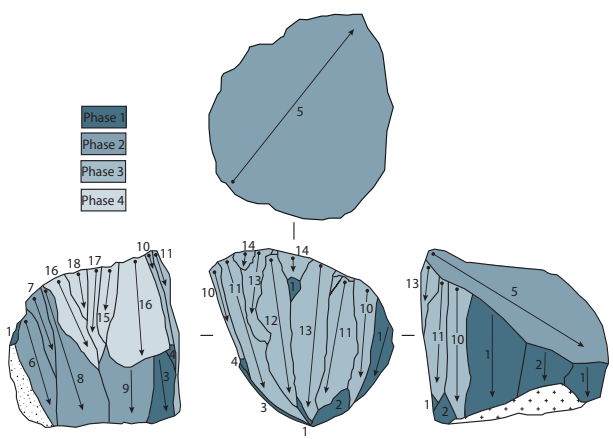
**S1 Fig. Plan view of the cave.** Squares colored yellow are square meters where all cores, all tools and tool fragments, all complete and almost complete blades and bladelets, and all by-products deemed to have had a significant role in the reduction process were studied. Additionally, in squares colored brown all blades and bladelets greater than 1.5 cm regardless of the fragmentation index and all flakes with preserved butts greater than 2.0 cm were analyzed.



**S2 Fig. Core diacritic analyses.** Schematic drawings of semi-circumferential blade (a) and bladelet (b, e) cores, wide-faced flat blade-bladelet (c) and blade (h) cores, narrow-sided bladelet cores (d, i), transverse carinated bladelet core (f), and multi-platform bladelet core (g). See individual captions for interpretation of core reduction procedures, and the legend for explanation of the symbols and graphic criteria used to draw cores (drawings: A. Falcucci).

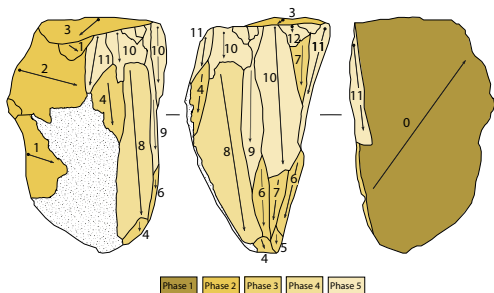


**a. Semi-circumferential blade core.** Phase 1: core decortication; Phase 2: shaping of the striking platform; Phase 3: removal of a naturally backed blade; Phase 4: blade production; Phase 5: hinged removal (9) and failed attempt to strike a technical transverse flake (10).

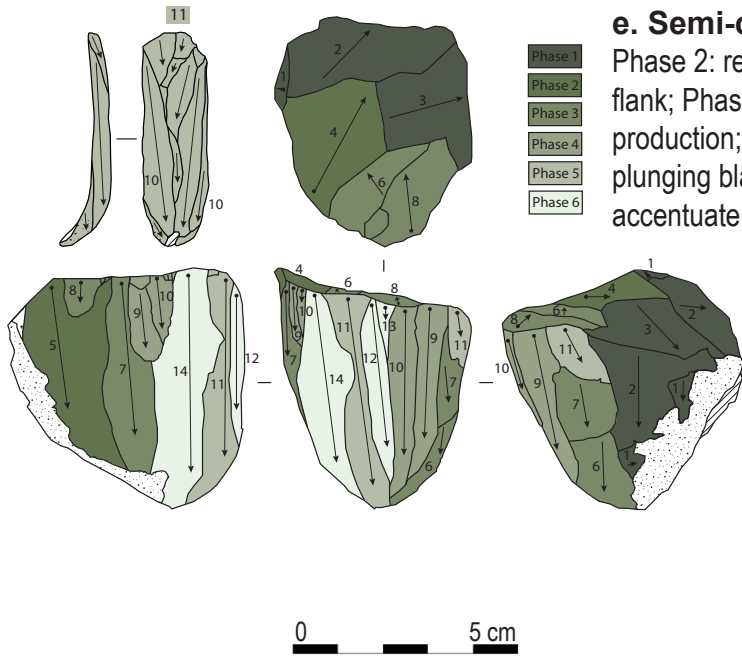


**c. Wide-faced flat blade-bladelet core.** Phase 1: early phase of blank production; Phase 2: maintenance operations at the core back and base and removal of a core tablet; Phase 3: simultaneous blade-bladelet production.

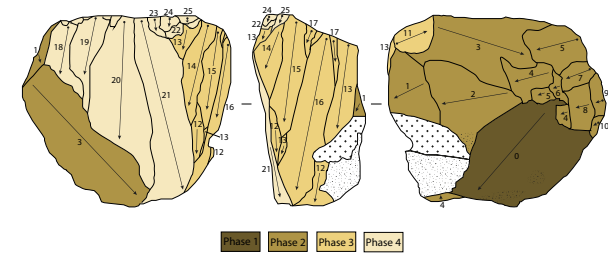
**b. Semi-circumferential bladelet core.** Phase 1: early stage of core preparation and isolation of a narrow surface (see removal 3). The related bladelet production is no longer visible; Phase 2: removal of a total core tablet and new isolation of the flaking surface; Phase 3: bladelet production; Phase 4: last attempt to reshape and isolate a narrow surface.



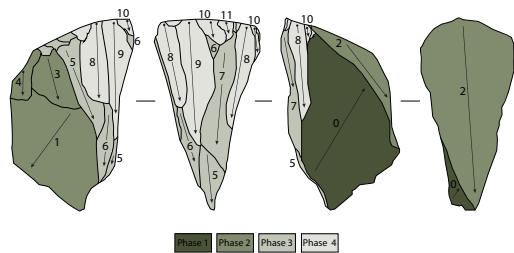
**d. Narrow-sided bladelet core.** Phase 1: core blank is a thick cortical flake; Phase 2: creation of a dorsal crest and of a striking platform; Phase 3: bladelet production; Phase 4: a lateral blade is detached; Phase 5: last set of hinged bladelets.



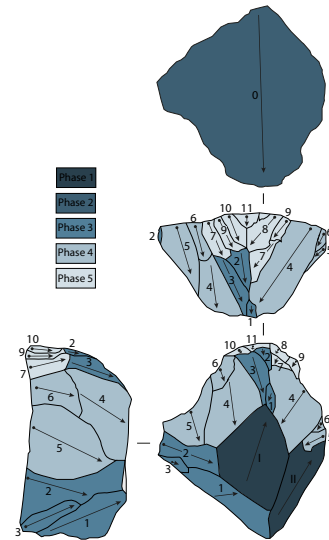
**e. Semi-circumferential bladelet core.** Phase 1: core decortication; Phase 2: re-preparation of the striking platform and maintenance of the core flank; Phase 3: Isolation of a narrow and convex surface; Phase 4: bladelet production; Phase 5: new isolation of an adjacent surface (see also the related plunging blade 11); Phase 6: bladelet production and last failed attempt to accentuate the transversal convexity (14).



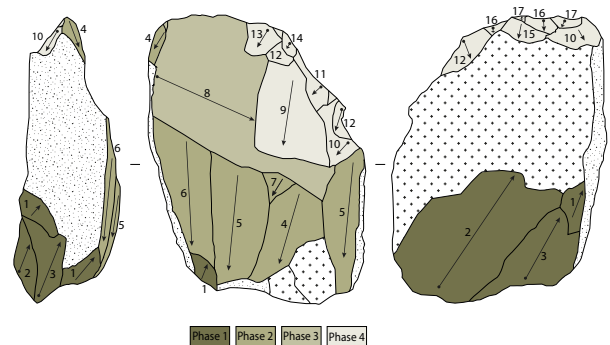
**g. Multi-platform bladelet core.** Phase 1: core blank is a flake; Phase 2: shaping of a dorsal crest and preparation of the core flanks; Phase 3: bladelet production based on the narrow face; Phase 4: re-orientation of the core and a set of broad bladelet removals on a broad, disjointed face.



**i. Narrow-sided bladelet core.** Phase 1: core blank is a flake; Phase 2: shaping of the core flank and creation of the striking platform; Phase 3: bladelet production; Phase 4: last set of bladelet removals, some of them hinged.

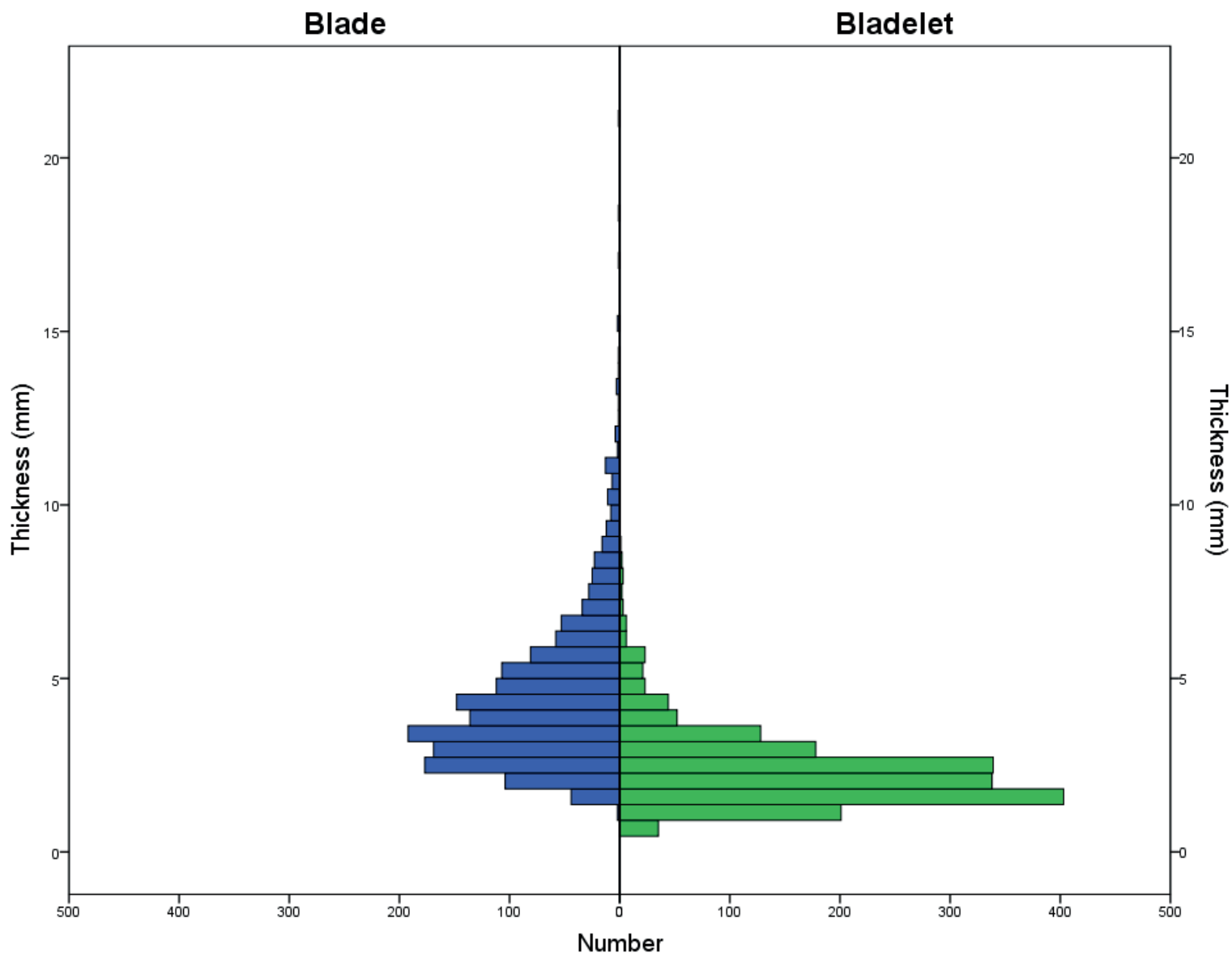


**f. Transverse carinated bladelet core.** Phases 1 & 2: core blank is a thick flake; Phase 3: lateral isolation of the flaking surface and early bladelet production; Phase 4: new isolation of the flaking surface that gives the core a nosed shape; Phase 5: last set of hinged removals.



**h. Wide-faced flat blade core.** Phase 1: maintenance operations on the core base and back; Phase 2: blade production; Phase 3: strike of an orthogonal rejuvenation flake; Phase 4: re-preparation of the striking platform by short hinged flakes (faceted platform) and failed attempt to pursue the blank production.

**S3 Fig. Comparison between the distribution of blade thickness values (in millimeters; blue) and bladelet thickness values (in millimeters; green).**





**S1 Table. Summary of length measurements across complete blanks (flakes, blades, and bladelets together) with different grades of cortex coverage. SE: standard error; SD: standard deviation.**

	<b>Number</b>	<b>Range</b>	<b>Mean</b>	<b>SE</b>	<b>SD</b>	<b>25 prctl</b>	<b>Median</b>	<b>75 prctl</b>
<b>1-33%</b>	299	11.9 to 103.3	44.5	0.89	15.43	33.7	42.8	51.6
<b>33-66%</b>	94	19.7 to 95.0	46.0	1.64	15.95	34.3	44.1	56.3
<b>66-99%</b>	51	17.8 to 91.0	47.0	2.45	17.49	32.5	43.4	57.2
<b>100%</b>	31	15.8 to 75.0	43.6	2.57	14.33	36.5	42.1	53.6

**S2 Table. Summary of metric attributes of blades made from Oolithic flint and blades made from all other raw material types. SE: standard error; SD: standard deviation.**

	Number	Range	Mean	SE	SD	25 prctl	Median	75 prctl
<b>Oolithic</b>								
Length	4	69.0 to 95.0	78.6	6.0	12.0	69.3	75.2	91.3
Width	41	12.6 to 31.5	22.1	0.83	5.38	17.0	21.8	26.4
Thickness	41	1.7 to 12.0	6.0	0.37	2.35	4.1	5.8	7.4
<b>Other</b>								
Length	417	24.2 to 102.5	49.4	0.64	13.06	39.8	47.5	57.8
Width	1543	12.1 to 35.8	16.4	0.10	3.90	13.6	15.3	18.0
Thickness	1543	1.1 to 21.0	4.4	0.06	2.21	2.9	3.9	5.4

**S3 Table. Summary of length measurements across complete technical flakes with blade, bladelet, and simultaneous blade-bladelet scars.** Complete technical flakes with undetermined scars (n=6) are excluded. SE: standard error; SD: standard deviation.

	<b>Number</b>	<b>Range</b>	<b>Mean</b>	<b>SE</b>	<b>SD</b>	<b>25 prctl</b>	<b>Median</b>	<b>75 prctl</b>
<b>Blade</b>	16	36.2 to 116.0	52.8	4.80	19.20	42.9	49.0	51.8
<b>Bladelet</b>	55	10.9 to 60.0	39.4	1.21	9.09	33.6	38.7	44.4
<b>Blade-bladelet</b>	10	36.0 to 76.0	50.0	4.31	13.66	38.5	46.8	59.9

## **Protoaurignacian core reduction procedures: blade and bladelet technologies at Fumane Cave**

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## **Protoaurignacian core reduction procedures: blade and bladelet technologies at Fumane Cave**

The Protoaurignacian is one of the European techno-complexes that marks the beginning of the Upper Paleolithic. During this time bladelet implements, frequently intended to be hafted in composite tools, become the primary goal of lithic production. The growing number of technological investigations carried out on several assemblages has revealed that, in most cases, bladelets are not the result of the reduction of blade cores. However, the detailed procedures involved in the production of blades and bladelets have rarely been reconstructed. Here we report on diacritic investigations of early stage and exhausted cores from the Protoaurignacian layers of Fumane Cave in northeastern Italy. We show that core reduction is influenced by two distinct operational concepts that relate to the manufacture of different predetermined products. The first is characterized by a linear and consecutive knapping progression that aims to obtain blades and, to a minor extent, bladelets with sub-parallel edges. The second is characterized instead by an alternated knapping progression that is exclusively used to produce slender bladelets with a convergent shape. We also show that carinated cores do not significantly differ, technologically, from semi-circumferential bladelet cores. We conclude by suggesting that there existed strong technological traditions shared between hunter-gatherers across the geographical extent of the Protoaurignacian.

Keywords: lithic technology; Protoaurignacian; Upper Paleolithic; core reduction; blade and bladelet technologies; diacritic analysis

### **Introduction**

The Protoaurignacian, first recognized by Laplace (1966) in southern Europe, is an Early Upper Paleolithic techno-complex that focuses on bladelets (Kozłowski and Otte, 2000; Kuhn, 2002; Bon, 2005; Tsanova et al., 2012). However, although a growing number of technological analyses carried out on several assemblages (Bon and Bodu, 2002; Ortega Cobos et al., 2005; Slimak et al., 2006a; Porraz et al., 2010; Tafelmaier, 2017) has allowed to better isolate the Protoaurignacian lithic technology, detailed

reconstructions of the lithic production processes remain rare. Our recent investigation carried out on the lithic assemblage from Fumane Cave in northeastern Italy has shown that bladelet production is based on variable and independent reduction strategies that are not the result of the progressive reduction of blade cores (Falcucci et al., 2017). Bladelets are variable from a metric point of view and frequently have convergent edges. They are often retouched to shape and/or straighten a pointed distal end (Falcucci et al., 2016). Blades are the second goal of the lithic production. They are produced from independent reduction strategies, but also from simultaneous blade-bladelet cores. Blades have generally sub-parallel edges and are relatively small in size, although the production of some large-sized blades is observed. Both blades and bladelets are extracted with direct marginal percussion after an accurate abrasion of the platform edge.

With the aim of contributing to our current understanding of Protoaurignacian technology, here, we investigate the procedures involved in the production of blades and bladelets at Fumane Cave, units A2-A1, conducting diacritic investigations of early stage and exhausted cores. By carefully studying the chronological order of the removal scars visible on cores, and by associating the information gained from the analysis of by-products, it is possible to examine the technological variability of a lithic assemblage and to interpret the flexibility of the knappers in relation to raw material constraints and production objectives. The identification of operations that relate to common conceptual schemes thus permits us to address whether technological traditions were shared by different groups of hunter-gatherers across Europe.

## **Materials and methods**

Fumane Cave is located in the Venetian Prealps (northeastern Italy). The cave has been meticulously excavated for decades and is characterized by a high resolution

stratigraphic sequence spanning the Mousterian, Uluzzian, Protoaurignacian, and Aurignacian lato sensu (Bartolomei et al., 1992; Broglio et al., 2005; Peresani, 2012; Bertola et al., 2013; Peresani et al., 2016; Falcucci et al., 2017). Today, it represents a key site for understanding the complex processes that led to the demise of Neandertal populations and the spread of modern humans across Europe (Benazzi et al., 2015).

This study considers layers A2-A1, which date the appearance of the Protoaurignacian to 41.2–40.4 ka cal BP (Higham et al., 2009). Here, layers A2-A1 are grouped in a single analytical unit because they do not show significant differences on typo-technological (Falcucci et al., 2017) or chronological (Higham et al., 2009) grounds, and were indistinguishable in the cave mouth during the excavations. No significant differences in the distribution of core types were found when the part of the cave in which A2 and A1 could be distinguished was compared (see Supplement A; Pearson's chi-squared test=1.1086, p=0.9). Besides several thousands of lithic artifacts, layers A2-A1 contain dwelling features (Broglio et al., 2006), bone tools (Broglio and Dalmeri, 2005; Bertola et al., 2013), and ornamental objects made from perforated marine shells and grooved red deer incisors (Broglio and Dalmeri, 2005; Gurioli et al., 2005).

We analyzed all early stage (n=26) and exhausted (n=89) blade and bladelet cores, except a small number of cores that are on display in permanent exhibitions at the Museo Paleontologico e Preistorico di Sant'Anna d'Alfaedo. Multidirectional (n=9) and centripetal (n=5) flake cores, as well as core fragments (n=26), were excluded from this study. Core fragments belong almost exclusively to laminar cores, even if most of them are difficult to further classify. Additionally, we took into account all blanks belonging to the preparation and maintenance of blade and bladelet cores in order to include detailed information from different stages of the reduction sequence.

This work is framed in a chaîne opératoire approach (Boëda et al., 1990; Inizan et al., 1995; Soressi and Geneste, 2011). We performed diacritic analyses, following Dauvois (1976), to reconstruct the detailed biography of each core and of the technical actions conducted on them. Diacritic investigation has proven to be a powerful method of overcoming static core classifications (Boëda, 2001; Roussel, 2011). A comparable approach, the Working Stage Analysis, was developed by Pastoors (2001) to reconstruct the production concepts and rejuvenation phases of bifacial tools. Recently, it was used to analyze Middle and Upper Paleolithic cores (Pastoors et al., 2015; Bataille, 2017).

The organization (position, chronology, and direction) and the shape of last visible scars permit identification of different reduction phases and the operation carried out to prepare and maintain the core volumetric structure. The chronology and direction of removals are easily discernable by the naked eye or with the support of magnification (ranging from 10–20×), thanks to a series of noticeable features of the imprint left by removals (for an explanation see: Inizan et al., 1995; Soressi, 2002; Pastoors et al., 2015). Schematic drawings represent the analytical tool that permits the data acquired during the analysis to be recorded and interpreted. In these drawings, negatives that are chronologically related and have been produced for the same purpose are grouped together in a reduction phase and are colored with the same tone. The oldest reduction phases are darker, while the successive phases are lighter. Arrows indicate the direction of removals, which are numbered in ascending order to show their chronological succession (see the legend in Figure 1 for a detailed explanation of the graphic criteria used to draw artifacts). Negatives labeled with roman numerals are removals that belong to a stage that preceded the detachment of the flake used as core blank.

Core classification is based on the work of Pelegrin (1995) and takes into account criteria such as the orientation of the flaking surface, knapping progression, and



the number of platforms and faces exploited. Initial cores are typed after Conard et al. (2004) and include all artifacts that display only few removal scars. They reflect the early stages of knapping in which much of the original piece is still unmodified. Initial cores represent an important source of information because they show the preliminary flaking and configuration of the selected blanks before their overall morphology is modified and the volume is reduced.

Technological attributes recorded on cores and blanks are based on well-known methods of lithic analysis (Inizan et al., 1995; Andrefsky, 1998) and on recent studies that focus on laminar technologies (Nigst, 2012; Zwyns, 2012). Laminar removal scars are considered bladelets when the width is less than 12.0 mm.

The Protoaurignacian industry of Fumane Cave is made up of flint from different carbonatic formations that are easily collected from primary outcrops, but also from loose coarse stream or fluvial gravels, slope-waste deposits, and soils in the immediate surroundings of the cave (Bertola, 2001). Jurassic and Tertiary calcarenites, frequently found in large-sized and homogeneous nodules, are almost exclusively used to produce blades (Falcucci et al., 2017). A small sample of bladelets and associated by-products is made from an extra-local Radiolarite ascribable to the Lombard pre-Alps (Bertola et al., 2013).

## **Results**

### ***General core classification***

Table 1 gives a classification of exhausted cores according to the identified reduction strategies and objectives of the blank production. The detailed analysis of each artifact has permitted us to isolate knapping patterns that are shared across core types and those that are, instead, specific of each reduction strategy (see below). Narrow-sided cores are

exploited along the longitudinal axis on one of the narrow faces, while semi-circumferential cores display removals around at least two faces in continuity. Wide-faced flat cores are exploited on one of the broader faces. Transverse carinated cores differ from semi-circumferential cores in that they have been oriented according to the transversal axis of the blank, to exploit the thickness of the core. The most heterogeneous category groups all multi-platform cores. They are exploited during independent reduction phases on one or more faces, starting from different platforms. Multi-platform cores can further be sorted into five sub-categories:

- *Wide-faced consecutive cores (n=4)*. Blank production is carried out in the same face, but at two separate times. Striking platforms are opposite or orthogonal to each other;
- *Wide-faced mirrored cores (n=5)*. Blank production is carried out in two opposite broad faces, using two different striking platforms;
- *Circumferential consecutive cores (n=4)*. Cores are exploited along all available faces in independent and opposite reduction phases;
- *Disjointed wide-faced and narrow-sided cores (n=7)*. Cores are exploited on a broad and on one or two (n=2) narrow faces at separate times;
- *Narrow-sided consecutive cores (n=3)*. Blank production is carried out on the narrow faces, using different and opposed platforms.

### ***Core configuration***

Knappers selected blocks, slabs, and thick flakes to conduct complete reduction sequences on-site. Most of the identified initial cores were intended to be bladelet cores. Only five blocks have a volume that may have permitted to carry out a proper blade production (Falcucci et al., 2017). In most cases, the core initial shaping begins with the

preparation of a flat striking platform that is usually placed above a narrow face of the blank in order to exploit the longer available surface (Figure 2a–d, f). Only five initial cores are oriented according to the thickness of the blank (Figure 2e). They are made from flakes or block fragments. The flaking surface is roughly prepared and the decortication is partial (Figure 2a, c) or even absent (Figure 2f). Blank production usually starts with a laminar removal that takes advantage of a natural ridge of the raw material nodule. A favorable angle is usually found on the narrow face, at the intersection with one of its broad faces (n=20; Figure 2c). Prior interventions to modify the core structure are sometimes required. In these cases, an artificial crest is created by removing short orthogonal flakes along the longitudinal axis of the flaking surface. Remains of these operations are not frequent among initial cores (n=3). Crests can be produced directly from a cortical edge (Figure 2f), after a partial decortication of the raw material nodule (Figure 2a), or at the junction with the ventral face in the case of cores on flake (Figure 2b). Among blanks, crest scars are usually continuous and more pronounced in the mesio-distal side to accentuate the core distal convexity. Two-sided crests are less common and are used almost exclusively on comparatively larger raw material nodules (Falcucci et al., 2017). Shaping of the non-active part of the core is uncommon. Only five initial cores on flake display dorsal cresting (Figure 2d). In all of these cases, flakes are removed from the core back towards the flanks.

After this preliminary volumetric preparation, cores are characterized by a symmetrical flaking surface framed by two flanks and a steep striking platform. Only two initial cores have an opposed platform (Figure 2d), which is, however, accessory and related to operations carried out at the core base. The first set of removals follows a sub-parallel reduction pattern and results in the production of semi-cortical blanks. On most of the initial bladelet cores removal scars that correspond to short blades are

visible (Figure 2b–d). These products are common among the blank assemblage, complicating the definition of a metric boundary between blades and bladelets (Falcucci et al., 2017).

### ***Knapping progression***

#### *Narrow-sided cores*

Narrow-sided cores (Figure 3) are used to exclusively produce bladelets. These cores are made from flakes (n=16) or flat raw material nodules (n=6). One blank is undetermined. As evident in the initial narrow-sided core in Figure 2b, blanks can also be selected from blade production waste. The flaking surface is framed by two perpendicular flanks, that, in case of cores on flake, are the dorsal and ventral face of the blank. Dorsal crestring (n=10; Figure 3a–c) is an operation carried out exclusively in this type of core and is finalized to isolate the flaking surface and facilitate the removal of core tablets (Pigeot, 1987). Striking platforms are flat and frequently re-shaped by the removal of core tablets. A second opposing platform (n=3) can be used to maintain the core distal convexity (Figure 3e). The flaking direction is strictly unidirectional and striking angle is steep ( $67^{\circ}\pm 9^{\circ}$ ). The knapping progression is frontal and symmetrical to the core axis, with possible partial invasion of one of the flanks (n=7) for short maintenance operations carried out along the longitudinal axis of the core. Blank production usually follows a convergent knapping pattern that alternates removals at the center of the flaking surface with lateral oblique products. This pattern facilitates auto-maintenance of longitudinal and transversal convexities and allows the knapper to obtain straight and frequently convergent bladelets at the center of the flaked surface. At discard, narrow-sided cores often have a sub-pyramidal morphology.

### *Semi-circumferential cores*

Semi-circumferential cores (Figure 4) show removal scars located on at least two adjacent faces that progressively merge into a single convex surface. Most of the semi-circumferential cores are made from blocks (n=15), some of them of relatively small dimensions. Contrary to narrow-sided cores, the non-active part of the flaking surface is never shaped. The knapping direction is strictly unidirectional and short bidirectional removals (n=4) are only used to maintain the core distal side. Striking platforms are frequently re-shaped by partial and total core tablets and only a blade core displays a faceted platform. The striking angle is steep ( $64^{\circ}\pm 7^{\circ}$ ).

Semi-circumferential cores are characterized by two different reduction strategies, related to the extraction of different blanks. In the first, knapping progresses parallel to the axis of core symmetry and the reduction pattern is sub-parallel (Figure 4a). All blade and simultaneous blade-bladelet cores, as well as few bladelet cores (n=4), are reduced following this strategy. The flaking surface is framed by two perpendicular flanks that are progressively invaded by the development of the knapping. Blanks are produced in a linear consecutive progression (Figure 5) along the whole perimeter of the flaking surface. Maintenance and predetermined products are thus part of a single and sequential concatenation of removals.

Bladelet production is, instead, usually characterized by a reduction strategy that requires the application of an original procedure to obtain slender and convergent bladelets (n=10; Figure 4b–e). Lateral products, transverse to the main core axis, isolate a narrow surface on a favorable area of the core. They are usually complemented by oblique removals that accentuate the local transverse convexity and permit extraction of a short sequence of bladelets following an alternated pattern, as in the case of narrow-sided cores. Once the surface has lost its convexities, a new, independent phase of core

preparation is carried out in a nearby area or in the same area with a slight change in the flaking direction (Figure 6 and 7). In the latter case, the first blank of the new, short sequence of removals displays a set of oblique scars, belonging to the previous reduction phase, partially covered by a transverse blow (Figure 8). In an advanced stage of reduction, this back and forth from the core periphery to its center gives, to certain cores, a circumferential progression. Removals that shape the core flanks have sub-parallel edges and are broader than convergent products belonging to the optimal production phases (Figure 4d, e). To conclude, the final morphology of the core is progressively acquired throughout independent reduction phases that allow pointed bladelets to be produced from the early stages of core reduction (Figure 7a–c, e).

#### *Wide-faced flat cores*

Wide-faced flat cores (Figure 9) can be considered semi-circumferential cores that are flattened by a prolonged and successful blank extraction. For this reason, core blank is, in most cases, undetermined (n=9) and at least one flank is missing. The core back is parallel to the opposite face and bears removals scars linked to maintenance operations that occurred, usually, in an advanced stage of reduction. The striking platforms are flat and re-prepared by complete core tablets. Only one blade core has a faceted platform (Figure 9d). Flaking angle is steep ( $67^{\circ}\pm 9^{\circ}$ ). The knapping progression is parallel to the axis of core symmetry and the reduction pattern can be sub-parallel (n=8) or convergent (n=5). The sub-parallel pattern is applied to blade cores (Figure 9a, d), simultaneous blade-bladelet cores (Figure 9c), and to some of the bladelet cores (n=4). One core is undeterminable due to a rejuvenation flake that obliterates most of the previous removal scars. This pattern exploits the whole available flaking surface by removing sets of blanks in a linear consecutive progression. Maintenance blanks can even be struck from an opposing platform (Figure 9a). The convergent pattern is, instead, carried out

exclusively on bladelet cores, using the solution previously described for semi-circumferential bladelet cores. Their peculiarity resides in the fact that, in all cases, the lateral transverse blank is complemented by a set of short opposite removals struck from the opposed side. They complete the isolation of the narrow surface and accentuate its longitudinal convexity (Figure 9b).

#### *Transverse carinated cores*

Transverse carinated cores (Figure 10) are distinct from the other categories because the frontal regression of the flaking penetrates orthogonally along the longitudinal axis of the blank. Comparatively shorter bladelets (Falcucci et al., 2017) are the exclusive goal of the production. Transverse carinated cores are made from thick flakes (n=8), but also small blocks (n=2). The striking platform is always located above the ventral face of the flake, and is re-shaped in only two cases. Flaking angles are steep ( $67^{\circ}\pm 7^{\circ}$ ). Crests are never used to shape the core base. The knapping pattern is strictly unidirectional and its progression is semi-circumferential, or even circumferential (n=2). Maintenance operations are comparable to what has been described for semi-circumferential bladelet cores. The flaking surface is always isolated by broad plunging flakes. These flakes are removed at the intersection with the core flanks and are transversal to the main production axis, even if they usually do not converge towards the center of the flaking surface. These operations are conducted at different phases throughout the reduction sequence. For this reason, cores may acquire a typical nosed morphology (Figure 10c; Le Brun-Ricalens, 2005). In most cases, the flaking surface is exploited with an alternated convergent reduction pattern (n=8).

#### *Multi-platform cores*

Diacritic analyses are of fundamental importance to understand the reduction phases

that take place on multi-platform cores (Figure 11). This reduction strategy permits raw material efficiency to be maximized, exploiting most of the available volume. For this reason, the original core blank is, in most cases, undetermined (n=14). The remaining cores are made from blocks (n=5) and flakes (n=4). Among multi-platform cores are visible narrow-sided, semi-circumferential, and wide-faced cores that have been exploited by alternating different reduction concepts, without going through complex reorganizations of their architecture. Most of the cores display two successive platforms and only five cores bear evidence of three successive platforms. Flaking surfaces are placed on the same or on different faces according to the general morphology of the core acquired during its reduction. Two blade cores are reoriented to conduct independent bladelet production phases (Figure 11a), while a simultaneous blade-bladelet production is followed by a set of short and curved bladelets struck from an opposing platform (Figure 11b). The knapping pattern is unidirectional and the striking angle is steep ( $69^{\circ}\pm 8^{\circ}$ ). Maintenance operations are similar to what has been described for the other core categories. A particular operation facilitates the rotation of the core and the beginning of a new reduction phase based on the same surface. It consists of the use of the previous transverse removal scars as core crest to easily remove the first laminar blank. This operation is also well-documented in more recent techno-complexes (Walczak, 1998).

### ***Core maintenance***

Several operations are conducted to maintain the core structure throughout the reduction sequence (Falcucci et al., 2017). Maintenance products are usually detached at the intersection of core faces. Naturally backed blanks have a lateral steeped cross-section and are produced following the flaking axis to maintain the transverse core convexity. In some cases, the detachment of backed products is preceded by the creation of neo-



crests, still visible in three cores (Figure 11b). Neo-crest removals are orthogonal and, in most cases, are created from the flaking surface towards a core flank. Although neo-crests are mostly used during sub-parallel reduction patterns, in a few cases, they are complementary to operations conducted on bladelet cores with a convergent reduction pattern (Figure 6a, i). The most frequent maintenance operation of convergent cores results in the removal of lateral blanks that tend to envelop the distal side of the flaking surface and allow discontinuous knapping progression (Figure 6). These blanks are usually the size of small blades.

Core tablets are used to maintain the striking platforms. Core tablet removals are visible among almost all of the analyzed cores (with the exception of transverse carinated cores) and are well-represented in the blank assemblage. Partial or total core tablets are usually detached from the anterior side of the core (73.8%), but also from a flank (22.6%) or the dorsal face (3.7%). In most cases they bear evidence of prior removals, indicating that this operation is conducted throughout the reduction sequence. The striking angle recorded on core tablets ( $77^{\circ}\pm 6^{\circ}$ ) is larger than the angle recorded across exhausted cores (Mann-Whitney's test,  $U=2296$ ;  $p < 0.01$ ), suggesting that this maintenance operation aims to re-establish a steep flaking angle.

Flaking surface rejuvenation is conducted by striking broad and usually plunging flakes and blades (Figure 5 and 7). These products are usually detached from the main flaking surface along the longitudinal core axis (Figure 3c), but may also be detached from the core flanks with an orthogonal direction (Figure 9d). Technical flakes are also used to maintain the core lateral convexities. For this reason, they are sometimes struck at the intersection with the striking platform (31.5%), or with a core flank (7.4%). In most cases, however, they remove only part of the flaking surface (61.1%).

### ***Core discard***

Cores are discarded in an advanced stage of reduction. A reduction sequence that is not interrupted by knapping mistakes can be protracted until the core is flattened, as exemplified by wide-faced flat cores. Maintenance operations are expensive in terms of raw material. The repeated removal of complete core tablets and plunging technical blanks progressively reduces the core volume. The goal of blank production remains, however, stable throughout the reduction sequence. Blade cores are not progressively reduced to bladelet cores and, even if intensively reduced, last removal scars still belong to blades. The highest investment of raw material is visible among semi-circumferential bladelet cores with discontinuous convergent reduction patterns. Although transverse carinated cores are less expensive in terms of raw material exhaustion (e. g. core tablets are almost never detached), they do not seem to be more productive than other core reduction strategies. Indeed, in most cases, blank production is interrupted after a relatively short sequence of removals.

### **Discussion**

This detailed analysis has permitted us to accurately reconstruct the technological procedures involved in the reduction of blade and bladelet cores. Our study confirms that bladelets are the main objective of the lithic production and that blades are obtained from independent and, to a lesser extent, simultaneous reduction sequences.

Overall, blade and bladelet cores represent a homogeneous group. All the identified types share a certain degree of technological overlap; a consequence of a volumetric and unidirectional approach to the knapping. Cores are prepared using simple shaping process. The orientation of the flaking surface in relation to a flat striking platform depends on the initial volume of the blank and by the intended

production goal. A laminar blank that takes advantage of a natural steep angle or, in some cases, a crest starts the production. After a first set of removals that aims to shape a symmetrical flaking surface, initial cores are framed by two flanks, in most cases perpendicular.

Knapping progression is then conditioned by two distinct operational concepts that influence the organization of knapping depending on the nature of the core blank and the production objectives. The first is based on the exploitation of a broad area during a linear and consecutive knapping progression that follows a sub-parallel reduction pattern. This concept is represented less among bladelet cores and is the sole concept involved in the production of blades. At Fumane, the reduction strategy of blade cores is thus not dissimilar to what is known from Early Aurignacian assemblages (Hahn and Owen, 1985; Le Brun-Ricalens, 1993; Bon, 2002). The second is, instead, based on the exploitation of narrow areas following an alternated convergent reduction pattern. With this procedure, the width of the end-products is easier to control and it is possible to obtain slender bladelets.

The dichotomy between blade or blade-bladelet productions based on broad surfaces and bladelet productions based on narrow surfaces also characterizes the Protoaurignacian assemblage of Observatoire (Porraz et al., 2010). At Fumane, however, the use of an original procedure permits narrow and convex surfaces to be isolated, independently from the location of the flaking surface, during discontinuous reduction phases. Each phase permits the production of a short series of regular bladelets with pointed distal ends. This recurrent flaking pattern can be based on a surface that is continuously reshaped, or on several core faces consecutively and reciprocally invaded.

The technological strategy used to exploit narrow flaking surfaces in the framework of bladelet production is evident at other Protoaurignacian sites. At Louza, most of the operations conducted on bladelet cores aim to isolate narrow surfaces (Sicard, 1995), while at Esquicho-Grapaou the production is sometimes based on a knapping progression that alternates removals at the center of the flaking surface with maintenance products that invade the core flanks (Sicard, 1994). At Mandrin, narrow and convergent flaking surfaces are instead isolated by sets of transverse removals detached from an adjacent core face (Slimak et al., 2006a, 2006b). Interestingly, the first blanks removed from the main flaking surface display an edge with an oblique scar pattern, opposed to a transverse removal that follows the main axis of detachment. This operation is comparable with the operations of isolation conducted at Fumane.

The use of lateral maintenance products in the framework of a convergent reduction pattern has been identified in many Protoaurignacian assemblages (Sicard, 1994; Bon and Bodu, 2002; Normand and Turq, 2005; Tsanova, 2008; Bataille, 2017; Tafelmaier, 2017) and seems to be related to convex flaking surfaces that are progressively invaded by the progression of knapping.

Carinated cores are a regular component of the Protoaurignacian (Maillo-Fernandez, 2003; Normand et al., 2008; Santamaría, 2012; Sitlivy et al., 2012; Tafelmaier, 2017), although they are generally less common than in Early Aurignacian assemblages (Bon, 2002; Chiotti, 2005; Le Brun-Ricalens, 2005). Only at Arbreda does carinated technology represent the main lamellar reduction strategy (Ortega Cobos et al., 2005). At Fumane, transverse carinated cores do not differ much from semi-circumferential bladelet cores. The use of lateral removals to isolate the flaking surface and the discontinuous knapping pattern represent the main shared features.

## **Conclusions**

Cores are the most informative artifacts found in a lithic assemblage. By analyzing the processes that led to their final morphology, the knapping procedures that are behind the formation of a given assemblage can be investigated. In the specific case of Protoaurignacian lithic technology, reconstruction of the detailed actions conducted by knappers to obtain blades and bladelets was of fundamental importance, given that in many available studies its technological variability has been underestimated and the role of what is known as a continuous reduction sequence (Bon et al., 2010; Teyssandier et al., 2010) has been over-emphasized. Our study has confirmed that blades and bladelets have their own reduction history which, in some cases, is complementary, but not successive.

At Fumane, two main technological concepts were isolated across the identified reduction strategies. A linear and consecutive knapping progression, based on a broad surface, is devoted to the production of blades and, to a minor extent, bladelets with sub-parallel edges. An alternated knapping progression based on narrow surfaces is, instead, exclusively devoted to the production of slender bladelets with convergent outlines. Applying these conceptual procedures to different core blanks is possible with original and flexible knapping strategies whose technical effort to adapt the morphology of different raw material nodules underlines how important are pointed bladelets in the framework of lithic production.

Overall, the identification of independent reduction strategies devoted to the production of bladelets with convergent outlines in several assemblages suggests the existence of strong technological traditions. These traditions were shared over a large geographical extent, under different environments, and probably over the course of several millennia. This final observation should not be taken to underestimate the

behavioral variability that characterized Protoaurignacian foragers (Riel-Salvatore and Negrino, 2018), and future reconstructions should overcome the reductive view of the Protoaurignacian as the pioneering phase of modern humans' arrival in Europe (but see: Anderson et al., 2015).

## Acknowledgments

Research at Fumane is coordinated by the Ferrara University (MP) in the framework of a project supported by the Ministry of Culture - Veneto Archaeological Superintendence, public institutions (Lessinia Mountain Community - Regional Natural Park, Fumane Municipality), Foundations (Leakey Foundation, Spring 2015 Grant), and private associations and companies. The doctoral studies of Armando Falucci are funded by the state of Baden-Württemberg and the University of Tübingen. The authors are grateful to the Editor and to two anonymous reviewers for providing feedback that considerably improved the paper. The authors declare that they have no potential conflict of interest.

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<b>Core classification</b>	Blade	Bladelet	Blade- Bladelet	Blade- Flake	Undet.	Total
Narrow-sided	-	23	-	-	-	23 (26%)
Semi-circumferential	4	15	1	-	-	20 (22%)
Wide-faced flat	2	9	1	-	1	13 (15%)
Transverse carinated	-	10	-	-	-	10 (11%)
Multi-platform	-	19	3	1	-	23 (26%)
<b>Total</b>	<b>6 (7%)</b>	<b>76 (85%)</b>	<b>5 (6%)</b>	<b>1 (1%)</b>	<b>1 (1%)</b>	<b>89 (100%)</b>

Table 1. Distribution of core categories according to the identified reduction strategy and the objectives of the blank production. Note that multi-platform blade-bladelet cores have produced bladelets in independent phases (n=2) or simultaneously with blades, followed by an independent reduction phase (n=1). Rounded percentages are given in brackets.

Figure 1. Legend for explanation of the symbols and graphic criteria used to draw cores and blanks.

Figure 2. Initial cores. **a**: initial bladelet core. Phase 1: split of a cobble; Phase 2: preparation of a striking platform and partial decortication; Phase 3: shaping of a crest; Phase 4: attempt to remove the crested blank (11) and set of hinged removals. **b**: initial narrow-sided bladelet core. Phase 1 & 2: selection of a rejuvenation flake from a large-sized blade core; Phase 3: preparation of a striking platform and shaping of the core base; Phase 4: shaping and removal of a crested bladelet; Phase 5: reorganization of the platform and removal of a few hinged blanks. **c**: initial bladelet core. Phase 1: partial decortication of a small cobble and preparation of a striking platform. Phase 2: reorganization of the striking angle and short series of laminar removals. **d**: initial narrow-sided bladelet core. Phase 1 & 2: selection of a flake; Phase 3: shaping of a bifacial dorsal crest; Phase 4: preparation of a flat striking platform and isolation of the flaking surface; Phase 5: first set of laminar removals; Phase 6: last set of hinged removals. **e**: initial carinated core. Phase 1: preparation of a striking platform and shaping of the core flank and base; Phase 2: shaping of the flaking surface; Phase 3: creation of the transversal convexities; Phase 4: reshaping of the striking platform and set of hinged removals. **f**: refitted initial core. Phase 1: preparation of a striking platform and shaping of a crest; Phase 2: reorganization of the platform to reduce the striking angle and removal of the hinged crested blade. (drawings: A. Falcucci).

Figure 3. Narrow-sided bladelet cores. **a**. Phase 1: core blank is a flake; Phase 2: creation of an invasive bifacial dorsal crest; Phase 3: bladelet production; Phase 4: last set of hinged bladelet removals. **b**. Phase 1: core blank is a thick cortical flake; Phase 2: creation of a dorsal crest and of a striking platform; Phase 3: bladelet production; Phase 4: a lateral blade is detached; Phase 5: last set of hinged bladelets. **c**. Phase 1: creation of a bidirectional crest on a small block; Phase 2: shaping of the flaking surface; Phase 3: re-preparation of the striking platform and bladelet production; Phase 4: rejuvenation blade axial to the flaking surface; Phase 5: last set of hinged removals and attempt to reshape the core convexities (19–23). **d**. Phase 1: core blank is a flake; Phase 2: shaping of the core flank and creation of the striking platform; Phase 3: bladelet production; Phase 4: last set of bladelet removals, some of them hinged. **e**. Phase 1: core blank is a thick flake; Phase 2: shaping of the core base and creation of the striking platform;

Phase 3: bladelet production; Phase 4: core maintenance with a lateral blade and a hinged flake; Phase 5: bladelet production. (drawings: A. Falcucci).

Figure 4. Semi-circumferential cores. **a**: blade core. Phase 1: core decortication; Phase 2: shaping of the striking platform; Phase 3: removal of a naturally backed blade; Phase 4: blade production; Phase 5: hinged removal (9) and failed attempt to strike a technical transverse flake (10). **b**: bladelet core. Phase 1: shaping of the core flanks and preparation of a striking platform; Phase 2: removal of two lateral blanks that isolate a convergent flaking surface; Phase 3: bladelet production; Phase 4: last set of hinged removals. **c**: bladelet core. Phase 1: core decortication and preparation of a striking platform; Phase 2: isolation of a narrow, convergent surface; Phase 3: bladelet production; Phase 4: last set of hinged removals. **d**: bladelet core. Phase 1: core decortication; Phase 2: re-preparation of the striking platform and maintenance of the core flank; Phase 3: Isolation of a narrow and convex surface; Phase 4: bladelet production; Phase 5: new isolation of an adjacent surface (see also the related technical plunging blade 11); Phase 6: bladelet production and last failed attempt to accentuate the transversal convexity (14). **e**: bladelet core. Phase 1: early stage of core preparation and isolation of a narrow surface (see removal 3). The related bladelet production is no longer visible; Phase 2: removal of a total core tablet and new isolation of the flaking surface; Phase 3: bladelet production; Phase 4: last attempt to reshape and isolate a narrow surface. (drawings: A. Falcucci).

Figure 5. Example of blanks with evidence of the linear consecutive knapping progression. **a** and **d**: technical blades; **b**: naturally backed blade; **c** and **e**: core rejuvenation flakes. Note that **e** is a spall removed from a rejuvenation flake. (drawings: A. Falcucci).

Figure 6. Example of lateral blades involved in the maintenance of bladelet cores with discontinuous convergent knapping progression. note that **a** and **i** also bear evidence of neo-crest remains. (drawings: A. Falcucci).

Figure 7. Example of by-products involved in the maintenance of bladelet cores with discontinuous convergent knapping progression. **a**, **c**, and **e** are technical blades, while **b**, **d**, and **f** are technical flakes. (drawings: A. Falcucci).

Figure 8. Example of bladelets with oblique scar patterns partially covered by the negative of a lateral maintenance blank that indicate the beginning of a new, short sequence of bladelets production. (drawings: A. Falcucci).

Figure 9. Wide-faced flat cores. **a:** blade core. Phase 1: early shaping of the core flank and back; Phase 2: early blade production phase; Phase 3: preparation of an opposed platform and removal of an opposed maintenance blade; Phase 4: blade production; Phase 5: failed attempt to remove a new series of blades. **b:** bladelet core. Phase 1: undetermined early core preparation; Phase 2: early blank production; Phase 3: isolation of a convergent flaking surface; Phase 4: bladelet production; Phase 5: loss of the core convexities and set of hinged removals. **c:** simultaneous blade-bladelet core. Phase 1: early phase of blank production; Phase 2: maintenance operations at the core back and base and removal of a core tablet; Phase 3: simultaneous blade-bladelet production. **d:** blade core. Phase 1: maintenance operations on the core base and back; Phase 2: blade production; Phase 3: strike of an orthogonal rejuvenation flake; Phase 4: re-preparation of the striking platform by short hinged flakes (faceted platform) and failed attempt to pursue the blank production. (drawings: A. Falcucci).

Figure 10. Transverse carinated cores. **a.** Phase 1: core blank is a thick flake; Phase 2: lateral isolation of the flaking surface; Phase 3: bladelet production. **b.** Phase 1: preparation of a striking platform and decortication of the flaking surface and core base; Phase 2: lateral isolation of the flaking surface that accentuates the transversal convexities; Phase 3: bladelet production; Phase 4: maintenance of the lateral convexities; Phase 5: last set of hinged bladelets. **c.** Phases 1 & 2: core blank is a thick flake; Phase 3: lateral isolation of the flaking surface and early bladelet production; Phase 4: new isolation of the flaking surface that gives the core a nosed shape; Phase 5: last set of hinged removals. (drawings: A. Falcucci).

Figure 11. Multi-platform cores. **a:** disjointed wide-faced and narrow-sided core. Phase 1: evidence of early blade production on a wide core face; Phase 2: core rotation and preparation of a new striking platform on the former core base; Phase 3: bladelet production on one of the narrow faces; Phase 4: shaping of the core flank and preparation of a new platform on the opposed narrow face; Phase 5: bladelet production. **b:** wide-faced consecutive core. Phase 1: undetermined core preparation; Phase 2: re-organization of the striking platform; Phase 3: bladelet production that ends with a last



set of hinged blanks; Phase 4: core rotation, shaping of a partial neo-crest and removal of a lateral neo-crested blade to shape a convergent flaking surface; Phase 5: bladelet production. **c**: disjointed wide-faced and narrow-sided core. Phase 1: core blank is a thick flake; Phase 2: core preparation; Phase 3: blade-bladelet production that starts on a narrow face and progresses towards the wide face (note that removal 1 is a maintenance blank struck from an opposed platform); Phase 4: preparation of a striking platform and new blank production phase on the opposite narrow face, following an oblique orientation; Phase 5: core rotation and preparation of a striking platform to obtain a short series of bladelet removals on the narrow face previously exploited in Phase 3. **d**: Disjointed wide-faced and narrow-sided core. Phase 1: core blank is a flake; Phase 2: shaping of a dorsal crest and preparation of the core flanks; Phase 3: bladelet production based on the narrow face; Phase 4: re-orientation of the core and a set of broad bladelet removals on a broad, disjointed face. (drawings: A. Falcucci).

## **Protoaurignacian core reduction procedures: blade and bladelet technologies at Fumane Cave**

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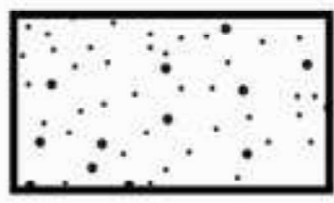
<sup>a</sup> email address: armando.falcucci@ifu.uni-tuebingen.de, telephone number: 0049(0)70712978918, ORCID: [orcid.org/0000-0002-3255-1005](https://orcid.org/0000-0002-3255-1005), Twitter: @ArmandoFalcucci

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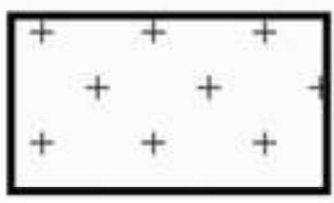
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Marco Peresani (Ph.D. 1993, University of Bologna) is an Associate Professor in Anthropology at the University of Ferrara and coordinates projects on the human population in the Alps and central Italy during the Paleolithic and the Mesolithic. His main focuses are the Middle Paleolithic – Upper Paleolithic transition and Late Glacial to Early Holocene hunter-gatherer settlement dynamics. Using lithic technology as his primary research tool, he infers cases of behavioral variability. He has published over 250 articles and books on arguments from these different periods.

