PEDRO EZEQUIEL GUEDES HORTA

O PAPEL DAS TECNOLOGIAS LÍTICAS BIPOLARES NA ADAPTAÇÃO DOS PRIMEIROS HUMANOS NA EUROPA

THE ROLE OF LITHIC BIPOLAR TECHNOLOGY IN THE ADAPTATION OF THE FIRST HUMANS IN EUROPE

UNIVERSIDADE DO ALGARVE

Faculdade das Ciências Humanas e Sociais

2022

PEDRO EZEQUIEL GUEDES HORTA

THE ROLE OF LITHIC BIPOLAR TECHNOLOGY IN THE ADAPTATION OF THE FIRST HUMANS IN EUROPE

Doctoral dissertation in Archaeology

Dissertation done under the supervision of:

Professor João Miguel Mico Cascalheira

Professor Nuno Ferreira Bicho

UNIVERSIDADE DO ALGARVE

Faculdade das Ciências Humanas e Sociais

2022

THE ROLE OF LITHIC BIPOLAR TECHNOLOGY IN THE ADAPTATION OF THE FIRST HUMANS IN EUROPE

Work Authorship Declaration

I declare to be the author of this work, which is unique and unprecedented. Authors and works consulted are properly cited in the text and are included in the listing of references.

Pedro Ezequiel Guedes Horta

ESTE TRABALHO É DEDICADO A ANTÓNIO E ELIZABETE GUEDES

"*Do not compete with what is happening. To prepare to compete is to prepare for failure. Do not be trapped by the need to achieve anything. This way, you achieve everything*"

Frank Herbert

ACKNOWLEDGMENTS

Despite the fact that this thesis is written in English, I took the liberty to replicate this section in Portuguese. I am and always will be a proud son of the “nação valente, imortal”. This thesis represents the culmination of 11 years of work in Archeology and at the same time represents just another step on an endless road. Siddhartha Gautama reached the state of enlightenment by seeking the impossible while meditating through endless nights. The important thing is the journey and not the destination. I can proudly say that I have enjoyed this journey. Getting to this point would not have been possible without the support of a group of people and institutions that had an impact on my personal and professional life.

First of all, I would like to thank the Fundação da Ciência e Tecnologia for the funding that allowed me to dedicate myself to this research full-time and allowed me to carry out this work. Likewise, I thank the University of Algarve and ICArEHB, institutions that welcomed me and provided me with resources to conduct this research.

I thank the Max Planck Institute specifically the Department of Human Evolution and the Bulgarian Academy of Sciences, in particular Tsenka Tsanova and Nikolai Sirakov for the invitation to study and be part of the Bacho Kiro project, two people with whom I hope to continue working in the future. I also thank the Museum of Natural History in Paris and in particular Laurent Chiotti for providing me with unrestricted access to Abri Pataud. I also thank Professor Nuno Bicho for access to the archaeological site of Vale Boi. Finally, special thanks go out to Shannon McPherron for supporting this research, providing constructive feedback throughout this work, and facilitating, and providing access to the sites of Bacho Kiro, Abri Pataud, and Jebel Irhoud.

Academically and in a personal way, I would like to thank Professors Maria João Valente, António Faustino de Carvalho, and João Pedro Bernardes who, over the last decade, had a major impact on my professional growth. Likewise, I want to thank several colleagues and friends without whose support I would not be writing this. I thank João Varela and Mussa Raja my brothers and partners in crime. I thank my colleagues and friends in the laboratory and field who are too many to list. I thank Zeljko Rezek and João Marreiros, two friends with whom I spent endless hours discussing my research and career and who have shown me their unconditional support from day one. I close this section with a special thanks to my “older sister” Célia Gonçalves who has been the embodiment of unconditional support.

It would not have been possible to reach this point without the support of my family. In fact, there are no words to describe the significance of those who I love above all else. My sources of strength, support, and encouragement. To my father who fights daily to provide me with the possibility to continue to pursue this dream. To my queen, my inspiration and the personification of struggle, persistence, resistance, rigor, and excellence. To my brother who is my opposite and is simply the best of me. Thank you, today and forever.

Last but not least, I want to give special thanks to two gentlemen who have had the most significant impact on my career. To whom I will always be connected and will carry their legacy within my work and heart until the end of my career. Several friends told me that there isn't a PhD student who doesn't hate supervisors at the end of the PhD process. I am pleased to say that I am the exception to the rule.