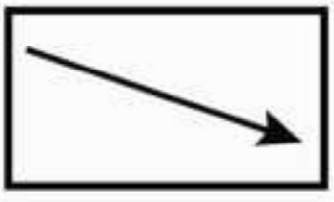
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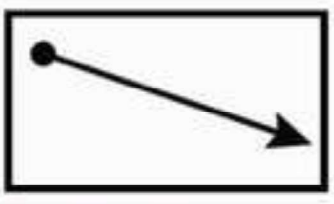
Cortex



Natural surface



Direction of removal



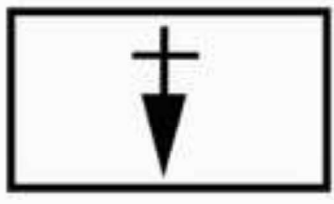
Direction of removal with bulbar negative



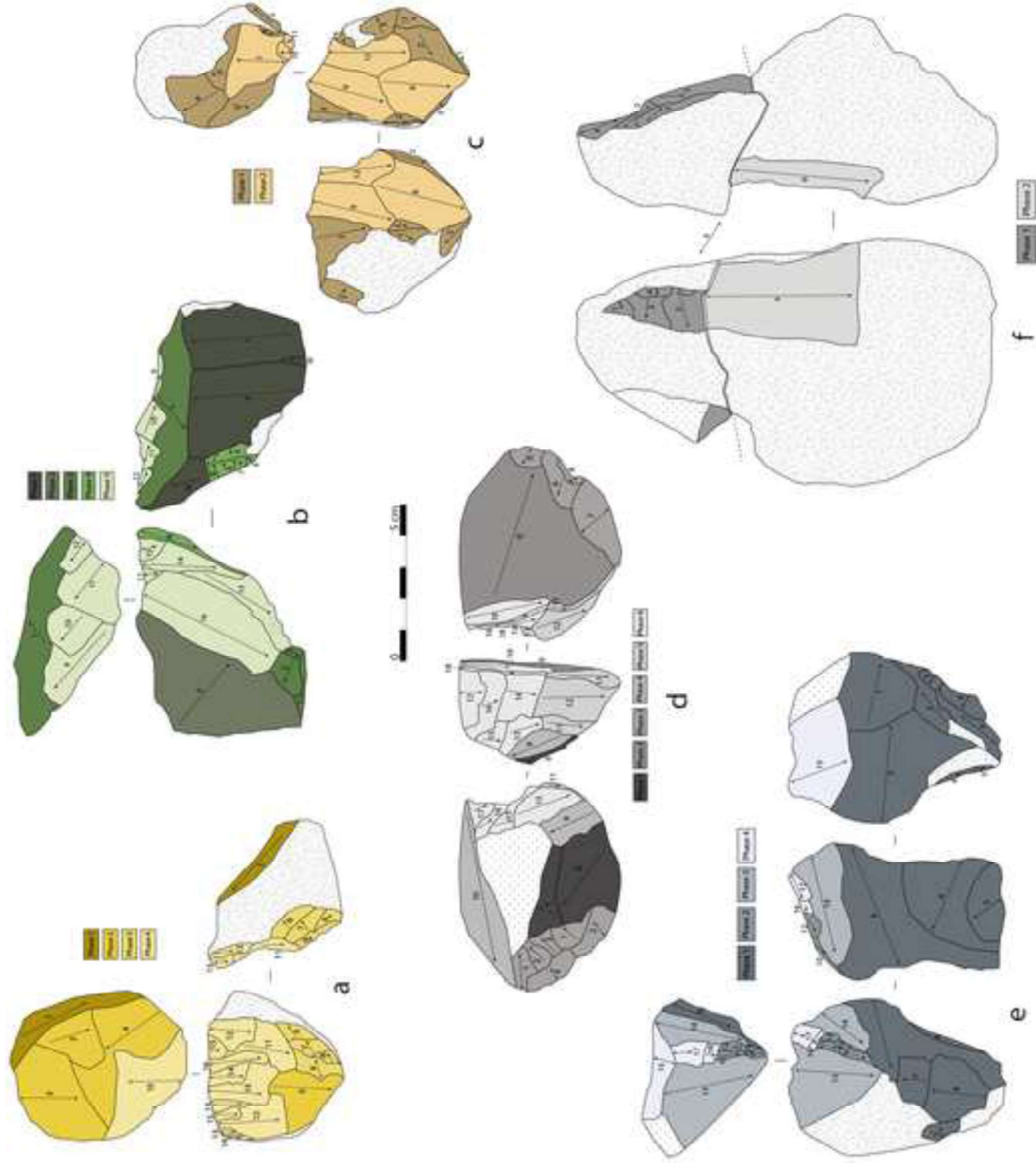
Ventral face



Direction of the blow with preserved bulb



Direction of the blow



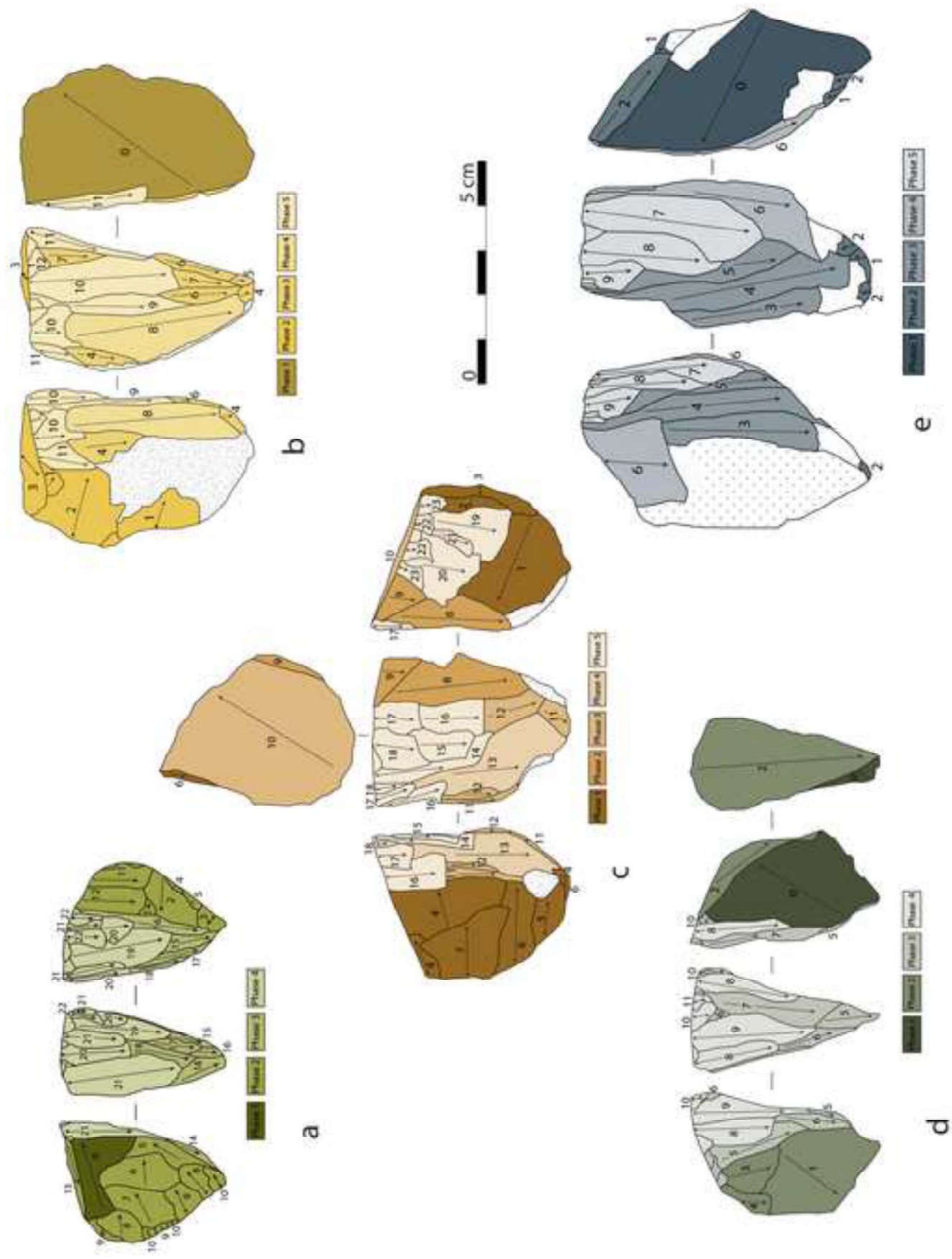
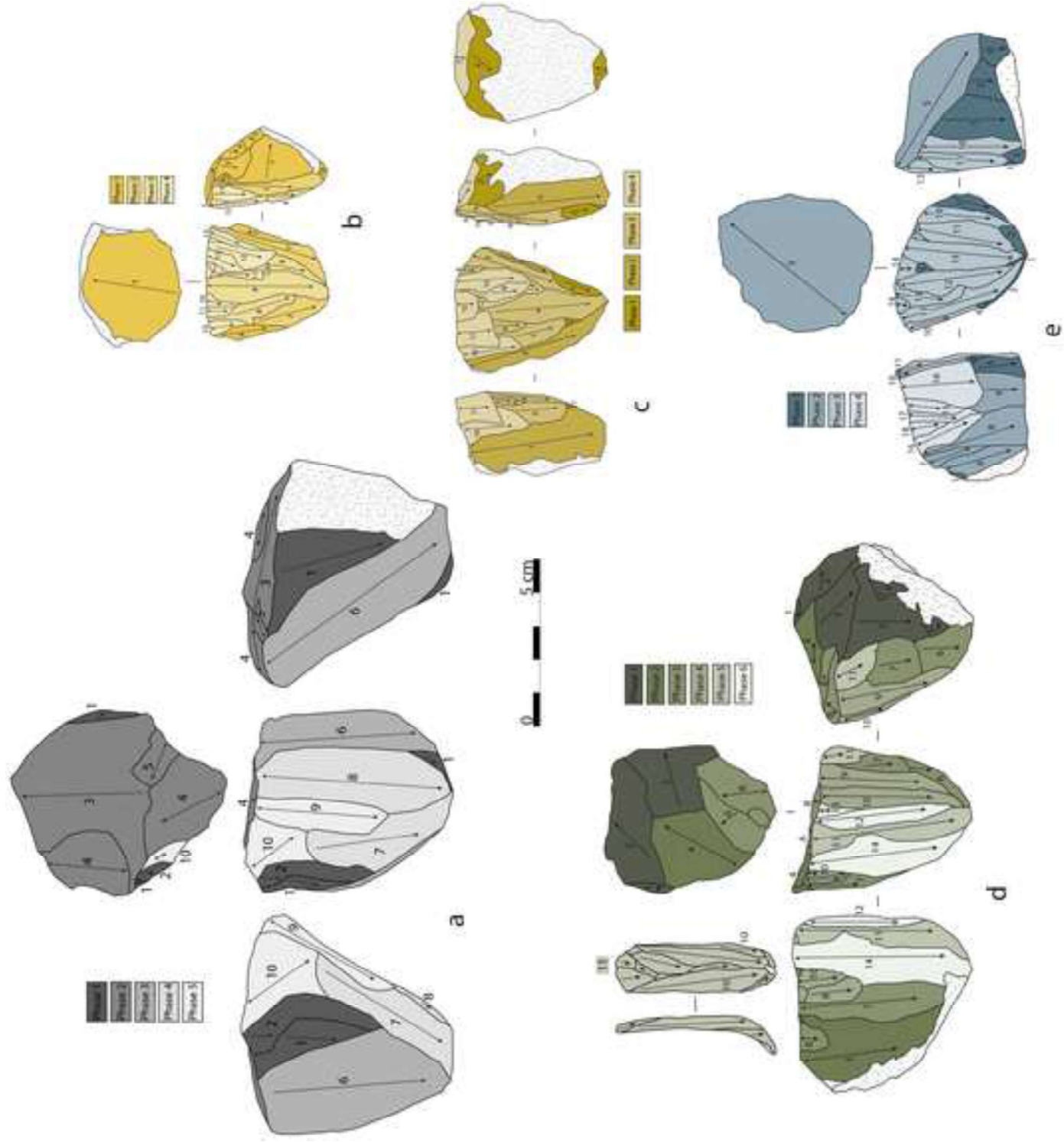
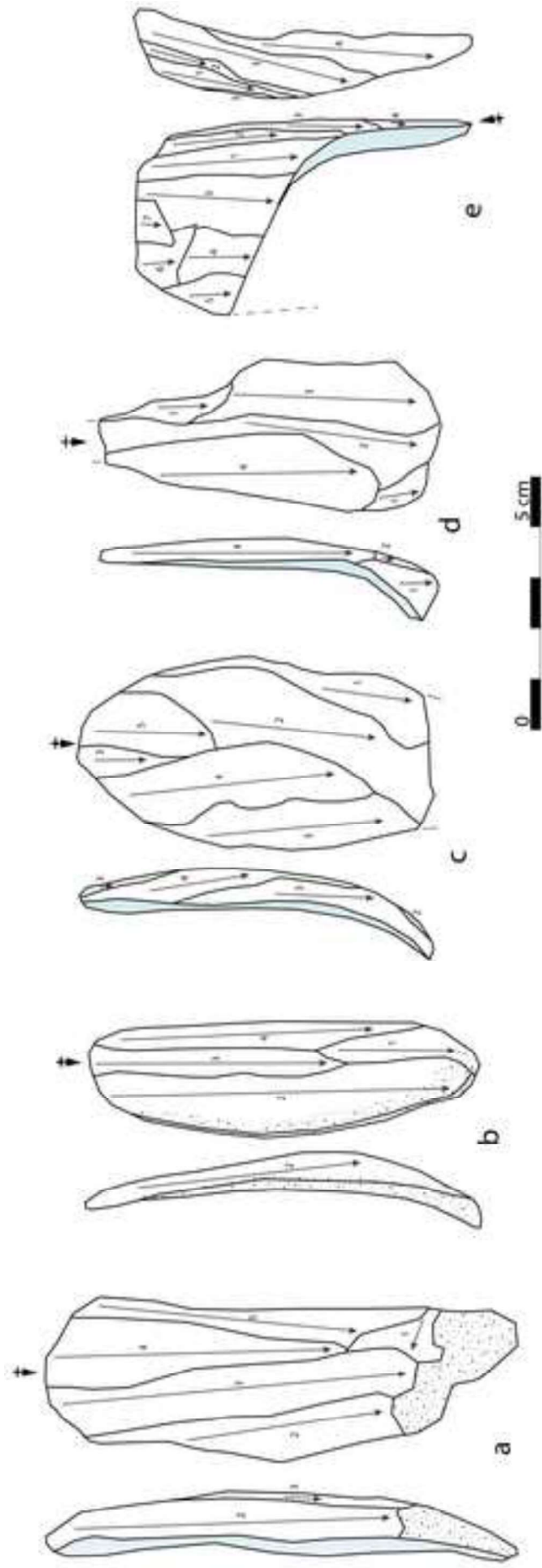
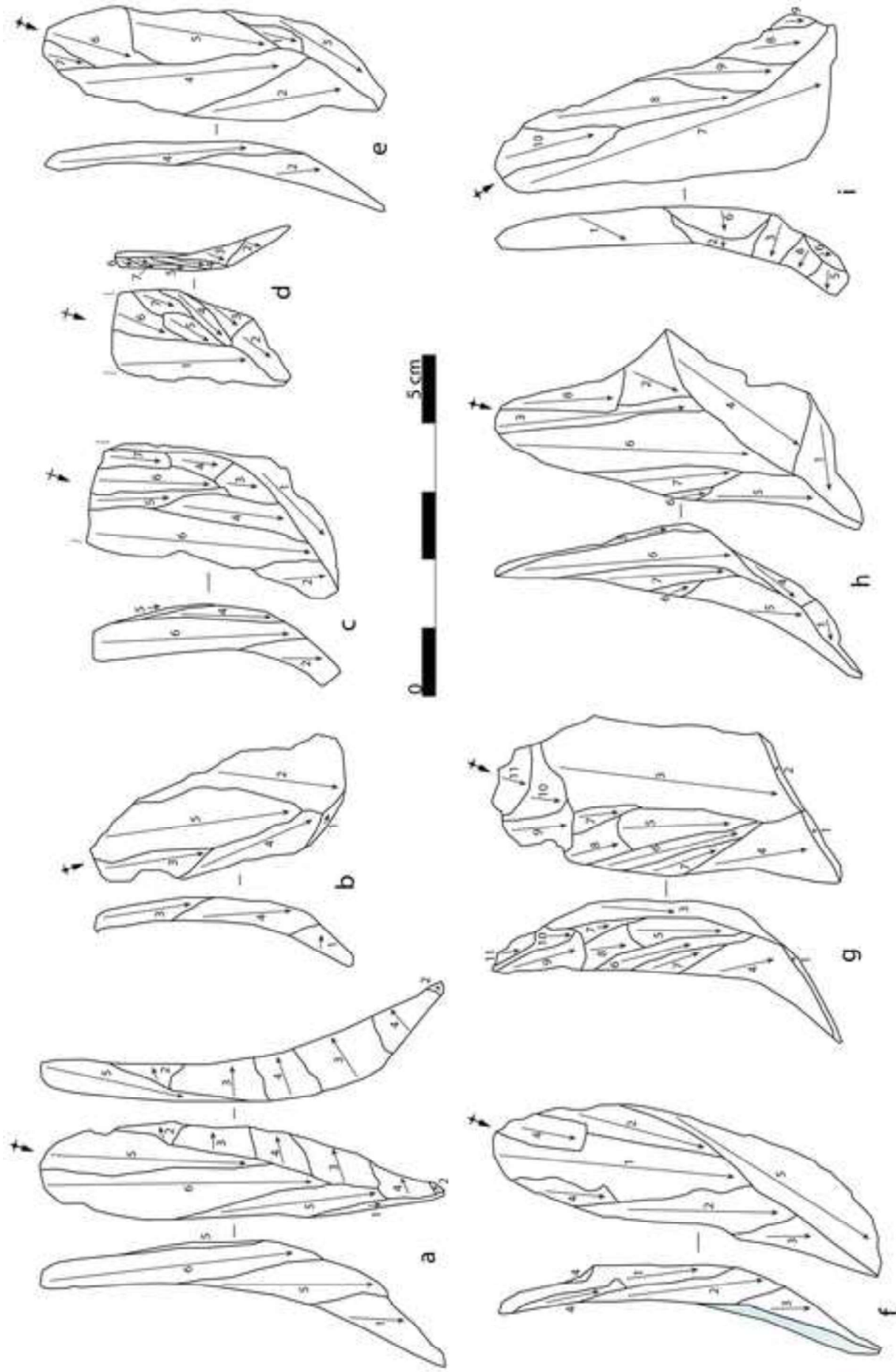


Figure 3









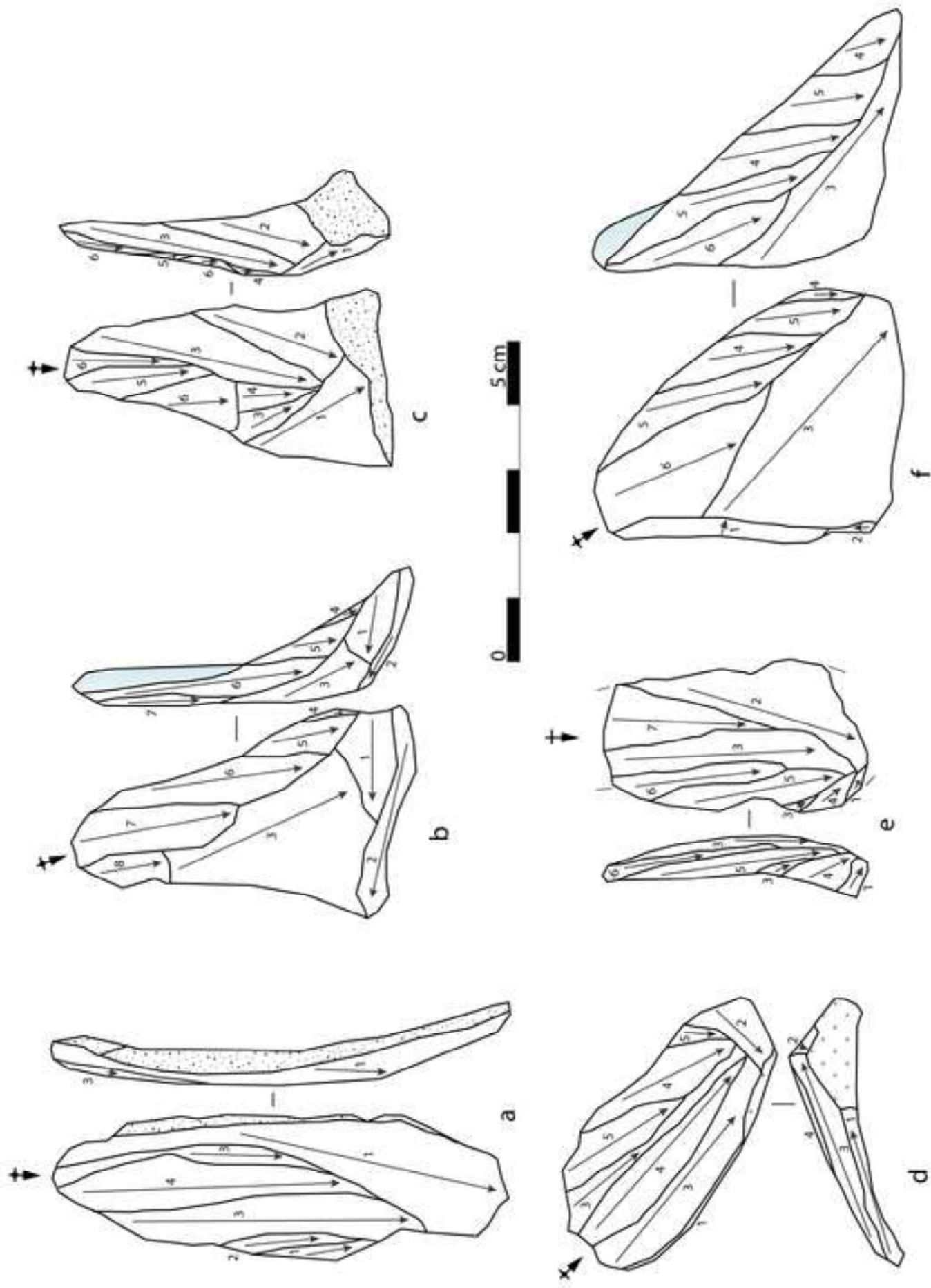
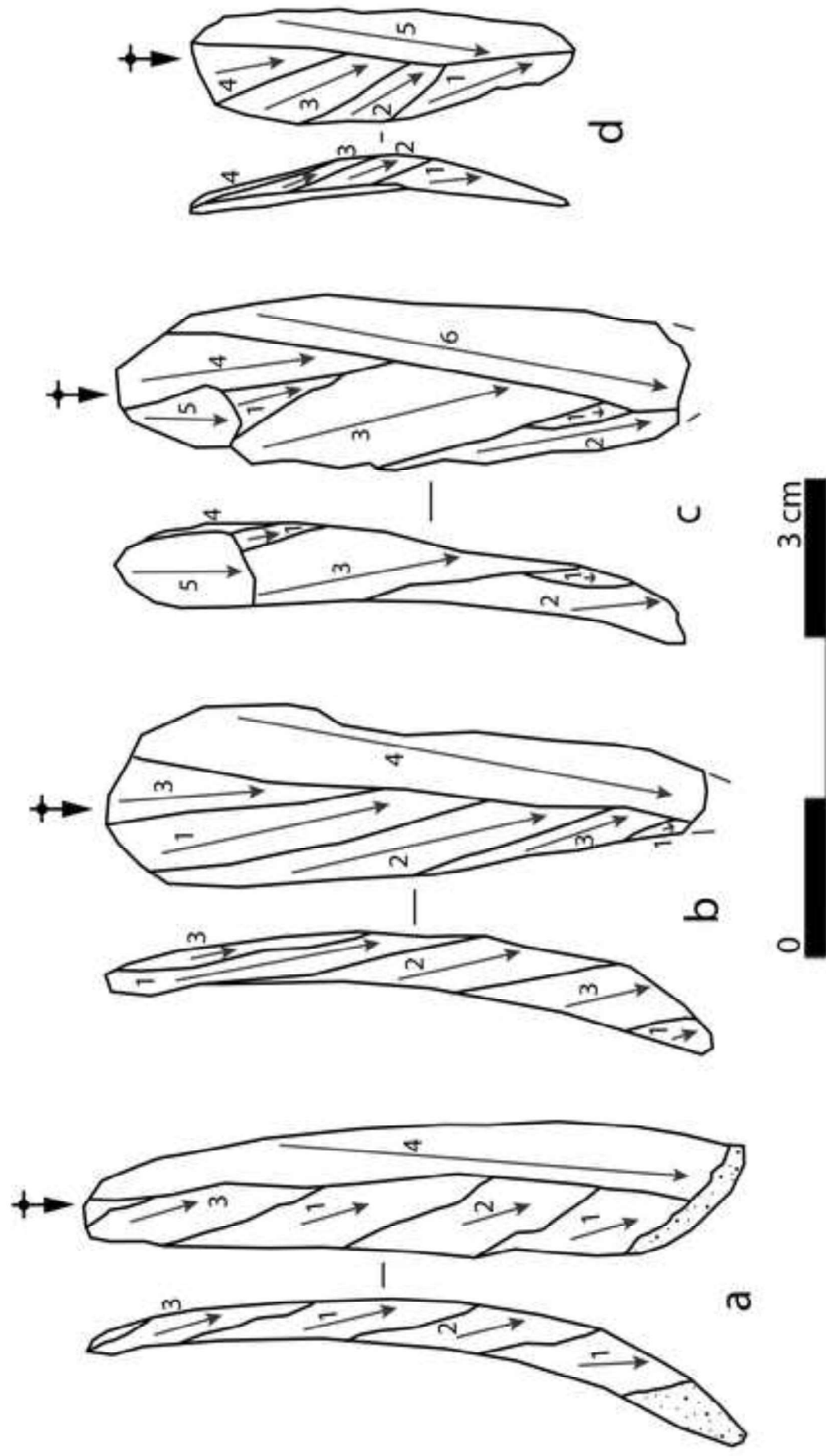


Figure 7



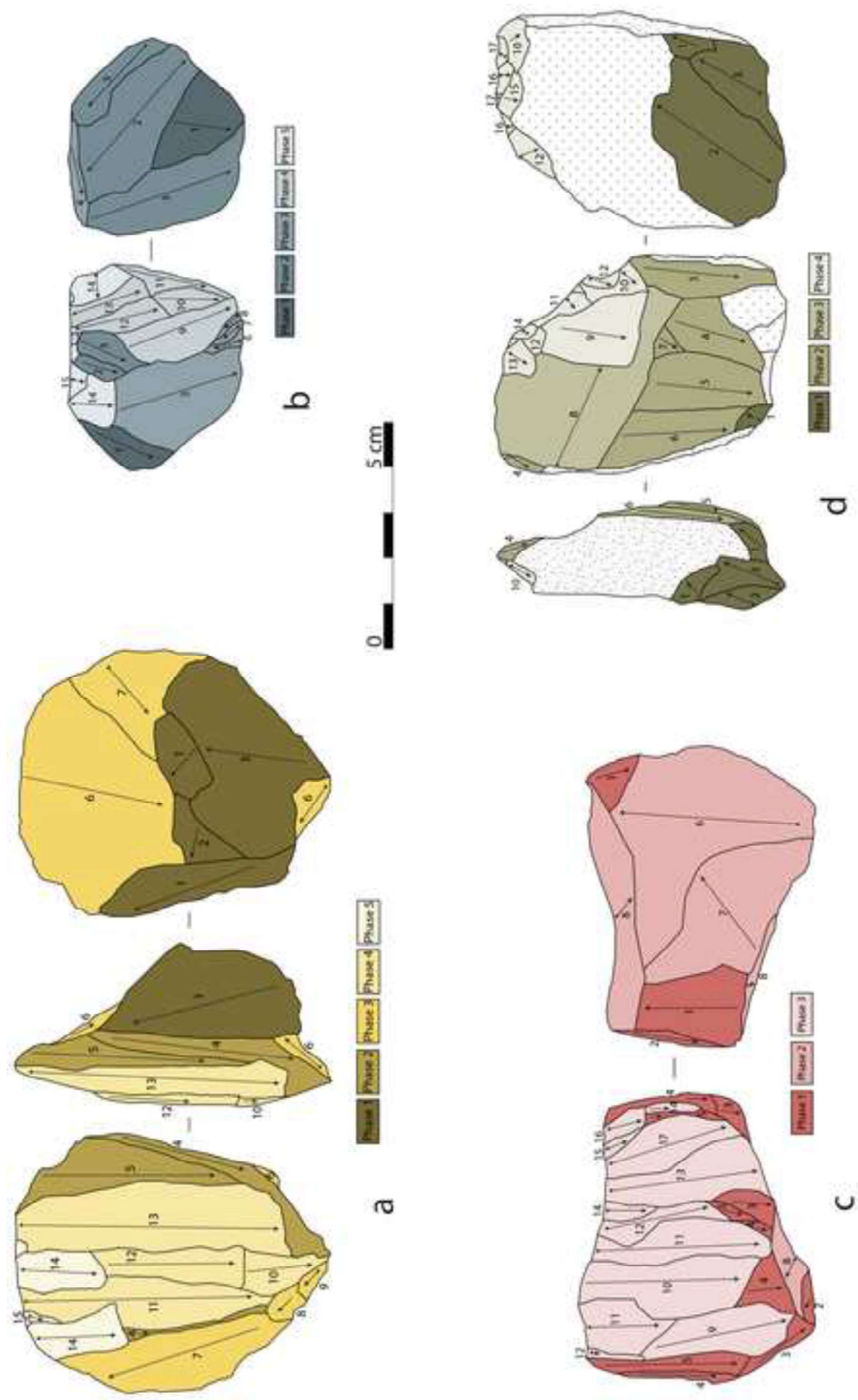
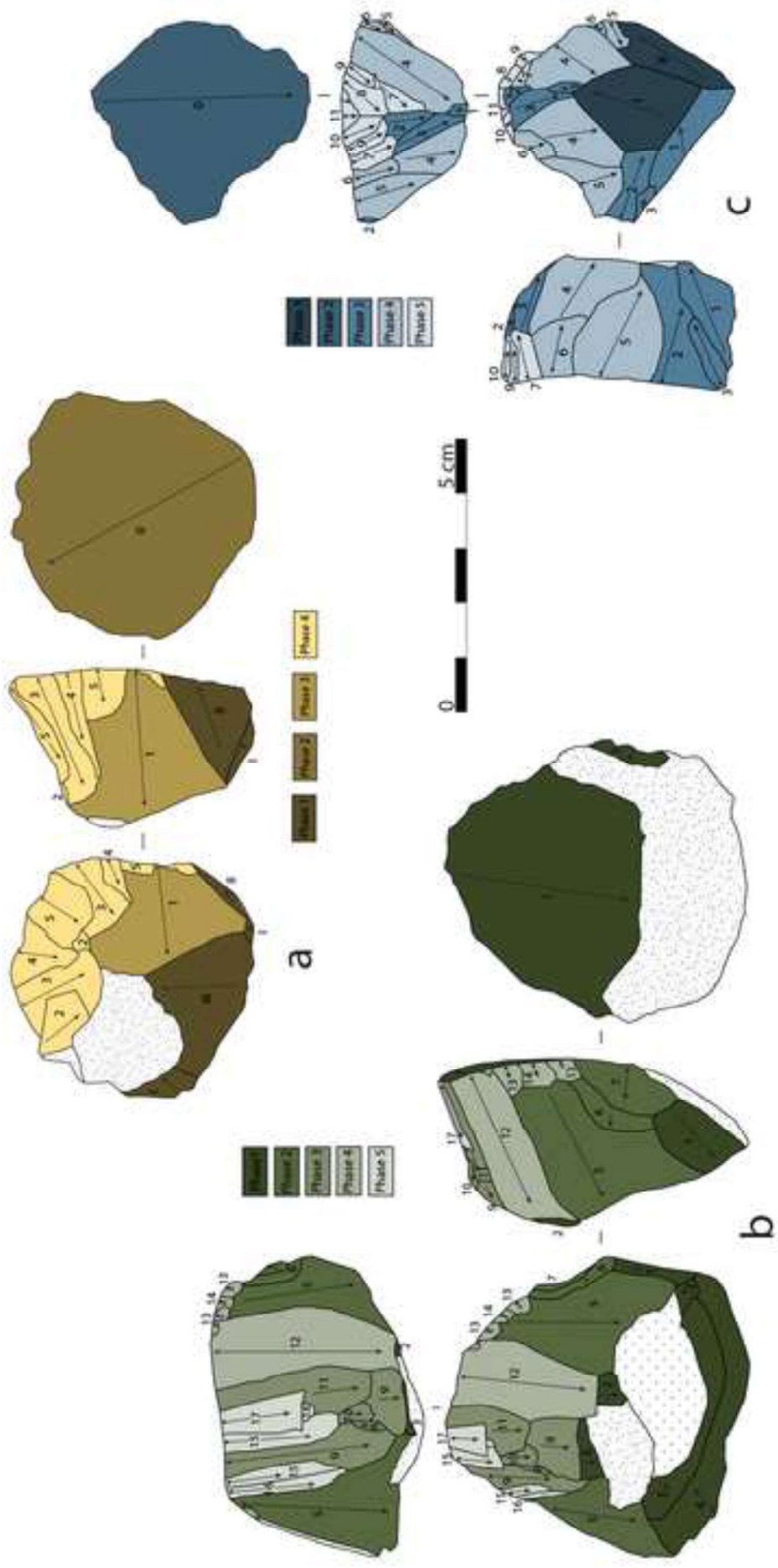
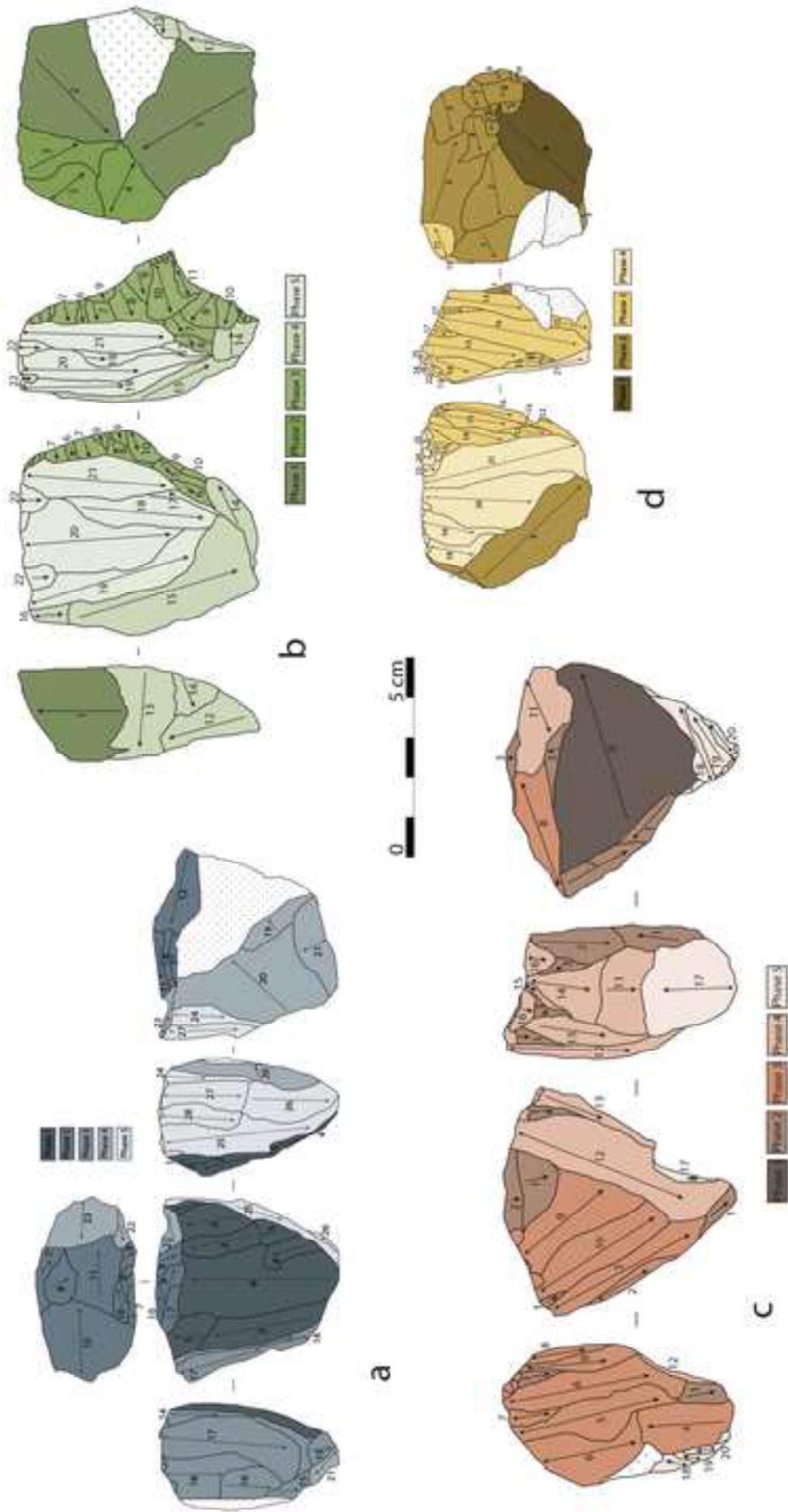


Figure 9





## Protoaurignacian core reduction procedures: blade and bladelet technologies at Fumane Cave

Armando Falucci & Marco Peresani

### Supplement A

**Table.** Distribution of core categories in layers A1 and A2. This count considers only cores that were found in the external part of the cave in which A1 and A2 could be distinguished.

Core classification	A1	A2
Narrow-sided	6 (25%)	5 (22.7%)
Semi-circumferential	6 (25%)	7 (31.8%)
Wide-faced flat	3 (12.5%)	3 (13.6%)
Transverse carinated	1 (4.2%)	2 (9.1%)
Multi-platform	8 (33.3%)	5 (22.7%)
Total	24 (100%)	22 (100%)



Armando Falcucci<sup>a</sup>, Marco Peresani<sup>b</sup>, Morgan Roussel<sup>c d</sup>, Christian Normand<sup>c</sup> & Marie Soressi<sup>c f</sup>

## What's the point? Retouched bladelet variability in the Protoaurignacian. Results from Fumane, Isturitz, and Les Cottés

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### Acknowledgements:

Armando Falcucci thanks Nicholas Conard for supervising his research project and the state of Baden-Württemberg and the University of Tübingen for funding his doctoral studies. Armando Falcucci would also like to thank François Bon and Nicolas Teyssandier for valuable discussions and for the hospitality he received during his staying at the University of Toulouse Jean Jaures.

Research at Fumane is coordinated by the Ferrara University in the framework of a project supported by the Ministry of Culture - Veneto Archaeological Superintendency, public institutions (Lessinia Mountain Community - Regional Natural Park, Fumane Municipality, Veneto Region - Department for Cultural Heritage), Research Centres (MPI-EVA), Foundations (Leakey Foundation, Spring 2015 Grant), associations and companies (National Geographic Society, Valpolicella-Benaco BCC Bank, Roberto Gardina & C. and others). Research at Les Cottés is funded by the French Ministry of Culture and by the Department of Human Evolution of the Max Planck institute EVA in Leipzig Germany. Part of this research was done within the frame of a Fyssen foundation research grant awarded to M. Soressi.

The authors are grateful to two anonymous reviewers for constructive suggestions, and to Kristen Heasley for improving the English.



## Abstract

The Protoaurignacian is considered a cultural proxy for one of the first expansions of Anatomically Modern Humans across Europe. The stabilization of bladelet industries that characterizes this techno-complex is therefore often used as supporting evidence for the break from previous stone knapping traditions and also for the increase of human mobility through wider territories. Despite the cultural importance that bladelets have gained, a careful inter-regional comparison, stressing similarities and differences, has not yet been attempted. Moreover, the use of traditional typologies has blurred the morpho-metrical variability that characterizes lamellar tools. Here, a study has been carried out on retouched bladelets from three pivotal sites: Fumane (northeast Italy), Isturitz (southwest France) and Les Cottés (northern France). By using morphological, dimensional, and retouching attributes, and by evaluating the statistical significance of the main differences, the first detailed analysis of the variability of retouched bladelets within the Protoaurignacian has been documented. The results indicate that the features that best discriminate the bladelet assemblages are the presence and the relative variability of bladelets with convergent retouch, although a reassessment of existing studies and new methodological approaches are required to test the latter hypothesis. Throughout this paper we demonstrate the merits of using a unified classification of retouched bladelets for comparing behavior in between groups distant in space. We hope that this paper will be a new incentive to develop unified taxonomies for the study of Early Upper Paleolithic lithics in Western Eurasia.

**Keywords:** Protoaurignacian, Retouched Bladelets, Morpho-metrical Analysis, Lithic Typology, Early Upper Paleolithic, Anatomically Modern Humans

## 1.0. Introduction

Anatomically Modern Humans arrived in Europe between 45 and 40 ky cal BP, during a complex cultural and biological process (d'Errico et al. 1998; Bar-Yosef 2002; Hublin 2012, 2015; Higham et al. 2014; Villa and Roebroeks 2014; Wood et al. 2014; Benazzi et al. 2015). This period is known as the Early Upper Paleolithic and is characterized by the development of several techno-complexes (Bar-Yosef 2006; Tsanova 2008; Flas 2011; Nigst 2012; Otte 2014), among which the earliest stages of the Aurignacian played a key role. The Aurignacian is considered as an archaeological proxy for the spread of modern humans from the Levantine corridor to Europe (Kozłowski and Otte 2000; Bar-Yosef 2006; Mellars 2006; Hublin 2015). Modern human remains, especially teeth, found in several Aurignacian layers represent the anthropological evidence for such a theory (Bailey and Hublin 2005; Benazzi et al. 2015). The increased variety of material culture, characterized by the widespread use of personal ornaments (Taborin 1993, 2003; Vanhaeren 2002; Gurioli et al. 2005; Vanhaeren and d'Errico 2006), the birth of figurative art (Valladas et al. 2005; Broglio et al. 2009; Conard 2009; Higham et al. 2012), and the production of several types of bone tools and bone points (Maroto et al. 1996; Kuhn and Stiner 1998; Bordes 2002; Schmider 2002; Broglio and Dalmeri 2005) is thus used as supporting evidence for the biological replacement that occurred in Europe. The earliest stages are known as the Protoaurignacian and Early Aurignacian (for a historical background see: de Sonneville-Bordes 1960; Laplace 1966; Bon et al. 2006); the first is more frequent in the Mediterranean region, while the second is thought to be more of a continental culture.

This paper is focused on the Protoaurignacian, which has been recognized in several regions near the Mediterranean boundaries, particularly in Italy (Broglio 1993; Palma di Cesnola 1993, 2006; Gambassini 1997; Kuhn and Stiner 1998), southeast France (Onorati 2004; Bazile 2005, 2006; Porraz et al. 2010), the Pyrenean region (Arrizabalaga 2006; Normand 2006), Catalonia (Maroto et al. 1996), and Cantabria (Maíllo-Fernández et al. 2001, Maíllo-Fernández 2006), as well as in the Aquitaine (Bordes 2002, 2005) and northern France (Brou 2001; Schmider 2002; Soressi et al. 2010). Several Eastern European lamellar-based industries have been described as Protoaurignacian: Tincova in Romania (Sitlivy et al. 2014), Kozarnika in Bulgaria (Guadelli and Sirakov 2005; Tsanova 2008) and Siuren I in Crimea (Demidenko et al. 2012; Zwyns 2012). The industry of Krems-Hundssteig in Lower Austria has also been attributed to the Protoaurignacian (Broglio 2000; Teyssandier 2007), despite the absence of a stratigraphic context and similarities with local Gravettian industries. Two techno-complexes, the Baradostian (Otte et al. 2007, 2011) and the Early Ahmarian (Goring-Morris and Belfer-Cohen 2003), partly contemporaneous to the Protoaurignacian (Douka et al. 2013; Kadowaki et al. 2015), can be viewed as the Middle Eastern and Levantine counterpart of the lamellar revolution that occurred in Western Eurasia at the dawn of the Upper Paleolithic (Tsanova et al. 2012).

It has been argued that in southwestern France the Protoaurignacian is always stratigraphically placed below the Early Aurignacian (Bon 2002; Banks et al. 2013a). The situation is more difficult to interpret in Central Europe, where the Protoaurignacian is almost unknown and the Early Aurignacian seems contemporaneous or even older (Higham et al. 2012; Nigst and Haesaerts 2012; Nigst et al. 2014). It would be no more possible to consider the Early Aurignacian as the successive stage of the Protoaurignacian, and in particular the response of human populations to the deterioration of the environment that occurred at the onset of the Heinrich event 4 (HE4) (Banks et al. 2013a), if those chronologies were to be confirmed (for a critical interpretation see: Banks et al. 2013b).

In comparison to the Late Mousterian (Slimak and Lucas 2005; Peresani et al. 2013) and Châtelperronian assemblages (Roussel 2011, 2013; Roussel et al. 2016), it is with the advent of the Protoaurignacian and Early Aurignacian and during the later Upper Paleolithic that bladelets start to achieve a primary role in hunter-gatherer equipment. Bladelet production serves as further evidence for the increase of human mobility through wider territories, being that those products are

lighter and easily replaceable (Bon 2005). Some authors suggest a functional division between blades and bladelet tools. The first would be used for domestic activities, and the second for hunting activities (Bon 2002, 2005; Le Brun-Ricalens et al. 2009), although recent micro-wear analyses have shown that Protoaurignacian bladelets may have been used both for butchery and scraping activities as well as for weaponry (Broglia et al. 1998; O'Farrell 2005; Normand et al. 2008; Porraz et al. 2010; Pasquini 2013) (however, for a critical note on impact fracture see: Rots and Plisson 2014).

Despite the long-standing interest in bladelets, a careful inter-regional comparison stressing similarities and divergences within the Protoaurignacian has not yet been attempted. Bon et al. (2010) suggested that bladelets with convergent retouch may be more frequently found in the eastern extension of the Protoaurignacian. Unfortunately, the use of loose terminology in the literature does not allow the issue to be addressed without direct reassessments of the lithics across Western Eurasia. Two major tool types, the Dufour bladelet and the Font-Yves or Krems point (Demars and Laurent 1992), have been used to describe retouched bladelets in the Early Upper Paleolithic of Western Europe. Within the Dufour type, Demars and Laurent (1992) propose to distinguish two sub-types according to dimensional and profile attributes: sub-type Dufour and sub-type Roc-de-Combe. The former characterizes the earlier stages of the Aurignacian, is usually 30–45 mm long and has a curved profile, while the latter is typical of the recent Aurignacian, and is shorter (between 15–20 mm) and twisted (Lucas 1997, 1999). Retouch can be alternate and inverse, but also direct. Among the Dufour sub-type Dufour bladelets, Le Brun-Ricalens et al. (2009) separate long and straight bladelets obtained from prismatic and pyramidal cores, typical of the Protoaurignacian, from smaller curved bladelets obtained from carinated cores, which are more frequent within assemblages attributed to the Early Aurignacian.

Terminological confusion exists for Font-Yves or Krems point types. Both terms are currently used in Protoaurignacian contexts to describe the same tool type, which is produced on lamellar blanks and is modified by a direct, but also alternate, retouch. The term Font-Yves is especially used in Western European contexts (e.g. Bon 2002; Le Brun-Ricalens 2005), while the term Krems is more used in Central and Eastern European contexts (e.g. Hahn 1977; Teyssandier 2007; Tsanova et al. 2012). Demars and Laurent (1992) describe a Font-Yves bladelet as a tool characterized by a curved profile and modified by direct bilateral retouch, which rarely extends to the distal end. No reference is made to the size of a Font-Yves bladelet, but some authors suggest that they are bigger than the Dufour types (e.g. Lucas 1997; Teyssandier 2007). Nowadays, the terms Font-Yves and Krems are perceived as synonymous; but Hahn (1977) used both terms to describe the bladelets with convergent retouch found in the site of Krems-Hundssteig. Included into the Font-Yves type were bladelets made pointed by direct retouch, while grouped into the Krems type were bladelets made pointed by alternate retouch. However, some authors prefer to include bladelets with convergent alternate retouch into the Dufour taxonomic group (e.g. Ortega et al. 2005; Zwyns 2012). To sum up, the usage of the terms Dufour bladelets and Font-Yves/Krems points is problematic because of the partial overlapping of different types and non-consistent usage of types across geographical space and between authors.

Here, we will use a simplified and unified typology to describe the retouched bladelets found at sites distributed between the golf of Biscay, the Adriatic northern margins, and the south-west of the Parisian basin. We will enhance our typological description with a detailed morpho-metrical description, based on the lithic assemblages found at three reference sites: Fumane (northeast Italy), Isturitz (southwest France) and Les Cottés (northern France). By doing so, we attempt to provide the first detailed analysis of retouched bladelet variability within the Protoaurignacian across several hundred kilometers.

## 2.0. Materials and methods

### 2.1. Grotta di Fumane

Fumane Cave, excavated since 1988, lies at the foot of the Monti Lessini Plateau (Venetian Prealps) (Fig. 1). Details about the cave's structure, Late Pleistocene stratigraphic sequence, and palaeoclimatic significance, as well as its palaeontological and cultural content are available in numerous publications (Fiore et al. 2004; Broglia and Dalmeri 2005; Higham et al. 2009; Peresani 2012; Benazzi et al. 2014; López-García et al. 2015). A main cave and two associated tunnels preserve a finely-layered sedimentary succession spanning the late Middle Paleolithic and the Early Upper Paleolithic, with structures and dense scatters of remains in units A11, A10, A9, and A6–A5 (Mousterian: Peresani et al. 2011; Peresani 2012), A4 and A3 (Uluzzian: Peresani et al. 2016), A2 and A1 (Protoaurignacian), and D3 (Aurignacian *sensu lato*). Unit A2 dates the appearance of the Protoaurignacian at 41.2–40.4 ky cal BP (Higham et al. 2009; Benazzi et al. 2015). The Protoaurignacian and Aurignacian layers contain dwelling structures, red mineral pigment, stone tools, bone and antler tools, painted stones, and ornamental objects (Broglia et al. 2006; Bertola et al. 2013). The lithic implements are regular blades and bladelets produced by direct percussion from carenoid-type, pyramidal, and prismatic unipolar cores. Common retouched tools include end-scrapers, blades, and burins. Retouched bladelets are the typical Protoaurignacian implements (around 80% of the retouched assemblage) (Broglia et al. 2005; Bertola et al. 2013). Ornaments consist of a few grooved red deer incisors and over 800 perforated shell beads belonging to 60 different taxa (Gurioli et al. 2005). Rock fragments were painted with red ochre, depicting an anthropomorphic figure with the head surmounted by two horns, an animal, and other motifs (Broglia et al. 2009).

### 2.2. Grotte d'Isturitz

1 Isturitz Cave is located near the western Pyrenees foothills, 30 km from the current Atlantic Ocean shoreline (Fig. 1). The  
2 cave penetrates into a hill constituted of Urgonian limestone (209 m asl). Two main areas have been distinguished: Saint-  
3 Martin Gallery (or South Gallery) and Isturitz Gallery (or North Gallery). Details about the history of research, geo-  
4 stratigraphic sequence, and material culture in this area can be found in various publications (Passemard 1944; Saint-  
5 Perier 1965; Laplace 1966; Normand and Turq 2005; Normand 2006; Normand et al. 2007). The recent fieldwork took  
6 place from 1996 to 1998 under the supervision of C. Normand and A. Turq and under the supervision of C. Normand  
7 from 2000. Excavations focused on the Saint-Martin gallery, which was not depleted by the several excavations that took  
8 place in the Isturitz gallery (Normand and Turq 2007). Those excavations were advantageous in clarifying the Aurignacian  
9 sequence, which starts from the Protoaurignacian (C4d1 and C4III) and continues with a so-called “transitional  
10 Protoaurignacian” (C4c4 and C4II), an Early Aurignacian (C4b2, C4b1, C4I and E4I), and an Evolved Aurignacian (C3b  
11 and C3I). Units C4d1 and C4III, on which this paper focuses, are dated to at least 42 ky cal BP (Szmidski et al. 2010).  
12 Dwelling structures or hearths have not been recognized, while bone and antler products and personal ornaments made  
13 from shells and teeth have been evidenced (Normand et al. 2007). Stone tool production is based on blade and bladelet  
14 implements, obtained from several pyramidal, prismatic, burin-like, and carinated unipolar cores. Retouched bladelets  
15 constitute about 60% of the retouched tools (Normand and Turq 2005; Normand et al. 2008). Units C4d1 and C4III from  
16 Isturitz have been here grouped together because, although these are positioned in two different sectors of the cave,  
17 previous studies did not report divergences so significant as to separate them (Normand et al. 2008).

### 18 **2.3. Grotte des Cottés**

19 Les Cottés Cave is located at the southwestern margins of the Parisian basin (Soressi et al. 2009) (Fig. 1). The cave,  
20 formed of two chambers, was discovered at the end of the 19th century, giving way to the first excavations in 1880 under  
21 the supervision of R. de Rochebrune (for the history of research see: Rochebrune 1881; Pradel 1961; Soressi et al. 2010).  
22 In 2006, a new excavation program started at this site using a multidisciplinary approach including micromorphological,  
23 taphonomic, faunal and lithic studies, and radiometric dating (Soressi et al. 2010; Soressi and Tavormina 2011; Frouin  
24 et al. 2013; Rigaud et al. 2014; Welker et al. 2015). The excavations focus on the external area of the cave, where the  
25 archaeological deposit has not been damaged by the previous fieldwork. The cultural sequence starts from the Mousterian  
26 (US08) up to the Châtelperronian (US06), Protoaurignacian (US04 lower), Early Aurignacian (US04 upper) and Recent  
27 Aurignacian (US02). The Protoaurignacian layer has been dated to 39–40 ky cal BP using C14 AMS measurements on  
28 bone as well as OSL on quartz and feldspar, and ages obtained for the Protoaurignacian are indistinguishable from ages  
29 obtained from the overlying Early Aurignacian layer (Talamo et al. 2012; Jacobs et al. 2015). Protoaurignacian lithic  
30 production was aimed at the production of blades and especially bladelets from cores of pyramidal and prismatic  
31 morphology. Retouched bladelets are the most commonly found tool type (54%) (Roussel and Soressi 2013).

### 32 **2.4. Compared assemblages**

33 Every other available Protoaurignacian lithic assemblage studied with description criteria compatible with ours was used  
34 for comparative purposes. A list of these sites (geographically localized in Fig. 1) can be found in Table 1.

### 35 **2.5. Sample selection**

36 We studied the entirety of Protoaurignacian retouched bladelets found in Fumane – unit A2 (n = 1,751), Isturitz – units  
37 C4d1–C4III unified (n = 963), and Les Cottés – unit 04 lower (n = 151, 2006–2013 excavation seasons). The criteria of  
38 edge regularity and a uniform modified edge of at least 5 mm in length was used to separate the deliberate retouching  
39 from post-depositional scarring and unintentional use traces in cases of slight modifications. The study was conducted by  
40 the naked eye or with the support of magnification (ranging 10–20X). All retouched bladelets with a maximum width of  
41 1.2 cm (Tixier 1963) were considered, but a few retouched bladelets slightly larger than 1.2 cm have also been included  
42 here. The morphology and the retouching of these outliers did not reveal differences compared to other retouched  
43 bladelets.

### 44 **2.6. Description of the retouched bladelets**

45 Bladelets were oriented according to Inizan et al. (1995); then a proximal, mesial and distal part and a left and right edge  
46 were distinguished. Each assemblage has been sub-grouped according to its degree of breakage. Specimens classified as  
47 “almost complete” lack the very distal tip or part of the butt.

48 For each retouched bladelet, several attributes have been recorded: direction and number of scars on the dorsal face, butt  
49 and bulb morphology, profile curvature (Bon 2002), edges morphology, basal and distal modification. Retouch type  
50 attribute takes into account a combination of features: position, localization, distribution, extent, and angle.

51 Bladelets with convergent retouch have been classified as such only when the apex is preserved and has been  
52 unambiguously modified by retouch. Naturally convergent bladelets have not been included within the bladelet with  
53 convergent retouch category and have been classified as bladelets with lateral retouch.

54 Due to the high degree of fragmentation (see Table 2), when it came to studying profile curvature and edge morphology  
55 complete and almost complete specimens have been studied separately from the rest of the fragments. Doing that has  
56 avoided the risk of an overestimation of some traits, such as straight sagittal profiles and sub-parallel edges, which  
57 characterize the majority of mesial fragments.

When it came to comparing the retouch of the apex, only specimens with complete distal tips were taken into account. Although this approach drastically reduced the sample size, it was considered the only way to objectively point out the frequency and the variability of bladelets with convergent retouch among the studied collections. The morphological and retouch characteristics of all three collections were compared using Pearson's chi-square tests implemented in IBM SPSS 20.0 Statistics.

Length, width, and thickness at discard were measured using standard digital calipers with an error range of 0.01 mm. The three assemblages were then compared at the level of the median values. Being that the samples were not normally distributed as determined by Shapiro-Wilk tests, Mann-Whitney tests in IBM SPSS 20.0 Statistics were performed.

### 3.0. Results

#### 3.1. Fragmentation

The large majority of the analyzed retouched bladelets are broken (> 95%) (Table 2). As already noted in former analyses of Protoaurignacian assemblages, mesial fragments are overrepresented, followed by proximal fragments then by distal ends (Bon 2002; Le Brun-Ricalens 2005). The discrepancy between proximal and distal fragments could be explained as the effect of retouching; indeed, a large number of bladelets were frequently not retouched in the last millimeters (Perpère and Schmider 2002), and, as a result, fragmented tips are difficult to discriminate.

#### 3.2. Morpho-technical features and blank selection

Butts are plain and linear. This feature, together with the presence of lips, diffused bulbs, and abraded platforms, provides evidence for marginal percussion (Pelegrin 2000; Soriano et al. 2007; Roussel et al. 2009). The negatives of removals are unidirectional and, in most cases, two or three scars on the dorsal face give a triangular (> 50%) or trapezoidal section. Scars and edges are regular. Slightly curved and straight profiles are more numerous than curved profiles. The majority of the specimens are more curved in their distal portion. There is little evidence for twisted blanks. Sub-parallel and convergent bladelets are frequent. The frequency of convergent forms, both naturally pointed and those made pointed by retouch, is better appreciable by the analysis of complete and almost complete specimens (Table 3). Bases, mostly rounded or squared, can be retouched. At Les Cottés retouched bases have not been found, while 84 (13.3%) were found in Fumane and 44 (17.5%) in Isturitz. The chi-square test reveals no significant differences between Fumane and Isturitz ( $\chi^2 = 2.6$ ,  $p = 0.1$ ). Distal ends can be pointed by retouch: in Fumane 184 (59.2%) and Isturitz 39 (33.3%) complete and distal specimens can be classified as bladelets with convergent retouch. The difference is significant ( $\chi^2 = 22.7$ ,  $p < 0.01$ ) and highlights a higher importance for this tool type in Fumane. No bladelets with convergent retouch were found in Les Cottés.

#### 3.3. Retouching

Retouching is marginal, semi-abrupt, and continuous. The intensity is rarely constant, varying in function of the initial morphology of the blanks. The retouching is more pronounced in the mesial portion of the edge and, in case of bladelets with convergent retouch, in the distal extremity. On the specimens with alternate retouch, the inverse retouch is usually more intensive and uniform than the direct retouch. The major difference between the assemblages pertains to the retouch position. As shown in Table 4, in Fumane the alternate retouch is more frequent than direct and inverse. In Isturitz, alternate and inverse retouch is almost equal in proportion, while in Les Cottés inverse retouch has a leading role. Differences in the incidence of retouch position between Fumane, Isturitz, and Les Cottés are significant (Fumane/Isturitz:  $\chi^2 = 206.6$ ,  $p < 0.01$ ; Fumane/Les Cottés:  $\chi^2 = 359.2$ ,  $p < 0.01$ ; Isturitz/Les Cottés:  $\chi^2 = 115.4$ ,  $p < 0.01$ ). Very interestingly, all of the assemblages show clear lateralization of the ventral retouch, almost always located on the right side (> 96%). This characteristic feature has been already stressed in various Aurignacian sensu lato assemblages (Laplace 1977; Lucas 1997; Schmider 2002; Bordes 2005; Maillo-Fernández 2005; Pelegrin and O'Farrell 2005; Bazile 2006), although it remains an issue to investigate further.

An evident link between the presence of a pointed, retouched apex and retouch position has been found in Fumane and Isturitz (Table 5). In Fumane, direct retouch was used to manufacture bladelets with convergent retouch, while in Isturitz the same target was obtained by applying, in most cases, alternate retouch. The differences are significant for both the comparison between Fumane and Isturitz ( $\chi^2 = 18.4$ ,  $p < 0.01$ ) and within each assemblage between bladelets with lateral retouch and bladelets with convergent retouch (Fumane:  $\chi^2 = 60.6$ ,  $p < 0.01$ ; Isturitz:  $\chi^2 = 42.8$ ,  $p < 0.01$ ).

#### 3.4. Metrical attributes

Table 6 provides a summary of statistics regarding the length, width, and thickness of retouched bladelets. Box plots show the respective width (Fig. 2) and thickness (Fig. 3) differences, pointing out the dimensional dispersion in all assemblages. The majority of the bladelets can be placed within a range of few millimeters. Box plots for length values have not been included because of the small amount of complete bladelets. However, the length of the majority of them can be placed between 15 and 30 mm.

In Fumane and Les Cottés, bladelets are significantly wider and thicker than in Isturitz (Fig. 2 and 3; and see Mann Whitney U-tests in Table 7). However, within each site, there are apparently no statistical differences in width between bladelets with lateral retouch and bladelets with convergent retouch (Fumane: U value = 11276.  $p = 0.6$ ; Isturitz: U value

= 1311.5,  $p = 0.2$ ). Also, in Isturitz there are no significant differences between the thickness of bladelets with convergent retouch and bladelets with lateral retouch ( $U$  value = 1442.5,  $p = 0.65$ ), while in Fumane bladelets with convergent retouch are thicker (Fig.4;  $U$  value = 8900.5,  $p = < 0.01$ ).

In Fig. 5 the mean width and the mean thickness of the retouched bladelets from the three study sites are compared to some of the Protoaurignacian assemblages listed in Table 1. The scatterplot show that the majority of the mean values are distributed within a range of few millimeters, with the exception of Isturitz and Arbrede, which are very closely related to each other.

#### 4.0. Discussion

Protoaurignacian retouched bladelets at Fumane (Fig. 6), Isturitz (Fig. 7) and Les Cottés (Fig. 8) can be sub-grouped into two major tool categories: bladelets with convergent retouch and bladelets with lateral retouch. The first group includes all of the bladelets retouched up to the apex, with the clear intention to modify and rectify the main tool attribute. The second group includes the rest of the bladelets that, even if naturally convergent in their distal part, are modified only on the lateral edge(s). It shall be the task of residue and use-wear analyses to clarify the relationships between naturally convergent bladelets and bladelets with convergent retouch, testing if morphological similarity is related to a comparable range of activities, where the distal end is considered the active part of the tool, or if it is just the result of technological choices. Functional analysis at Isturitz identified two main lamellar categories. The first includes bladelets that display complex impact fractures due to their use as projectiles. The second is formed of larger bladelets used for multiple activities, such as butchery, scraping, and cutting on both soft and hard materials. From a dimensional point of view, the first are narrower (around 4–4.5 mm) and thinner (around 1–1.5 mm) while the second are bigger (Normand et al. 2008). Similar conclusions were reached at Les Cottés (Pasquini 2013). Such dimensional differences within retouched bladelet populations is not exclusive to the Protoaurignacian, as it has also been observed in bladelets from several sites of the Late Upper Paleolithic in Basque Country (Ibáñez and Gonzalez 1996).

#### 4.1. Comparison within Europe

Within the assemblages available for comparison (see Table 1), it is clear that the knappers also aimed to produce bladelets with regular edges and with slightly curved or straight sagittal profiles. Twisted bladelets are not common and are reported only in Arbrede (27%) (Ortega et al. 2005) and Grotte du Renne (25%) (Perpère and Schmider 2002; Paris 2005). Comparative data on basal morphology are not available, as only weak evidence for bladelets with convergent retouch are reported. Bladelets with convergent retouch are often hidden within the ambiguous categories of Font-Yves or Krems points, which also encompass non-pointed retouched bladelets, and Dufour bladelets. In Le Piage, 31 Font-Yves bladelets (12% of the retouched bladelets) are reported; however, this category encompasses, in accordance with Demars and Laurent (1992), all retouched bladelets with bilateral direct retouch (Bordes 2002). Following the approach of the present study, some of the specimens could not be considered points because of the lack of the distal part. In Arbrede, 2 Font-Yves points (0.9% of the whole retouched assemblage) are signaled (Maroto et al. 1996), while only one is reported in Mochi (Laplace 1977; Kuhn and Stiner 1998). At Kozarnika, 32 bladelets with convergent direct retouch (80% of the retouched bladelets sample) are reported (Tsanova 2008). For the other sites listed in Table 1 no bladelets with convergent retouch are reported.

As for the previous attributes, retouch position is not always well defined in the literature, with the exception of few sites listed in Table 1. In Le Piage, the majority of retouch is inverse (48.9%), then alternate (28.4%) and direct (22.6%) (Bordes 2002). In Castelcivita, 68% of retouch is inverse, 25% alternate, and 7% direct (Gambassini 1997). Just as at Les Cottés, in Grotte du Renne more than 90% of the bladelets have an inverse retouch (Paris 2005). In Kozarnika, the situation appears to be different because of the high impact of the direct (80%) followed by alternate (7.5%) and inverse (2.5%) retouch (Tsanova 2008). In the majority of the sites, both alternate and inverse retouched bladelets are classified as Dufour bladelets or as sub-type Dufour bladelets (Demars and Laurent 1992), without further morpho-technical characterization. Such tools, however, are highly variable and cannot be lumped together within a unique and broad category.

Overall, the lamellar assemblages analyzed belong to common stone knapping traditions that aimed to produce regular, relatively straight, and dimensionally comparable bladelets, even if in some of them the retouch expresses distinct finalities. Indeed, the main differences can be found in the presence, proportion, and relative retouch position of bladelets with convergent retouch. In Fumane, bladelets with convergent retouch, mostly modified by direct retouch, represent a primary finality in stone tool manufacture. Nevertheless, the present study has recognized bladelets with convergent retouch in Isturitz too, which were not mentioned in a previous analysis (Normand et al. 2008). At Isturitz, bladelets with convergent retouch are produced on small blanks and are usually modified by alternate retouch, with the occasional use of direct retouch. Also, Ortega et al. (2005) report a series of bladelets made pointed by retouch from Arbrede that are, however, included in the Dufour category, together with the rest of the retouched bladelets.

The evidence provided here in some ways supports the idea that the proportion of bladelets with convergent retouch decreases to the west, and especially to the northwest. However, the scant evidence for bladelets with convergent retouch among other western Protoaurignacian assemblages (Bon et al. 2010) may be in part attributable to the approach employed in the study of retouched tools. We indeed think that it is not possible yet to be confident in the decrease, or even in the

1 absence, of bladelets with convergent retouch towards the west. More assemblages have to be studied applying the  
2 approach used here. Reliable evidence for the lack of bladelets with convergent retouch is found only in northern France,  
3 as exemplified at Les Cottés (this study) and Grotte du Renne (Schmider 2002; Paris 2005). In our opinion, bladelets with  
4 convergent retouch did not play a significant role in the toolkit of the Protoaurignacian groups settled in that specific  
5 region.

#### 6 **4.2. Comparison outside of Europe**

7 Bladelet assemblages contemporaneous with those of the Protoaurignacian are reported in some eastern European and  
8 Middle Eastern sites, but also in Early Ahmarian Levantine assemblages. In these collections, the presence of bladelets  
9 with convergent direct retouch is frequently verified. Terminological uncertainty is worthy of consideration, due to the  
10 use of regional terms together with borrowed European tool types. In the open-air site of Tincova, 3 Font-Yves points are  
11 reported together with 22 Dufour bladelets (Sitlivy et al. 2014). Even if the sample is relatively small, Teyssandier (2008)  
12 concludes that in Tincova there are two retouched bladelet populations, one with bladelets pointed by bilateral direct  
13 retouch and the other with non-pointed alternate Dufour bladelets. Units G and H at Siuren I have been attributed to the  
14 Aurignacian type Krems-Dufour (Demidenko and Otte 2002), although the estimated chronology of 31–27 ka BP  
15 (Demidenko and Otte 2001) is frequently compared to the Protoaurignacian (Demidenko and Otte 2001; Tsanova et al.  
16 2012). In both units Zwyns (2012) reports bladelets with convergent alternate and direct retouch, named Dufour bladelets  
17 when pointed by alternate retouch, alongside bladelets with alternate and inverse lateral retouch. The case of Kozarnika  
18 has already been discussed. Tsanova (2008) describes a sample of bladelets with convergent direct retouch that have been  
19 separated from the rest of the retouched bladelets according to morpho-technical and retouch attributes.

20 The Baradostian is an Early Upper Paleolithic industry well known in the Zagros region, Iran. Several technological and  
21 typological features of the Baradostian are similar to the Protoaurignacian (Otte and Kozłowski 2004). In the sites of  
22 Yafteh and Warwasi, large and straight bladelets are obtained from unipolar, but also bipolar, prismatic cores, while small  
23 and twisted bladelets are obtained from burin-like cores. Two principal populations of retouched bladelets have been  
24 identified: “Dufour” bladelets with alternate or inverse lateral retouch, both on straight or twisted blanks, and bladelets  
25 with convergent direct retouch. In this region bladelets with convergent retouch are typed as Arjeneh points and are  
26 frequently compared to Krems and Font-Yves types (Otte et al. 2007, 2011). Tsanova et al. (2012) report that many of  
27 the retouched bladelets cannot be included in the Dufour or Arjeneh types based on both morphological and retouch  
28 attributes. New reassessments will be helpful in highlighting the variability of the Baradostian bladelet assemblages.

29 The Early Ahmarian has also been seen as sharing similar concepts with the Protoaurignacian in lithic technology (Goring-  
30 Morris and Belfer-Cohen 2003). Even if there are several differences between the northern and the southern extension of  
31 the Early Ahmarian (Kadowaki et al. 2015), both are characterized by elongated and convergent laminar and lamellar  
32 blanks, which are often described as retouched into El-Wad points (Belfer-Cohen and Goring-Morris 2003; Goring-  
33 Morris and Davidzon 2006). The problem concerning the terminology employed to characterize the variability of  
34 retouched bladelets is underlined, since the term El-Wad is used to refer to several different retouched bladelet types  
35 (Bergman 2003), for which Le Brun-Ricalens et al. (2009) have proposed a new techno-typological classification. Early  
36 Ahmarian points are described to be produced on straight or slightly curved blanks, whose sizes are relatively variable.  
37 Even if the majority of El-Wad points are modified by direct bilateral retouch, some authors also report the existence of  
38 bladelets with convergent inverse and alternate retouch (Tsanova et al. 2012).

#### 39 **5.0. Conclusion**

40 This study demonstrates that morpho-metrical analyses of retouched tools, following well stated criteria and easily  
41 comparable attributes, represent a powerful method to characterize lithic assemblages. Several differences have been  
42 found among the bladelet collections of Fumane, Isturitz, and Les Cottés, even though it appears certain that they belong  
43 to the shared stone tool manufacture traditions that characterize the Protoaurignacian and, more generally, the beginning  
44 of the Upper Paleolithic in Western Eurasia. Two main categories of lamellar tools can be highlighted, for which we have  
45 suggested the use of a classification that is not based on existing typologies: bladelets with convergent retouch and  
46 bladelets with lateral retouch. Both types can be modified by alternate, inverse, or direct retouch, and can be variable in  
47 size. The feature that seems to best discriminate the bladelet assemblages of Fumane, Isturitz, and Les Cottés is the  
48 presence and the relative variability of bladelets with convergent retouch. Whether those differences are attributable to  
49 regional traditions, functional needs, chronological divergences, or adaptive response to different ecological contexts, still  
50 needs to be further investigated. With further evidence it would be possible to connect the studies on lithic morpho-  
51 metrical and technological variability to the analyses based on other artifacts made by organic materials, as well as to  
52 archeozoological, site-function, and ecological reconstructions.

53 New classifications that go beyond classic typologies by focusing on blank size and morphology are needed for  
54 Aurignacian retouched bladelets, and more generally for the lamellar industries of the Western Eurasian Early Upper  
55 Paleolithic. Using new categories like bladelet with convergent retouch and bladelet with lateral retouch, will enable  
56 comparisons between lamellar tools all over Eurasia, and in turn shall help to clarify the prehistoric reasons for the success  
57 of the bladelet technology at the onset of the Upper Paleolithic and beyond.

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**Figure captions**

- Fig. 1** Map showing the localization of Fumane, Isturitz, Les Cottés, and other Protoaurignacian sites listed in Table 1
- Fig. 2** Box plot of width values for the entirety of retouched bladelets from Fumane, Isturitz, and Les Cottés (the line indicates the median value, while the X indicates the mean value)
- Fig. 3** Box plot of thickness values for the entirety of retouched bladelets from Fumane, Isturitz, and Les Cottés (the line indicates the median value, while the X indicates the mean value)
- Fig. 4** Box plot for the thickness values of bladelets with lateral retouch and bladelets with convergent retouch from Fumane (the line indicates the median value, while the X the mean value)
- Fig. 5** Scatterplot showing width and thickness mean values of retouched bladelets for some of the assemblages listed in Table 1, compared to Fumane, Isturitz, and Les Cottés
- Fig. 6** Dorsal and ventral views of a sample of bladelets with convergent retouch (1–5, 7-8, 11–12, 14) and bladelets with lateral retouch (6, 9–10, 13) from Fumane. On dorsal view, solid lines indicate the localization of the direct retouch, while dashed lines show the localization of the inverse retouch (Photo: A. Falcucci)
- Fig. 7** Dorsal and ventral views of a sample of bladelets with convergent retouch (2–3, 6, 10) and bladelets with lateral retouch (1, 5, 7–9) from Isturitz. On dorsal view, solid lines indicate the localization of the direct retouch, while dashed lines show the localization of the inverse retouch (Photo: A. Falcucci)
- Fig. 8** Dorsal, ventral and profile views of a sample of bladelets with lateral retouch (1–13) from Les Cottés. On ventral view, dashed lines indicate the localization of the inverse retouch (Photo: S. Lascht)

Table 1

Site	Layer/Level/Unit	References
Cueva Morín	8	Maillo-Fernández 2005, 2006
Le Piage	K	Bordes 2002, 2005
Grotte du Renne	VII	Schmider 2002; Paris 2005
Arbreda	H	Maroto et al. 1996; Ortega et al. 2005
L'Observatoire	Hearths G-F	Porraz et al. 2010
Mochi	G	Laplace 1977; Kuhn and Stiner 1998
Castelcivita	6	Gambassini 1997
Kozarnika	VII	Guadelli and Sirakov 2005; Tsanova 2008

**Table 1** List of sites and relative archaeological horizons that have been used for comparative purposes. The n

ain references for lithic assemblages are listed



Table 2

	<b>Fumane (n = 1751)</b>	<b>Isturitz (n = 963)</b>	<b>Les Cottés (n = 150)</b>
Complete	85 (4.9%)	15 (1.6%)	2 (1.3%)
Almost complete	62 (3.5%)	17 (1.8%)	2 (1.3%)
Proximal	498 (28.4%)	237 (24.6%)	46 (30.7%)
Mesial	845 (48.3%)	557 (57.8%)	87 (58%)
Distal	261 (14.9%)	137 (14.2%)	13 (8.7%)

**Table 2** List of the analyzed retouched bladelets sub-grouped according to their degree of breakage

Table 3

	<b>Fumane</b>		<b>Isturitz</b>		<b>Les Cottés</b>	
	<b>a (n = 1751)</b>	<b>b (n = 147)</b>	<b>a (n = 963)</b>	<b>b (n = 32)</b>	<b>a (n = 150)</b>	<b>b (n = 4)</b>
Sub-parallel	1026 (58.6%)	54 (36.7%)	684 (71%)	8 (25%)	91 (60.7%)	0
Convergent	386 (22.1%)	54 (36.7%)	184 (19.1%)	14 (43.8%)	29 (19.3%)	2
Convex	242 (13.8%)	28 (19%)	47 (4.8%)	6 (18.7%)	23 (15.3%)	2
Irregular	97 (5.5%)	11 (7.5%)	48 (5%)	4 (12.5%)	8 (5.3%)	0

**Table 3** Blank morphology of retouched bladelets considering the whole samples (**a**) and only the complete and al

lmost complete specimens **(b)**

Table 4

	<b>Fumane (n = 1751)</b>	<b>Isturitz (n = 963)</b>	<b>Les Cottés (n = 150)</b>
Alternate	938 (53.6%)	408 (42.4%)	2 (1.3%)
Inverse	375 (21.4%)	449 (46.5%)	140 (93.3%)
Direct	438 (25%)	106 (11%)	8 (5.3%)

**Table 4** Retouch position on the entirety of the analyzed retouched bladelets

Table 5

<b>Fumane</b>		
	Blad. with convergent ret. (n = 184)	Blad. with lateral retouch (n = 130)
Alternate	65 (35.3%)	70 (53.8%)
Inverse	9 (4.9%)	33 (25.4%)
Direct	110 (59.8%)	24 (18.5%)

**Table 5** Frequency of alternate, inverse and direct retouch on the bladelets with convergent ret

<b>Isturitz</b>	
Blad. with convergent ret. (n = 39)	Blad. with lateral retouch (n = 78)
28 (71.8%)	18 (23.1%)
2 (5.1%)	54 (69.2%)
9 (23.1%)	6 (7.7%)

ouch and the bladelets with lateral retouch. Both groups are composed of the sum of complete bladelets and distal fragr

nents

Table 6

		n	Mean	Minimum	Maximum	SD	25 prentil
<b>Fumane</b>	Length	85	26.6	13.6	54.5	8.91	19.9
	Width	1751	6.51	2	14.7	1.73	5.3
	Thickness	1751	1.73	0.7	7.3	0.59	1.3
<b>Isturitz</b>	Length	15	25.14	12.3	43.9	9.53	17.3
	Width	963	5.25	2.1	11.5	1.65	4
	Thickness	963	1.49	0.4	5.6	0.52	1.1
<b>Les Cottés</b>	Length	2	26.7	26.6	26.8	-	-
	Width	150	6.8	2.7	13.1	1.96	5.5
	Thickness	150	1.88	0.8	3.9	0.63	1.4

**Table 6**  
 Descriptive statistics for length, width and thickness measurement s (n: number of cases; SD: standard deviation; 25 prentil: 25 percentil; 75 prentil: 75 percentil; CV: coefficient of variation)



Median	75 prntil	CV
23.9	30.4	33.5
6.3	7.5	26.7
1.6	2	34.28
24	32.5	37.91
5	6.2	31.52
1.4	1.8	35.4
-	-	-
6.55	7.9	28.8
1.8	2.2	33.57

Table 7

	<b>Fumane vs. Isturitz</b>		<b>Fumane vs. Les Cottés</b>		<b>Isturitz vs. Les Cottés</b>	
	<i>U value</i>	<i>p</i>	<i>U value</i>	<i>p</i>	<i>U value</i>	<i>p</i>
Width	4.89E+05	< <b>0.01</b>	1.21E+08	0.1	1556.5	< <b>0.01</b>
Thickness	6.25E+05	< <b>0.01</b>	1.12E+09	< <b>0.01</b>	43941	< <b>0.01</b>

**Table 7** Results of Mann Whitney U-tests for median width and thickness differences between the studied assemblages.

. Bold indicates statistically significant differences at  $p < 0.01$

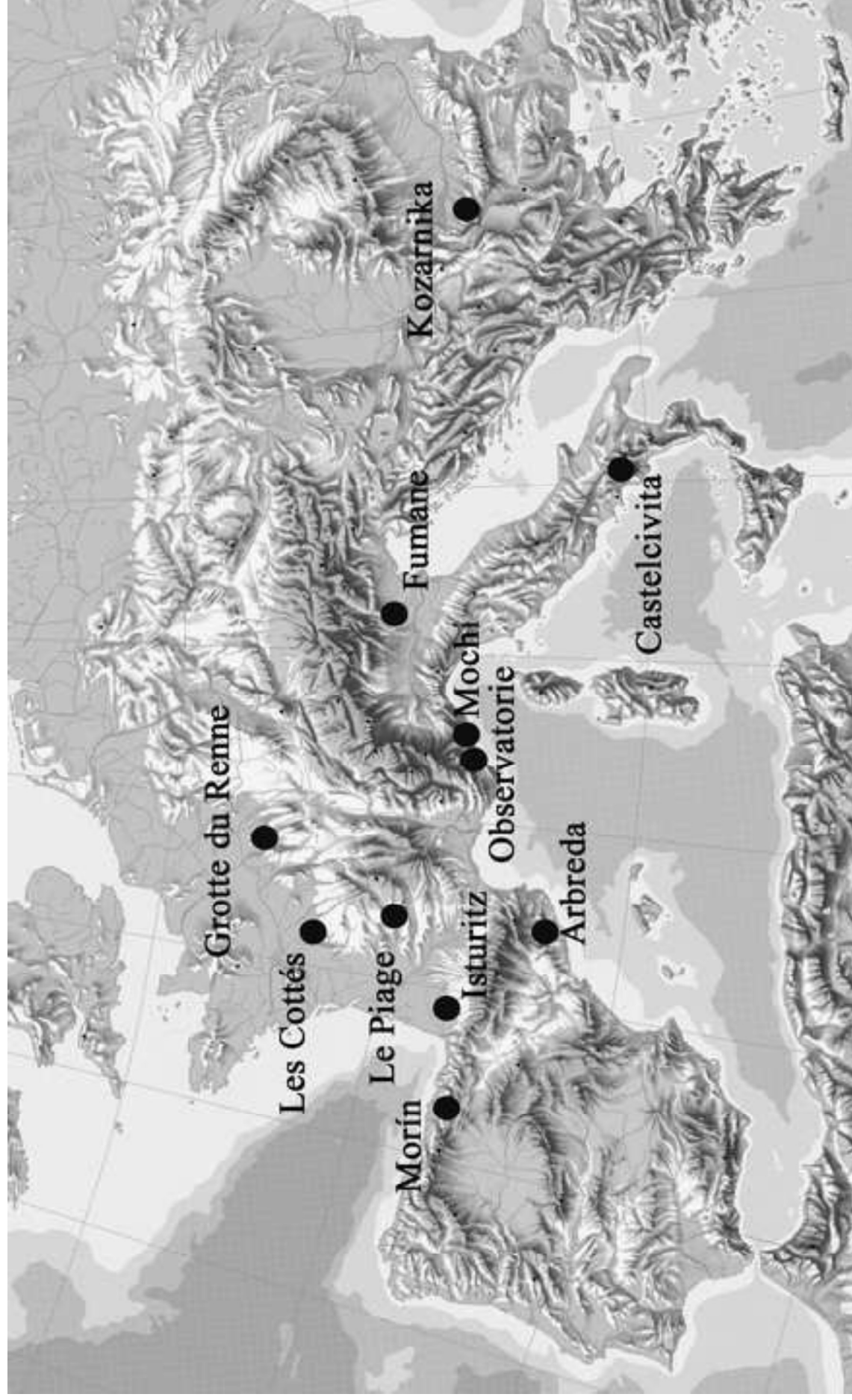


Figure 1

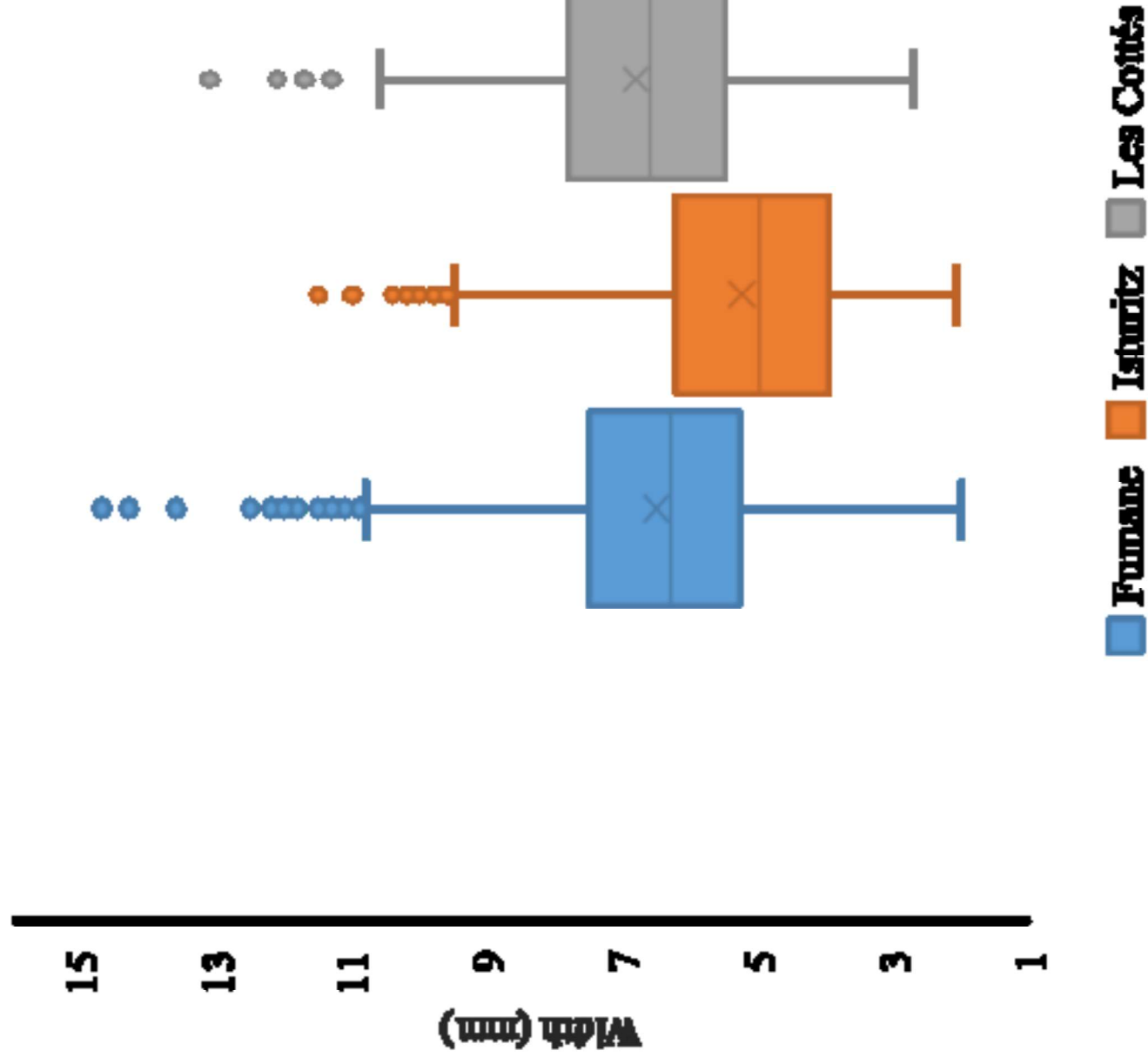


Figure 2

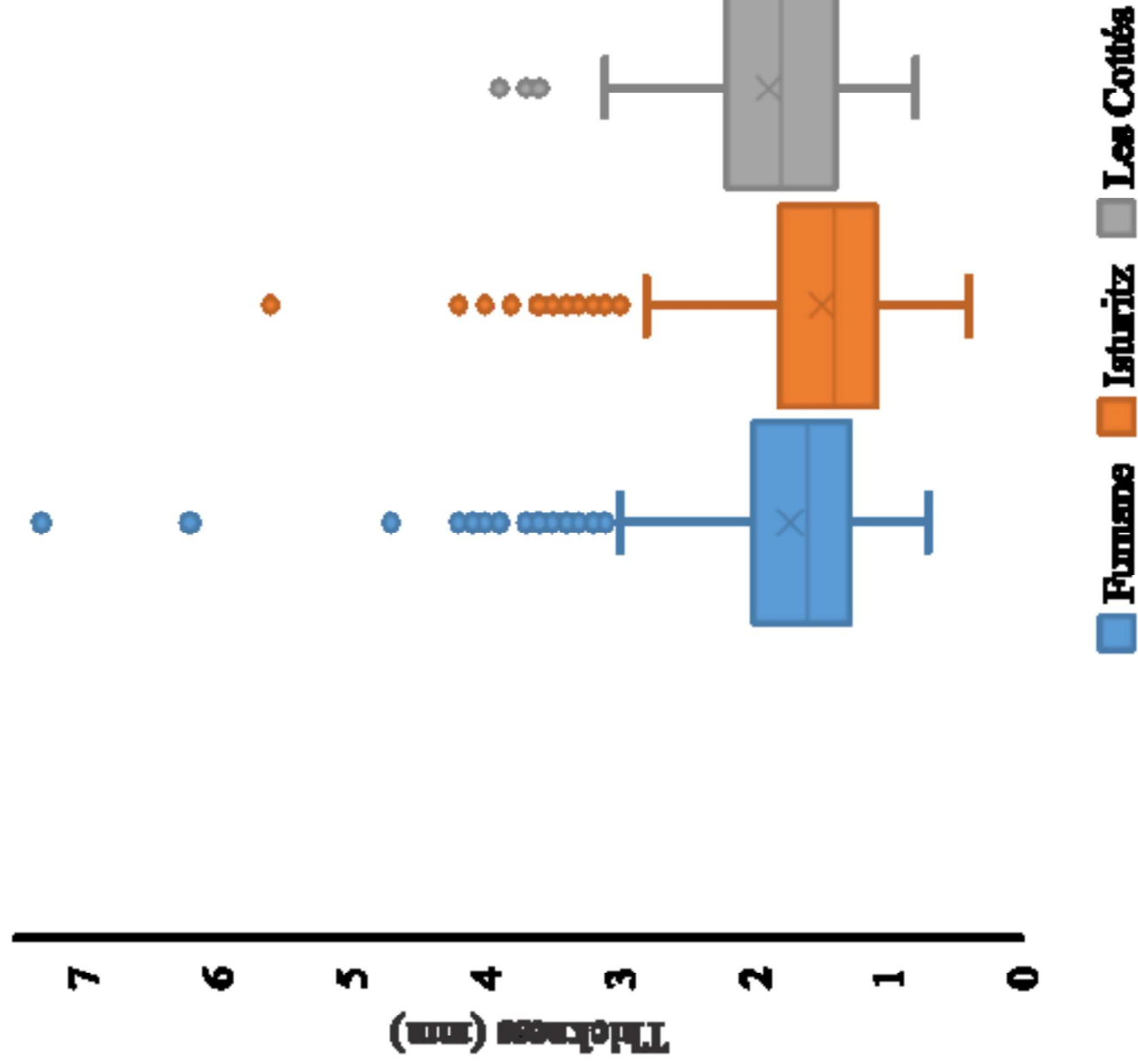
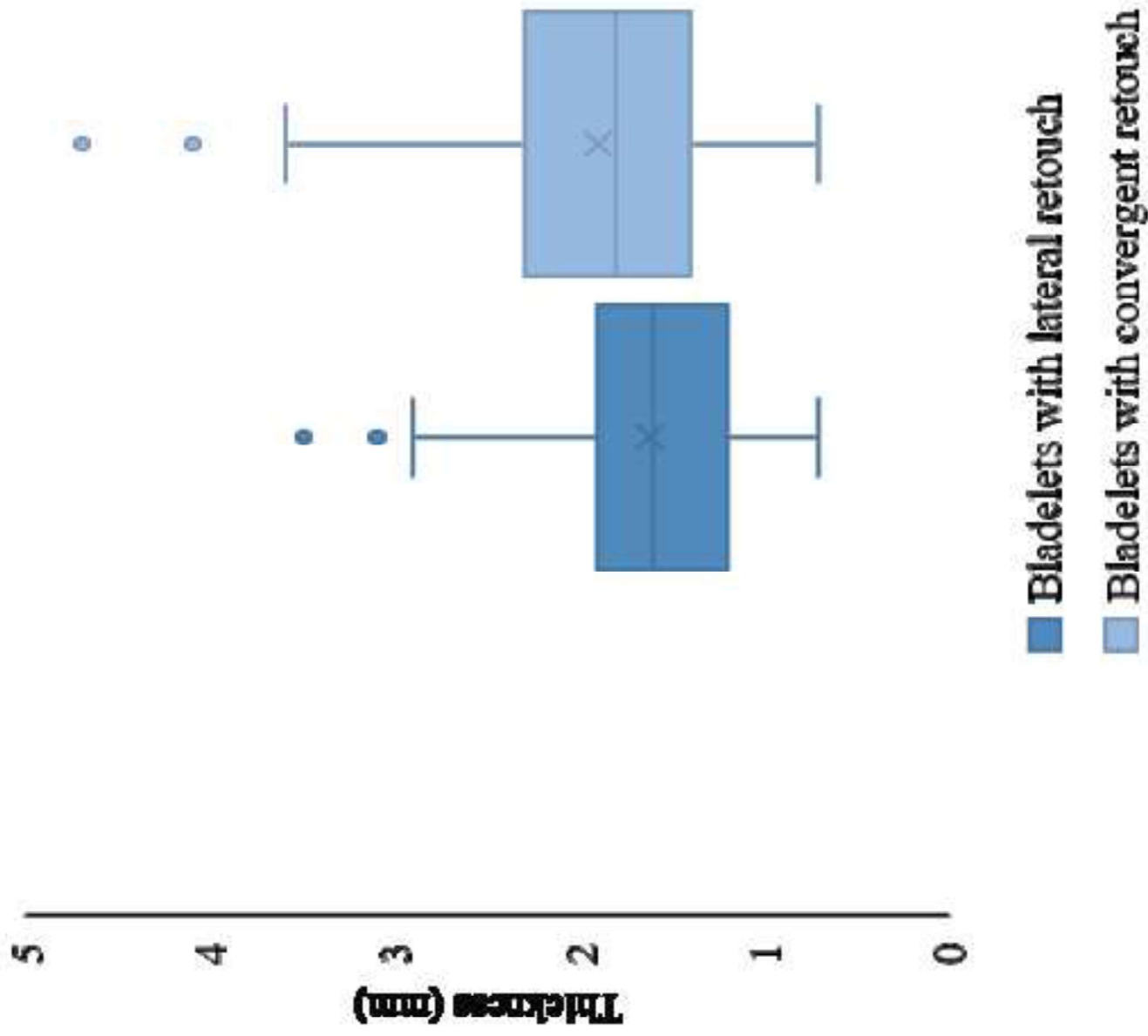


Figure 3



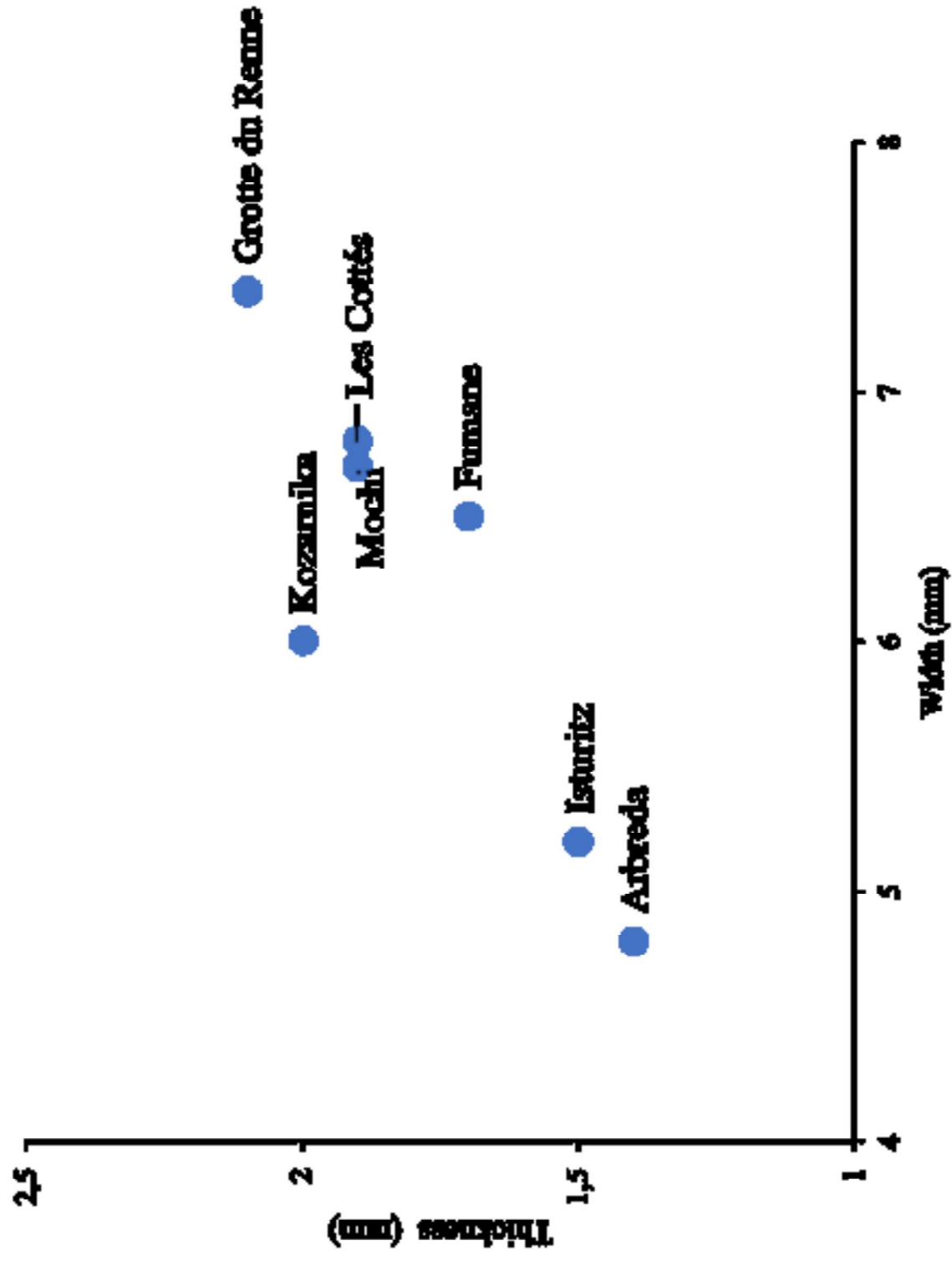




Figure 6

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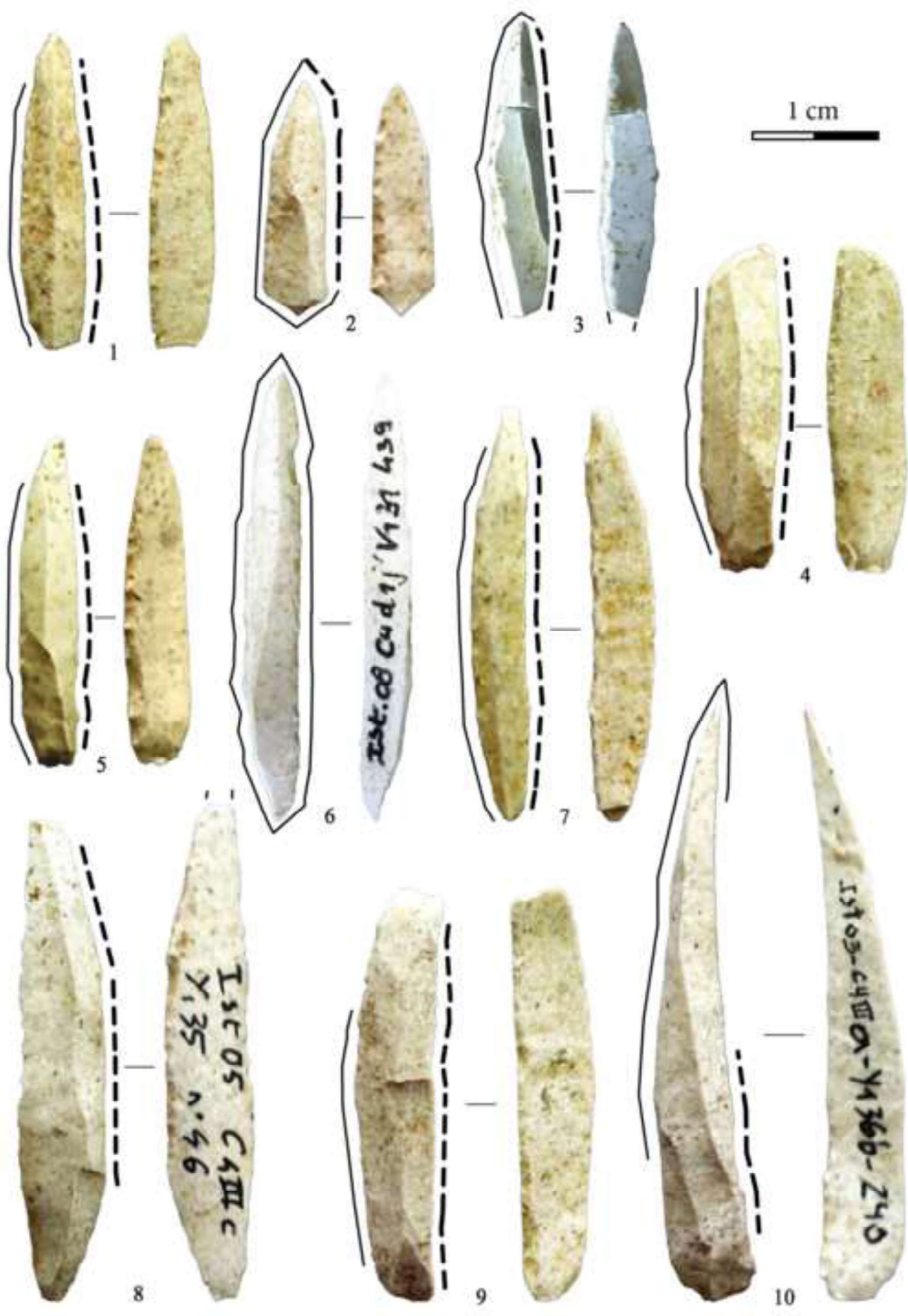


Figure 8

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# **An Integrated Method for Understanding the Function of Macro-Lithic Tools. Use wear, 3D and Spatial analyses of an Early Upper Palaeolithic assemblage from North Eastern Italy**

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## **Abstract**

The article presents an original analysis which combines use-wear, 3D modelling and spatial analyses to experimental archaeology in order to investigate Early Upper Palaeolithic flint-knapping gestures and techniques involving the use of macro-lithic tools. In particular, the methodological framework proposed in this paper was applied to the study of Protoaurignacian and Aurignacian macro-tools from Fumane Cave (Verona, Italy). Combining spatial analysis and use wear investigation, both at low and high magnifications, permitted the identification and detailed description of the use-related traces affecting both the hammerstones and retouchers which, at Fumane Cave, were used at different stages during flint tool production. Several experimental activities were performed including core reduction, maintenance, and blank production together with different types of edge retouching. From a methodological perspective, the protocol of analysis permitted to codify specific traces and to produce quantitative data related to their geometry and distribution over the tool's surface, according to the activities and gestures performed. The results obtained allowed a careful investigation of the function and the gestures associated to the use of the macro-lithic tools coming from the Protoaurignacian and Aurignacian levels of Fumane Cave while providing a methodological tool for interpreting different archaeological samples.

**Keywords:** Macro-lithic tools, Use wear, Spatial analysis, 3D Modelling, Upper Palaeolithic

## **1. Introduction**

Interest in the study of macro-lithic tools has increased in recent years, in relation to their potential for reconstructing the variability of adaptive human choices. First coined by Adams and colleagues [1], the term “macro-lithic tools” refers to a rather varied category of stone artefacts used for percussion, abrasion, polishing, cutting and grinding activities. The variability in the use of macro-tools in the past led to in-depth study of this category of artefacts, which has been analyzed from both a technological [2–6] and functional point of view, through the observation of macro and micro-traces [2,5,15–23,7–14]. There have also been important studies of the mechanical [24–26] and physical properties of the rocks [27], applying UBM laser profilometry methods [28], and of the residues [29–38]. Furthermore, the principles of tribology have made a great contribution to the study of macro-lithic tools for understanding the various processes that lead to use wear development [39–48].

So far, most of the functional data regarding macro-lithics comes from later prehistoric contexts – e.g. the Neolithic and Chalcolithic – while little information is available on the early use of such tools during the Palaeolithic and Mesolithic. Recent studies carried out on the tools found in the Bilancino site [49–52] and Grotta Paglicci [53], both in Italy, have emphasized the relationship between these tools and technological aspects such as plant food processing during the Upper Palaeolithic. Skills involved in the processing of different raw materials, such as plants [54–59] and minerals [60–64] have little visibility in the archaeological record. It is clear that it is necessary to intensify the functional studies on this category of artefacts, especially with regards to hunter-gatherer societies. The techno-cultural choices of these groups, for example in relation to a general evolution of human cognition and social interaction, could have been much more complex [65]. These choices encouraged the creation or the adoption of innovative technologies combined with a series of collateral activities, such as the ability to collect raw materials, transport strategies, the complementary use of tools to produce other tools, or to process organic and inorganic raw materials [66].

Tools used in percussion activities, such as spheroids and anvils, are evident since the earlier phases of the Palaeolithic [67–70], being made out of different raw materials and used to process different substances.

Macro-lithic tools are also related to the production of knapped stone tools. Indeed, hammerstones and retouchers made of stone [4,21,71–73] and bone [74,75], are found in numerous contexts, especially related to the later phases of the Palaeolithic [4]. As an example, bone retouchers have been found in different Middle and Late Pleistocene sites [76,77,86,78–85]. Rarer are the antler billets [87–89] or wood retouchers [90].

To date, functional studies on this tool category are still lacking. Indeed, the use and the type of hammerstone or retoucher (e.g. hard or soft) is determined, or hypothesized, indirectly through the scrutiny of some morpho-metric features observed on the produced blanks (e.g. features of the impact point and the bulb, the internal and external platform angle, the dimensions of the striking platform and the morphology of the detachment scars or ridges of the dorsal face) or the retouched edge (e.g. features of scars and the bulb, the inclination of the retouch scars with respect to the opposed face, and the morphology of the scars). The identification of knapping techniques has usually been carried out in combination with experimental activities and numerous contributions have been published over the years [91–98], while more generic information is available for the use of hammers on bones [99]. Even though this type of analysis provides interesting information, some limitations do exist. Firstly, the analysis of these features focuses mainly on the knapping techniques. Secondly, it is an indirect analysis, which is exclusively based on diagnostic features on the “product”, even in those cases where the presence of hammerstones and retouchers or of ones potentially in the archaeological record would allow a detailed study of the percussion and retouching techniques. In this respect we often read about the presence of “fluvial pebbles”, which were probably used at the site as hammers, but have not been analysed by means of use wear analysis [100].

In this paper we present a multidisciplinary analysis of the repertoire of pebbles associated with the Protoaurignacian and Aurignacian levels of Fumane Cave. Such tools represent a valuable opportunity to detail the gestures of Early Upper Palaeolithic percussion activities, and the criteria involved in raw material selection and macro-lithic tool exploitation at the site. The combination of experimental archaeology, use wear analysis and GIS analysis allows further enhancement of the results provided by functional analysis, through the addition of quantitative data, and its potential has been already proved by the pioneering studies performed by De la Torre and colleagues [101], Caruana and colleagues [102] and more recently by Benito-Calvo and colleagues [103–105].

Our results further confirm the reliability of this combined methodology and provide new and relevant insights regarding the variety of percussion activities performed during the early Upper Palaeolithic occupation of Fumane Cave.

## 1.1 The Archaeological context: the Protoaurignacian and Aurignacian at Fumane Cave

Fumane Cave is located in the Venetian Prealps (north-eastern Italy) (**Fig 1**). The cave has been under excavation since 1988 and is characterized by a high-resolution stratigraphic sequence [106,107] spanning the Mousterian [108], Uluzzian [109], Protoaurignacian [110,111], and Aurignacian [112]. Today, it represents a key site for understanding the complex processes that led to the demise of Neanderthal populations and the spread of modern humans across Europe [113]. Layers A2 and A1 date the appearance of the Protoaurignacian to 41.2–40.4 ky cal BP, while a combustion feature embedded in the stratigraphic complex D3 dates the youngest Aurignacian phase to 38.9–37.7 ky cal BP [114]. A recent assessment of the Protoaurignacian [111,115] and Aurignacian [116] lithic technologies, has permitted an accurate narrative of the diachronic changes that occur throughout the stratigraphic sequence and enables us to critically address the techno-typological signature of the Aurignacian in northern Italy. Overall, bladelets were the first goal of the lithic production in all the studied assemblages. They were obtained from a broad range of independent reduction strategies, among which carinated technology seems to increase towards the top of the sequence. The rather standardized reduction procedures, reconstructed from the study of blanks and initial and exhausted cores, were tailored for the production of regular and frequently pointed bladelets by means of unidirectional convergent knapping progressions. Blades represented the second goal of the lithic production system and their frequency remains stable throughout the sequence. Blades were obtained from sub-prismatic cores using direct marginal percussion on flat striking platforms and were also produced during several maintenance operations carried out on bladelet cores. Unlike blades, flake production increases in the Aurignacian assemblages, where it also appears to be more standardized [117]. Tool assemblages are dominated by retouched bladelets, with frequencies that progressively decrease from layer A2 (around 80%) to the top of layer D3 (around 50%). Modification is in most cases marginal, semi-steep, and was conducted to shape bladelets with convergent retouch and bladelets with lateral retouch [118]. In both cases retouch delineation is regular and generally follows the initial morphology of the blank. Among common tools, laterally retouched blades and burins are more prevalent in the Protoaurignacian layers, while endscrapers significantly increase in the Aurignacian assemblages. Laterally retouched blades present unilateral or bilateral retouches. Modification is in most cases direct and, especially on the thicker blanks, has a scaled morphology. The so-called Aurignacian retouch [119] is instead rare. Endscrapers, both on blade and flake, display in most cases a thin working edge shaped by short lamellar removals. Some of them were made on retouched blanks. The working edge was frequently reshaped, and several wear traces were identified. Finally, thick endscrapers, such as carinated and nosed forms, were in most cases used as cores for the extraction of small and curved bladelets.

## 2. Materials and methods

### 2.1 The archaeological sample

The archaeological sample coming from the Protoaurignacian and the Aurignacian levels of Fumane Cave, is composed of 7 specimens, that characterize the entire assemblage (General Inventory Number VR67993) (**Fig 2**). These are naturally rounded pebbles originated in a fluvial sedimentary context. As suggested by previous studies [120] pebbles with a high degree of rounding have been collected, more likely, from fluvial deposits originating from high-energy water courses, like the Adige river which currently flows 20km south of Fumane. Indeed, they do not present any technological modification, their morphologies are rather recurrent, circular or oval with oval section.

The overall dimensions are small, the average length equals to 68 mm, with an average width of 56 mm and an average weight of 322 gr.

Pebbles are made of sedimentary and metamorphic rocks: a) compact limestone, with fine texture (n 4); b) soft limestone, with a characteristic pink and white colour (n 2); c) ophicalcite<sup>1</sup>, a metamorphic rock with carbonate cement veins of allochthonous origin (n 1).

However, as stressed by Bertola and colleagues [120] in the case of sedimentary rocks, the lithologies are various, attributable to different horizons included in the carbonatic formations cropping in the area, from Upper Cretacic Scaglia Rossa to Jurassic “Calcari Grigi”.

Within the archaeological sample, 6 artefacts are intact or with perfectly reassembling parts, while 1 sample are fragmentary, along with one specimen characterised by fractures caused by a probable source of heat that caused it to expand (**Table I**). No permits were required for the artefacts’ study as one of the authors (MP) is Director of the excavation at the site of Fumane Cave and responsible for the scientific activity carried out on the archaeological findings recovered from the site. Regular permits have been received (ref. DG-APAB4646) for all aspects of this work from the archaeological authority, the Soprintendenza Archeologia, Belle Arti e Paesaggio per le Province di Verona, Rovigo e Vicenza (SAPAB - VR).

US	ID	Length (mm)	Width (mm)	Thickness (mm)	Weight (g)	Integrity	Raw Material	Colour	Morphology
D3	RF73	66	71	42	364.4	Intact	Soft Limestone	Pink	Circular/Oval Section
D3	RF138	69	99	75	206.8	Fragments (n.2)	Soft Limestone	Pink	Sub-Oval/Plane-Convex Section
D3	RF37	85	48	26	188.9	Alteration	Limestone	Brown	Oval/Oval Section
D3+D6	RF92	98	55	22	246.3	Intact	Ophicalcite	Grey/White veins	Oval/Oval Section
D6	RF80	48	43	18	81.8	Intact	Compact Limestone	White	Circular/Oval Section
A1	RF67	73	51	15	119.0	Intact	Compact Limestone	Brown	Oval/Oval Section
A2	RF127	52	43	16	88.6	Intact	Compact Limestone	Brown	Circular/Oval Section

Table I. Information on archaeological sample. US, dimensions, raw material, integrity, colour and morphology.

## 2.2 Use wear analysis

The artefacts were analyzed applying a functional approach along with the design and application of a dedicated experimental framework. The functional approach is based on the analysis of different aspects related to the use of macro-lithic tools.

For the study, the specimens were observed utilizing a Zeiss Axio Zoom V16 binocular stereo microscope, oculars PI 10x/23, objective 1x/0.25 FWD 56mm, with progressive magnifications ranging between 10x and 80x. This low-magnification observation allowed us to propose a hypothesis regarding the gestures and details related to the kinetics of the object. Furthermore, it allowed us to determine the nature and status of the processed matter with which the object came into contact. Topography and microtopography, grain shapes, pits, striation and fracture morphologies on experimental and archaeological artefacts have been described according to parameters already described in literature [3,20]. 3D models of the surface were produced utilizing Mountain Map

<sup>1</sup> Determination by Stefano Bertola.

Premium 7.2, which provided more information related to the evolution of the microtopography and details concerning the morphology of the identified traces.

A second level of observation consisted of the analysis of the specimens at higher magnification (50-500x) using Zeiss Scope A.1 metallographic microscope equipped with 10x oculars and with objectives ranging from 5x to 50x. This allowed the investigation of micro wear (e.g. micro-striations and micro-polishes) to achieve more information about the use of the tools. Polishes have been described by taking into account their texture, topography, distribution, extension and linkage (for more details see [23,121,122]). The surfaces have been documented using a Zeiss Axiocam 305/506 color camera and were washed with neutro phosphate detergent (Derquim<sup>®</sup>) and ultrasonic cleaner AU-32 (ARGO LAB) for 15/20m.

### 2.3 Photogrammetry

3D Models of both experimental and archaeological samples have been created through the application of photogrammetry. Following the protocol developed by Porter and colleagues [123] 3D models of the artefact were built using Agisoft Photoscan 1.3.4.

The tools were placed on an automatic turntable in order to produce 360° sets of each of the tool's surfaces. Pictures of the tools were shot using a Nikon D7200 DSLR camera equipped with a Nikkor 105 Macro Lense. Each picture was taken every 15°, and at every full revolution the camera was lifted and slightly titled towards the target for a total of 72 picture per object side. A total of 144 pictures were taken per object, which were subsequently imported in Agisoft Photoscan Pro 1.3.4 to produce high quality dense point clouds and meshes.

### 2.4 Surface Morphometric Analysis

GIS analysis has been adopted to analyse the morphometric characteristics of both experimental and archaeological samples. Applying both the methodologies proposed by Caruana et al [102], Benito-Calvo et al [103] and de la Torre et al [101] it has been possible to analyse and quantify use wear patterns originated from both retouching and percussive activities. After the creation of 3D Models, Digital Elevation Models (DEM) featuring a resolution of 0.5mm were created in Agisoft Photoscan 1.3.4 and imported as raster files in ArcGIS 10.5.

Digital Surface Models were generated in order to analyse the topographic features characterising the tool's surface. At first a Hillshade model of the entire surface was created. This allowed a first morphometric assessment of the surface topography that permitted the identification of the Functional Area/s (FA) of the surface which are affected by use.

Once identified, the FA of the tool was extracted from the original DEM as a new raster surface and three kinds of Digital Surface Models (DSMs) were generated to identify and interpret use wear.

Slope, which identifies the rate of change in the z-value from each of the cells composing a raster surface allows the identification of changes in the surface elevation such as depressions or pits characterising the objects FA. Subsequently, two DSMs devoted to the analysis of surface roughness were generated. Analysing surface roughness permits the analysis of the degree of homogeneity or heterogeneity characterising the tool's surface. As already stated by Benito-Calvo and colleagues (2015) the measurement of surface roughness can lead to the identification of polished areas (low roughness) generated by use. Two methods of surface roughness measurement have been applied: *Terrain Ruggedness Index (TRI)* and *Vector Ruggedness Measure (VRM)*. *TRI* is based on the algorithm proposed by Riley and colleagues [124] and calculates the sum change in elevation between a grid cell and its neighbourhood. In the resulting DSM, a TRI value of 0 represents the minimum degree of roughness (i.e. homogeneous surface). *Vector Ruggedness Measure (VRM)* measures roughness as the dispersion of vectors orthogonal to the surface within a specific neighbourhood. This method captures variability in slope and aspect into a single measure. A value of 0 represents no terrain variation (or lowest roughness) while a value of 1 represents a complete terrain variation (maximum roughness). In the case of the experimental replicas, 3D models and resulting DSMs were



made before and after use. This allowed the mapping and quantification of the degree of variation in surface topography related to each of the experimental activities performed.

Following the methodological framework proposed by Caruana et al [102] the FAs of both experimental and archaeological implements were analysed through Topographic Position Index in order to identify areas of high micro topographic roughness coinciding with use related damage.

*Topographic Position Index (TPI)* is an elevation residual analysis which is applied to identify depressions and ridges affecting the artefacts surface topography [103]. The DSM generated is based on the computation of the difference between the elevation of a cell and the mean elevation in a neighbourhood surrounding that cell. Neighbourhood mean elevation is calculated using a moving window centred on the cell of interest. TPI positive values indicate that the cell is higher than its neighbourhood while negative values indicate the cell is lower, corresponding to either ridges and depressions. Hot Spot Analysis (Getis-Ord GI\*) was performed on the generated surface in order to identify clusters of pits and ridges highlighted by TPI and corresponding to wear caused by use. The patterns identified through Hot Spot Analysis (Getis-Ord GI\*) were then transformed into polygons, which provided metric data (e.g. area, perimeter) to be statistically compared (**Fig 3**).

## 2.5 Experimental Framework

A dedicated experimental reference collection was necessary in order to understand the use of macro-lithics at Fumane cave, and to isolate specific gestures involved in percussion activities. The experimental framework consisted of different stages. Raw materials were collected according to the size and morpho-metric features of the archaeological specimens. Small and rounded pebbles (mean length 50 mm) of compact limestone were gathered along the Adige river bank, about 20 km away from Fumane. Coarse limestone pebbles were collected in a stream bed close to the site. The latter showed a pink/white colour, probably due to geochemical alterations related to the particular depositional environment.

The collected items (5 retouchers, 3 retouchers/hammerstones, 9 hammerstones, 2 anvil) were used in several experimental tests ) and their surface was documented using both the stereo and metallographic microscopes before and after their use, in order to observe the modifications caused by use.

After a preliminary observation of the archaeological sample, it became clear that the Fumane macro-lithics had been used in various activities related to the processing of stone and materials of a non-organic nature. The experimental framework involved 19 pebbles used as hammers in various stages of bladelet production and retouchers, according to the technical solutions known from the analysis performed on the lithic artefacts from the Protoaurignacian and Aurignacian levels of the site, in which core reduction and maintenance are illustrated along with the morpho-technical features of the laminar products and the typology of the retouched tools [110,111,115,120].

For our experimental purposes, nodules of fine-grained flints were used. Several tests have been performed by the flint-knapper, following a precise strategy: a single hammer has been used to perform a specific action with the aim of isolating the functional traces, while others have been involved in different technical gestures to produce experimental replicas showing multi-functional surfaces (a complete list of uses has been illustrated in **Table II**).

Gestures have been described following the criteria outlined by Bourguignon [78]. The following points aim to explain the different phases and the relative technical gestures performed by the expert knapper during the experimental activities:

- cortex removal and core-shaping. The soft stone hammers (103x55mm, average dimensions) were used for opening of the nodules to remove cortical flakes in order to shape a pre-form core composed of a single flaking surface related to a single striking platform. During this step, the hammer's marginal ends have been used as active parts, performing a punctual gesture consisting of a wide rectilinear trajectory of the arm, related to the force necessary to remove larger products. Despite their effectiveness in flake detachment (cortical and non-cortical), they broke after a reduced number of

blows (conchoidal fracture along the functional end or straight fracture following the percussion axis). Therefore, their use during this stage was evaluated as not functional;

- flaking surface and striking platform configuration. After having designed the core volume, the soft hammers (50x50mm, average dimensions) were used to open a flaking surface and prepare the platform and the flaking angle through tiny flake removal. During this phase, flakes of various sizes were removed alternating with abrasion of the overhang performed with the same hammer. This latter action required consequential and rapid gestures with resting percussion, aimed to remove micro-flakes from the overhang. This resulted in a more continuous action that involved a wide contact area – usually along the flat axis or lateral along the pebble edge – between the hammer and the core face. Removals of larger maintenance flakes required slower and more precise blows with a curvilinear trajectory, variable amplitude and force related to the size of the desired flake to be removed. This action involved the use of the marginal ends of the pebble along the minor axis;

- blank production and core maintenance. After having shaped the core, we proceeded to the extraction of lamellar blanks using an organic hammer (deer antler; [120], p.133) and a soft stone hammer, as hypothesized in a recent revision of the bladelets' technical attributes ([111] p.27). During this phase, the stone hammers (sized 50-40mm in length, average dimensions) were always used with a rectilinear trajectory on their marginal ends. They performed effectively in blade production, even though small conchoidal fractures appeared in the functional area which, however, did not lead to discarding the tool. Flake detachment and abrasion operations were also carried out, aimed at maintaining the flaking angle and the transverse and longitudinal convexities of the core;

- bipolar percussion. Due to the presence of some splintered pieces in the archaeological assemblage ([120], p.139) we tested the bipolar percussion by placing the core on a base, consisting of a large flat pebble selected among the collected items. At this stage, the core was of very reduced size and allowed the application of this technique despite the small size of the anvil (50x50x30 mm, average dimensions);

- retouching. Several gestures have been tested according to the different morphologies and intensity of retouching documented for Protoaurignacian and Aurignacian levels at Fumane cave. The occurrence of retouch features was strictly combined with the gesture and the technique, which involved different uses of the functional areas of the pebbles (e.g. short edge or flat face).

a) Direct percussion. A rapid and consequential gesture was performed: the knapper's arm moved following an oblique dragging trajectory against the blank's edge, striking it very quickly using the tool's flat face along the apical area. This movement allowed the removal of tiny flakes and was particularly effective for delineating straight cutting edges with marginal and abrupt retouch on thinner edges, due to the limited contact area between the hammer and the blank edge of a wide spectrum of blank morphologies from simple flakes to blades sharing a consistent thickness (**Fig 4a, 5b**). We noted that this type of retouch can also be performed with different trajectories (e.g. perpendicular to the blank axis). This technique was also used to delineate the front of carinated end-scrapers and of some thin scrapers, even though the short edge of the retoucher was used. This allowed the removal of tiny bladelets and elongated flakes by adopting a marginal percussion (cfr. [125]). A more punctual gesture produced a more invasive retouch of a scaled type (**Fig 4b, 5a**), due to a larger contact area between the hammer flat face and the blank to be retouched. This action followed a perpendicular trajectory, with respect to the blank edge, with a movement from the top to the bottom of the arm and a final flexion downwards. This type of retouch has been performed on blades for delineating the front of the end-scrapers (cfr. [111,120]).

b) Direct percussion on anvil (**Fig 6**). This technique was aimed at retouching tiny bladelets: a flat pebble was used as anvil on which the blank edge was modified through the use of a retoucher by percussion ([98,126,127]). The trajectory was found to be variable depending on the position of the blank to be retouched on the anvil: in a central position a perpendicular trajectory was adopted, while when slightly inclined in proximity of the lateral edge of the

anvil an oblique trajectory was adopted. In both cases, the short edges of the retoucher were used.

- c) Edge abrasion (or *égrisage*, [127]). The bladelet edge was modified by rubbing against the pebble with the aim of delineating a straight edge (**Fig 4c**). This reciprocal contact permitted the detachment of micro-flakes.

Exp. No	Type	Action	Knapper	L (mm)	Wi (mm)	T (mm)	We (g)	Raw material	Morphology	Working Time	Effectiveness of the experiment	Integrity
FR S-1	Retoucher	Scaled retouching	Expert, right-handed	65	50	15	87	Compact grey limestone	Oval/Oval section	30m	High	Intact
F1	Retoucher	Scaled retouching	Expert, left-handed	65	44	25	110	Compact brown limestone	Oval/Oval section	45m	High	Intact
F18	Retoucher/hammerstone	Scaled retouching; Striking platform maintenance; Core shaping	Expert, right-handed	78	43	28	131	limestone with white veins	Oval/Oval section	3h	High	Small flake removal (L.10mm)
FR P-1	Retoucher	Marginal/abrupt parallel retouching	Expert, right-handed	65	46	15	73	Compact grey limestone	Oval/Oval section	30m	High	Intact
F11	Retoucher/hammerstone	Scaled and marginal retouching / striking platform maintenance, small flakes production	Expert, right-handed	55	45	14	52	Compact grey limestone	Oval/Oval section	1h 30m	High	Intact
FB R-2	Retoucher/hammerstone	Marginal/abrupt parallel retouching; Striking platform maintenance and Bladelets removal	Expert, right-handed	49	43	28	83	Compact white limestone	Circular/ Oval section	2h	High	Intact
F20	Hammerstone	Striking platform maintenance	Expert, right-handed	60	29	24	65	Compact brown limestone	Oval/Oval section	45m	High	Intact
F17	Hammerstone	Striking platform maintenance	Expert, right-handed	68	56	28	148	Compact white limestone	Oval/Oval section	1h	High	Intact
F10	Retoucher	Marginal/abrupt parallel retouching	Expert, left-handed	49	38	20	56	Compact grey limestone	Oval/Oval section	2h	High	Intact
F12	Hammerstone	Bladelets removal; Overhang abrasion; Striking platform maintenance	Expert, right-handed	72	47	15	76	Soft pink limestone	Oval/Oval section	2h	High	Small flake removal (L.24mm)
FS PM -13	Hammerstone	Striking platform maintenance; Overhang abrasion; Bladelets removal	Expert, right-handed	59	35	16	54	Soft limestone	Oval/Oval section	2h	High	Small flake removal (L.23mm)
F14	Hammerstone	Core shaping	Expert, right-handed	103	55	51	383	Compact pink limestone	Oval/Oval section	30m	Low	5 flakes removal (L.34mm)
F15	Hammerstone	Striking platform maintenance; Bladelets removal; Overhang abrasion; Scaled retouching; Marginal/abrupt parallel retouching	Expert, right-handed	88	61	23	171	Compact grey limestone	Oval/Oval section	45m	Medium	Small flakes removal (L.12mm)

F16	Hammerstone	Bladelets removal	Expert, right-handed	88	64	30	236	Compact grey limestone	Oval/Oval section	20m	Low	Broken, Longitudinal flake (L.70mm)
FA-8	Anvil	Anvil for flakes removal	Expert, right-handed	80	60	23	177	Compact brown limestone	Oval/Oval section	45m	High	Intact
F19	Hammerstone	Bladelets removal	Expert, right-handed	52	67	33	193	Soft pink limestone	Oval/Oval section	45m	High	Flakes removal (L.50mm)
F3	Hammerstone	Striking platform maintenance; Overhang abrasion	Expert, right-handed	63	38	20	57	Soft pink limestone	Oval/Oval section	30m	High	Intact
FA R-8 bis	Anvil	Anvil for bladelets retouching	Expert, right-handed	80	64	30	236	Compact grey limestone	Oval/Oval section	30m	Low	Intact
F20	Retoucher	Edge abrasion	Expert, right-handed	60	50	30	200	Compact grey limestone	Oval/Oval section	25m	High	Intact

Table II. List of experimental samples used in different phases of the chipped tools production.

### 3. Results

The replicas used during the experimental protocol comprised: a) hammerstones, used for removing cortex and shaping cores, abrasion of core edges and detachment of flakes and bladelets (n.9); b) retouchers, used to produce different types of retouch (n.5); c) anvil, used as a passive base for detaching flakes (n.2); hammerstones/retouchers used with mixed activity (n.3).

#### 3.1 Hammerstones

The types of use-wear observed on the hammerstones were:

- during cortex removal and core-shaping large longitudinal flake scars (50mm) located along the short edge were produced. In association with these scars there were residual surfaces with pits, similar to the deep scales, of around 6mm in size, with a triangular section. Micro-polishes were absent (**Table III**).
- Overhang abrasion activity produced long, deep striations alternated with more superficial striations, with different orientations, often associated with the configuration of the striking platform. These striations were located on the flat and/or on the long edge of the tool and showed polishing on the bottom with a rough texture when observed at the metallographic microscope (**Fig 7**).
- During the configuration of the striking platform of the core, the removal of small flakes produced small pits with sub-oval morphology. The pits often overlapped short superficial striation. These traces were located on the short edges of the tool; if this is circular, use-wear traces were distributed all around its perimeter. A micro-polish was observed, extended on the top of the grains, with a smooth texture, flat topography, uniformly oriented striations, with concentrated-separated distribution (**Fig 8**).
- During blank production and core maintenance small sub-circular pits overlapping with small striations and chaotic orientation were produced; flake scars (20/30mm) due to the blow for the extraction of the blank were also observed. The mechanical levelling led to the production of short strips and sporadic polishing with loose-separated distribution on the top of the grains, with deep striation with the same orientation, and a rough texture and domed topography. The traces were located on the short edge of the hammerstone (**Table III**).