The first contact I had when I entered the University was with this gentleman. I happily remember the trips to my first excavation, where we talked about my future in Archaeology. At the time I told him that I would never work with lithic materials, and the answer was “We will see…”. From when he told me that he would have to study a Mesolithic collection when I wanted to study a Paleolithic collection, which at the time I did not appreciate. I could write pages and pages of discussions, conversations, advice you've given me over the last decade. To my mentor, advisor, and one of the main reasons why I am who I am as a thinker and researcher. I thank you from the bottom of my heart. Thank you, Nuno.

I would like to end this section with a special thanks to João Cascalheira. Someone who became one of my best friends throughout these 11 years. We laughed, cried, argued, and shared countless hours debating everything from Archeology to international politics. Even if life takes us on different paths, we will always be together. If there is anyone who has had a direct bearing on the final result of this work and on the researcher, I have become and will become, it is you. Thank you, João.

AGRADECIMENTOS

Esta tese representa o culminar de 11 anos de trabalho em Arqueologia e ao mesmo tempo representa apenas mais um passo numa estrada sem fim. Sidarta Gautama atingiu o estado de iluminação ao meditar noites inteiras. O importante é a viagem e não o destino e eu posso dizer que tenho aproveitado esta viagem. Tomei a liberdade de escrever esta secção em ambos português e inglês, uma vez que chegar a este ponto não seria possível sem o apoio de conjunto de pessoas e instituições que tiveram um grande impacto na minha vida pessoal e profissional.

Em primeiro lugar quero agradecer à Fundação da Ciência e Tecnologia pelo financiamento que possibilitou dedicar-me a tempo inteiro à investigação e permitiu-me realizar este trabalho. Do mesmo modo agradeço à Universidade do Algarve e ao ICArEHB, instituições que me acolheram e que permitiram ter acesso aos recursos necessários para a realização deste trabalho.

Agradeço ao Instituto Maxplanck para a Evolução Humana e à Academia de Ciências da Bulgária, em particular a Tsenka Tsanova e Nikolai Sirakov pelo convite de estudar e fazer parte do projeto de Bacho Kiro. Duas pessoas com quem eu espero continuar a trabalhar no futuro. Do mesmo modo agradeço ao Museu de História Natural de Paris e em particular a Laurent Chiotti por ter-me proporcionado o acesso incondicional ao sítio de Abri Pataud. Agradeço ao Professor Nuno Bicho também pelo acesso incondicional ao sítio arqueológico de Vale Boi. Por fim, um especial agradecimento a Shannon McPherron por ter apoiado esta investigação, pelas inúmeras trocas de ideias que tivemos ao longo da sua realização, e por ter facilitado e proporcionado o acesso aos sítios de Bacho Kiro, Abri Pataud e Jebel Irhoud.

Seguindo uma linha académica e de um modo pessoal quero agradecer aos Professores Maria João Valente, António Faustino de Carvalho e João Pedro Bernardes que ao longo da última década tiveram um grande impacto no meu crescimento e amadurecimento profissional. Do mesmo modo quero agradecer a uma lista de colegas e amigos sem os quais eu não estaria a escrever este texto. Agradeço a João Varela e Mussa Raja os meus irmãos e companheiros de secretária e luta, Kanimambo. Agradeço aos meus colegas e amigos do “laboratório” e do campo que são demasiados para enumerar. Agradeço a Zeljko Rezek e João Marreiros dois amigos com quem perdi horas sem fim a discutir a minha investigação e carreira e que me têm mostrado um apoio incondicional deste o primeiro dia. Termino esta secção com um agradecimento especial à minha irmã mais velha Célia Gonçalves que tem sido a personificação de apoio incondicional.

Não seria possível chegar a este ponto sem o apoio da minha família. De facto, não há palavras para descrever a significância de quem eu amo acima de tudo e da fonte de força e estrutura de apoio e incentivo da qual eu beneficio. Ao meu pai que luta diariamente para me proporcionar este sonho. À minha rainha, a minha inspiração e a personificação de luta, obstinação, persistência, resistência, rigor e excelência. Ao meu irmão que é o meu oposto e é simplesmente o melhor de mim. Obrigado, hoje e sempre.

Por fim, quero fazer um agradecimento especial a dois cavalheiros que tiveram o maior impacto na minha carreira. A quem estarei sempre ligado e carregarei comigo o seu legado no meu coração e trabalho até ao final da minha carreira. Vários amigos disseram-me que não existe um aluno de doutoramento que não tenha ódio aos orientadores no final do processo. Tenho o prazer de dizer que sou exceção à regra.

O primeiro contacto que tive quando entrei na Universidade foi com este senhor. Lembro-me alegremente das viagens para a minha primeira escavação no concheiro do Cabeço da Amoreira em Muge, na qual conversámos sobre o meu futuro dentro da Arqueologia. Na altura disse-lhe que nunca trabalharia com matérias líticos, e a resposta foi "Pois…Veremos…". De quando me disse que teria que estudar uma coleção mesolítica quando eu sempre quis estudar o paleolítico. Poderia escrever páginas e páginas de discussões, conversas, conselhos que me deu ao longo desta última década. Ao meu mentor, orientador, e uma das principais razões por eu ser quem sou enquanto pensador e investigador, agradeço do fundo do meu coração. Obrigado Nuno.

Termino esta secção com um especial agradecimento a João Cascalheira, que nestes 11 anos tornou-se num dos meus melhores amigos. Rimos, discutimos e partilhámos inúmeras horas a debater tudo, desde Arqueologia, a política internacional e às nossas vidas pessoais. Mesmo que a vida nos leve para caminhos diferentes estaremos sempre juntos. Se há alguém que tem um cunho direto no resultado final deste trabalho e no investigador que me tornei e tornarei és tu. Ao meu amigo e fonte de inspiração eu digo de agrado, Obrigado João.

ABSTRACT

The means through which *Homo sapiens* expanded and settled across the Old World continues to be a longstanding question in Human Evolution studies. In Europe, their adaptation to the environmental setting, including the eventual assimilation and replacement of Neanderthals, remains a largely unanswered topic. One of the many reasons that may have led our species to succeed in settling in this new territory was the use of different adaptive strategies, including bipolar technology. The latter, rarely used by Neanderthals, was constantly present in *Homo sapiens* assemblages between 45-30ka BP.

This dissertation's main goal is to understand if and what role this technology played in the adaptation of the first humans in Europe. Additionally, it aims to provide important advances in both methodology and the understanding of bipolar methods in Human Evolution. In order to reach these goals, a combination of metanalytics and the analysis of 3 early *Homo sapiens* occupations was used. This mixed approach revealed patterns of artifact use, technological traditions, efficiency evaluation, resource intensification strategies, and expediency.

Homo sapiens were recurrently using bipolar methods to increase their efficiency in resource exploitation, making them more adaptable to environmental pressure. Bipolar knapping was used to: conserve raw material by continuously reducing raw material volumes too small or too irregular to be held in hand or as a fast solution to obtain sharp edges. Wedging was used to increase their efficiency in exploiting organic materials including carcass processing, bone shaping, bone tool production, ornament production, and wood and antler shaping and processing. While this was likely not a major contributing factor to the demise of Neanderthal groups that co-existed with Humans in the same territories, it was likely another piece of the puzzle that helped humans thrive over them.

KEYWORDS: Upper Paleolithic; *Homo sapiens* expansions; Adaptive strategies; Bipolar Technology; Human Evolution.

RESUMO

Os meios pelos quais os *Homo sapiens* se expandiram e colonizaram o velho mundo continua a ser uma questão elusiva e altamente especulada em estudos de Evolução Humana. Na Europa a adaptação destes grupos ao meio ambiente incluindo os contactos e a eventual assimilação dos Neandertais continua a ser uma questão em aberto. No entanto, o processo de expansão das populações de humanos pela Europa é indissociável do aparecimento de um conjunto de estratégias adaptativas, significativamente distintas das empregues pelas populações locais de Neandertais. Entre as principais novidades, denota-se um crescimento considerável no uso da tecnologia lítica bipolar, em que os utensílios são produzidos através de percussão sobre bigorna, e/ou utilizados na exploração, mediante fragmentação controlada, de materiais orgânicos duros. Durante o período entre 45 e 30ma BP esta tecnologia foi recorrentemente utlizada por estas comunidades humanas enquanto que foi apenas pontualmente empregue pelas populações Neandertais.

Os estudos efetuados até ao momento sobre esta tecnologia centraram-se, maioritariamente, na classificação funcional dos artefactos, ignorando questões fundamentais relacionadas com o seu papel nos processos de adaptação. Desde modo, o principal objetivo da presente tese é o de contribuir para uma melhor caracterização e entendimento das estratégias adaptativas dos primeiros humanos modernos na Europa, através da investigação de um dos principais componentes de mudança associados à expansão dessas comunidades – a intensificação da utilização da tecnologia bipolar nas indústrias líticas. De um modo secundário esta tese tem como objetivos adicionais: providenciar avanços metodológicos na análise de tecnologias bipolares e o entendimento de um modo geral do papel que estas tecnologias desempenharam ao longo da Evolução Humana.