Pits produced by the trimming of the striking platform and the production of blanks and core maintenance looked very similar in their distribution and morphology. Often overlapping, pits were not well defined, but polishes looked different. In particular, the trimming of the striking platform produced polishing as a consequence of repeated contact between the hammer and the edge of the flint tool. On the contrary, the detachment of the blades/bladelets consisted of a more precise blow.

### 3.2 Bipolar percussion

Bipolar percussion makes large pits with sub-quadrangular/triangular morphology located in the central area of the flat surface of the tool. The texture grains appear fractured, polishes are absent (**Fig 9**).


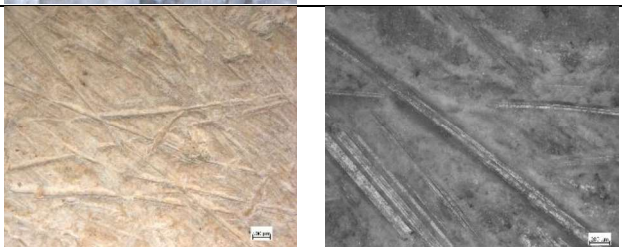
### 3.3 Retouchers

Retouchers presented different types of use-wear. In detail, the scaled retouch generated a series of contiguous pits of a linear form (reduced half-moon) with a rough bottom and an asymmetric triangular section, localised on the flat surfaces of the tool concentrated near the apices. There were also striations: short, more sporadic and superficial (**Fig 10**). The micro-polishes were probably absent because the traces resulted from a punctual contact between the retoucher and the edge of the flint tool (the dragged gesture is absent).

Marginal retouch led to an association of small circular pits and dense long parallel striations. Use-wear traces concentrated over the apical area of the flat surface, with oblique orientations. Bands of polishing with striations were present, with covered-closed distribution, a rough texture and domed topography. The dragging movement (oblique trajectory) related to the marginal retouch, produced a mechanical levelling of the surface where the polishes were present (**Fig 11**).

Other types of retouching were tested, including edge abrasion. This activity produced traces located in a small area between the short edge and the apical area of the retoucher. The traces consisted of small pits with sub-quadrangular morphology and short striations. The rough polishes were present. Retouching on an anvil produced, on the passive base, superficial small pits with a sub-circular morphology and short striation. The use wear was located on the flat surface. The polishes were absent. The same traces were present on the active retoucher but located on the short edge (**Table III**).

On the experimental samples, prehension traces were visible at high magnification. Macroscopically, the prehensive area was smoothed, with several patches of smooth/flat polishing, affecting the top of the grains. Polishes visible between 20x and 50x developed on the flat and central portion of the tool, favoured by a type of prehension in which a large portion of the finger (fingertip) was in contact with the flat surface of the tool. Polishing was not observed in cases where the hammer or the retoucher was gripped by the short margins (tridigital prehensions) and the contact occurred with a reduced portion of the finger (**Fig 12**).

Experimental Activity	Macro-traces	Micro-traces	Use wear Localisation	Use wear
Cortex removal and core-shaping	Detachment of large flakes; pits with scale morphology and triangular section	Absent	Marginal ends	
Overhang abrasion	Long and deep striations, in some cases alternating with other less deep; triangular section; oriented in according to the gesture	Rough polish on the bottom of the striation	Flat surface or long edges	


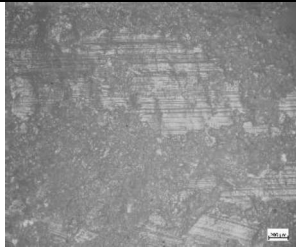


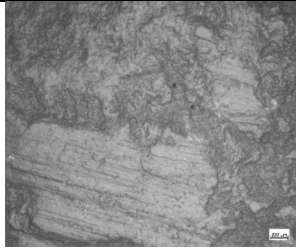


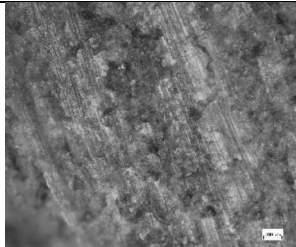

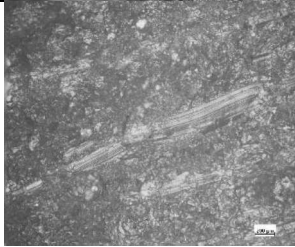
Blank production and core maintenance	Sub-circular pits, overlapping, with small striations with a chaotic orientation; there are negatives present of flakes (20/30mm), due to the blow for the extraction of the support	Mechanical levelling leads to the production of short strips and sporadic polishes with loose-separated distribution, on the top of the grains, with deep striations with the same orientation; rough texture, domed topography	Short edge		
Bipolar percussion for flake detachment. Passive tool	Large pits with sub-quadrangular/triangular morphology; grain micro-fractured	Absent	Central area of the flat surface		
Striking platform configuration	Small pits with a sub-oval morphology, a consequence of small flake removal from the core. Often, the pits can appear overlapped with short superficial striation	Extended onto the top of the grains, with smooth texture, flat topography, striation with the same orientation, with concentrated-separated distribution	Short edges of the instrument or all around his perimeter		
Scaled retouching	Contiguous pits of linear form (half-moon), with rough bottom, and triangular section	Absent	Flat surfaces of the tool, concentrated near the apices		
Marginal retouching	Small circular pits and dense long parallel striations	Band of polishing with striations, covered-closed distribution, rough texture and domed topography	Concentrated over the apical area of the flat surface		
Retouching through edge abrasion. Active tool	The traces consist of small pits with sub-quadrangular morphology and short striations	Rough polishes	Small portion between the short edge and the apical area		

Table III. List of experimental activity and the use wear associated

### 3.4 GIS Analysis - Experimental Sample

Overall, the raw material characterising the experimental sample presented in this work was homogeneous. This led to minimal modifications of the tools surfaces in particular concerning their roughness. On the other hand, the analysis of slope revealed several differences between the activities performed (**Fig 17**).

The experimental replicas utilised to produce scaled retouch recorded the development of depressions exhibiting a mean slope value of 9.94°. Surface ruggedness measured through TRI and VRM appeared low with a mean TRI value of (0.0015) and a VRM mean value of (0.001). Most of the variability was concentrated over the apices of the tool. Scaled retouch (**Fig 13-I, Table IV**) led to the development of use-related wear on the apical portion of the tool. Wear features were characterised by an average perimeter and an area of 8.6 mm and 1.5 mm<sup>2</sup> respectively. The average distance of the wear feature from the centre of the tool was 16 mm while the average from its edge was 13 mm. Traces are concentrated over the central portion of the tool apex as suggested by the standard deviational ellipse elongation value (0.87 ad). As in the case of scaled retouch, use wear generated by marginal retouch (**Fig 13-II, Tab IV**) also affected the apical portion of the retoucher. The depression caused by use featured a slope mean value of 18.8°. The surface showed an overall homogeneity as indicated by the recorded TRI (0.0015) and VRM (0.0023) mean values, with most of the surface variability localised on the tool apical areas. Use related wear exhibited an average perimeter of 9 mm and a mean area of 1 mm<sup>2</sup> along with an average distance from the tool centre and edge of 15 mm and 12 mm respectively. Traces generated by marginal retouch were well spread over the retoucher apical portion as suggested by the standard deviational ellipse elongation value (1.7 ad), higher than the value observed on the experimental replica used in scaled retouching.

Passive percussion (**Fig 14-I, Table IV**) led to the development of wear over the central area of the tool used as anvil, where depressions developed featuring a mean slope value of 11.2°. The surface was overall homogeneous (TRI mean value 0.007) with a low topographic variability (VRM mean value 0,0009) mostly at the bottom of the produced wear. Use marks generated by passive percussion featured a mean perimeter of 7.2 mm and an average area of 1 mm<sup>2</sup>. Traces were localised near the centre of the tool, with an average distance from the centre of 9 mm, while their average distance from the edges averaged 21mm. Traces were concentrated on the tool surface centre as indicated by the standard deviational ellipse elongation value of 0.7 ad.

Adjustment of core ridges (**Fig 14-II, Table IV**) led to the development of use wear over the apical portion of the tool and in a minimal part over its inner areas. Depressions caused by use featured a mean slope value of 14°, while the TRI and VRM mean values, 0.0011 and 0.0034 respectively, suggest an overall homogeneous surface topography with its higher topographic variability localised over the outer portion of the tool apical area. Marks generated by use were relatively large given their average perimeter of 14 mm and mean area of 3 mm<sup>2</sup>. While the inner area of the object was also affected, most of the traces generated by the adjustment of core ridges were located near the tool edge (average distance 10 mm) rather than its centre (mean distance 20 mm). Use related damage was well spread over the affected area of the tool as indicated by the standard deviational ellipse elongation value of 1.2 ad.

For the purpose of bladelets production (**Fig 15, Table IV**), the short edge of the experimental replicas was used rather than its surface. Over the used portion the depressions generated by use were characterised by an average slope value of 23.7°. The used area of the tool was characterised by a higher degree of heterogeneity when compared to the other experimental samples presented in this work, as indicated by TRI (mean value 0,0025) and VRM (mean value 0,0067). Of particular interest is the fact that surface roughness was lower in proximity to the centre of the used surface area, where the bigger traces were located. Wear generated by bladelets production featured an average perimeter of 3.8 mm and a mean area of 1 mm<sup>2</sup>. Damage affected most of the used area of the tool as indicated by the standard deviational ellipse elongation value (2.3ad) (**Fig 16, Table IV**).

	FRS-1	FRP-1	FA-8	FSPM-13	FBR-2
<b>Perimeter (mm)</b>					
<i>Minimum</i>	3.5	3.2	3	2.9	1.6
<i>Maximum</i>	34	21	28	74	22

<i>Average</i>	8.6	9	7.2	14	3.8
<b>Area (mm<sup>2</sup>)</b>					
<i>Minimum</i>	0.5	1	1	1	1
<i>Maximum</i>	6.7	5	9	17	5
<i>Average</i>	1.5	1	1	3	1
<b>Distance from Centre (mm)</b>					
<i>Minimum</i>	7.6	9.7	0.1	11	
<i>Maximum</i>	26	21	18	33	
<i>Average</i>	16	15	9	20	
<b>Distance from Edge (mm)</b>					
<i>Minimum</i>	4.1	8.1	12	1.8	
<i>Maximum</i>	21	18	27	20	
<i>Average</i>	12	12	21	10	
<b>Standard Deviation</b>					
<b>Ellipse</b>					
<i>Perimeter (mm)</i>	52	38.8	61	63	43.2
<i>Area (mm<sup>2</sup>)</i>	216	106	281	311	116
<i>Elongation (ad)</i>	0.87	1.7	0.7	1.2	2.3
<b>Used Area (%)</b>	3	1	3	6	2
<b>Pits Density (mm<sup>2</sup>)</b>	0.02	0.01	0.02	0.02	0.02

Table IV. Morphometric features of the wear identified on the utilised areas of the experimental replicas. In detail, scaled retouch (FSR-1), marginal retouch (FRP-1), bipolar percussion (FA-8), striking platform maintenance (FSPM-13) and bladelet removal (FBR-2).

### 3.5 Archaeological sample

#### 3.5.1 Use wear analysis

In the archaeological sample, traces of use were identified on 7 objects. These allowed the determination of the use of the tools at Fumane cave as: **a)** hammerstones (n. 3, RF37, RF138, RF73); **b)** retouchers (n.2, RF80 and RF67); **c)** hammerstone/retoucher (n.1, RF127); anvil/retoucher (n.1, RF92). The artefacts showed a general rounding due to post-depositional alteration, probably of chemical nature. Invasive patinas or concretions were visible in one case (RF73 around the edge) (**Table V**).

##### 3.5.1.1 Hammerstones

In four cases (RF127, RF73, RF138, RF37) pits and flake scars were localized on the short edges of the tool, namely on the opposing short margins or, if the instrument presents a sub-circular shape, all around its perimeter. Small pits overlapped, often associated with short and chaotic striations (RF127) (**Fig 18**). Polishing was not present, probably due to the overall rounding of the surface caused by post-depositional alterations. For the same reason, the pits morphologies were not well defined. However, they shared characteristics similar to those observed on wear produced during core maintenance, related to the detachment of small flakes observed during the experimental knapping of bladelets. One hammerstone (RF138) was characterised by pits associated with negative flake scars (average dimensions 25mm) localised on the short edge of the tool. Deep, long striations were localised on the flat surface, or on the long edge (RF73 and RF37). The flake scars looked very similar to the experimental ones produced during bladelet removal and in overhang abrasions during core management. In one case (RF73) there was an association between the pits, in the marginal extremities, and long and deep striations on the flat surface (**Fig 19**). Moreover, on RF127 polishing was observed associated with intense rounding of the grains over the central area of the flat surface. These latter patches of polish, affecting the top of the grains were characterised by a flat topography and a smooth texture similar to that observed on the experimental sample and related to prehension (**Fig 20**).

##### 3.5.1.2 Anvil

Artefact RF92 featured pits with sub-triangular morphology over its central area. These had a rough bottom with microcracks visible over the grains. Polishing was not present. The observed functional



patterns were similar to the experimental sample used as a passive anvil for flake detachment (Fig 21).

### 3.5.1.3 Retouchers

Macro-traces observed at the stereo-microscope were represented by pits and striations. However, the pits displayed differences in morphology and location. In two cases (RF67 and RF127) the pits were located on the apices opposite to the flat surfaces (on one or both surfaces). The morphology of the pits was linear (reduced half-moon), with a triangular section. Polishing was not present (Fig 22, 23). In two other cases (RF80 and RF92) (Fig 24) pits were always located on the flat surfaces of the tool over the apices and were characterized by circular morphology, associated with the presence of long, parallel, superficial and overlapped striations. These traces were very similar to ones observed in the experimental replica used for marginal retouching.

Id	Type	Activity	Macro traces	Micro traces	Traces Localisation	Prehension	Note
RF73	Hammerstone	Core maintenance and overhang abrasion	Isolated striations, chaotic, deep and long; overlapping pits.	Absent	Pits located on short margins; striations on the flat surfaces	Absent	The sample is altered (grain detachment and rounding)
RF127	Hammerstone and Retoucher	Core maintenance and scaled retouch	Small pits, overlapping with associated small striations; linear (half-moon) pits.	The bottom of linear pits is not polished	Pits overlapping located all around the short margin; linear pits located on the two flat surfaces	Yes, in the central area, on the flat surface (rounding of grain, organic film, and patches of polish)	
RF67	Retoucher	Scaled retouch	Linear (half-moon) pits	The bottom of linear pits is not polished	Pits located on the two flat surfaces, opposite apices	Absent	Ochre residues; General rounding
RF92	Anvil and retoucher	Marginal retouch; passive anvil	Long, superficial striations with the same orientation, associated with small sub-circular pits; pits with sub-triangular or quadrangular morphology.	The bottom of the striations is not polished	Pits and associated striations located along the apices of the flat surfaces; pits with sub-triangular/quadrangular morphology in the central area on the flat surface	Absent	
RF80	Retoucher	Marginal retouch	Circular pits and associated striations on the apical areas of the flat surface	The bottom of the striations is not polished	On the apical areas of one flat surface	Absent	
RF138	Hammerstone	Bladelet removal	Flake detachment and overlapping pits. Morphology of the pits is not defined.	Polishing not present	Along the short, opposing, edges	Absent	Alterations, general rounding
RF37	Hammerstone	Overhang abrasion and percussion activity	There are long and deep striations and overlapping pits	Absent	Striations on one of the flat surfaces; and sporadic pits on a long margin	Absent	Alteration due to thermal contact; general rounding

Table V. Archaeological sample and use wear description and interpretation.

### 3.1.4 GIS Analysis - Archaeological sample

As in the case of the experimental replicas, the raw material characterising the archaeological specimens presented in this work was of a homogeneous nature overall.

Specimen RF67 was interpreted through use wear analysis as likely to be a retoucher used to produce scaled retouching based on the presence of traces of use over its apical area, where depressions characterised by a mean slope value of  $9.8^\circ$  were present. The topography of the surface was homogeneous overall with a low to medium degree of surface roughness (TRI mean value 0.00138) along with a low degree of topographic variation as indicated by the VRM mean value (0.0032). Wear generated by use featured a mean perimeter of 9 mm and mean area of  $1 \text{ mm}^2$ . As observed on the experimental replica, use related traces were located towards the artefact edge (mean distance 12mm), while their average distance from the tools centre was 20mm. Wear results were well dispersed over the apical area of the retoucher as indicated by the standard deviational ellipse elongation value (1.6 ad).

Use wear identified on artefact RF80 (**Fig 25-II, Table VI**) allowed us to interpret its function as a retoucher utilised for marginal retouching. As in the case of artefact RF67 (**Fig 25-I, Table VI**) wear was located over the apical area of the object, where depressions bearing a mean slope value of (13.8°) were visible. The utilised area was characterised by a rough surface (TRI mean value 0.0021) becoming smoother towards the centre of the tool. The same pattern was evinced from VRM (mean value 0.0016), with a higher degree of topographic variation towards the outer portion of the tool apical area and lower values characterising its inner portion. This phenomenon can be explained by the fact that the outer area of the tool's apex suffered a higher degree of surface crushing compared to its inner area. The traces observed on RF-80 were relatively small with an average perimeter of 2.8 mm and an average area of 0.33 mm<sup>2</sup>. Use related damage was localised nearer the edge of the retoucher (average distance 11 mm) than its centre (mean distance 14 mm). Use wear appeared dispersed over the apical area of the tool as indicated by the standard deviational ellipse value (1.3 ad).

Two distinctive functional areas were identified on artefact RF92 (**Fig 26-I, Table VI**), one localised at the centre of the object and one corresponding to its apical area. The wear identified on each of the FAs was related to two different activities, passive percussion (RF-92a) and marginal retouching (RF92b). RF-92a was characterised by the presence of depressions with a mean slope value of 22.6°, while more gentle slopes (mean value 15.6°) characterised the depressions identified over RF92b. The surfaces of both the functional areas exhibited a medium to high degree of roughness, with RF92a exhibiting a TRI mean value of 0.0022 and RF-92b featuring a TRI mean value of 0.0029. A difference between the two surfaces was found in their topographic variability. While RF92a was characterised by a low VRM mean value (0.0008), with the higher values corresponding to the bottom of the traces generated by use, a higher variability characterised RF-92b (VRM mean value 0.0023) where higher values were spread over the entire used surface. Traces observed on the central area exhibited a mean perimeter of 7mm and an average area of 1mm<sup>2</sup>. The damage was located close to the centre of the tool (mean distance 10 mm) and were concentrated, as indicated by the standard deviational ellipse elongation value of 0.7ad.

Use related damage identified on RF92b featured a mean perimeter of 7mm and an average area of 1 mm<sup>2</sup>. Traces were localised in proximity of the tool's edge (average distance 12mm) and were dispersed over the utilised area (stde elongation 2 ad).

Use wear associated with the adjustment of the core ridges was identified over artefact RF73 (**Fig 26-II, Table VI**). The utilised area of the tool was characterised by depressions bearing a mean slope value of 9.6°. Overall the surface topography was characterised by a medium to high degree of roughness (TRI mean value 0.0021) along with a low to medium degree of topographic variability (VRM mean value 0.0014). Traces related to use featured an average perimeter of 7 mm and an average area of 1 mm<sup>2</sup>. Damage was localised near the artefact's centre (mean distance 10mm) and was moderately dispersed over the used surface (stde elongation 1.3ad).

Three functional areas were identified on artefact RF127, corresponding to its apices (RF127a; RF127b) (**Fig 27-I, Table VI**) and its short edge (RF-127c) (**Fig 27-II, Table VI**). The wear identified on the apical area was associated with the production of scaled retouching, while the traces affecting its short edge were related to percussion activity involving the production of blank and core management. The apical area of the tool was characterised by a medium degree of surface roughness: TRI mean value 0.0015 (apical top) and TRI mean value 0.0021 (apical bottom). Both the apices were characterised by a low degree of topographic variability as indicated by the VRM mean values of 0.0012 (apical top) and 0.0011 (apical bottom). Use related damage affecting the top apical area featured a mean perimeter of 6.3 mm and an average area of 1 mm<sup>2</sup>. Similar dimensions were recorded within the traces located on the bottom apical area of the tool (average perimeter 6.7 mm and mean area 1 mm<sup>2</sup>). On both functional areas use related damage was dispersed over the surface as indicated by the recorded standard deviational ellipse value of 1.3 ad. The short edge of RF127 was instead characterised by slightly steeper depressions (mean value 20°) compared to the ones observed over its flat surface. The topography of the surface was moderately rough (TRI mean value of 0.0021) with

the lower values coinciding with the area of the edge mostly affected by use related damage. The surface topographic variability was low, given the VRM mean value of 0.0006. The traces identified on the short edge of RF127 exhibited a mean perimeter of 2.7 mm and an average area of 1 mm<sup>2</sup>. They appeared highly dispersed over the utilised surface, as indicated by the high standard deviational ellipse elongation value of 2.5 ad (Fig 28, Table VI).

	RF-67	RF-80	RF-92 (a)	RF-92 (b)	RF-73	RF-127 (a)	RF-127 (b)	RF-127 (c)
<b>Perimeter (mm)</b>								
<i>Minimum</i>	3.7	1.1	3.7	4	2.8	3.5	3.4	0.1
<i>Maximum</i>	18	10	32	14	26	13	10.5	17
<i>Average</i>	9	2.8	7	7	7	6.3	6.7	2.7
<b>Area (mm<sup>2</sup>)</b>								
<i>Minimum</i>	1	0.1	1	1	1	1	1	1
<i>Maximum</i>	4	1.5	10	2	6	2	2	4
<i>Average</i>	1	0.3	1	1	1	1	1	1
<b>Distance from Centre (mm)</b>								
<i>Minimum</i>	13	9.2	2.4	26	0.4	9.5	12	
<i>Maximum</i>	29	19	19.4	40	18	20	22	
<i>Average</i>	20	14	10	32	9.5	16	17	
<b>Distance from Edge (mm)</b>								
<i>Minimum</i>	6	6	10	6	13	4.6	4.6	
<i>Maximum</i>	18	15	26	19	33	16	14	
<i>Average</i>	12	14	20	12	25	10	9	
<b>Standard Deviational Ellipse</b>								
<i>Perimeter (mm)</i>	42	27	69	50	65	32.7	29	42
<i>Area (mm<sup>2</sup>)</i>	130	55	372	170	330	81	64	180
<i>Elongation (ad)</i>	1.6	1.3	0.7	2	1.3	1.3	1.3	2.5
<i>Used Area (%)</i>	2	<1	1	1	1	<1	<1	4
<b>Pits Density (mm<sup>2</sup>)</b>	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table VI. Morphometric features of the wear identified on the utilised areas of the archaeological specimens.

#### 4. Discussion

Through the application of a dedicated experimental framework we were able to test the usage, and suitability for the task, of different areas of the hammerstone or retoucher. Use wear analysis, performed at low and high magnification, permitted the definition of the morphological characteristics of wear associated with each of the performed activities. In the study of archaeological samples from Fumane Cave, macro-trace analysis, performed at low magnification, resulted to be more indicative than the observation of micro wear at high magnification, due to the fact that in some cases chemical alteration had prevented the preservation of the micro traces. GIS analysis allowed the investigation of the macro-traces from a quantitative point of view, analysing aspects such as dimensions and spatial distribution of the wear generated by each activity. Moreover, it permitted the collection of data concerning the topographic characteristics (e.g. slope, roughness and topographic variability) of the utilised area of the tool.

Overall, the dedicated experimental framework allowed the isolation of both qualitative and quantitative features concerning use wear deriving from both percussion and retouching activities. The microscopic analysis of the surfaces provided qualitative aspects such as development of polish, micro-striations etc. GIS analysis revealed quantitative data (distance from centre, distance from edge and wear dispersion, this latter defined by the standard deviational ellipse elongation value) concerning the morphometry of use related damage associated to retouching activity, bipolar percussion and core maintenance activities.

Comparing the experimental and archaeological datasets provided positive results (Fig 29, 30, 31), supporting interpretation derived from use wear analysis. However, on this matter, a note of caution needs to be made. When the dimensions of damage were compared, those of the wear on the

experimental replicas resulted to be much larger than those observed on the archaeological materials. This is due to the post depositional alteration affecting the archaeological specimens and leading to an overall rounding and modification of the wear morphology, suggesting that dimensions alone cannot be considered as a diagnostic feature in the interpretation of tool use.

Within the Fumane Cave macro-lithic sample, several implements exhibited use patterns resembling the ones recorded on the experimental replicas used in scaled and marginal retouching. In particular, artefacts RF67 and RF127 have been interpreted as retouchers used for scaled retouching, while the apical area of artefact RF92 and RF80 exhibited use wear features which led to their interpretation as retouchers used to produce marginal retouching. On 4 archaeological artefacts coming from Fumane Cave, the presence of overlapping pits over the short edges of the tools (RF127, RF138) and of deep long striations affecting the flat surface of the implements (RF73, RF37) led to the interpretation of the artefacts as hammerstones used in both blank production and core maintenance activities. Wear patterns similar to the ones associated with bipolar percussion have been identified on the central surface area of artefact RF92 leading to the interpretation of the use of its central area as an anvil (**Fig 32**). Our results enabled the identification of specific functional patterns related to the use of hammerstones and retouchers at Fumane Cave. We have been able to isolate specific patterns both regarding the morphology of the wear, its spatial distribution and the topography of the used area associated with each of the activities performed. This permitted the placing of the Protoaurignacian and Aurignacian macro-tools of Fumane Cave into specific stages of the production process of chipped tools. Our analysis underlined the high efficiency of the Fumane cave macro-tools in activities concerning core maintenance, blank production and tool retouching. The use of these implements in advanced stages of core maintenance and blank production is suggested by the absence of artefacts bearing traces associated with the initial stage of core reduction. Furthermore, the analysis of the retouchers suggests relevant behavioural insights regarding the choice of objects with specific features (i.e. different types of limestones, soft or compact; the morphological features that favours the success of the product;). Moreover, the analysis of wear from a morphological and spatial point of view permitted to formulate a preliminary hypothesis, that will be confirmed in the future, under which the archaeological tools were used employing two preferential gestures, perpendicular and oblique, involved in the production of scaled, marginal and abrupt retouches. The experimental results showed how, adopting a scaled retouch, it was possible not only to package or maintain formal tools such as end-scrapers, but also to delineate the lateral edges of some thicker blades. On the contrary, marginal and abrupt retouch was mainly used to transform the flake/blade edges. Retouching on an anvil, and edge abrasion techniques aimed at bladelet retouching, currently do not match with the archaeological traces and, following our results, it was difficult to use the flat surface of the retoucher to perform the former activity. The absence of these types of use wear does not exclude that other raw materials and techniques have been used in the production of the Dufour and pointed bladelets at Fumane Cave.

## **5. Conclusion**

Given the lack of functional studies focused on the uses of hammerstones and retouchers, the combined approach presented here enhances our current knowledge of this specific kind of tool. This approach provides data not only related to the use of the tools at the site (e.g. [128]) but also involving the gestures and ergonomic choices characterising the Protoaurignacian and Aurignacian human groups of Fumane Cave. As emphasized by Bracco et al. [129] the reconstruction of gesture plays a major role within the analysis of technical processes. The traces of prehension observed and documented during the experimental phase, and evidenced in the archaeological sample, reveal that in Fumane Cave there were different ways of handling the objects. However, it is evident that the

study of the variables on the modalities of prehension requires the formulation of a specific experimental protocol.

The preliminary study conducted here showed the potentials of an integrated method applied to the study of prehistoric macro-lithic tools, which can be successfully increased in the future with the support of a broader experimental collection. Our results emphasize the importance of the combination of qualitative (use wear) and quantitative (GIS analysis) approaches which can be applied to a variety of tool categories, providing new data enhancing not only our knowledge regarding the use of ancient Palaeolithic or Mesolithic tools but also, in a broader way, our understanding of ancient human behaviour.

## Acknowledgements

We are grateful to Giulia Formichella for the drawing in Fig.6 and to the two anonymous reviewers for their careful reading of the manuscript and constructive comments, which helped us to improve the first version of the article.

**Authors Contribution:** IC, EC, MP conceived and planned the project; IC, AZ, DM, GM, AF, RD, MP, EC wrote the paper; IC, AZ performed analytical work and data analysis and interpretation (IC performed the use wear analysis and AZ performed the GIS analysis); IC, AZ, DM, RD, MP, EC conceived and designed the experimental activity; IC, AZ, DM, RD performed the experimental activity; MP designed and directed the excavation at the Fumane Cave and tool sampling; MP, AF supervised the archaeological coherence of the experimental framework; all authors read, revised and approved the final version of the manuscript.

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## Captions

**Figure 1. Map showing the localization of Fumane Cave (Verona, Italy).**

**Figure 2. The Protoaurignacian and Aurignacian pebbles discovered in Fumane Cave (Verona, Italy).**

**Figure 3. Schematic representation of the methodology applied for the creation of 3D models and the spatial analysis of the utilised areas of the tools.**

**Figure 4. Experimental retouching.** a) Production of marginal and abrupt retouch; b) production of scaled retouch on the lateral edge of a laminar flake; c) blank retouch through edge abrasion.

**Figure 5. Schematization of the gestures used during the retouching experimental activity.** a) The marginal and abrupt retouch: a rapid and consequential gesture was performed. The knapper’s arm moved following an oblique dragging trajectory against the blank’s edge, striking it very quickly using the tool’s flat face along the apical area.; b) the scaled retouch: This action followed a perpendicular trajectory, with respect to the blank edge, with a movement from the top to the bottom of the arm and a final flexion downwards.(drawings by Giulia Formichella).

**Figure 6. Experimental bipolar percussion and retouch on anvil.** a) Bipolar percussion for flake production; b) hinged laminar flake retouch on anvil adopting a rectilinear trajectory; c) bladelet retouch on anvil adopting an oblique trajectory.

**Figure 7. FSPM-13 use wear on experimental replica used in overhang abrasion.** a) Macro-traces (30x) long, deep striations alternate with more superficial striations, with different orientations. They are located on the flat and/or on the long edge of the instrument; b) micro-traces (200x), striations with polishes on the bottom, with rough texture; c) 3D microtopography of the unused surface and profile; d) 3D microtopography of the used surface and profile.

**Figure 8. FBR-2 use wear on an experimental replica used in the configuration of the striking platform of the core.** a) Macro-traces (30x) highlight the presence of overlapping pits with sub-oval morphology, located all around the marginal perimeter of the object; b) micro-traces (200x) are extended onto the top of the grains, with smooth texture, flat topography, striation with the same orientation, and concentrated-separated distribution; c) 3D microtopography of the unused surface and profile; d) 3D microtopography of the used surface and profile.

**Figure 9. FA-8 use wear on experimental replica used in passive percussion.** a) Macro-traces (40x) consisted of large pits with sub-quadrangular/triangular morphology, grains appeared fractured, located in the central area of the flat surface of the pebble; b) the micro-traces (200x) are absent, the bottom of the pits appear rough; c) 3D microtopography of the unused surface and profile; d) 3D microtopography of the used surface and profile.

**Figure 10. FRS-1 use wear on experimental replica used in scaled retouch.** a) Macro-traces (30x), contiguous pits of linear form (half-moon), with rough bottom, and triangular section; the traces are located in the centre of the apical area; b) polishes (200x) are absent; c) 3D microtopography of the unused surface and profile; d) 3D microtopography of the used surface and profile.

**Figure 11. FRP-1 use wear on experimental replica used in marginal retouch.** a) Macro-traces highlight area characterized by a concentration of micro-pits (25x) with sub-circular morphology; b) long striation (20x) associated with the pits and with the same orientations; the traces are located in apical top with oblique orientation; c) micro-traces (200x), band of polishes with striations, covered-closed distribution, rough texture and domed topography; d) 3D microtopography of the unused surface and profile; e) 3D microtopography of the used surface and profile (striations and pits).

**Figure 12. Experimental use wear related to the prehension.** a-b) Patch of polishing visible through the metallographic microscope (100x), localised on the top of the grain; c-d) smooth/flat patch of polishing visible through the metallographic microscope (200x).

**Figure 13. Experimental objects utilized for scaled retouch (I) and marginal retouch (II).** a) Spatial distribution of the identified wear; b) slope; c) terrain roughness index; d) vector roughness measure.

**Figure 14. Experimental object utilized in passive percussion (I) and core ridge adjustment (II).** a) Spatial distribution of the identified wear; b) slope; c) terrain roughness index; d) vector roughness measure.

**Figure 15. Experimental object utilized for bladelet production.** a) Spatial distribution of the identified wear; b) slope; c) terrain roughness index; d) vector roughness measure.

**Figure 16. Perimeter of the wear.** a) Dimensions of the wear identified over the utilized areas of the experimental replicas; b) mean distance of the identified wear from the object centre; c) mean distance of the identified wear from the object edge; d) dispersion of the identified wear over the tool surface defined by the elongation of the standard deviational ellipse.

**Figure 17. Comparison of the surface topography before and after the use of the tool to produce scaled and marginal retouch, percussion activities and bladelet production.** Digital Surface Maps of Slope, TRI and VRM respectively.

**Figure 18. Use wear identified on artefact RF127.** a) Macro-traces (25x), overlaid pits with sub-circular morphology; b) macro-traces (10x), pits located around the short edge of the artefact; c) 3D microtopography of the used surface and profile.

**Figure 19. Use wear identified on artefact RF73.** a) Macro-traces (20x), long striations with different orientations located on the flat surfaces in the central area; b) pits (20x) on the marginal surface, overlapping, covered by the patina. The artefact is affected by dissolution; c) 3D microtopography of the used surface and profile.

**Figure 20. RF127b archaeological sample with intense rounding of the grains over the central area of the flat surface.** a) Polishing (100x) affecting the top of the grains; b) patch of polish characterised by a flat topography and smooth texture (200x).

**Figure 21. Use wear identified on artefact RF92.** a) Macro-traces (20x), micro-pits with sub-circular morphology associated with long parallel striations, located in the apical top with oblique orientation; b) micro-traces (200x) are absent, a general rounding is visible; c) macro-traces (20x), pits with triangular morphology, located in the centre area of the flat surface; d) polishing is absent (200x); e) 3D microtopography and profile of the used surface related to a-b); f) microtopography and profile of the used surface related to a-b).

**Figure 22. Use wear identified on artefact RF67.** a) Macro-traces (10x), contiguous pits of linear form (half-moon), with rough bottom and triangular section, located on the centre of apical area; b) micro-traces (200x) are absent; c) 3D microtopography of the used surface and profile.

**Figure 23. Use wear identified on artefact RF127.** a) Macro-traces (30x), contiguous pits of linear form (half-moon), with rough bottom, located on the centre of apical area; b) pits with rough bottom (200x); c) 3D microtopography of the used surface.

**Figure 24. Use wear identified on artefact RF80.** a) Macro-traces (20x), small circular pits associated with long parallel striations, located in apical top with oblique orientation; b) micro-traces (200x), polishing is absent, a general rounding of the artefact can be observed; c) 3D microtopography of the used surface.

**Figure 25. Archaeological items, RF67 (I) and RF80 (II), utilized in scaled retouching and marginal retouching.** a) Spatial distribution of the identified wear; b) slope; c) terrain roughness index; d) vector roughness measure.

**Figure 26. Archaeological items RF92 (I) and RF73 (II) utilised in retouch and percussion activities (RF92) and core ridge adjustment (RF73).** a) Spatial distribution of the identified wear; b) slope; c) terrain roughness index; d) vector roughness measure.

**Figure 27. Archaeological items RF127.** The surface of the tool (I) has been used in retouch activities while its edge (II) was used to produce bladelets/core adjustment. a) Spatial distribution of the identified wear; b) slope; c) terrain roughness index; d) vector roughness measure.

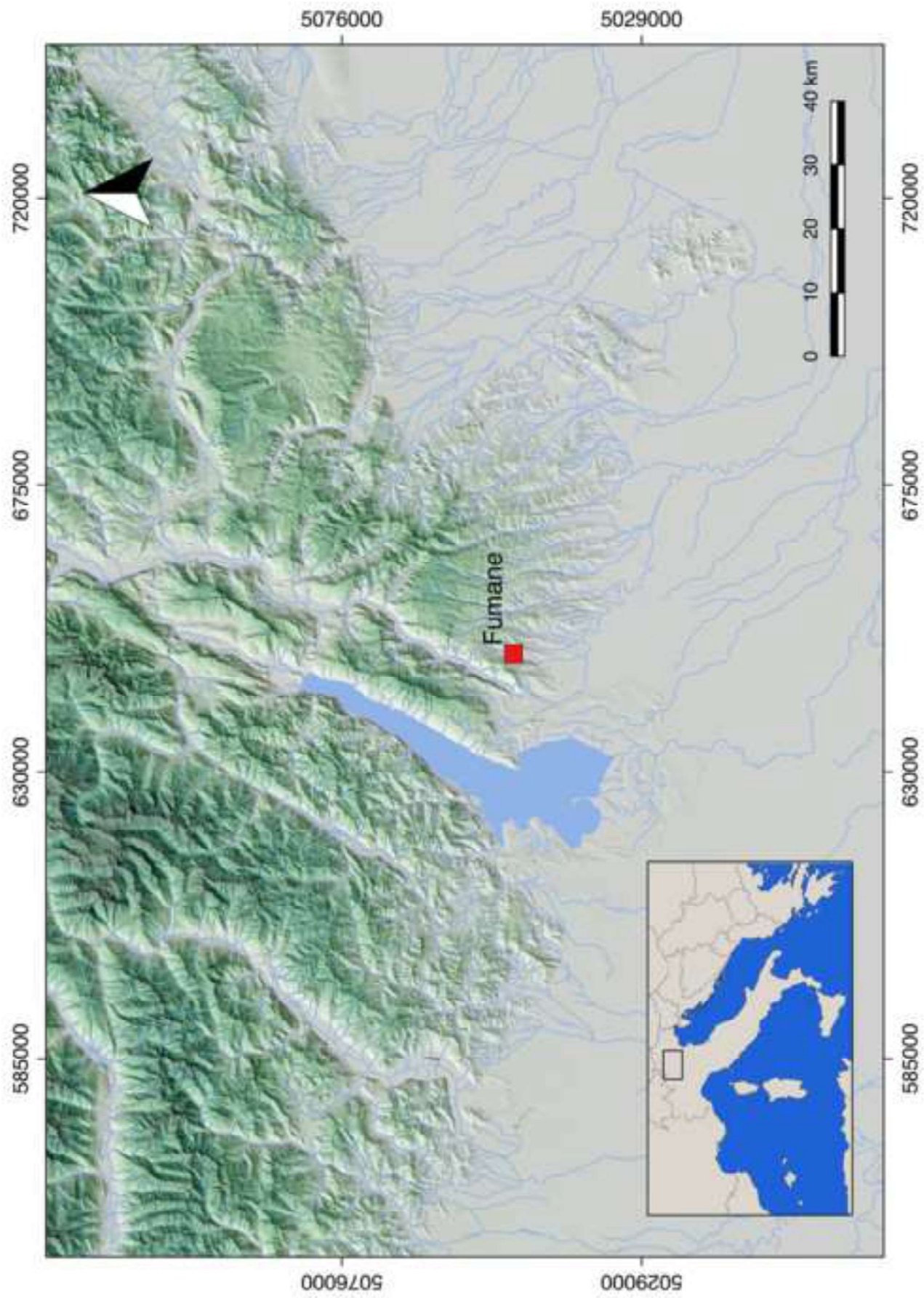
**Figure 28. Archaeological specimens.** a) Dimension of the wear identified over the utilized areas; b) mean distance of the identified wear from the object centre; c) mean distance of the identified wear from the object edge; d) dispersion of the identified wear over the tool surface defined by the elongation of the standard deviational ellipse.

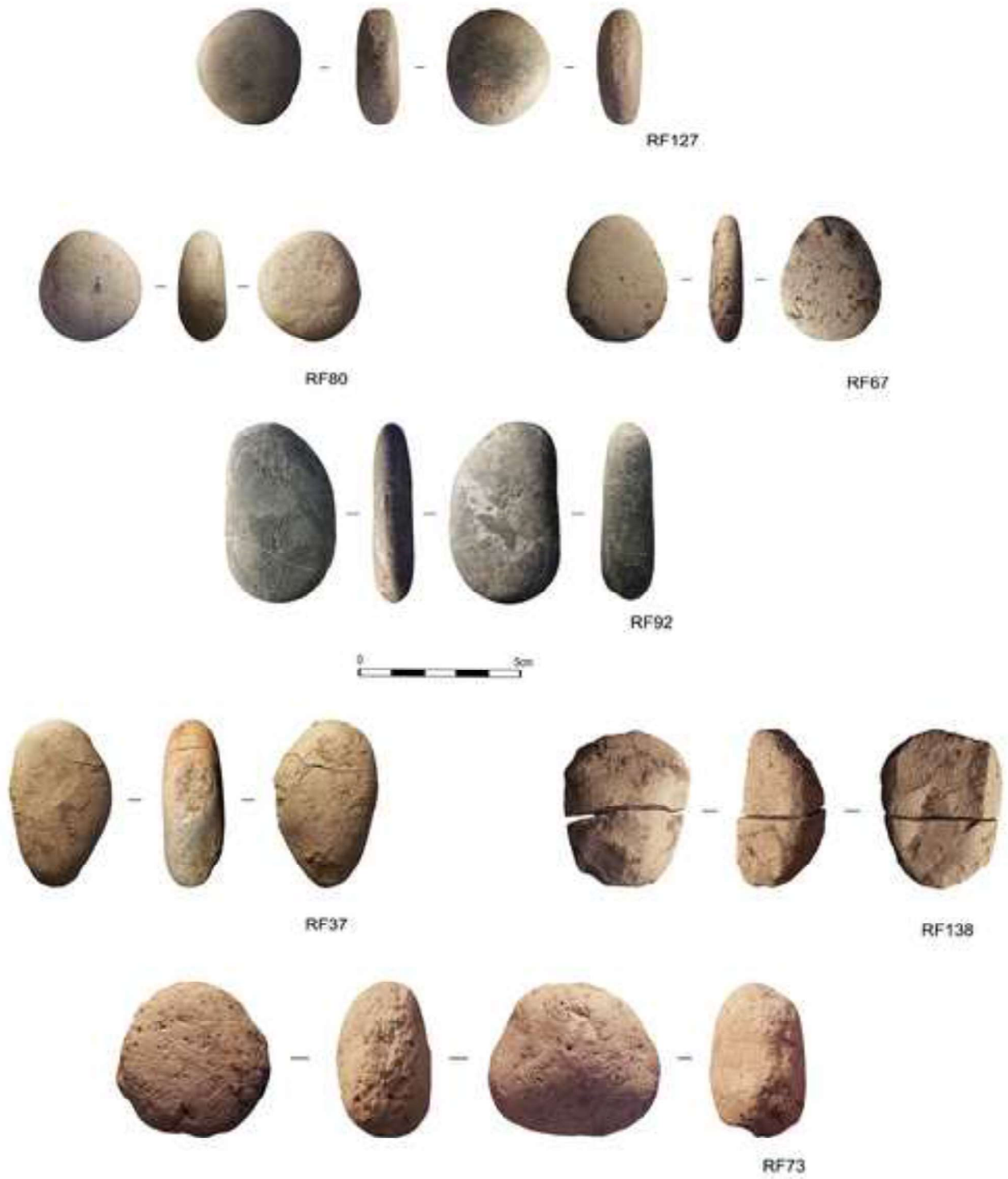
**Figure 29. Comparison between the perimeters of the wear observed on the experimental=green, and archaeological=blue specimens.**

**Figure 30. Comparison between the mean distances from the centre and the edge of the tool observed on the experimental and archaeological specimens.**

**Figure 31. Comparison between the mean perimeter of the wear identified on the experimental and archaeological specimens.** In detail, crosses = retouch activities; diamonds=bipolar percussion; triangles=striking platform management; square=bladelets production).

**Figure 32. Comparison between the experimental and archaeological use wear and their distribution.** a) Experimental striations (10x) related to the overhang abrasion, localised (b) on the flat surface of the pebble; c) archaeological striations (10x), localised (d) on the flat surface of the sample; e) experimental pits (15x) related to core maintenance/bladelets removal, with sub-oval morphology, localised (f) around the short edge of the pebble; g) archaeological pits (10x) with sub-oval morphology, (h) localised around the short edge of the sample; i) experimental pits (40x) related to scaled retouching, with linear (half-moon) morphology, rough bottom, localised (l) on the apices of the flat surface; m) archaeological pits (40x) with linear (half-moon) morphology, rough bottom, localised (n) on the apices of the flat surface; o) experimental pits (20x), related to the anvil used for the flakes detachment, with sub-triangular morphology, localised (p) in the centre of the pebble; q) archaeological pits (20x), with sub-triangular morphology, localised (r) in the centre of sample; s) experimental circular pits associated with the striations (20x), related to marginal retouching, localised (t) on the apices of the flat surface with oblique orientation; u) archaeological circular pits and striations associated (20x), localised on the apices of the flat surface with oblique orientation.





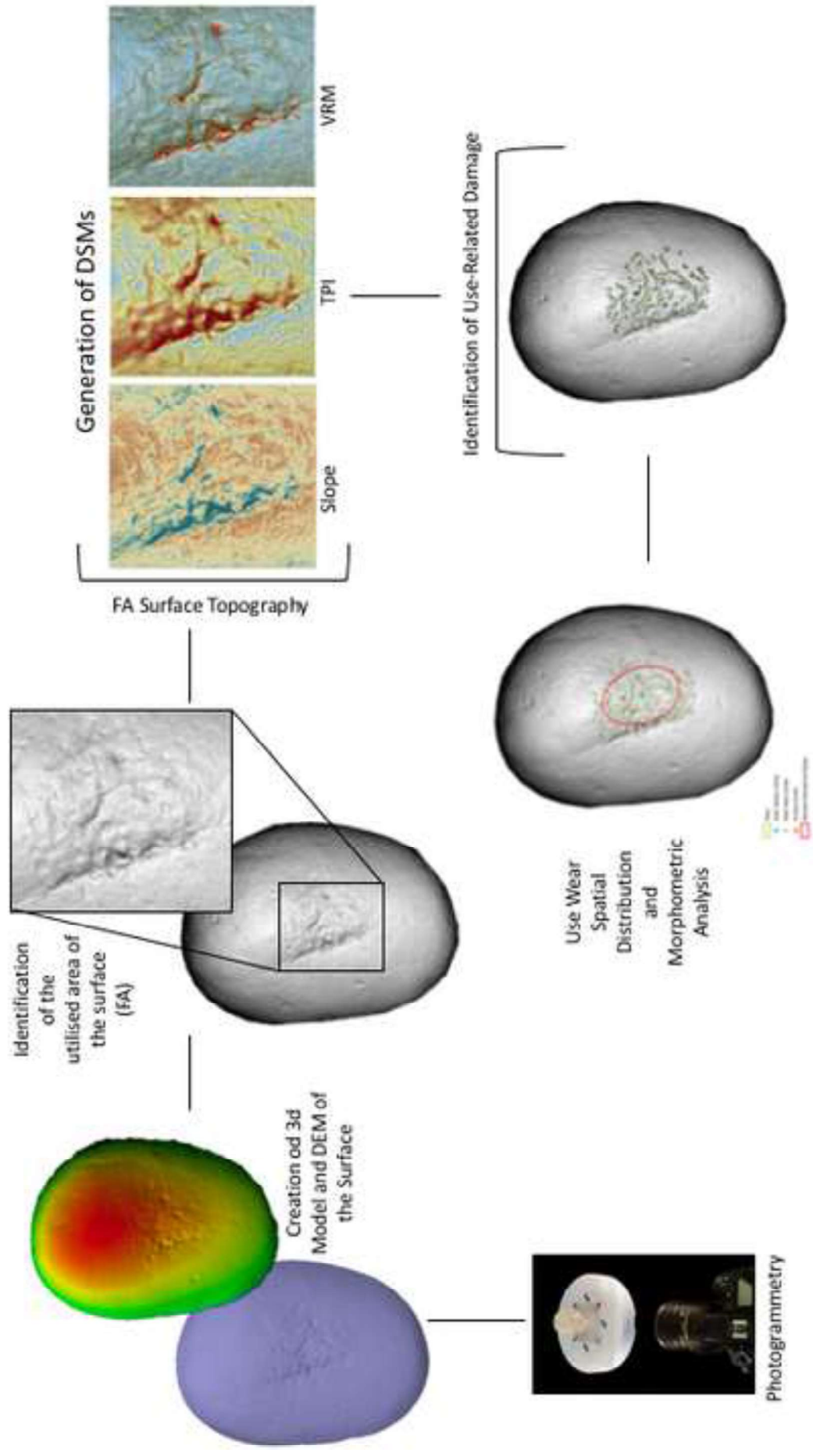
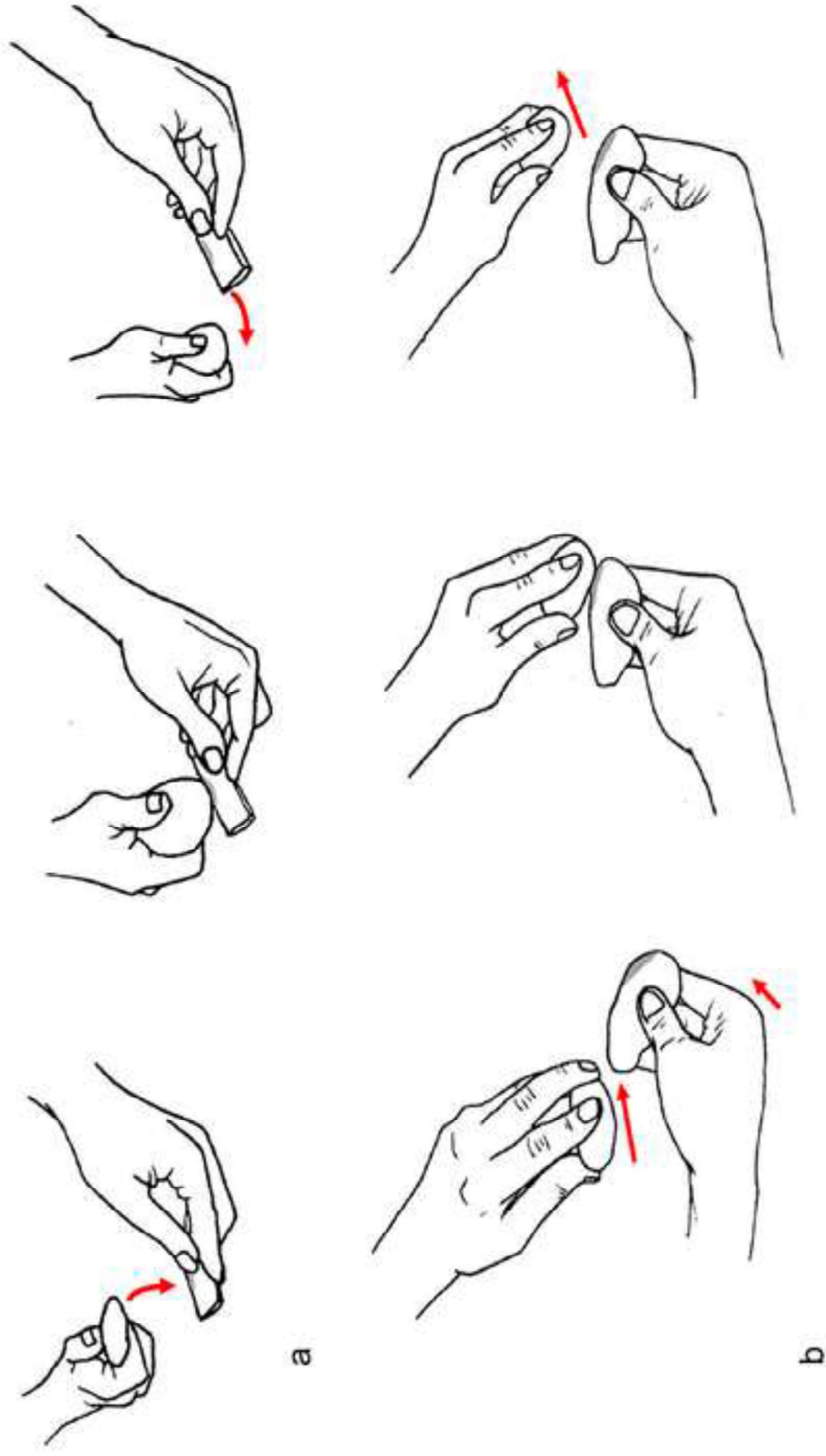


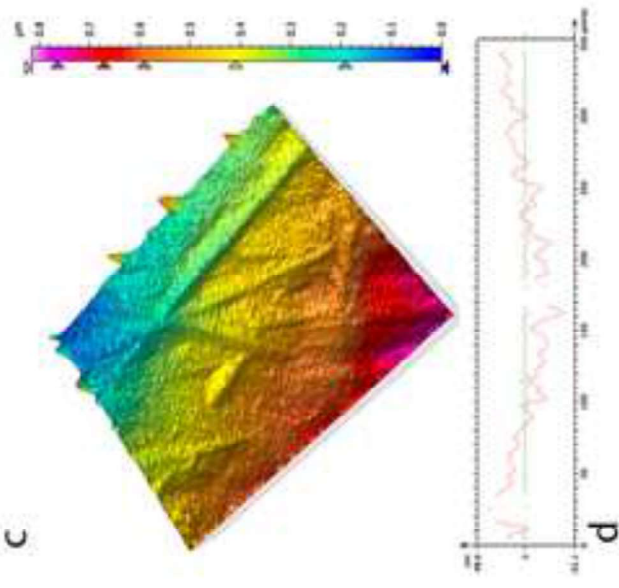
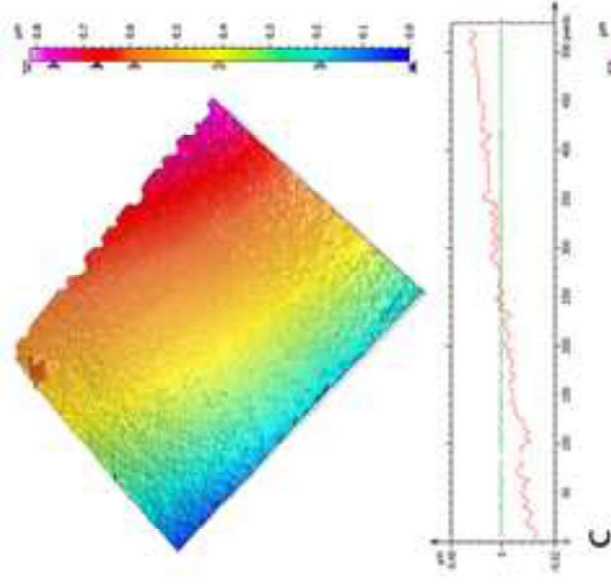
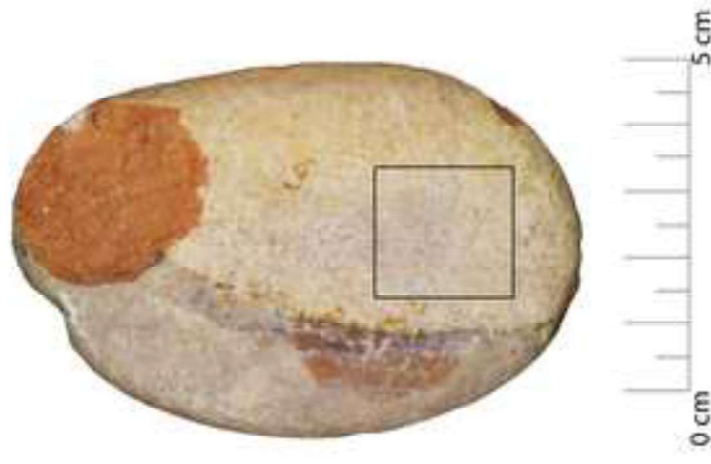
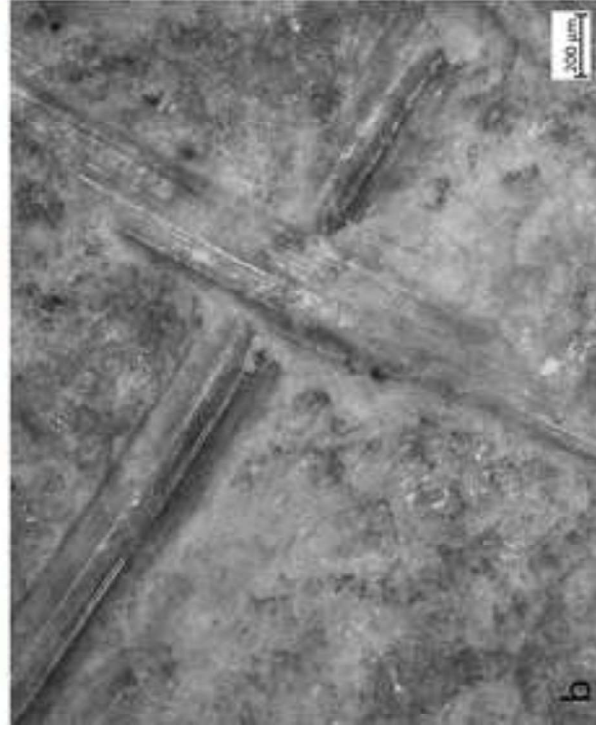
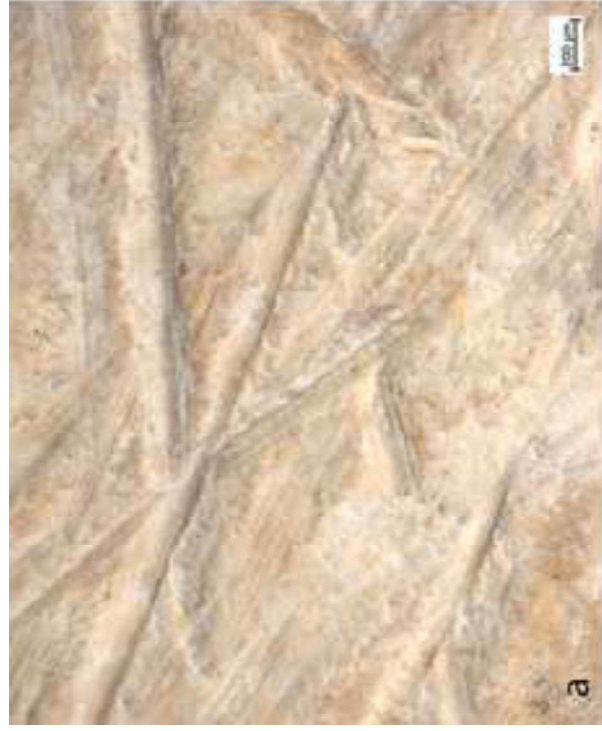
Figure 3