De modo a atingir estes objetivos foi levada a cabo uma abordagem metodológica inovadora neste campo. Foi feita uma meta análise (metodologia amplamente utilizada em áreas científicas como a Ecologia, Biomedicina, Ciências do Desporto, etc.) que abordou o tema do uso desta tecnologia ao longo do Paleolítico no Velho Mundo. Esta

abordagem foi tomada de modo revelar questões ainda não abordadas na literatura como o seu papel em estratégias adaptativas ao longo da Evolução Humana. Os dados e questões resultantes desta abordagem foram depois conjugados com uma análise tecnológica e morfo-funcional de um alargado conjunto de elementos integráveis nos sistemas de exploração bipolar provenientes de sítios arqueológicos com ocupações seguramente atribuíveis aos primeiros humanos modernos em cada respetiva região: Vale Boi (Portugal), Abri Pataud (França) e Bacho Kiro (Bulgária). A conjugação dos resultados da análise em conjunto com os dados do registo arqueológico de cada sítio e a sua comparação com outras regiões europeias (nomeadamente o Norte de Itália durante o tecno-complexo Uluziense) permitiram explorar hipóteses relativas às questões, que constituem os objetivos específicos da tese: (1) qual o papel da tecnologia bipolar nas estratégias adaptativas, nomeadamente, qual o seu enquadramento na resposta aos padrões de intensificação e diversificação na exploração de recursos bióticos e abióticos aparentes durante o início do Paleolítico Superior; (2) que relação tem esta tecnologia com os padrões de mobilidade destas comunidades no âmbito da adaptação à ocupação de novos territórios, e como se reflete a sua diversidade na organização e funcionalidade das ocupações; (3) de que forma os elementos bipolares integram os padrões tecnológicos de cada sítio, no que diz respeito à sua incorporação nas cadeias operatórias de cada sítio arqueológico, à exploração da diversidade de matérias-primas utilizadas, ou às escolhas efetuadas ao nível da seleção dos utensílios; (4) e por último, qual a diversidade de funcionalidades para as quais foram os elementos bipolares utilizados, prestando particular atenção à distinção entre materiais utilizados como núcleos e utilizados como cunhas.

Os resultados desta combinação de combinação revelaram um conjunto de respostas e questões relativamente aos objetivos da tese. A meta análise compilou dados de cerca de 168 ocupações Paleolíticas contendo tecnologia bipolar cujos resultados foram os seguintes: (1) a tecnologia bipolar foi utlizada como uma estratégia adaptativa ao longo do tempo por várias espécies de hominídeos; (2) os métodos bipolares foram utilizados de modo a aumentar a eficiência em tarefas relacionadas com a extração e exploração de recursos bióticos e abióticos; (3) a recorrência do recurso ao talhe bipolar (sobre bigorna) aconteceu devido a ser uma solução latente através de convergência evolucionária; e (4) a técnica da utilização de ferramentas líticas como cunhas para explorar recursos orgânicos, aparenta ter sido exclusivamente utlizada por *Homo sapiens*. Estas questões

foram posteriormente abordadas na análise tecno-funcional das 3 jazidas arqueológicas de Vale Boi (Portugal), Abri Pataud (França) e Bacho Kiro (Bulgária), e a sua subsequente comparação entre si e com jazidas no Norte de Itália o que resultou nas seguintes conclusões: (1) a tecnologia bipolar teve um papel importante na adaptação dos primeiros humanos na europa ao proporcionar-lhes como um mecanismo versátil e eficiente para maximizar a exploração de recursos bióticos e abióticos; (2) através do talhe bipolar estes grupos maximizaram economicamente a gestão de matérias-primas ao permitir-lhes continuar a reduzir volumes de matéria-prima demasiado pequenos ou irregulares para serem segurados na mão; (3) em situações em que a falta de matéria-prima não era uma preocupação, o talhe bipolar possibilitou a produção rápida e expediente de suportes e gumes agudos, independentemente do nível de experiência do talhador; (4) estes grupos recorreram à utilização de cunhas como forma de aumentar a eficiência na exploração de recursos orgânicos, nomeadamente: no processamento de carcaças, produção de ferramentas de osso e ornamentos e no processamento de hastes e madeira para o fabrico de ferramentas; (5) as vantagens da utilização destes métodos nestes senários de exploração de recursos foram transmitidas ao longo de todo o Paleolítico Superior através de várias culturas, tradições tecnológicas e independentemente do contexto ambiental ou cultural; por fim (6) estas vantagens adaptativas proporcionadas pela utilização desta tecnologia poderão ter sido um de vários fatores que levaram ao sucesso adaptativo dos humanos neste território em detrimento das populações Neandertais.