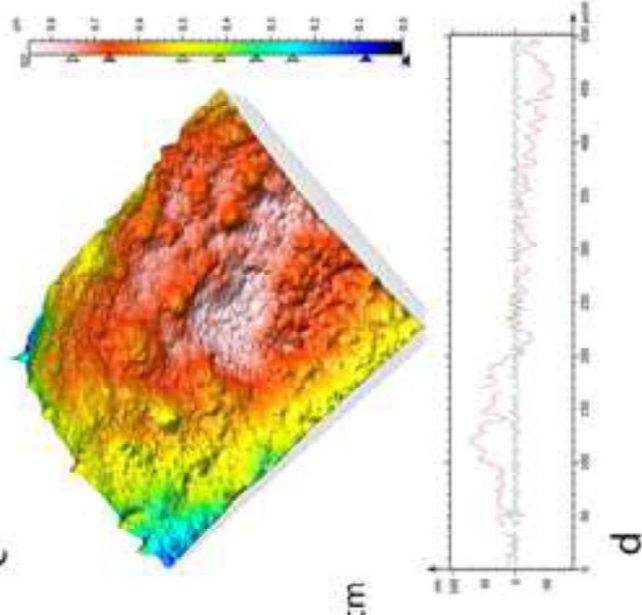
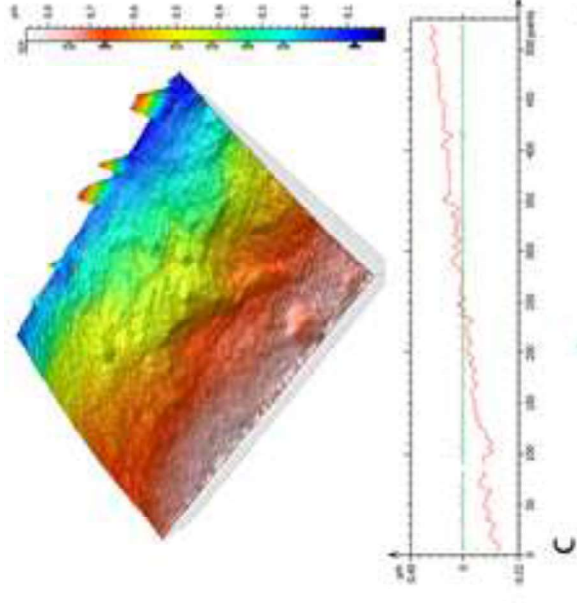
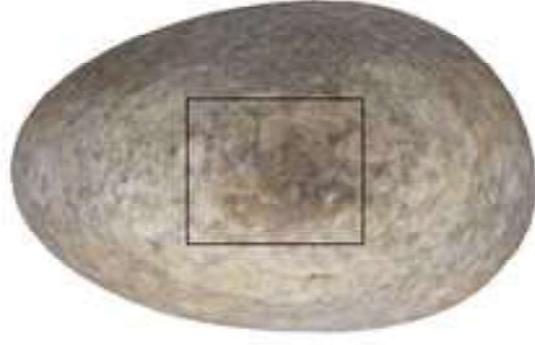
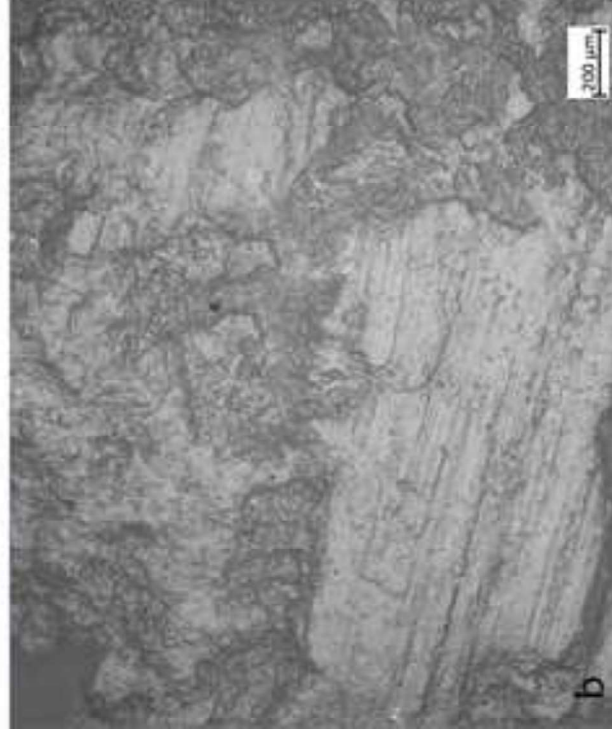


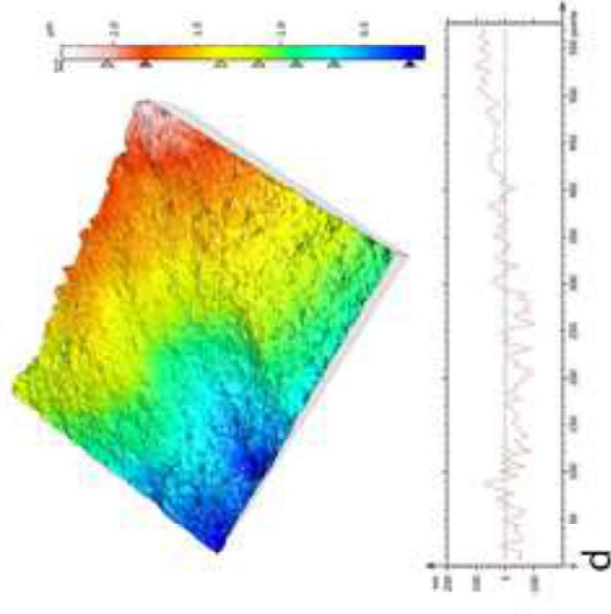
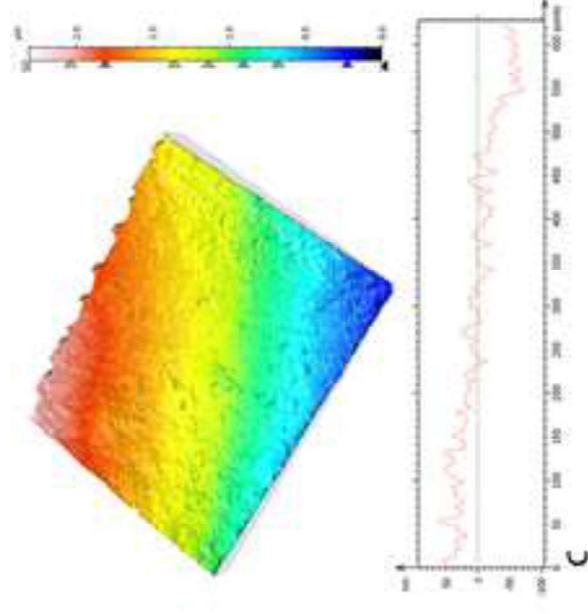
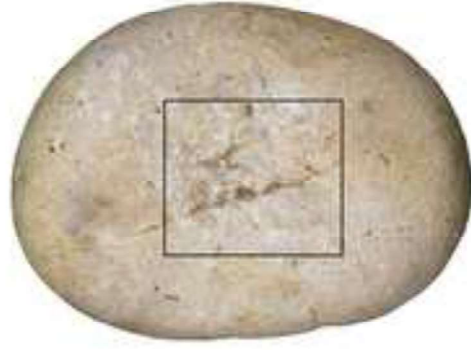
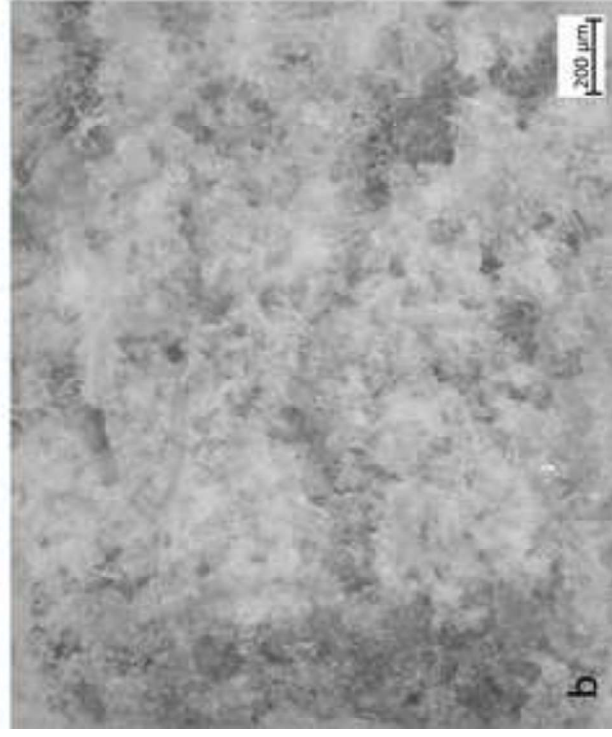
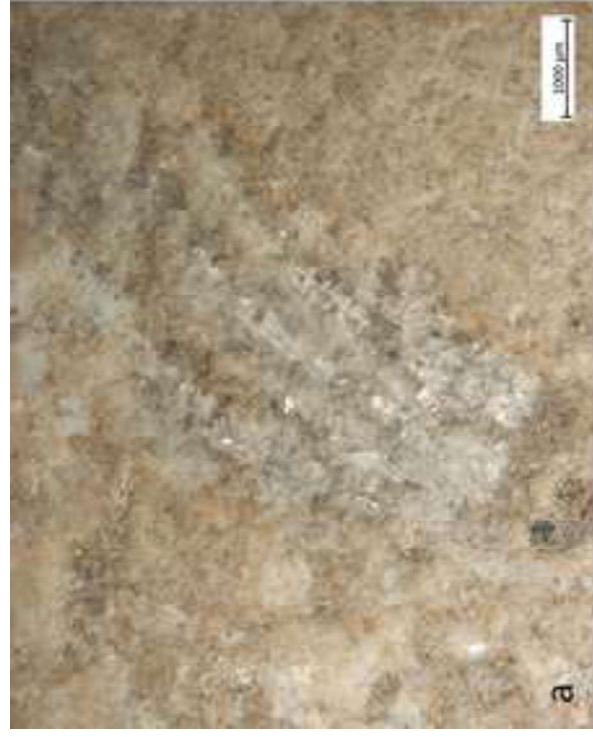


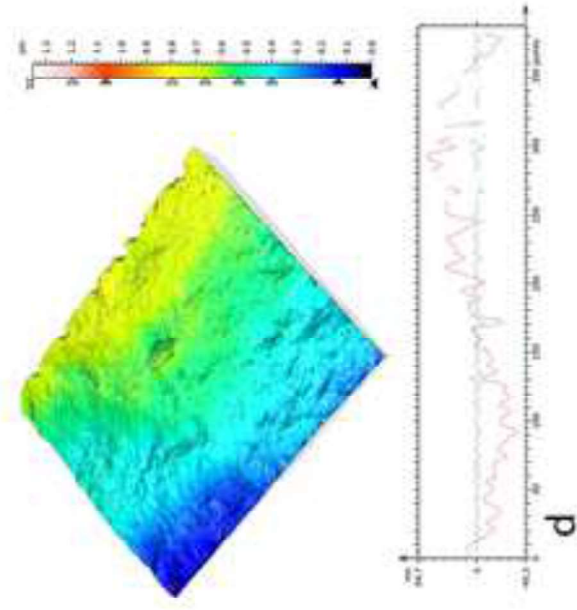
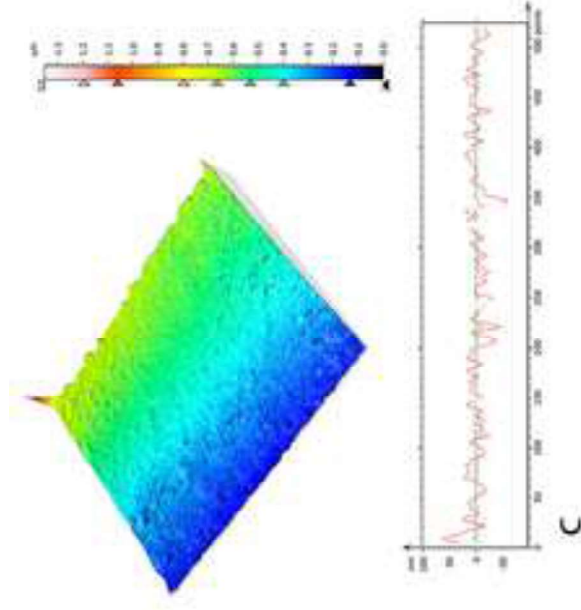
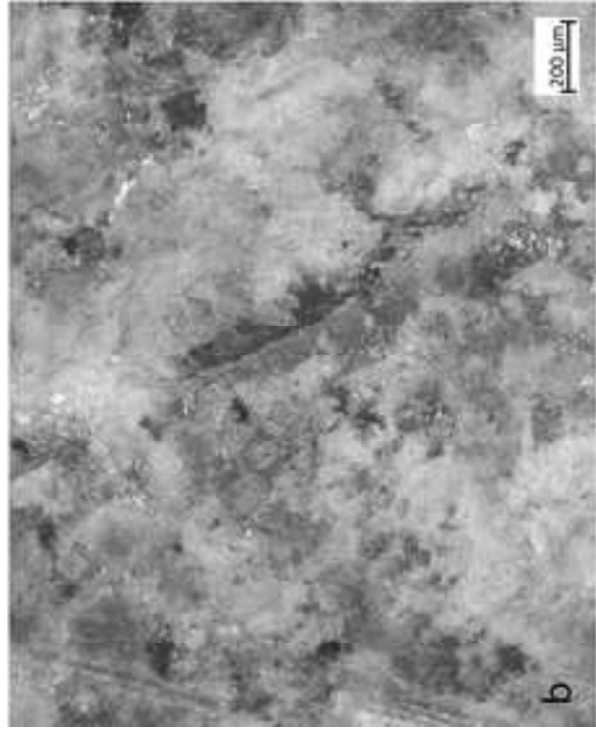


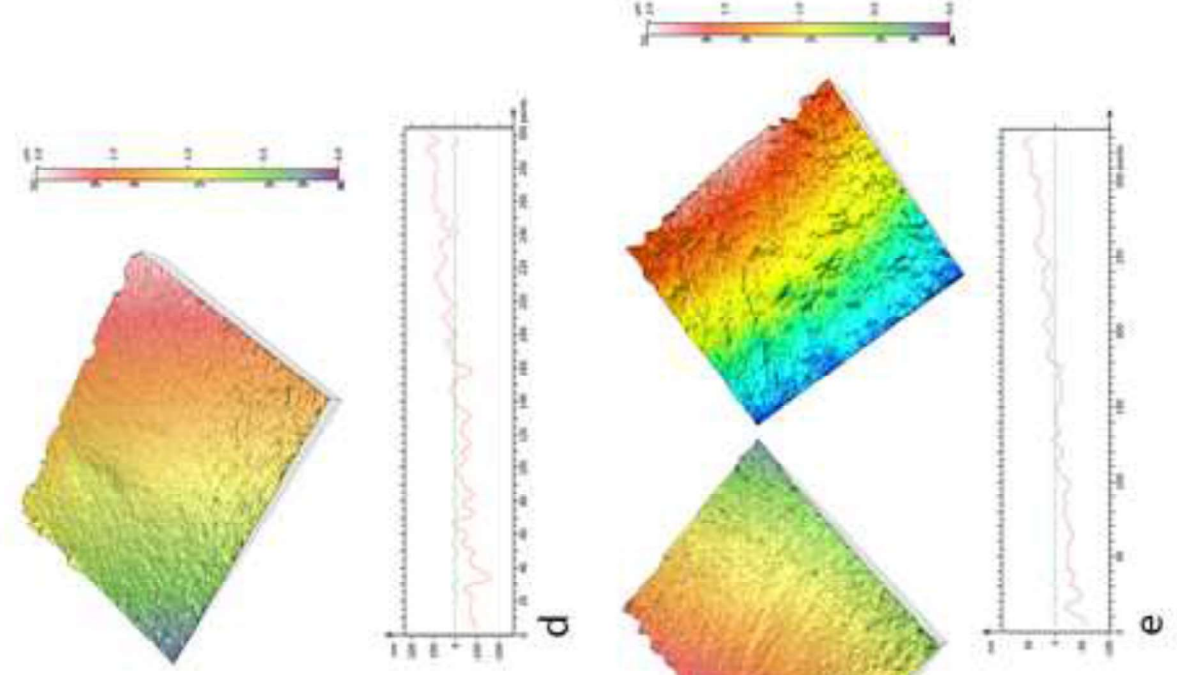
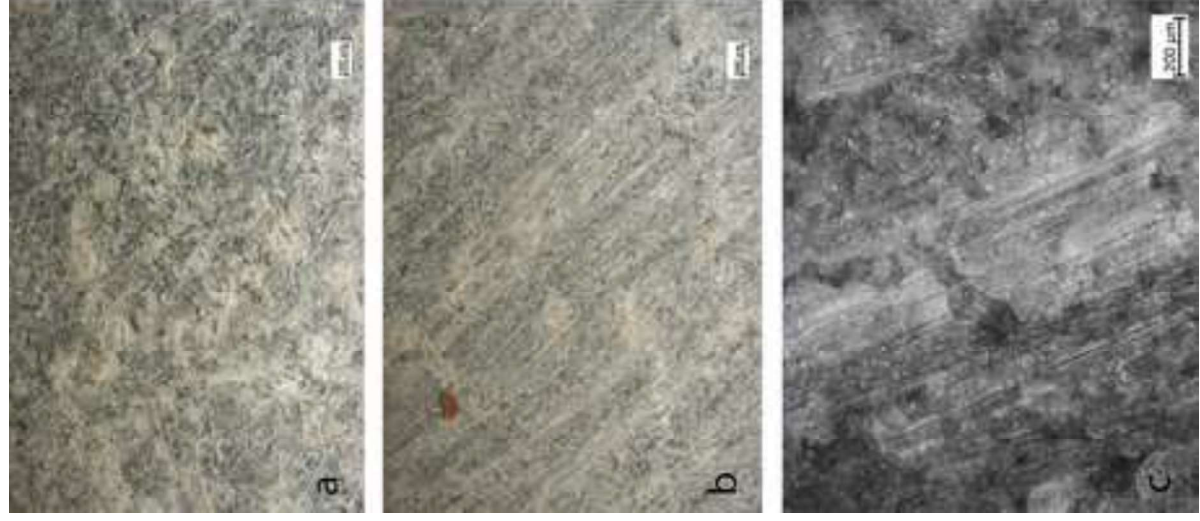


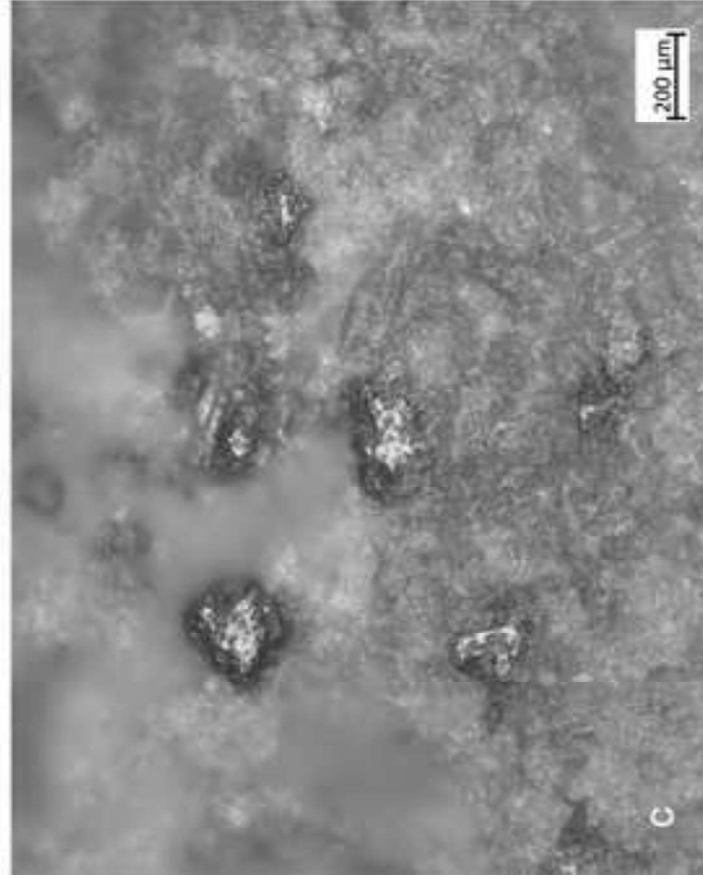
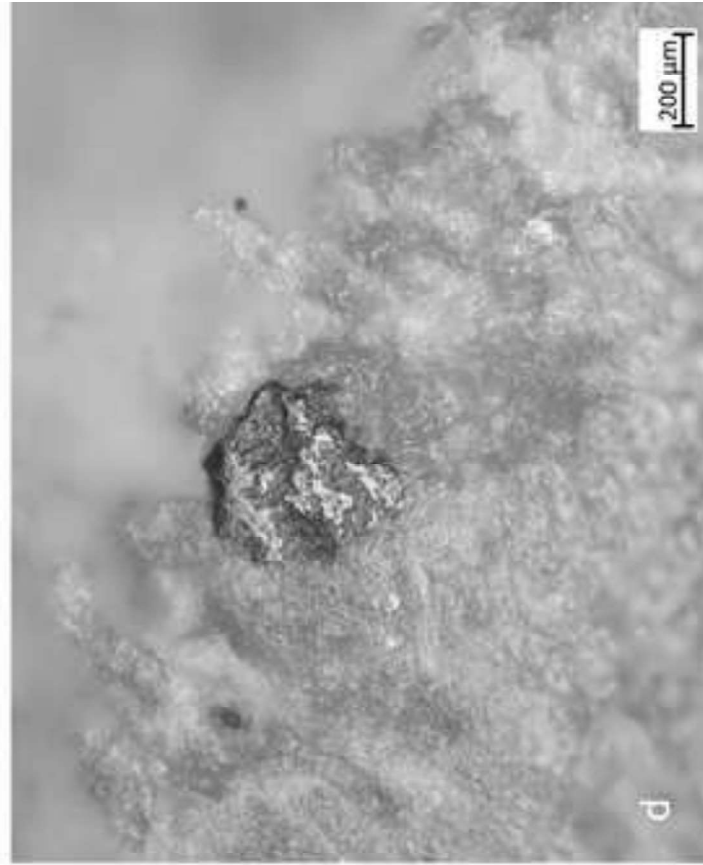
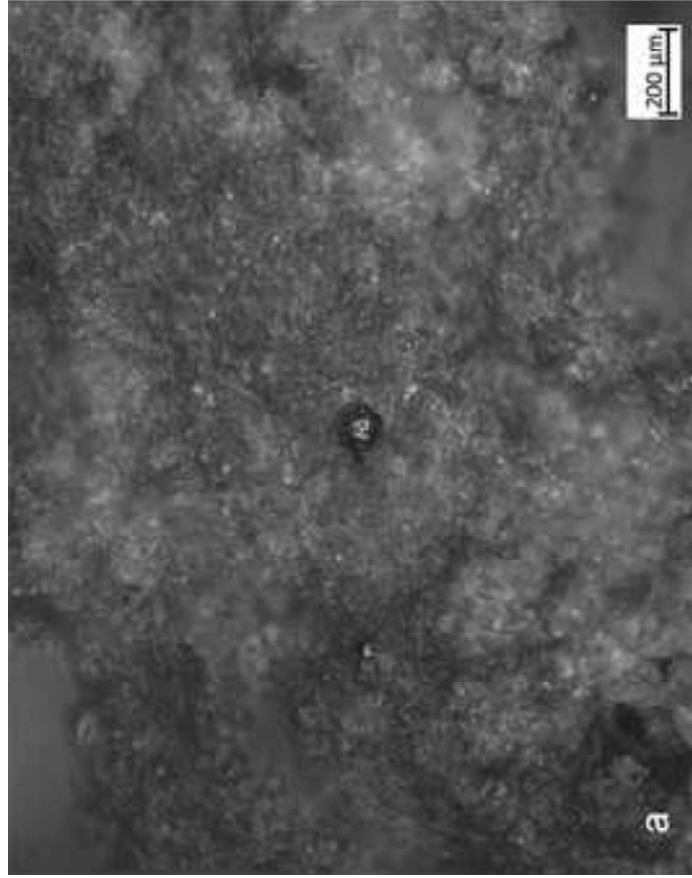
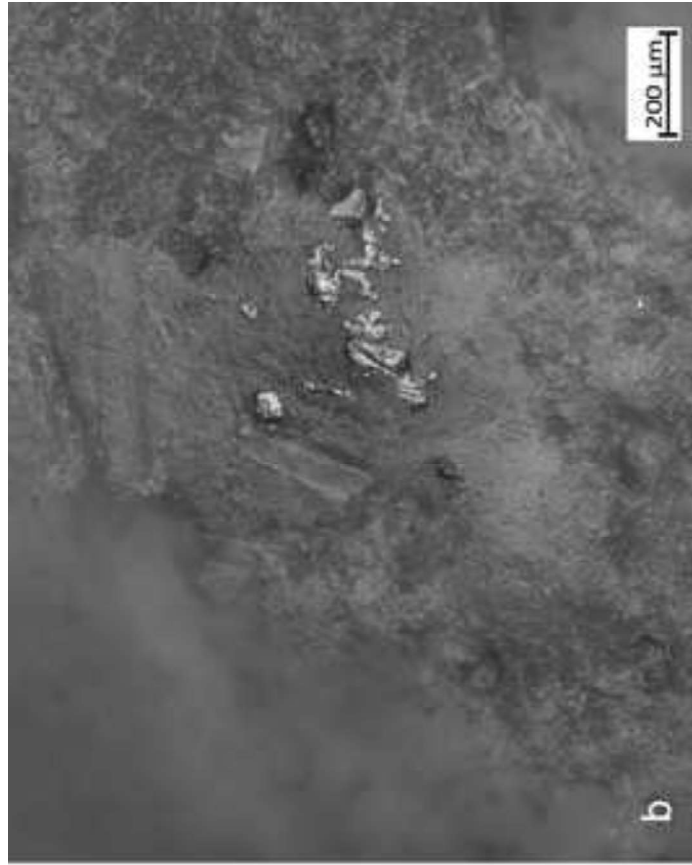




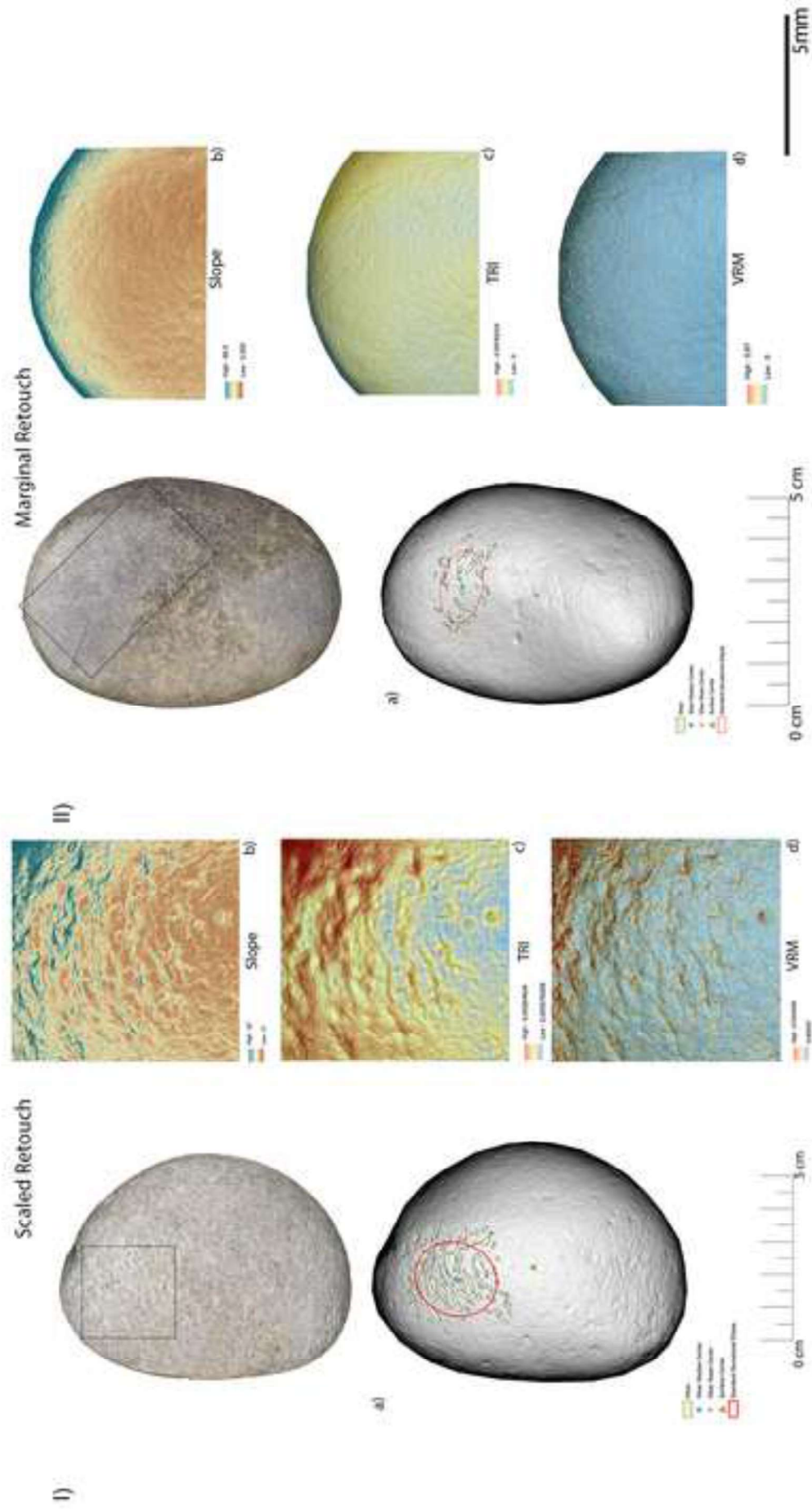


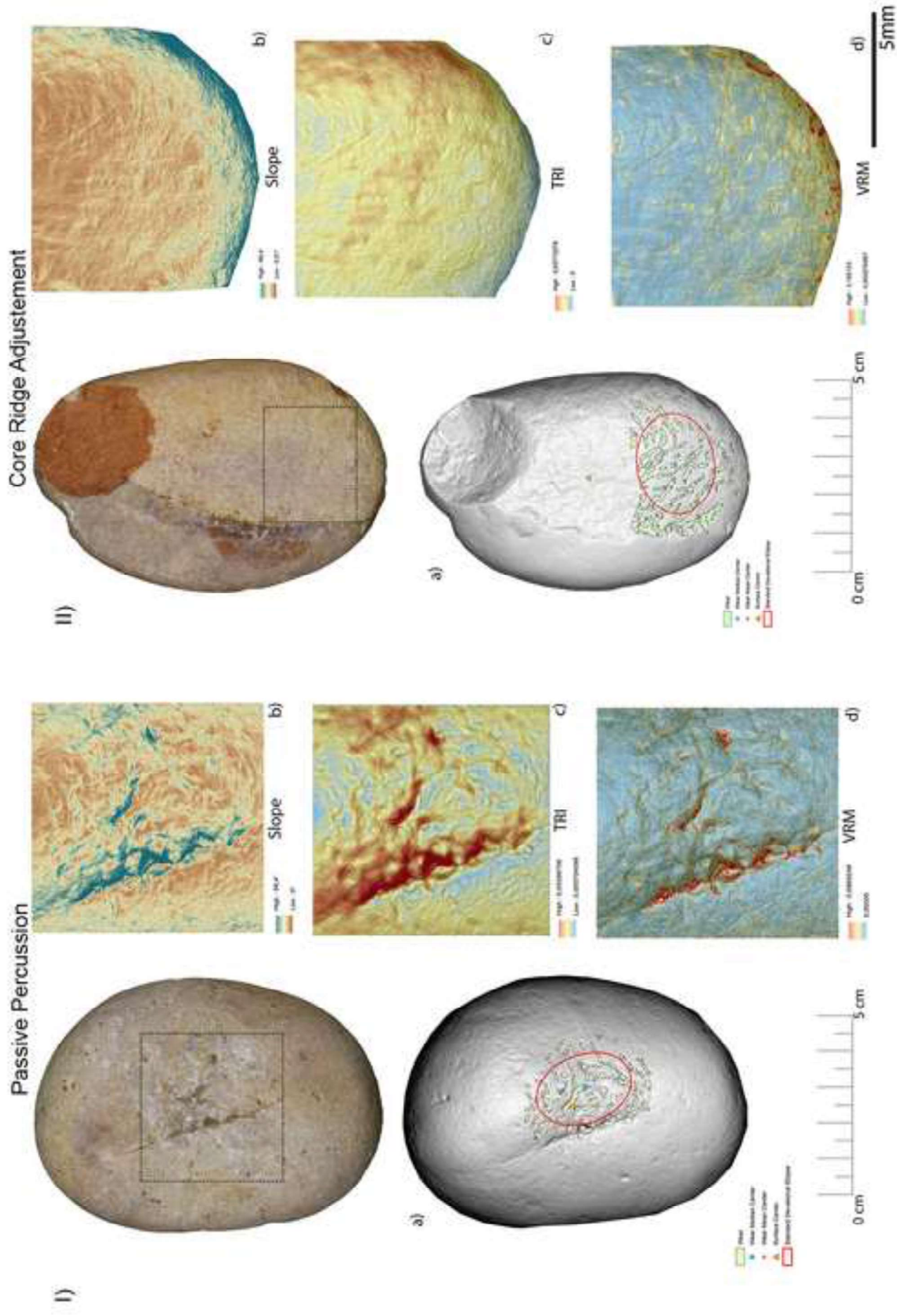








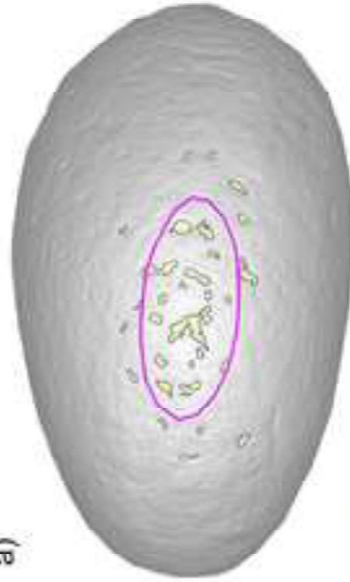




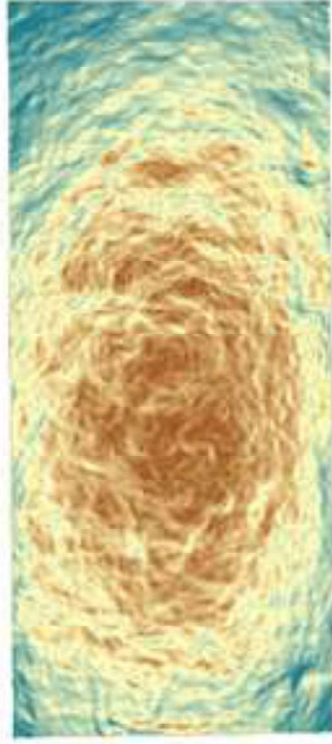
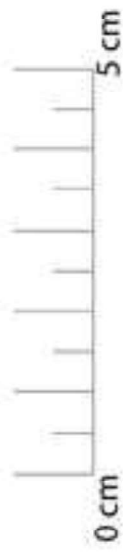
### Bladelet Production



a)



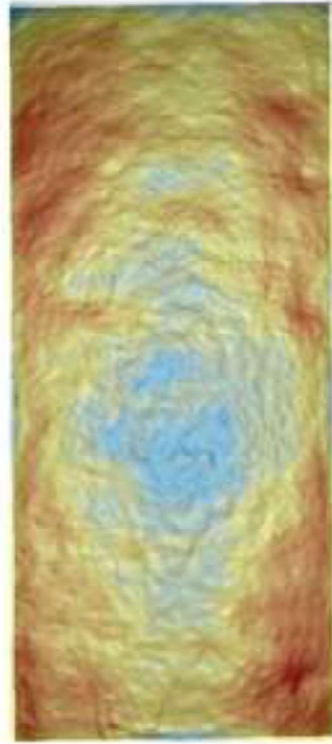
Wear  
Standard Deviation Ellipse



b)

Slope

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Low : 0.03°



c)

TRI

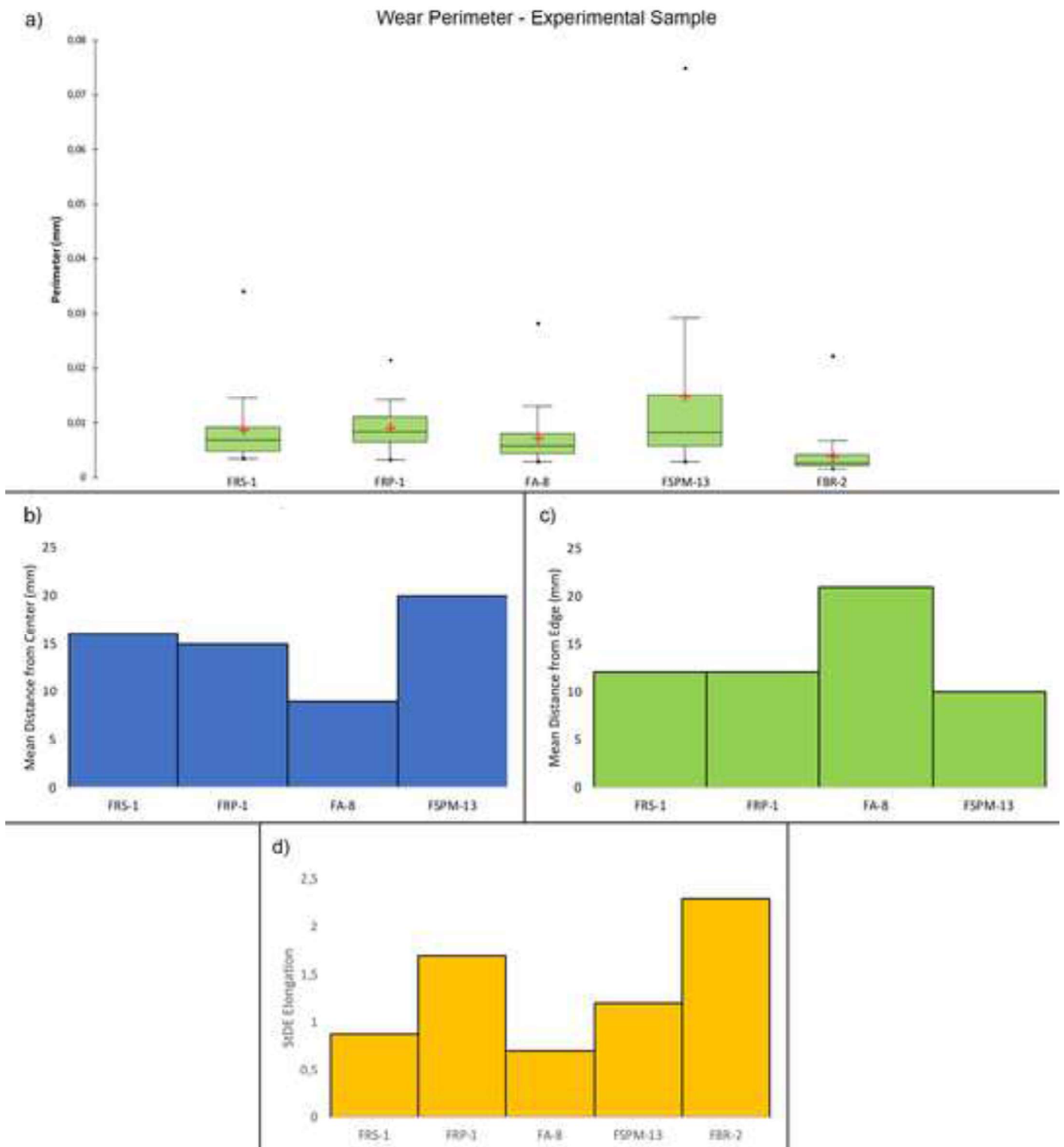
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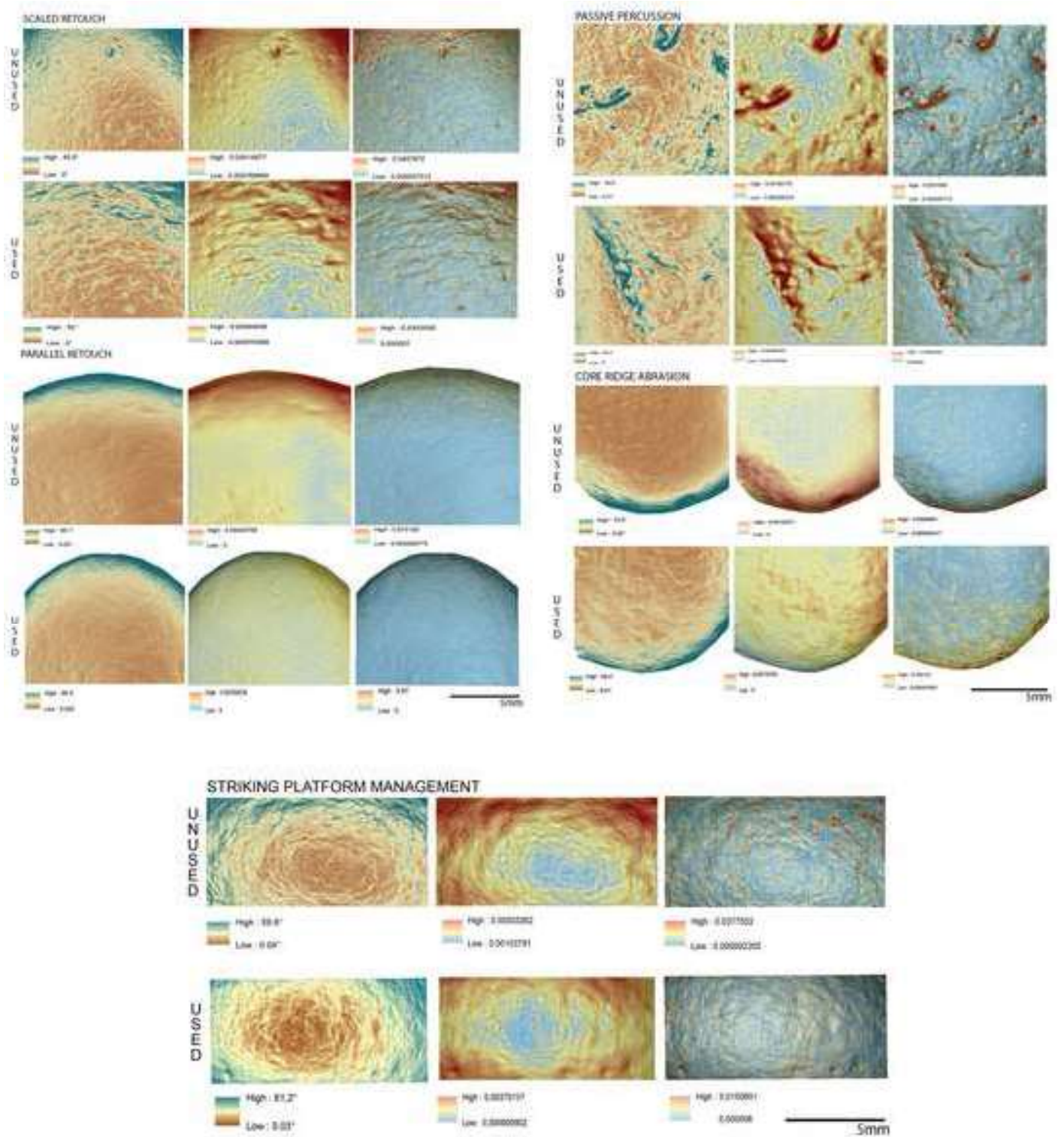


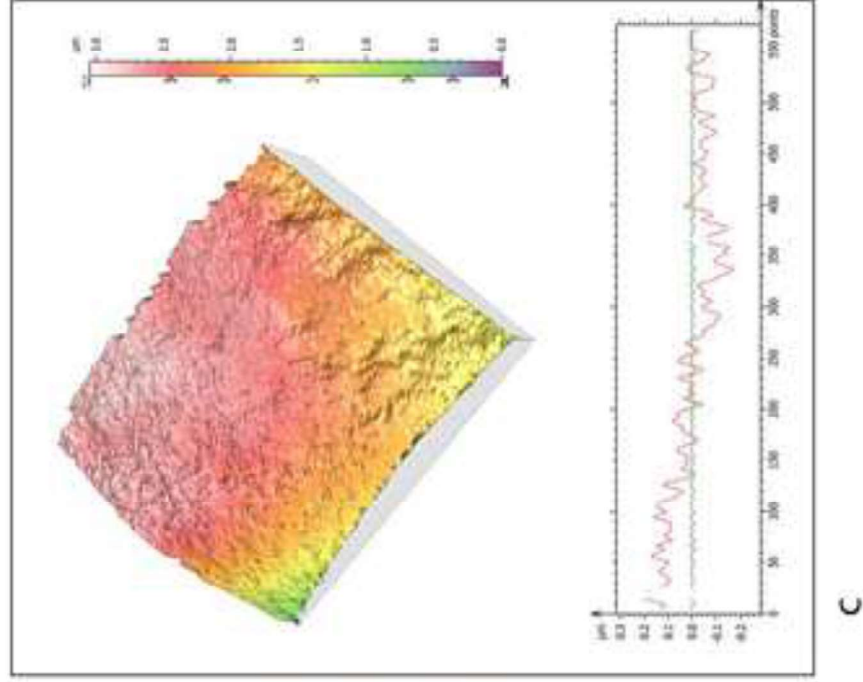
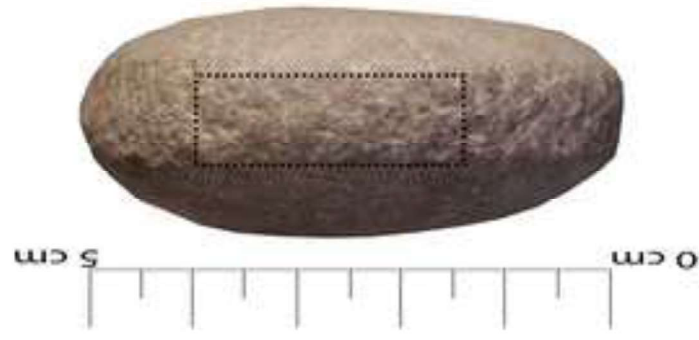
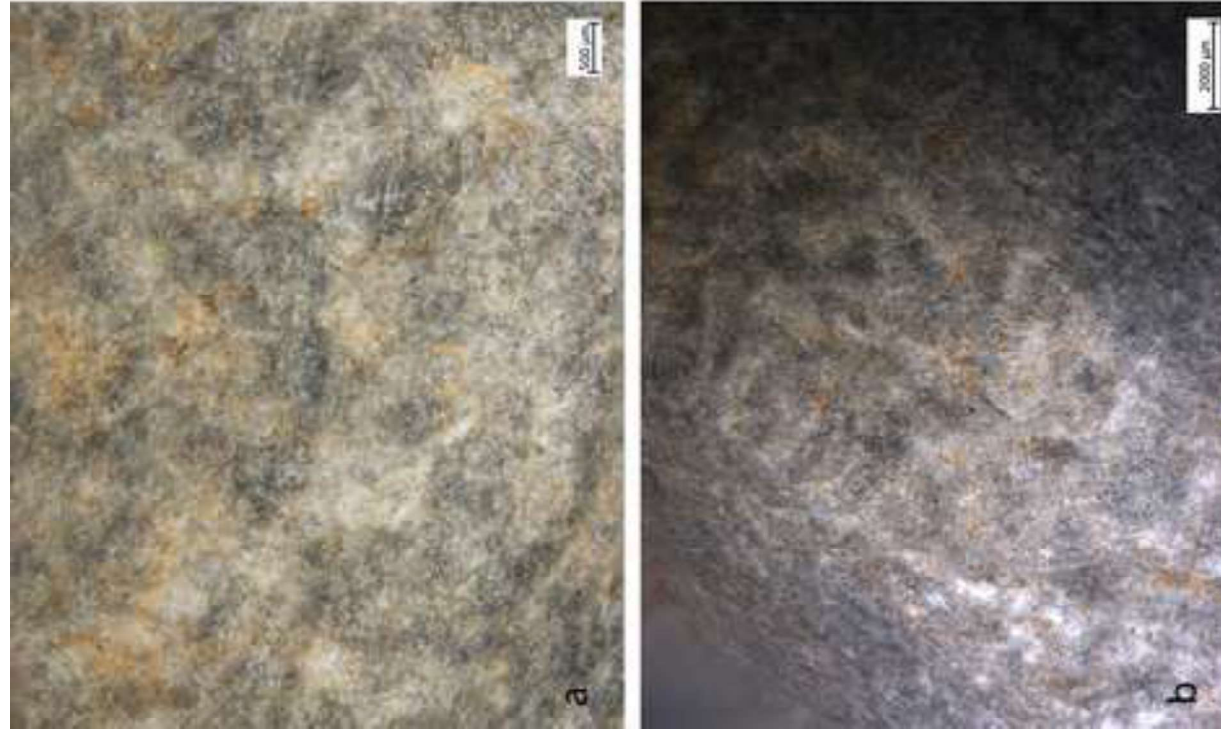
d)

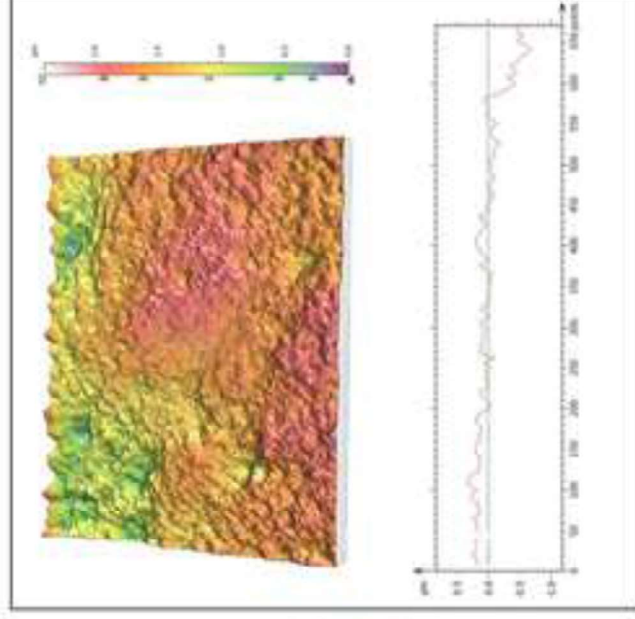
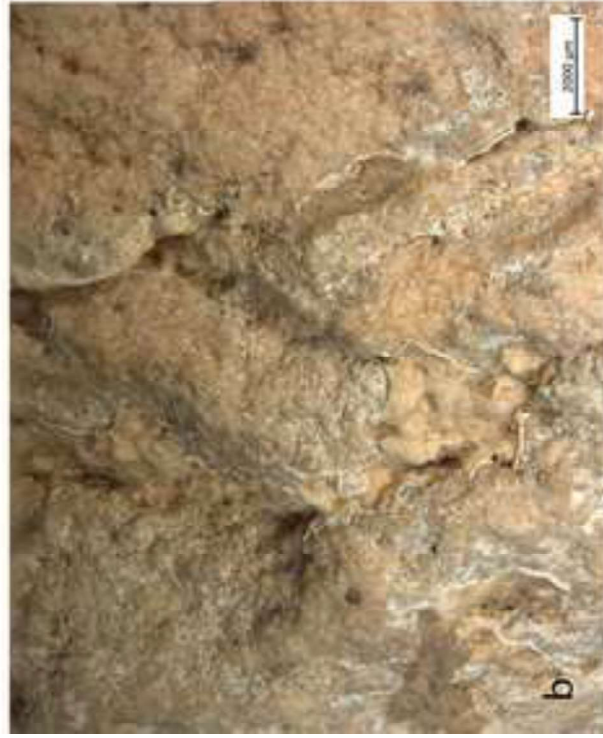
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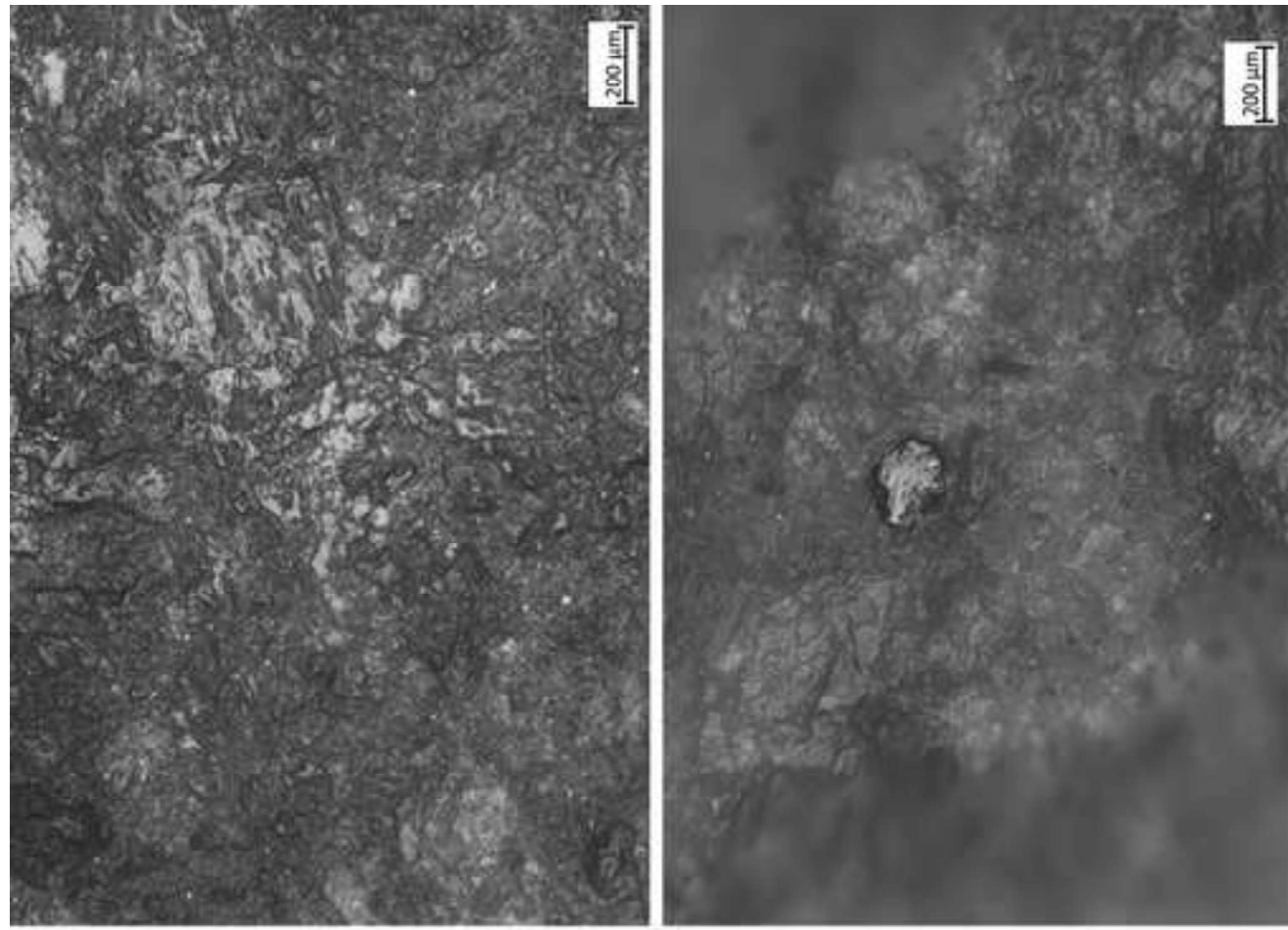
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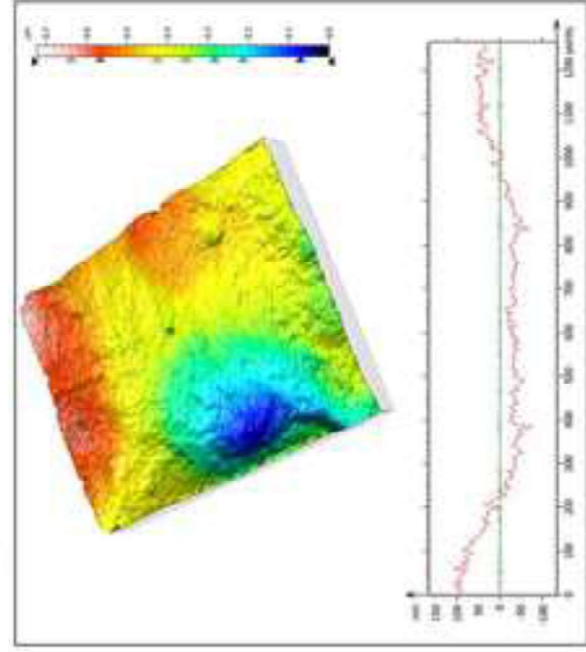
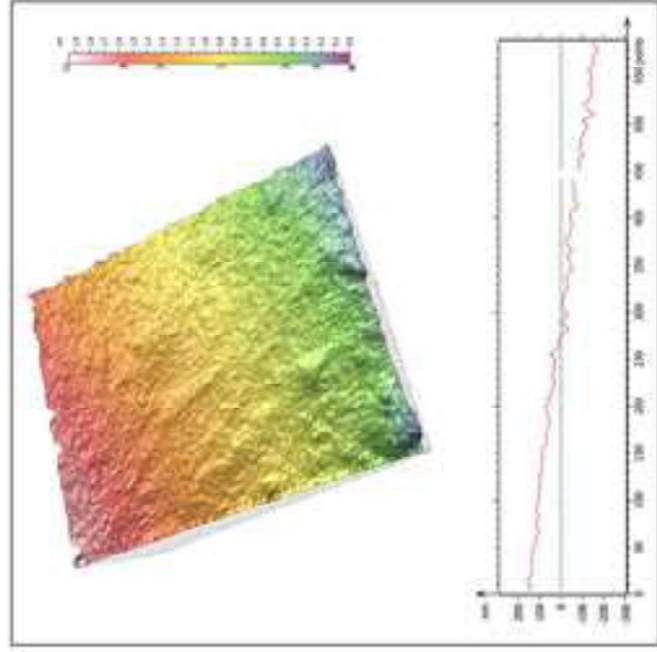
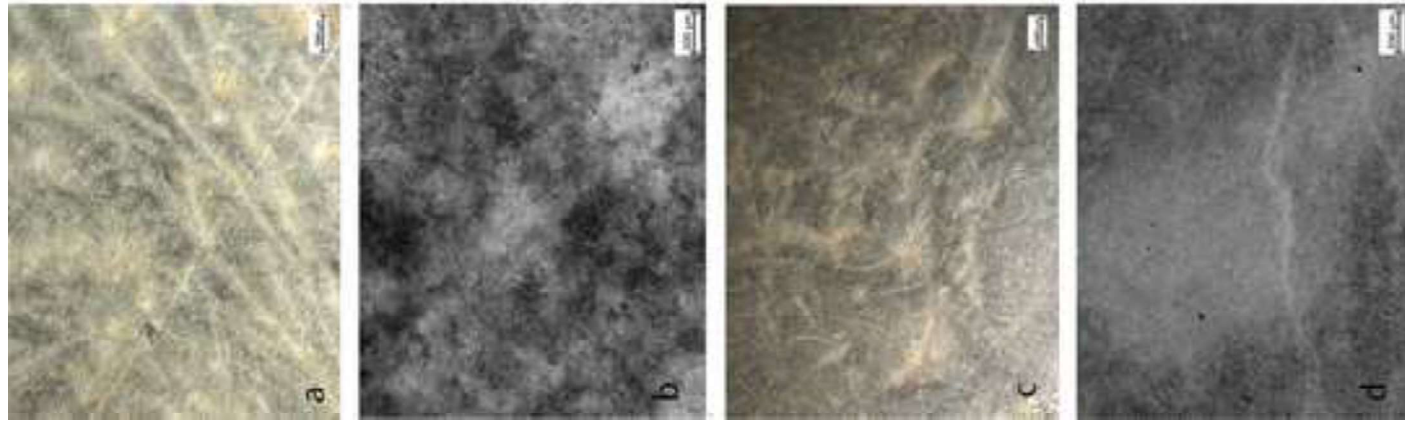