Concluindo, a tecnologia bipolar teve um papel de estratégia adaptativa para os primeiros humanos na Europa. O reconhecimento das suas vantagens na extração de recursos possibilitou a estes grupos sobreviver e mediar sucessivas pressões ambientais. Vantagens estas que tiveram de tal forma impacto nas estratégias adaptativas destes grupos que o conhecimento foi passado ao longo de todo o Paleolítico Superior na Europa, enquanto que outras tecnologias foram continuamente substituídas ou adaptadas. Ainda que não seja possível considerar a utilização da tecnologia bipolar como um dos fatores-chave para a assimilação e desaparecimento dos Neandertais, é, no entanto, claro que contribuiu para o sucesso da expansão e adaptação dos humanos na Europa.

PALAVRAS-CHAVE: Paleolítico Superior; Expansão do *Homo sapiens*; Estratégias adaptativas; Tecnologia Bipolar; Evolução Humana.

TABLE OF CONTENTS

TABLE INDEX

FIGURE INDEX

APPENDIXES

LIST OF ABREVIATIONS

AP – Abri Pataud

APEA – Abri Pataud Early Aurignacian

APEAs – Abri Pataud Early Aurignacian short occupations

APEAl – Abri Pataud Early Aurignacian long occupation

APEvA – Abri Pataud Evolved Aurignacian

BC – Bipolar Core

BK – Bacho Kiro

EA – Early Aurignacian

EvA – Evolved Aurignacian

IUP - Initial Upper Paleolithic

GF – Grotta di Fumane

MP – Middle Paleolithic

LRJ – Lincombian-Ranisian-Jerzmanowician

UP – Upper Paleolithic

VB – Vale Boi

RB – Riparo Broin

SP – Splintered Piece

Chapter I

INTRODUCTION

How hominins selected and evaluated tool efficiency for resource exploitation and how it drove their adaptive strategies remains a largely unanswered question in Human Evolution studies. The ability to strategically modify the environment is one of many behaviors that drove hominins to expand and survive in various ecological and climatic settings (Wells and Stock, 2007; Roberts and Stewart, 2018). Tool production, modification, and use have all played an incremental role in adaptive strategies, which is reflected by the non-linear evolution of lithic technology. Nevertheless, despite many theoretical contributions, the technological means by which hominins achieved and evaluated stone tool efficiency to adapt to different pressures in their environment remains largely unknown.

How did hominins evaluate stone tool efficiency? What made them choose one method over another? What part did skill and raw material availability have in these choices? Knowing the answer to these questions would facilitate understanding how different types of technologies and techniques structured hominin survival and expansion through space and time. The literature has shown that hominins' toolkits were comprised of a diverse set of techniques that produced stone tools and sharp edges (Rezek et al., 2018). While the basic principles of flaking remained the same, knapping methods varied through time (Stout, 2011). Recent evidence has made it clear that combinations of different knapping techniques can be seen as early as the oldest stone tools assemblages (Harmand et al., 2015a). Hominins were often applying a mix of bipolar and free-hand methods to produce sharp edges in order to survive and adapt (Jones et al., 1994; Ludwig et al., 1998; Whiten et al., 2009; de la Torre, 2011; Diez-Martín et al., 2011; Harmand et al., 2015a).

Unlike some free-hand methods (e.g., Levallois, Kombewa, Bifacial technologies), the bipolar method can be recurrently found in prehistoric assemblages all over the world (Octobon 1938; Leaf 1979; Hayden 1980; Shott 1989; LeBlanc 1992; Shott 1999; Arzarello and Peretto 2010; de la Peña 2011; de la Torre 2011; Langejans 2012; Bader et al. 2015; Horta et al. 2019). In Europe, the most significant rise in the frequency of bipolar methods is linked with the arrival of humans (de la Peña, 2011; Villa et al., 2018; Horta et al., 2019, 2022). In fact, it can be said that bipolar technology and, in particular, splintered pieces have been referred to as one of the most common tool types found in Upper Paleolithic assemblages (Zilhão, 1997; de la Peña, 2011; Sano, 2012; Douka et al., 2014; Villa et al., 2018; Horta et al., 2019; Arrighi et al., 2020; Kolobova et al., 2021). However, the link between the rise of bipolar methods and human migrations and adaptations is virtually unexplored in the literature.