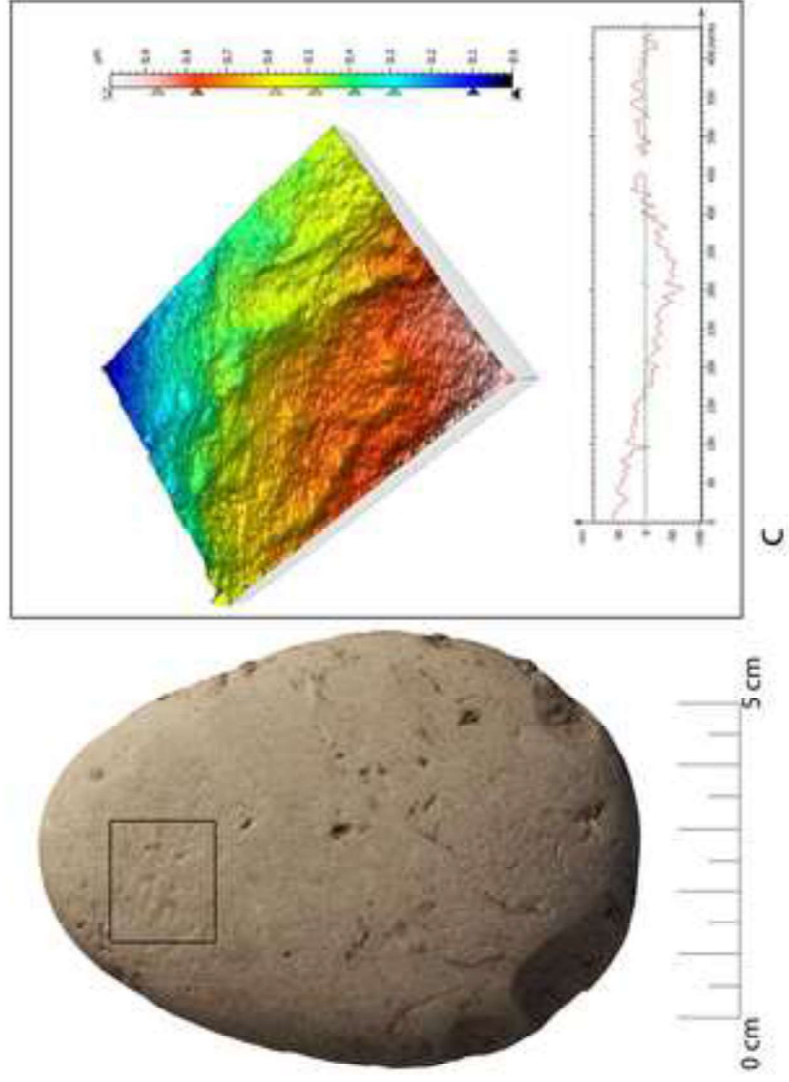
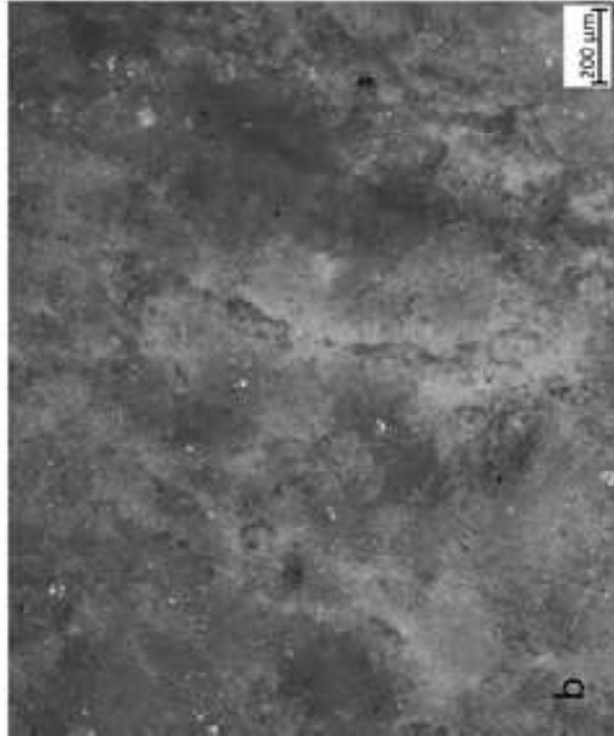
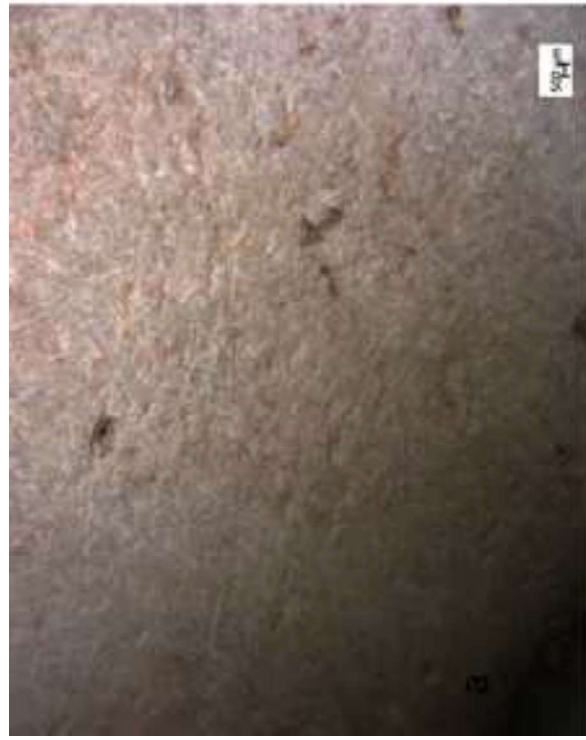


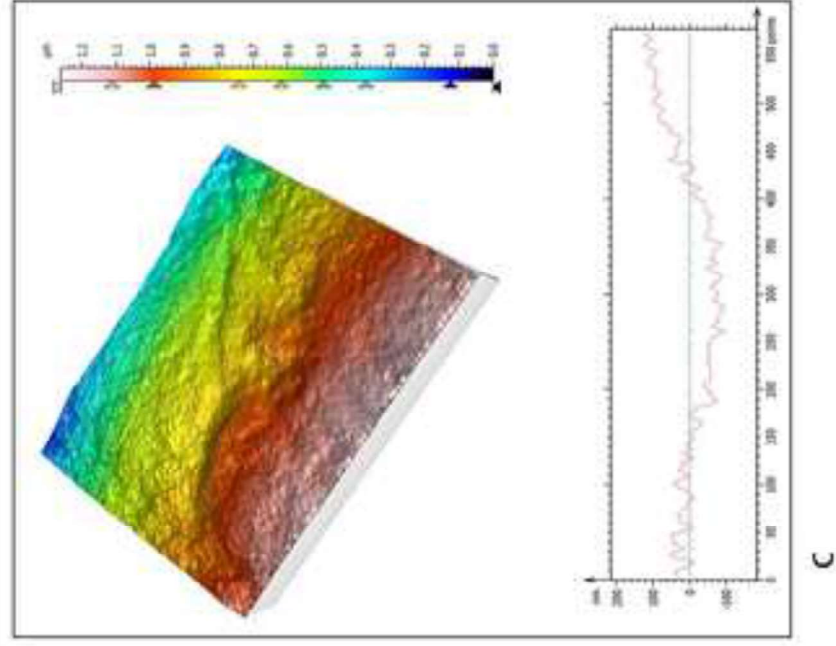
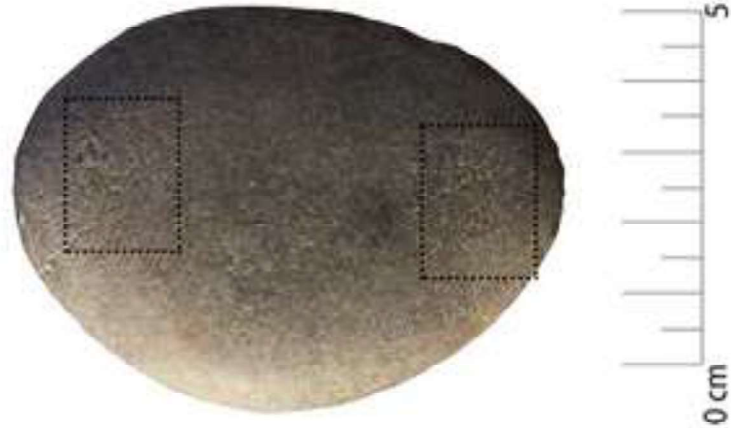
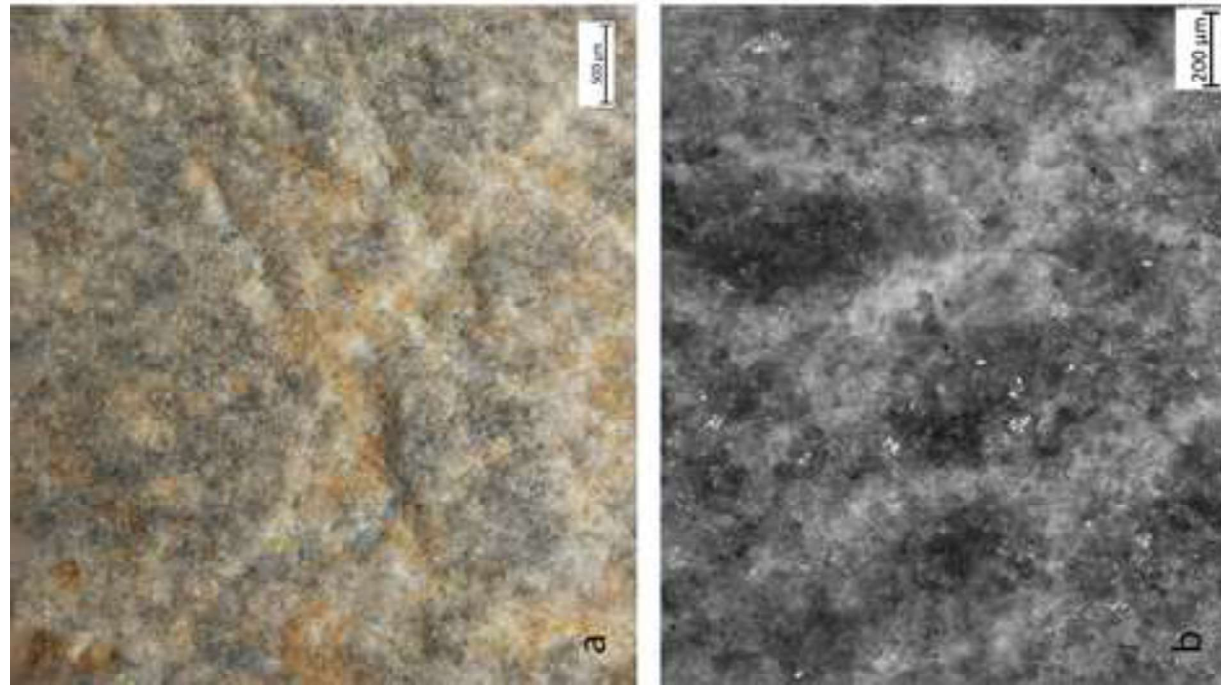


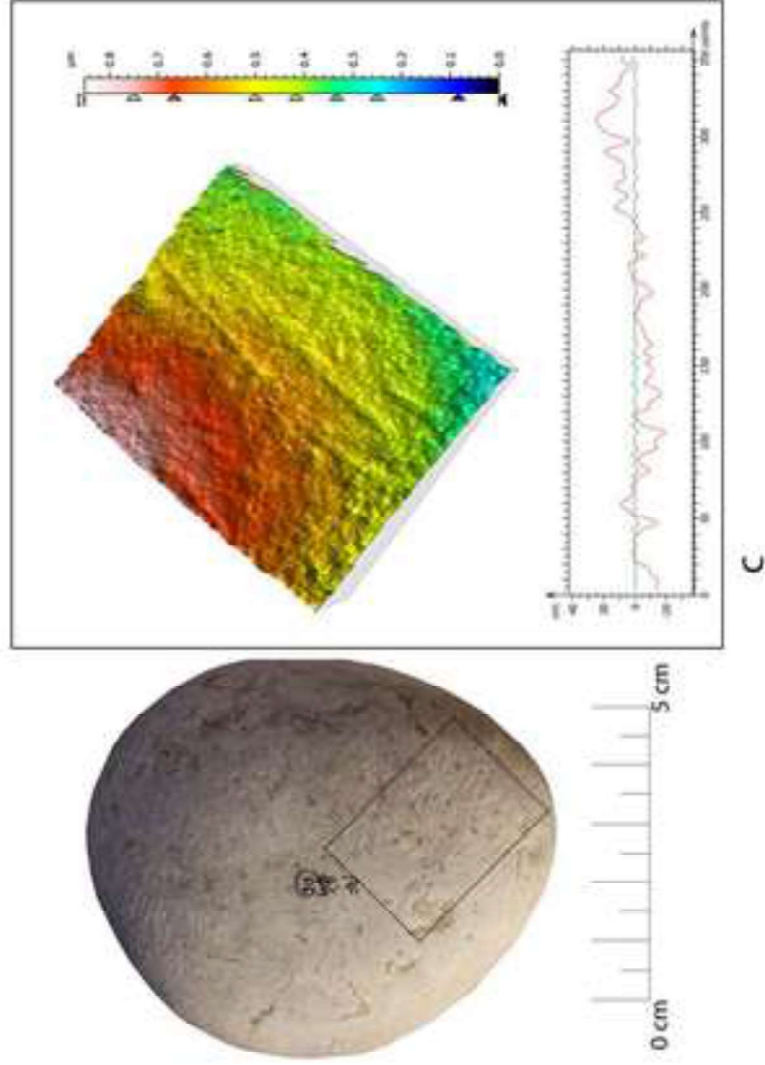
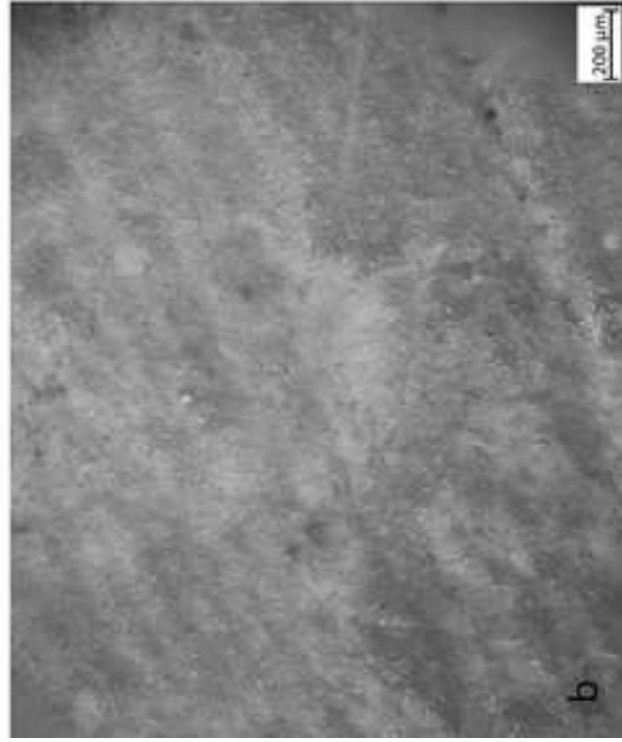








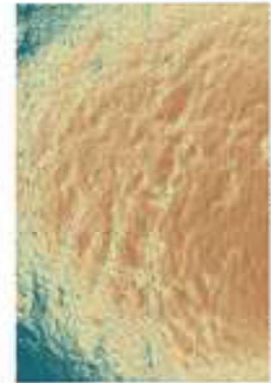




RF. 67



i)



Slope

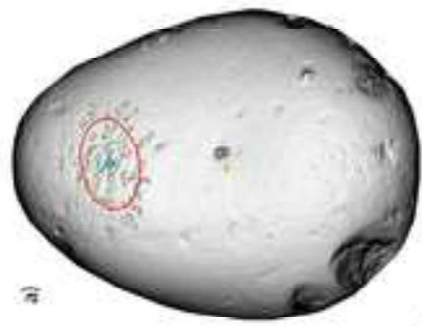


TRI



VRM

a)



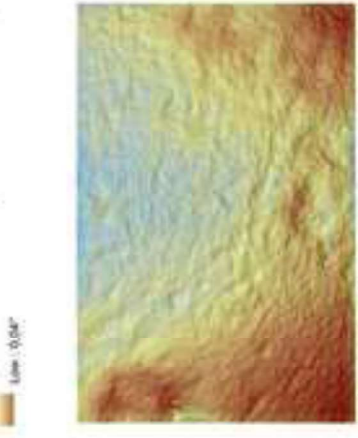
RF - 80



ii)



Slope

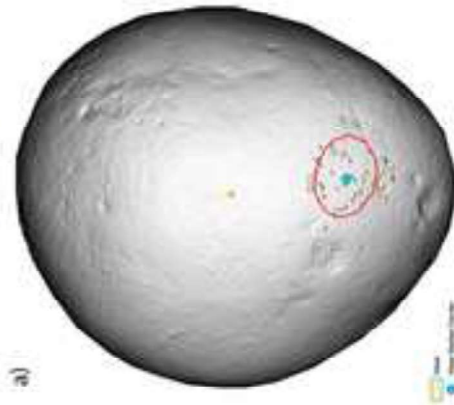


TRI

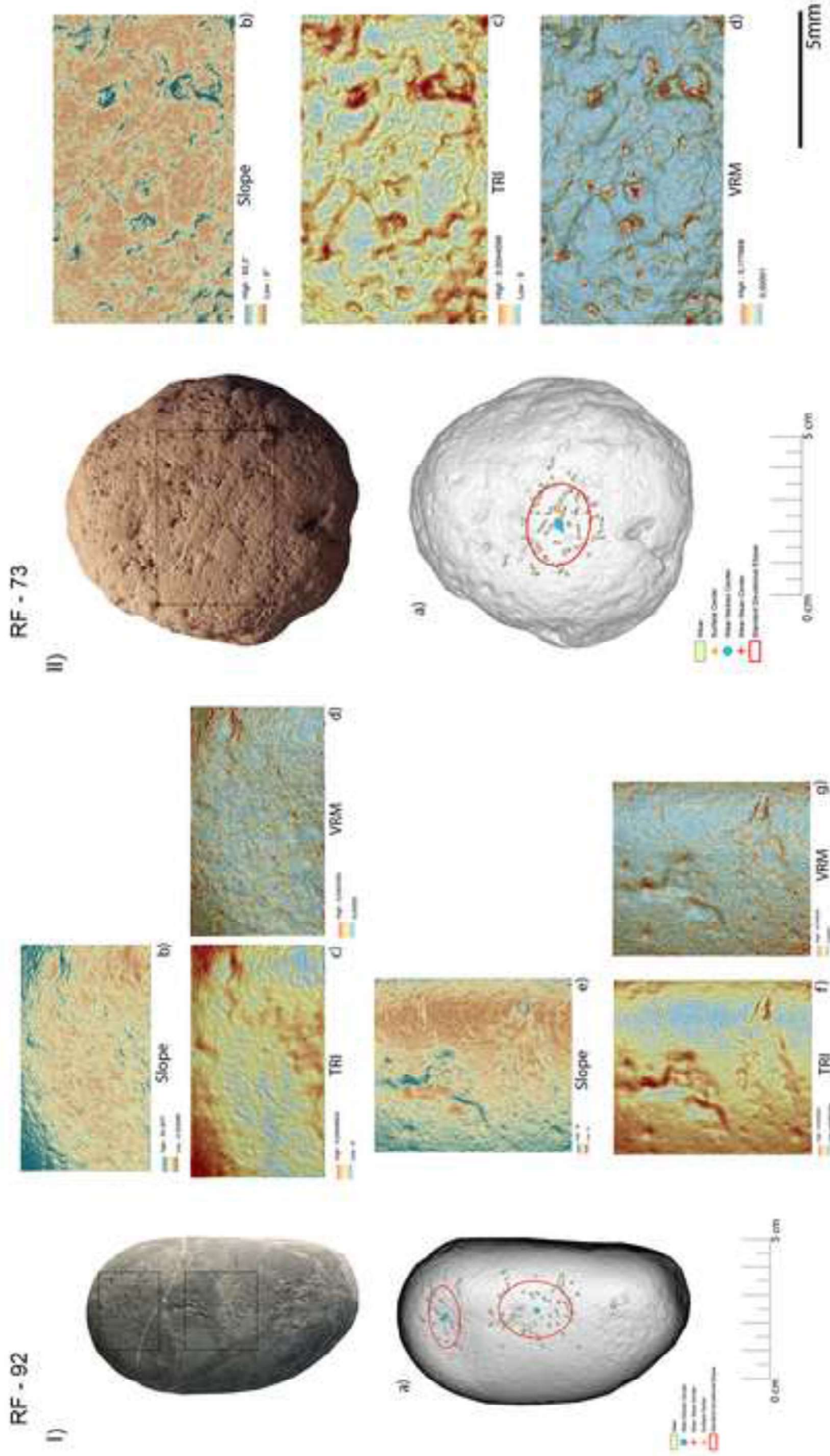


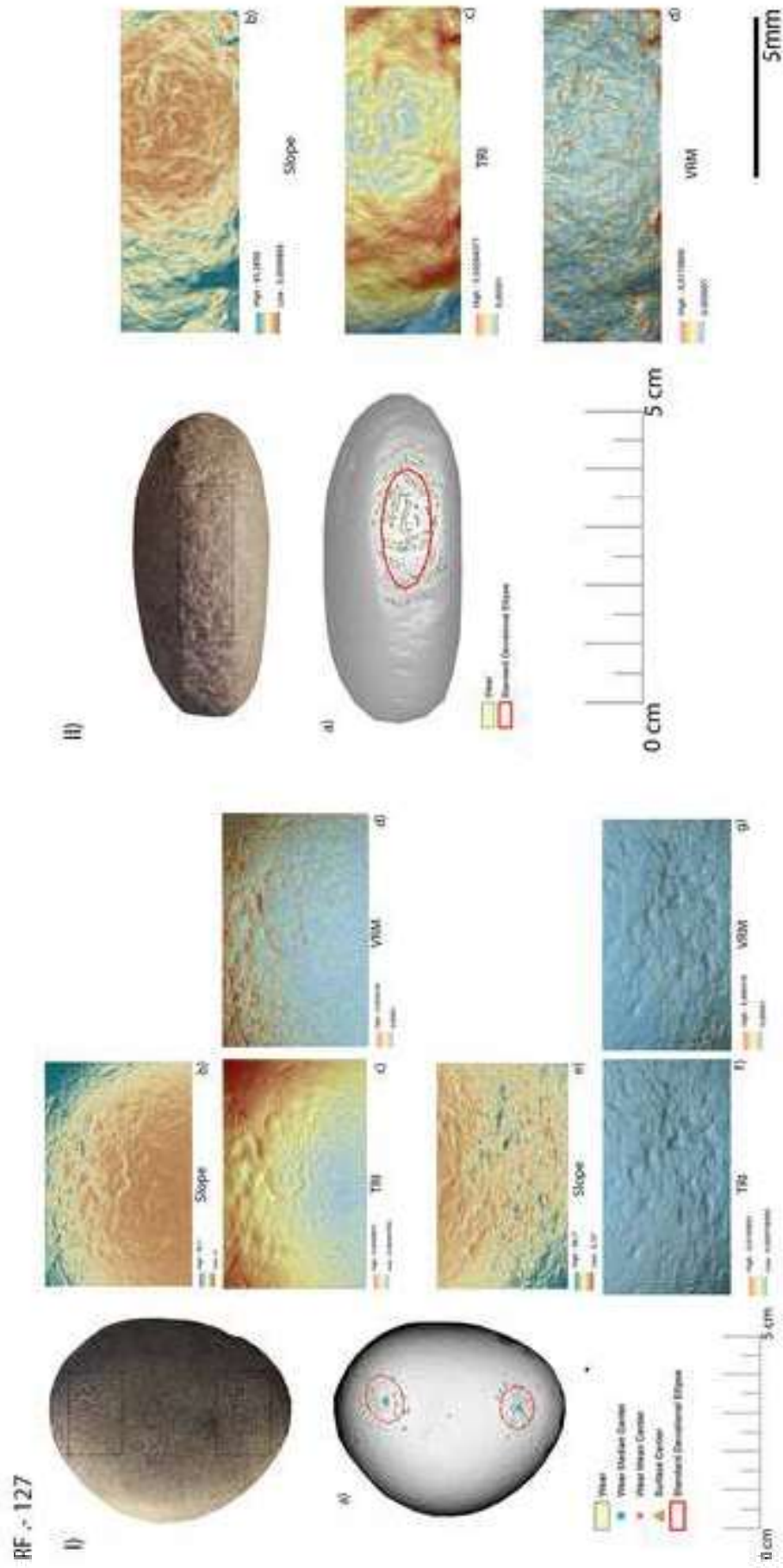
VRM

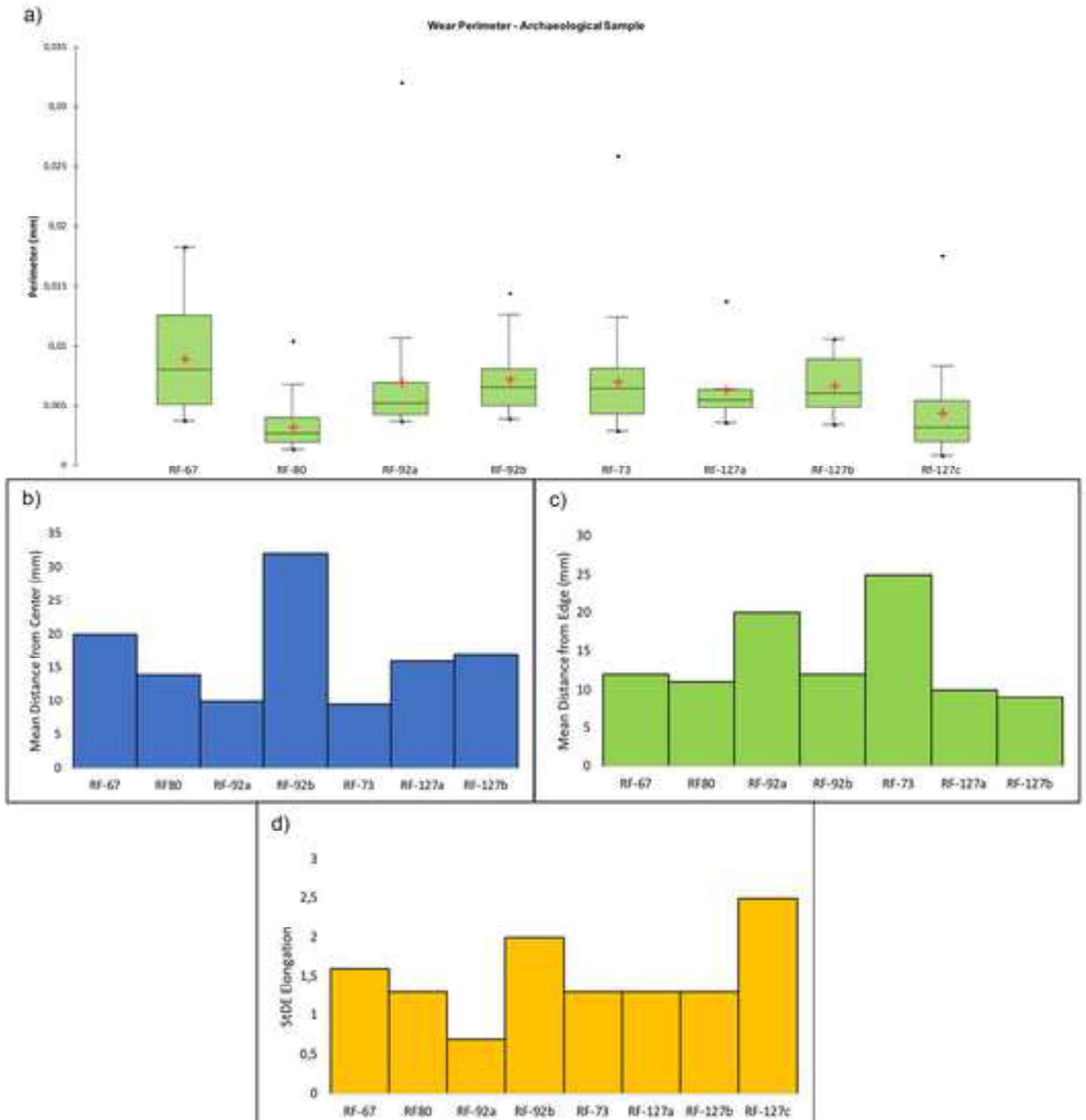
a)



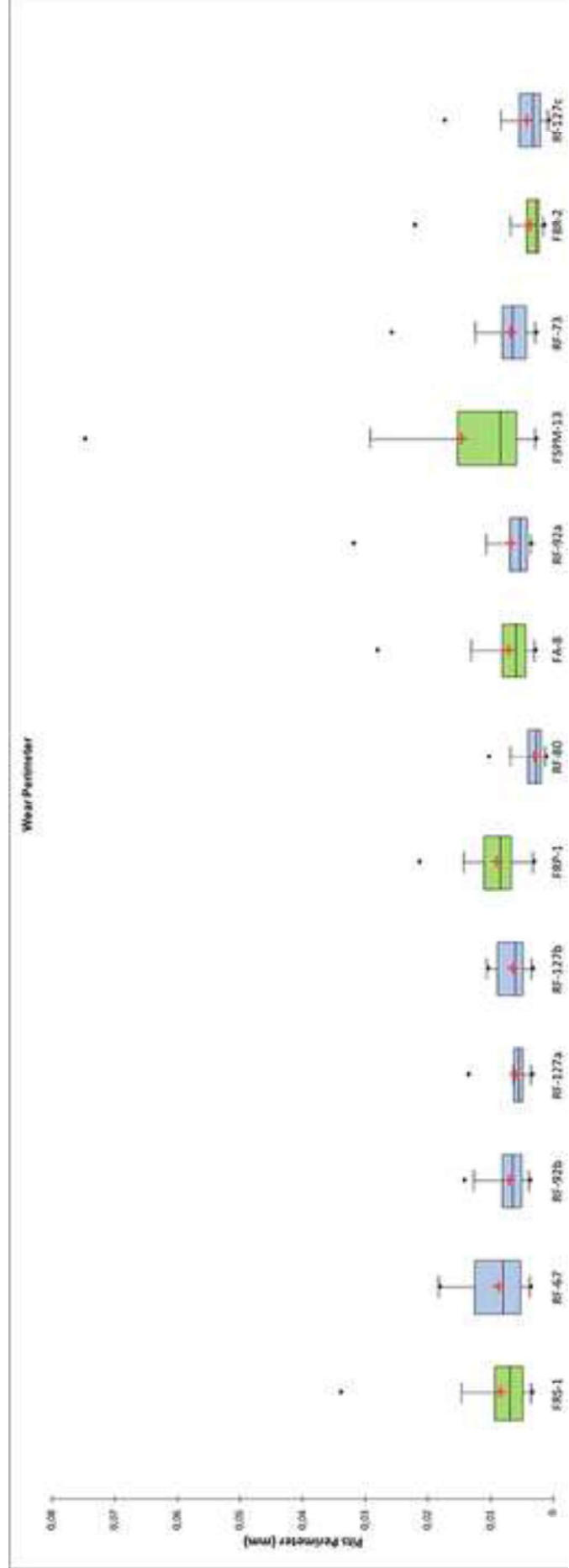
5mm

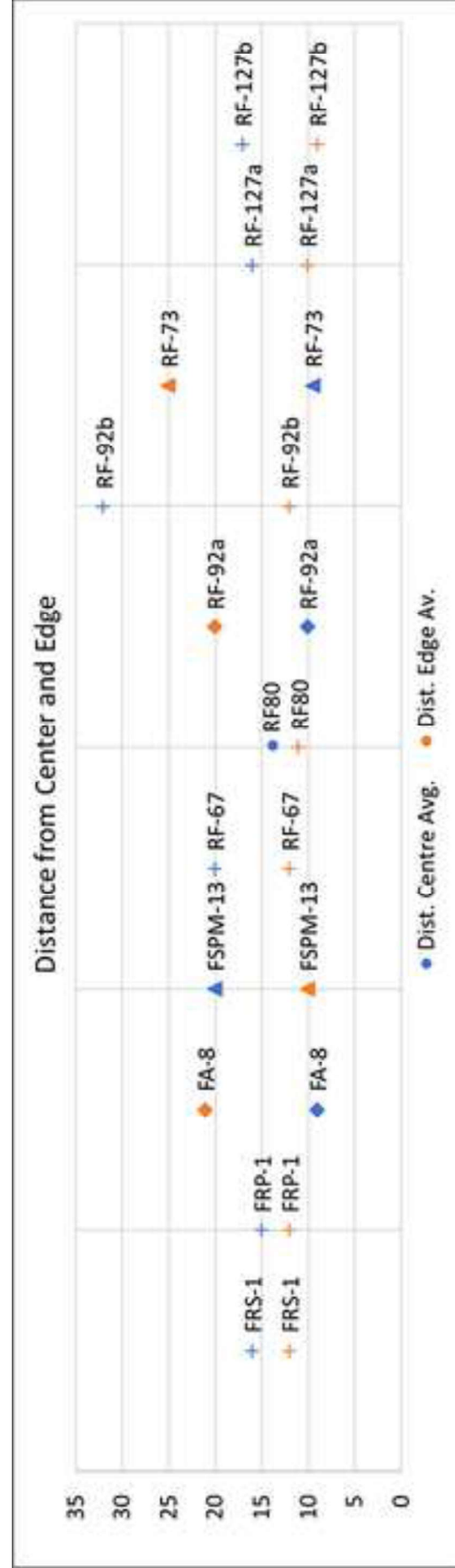


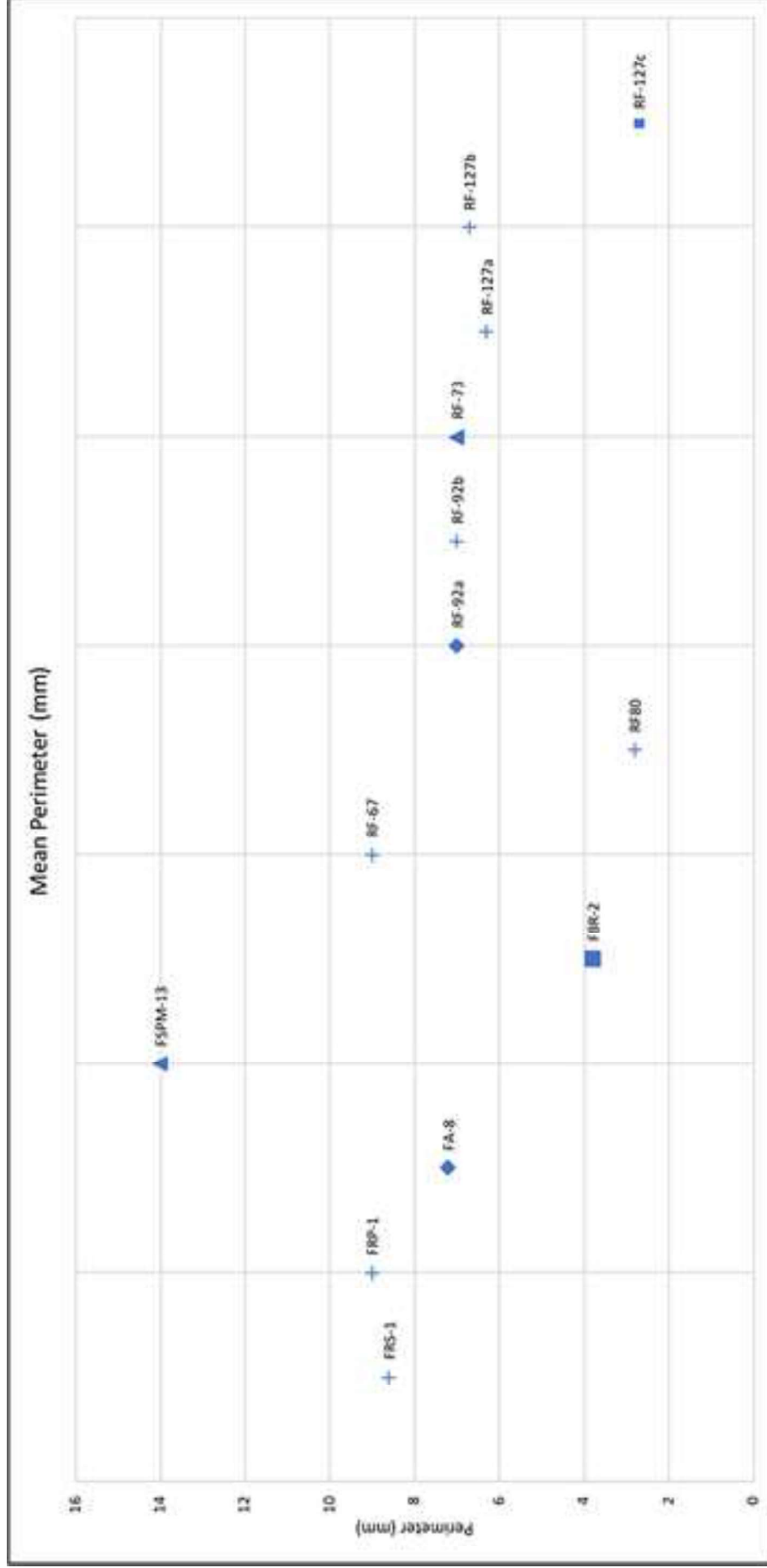


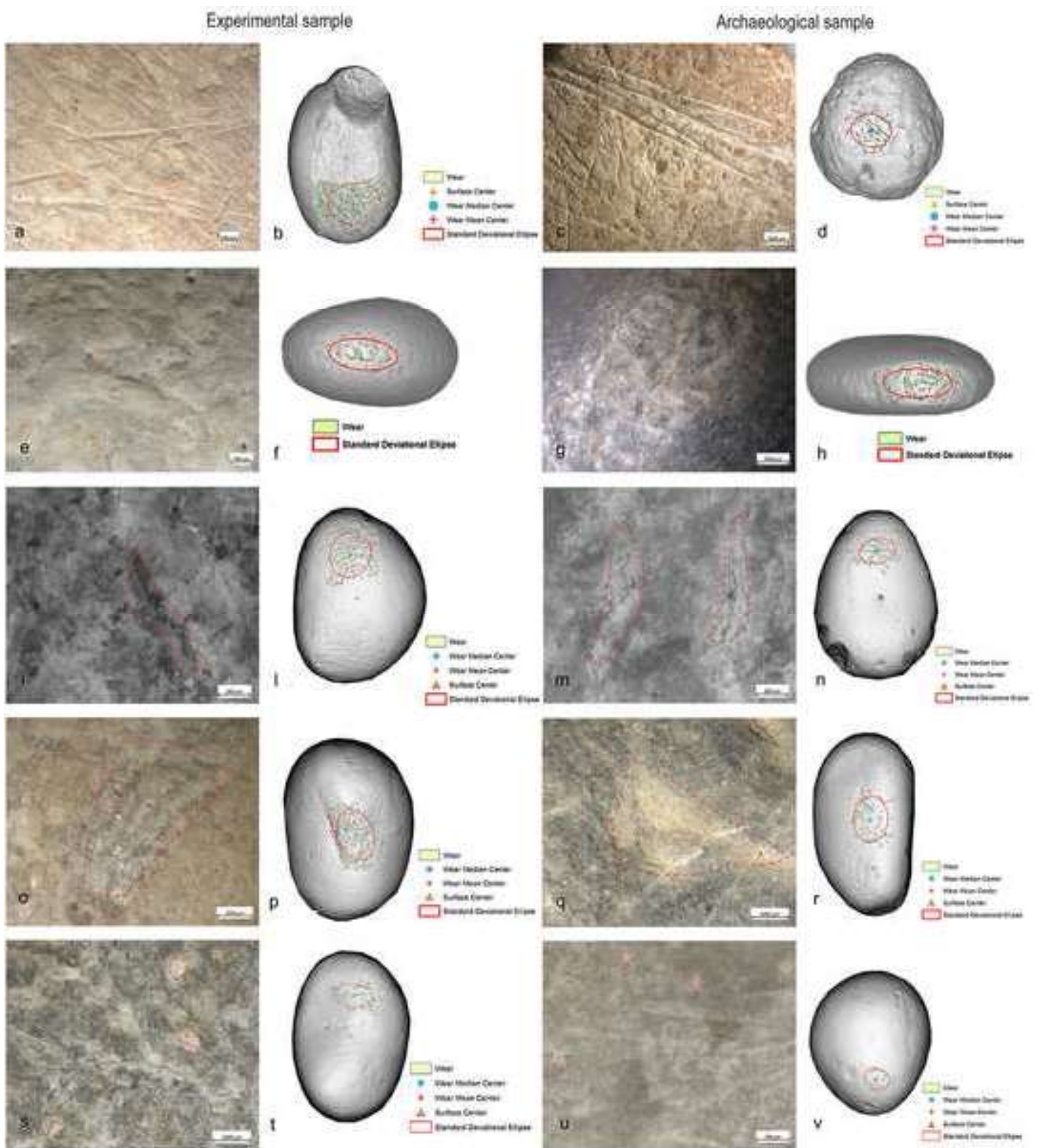












# Breaking through the Aurignacian frame: A re-evaluation on the significance of regional variants during the Early Upper Paleolithic as seen from a key record in southern Europe

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## Abstract

The cultural dynamics that led to the appearance of the Aurignacian have intrigued archaeologists since the start of Paleolithic research. However, cultural reconstructions have often focused on a restricted region of Europe, namely the northern Aquitaine Basin. The Mediterranean Basin, though, is also a region worthy of consideration when testing if the Protoaurignacian was followed by the Early Aurignacian adaptive system. Fumane Cave is a pivotal site for tackling this issue because it contains evidence of repeated human occupations during the time span of the European Aurignacian. Here we investigate the diachronic variability of the lithic assemblages from five cultural units at Fumane Cave using a combination of reduction sequence and attribute analyses. This paper also reassess the presence and stratigraphic reliability of the organic artifacts recovered at Fumane. Our results show that the Protoaurignacian techno-typological features clearly persist throughout the stratigraphic sequence, and by extension, to the onset of Heinrich Event 4. Additionally, the appearance of split-based points in the youngest phase is evidence of extensive networks that allowed this technological innovation to spread across different Aurignacian regions. In light of our data, we conclude by proposing an alternative to the Aquitaine-centric scenario that moves beyond cultural taxonomic issues.

**Keywords:** Aurignacian; Paleolithic archaeology; human evolution; lithic technology; anatomically modern humans; Early Upper Paleolithic

## 1.0. Introduction

### 1.1. Background and aim of research

Given its chronological position and geographic spread, the Aurignacian is perhaps the most studied techno-complex of the Upper Paleolithic (e.g. Breuil 1912; Peyrony 1933; Garrod 1938; de Sonneville-Bordes 1960; Laplace 1966; Delporte 1968; Djindjian 1993; Bon 2006). The cultural and economic changes that occur in this period mark a turning point in human evolution that is perceived as evidence for the definitive spread of anatomically modern humans (AMHs) into Europe (Conard 2002; Mellars 2006a; Davies 2007; Hublin 2015). Human remains, found in a few stratified sites, strongly support this scenario (Bailey 2006; Bailey et al. 2009; Benazzi et al. 2015). The oldest appearances of the Aurignacian are dated to roughly between 43–42 ky cal BP and are mainly found along the Mediterranean boundaries and the Danube Basin, both considered to be natural paths to the European sub-continent (Davies and Hedges 2008; Szmidsztajn et al. 2010; Douka et al. 2012; Higham et al. 2012; Nigst et al. 2014; Wood et al. 2014; Davies et al. 2015; Hopkins et al. 2016; Barshay-Szmidsztajn et al. 2018).

In the last decades, a constantly growing database has permitted researchers to define the main features of the Aurignacian phenomenon and various attempts have been made to disentangle its complex synchronic and diachronic variability (Laplace 1966; Hahn 1977; Bon 2002; Le Brun-Ricalens 2005b; Bar-Yosef and Zilhão 2006; Bon et al. 2006). However, most previous research has been conducted in the northern Aquitaine Basin, a region that had a prominent role in the construction of Paleolithic research itself (Groenen 1994). As a result, a slightly biased narrative of the Aurignacian cultural phenomenon has been constructed (Anderson et al. 2018).

The Aurignacian was first divided into four successive stages based on the typological variability of lithic and organic tools (Peyrony 1933, 1935; de Sonneville-Bordes 1960; Delporte 1964, 1968; Demars 1992; Demars and Laurent 1992; Bordes 2006). These definitions were then complemented by technological studies conducted over the last decades (Le Brun-Ricalens 1993; Bon 2002; Bon and Bodu 2002; Bordes 2002; Chiotti 2005; Le Brun-Ricalens 2005b; Bon et al. 2010). Outside of southwestern France, Aurignacian assemblages have been discovered in several cave and open-air sites. Rather than focusing on defining regional signatures, the main concern of archaeologists has often been to extend the “Aquitaine Model” to the rest of the Europe (e.g. Laplace 1966; Hahn 1977; Zilhão and d'Errico 1999; Broglio 2000; Kozłowski and Otte 2000; Otte and Derevianko 2001; Demidenko et al. 2012). Recently, researchers, ourselves included, have raised doubts about the application of this model on a supra-regional scale (Conard and Bolus 2006; Sitlivy et al. 2012; Bataille 2013; Conard and Bolus 2015; Falcucci et al. 2017; Tafelmaier 2017; Bataille and Conard 2018; Bataille et al. 2018). We have argued, in fact, that the variability and definition of the oldest stages, known as Protoaurignacian (PA) and Early Aurignacian (EA), have been over-simplified to better construct scenarios of AMHs’ arrival into Europe. According to some, these variants represent two distinct routes of dispersal along natural paths such as the Mediterranean boundaries and the Danube Basin (Conard and Bolus 2003; Mellars 2004, 2006b; Hublin 2015). To others, they are instead successive stages reflecting different settlement dynamics (Bon 2005; Anderson et al. 2015).

In this regard, a recent study has concluded that the shift from the PA to the EA adaptive system was triggered by the deterioration of the environment at the onset of the Heinrich Event 4 (Banks et al. 2013a, b; contra: Higham et al. 2013; Ronchitelli et al. 2014). This model is based on the subdivision of the Aurignacian in the Aquitaine Basin, although it clearly aims to be applied over the whole extension of Europe. But does the archaeological evidence from the southern Alpine range and the Italian Peninsula support this scenario? Careful investigations and reassessments of pivotal sites are the best way to respond to this question and further understand the complex population dynamics that characterized the Early Upper Paleolithic.

The Italian Aurignacian is represented by several stratified sites and surface collections that are distributed in different environmental settings, close to the modern coastlines and up to Alpine and Apennine regions (Palma di Cesnola 2001; Mussi 2002). The Italian research tradition was strongly influenced by work conducted by G. Laplace in the late sixties and seventies (Laplace 1966, 1977; Plutniak and Tarantini 2016) and technological assessments have been conducted in only a few cases (e.g. D'Angelo and Mussi 2005; Dini et al. 2010; Dini et al. 2012; Bertola et al. 2013). Among those, Fumane Cave is the site that has received the attention, although research has mostly focused on the earliest manifestations of the Aurignacian (Broglia et al. 2005; De Stefani et al. 2012; Bertola et al. 2013; Falcucci et al. 2017; Falcucci and Peresani 2018). The presence of several cultural units that both pre- and postdate the occurrence of H4, allow us to carefully address the internal variability of the Aurignacian in the Venetian region. Here, besides Fumane Cave, evidence of Aurignacian sites is poor and difficult to evaluate. At Tagliente Rockshelter, located in the Monti Lessini, an Aurignacian assemblage was found within a stratigraphic unit that was partially mixed with Mousterian and Epigravettian implements (Bartolomei et al. 1982). At Paina, in the Colli Berici, few Aurignacian lithic implements were found together with a fragmented organic point (Bartolomei et al. 1988). Few open-air sites distributed in the pre-Alpine range and in the sub-Alpine belt complement the Aurignacian in this area (Broglia et al. 2003).

Some authors have suggested that PA technical traditions persisted longer in Italy than in other regions (Palma di Cesnola 2001; Mussi 2002; Bon et al. 2010; Anderson et al. 2015). For this reason, Palma di Cesnola (2001) and Mussi (2002) proposed that the prefix Proto- be abolished because it gives the impression that assemblages included in this group have an absolute chrono-stratigraphic significance with respect to others, as for instance, is the case with the corresponding “Aurignacian 0” in western Europe (Bordes 2006; Bon et al. 2010). Fewer “typical” Aurignacian assemblages exist and have been sorted mainly by the presence of split-based points (SBPs) and other organic artifacts (Blanc and Segre 1953; Laplace 1977; Palma di Cesnola 2001; Mussi et al. 2006; Tejero and Grimaldi 2015), although some authors have suggested that the two variants be lumped together, given the high resemblance of their main typological features (Gheser et al. 1986). Careful reassessments are needed to address these issues in a more parsimonious way, emphasizing technological signatures and diachronic variability of stratified sites. In this framework, new data have been recently produced at Bombrini, in northwestern Italy, by Riel-Salvatore and Negrino (2018a, 2018b). Their results suggest that the PA was a technological system that survived well

beyond the H4 and the roughly contemporaneous Campanian Ignimbrite volcanic eruption (see references in: Giaccio et al. 2017). Similar conclusions, even if at a preliminary level, were reached by Broglio and the research team of Ferrara University at Fumane Cave (Broglio 1997; Higham et al. 2009).

With the aim of shedding new light on the cultural dynamics that characterized the Aurignacian in northeastern Italy, we present a detailed comparison of five cultural units (A2, A1, D3base, D3*alpha*, and D3ab) from Fumane Cave. We investigate assemblage variability and re-evaluate the organic artifacts to detect evidence of cultural modifications and/or stability throughout the stratigraphic sequence. We thus test whether the earliest PA cultural units A2–A1 (Falcucci et al. 2017) are followed by assemblages that can be attributed to the EA (as defined by: Bordes 2006; Teyssandier 2007; Arrizabalaga et al. 2009; Bon et al. 2010; Teyssandier et al. 2010). Finally, we propose an alternative to the Aquitaine-centric scenario for the beginning and development of the Aurignacian that moves beyond taxonomical issues and opens up a more dynamic interpretation of its many regional facets.

## **1.2. Fumane Cave and the Aurignacian stratigraphic sequence**

Fumane Cave, excavated since 1988, lies at the foot of the Monti Lessini Plateau (Venetian Pre-Alps). Details about the cave's structure, Late Pleistocene stratigraphic sequence, and paleoclimatic significance, as well as its paleontological and cultural content, are available in numerous publications (Bartolomei et al. 1992a; Cassoli and Tagliacozzo 1994; Broglio et al. 2003; Broglio et al. 2005; Broglio and Dalmeri 2005; Higham et al. 2009; Peresani 2012; Benazzi et al. 2015; López-García et al. 2015; Peresani et al. 2016a; Falcucci et al. 2017). A main cave and two associated tunnels preserve a finely-layered sedimentary succession spanning the late Middle Paleolithic and the Early Upper Paleolithic, with features and dense scatters of remains in units A11, A10, A9, and A6–A5 (Mousterian: Peresani 2012; Peresani et al. 2013), A4 and A3 (Uluzzian: Douka et al. 2014; Peresani et al. 2016a), A2–A1 (Protoaurignacian: Broglio et al. 2005; Bertola et al. 2013; Cavallo et al. 2017; Falcucci et al. 2017; Falcucci and Peresani 2018; Falcucci et al. 2018), D6, D3, and D1c (Aurignacian *lato sensu*: Broglio and Dalmeri 2005), and D1d (Gravettian: Bartolomei et al. 1992b).

Unit A2 dates the appearance of the Aurignacian to 41.2–40.4 ky cal BP (Higham et al. 2009; Higham 2011). Its boundary with layer A3 is clearly marked by a dispersion of ocher over a large extent of the area (Cavallo et al. 2017; Cavallo et al. 2018) and by a considerable change in the content of anthropogenic material (Broglio et al. 2009). In the cave entrance, unit A2 is covered by A1, a thin anthropic level with horizontal bedding which makes it indistinguishable from A2 in the cave mouth. A2 thus extends throughout the whole cave. Post-depositional processes, due to frost activity, affected layers A3 and A2 in the easternmost part of the cave entrance and allowed materials from A2 to infiltrate into A3 (Benazzi et al. 2014; Peresani et al. 2016a). Stratigraphic deformations have been reported in the inner eastern side of the cave mouth, where layer A2 was tilted and compressed towards the cave wall, forming a pronounced fold. Despite this deformation, during the excavation layer A2 appeared to be a clearly discernible sedimentary body preserved with variable thickness from a few centimeters to 10 centimeters, due to its dark-brownish color, its texture



and its high charcoal, bone and stone implement density, as well as the occurrence of features (i.e. hearths, post-holes, and toss-zones) mostly located at the cave entrance (Peretto et al. 2004; Broglio et al. 2006a; Broglio et al. 2006b). Some of these hearths were located within shallow basins excavated at the edges of the Uluzzian (Peresani et al. 2016b) and final Mousterian layers below, thus producing possible dispersion of a few flaked stones in the A2–A1 assemblages.

In the front part of the cave, a series of layers from the stratigraphic complex D3 correspond to the youngest Aurignacian phase. From a sedimentological point of view, the macro-unit D is mostly formed of very coarse materials (boulders and stones) collapsed from the cave walls that progressively sealed the cave entrance. These events correspond to a long period of climatic deterioration (Broglio et al. 2003; López-García et al. 2015), where the traces of human presence become less dense than in A2 and A1. Archaeological materials were, however, found in layers embedded in macro-unit D. Due to differences in the composition of the sediments and excavation history, the stratigraphy of the cave mouth of the D complex is different than that of the cave entrance. At the entrance, D3 was divided into several units. At the base of the sequence, D3base was a thin layer that marked the transition with A1. Above D3base, two layers were recognized and then considered as a single accumulation event. They are D3d and D3*balpha* and, in this paper, they will be grouped together and referred to as D3*balpha*. Here, human activity is the most evident. D3d stands for *Dallage* and was initially restricted to a deliberate human feature composed of a series of angular, small sized (ca. 10 cm) blocks sub-horizontally arranged to form a regular pavement with a diameter of ca. 120 cm bounded by boulders. In D3*balpha*, a combustion feature was uncovered together with an accumulation of several lithic artifacts and a SBP (Broglio et al. 2006a). A radiocarbon date produced from a sample taken from the combustion feature suggests that this event took place at about 38.9–37.7 ky cal BP (95.4% of reliability), thus after the H4 (Higham et al. 2009). The top of the D3 complex is divided into two spits: D3a and D3b. They are the most extended deposits, although the archaeological materials are fewer compared to the lower units. During excavation, D3a was considered almost sterile. Sediments were quickly removed and sieved only for samples from a few square meters. The number of small lithics, such as bladelets, may therefore be slightly underestimated. Here, D3a and D3b are considered as a single unit named D3ab. The consistency of the Aurignacian assemblages is secured by the lack of any evidence supporting massive percolation of stone implements from and to the D3 complex. Clear boundaries between stratigraphic layers, as well as the lack of significant deformations in a large part of the excavated area, suggest that perturbations between the Aurignacian occupations should be excluded. In the cave mouth the situation looks very different and correlation to the previously described units is problematic. They are therefore excluded from this study. In this area, due to post-depositional processes that are under examination, the eastern part of the upper sequence appears to be different than that of the western portion. Above a loose stony layer (D6), a thick layer named D3+D6 was described. In the western side, layer D6 was instead covered by a sequence comprising a thin level named D3a+b and the stratigraphic complex D1. The latter was divided in different units, among which D1c was described as Aurignacian, D1d as Gravettian (Bartolomei et al. 1992b; Broglio

1997), and D1e as sterile. We are analyzing the D1 complex to assess the cultural attribution of these units (Falcucci et al., in preparation).

Macro- and micro-faunal remains shed light on the Aurignacian ecological context. They show an association between forest fauna and cold and open habitat species typical of the alpine grassland steppe above the tree line (Cassoli and Tagliacozzo 1994; Broglio et al. 2003; Gurioli et al. 2005b). This context reflects a clear climatic cooling with relative decreases in woodland formations. Two main phases were detected: the first (A2–A1) was a cold and dry phase probably related with H4 event, while the second (D3 complex) was a cold and humid phase. The formation of D1d is instead characterized by a warm period. Finally, Heinrich event 3 was identified in D1e (López-García et al. 2015).

## **2.0. Materials and methods**

Given that the aim of this paper is a diachronic comparison between the different Aurignacian assemblages, we have restricted our sample to all materials recovered in the front part of the cave, where the stratigraphy is fine grained and the youngest phase is divided into several units (Figure S1). Also, A2 and A1 are easily distinguishable in this area. We have thus decided to consider them as two different analytical units, contrary to our previous study (Falcucci et al. 2017). By doing so, we will be able to give a more accurate narrative of the Aurignacian at Fumane Cave. We consider five cultural units in this study: A2, A1, D3base, D3*balpha*, and D3ab. The number of lithic artifacts recovered in the lowermost layers is much higher than that available for the upper layers. During the formation of A2 and A1 the occupation of the site was more intense, while the D complex accumulated during a period in which the cave started to collapse, which resulted in a faster formation of the deposit. However, cores, blanks, tools, and by-products of the reduction sequences are available for all units, which allows for an accurate technological comparison.

The Aurignacian deposits in the external part of the cave have been excavated since the beginning of the fieldwork at the site. Most of the studied materials were recovered from 1988 to 2006 under the supervision of A. Broglio and one of us (MP). Before systematic excavations, the D3 complex was partially damaged by clandestine excavations in the eastern part of the cave. For this reason, most of the artifacts from the youngest units come from the central-western side of the present-day cave. The archaeological material was either directly excavated using a 33×33 cm grid or recovered from wet sieving. All artifacts are available for detailed investigations, except for a small set of cores (n=5) and tools (n=17) from A2–A1 that are on display in permanent exhibitions at the Museo Paleontologico e Preistorico di Sant’Anna d’Alfaedo (Veneto, Italy). In order to conduct an extensive technological analysis of the Aurignacian lithics, all artifacts greater than 1.5 cm in maximal dimension were counted and divided according to several technological classes and the sub-square of provenience. For A2 and A1, the sampling procedure is based on our previous work (Falcucci et al. 2017), but all artifacts belonging to the back of the cave were excluded. Several square meters were selected, most of them located in the vicinity of the combustion features identified during the excavations. In these square meters, all blades and bladelets greater than 1.5 cm in maximal dimension, regardless of the degree of fragmentation, were analyzed, while only flakes with preserved butts greater than 2.0 cm in

maximal dimension were fully analyzed. Furthermore, the external part of the cave was sampled in order to isolate and include in the database all cores, tools and tool fragments, all complete and almost complete blades and bladelets, and all by-products deemed to have had a significant role in the reduction process. Given the smaller sample sizes available for the uppermost layers (D3base, D3*alpha*, and D3ab), the whole extension of the cave entrance was sampled and all recovered artifacts greater than 1.5 cm in maximal dimension were fully analyzed.

The lithic analysis approach combines two complementary methods: reduction sequence analysis (Boëda et al. 1990; Inizan et al. 1995; Conard and Adler 1997; Soressi and Geneste 2011) and attribute analysis (Andrefsky 1998; Odell 2004; Tostevin 2013). The first identifies the methods of core reduction and the stages of knapping, use, and discard of stone artifacts. The second is particularly valuable because it provides quantitative data on the numerous discrete and metric features that can be recorded on individual artifacts. The attributes recorded in the database are based on recent studies and have been shown to be valuable for understanding laminar technologies at the onset of the Upper Paleolithic (e.g. Nigst 2012; Zwyns 2012). Additionally, diacritic analyses (Dauvois 1976; Roussel 2011; Pastoors et al. 2015) were performed to reconstruct the chronology, the direction of removals, the stages of production on exhausted and initial cores, and short sequences of removals on blanks. By doing this, the detailed core reduction processes can be identified (Falcucci and Peresani 2018).

We use the unified taxonomy by Conard et al. (2004) in order to give a general overview of core categories, while the sub-classification of platform reduction strategies are based on our previous works (Falcucci et al. 2017; Falcucci and Peresani 2018). Carinated cores have been sorted, after a techno-typological analysis, in three sub-categories: core-like, end-scrapers, and burin forms. The latter two have also been included in the tool list. In our previous analysis of units A2–A1, we did not include carinated burins in the core list. Here, after a re-evaluation of the tool assemblage, we have decided to include them as one of the possible reduction strategies used for bladelet production. Core-like forms are sometimes typed as *Rabot* in the French literature (de Sonneville-Bordes 1960; Demars and Laurent 1992). Here, we will not list them as tools. In order to more objectively define carinated pieces, only endscrapers and burins that display regular lamellar negatives longer than 15.0 mm have been typed so. Concerning the general typological list, we present a revised and simplified version of the most used Upper Paleolithic typologies (de Sonneville-Bordes 1960; Demars and Laurent 1992).

In order to assess the curvature of blanks, dorsal scars, and shape, we took only complete and almost complete specimens into account. This is beneficial in that it avoids biases due to the high degree of fragmentation of the assemblage. We quantified profile curvature using the categories defined by Bon (2002). We excluded retouched tools from the analysis of morphology and distal ends due to the modification of the shape via retouching. The metric boundary between blades and bladelets was placed at 12.0 mm (Tixier 1963), in agreement with most of the studies conducted on Aurignacian assemblages and according to our case study. Overall, our technological comparison between units is made in both a qualitative and a quantitative way. Differences were statistically tested by using both discreet and metrical

variables in IBM SPSS Statistics 24. Pearson's chi-squared tests were used for discrete variables while metric differences were assessed by using non-parametric tests (Mann-Whitney and Kruskal-Wallis), given that our samples are not normally distributed according to Shapiro-Wilk and Kolmogorov-Smirnov tests. Finally, we used the Holm-Bonferroni sequential correction test to reduce the probability of performing a type 1 error (Holm 1979).

### **3.0. Results**

#### **3.1. Raw material procurement**

The knappers selected flints from different carbonatic formations, which, in the western Monti Lessini, range from the Upper Jurassic to Middle Eocene. They were easily collected within 5–15 km from the site. The most widespread types, distinguishable based on macroscopic features (Bertola 2001), are from the Maiolica, the Scaglia Rossa, the Scaglia Variegata, and the Ooliti di San Virgilio formations. Excellent, knappable raw material nodules also abound in loose coarse stream or fluvial gravels, slope-waste deposits, and soils in the immediate surroundings of the cave. Jurassic and Tertiary coarse flint originating from carbonatic sandstones, frequently found in large-sized and homogeneous nodules, were almost exclusively used to produce blades (Falcucci et al. 2017). In units A2–A1, a small sample of blanks (n=70) and retouched bladelets (n=9) have been made on the extra-local red Radiolarite of the Lombard Pre-Alps, found today all along the Lombardy Basin, ca. 50 km from the site (Bertola et al. 2013). Besides Radiolarite, knappers principally used the same range of flints throughout the sequence.

#### **3.2. Quantitative analysis of the knapped assemblage**

The quantitative analysis of assemblages A2–D3ab shows little diachronic changes (Table 1). Blanks dominate all assemblages, followed by tools, angular debris, and cores. There is no difference between the frequency of blanks compared to tools ( $\chi^2=49.922$ ,  $p=0.3$ ), with tool frequency remaining stable throughout the sequence. Core assemblages are dominated by bladelet and blade cores and remain at low values, with a slight increase in layers D3*alpha*–D3ab. Overall, the paucity of cores (n=102, 0.6%) suggests that knappers reduced raw material nodules intensely on-site and often exported non-exhausted cores. Table 2 summarizes the frequency of the main blank types across the assemblages and gives a technological overview for each class. Laminar products (blades and bladelets together) dominate A2–A1, while they progressively decrease towards the top of the sequence (Figure 1). Specifically, while the frequency of blades is rather stable, the frequency of bladelets is low in layer D3ab. Instead, flakes start to increase from D3base–D3*alpha*.

FIGURE 1 ABOUT HERE.

All steps of the reduction sequence are represented, from the decortication to the discard of exhausted cores. Raw material decortication resulted mostly in the production of blades and flakes of variable sizes and with unidirectional removal scars. For this reason, and as already noted in A2–A1 (Falcucci et al. 2017), bladelets with cortical remains are rare (about 5–8%).

### **3.3. Blank production**

#### **3.3.1. Flake production**

A discussion about flake production in a laminar-dominated assemblage is always complicated by the fact that many of the flakes recovered are the outcomes of the various operations carried out to shape and maintain blade and bladelet cores. Furthermore, the flake class is generally very broad because it includes all those products that fall outside of the common definition of laminar blank. Cores are therefore the most useful artifacts to evaluate the presence of independent flake reduction strategies. Flake cores are present in all the studied assemblages, with percentages that increase from the 9% in A2 to the 21% in D3ab. The higher share of flake cores in D3*alpha*–D3ab is in agreement with the general increase of flakes.

There are some differences in the identified core reduction methods (Table 3). Parallel cores are only found in the oldest units. These cores follow a centripetal system of reduction and are similar to the centripetal cores recovered in the Uluzzian units (Peresani et al. 2016a). We suggested that the presence of these objects may represent the outcomes of minor post-depositional processes that affected A2–A1 (Falcucci et al. 2017). Multidirectional cores are present in all assemblages. This group includes cores that have removals from two or more faces and multiple striking platforms. They have polyhedral morphologies and frequently display hinged negatives of removals. Finally, in D3*alpha*–D3ab flakes were mostly obtained from platform cores (Figure 2a–b). These cores are made from nodules and thick cortical flakes and show flat striking platforms and straight flaked surfaces. The flaking direction is unidirectional and the reduction pattern sub-parallel. Last negatives are frequently hinged. Flakes with unidirectional hinged scars and plain butts are common among blanks and are likely to be the result of this reduction strategy (Figure 2d–g). The diacritic analyses suggest that the multidirectional cores recovered in D3*alpha*–D3ab were reduced by following a series of independent and rather organized reduction phases based on the platform reduction strategy (Figure 2c and h). The knapping progression usually started with a set of flakes detached from a flat striking platform. Once the flaking surface had lost its convexities, the core was rotated to begin a new, unidirectional reduction phase from an opposite or perpendicular removal surface. This pattern has not been found in A2–D3base, where flakes were removed from different faces without any specific organization.

#### FIGURE 2 ABOUT HERE.

To summarize, flake production is more important in the youngest cultural units of Fumane Cave, where flake cores show, in some cases, a degree of predetermination that was not found in the oldest assemblages. Nevertheless, flakes never represent the main goal of the knapping.

### 3.3.2. Blade and bladelet productions

We have divided laminar cores into different reduction strategies according to the objectives of production (Table 4). All the reduction strategies identified in A2–A1 (Falcucci et al. 2017) were also found in the youngest cultural units. Core reduction procedures in these layers do not differ from what we have already described in Falcucci and Peresani (2018). The listed core types do not represent strict categories. They share several technological features such as the preparation of flat striking platforms and a unidirectional approach to knapping. Cores were made from nodules, thick flakes, and by-products of lithic production. The selected blanks were roughly prepared and flaking surface decortication was partial or even absent. In the case of nodules, the most common operation consisted of the removal of a thick cortical flake to open a steep striking platform. A laminar blank was then detached along the longitudinal axis of the core, usually on a narrow face, to make blank production easier to start. Non-invasive crests were applied only when the morphology of the core blank did not permit laminar products to be directly extracted. In some cases, cores were oriented according to the transversal axis to exploit their thickness in the framework of carinated reduction strategies. In most cases, the goal of blank production was bladelets. Blade cores are less common than bladelet cores, while blade-bladelet cores were found in A2, A1, and D3ab. Most of these cores attest to a simultaneous production of blanks of varied sizes.

Independent and systematic blade productions were carried out on semi-circumferential and wide-faced flat cores. Only in D3*alpha* was blade production performed on the narrow side of a thick semi-cortical flake (Figure 3). This core has a few blade negatives, up to 93.2 mm in length. These are followed by a reorganization of the core's structure to perform an independent bladelet production.

FIGURE 3 ABOUT HERE.

Blade cores are always characterized by a unidirectional sub-parallel reduction pattern. Blanks were produced in a linear and consecutive knapping progression along the perimeter of the flaking surface (Figure 4). Lateral convexities were usually maintained through the use of naturally backed and neo-crested blades. Flat striking platforms were, in most cases, prepared and reshaped using core tablets. In A1 and D3ab (Figure 4b), two blade cores display faceted striking platforms. Blades with faceted platforms do never represent more than the 2% of the blank assemblages. The knapping technique used to produce blades shows little variability (Table 5). The external platform angle is usually under 75 degrees ( $\geq 96\%$ ) and blades frequently display ventral lipping, dorsal thinning, and narrow platforms that, together, are evidence for the use of a direct marginal percussion. There are some differences in the presence of bulbs and intensity of lipping, but it is not clear what the meaning of such variability expresses. The assessment conducted on the macro-tool category suggests that soft stone hammers were used during the maintenance and optimal production phases of platform cores (Caricola et al. accepted). From a morpho-metrical standpoint, blades usually have sub-parallel edges and dorsal scar patterns, which is in agreement with the observations made on blade cores. Blades are similarly sized across the assemblages (Table 6). There are no differences in

thickness or robustness of blanks, while there are some differences in the distribution of the width values. Descriptive statistics show that blades from D3ab are broader, while blades from D3base are slightly narrower. Concerning the length, complete blades from D3base–D3ab are too few to draw conclusions. If complete blades from these units are grouped (overall median: 46.3 mm) and compared to A2 (median: 47.4 mm), differences are not significant (Mann–Whitney,  $U=1870$ ;  $p=0.5$ ).

FIGURE 4 ABOUT HERE.

Blade cores show an intense degree of exploitation, although they were usually discarded when blade production could not be pursued. In other words, blade cores were not systematically reduced into bladelet cores (for a detailed explanation see: Falcucci et al. 2017). Blade and bladelet productions were, however, not strictly separated. Exhausted blade cores could be selected and reorganized to carry out independent bladelet productions. This is the case for two cores from A1 and D3*balpha*. Blades were also detached during the elaborate maintenance operations carried out on semi-circumferential and narrow-sided bladelet cores (see below) and during simultaneous reduction strategies. As a result of these operations, blades displaying from one to multiple bladelet negatives on the dorsal side were produced. The frequency of these blanks does not differ across the studied assemblages ( $\text{Chi}^2=6.8492$ ;  $p=0.1$ ), suggesting consistency in the overall technological organization.

Cores with bladelet scars are the most common type of core in the assemblages, with frequencies that vary from 86% in A2 to 70% in D3ab (Table 4). Bladelet production was based on several and, in most cases, independent reduction strategies, whose presence and frequency show few diachronic changes and demonstrate the need to produce end-products of different sizes. Bladelet cores can be divided into two macro-classes: cores that have been oriented according to the longitudinal axis of the blank, such as semi-circumferential and narrow-sided cores, and cores oriented according to the transversal axis, classified as carinated cores. In A2–A1, bladelet production is mostly based on the longitudinal axis of the core blank (Figure 5a–d).

FIGURE 5 ABOUT HERE.

Carinated technology is also common and results in the discard of carinated burins (Figure 6a and c), carinated cores-like (Figure 7b), and carinated endscrapers (Figure 7a). Carinated cores increase in the upper sequence. Carinated burins were only recovered in D3base (Figure 6b and d), while in D3*balpha*–D3ab, carinated reduction strategies are only conducted on carinated cores-like (Figure 6d) and carinated endscrapers (Figure 7e–h). Besides carinated cores, semi-circumferential cores are still very important (Figure 5e–f). Multi-platform cores were not found in D3base–D3*balpha*, while they are present in D3ab. Here, one bladelet core displays two different reduction phases that combine carinated technology and a narrow-sided reduction strategy (Figure 7g). In D3*balpha*, bladelet cores were likely exported. Many of the

recovered cores were in fact abandoned during the initial phases of blank production because of knapping mistakes and irregularity in the selected raw materials (S2 Figure).

FIGURE 6 ABOUT HERE.

The variability highlighted in the bladelet production falls within a rather coherent technological spectrum. The reduction procedures conducted on carinated cores are very similar across the studied units. The flaking surface is often isolated by detaching flakes at the intersection with the core flanks, transverse to the main production axis. This operation leads some cores to acquire a nosed morphology (Figure 7d, f, and h), although twisted bladelets are never the goal of this reduction strategy. Bladelet negatives are relatively short, curved, and on-axis. The alternated convergent reduction pattern and the maintenance operations carried out on carinated cores are comparable to what we observed among semi-circumferential bladelet cores (Falcucci et al. 2017; Falcucci and Peresani 2018). At this point, it must be stressed that the association between carinated pieces and bladelet production is not always straightforward. At Fumane, the use-wear analysis conducted on the endscrapers has shown that some of the carinated artifacts were used to work soft materials, such as hide (Aleo et al. 2017). It is interesting that tools with wear traces show, in most cases, a flaked surface shorter than 20.0 mm – a value that is under the 25<sup>th</sup> percentile of bladelet length values (see below).

FIGURE 7 ABOUT HERE.

Overall, the objective of lithic production was usually a bladelet with convergent edges obtained by a knapping progression that alternated removals at the center of convergent flaking surface with lateral oblique blanks that maintained its lateral convexities. When the core blank was a nodule, a narrow and convergent surface was isolated on a favorable area of the core in order to produce a set of pointed bladelets (Falcucci and Peresani 2018). This operation was very common among semi-circumferential cores and allowed the production to be pursued over the course of several reduction phases. Common maintenance blanks were lateral comma-like and technical blanks. In some cases, these blanks were the size of small blades displaying multiple bladelet negatives on the dorsal face (Falcucci et al. 2017).

The discreet attributes recorded on bladelets from A2–D3ab cultural units (Table 7) attest to the production of bladelets with similar properties and support the strong technological link between the studied assemblages. Curved profiles, of different intensity grade, dominate. Twisted bladelets, that are said to be obtained from the sides of carinated cores (Le Brun-Ricalens 2005a), are always represented in low frequencies and the twisting is slightly pronounced. Blank orientation is, in most cases, axial to the flaking direction. Unidirectional convergent dorsal scars are the most common pattern, with the exception of A1. Differences are, however, not significant. The same can be said of pointed distal ends. The metric analysis shows some differences between the different cultural units that are statistically significant (Table 8), though



it is not possible to detect a progressive reduction of bladelets' sizes. Based on the descriptive statistics, the groups that stand out are A1 and D3*alpha*. In the former, longer bladelets were produced, while in the latter bladelets are smaller both in length and width values. Therefore, Kruskal–Wallis tests were repeated without A1 when comparing length values ( $H=3.472$ ;  $p=0.3$ ) and without D3*alpha* when comparing width values ( $H=5.6$ ;  $p=0.1$ ). In both cases, the differences were insignificant.

### **3.4. Tools**

#### **3.4.1 Common tools**

The typological composition of the studied assemblages is listed in Table 9. All assemblages are dominated by retouched bladelets: the highest frequency is found in A2, and the lowest in D3ab. Differences in the distribution of common tool types are easier to appreciate by excluding retouched bladelets from the general count (Figure 8).

FIGURE 8 ABOUT HERE.

In A2–A1 (Figure 9), laterally retouched blades and burins are more abundant, while in D3*alpha*–D3ab (Figure 10), endscrapers increase in frequency. Laterally retouched blades have evidence of unilateral and bilateral retouch, and only in a few cases are these pointed by retouch. Retouching is, in most cases, direct and usually has a scalariform or marginal shape (Figure 9d–e and Figure 10d). Aurignacian retouch is rare (Figure 9f and figure 10h) and missing in D3base and D3*alpha*. The majority of burins are simple and made mainly on blades. Only in A2–D3base were dihedral (Figure 9b–c) and carinated burins found. In D3base, one carinated burin can be further classified as busked (Figure 6b). Most endscrapers display a thin working edge shaped by short lamellar removals. Some are made on retouched blanks (Figure 9h, j, and k and Figure 10j). The working edge was frequently reshaped and we identified several traces of the different activities conducted (Aleo et al. 2017). Carinated endscrapers increase in frequency towards the top of the sequence. Two thick-nosed endscrapers were recovered in D3ab, while one flat-nosed endscraper was recovered in D3*alpha* (Figure 10g). Finally, retouched flakes are more common in the youngest phases (Figure 10f). Overall, common tools were made on blades and flakes and only few on bladelets (S1 Table). The number of tools on flakes increases in D3base, which agrees with the general frequency of flakes in the youngest units.

FIGURE 9 ABOUT HERE.

FIGURE 10 ABOUT HERE.

#### **3.4.2. Retouched bladelets**

The distribution of retouched bladelets, according to the preserved parts, is not significantly different across the units (Table 10;  $\chi^2=23.011$ ;  $p=0.1$ ). The degree of breakage is very high; proximal and mesial fragments are represented the most. In D3ab, no complete retouched bladelets were found. Given that the

large majority of bladelets are broken, a morphological and technological comparison across assemblages is complicated. However, it can be said that retouched bladelets do not differ from unretouched ones. They usually have slightly curved and curved profiles, with little or no twisting present. Distal ends are almost never off-axis. Sub-parallel and convergent scar patterns are represented in similar percentages to those found in the blank assemblages. They have, in almost all cases, regular outline morphologies and tools with preserved cortical remains are always below the 2% of the overall samples. Retouched bladelets are made on by-products of the production in only two cases: One in A2 and one in D3*alpha*.

Retouching is usually marginal, semi-steep, and continuous all along the edge(s) (Figure 11). The shape is regular and generally follows the initial morphology of the blanks. On the bladelets with alternate retouch, the modification on the dorsal side is less invasive compared to the retouch on the ventral side. Sometimes it can be described as a slight abrasion that creates a thin angle. Overall, the intensity of retouch varies in relation to the morphology of the selected blank and the objective of production. In fact, bladelets with convergent retouch show a higher retouch intensity on the distal side with angles close to 90 degrees with respect to the ventral face. All studied assemblages show a strong lateralization of ventral retouch, almost always located on the right side (between 96% and 98%). This pattern is typical of the Aurignacian techno-complexes (Le Brun-Ricalens 2005b; Le Brun-Ricalens et al. 2009; Tsanova et al. 2012; Falcucci et al. 2018).

#### FIGURE 11 ABOUT HERE.

We have categorized bladelets with lateral retouch, convergent retouch, and retouched bladelets with truncation according to the position of retouch (Table 11). There is little diachronic variability in the distribution of alternate, direct, and inverse retouches. Alternate retouch decreases in frequency towards the top of the sequence, while direct and inverse retouches increase slightly. In D3*alpha*, bladelets with direct retouch are the most represented types. Bladelets with convergent retouch are frequent at Fumane. In most cases, they are modified first by direct retouch and second by alternate retouch. In a previous work, we showed that the frequency of these tools is underestimated due to the high degree of breakage (Falcucci et al. 2018). When only specimens with a preserved distal tip (complete blanks and distal fragments) are considered, the frequency of bladelets made pointed by retouch is much higher in each of the studied assemblages. Differences in the distribution of bladelets with lateral and convergent retouch across the cultural units are thus not significant (S2 Table;  $\chi^2=2.2044$ ;  $p=0.7$ ).

From a metric standpoint, retouched bladelets show differences in size that are statistically significant (Table 12), though no clear pattern can be identified. Compared to unretouched bladelets, they are always narrower and slender. The smaller tools are found in D3*alpha*, which is in agreement with what we noticed among the blanks. Instead, retouched bladelets from D3ab are comparable to the artifacts recovered in the lowermost assemblages. Finally, the robustness is similar across all samples.

### **3.5. Beyond lithics: organic tools and ornamental objects**

Before trying to summarize the outcomes of this techno-typological investigation, it is important to take into consideration the presence of other artifacts, such as ornamental objects, organic tools, and painted stones, within each of the studied units. To do so, we will consider only those artifacts that were recovered in the studied area. Extensive information on these findings can be found in numerous publications (Bartolomei et al. 1992b; Broglio et al. 2003; Broglio and Dalmeri 2005; Gurioli et al. 2005a; Broglio et al. 2006b; Broglio et al. 2009; Bertola et al. 2013).

Pierced marine shells are the most common ornaments at Fumane Cave and demonstrate the movements of peoples and/or contacts between peoples within a large area. It is worth mentioning that the Tyrrhenian and Adriatic coastlines were approximately 200 km and 400 km, respectively, from Fumane Cave at the time of the Aurignacian occupations (Waelbroeck et al. 2002; Siddall et al. 2008; Antonioli 2012). Shells are mostly concentrated in the back of the cave, while their number significantly decreases in the front part. Here, the major concentration was found in A2 (n=66), followed by the D3 complex (n=35), and A1 (n=21). The most common species of shell is *Homalopoma sanguineum*. Others species are rare, such as one *Dentalium sp.* found in A1 (Peresani et al. in press). The presence of an Atlantic species, *Littorina obtusata*, suggests that the Aurignacian foragers had contacts far beyond the Italian Peninsula (Vanhaeren and d'Errico 2006).

Besides pierced shells, one grooved deer incisor was recovered at the top of unit A1.

The bone industry is characterized by a series of common tools such as awls and perforators made from long bone diaphysis and also by antler points. In a few cases, the proximal part of the point is still preserved, allowing to point to be further classified as a SBP. Two SBPs were recovered in the D3 complex, but artifacts confidently attributable to this type were not found in A2–A1, although an antler point lacking its proximal part was found at the top of layer A1. Future research will focus on the presence of by-products from the manufacture of SBPs in order to further assess antler exploitation throughout the stratigraphic sequence.

Three stones painted with red ocher were recovered in the front part of the cave. These stones were part of the cave walls that partly collapsed because of climatic deteriorations. Two fragments, an anthropomorphic figure and an undetermined motif, were found in the upper sequence, and one fragment with a painted animal was found at the interface between A2 and D3base. The large amount of red ocher found in A2 (Broglio et al. 2009; Cavallo et al. 2017; Cavallo et al. 2018) may be interpreted as evidence for cave painting during the earliest occupations. Detailed comparative analyses of these fragments are required in order to ascertain from what part of the collapsed wall they originate.

## **4.0. Discussion**

### **4.1. The Protoaurignacian sequence of Fumane Cave**

We analyzed five successive lithic assemblages (A2–D3ab) from the Early Upper Paleolithic deposit of Fumane Cave. Results show that no major diachronic changes occur throughout the stratigraphic sequence. The variable and systematic bladelet productions and the dominance of retouched bladelets among tools are clear evidence of cultural continuity. However, it is important to underline the fact that continuity should not be interpreted as a stasis in the technological behavior of foragers that visited the cave over the course of several millennia. Based on the techno-typological variations and the re-evaluation of the organic artifacts therein recovered, we observed several similarities and differences.

Bladelets were the first goal of lithic production, and the reduction strategies identified in oldest cultural units were never abandoned. In A2–A1 major emphasis was placed in the selection of the longitudinal axis of the raw material nodule to carry out semi-circumferential and narrow-sided reduction sequences. In D3base–D3ab, carinated technology gradually increases, although it never represents the sole reduction strategy used. Carinated burins were only recovered in A2–D3base, while in D3*alpha*–D3ab carinated technology was exclusively based on core-like and endscraper forms. The strong similarities in the different bladelet productions are also clear when studying the morpho-metric attributes of lamellar blanks. Bladelets with convergent outlines of varied sizes represented the main production objective throughout the sequence. No significant changes were found in the organization of blade production. Blades were obtained from unidirectional cores by means of linear and consecutive knapping progressions, and only exceptionally from narrow-sided cores. In most cases, striking platforms were flat. Blanks with sub-parallel edges and similar metrical attributes were the objectives of production. At Fumane, the interdependence between blades and bladelets is a defining feature of A2–A1 (Falcucci et al. 2017) that is still represented in the youngest assemblages. Blades could either be simultaneously produced with bladelets or detached during maintenance operations conducted on bladelet cores. The youngest assemblages show a major emphasis in the production of flakes. Flakes from D3*alpha*–D3ab were obtained from platform cores, a different strategy than the parallel and multidirectional core reduction strategies represented in the underlying units.

The main differences between assemblages can be seen in the typological composition of tools. It is important to keep in mind that differences in the frequency of tools may be the outcome of factors such as uneven sample sizes, stochastic variation, and differences in site-use through time. We found that retouched bladelets, although always the most common tool type, gradually decrease in frequency towards the top of the sequence. As for the common tool's category, the lowermost assemblages are characterized by a higher frequency of laterally retouched blades and major typological variability in burins. Endscrapers, instead, gradually increase in frequency from D3base and represent the main type of tool in D3*alpha*–D3ab. Finally, in A2–A1 common tools are made on blades, while in D3base–D3ab tools on flakes are more frequent. In addition to the lithic artifacts at the site, all the studied units are characterized by ornamental objects manufactured on marine shell. Organic tools were made from bone and antler. No organic points were recovered in A2, while a mesio-distal antler point was found at the top of unit A1. SBPs made from antler were only recovered in D3*alpha*–D3ab.

Overall, this study supports our previous attribution of the A2–A1 assemblages to the PA (as defined in: Falcucci et al. 2017) and confirms that no differences can be identified, on a techno-typological ground, between the two cultural units. The rest of the studied assemblages present few differing features and can be grouped into two main phases: D3base and D3*balpha*–D3ab. D3base presents only few variations on the general composition of the lithic assemblage. It thus may be supporting evidence for a gradual modification of the technological system as seen in the earliest phase A2–A1, although some degree of mixing cannot be ruled out. D3base was in fact in direct contact with the underlying unit A1 and the overlying unit D3*balpha*. This issue will be addressed in a separate study. Differences are more marked in D3*balpha*–D3ab. We might refer to this phase as the *late* PA to emphasize the continuity, but also the changes, in the lithic technological system that occur throughout the stratigraphic sequence. We note that classifications of assemblages should be used as conceptual tools to describe and interpret the archaeological record (Brew 1946). As data accumulate and regional sequences are better defined, new interpretations are needed. One implication is that the prefix Proto- loses its literal meaning and is only used to refer to assemblages with similar sets of attributes and behavioral features, regardless of their chrono-stratigraphic position.

#### **4.2. Testing the adaptive shift to the Early Aurignacian**

According to Banks et al. (2013a), the adaptive shift that marked the beginning of the EA and the disappearance of the PA over the extension of the European sub-continent was triggered by the deterioration of the environment at the onset of H4. Several researchers have criticized the validity of this scenario because of both its discard of inconvenient data when running Bayesian modeling and for the strict cultural separation between the two Aurignacian variants (Higham et al. 2013; Ronchitelli et al. 2014; Falcucci et al. 2017). A growing chronological database attests to the beginning of the EA well before the cut-off of ca. 39.9–39.2 ky cal BP. This is, for instance, the case at Isturitz (Barshay-Szmidt et al. 2018), Pataud (Higham et al. 2011), Geißenklösterle (Higham et al. 2012), and Willendorf II (Nigst et al. 2014). Although criticisms have been raised over the dates obtained in Central Europe (Zilhão and d'Errico 2003; Banks et al. 2013b; Teyssandier and Zilhão 2018), this database suggests a statistical overlap, and thus coexistence, between assemblages that show either PA and EA affinities (Wood et al. 2014). In this framework, our assessment of the Aurignacian sequence of Fumane Cave, which contains evidence of human occupations that both pre- and postdate the occurrence of H4, provides us with the rare opportunity to address this issue and the archaeological validity of a model that relies on the assumption that the chrono-cultural sequence established in the Aquitaine Basin is applicable to all of Europe.

The signature of the *late* PA of Fumane Cave, which is in clear cultural continuity with the underlying units, provides a signal that is in contrast to the classic Aquitaine sequence, where it appears that consensus about the techno-typological features of the EA has been reached (de Sonneville-Bordes 1960; Bon 2002; Chiotti 2005; Bordes 2006; Bon et al. 2010; Teyssandier et al. 2010). Several major divergences can be underlined. At Fumane, blades from the youngest assemblages are not more robust and platforms are almost never faceted. Laterally retouched blades only rarely display the so-called Aurignacian retouch (de Sonneville-

Bordes 1960). This type of modification, which is said to be virtually absent in the PA and common in the EA (Bordes 2006), is represented in unit A2 and never increases in frequency in the upper sequence. The independence of bladelet production is not a viable characteristic with which to define the EA, given that this feature characterizes the PA also (Ortega Cobos et al. 2005; Slimak et al. 2006b; Normand et al. 2007; Porraz et al. 2010; Bataille 2017; Falcucci et al. 2017; Tafelmaier 2017; Bataille et al. 2018; Falcucci and Peresani 2018; Riel-Salvatore and Negrino 2018b). The EA is said to be characterized by a bladelet production that is almost exclusively conducted on carinated cores. At Fumane, carinated technology is never the sole reduction strategy responsible for the production of bladelets, though carinated pieces gradually increase in frequency throughout the sequence. Bladelets in EA assemblages are seldom retouched. Contrary to this, retouched bladelets are always the most common tool type within the sequence of Fumane Cave. Finally, the simultaneous production of blades and bladelets has only rarely been described in the EA (Chiotti 2005; Teyssandier 2007; Tafelmaier 2017), whereas at Fumane Cave it is a common feature. Our study thus challenges the tendency among Paleolithic archaeologists to transfer a regional sequence, although well-defined, to geographically and, in some cases, chronologically distant case-studies. It derives, in fact, a clear inconsistency between the archaeological data and the interpretative model. We cannot subdivide the Aurignacian into four development phases extrapolated from a restricted region, namely southwestern France, as several authors have already argued (e.g. Davies 2001; Clark and Riel-Salvatore 2005; Conard and Bolus 2006; Sitlivy et al. 2014; Conard and Bolus 2015; Moreau et al. 2015; Bataille and Conard 2018). Accepting that regional variation exists, one major implication is that the PA adaptive system, at least in northern Italy, cannot be seen as simply a pioneering, short-term phase of modern human dispersal into Europe, as recently suggested (Anderson et al. 2015).

There is increasing evidence that the PA was an efficient technological and behavioral adaptation that lasted for several millennia under changing climatic and environmental conditions. Our results are comparable to recent studies conducted in northwestern Italy, where long PA sequences also exist. At Bombrini, the PA units A2 and A1 accumulated during a period of about five millennia, from ca. 40,710 to ca. 35,640 ky cal BP (Benazzi et al. 2015). The cold phase associated to the onset of H4 took place in the lower unit A2 and did not result in the alteration of its defining characteristics, proving that these foragers had the capacity to adapt to shifting conditions (Riel-Salvatore and Negrino 2018a, b). At Mochi, the recent identification of two PA occupations (Grimaldi et al. 2014) that precede the well-known PA assemblage from unit G (Laplace 1977; Kuhn and Stiner 1998; Bietti and Negrino 2008) and the long chronological span that characterizes the latter (Douka et al. 2012) point towards similar conclusions.

Data from central and southern Italy is still incomplete, sometimes deriving from old excavations or surface collections. For instance, additional research is needed to test the hypothesis of an abrupt end of the PA due to the Campanian Ignimbrite volcanic eruption (but see: Lowe et al. 2012; d'Errico and Banks 2015), whose ashes have been found on top of PA layers at Castelcivita and Serino (Accorsi et al. 1979; Gambassini 1997; Wood et al. 2012), and of the possible cultural interactions that occurred between the makers of Uluzzian and Aurignacian techno-complexes (Palma di Cesnola 2001; Mussi 2002; Palma di Cesnola 2004; Mussi et al.

2006; Palma di Cesnola 2006; Riel-Salvatore 2007; Benazzi et al. 2011; De Stefani et al. 2012; Moroni et al. 2013; Ronchitelli et al. 2014; Giaccio et al. 2017; Villa et al. 2018). Differences between northern and southern Italy seem to be marked. For instance, the frequency of retouched bladelets in southern assemblages is lower when compared to the northern sites (Riel-Salvatore 2010). The further development of specific retouched bladelet types in the cultural units successive to the earliest PA at Castelcivita and Paglicci (Gambassini 1997; Palma di Cesnola 2004; Palma di Cesnola 2006) is evidence of specific regional adaptation mechanisms that need to be examined more closely.

The persistence of the PA in Italy, and thus the contemporaneity with the EA on a supra-regional scale, is considered possible by Bon (2002, 2006) and Anderson et al. (2015). Our data point toward the same direction, although it is now clear that technological continuity does not imply cultural isolation. This study has permitted us to identify an internal variability within the PA sequence of Fumane Cave. The gradual changes that occur attest to common chrono-cultural trends that link Fumane Cave to some western European regions, where a clear cultural break between PA and EA is difficult to detect. Differences with the classic definition of EA, as well as resilience of PA traits, are frequently emphasized. In the Pyrenean region the recently excavated site of Isturitz contains several layers that have been attributed to PA and EA occupations (Normand and Turq 2005). The EA from units C 4b1 and C 4b2 is characterized by the presence of SBPs (Normand et al. 2007), bovine teeth, and basket-shaped beads used as personal ornaments (White and Normand 2015). In terms of the lithic assemblages, the increase in the number of endscrapers and carinated cores and the presence of Aurignacian blades are considered supporting evidence for a shift to an EA phase. The researchers also emphasize that there are several differences compared to the classic definition, such as the high proportion of retouched bladelets (ca. 23% in C 4b1) and the interdependence of blade and bladelet reduction systems (Normand 2006; Normand et al. 2007; Barshay-Szmidt et al. 2018). The cultural unit C 4c4 is described as a transitional phase, suggesting a regional development of the EA (Normand 2006; Szmidt et al. 2010). In Cantabria, the PA unit VII and EA units VI–V of Labeko Koba (Arrizabalaga and Altuna 2000) were recently re-analyzed by Tafelmaier (2017). Tafelmaier shows the strong technological affinities that exist between PA and EA technological systems in the realm of bladelet production. As in the previous case, carinated reduction strategies increase in the EA, while from a typological standpoint retouched bladelets are less common (from ca. 50% to ca. 10%) and endscrapers are more common. It is also interesting to note that flakes are numerous in the EA units, similar to the youngest cultural phases of Fumane Cave. Similar data come from the site of La Viña (Fortea Pérez 1995; Santamaría 2012), although taphonomic processes may have resulted in the mixing of supposedly EA and late Aurignacian assemblages (Santamaría 2012; Wood et al. 2014). In northern France, the site of Les Cottés contains PA (US 04inf.) and EA (US 04sup.) units that are chronologically indistinguishable (Talamo et al. 2012). The EA unit consists of techno-typological traits that are also well represented in the underlying PA (Roussel and Soressi 2013). Research conducted some decades ago in southeastern France shows that sites such as Pêcheurs (Lhomme 1976), Esquicho Grapaou units B.R. 1 and C.C. 1 (Bazile 1974), Rainaude (Onoratini 1986), and Observatoire unit E (Onoratini et al. 1999), assigned to the EA based on the presence

of SBPs and carinated cores, present several features that diverge from the classic definition. For this reason, Slimak et al. (2006a) have observed that the use of two strict groups such as PA and EA does not allow us to well appreciate the development of the Aurignacian in the Rhone Basin. The authors conclude that a Mediterranean variant of the EA with several PA features is very likely. The duality that seems to exist between the Atlantic and Mediterranean Aurignacian has also been emphasized by other authors, who suggest that new regional assessments be conducted to identify better the defining features of the latter variant (Le Brun-Ricalens and Bordes 2007; Anderson et al. 2018).

If we broaden our focus to cover Central Europe, the scenario becomes more complex. In the Swabian Jura, for instance, the Aurignacian begins with assemblages that differ greatly from the PA identified in south and western Europe and that are rich in carinated cores and almost completely devoid of retouched bladelets (Hahn 1977; Conard and Bolus 2006; Teyssandier 2007). The lithic industries at Geißenklösterle have been described by Teyssandier (2007) as being close to the EA of the Aquitaine Basin, although Conard and Bolus (2006) have stressed that the Aurignacian of the Swabian Jura has a strong regional signal. Distinct chrono-cultural phases have not yet been identified, but Teyssandier (2008) has suggested a possible change in the organization of the lithic assemblages within the sequence of Geißenklösterle that may not be solely related to the functional variability of the site. Furthermore, new data from the ongoing excavations at Hohle Fels suggest that the technological features of the Aurignacian of the Swabian Jura are more diverse than previously thought (Bataille and Conard 2018). The analyses of the lowermost horizons will better define these components and the diachronic development of the Aurignacian in the region.

The data and examples presented above demand a new step in research on the beginning and development of the Aurignacian. Archaeologists should be less stuck in terminological and cultural taxonomic issues and more involved in researching the reasons behind the dichotomy between heterogeneity and commonalities that are evident when one focuses on a regional framework. In this regard, we and other authors have identified clear technological overlaps between PA and EA assemblages (Sitlivy et al. 2012; Sitlivy et al. 2014; Falcucci et al. 2017; Tafelmaier 2017; Bataille et al. 2018). We are aware that post-depositional and taphonomic processes may distort the archaeological record, but mixing cannot be considered the sole explanation for interpreting this cultural variability. As previously shown, variability in the Aurignacian is the rule, rather than the exception. A thought-provoking reconstruction proposed by Tafelmaier (2017) interprets the PA and EA as two *adaptive facies*. They are distinguishable on the basis of quantitative differences, although being rooted in the same technological repertoire, which is seen as the basal adaptation of an *early stage Aurignacian* that subsumes both variants. In this scenario, PA and EA would not represent two strictly distinct technical traditions, as instead suggested by Teyssandier et al. (2010).

Our data partially agree with this interpretation and suggest that the Aurignacian be considered a complex phenomenon where PA and EA represent conceptual tools to help describe a non-linear process with multiple poles of variability and no strict mutually-excluding features. Nevertheless, if only western and southern Europe are considered, two stages can be distinguished. The first coincides with the beginning of the Aurignacian in many stratigraphic sequences and is frequently named the PA (or complementary names;



see a discussion in: Bon et al. 2006). This early PA stage has been supposed by us as being technologically homogeneous across its geographical extent (Falcucci et al. 2017; Falcucci and Peresani 2018), although variability on a typological ground is expected (Falcucci et al. 2018). During the second stage, gradual modifications and the consolidation of regional components can be detected and are evident when studying the variability of organic tools, personal ornaments, and technological behaviors. *Late PA* assemblages in northern Italy appear to be synchronous with others grouped in the EA. However, we have shown that assemblages that express a high degree of internal variability are frequently classified under the term EA and future research should focus on better isolating particular regional trajectories.

### **4.3. Split-based points and cultural interactions between foragers**

The youngest cultural units at Fumane Cave cannot be grouped into the EA. This assessment has demonstrated that the PA was an efficient adaptive system that responded well to the needs of foragers gravitating to the Venetian Pre-Alps. Its techno-typological features clearly persist throughout the stratigraphic sequence with some temporal variations that are less distinct when compared to other regions. The use of similar reduction strategies to produce blades, and especially bladelets, can be seen as evidence for the presence of a stable population in northeastern Italy with strong knapping traditions. However, the isolation of general trends in the realm of lithic technology that link Fumane Cave to other southern and western European regions demonstrate the possibility of cultural interactions between foragers. Supporting evidence for this hypothesis is the appearance of SBPs at several sites across Europe (Liolios 2006; Doyon 2017).

The SBP has historically been considered a true expression of the EA (Peyrony 1933, 1935; de Sonneville-Bordes 1960), replaced by types of organic points in successive stages of the Aurignacian (but see: Moreau et al. 2015). This type of organic artifact remains important to the definition of the EA today (Teyssandier 2007; Banks et al. 2013b, a; Teyssandier and Zilhão 2018). Only a small percentage of sites contains SBPs and more generally organic points. Outside of the Aquitaine and the Swabian Jura, finds are scattered (Tafelmaier 2017). Nevertheless, it is not rare that archaeologists ascribe a cultural unit to the EA based solely on the presence of a SBP (de Sonneville-Bordes 1960; Hahn 1977; Banks et al. 2013a; Tejero and Grimaldi 2015). An example is Fumane Cave. Some authors have argued that units A1 (but see above) and D3 correspond to EA phases (Banks et al. 2013a, b; Teyssandier and Zilhão 2018). This interpretation is debatable because, as we have shown here, no clear cultural shift to the EA is visible in the lithic technology. The manufacture of a SBP requires a highly standardized procedure (Tartar and White 2013) that seems unlikely to have been reinvented in multiple regions without any technological transfer. Its presence in the *late PA* of Fumane Cave thus suggests the existence of inter-regional contacts between foragers that allowed technological innovations to spread over large areas. This is not unrealistic if one considers the extensive exchange networks required for the circulation of marine shells of both Mediterranean and Atlantic origins across hundreds of kilometers (Taborin 1993; Vanhaeren and d'Errico 2006). As for the timing of its appearance, the debate is still open. It is often said that when SBPs are found within a clear stratigraphic

framework, they are never associated to the lowermost cultural unit (Hahn 1977; Doyon 2017). Also, a chronological comparison of directly or indirectly dated SBPs across Europe suggests that this artifact type does not date to the earliest manifestations of the Aurignacian (Tafelmaier 2017). The ongoing excavations at Hohle Fels attest instead to the presence of SBPs in the lowermost Aurignacian horizons (Conard and Malina 2008). More data is thus needed to test whether SBPs were only manufactured starting from a second stage of the Aurignacian.

In Europe there were not insurmountable natural barriers at the time of the Aurignacian. In the specific case of Italy, the Ligurian corridor and the exposed land that is today under the northern Adriatic Sea allowed people to move both westwards and eastwards. In this type of favorable situation, the circulation and diffusion of ideas related to the manufacture of innovative tools is well documented in the ethnographic literature (Kroeber 1940; Murdock 1960; Mulvaney 1976; Wiessner 1983, 1984; Kelly 2013; Tostevin 2013). For instance, research shows that sub-contemporary foragers can be affected by material culture diffusing as far as 1200 km away from the source (Mulvaney 1976). In this framework, multi-lineal and reciprocal transfer of ideas are to be expected (Bataille 2013).

The nature of the spread and assimilation of new technologies depends on the degree of social intimacy that occurs between foragers, which is triggered by similarities in their respective material culture (Tostevin 2007, 2013). Social intimacy was likely high between regional groups of Aurignacian foragers that, as discussed in this paper and in Falcucci et al. (2017), shared a common technological background. Human groups that manifest similar cultural traits are in fact open to and likely to exchange information (Eerkens and Lipo 2007). For these reasons, the presence of SBPs, if not studied in combination with other features of a given archaeological assemblage, should not be used to infer on cultural attributions. In fact, the data from Fumane Cave demonstrate that SBPs are not exclusively relegated to EA-like assemblages. The development and assimilation of organic tools may have followed different trajectories compared to lithics that require further investigation.

## **5.0. Conclusions**

This paper presented a technological analysis of the lithic assemblages and a re-evaluation of the organic artifacts from five cultural units at Fumane Cave in northeastern Italy. Our goals were to define a chrono-cultural narrative of the Aurignacian at Fumane and identify a possible cultural break in the stratigraphic sequence that might be related to a shift from the PA to an EA adaptive system. Our results show that the PA techno-typological features (Falcucci et al. 2017) clearly persist throughout the stratigraphic sequence with some gradual variations that are less distinct when compared to other regions. PA features are not related to a certain time span and the occurrence of H4 does not coincide with a shift to the EA. This study thus challenges the generalization of applying the Aquitaine reference sequence (Bordes 2006; Bon et al. 2010) and the model proposed by Banks et al. (2013a) to all of Europe. In other words, all models have their own regional limits.

Our data provide further evidence that cultural attributions should not be drawn from single type fossils. For instance, SBPs cannot be used to identify an EA cultural unit if other features of the assemblage are considered as well. At best, the appearance of SBPs across a large geographical extent suggests the existence of extensive networks that allowed technological innovations to spread across hundreds of kilometers. The identification of a source region for this tool type seems unlikely, given that forager territories frequently overlap and the accuracy of our dating methods are still not ideal. In this regard, new findings from some eastern European regions seem promising (Hopkins et al. 2016; Hopkins et al. 2018), although they still need to be accurately described.

The Aurignacian represents a broad cultural taxonomic group with a polythetic nature of different technological features (sensu Clarke 1978). It can be seen as a landscape of spatial and temporal variability with multiple poles and end points. In this framework, the Aquitaine sequence represents only a regional pole of such variability. The development of the Aurignacian seems in fact to be characterized by a high heterogeneity that cannot be reduced to a static model in which technical traditions and/or adaptive systems are divided by temporal hiatuses or geographical domains.

The internal variability of Fumane Cave and the identification of some chrono-cultural trends across southern and western Europe, permit us to define two main stages within the early manifestations of the Aurignacian in this part of the subcontinent. The first corresponds to the *early* PA, which appears to be rather homogeneous across its extent (Falcucci et al. 2017). The second refers to a period of gradual modifications and consolidation of regional signatures. At Fumane, and more generally in northern Italy, this phase seems to be in strong cultural continuity with the underlying units and can be tentatively referred to as *late* PA. The main differences in stone artifacts are the increased proportion of carinated endscrapers and the decrease of retouched bladelets. When additional evidence in the North-Adriatic region will be produced and accurately described, there might be the possibility to discuss the use of Fumane Cave as a type site for regional variability and the definition of a new variant of the Aurignacian phenomenon, in coherence with evidence from the northern Tyrrhenian coastal belt. For what concerns here, we argue that PA and EA represent archaeological constructs that are used to macro-group a set of highly variable behaviors and no straightforward Pan-European reconstructions can be formulated.

In conclusion, the internal variability that characterizes the PA at Fumane Cave and the appearance of SBPs in the youngest cultural units demonstrate that foragers at the south of the Alps were not culturally isolated. They, however, maintained strong local traditions over the course of several millennia. Reassessments of pivotal sites will be beneficial in emphasizing the complexity of the Aurignacian and better defining regional trajectories. This work has been underestimated in the past years because of the need to develop a model that would explain the geographic expansion of AMHs into Europe.

The present study represents only the first step in the comprehension of the Aurignacian at Fumane Cave. Future research will address questions related to the use of the site and the mobility strategies adopted by foragers across time. This will allow us to further investigate the extent to which functional variables are responsible for the formation of the lithic assemblages at the site, which, we remind, can lead archaeologists

to define erroneously culturally distinct phases. Together, our techno-typological analyses provide a useful prerequisite for future work that seeks to develop explanations for the great variability observed in the material culture of the Aurignacian.

## Acknowledgments

Research at Fumane is coordinated by the Ferrara University (MP) in the framework of a project supported by the Ministry of Culture – Veneto Archaeological Superintendence, public institutions (Lessinia Mountain Community - Regional Natural Park, Fumane Municipality), Foundations (Leakey Foundation, Spring 2015 Grant), and private associations and companies. The doctoral studies of AF are funded by the state of Baden-Württemberg and the University of Tübingen (Evolution of Cultural Modernity research project). The authors are grateful to R. Duches and a team of students for organizing the lithic collections in 2015. The authors thank the Editor and anonymous reviewers for providing contribution to considerably ameliorating the paper and Gillian Wong for improving the English.

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## **Table captions**

**Table 1.** Quantitative analysis of the knapped assemblages (> 1.5 cm). Note that artifacts that were described both as tools and cores have been included in the tool category. Percentages are given in brackets.

**Table 2.** Distribution of blank types across the studied assemblages. The count includes blank types of tools. Rounded percentages are given in brackets.

**Table 3.** Distribution of flake cores according to the identified reduction strategies.

**Table 4.** Distribution of platform cores according to the identified reduction strategies and the objectives of production. Core fragments are excluded from the list. \*one core in A1 and one in D3ab show a carinated reduction strategy carried out prior to or after the re-orientation of the core.

**Table 5.** List of metric and discreet attributes recorded on blades to diagnose the knapping technique, and the results of the Kruskal–Wallis and Pearson’s chi–squared tests that we conducted. P-values in bold are significant. EPA stands for external platform angle. Rounded percentages are given in brackets.

**Table 6.** Metric comparison of the mean values (in millimeters)  $\pm$  standard deviations and median values (in millimeters) of blades, and results of the Kruskal–Wallis tests that we conducted. P-values in bold are significant. Length values are not considered given the small number of complete blades recovered in the youngest assemblages. Tools are excluded from the analysis.

**Table 7.** Comparison of the discreet attributes recorded on bladelets, and results of the Pearson’s chi–squared tests that were conducted. Note that profile curvature and dorsal scar pattern take into account only complete and almost complete specimens. Retouched tools are excluded from the analysis of the distal ends. Rounded percentages are given in brackets.

**Table 8.** Metric comparison of the mean values (in millimeters)  $\pm$  standard deviations and median values (in millimeters) of bladelets and results of the Kruskal–Wallis tests that we conducted. P-values in bold are significant. Tools are excluded from the analysis.

**Table 9.** Distribution of tool types. Rounded percentages are given in brackets.

**Table 10.** Distribution of retouched bladelets according to the degree of breakage. Rounded percentages are given in brackets.

**Table 11.** List of retouched bladelets divided according to the types defined in Falcucci et al. (2016) and the position of retouch. Rounded percentages are given in brackets.

**Table 12.** Metric comparison of the mean values (in millimeters)  $\pm$  standard deviations and median values (in millimeters) of retouched bladelets and results of the Kruskal–Wallis tests that we conducted. P-values in bold are significant. Statistic tests were not performed for length values given the small

number of available complete artifacts from the D3base–D3*balpha* assemblages and the absence of complete tools in D3ab.

**Table S1.** Distribution of common tool types according to the selected blank type. The “other” group includes bladelets and angular debris. Rounded percentages are given in brackets.

**Table S2.** Distribution and percentages of retouched bladelets with preserved distal tips (complete blanks and distal fragments) according to the presence and absence of distal modification via retouching.

## **Figure captions**

**Figure 1.** Frequencies of the main blank types (flakes, blades, and bladelets) produced throughout A2–D3ab. A2 is the oldest unit, while D3ab is the youngest.

**Figure 2.** Selection of flake cores and blanks (**d–h**) and their relative schematic drawings from the D3*balpha*–D3ab assemblages. **a** and **b** are platform cores, while **c** is a multi-platform core. Arrows indicate the direction of removals and, in the case of blanks, of the blow. The oldest reduction phases are colored darker, while the successive phases are lighter. (photo and drawings: A. Falcucci).

**Figure 3.** Narrow-sided blade-bladelet core and its schematic drawing from D3*balpha*. Arrows indicate the direction of removals, which are numbered in ascending order to show their chronological succession. The oldest reduction phases are colored darker, while the successive phases are lighter. Note that phases 5 and 6 correspond to the re-orientation of the core to perform an independent bladelet production that was, however, not pursued. (photo and drawing: A. Falcucci).

**Figure 4.** Wide-faced flat blade cores and their schematic drawings from A2 (**a**) and D3ab (**b**). Arrows indicate the direction of removals, which are numbered in ascending order to show their chronological succession. The oldest reduction phases are colored darker, while the successive phases are lighter. Note the faceting of the core from D3ab. (photo and drawings: A. Falcucci).

**Figure 5.** Bladelet and blade-bladelet cores and their schematic drawings. Narrow-sided bladelet cores from A2 (**b**) and A1 (**a**). Semi-circumferential bladelet cores from A2 (**d**), A1 (**c**), and D3ab (**f**). Semi-circumferential blade-bladelet core from D3ab (**e**). Arrows indicate the direction of removals, which are numbered in ascending order to show their chronological succession. The oldest reduction phases are colored darker, while the successive phases are lighter. (photo and drawings: A. Falcucci).

**Figure 6.** Carinated burins and their schematic drawings from A2 (**a** and **c**) and D3base (**b** and **d**). Note that **b** is a busked burin. Arrows indicate the direction of removals, which are numbered in ascending order to show their chronological succession. The oldest reduction phases are colored darker, while the successive phases are lighter. (photo and drawings: A. Falcucci).

**Figure 7.** Carinated endscrapers (**a**, **c**, and **e–h**) and cores-like (**b** and **d**) and their schematic drawings from A2 (**a**), A1 (**b**), D3base (**c**), D3balpha (**d–e**), and D3ab (**f–h**). Note that **g** is a multi-platform core with an associated narrow-sided reduction strategy. Note that **d**, **f**, and **h** have a nosed morphology acquired after the removal of maintenance flakes. Arrows indicate the direction of removals, which are numbered in ascending order to show their chronological succession. The oldest reduction phases are colored darker, while the successive phases are lighter. (photo and drawings: A. Falcucci).

**Figure 8.** Bar-charts comparing the frequencies of common tool types identified throughout A2–D3ab. See the color legend to identify the cultural units.

**Figure 9.** Selection of tools from assemblages A2–A1. Burin on truncation (**a**), dihedral burins (**b–c**), laterally retouched blades (**d–e**), Aurignacian blade (**f**), endscrapers on blade (**g**, **i**, and **l**), endscrapers on laterally retouched blade (**h** and **j**), and endscraper on laterally retouched flake (**k**). Arrows indicate the direction of the blow. (photo: A. Falcucci, drawings: G. Almerigogna).

**Figure 10.** Selection of tools from assemblages D3base–D3ab. Burin on breakage (**a**), burin on truncation (**b**), splintered piece (**c**), laterally retouched blade (**d**), endscrapers on flake (**e** and **i**), laterally retouched flake (**f**), flat-nosed endscraper (**g**), Aurignacian blade (**h**), endscraper on blade (**j**). D3base = a; D3balpha = b–g; D3ab = h–j. Arrows indicate the direction of the blow. (photo: A. Falcucci, drawings: G. Almerigogna).

**Figure 11.** Selection of retouched bladelets sub-grouped according to the cultural units of provenience. **a**, **b**, **f**, **g**, **k**, **n**, **p**, **r**, and **s** are bladelets with convergent retouch. **c–e**, **h–j**, **l–m**, **o**, **q**, and **t–u** are bladelets with lateral retouch. Artifacts are oriented with the butt at the bottom of the photo. (photo: A. Falcucci, drawings: G. Almerigogna).

**Figure S1.** Plan view of the Fumane Cave. The area analyzed in this paper is colored yellow.

**Figure S2.** Partially refitted semi-circumferential blade core from D3balpha. Note that the production was interrupted during the early stages of reduction. (photo: A. Falcucci).



TABLE 1

	Blank	Tool	Core	Angular Debris	Tested nodules	Total
D3ab	382 (73.0%)	70 (13.4%)	17 (3.3%)	54 (10.3%)	-	523
D3b $\alpha$	561 (78.2%)	106 (14.8%)	12 (1.7%)	38 (5.3%)	-	717
D3base	830 (79.5%)	144 (13.8%)	5 (0.5%)	65 (6.2%)	-	1044
A1	3235 (78.2%)	648 (15.7%)	34 (0.8%)	219 (5.3%)	1 (-)	4137
A2	8055 (77.2%)	1458 (14.0%)	34 (0.3%)	883 (8.5%)	4 (-)	10434
Total	13063	2426	102	1259	5	16855

TABLE 2

	A2	A1	D3base	D3balpha	D3ab
<b>Flake</b>	<b>3172 (33%)</b>	<b>1164 (30%)</b>	<b>407 (42%)</b>	<b>311 (47%)</b>	<b>242 (54%)</b>
Full production	2391	865	294	220	163
Semi-cortical	434	162	77	56	40
Initialization	215	69	20	20	11
Maintenance	132	68	16	15	28
<b>Blade</b>	<b>1973 (21%)</b>	<b>982 (25%)</b>	<b>156 (16%)</b>	<b>97 (15%)</b>	<b>84 (19%)</b>
Full production	1501	760	107	64	55
Semi-cortical	299	143	29	18	12
Initialization	53	18	3	3	3
Maintenance	120	61	17	12	14
<b>Bladelet</b>	<b>4361 (46%)</b>	<b>1735 (45%)</b>	<b>411 (42%)</b>	<b>259 (39%)</b>	<b>123 (27%)</b>
Full production	4061	1603	367	233	106
Semi-cortical	208	88	27	16	9
Initialization	23	11	7	1	1
Maintenance	69	33	10	9	7
<b>Undetermined</b>	<b>6 (-)</b>	<b>2 (-)</b>	<b>0 (-)</b>	<b>0 (-)</b>	<b>3 (1%)</b>
<b>Total</b>	<b>9512</b>	<b>3883</b>	<b>974</b>	<b>667</b>	<b>452</b>

TABLE 3

	A2	A1	D3base	D3balpha	D3ab
Parallel	2	1	-	-	-
Platform unidirectional	-	-	-	1	2
Multidirectional, unorganized	2	3	1	1	-
Multidirectional, organized	-	-	-	1	2
Total	4	4	1	3	4

TABLE 4

	A2	A1	D3base	D3balpha	D3ab
<b>Initial core</b>					
Narrow face	3	3	2	2	3
Broad face	1	-	-	2	-
Transverse	1	3	1	-	-
<b>Semi-circumferential</b>					
Blade	1	1	-	1	-
Bladelet	5	5	1	-	2
Blade-bladelet	1	-	-	-	1
<b>Narrow-sided</b>					
Blade	-	-	-	-	-
Bladelet	3	6	-	1	-
Undetermined	-	-	-	-	1
<b>Wide-faced flat</b>					
Blade	1	-	-	-	1
Bladelet	1	3	-	-	-
Blade-bladelet	1	-	-	-	-
<b>Carinated</b>					
Core-like	2	1	-	1	-
Endscraper	3	-	1	3	2
Burin	6	2	2	-	-
<b>Multi-platform*</b>					
Blade	-	-	-	-	-
Bladelet	4	6	-	-	3
Blade-bladelet	-	2	-	1	-
<b>Total</b>	<b>33</b>	<b>32</b>	<b>7</b>	<b>11</b>	<b>13</b>

TABLE 5

	A2	A1	D3base	D3balpha	D3ab	Test
<b>Platform measurements</b>						
Thickness	1.5 ± 1.0	1.5 ± 1.1	1.5 ± 0.8	1.8 ± 1.3	1.8 ± 1.0	H= 6.518; p=0.2
Width	4.2 ± 2.4	4 ± 2.5	4 ± 2.2	4.2 ± 2.4	4.4 ± 2.3	H= 2.911; p=1
W/T ratio	3.4 ± 2.7	3.3 ± 2.7	3 ± 2.1	2.7 ± 1.5	2.7 ± 1.1	H = 0.9003; p=0.9
<b>Platform type</b>						
Plain	344 (76%)	136 (69%)	65 (82%)	33 (72%)	37 (84%)	
Linear	54 (12%)	29 (15%)	9 (11%)	4 (9%)	3 (7%)	
Punctiform	6 (1%)	9 (5%)	-	2 (4%)	2 (5%)	
Cortical	9 (2%)	2 (1%)	2 (3%)	1 (2%)	1 (2%)	Chi2=34.257
Faceted	3 (1%)	3 (2%)	-	1 (2%)	1 (2%)	p=0.2
Dihedral	11 (2%)	2 (1%)	2 (3%)	-	-	
Abraded	5 (1%)	6 (3%)	-	2 (4%)	-	
Undetermined	19 (4%)	10 (5%)	1 (1%)	3 (7%)	-	
<b>Bulb</b>						
no	256 (57%)	101 (51%)	36 (46%)	18 (39%)	14 (32%)	Chi2=15.682
yes, moderate	183 (41%)	85 (43%)	42 (53%)	27 (59%)	28 (64%)	<b>p&lt;0.05</b>
yes, pronounced	12 (3%)	11 (6%)	1 (1%)	1 (2%)	2 (5%)	
<b>Lip</b>						
no	39 (9%)	20 (10%)	9 (11%)	11 (24%)	8 (18%)	Chi2=13.126
yes, moderate	170 (38%)	88 (45%)	49 (62%)	26 (57%)	26 (59%)	<b>p&lt;0.05</b>
yes, pronounced	242 (54%)	89 (45%)	21 (27%)	9 (20%)	10 (23%)	
Dorsal thinning, yes	398 (88%)	176 (89%)	71 (90%)	37 (80%)	37 (84%)	Chi2=3.755; p=0.4
Bulbar scars, yes	94 (21%)	42 (21%)	10 (13%)	8 (17%)	7 (16%)	Chi2=2.611; p=0.6

TABLE 6

	A2	A1	D3base	D3balpha	D3ab	Kruskall-Wallis tests
<b>Width</b>						
Mean ± st. dev.	16.2 ± 4.0	16.6 ± 4.1	15.8 ± 4.1	16.8 ± 4.8	17.6 ± 4.9	
Median	14.9	15.4	14.6	14.7	16.7	H=13.96; p<0.05
<b>Thickness</b>						
Mean ± st. dev.	4.2 ± 2.2	4.2 ± 2.1	4.1 ± 2.1	4.3 ± 1.9	4.5 ± 2.0	
Median	3.7	3.6	3.5	3.9	4.0	H=5.947; p=0.2
<b>Robustness (W/T)</b>						
Mean ± st. dev.	4.4 ± 1.6	4.6 ± 1.7	4.6 ± 1.9	4.3 ± 1.6	4.3 ± 1.4	
Median	4.2	4.4	4.4	3.9	4.1	H=2.746; p=0.6

TABLE 7

Morphological attributes	A2	A1	D3base	D3balpha	D3ab	Pearson's chi-squared tests
<b>Profile</b>						
Straight	82 (27%)	30 (26%)	9 (23%)	12 (29%)	4 (21%)	Chi2= 20.512 p=0.2
Slightly curved	82 (27%)	27 (23%)	6 (15%)	11 (26%)	4 (21%)	
Curved	81 (27%)	37 (32%)	13 (33%)	6 (14%)	7 (37%)	
Intense curvature	15 (5%)	6 (5%)	4 (10%)	8 (19%)	2 (11%)	
Twisted	44 (14%)	17 (15%)	7 (18%)	5 (12%)	2 (11%)	
<b>Orientation</b>						
	245	114				
Axial	(83%)	(90%)	75 (91%)	59 (88%)	29 (85%)	Chi2=6.166
Off-axis	49 (17%)	12 (10%)	7 (9%)	8 (12%)	5 (15%)	p=0.2
<b>Dorsal scar pattern</b>						
	147					
Unidirectional sub-parallel	(48%)	72 (62%)	23 (48%)	25 (51%)	12 (63%)	Chi2=8.2037
	131					
Unidirectional convergent	(43%)	34 (29%)	20 (42%)	24 (49%)	7 (37%)	p=0.08
Other	26 (9%)	11 (9%)	5 (10%)	-	-	
<b>Distal end - dorsal view</b>						
	157					
Pointed	(52%)	51 (40%)	43 (52%)	37 (55%)	17 (50%)	Test pointed/no pointed
Convex-concav	99 (33%)	58 (46%)	30 (37%)	20 (30%)	11 (32%)	Chi2= 6.2325
Straight	34 (11%)	16 (13%)	3 (4%)	10 (15%)	3 (9%)	p=0.2
Irregular	13 (4%)	2 (2%)	6 (7%)	-	3 (9%)	