It is of general consensus that out of all hominins, *Homo sapiens* displayed the highest adaptability (Wells and Stock, 2007; Roberts and Stewart, 2018) and that the development of lithic technologies played an integral role in their adaptability to different environments (Andrefsky, 2008, 2010; Cascalheira et al., 2017). Evidence shows that after 50ka, humans were actively managing lithic resources to achieve fitness advantages through complex behaviors (Rezek et al., 2018). For instance, new methods such as pressure flaking (Harrison, 2004; Mourre et al., 2010) were created to increase tool production precision. The behavioral complexity between using, managing, and modifying stone resources seems to have led, over time, to higher efficiency (Rezek et al. 2018) in human adaptive strategies. This higher efficiency in using stone resources for mediating environmental pressures is one of many aspects that may have led humans to thrive over climate and environmental change and other hominins (Wells and Stock, 2007; Rezek et al., 2018; Roberts and Stewart, 2018). However, one of the most unique and unchanged aspects of human adaptive strategies is the recurrent use of bipolar methods. Despite this, and compared to other reduction methods, the information available on the role of bipolar technology in adaptive strategies is lacking due to minimal studies on this subject.

Most studies have been dedicated to exploring reduction strategies and functional patterns (LeBlanc 1992; de la Peña 2011; Langejans 2012; Igreja and Porraz 2013; Pargeter and Peña 2017; Horta et al. 2019; Kolobova et al. 2021). Therefore, we currently understand how these techniques were functionally applied in several chronological and ecological contexts (e.g., Bader et al., 2015; P. de la Peña, 2015; Flood, 1980; Langejans, 2012; Shott, 1989). However, we still lack an understanding of the adaptive, technological, and cultural dynamics that led to the use of the bipolar methods, whether by hominins in general or humans specifically. This is especially important in the period between 45-30k years BP when *Homo sapiens* arrive and colonize Europe resorting to bipolar methods. Particularly, when Neanderthals were rarely using them (Flas, 2011; Moncel et al., 2012; Márquez et al., 2013; Van Kolfschoten et al., 2015a; Ravon et al., 2016). The reason for this difference may have impacted the replacement of one species over the other during this period of climactic instability (Müller et al., 2011).

1.1 Literature Review

1.1.2 *Homo sapiens* migration and adaptation strategies

One of the longstanding questions in Human Evolution studies is how our species was able to colonize the entire planet and persist beyond the extinction of other hominins (Wells and Stock, 2007; Roberts and Stewart, 2018; Bacon et al., 2021). Current data shows *Homo sapiens* emerging ca. 300ka years ago, using what is referred to as Middle Stone Age technology (Hublin et al., 2017; Richter et al., 2017). The spread of *Homo sapiens*, however, seems to have happened only around 100k years later, between ca. 200-100ka years ago (Groucutt et al., 2015; Hershkovitz et al., 2018). Migrations during this time period into East Africa and the Levant are associated with grassland and aquatic habitats and their extension during interstadial phases of climatic amelioration (Clark et al., 2003; Vaks et al., 2007; Hershkovitz et al., 2018). It is this expansion of homogeneous environments that likely allowed for the migration of previous hominin species out of Africa and into Eurasia (Dennell and Roebroeks, 2005; Martínez-Navarro, 2010).

During the Late Pleistocene, *Homo sapiens* would spread and settle throughout the Old World. Traditionally, it has been considered that this spread would be linked with similar phenomena of expansion of homogeneous environments. Namely, dispersal routes would follow the expansion of savannah, woodland, and forest corridors or through the use of coastal routes in warmer periods (Binford, 1968; Blome et al., 2012). In addition, the lack thereof of these environmental conditions would pose significant barriers to migrations. A growing body of data has shown that *Homo sapiens* were in fact, moving and occupying highly variable ecological settings including extreme environments, such as high altitude regions, deserts, tropical rainforests, and the colder, or northern regions of the globe (Clark, 1959; Madsen et al., 2006; Yuan et al., 2007; Perera et al., 2011; Groucutt and Petraglia, 2012; Blinkhorn et al., 2015; Pitulko et al., 2016).

For instance, within Africa, *Homo sapiens* were adapting and specializing in a mixture of rainforest, desert, high altitude and coastal settings (Bennett, 2011; Oestmo et al., 2012; Bader et al., 2015; Taylor, 2016; Demayumba, 2021). The large deserts of the Namib, Kalahari, and Sahara were initially occupied in wet periods, however, occupation persisted during the harsh arid periods (McCall et al., 2011; Spinapolice and Garcea, 2013; Garcea, 2016; Robbins et al., 2016). In these cases, adaptation was done through MSA technologies and regional variants like the Aterian MSA (Garcea, 2016). This allowed humans to survive and persist in different climates and environmental settings in these regions (Garcea, 2016). Likewise, in Central Africa, the Lupemban MSA industry was being used to adapt to mainly savannah but occasionally rainforest settings for an extensive period (Taylor, 2016). High altitude occupations in Lesotho occurred in both very cold and warmer moments, with episodes of abandonment during glacial periods (Brandt et al., 2012). In southernmost Africa, there was a persistent occupation and specialization to coastal settings (Henshilwood et al., 2001; Backwell et al., 2008; Jerardino and Marean, 2010; Archer et al., 2015; Lombard and Wadley, 2016).

Expansions eastward into the Near East and subsequently Eurasia may have initially occurred through the formation of lakes and rivers during periods of heavy precipitation, which led to migrations of large mammals and subsequently humans (Breeze et al., 2015). As in Africa, many ecological settings were occupied from 100ka onwards with MSA technologies (Blinkhorn et al., 2015; Bae et al., 2017; Dennell et al., 2020). The first occupation of the Thar desert in northwestern Indian happened as early as 96ka (Blinkhorn et al., 2015). Evidence for the occupation of rainforests happens shortly after (Perera et al., 2011), with recent data showing that Sumatra was at around 73ka (Westaway et al., 2017). Similarly, at ca 65ka, during a cold and wet period, humans occupied Northern Australia (Clarkson et al. 2017). Adaptation to the high altitude region of the Tibetan Plateau seems to occur as early as 30ka, with Upper Paleolithic industries (Madsen et al., 2006; Yuan et al., 2007). Recent data has shown that the rapid dispersal of humans throughout Southeast Asia occurred during the cooling event of MIS 4 (Bacon et al., 2021). The key factor for the rapid spread of humans in this region was the expansion of a densely forested landscape, which they rapidly adapted to (Bacon et al., 2021).

The ability to adapt to different ecological settings, including occasionally harsher environments, has been observed in other hominins species (Dominguez-Rodrigo et al., 2005; de la Torre, 2011; Potts, 2013; Shen et al., 2016). It is of general consensus that climate changes presented the most significant challenges to the adaptation of any species to a new environment (Buck et al., 2019). For instance, the shift from savannah and woodland settings to rainforest habitats between the Middle Pleistocene and the Late

Pleistocene was a major factor in the decline of *Homo erectus* and Denisovan populations in Asia (Louys and Roberts, 2020; Bacon et al., 2021). While in Europe the extreme cold during the Heinrich Event 5 resulted in Neanderthals abandoning central and northern Europe, therefore giving humans the opportunity to occupy this territory (Müller et al., 2011). On the other hand, humans were able to adapt to a multitude of environments (Clark, 1959; Madsen et al., 2006; Yuan et al., 2007; Perera et al., 2011; Groucutt and Petraglia, 2012; Blinkhorn et al., 2015; Pitulko et al., 2016). This ability to dynamically adapt to any climatic and ecological setting sets humans apart from the other species in the genus *Homo* (Wells and Stock, 2007). For this reason, *Homo sapiens* has been considered a generalist specialist, whose main advantage is the ability to adapt and specialize in any environment (Roberts and Stewart, 2018).

One of the main reasons cited in the literature for the ability to adapt to any environment has been the development of new cognitive capabilities post ca. 100ka (Dunbar and Shultz, 2007; Henshilwood and Dubreuil, 2011). These new capabilities would manifest in the archaeological record in the form of new technologies, complex symbolism, and ornamentation (Wadley et al., 2009, 2009; Shea and Sisk, 2010). The combination of these features would allow humans to actively mitigate environmental pressures and therefore adapt to a multitude of environments. While this combination of novel features cannot be separated from humans' adaptable versatility, there is an evident lack of understanding of how older technologies that persisted through time shaped human adaptive strategies. One of these, is Bipolar technology, a type of technique that persisted in time from the earliest stone tool assemblages all the way through to the Holocene across the world (Lothrop and Gramly, 1982; Barham, 1987; Shott, 1989; Curtoni, 1996; Diez-Martín et al., 2011; Gilabert et al., 2015; Harmand et al., 2015a; Kolobova et al., 2021; Horta et al., Under review). The arrival of humans in Europe and Asia (Niu et al., 2016; Shen et al., 2016; Horta et al., 2019) marks a considerable rise in the use of these techniques. Therefore, it is imperative to understand the connection between bipolar methods and migration and ultimately how these methods helped shape the adaptation of humans to new territories and climactic adversities.