TABLE 8

	A2	A1	D3base	D3balpha	D3ab	Kruskall-Wallis
<b>Length</b>						
Mean ± st. dev.	27.5 ± 9.7	30.2 ± 9.6	27 ± 9.0	23.8 ± 5.7	25.5 ± 6.0	
Median	25.4	29.6	25.7	23.5	25.2	H=14.41; p<0.05
<b>Width</b>						
Mean ± st. dev.	8.6 ± 2.0	8.9 ± 1.9	8.6 ± 2.0	8.3 ± 2.1	8.9 ± 2.1	
Median	8.7	9.1	8.7	8.4	9.1	H=11.12; p<0.05
<b>Thickness</b>						
Mean ± st. dev.	2.2 ± 1.0	2.4 ± 1.1	2.1 ± 0.9	2.1 ± 0.8	2.3 ± 0.9	
Median	2.0	2.1	2.0	1.9	2.1	H=11.45; p<0.05
<b>Robustness (W/T)</b>						
Mean ± st. dev.	4.4 ± 1.7	4.3 ± 1.6	4.5 ± 1.6	4.2 ± 1.4	4.2 ± 1.5	
Median	4.3	4.1	4.3	4.1	3.8	H=5.192; p=0.3
<b>Elongation (L/W)</b>						
Mean ± st. dev.	3.4 ± 0.9	3.5 ± 0.9	3.2 ± 0.9	3.3 ± 1.2	3.2 ± 1.0	
Median	3.2	3.5	3.0	2.9	2.8	H=8.991; p=0.06



TABLE 9

	A2	A1	D3base	D3balpha	D3ab
Retouched bladelet	1262 (87%)	541 (83%)	115 (80%)	67 (63%)	38 (54%)
Retouched blade	80 (5%)	43 (7%)	8 (6%)	8 (8%)	5 (7%)
unilateral	50	20	7	5	2
bilateral	28	19	1	2	2
Pointed	1	2	-	1	-
Aurignacian retouch	1	2	-	-	1
Burin	40 (3%)	16 (2%)	6 (4%)	3 (3%)	2 (3%)
simple	17	4	2	1	-
on prepared platform	9	4	1	2	2
on truncation	1	3	1	-	-
dihedral	7	3	-	-	-
carinated	6	2	1	-	-
busked	-	-	1	-	-
Endscraper	25 (2%)	15 (2%)	6 (4%)	11 (10%)	13 (18%)
on flake	7	7	5	4	5
on blade	12	6	-	3	6
flat-nosed	-	-	-	1	-
carinated, frontal	4	-	1	3	-
carinated, thick-nosed	-	-	-	-	2
double	1	-	-	-	-
circular	1	2	-	-	-
Composite	12 (1%)	7 (1%)	4 (3%)	2 (2%)	3 (6%)
burin + endscraper	1	1	-	-	-
burin + lateral retouch	4	4	1	1	-
endscraper + lateral retouch	7	2	3	1	3
Truncation	10 (1%)	3 (-)	2 (1%)	2 (2%)	-
Retouched flake	15 (1%)	16 (2%)	1 (1%)	8 (8%)	6 (8%)
Splintered piece	11 (1%)	6 (1%)	2 (1%)	5 (5%)	2 (3%)
Undet. Retouched piece	3 (-)	1 (-)	-	-	1 (1%)
Total	1458	648	144	106	70

TABLE 10

	Proximal	Mesial	Distal	Almost comp.	Complete	Total
D3ab	18 (47%)	15 (39%)	5 (13%)	-	-	38
D3b $\alpha$	25 (37%)	28 (42%)	7 (10%)	1 (1%)	6 (9%)	67
D3base	39 (34%)	49 (43%)	18 (16%)	-	9 (8%)	115
A1	186 (34%)	251 (46%)	84 (16%)	2 (-)	18 (3%)	541
A2	371 (29%)	627 (50%)	190 (15%)	10 (1%)	64 (5%)	1262

TABLE 11

	A2	A1	D3base	D3balpha	D3ab
<b>Bladelet with lateral retouch</b>					
Alternate	684 (54%)	270 (50%)	59 (51%)	22 (33%)	17 (45%)
Direct	208 (16%)	101 (19%)	20 (17%)	20 (30%)	10 (26%)
Inverse	252 (20%)	120 (22%)	24 (21%)	18 (27%)	10 (26%)
<b>Bladelet with convergent retouch</b>					
Alternate	48 (4%)	13 (2%)	3 (3%)	1 (1%)	1 (3%)
Direct	53 (4%)	26 (5%)	9 (8%)	6 (9%)	-
Inverse	3 (-)	-	-	-	-
<b>Bladelet with lateral retouch + truncation</b>					
Alternate	4 (-)	7 (1%)	-	-	-
Direct	7 (1%)	2 (-)	-	-	-
Inverse	3 (0%)	2 (-)	-	-	-
<b>Overall retouched bladelets</b>					
Alternate	736 (58%)	290 (54%)	62 (54%)	23 (34%)	18 (47%)
Direct	268 (21%)	129 (24%)	29 (25%)	26 (39%)	10 (26%)
Inverse	258 (20%)	122 (23%)	24 (21%)	18 (27%)	10 (26%)
<b>Total</b>	<b>1262</b>	<b>541</b>	<b>115</b>	<b>67</b>	<b>38</b>

TABLE 12

	A2		A1		D3base
	<i>mean</i>	<i>median</i>	<i>mean</i>	<i>median</i>	<i>mean</i>
Length	29.0 ± 8.9	27.8	28.4 ± 6.5	30.9	26.9 ± 6.8
Width	6.4 ± 1.7	6.2	6.7 ± 1.7	6.5	6.3 ± 1.7
Thickness	1.6 ± 0.5	1.6	1.7 ± 0.5	1.6	1.5 ± 0.4
Width/Thickness ratio	4.1 ± 1.1	3.9	4.1 ± 1.1	3.9	4.2 ± 1.1

	D3balpha		D3ab		Kruskall-Wallis	
	<i>median</i>	<i>mean</i>	<i>median</i>	<i>mean</i>		
	25.9	19.6 ± 4.4	19.2	n.a.	n.a.	-
	6.1	5.8 ± 1.7	5.5	6.2 ± 1.6	6.2	H=23.52; <b>p&lt;0.05</b>
	1.6	1.5 ± 0.6	1.4	1.5 ± 0.4	1.5	H=19.94; <b>p&lt;0.05</b>
	4.1	4.2 ± 1.3	4.1	4.2 ± 1.3	3.9	H=2.678; p=0.6

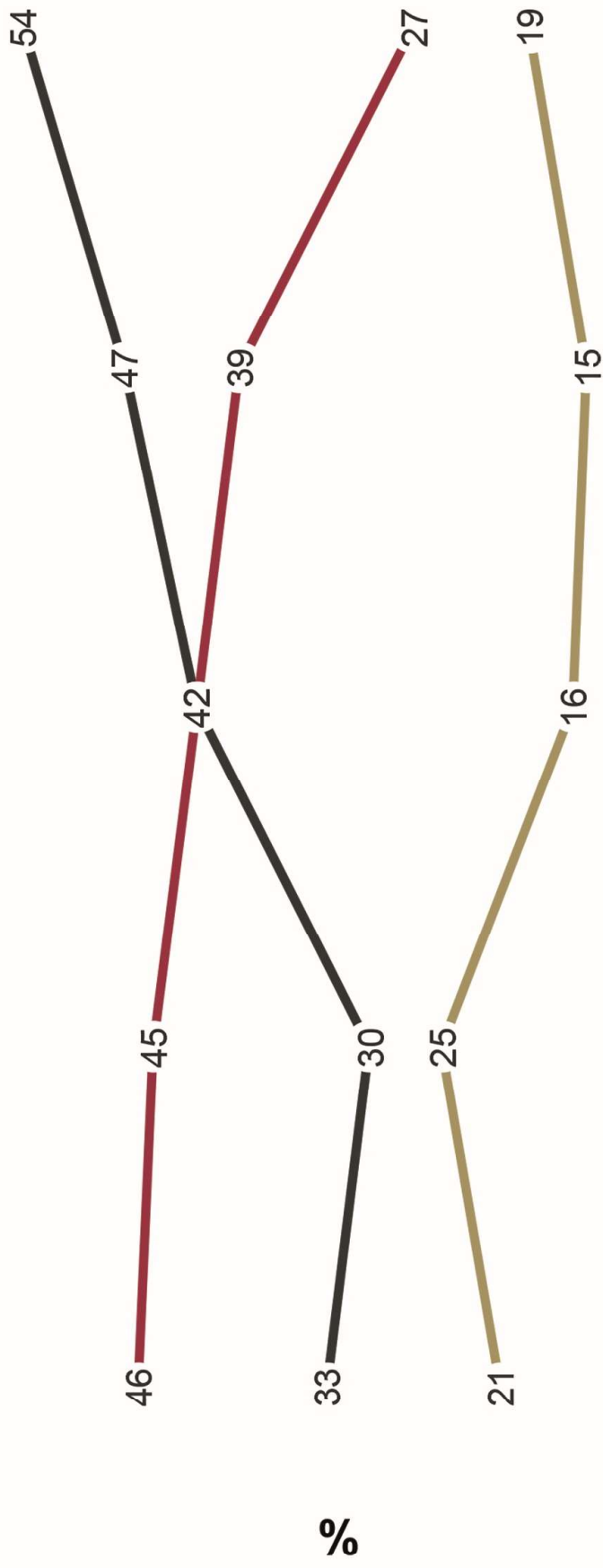
TABLE S1

	A2	A1	D3base	D3balpha	D3ab
<b>Endscraper</b>					
On blade	14	5	-	3	6
On flake	10	10	6	8	5
Other	1	-	-	-	1
<b>Burin</b>					
On blade	24	10	2	3	1
On flake	13	3	3	-	1
Other	2	3	-	-	-
<b>Lateral retouch</b>					
On blade	80	43	8	8	5
On flake	15	16	1	8	6
<b>Composite tool</b>					
On blade	12	6	2	1	2
On flake	1	1	2	1	1
Other	-	-	-	-	-
<b>Other</b>					
On blade	5	2	1	2	-
On flake	11	7	2	5	2
Other	7	1	1	-	1
<b>Overall blank</b>					
Total on blade	135 (69%)	66 (62%)	13 (46%)	17 (44%)	14 (45%)
Total on flake	50 (26%)	37 (35%)	14 (50%)	22 (56%)	15 (48%)
Other	10 (5%)	4 (2%)	1 (4%)	-	2 (6%)

TABLE S2

	Pointed retouch		Blunt	
	n	%	n	%
D3ab	1	20	4	80
D3b $\alpha$	6	43	8	57
D3base	10	36	18	64
A1	34	33	70	67
A2	34	41	49	59

- Flake - Blade - Bladelet



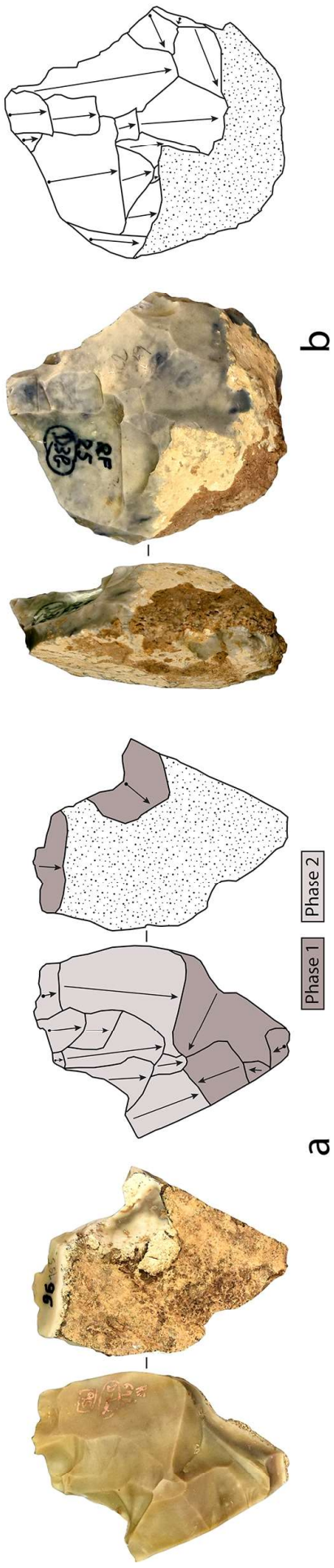
A2

A1

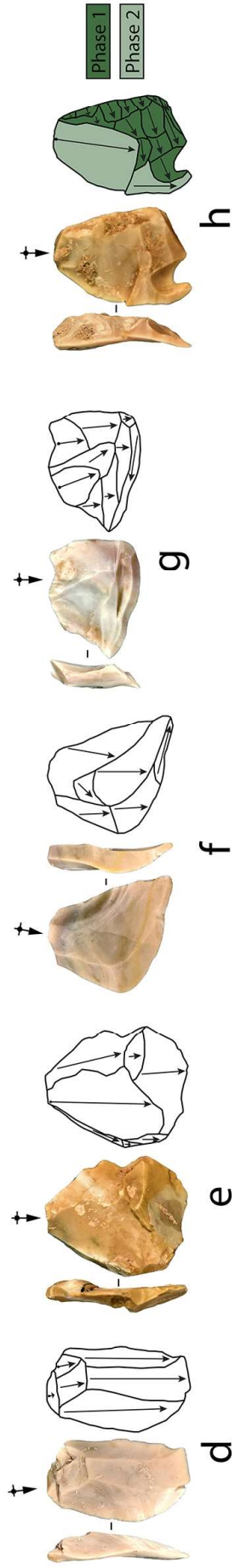
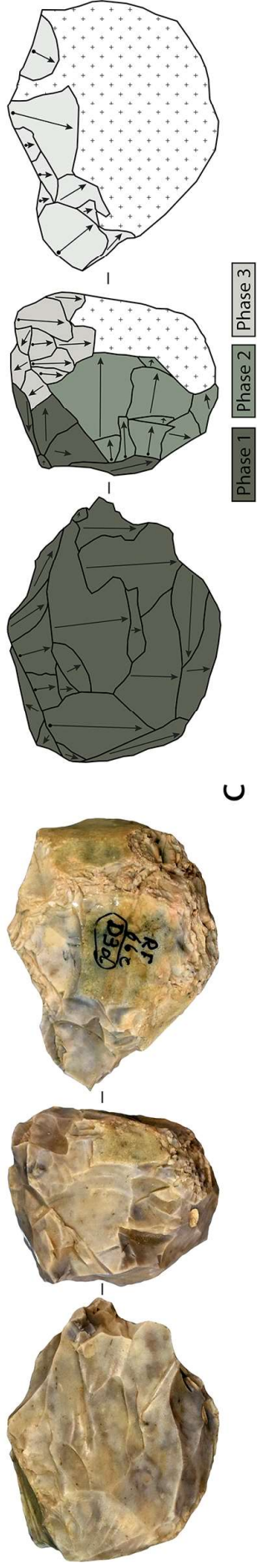
D3base

D3balpha

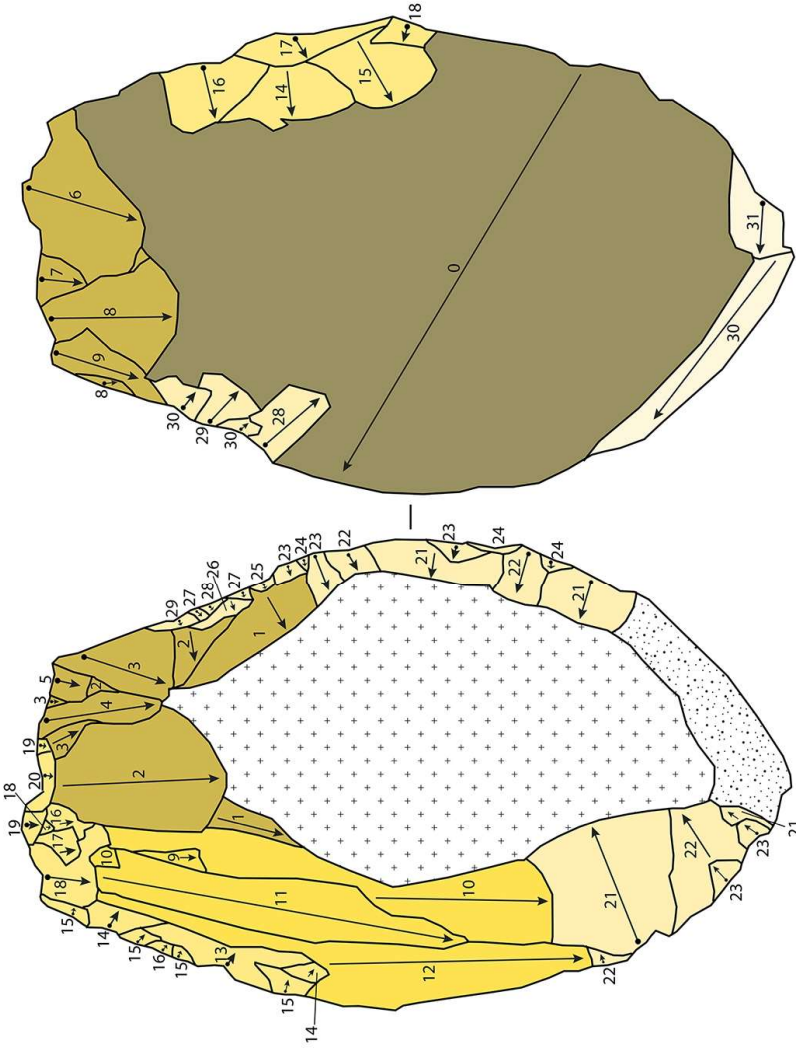
D3ab



0 5 cm

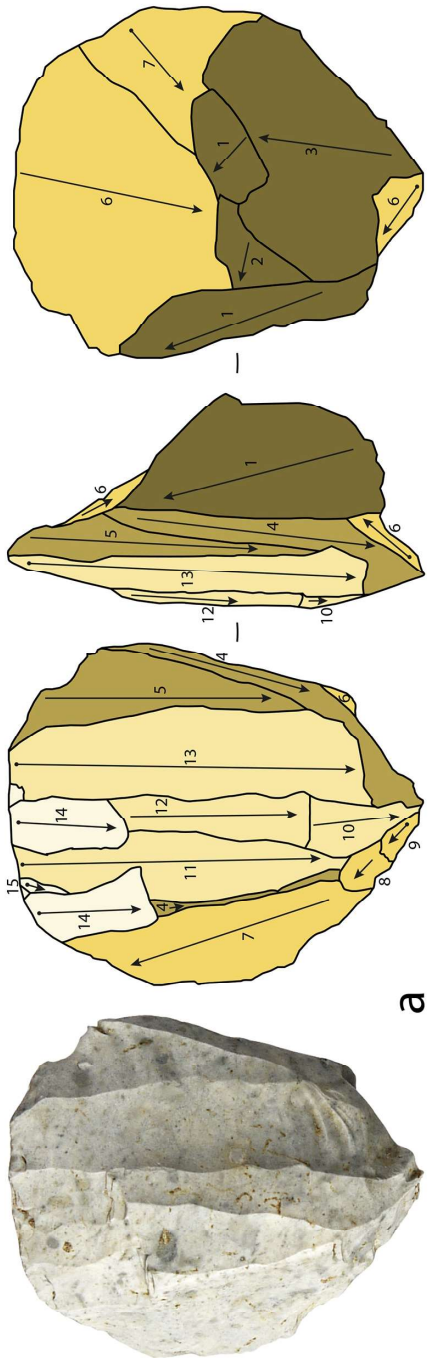






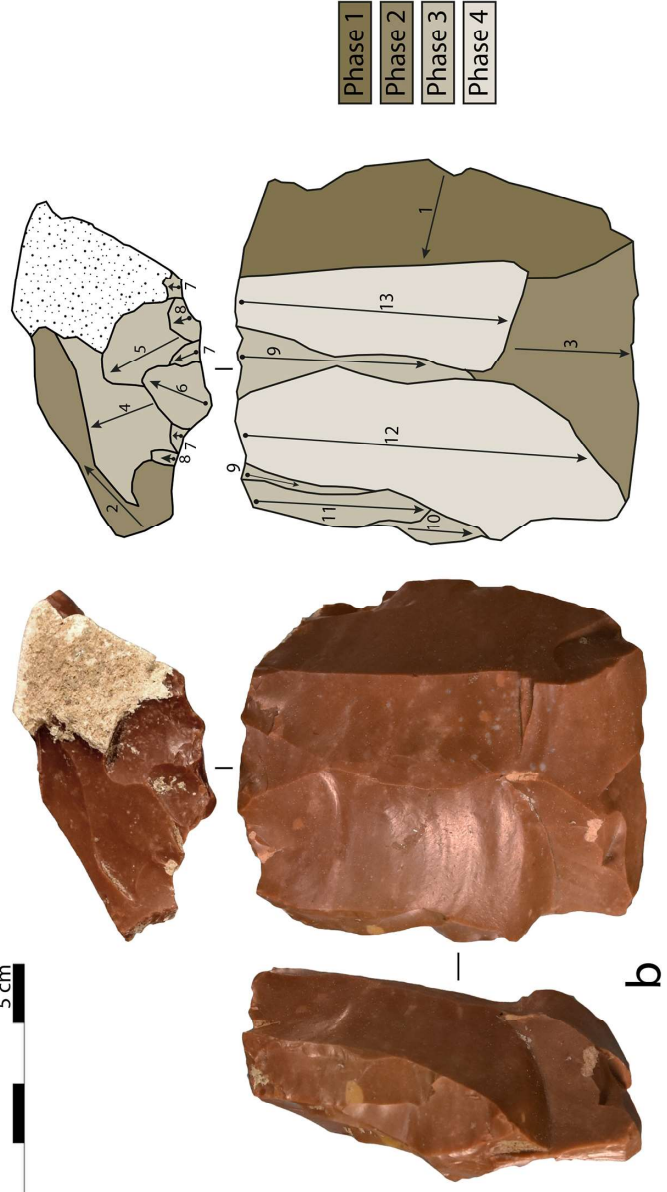
- Phase 1
- Phase 2
- Phase 3
- Phase 4
- Phase 5
- Phase 6

0 5 cm

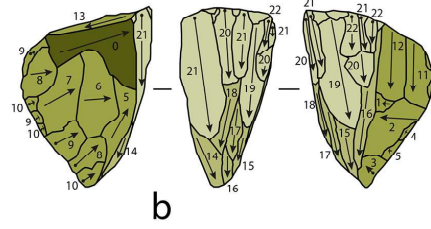
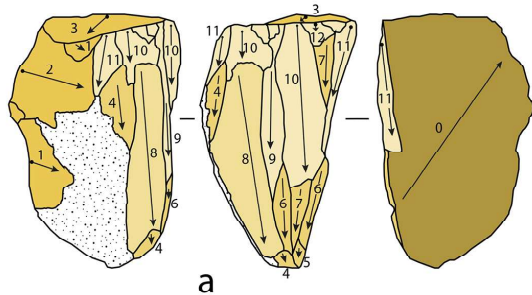
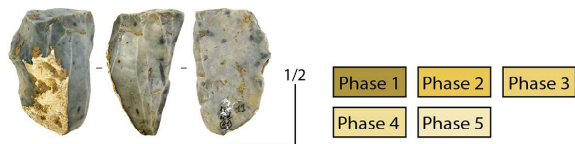


a

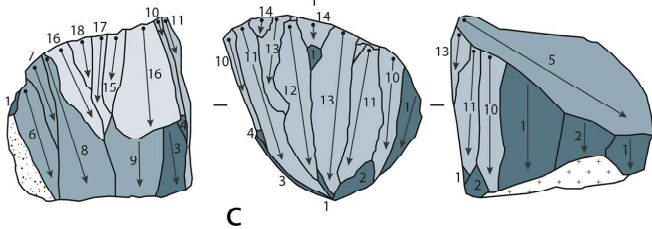
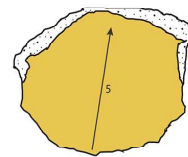
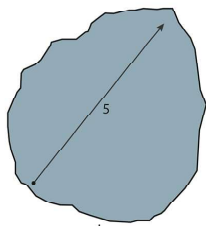
Phase 1 Phase 2 Phase 3 Phase 4 Phase 5



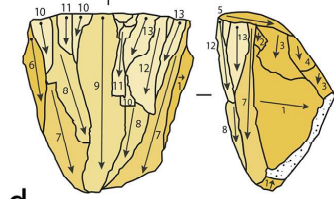
b



Phase 1  
Phase 2  
Phase 3  
Phase 4



d

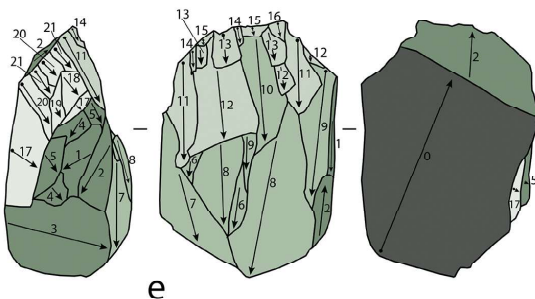


0 5 cm

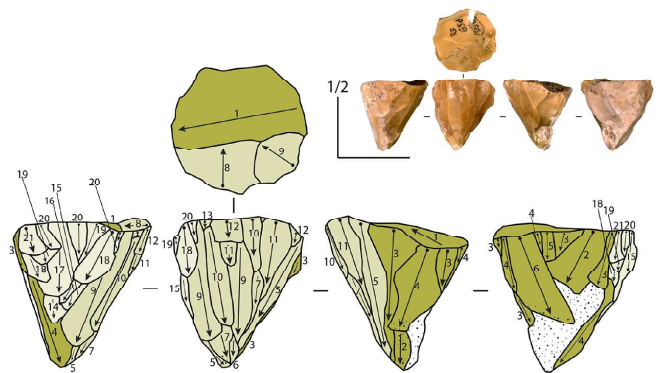
Phase 1 Phase 2 Phase 3 Phase 4



Phase 1 Phase 2 Phase 3  
Phase 4 Phase 5

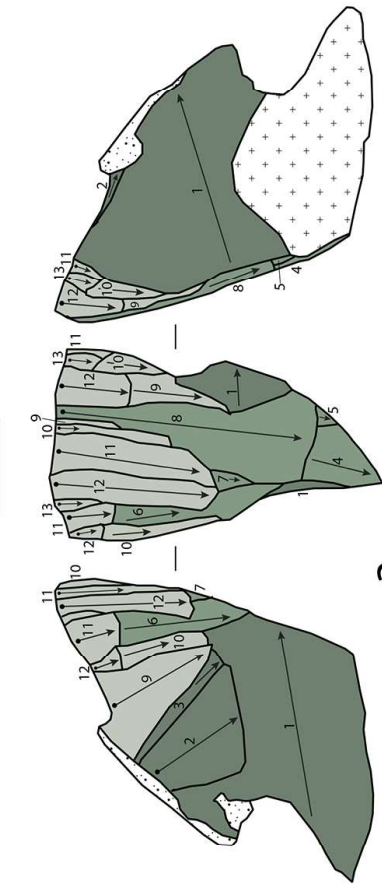
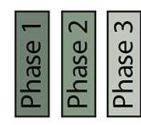


e

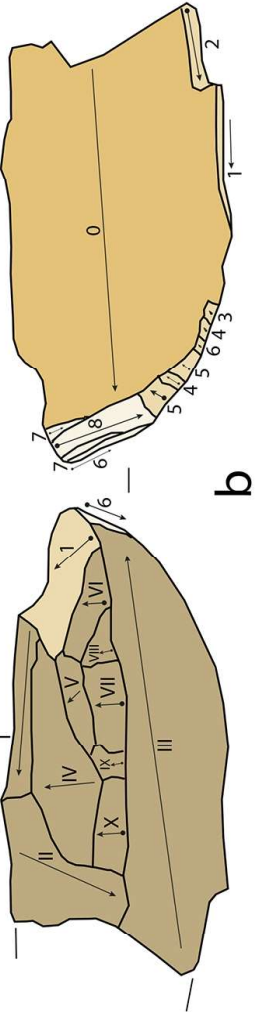


f

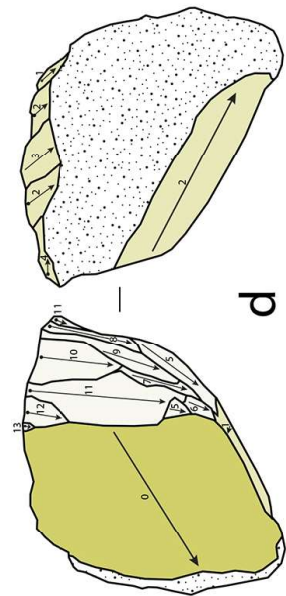
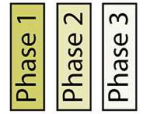
Phase 1 Phase 2 Phase 3



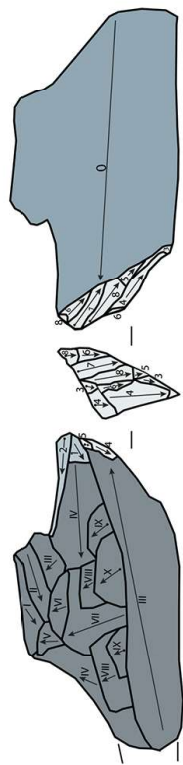
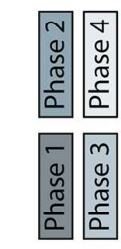
**a**



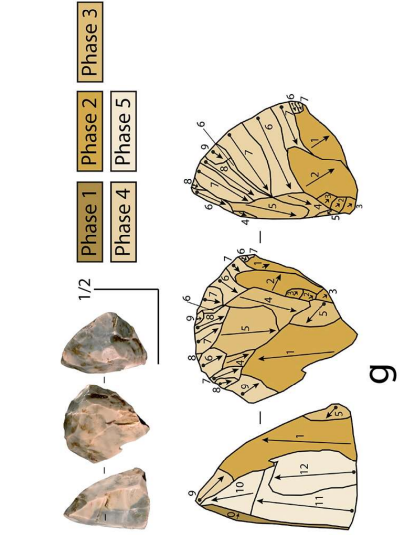
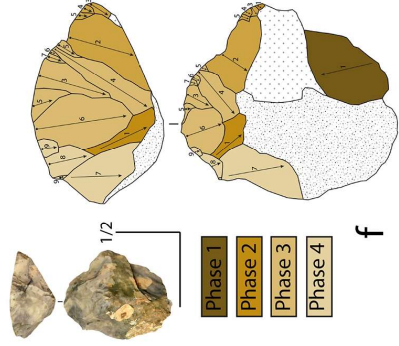
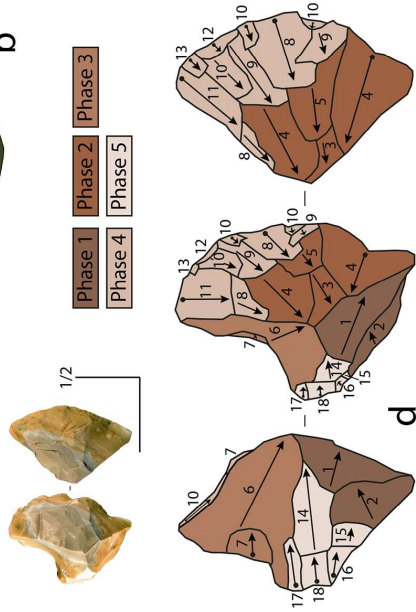
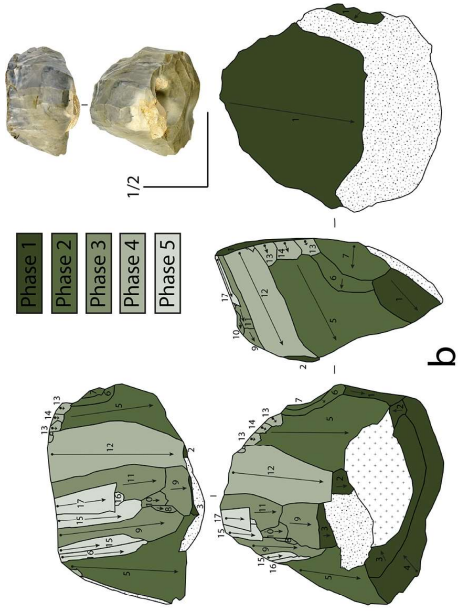
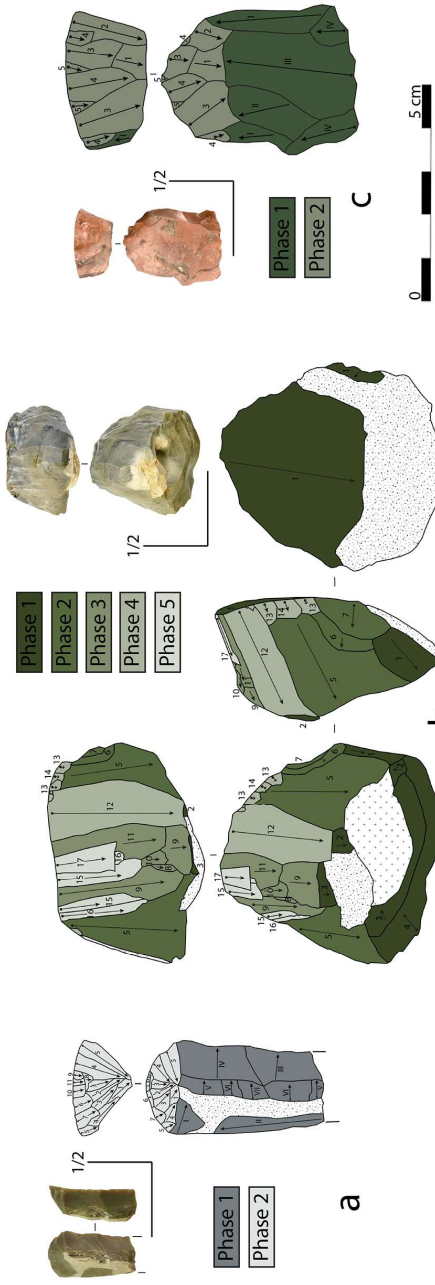
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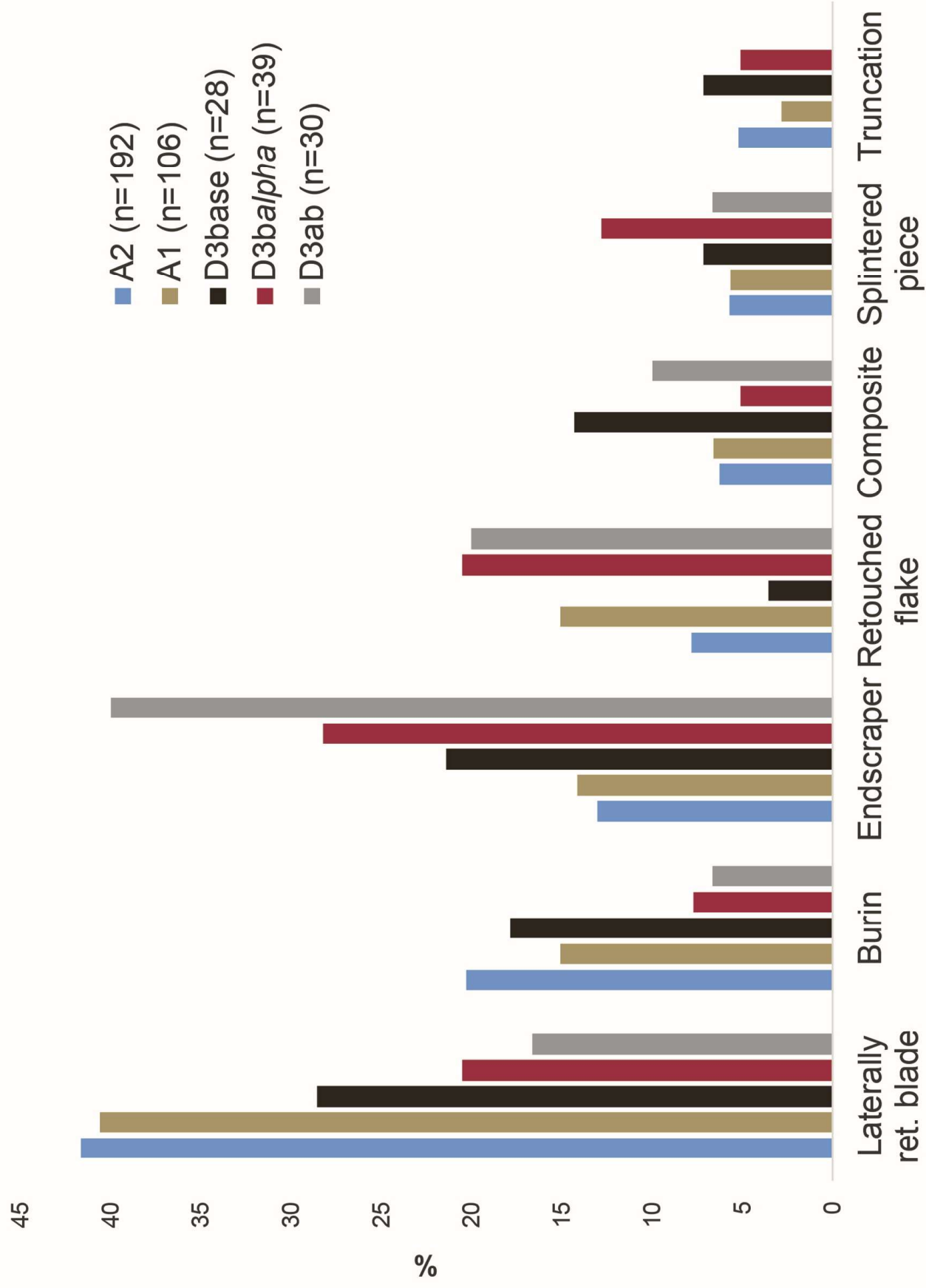


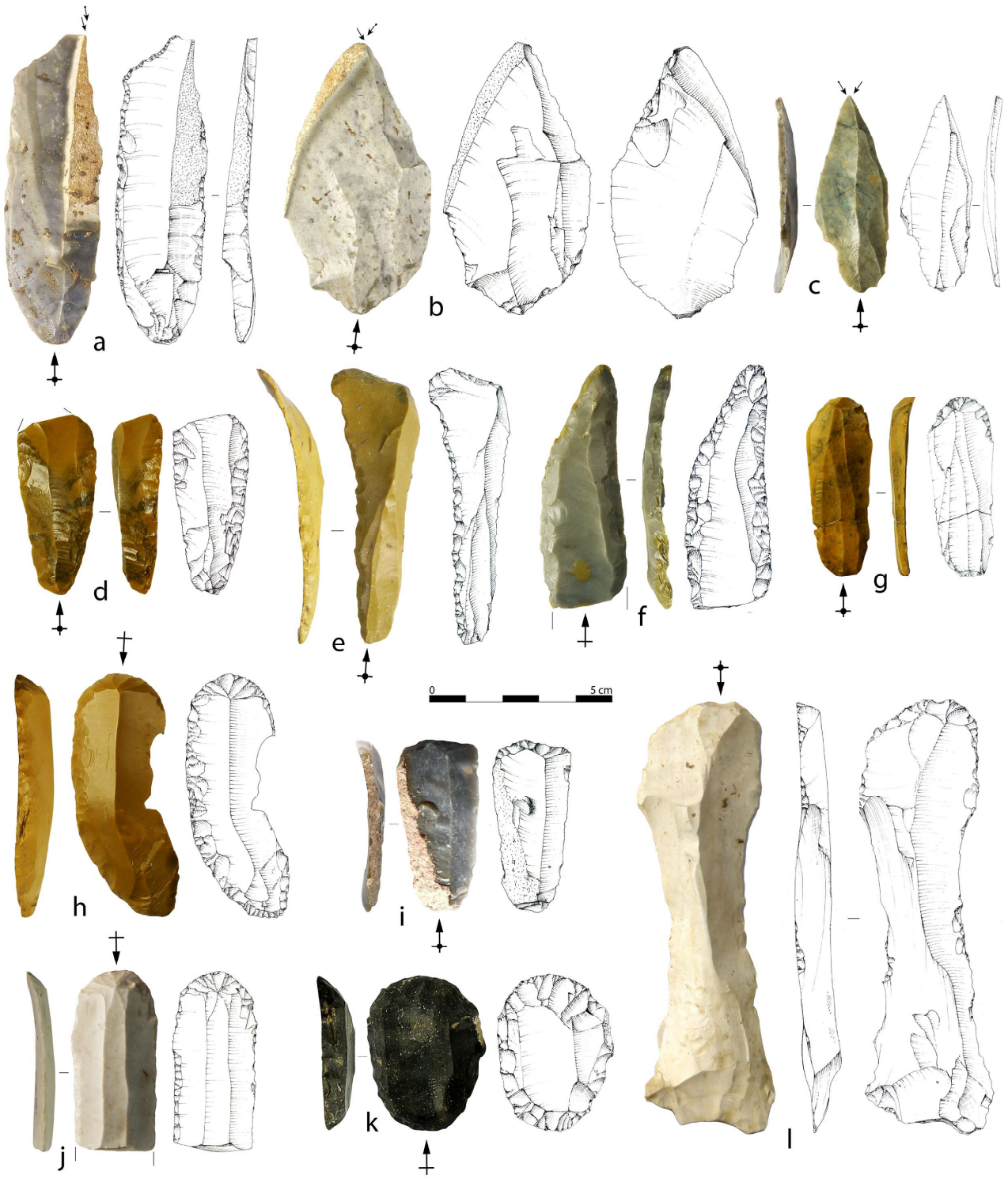
**d**

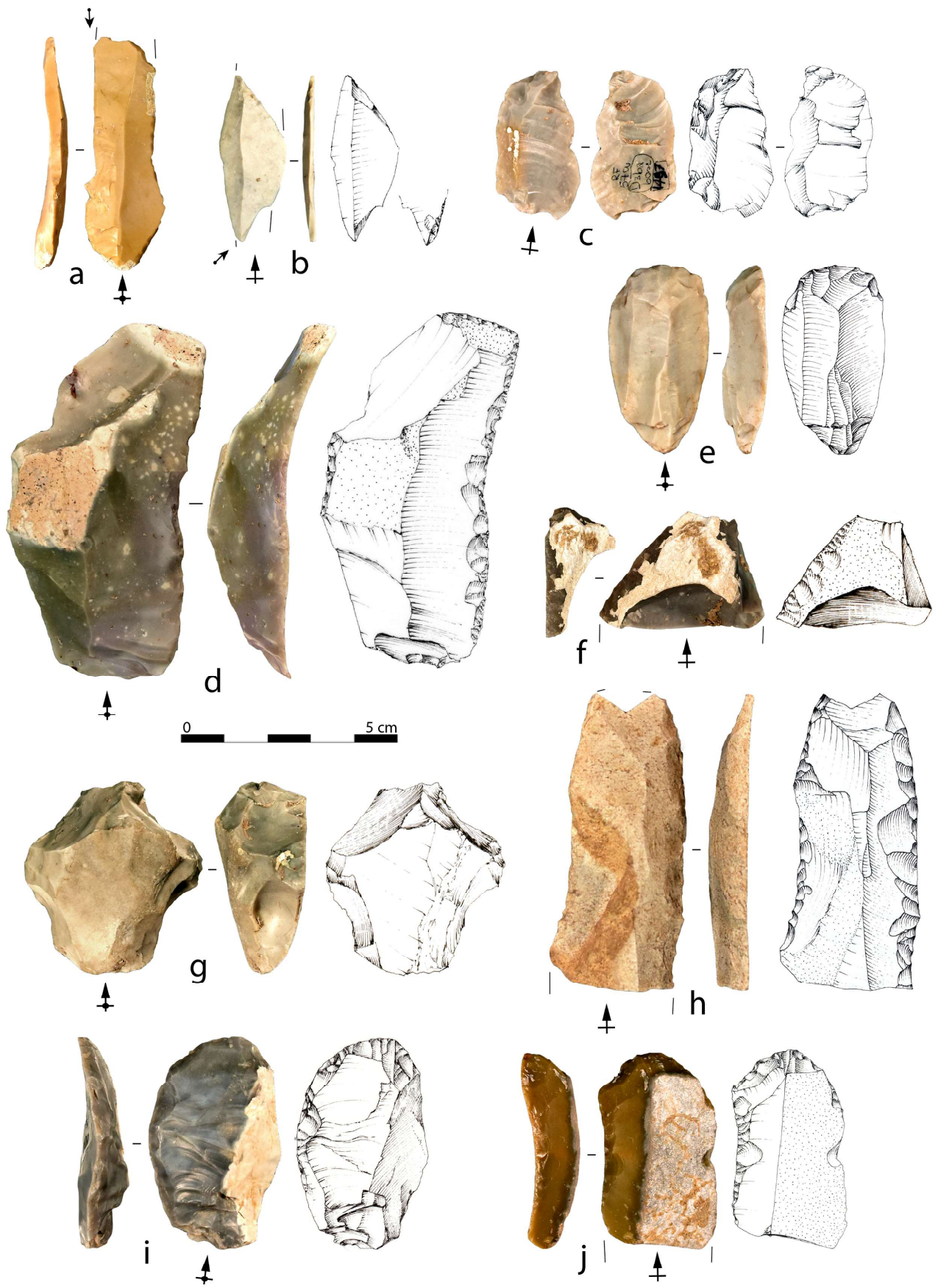


**c**



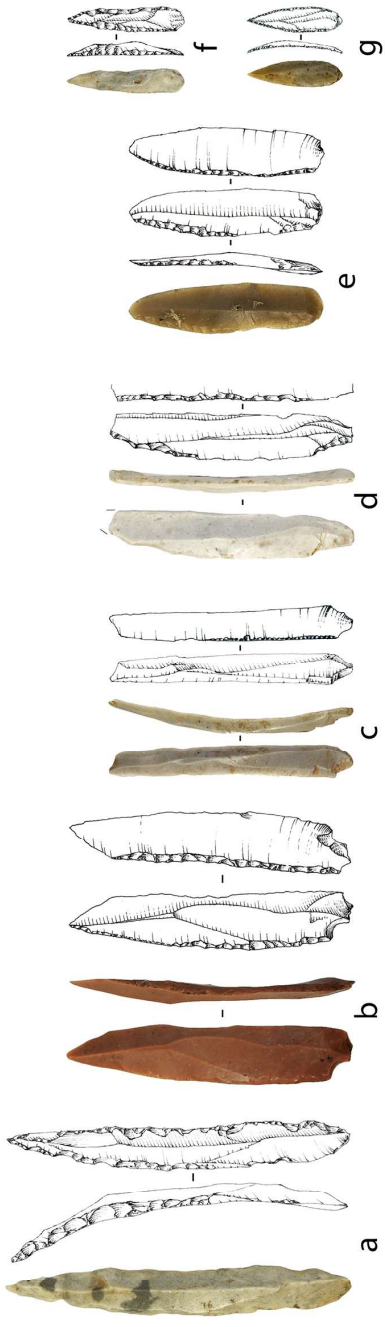




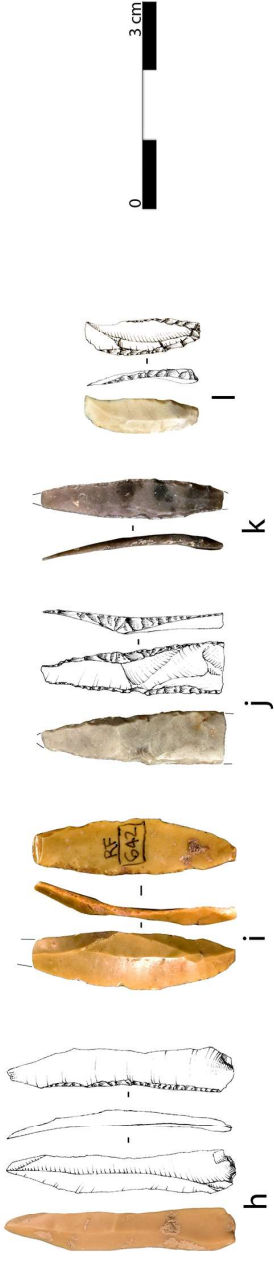




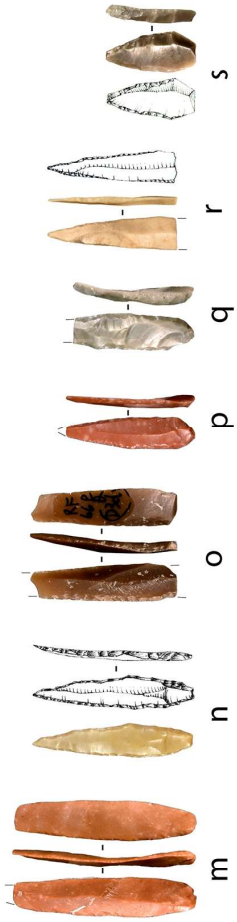
# A2-A1



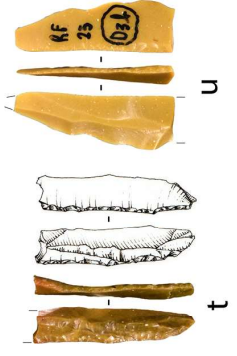
# D3base

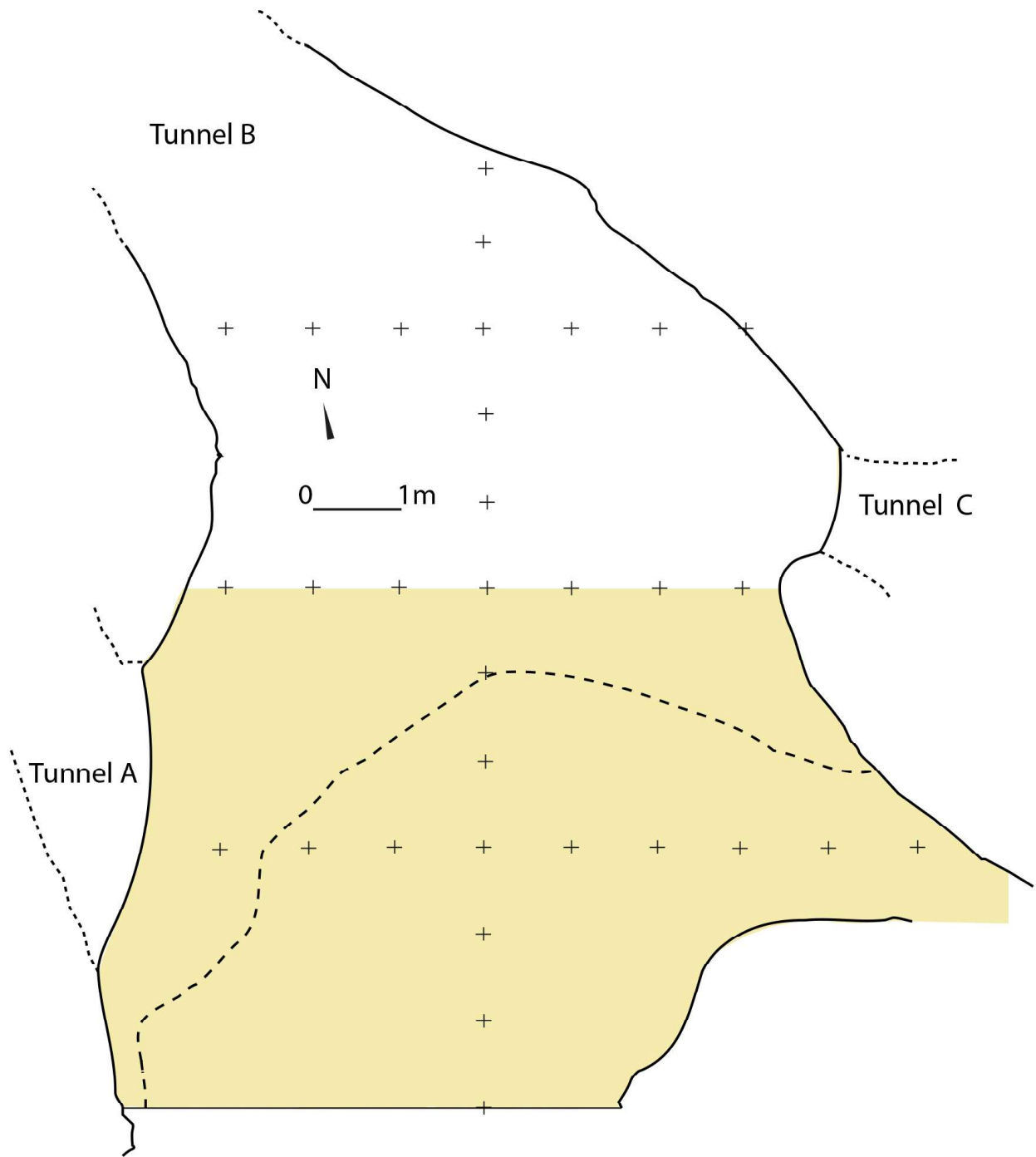


# D3balpha



# D3ab







# Armando Falcucci

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**Work address:** Department of Early Prehistory and Quaternary Ecology, University of Tübingen, Schloss Hohentübingen, Room 5b, 72070 Tübingen, Germany | **Private address:** Neckarhalde 28, 72070 Tübingen, Germany | **Cell phone:** +49(0)15151218732 | **Work phone:** +49(0)70712978918 | **Email:** armando.falcucci@ifu.uni-tuebingen.de

## Personal data

- Date of birth: September 1, 1990
- Place of birth: Marino, Italy
- Nationality: Italian

## Education

### 2015 – TODAY | DOCTORAL CANDIDATE IN PALEOLITHIC ARCHAEOLOGY

- Institution: Eberhard Karls Universität Tübingen, Mathematisch-Naturwissenschaftliche Fakultät, Germany
- Dissertation: A critical assessment of the Aurignacian: Insights from Fumane Cave in northern Italy
- Supervisors: Nicholas Conard & Michael Bolus

### 2013 – 2015 | MASTER DEGREE IN QUATERNARY, PREHISTORY, AND ARCHAEOLOGY

- Institution: University of Ferrara, Italy
- Dissertation: Morpho-metric variability of Protoaurignacian retouched bladelets. The cases of Grotta di Fumane, Grotte d'Isturitz and Grotte des Cottés
- Supervisors: Marco Peresani & Marie Soressi (Leiden University, Netherlands)
- Grade: 110/110 cum laude

### SEPTEMBER 2014 – FEBRUARY 2015 | ERASMUS+ EXCHANGE PROGRAMME

- Institution: University of Toulouse – Jean Jaurès, France
- Aim: Research thesis at TRACES - *Travaux et Recherches Archéologiques sur les Cultures, les Espaces et les Sociétés*, UMR 5608
- Supervisors: Nicholas Teyssandier & François Bon

### 2010 – 2013 | BACHELOR DEGREE IN CULTURAL HERITAGE SCIENCES

- Institution: University of Rome Tor Vergata, Italy
- Dissertation: The last Neanderthal: transition and extinction between Middle and Upper Paleolithic in the Iberian Peninsula
- Supervisor: Mario Federico Rolfo
- Grade: 110/110 cum laude

### SEPTEMBER 2012 – JULY 2013 | ERASMUS/LLP EXCHANGE PROGRAMME

- Institution: University of Granada, Spain
- Aim: Academic courses and research thesis at the Department of Prehistory
- Supervisor: Juan Antonio Cámara Serrano

## Scholarships & Fellowships

### PHD RESEARCH SCHOLARSHIP

- Funding institutions: State of Baden-Württemberg and University of Tübingen (ECM research project)
- Period: December 2015–November 2018

### VISITING RESEARCH FELLOW AT THE HEBREW UNIVERSITY OF JERUSALEM, ISRAEL

- Funding institution: Fondazione Atlante (Italy)
- Period: April 2015–July 2015

## Publications in peer-reviewed journals

- 1) **Falucci, A.**, Conard, N. J., Peresani, M. (submitted) Breaking through the Aurignacian frame: A re-evaluation on the significance of regional variants during the Early Upper Paleolithic as seen from a key record in southern Europe. *Journal of Anthropological Archaeology*.
- 2) Ioannidou, M. **Falucci, A.**, Röding, C., Kandel, A.W. (in preparation) Eighth Annual Meeting of the European Society for the Study of Human Evolution. *Evolutionary Anthropology*.
- 3) Caricola, I., Zupancich, A., Moscone, D., Mutri, G., **Falucci, A.**, Duches, R., Peresani, M., Cristiani, E. (accepted) Exploring Early Upper Palaeolithic knapping techniques and gestures. Use Wear and Spatial Analyses applied to the study of macro-lithic tools. *PLoS ONE*.
- 4) **Falucci, A.** & Peresani, M. (2018) Protoaurignacian Core Reduction Procedures: Blade and Bladelet Technologies at Fumane Cave. *Lithic Technology* 43:125-140. DOI:10.1080/01977261.2018.1439681.
- 5) **Falucci, A.**, Peresani, M., Roussel, M., Normand, C., Soressi, M. (2018) What's the point? Retouched bladelet variability in the Protoaurignacian. Results from Fumane, Isturitz, and Les Cottés. *Archaeological and Anthropological Sciences* 10:539–554. DOI:10.1007/s12520-016-0365-5.
- 6) **Falucci, A.**, Conard, N. J., Peresani, M. (2017) A critical assessment of the Protoaurignacian lithic technology at Fumane Cave and its implications for the definition of the earliest Aurignacian. *PLoS ONE* 12(12): e0189241. DOI:10.1371/journal.pone.0189241.

## Conference Proceedings

- 1) **Falucci, A.**, Conard, N. J., Peresani, M. (2018) The chrono-cultural narrative of the Fumanian Aurignacian supports the inapplicability of the Aquitaine Model on a supra-regional scale. *Proceedings of the Annual Conference of the European Society for the study of Human Evolution*, 7, 62.
- 2) **Falucci, A.**, Conard, N. J., Peresani, M. (2018) Testing technological definitions: a critical assessment of the Protoaurignacian at Fumane Cave. *Proceedings of the XVIII° UISPP World Congress*, sciencesconf.org:uispp2018:179543.
- 3) Aureli, D., Arrighi, S., Bortolini, E., Boscato, P., Boschin, F., Crezzini, J., **Falucci, A.**, Delpiano, D., Figus, C., Moroni, A., Negrino, F., Peresani, M., Riel-Salvatore, J., Romandini, M., Ronchitelli, A., Spinapolice, E., Benazzi, S. (2018) Italian Peninsula between 45 and 39 ky ago: the sunset of the "old" and the dawn of the "new"? Let the lithic industries tell! *Proceedings of the XVIII° UISPP World Congress*, sciencesconf.org:uispp2018:181484.
- 4) Bataille, G., Bolus, M., Conard, N. J., **Falucci, A.**, Peresani, M., Tafelmaier, Y. (2017) The technological variability of the European Aurignacian from a multi-regional and diachronic perspective. *Proceedings of the Annual Conference of the Hugo Obermaier Society for Quaternary Research and Archaeology of the Stone Age*, 59, 15–16.

- 5) Peresani, M., Delpiano, D., Aleo, A., Duches, R., **Faluccci, A.**, Forte, M., Gennai, J., Nannini, N., Romandini, M., Terlato, G. (2017) La transizione Neanderthal – Sapiens in Italia Nord-orientale: Ricerche dell'università di Ferrara. *Proceedings of the Annual Meeting of the TourismA Society for Archaeology and Tourism*, 2017 edition.
- 6) **Faluccci, A.** & Peresani, M. (2016) New investigations on the Protoaurignacian lithic technology of Fumane Cave. *Proceedings of the Annual Conference of the European Society for the study of Human Evolution*, 5, 90.
- 7) **Faluccci, A.**, Peresani, M., Rousset, M., Normand, C., Soressi, M. (2016) Protoaurignacian retouched bladelets: where do we stand? *Proceedings of the Annual Conference of the Hugo Obermaier Society for Quaternary Research and Archaeology of the Stone Age*, 58, 31–34.
- 8) Romandini, M., **Faluccci, A.**, Gurioli, F., Broglio, A. (2014) First European Anatomically Modern Humans and the “route of shells”: chronological and qualitative evidence from the Veneto plain region sites. *Proceedings of the XVII° UISPP World Congress*, Abstract book page: 247.

## Selected Fieldwork Experiences

### **JULY 2017 | MANOT CAVE, ISRAEL**

- Excavation activities and study of Ahmarian lithics under the supervision of O. Mader & O. Barzilai.

### **JULY–AUGUST 2015 | ARMA VEIRANA, ITALY**

- Excavation activities under the supervision of F. Negrino, J. Riel-Salvatore, et al.

### **JULY–AUGUST 2014 | LES COTTES & LE FONTENIOUX, FRANCE**

- Excavation and laboratory activities under the supervision of M. Soressi and M. Rousset.

### **MAY 2014 | COVOLETO DE NADALE, ITALY**

- Excavation and laboratory activities under the supervision of M. Peresani.

### **JULY–AUGUST 2013 | PASTENA CAVE, ITALY**

- Excavation and laboratory activities under the supervision of M.F. Rolfo.

### **JULY 2011 | CATIGNANO CASTLE, ITALY**

- Excavation and laboratory activities under the supervision of M. Mendera

## Language Skills

- Italian: native speaker
- English: fluent
- Spanish: fluent (DELE Certificate – C1)
- French: excellent command
- German: good command

## Computer Skills

- MS–Office (Word, Excel, Power Point, Outlook): Excellent
- Adobe (Photoshop & Illustrator): Excellent
- IBM SPSS: Very good