1.1.3 The arrival of *Homo sapiens* in Europe: Neanderthal-*Homo sapiens* contacts and adaptations

The arrival and spread of *Homo sapiens* in Europe starts c. 45ka years ago, during the Marine Isotopic Stage 3 (MIS 3) (Hublin et al., 2017; Fewlass et al., 2020). MIS 3 - ca. 60-27 ka (Lisiecki and Raymo, 2005) - was a period marked by rapid climate cycles, where rapid temperature increases were followed by gradual cooling within a short span of decades (Weber et al., 2018). During this period, the European continent experienced moments of extreme cold, namely during the Heinrich Events 3 to 5, which lasted thousands of years (Goñi et al., 2002; Cacho et al., 2012). HE5 proceeded the arrival of humans in Europe. This event brought extreme climate cooling with cold and dry conditions over all over Europe (Cadwell et al., 2003). The climatic conditions in Europe were comparable to the glacial maximum of MIS 4, which at the time, led to Neanderthals abandoning Central and Northern Europe and taking refuge in the South (Van Andel et al., 2003). Likewise, during HE5, Neanderthals abandoned large sections of Europe taking refuge in southern regions, leading to a demographic vacuum within the continent (Müller et al., 2011).

At the same time, large populations of *Homo sapiens* were occupying Northwestern Levant and were able to sustain their demography due to the existence of large freshwater bodies (Bartov et al., 2002; Müller et al., 2011). As previously mentioned, climatic adversity was ultimately not a deterrent for human migrations, however, as seen in both Africa and Asia (Garcea, 2016; Bacon et al., 2021), the expansion of savannah, woodland and forest corridors provided optimal paths for rapid migration. The subsequent warming of temperature close to GIS 12 (c. 47ka) turned the environments in the Levant from desert-steppe into open forest biomes (Bond et al., 1993; Müller et al., 2011). This resulted in suitable conditions for the entrance of modern humans into Europe. However, this climatic warming also led to Neanderthal populations starting to reoccupy Central and Northern Europe during GIS 13/14 (Van Andel et al., 2003). Ultimately, humans came into Europe during a time where there was a Neanderthal demographic gap within large parts of Europe and climate was still cold (Müller et al., 2011; Pederzani et al., 2021). The following millennia of GIS's 12-9 would see Europe go through periods of high climactic amplitudes, in which the environment often switched from open forest biomes to dry steppe or tundra biomes and vice versa (Müller et al., 2011). As a result, the period post 47ka likely led to contact and direct competition between both species in which rapid adaptation and versatility were a key factor for survival.

Archaeologically, this period of competition and adaptation in climactic volatile regions is marked by shifts in adaptive strategies from both modern humans and Neanderthals. This is evident in the form of ever-changing technological industries that are present in Europe between 45-30ka years go. Several of these industries have an ephemeral presence in limited geographical domains and sometimes for rather short periods of time, such as the Ulluzian in Italy, the Châtelperronian in western Europe, and the Initial Upper Paleolithic (IUP) in the Balkans (Hublin et al. 2020; Peresani 2012; Ruebens et al. 2015; Marie Soressi e Roussel 2014; Villa et al. 2018). In general, the occurrence of these industries is often linked to three (possibly four) different populations: (1) the first wave of humans that spread through Eastern Europe, the Levant and Asia with the IUP; (2) a second wave of Aurignacian humans who would colonize Europe eventually; (3) and lastly a possible fourth wave of humans that came with the Gravettian industries; and (4) the local Neanderthals with the LRJ and Châtelperronian mostly in central and western Europe (Hublin, 2015).

The first wave of modern humans that entered Europe came with the IUP industry, some 45ka (Hublin et al., 2020). It represents dispersal events of *Homo sapiens* migrating out of Africa and into Eurasia (Hublin, 2015; Kuhn and Zwyns, 2014; Zwyns et al., 2019). Previous works (Müller et al., 2011), have suggested that this initial wave of humans was partly unsuccessful due to the fact that they were not able to reach western Europe. Within Europe evidence for the IUP is restricted to the Balkans (Tsanova, 2006; Hublin et al., 2020). Despite previous data that suggests humans only entered Europe during warm periods of time, recent evidence from Bacho Kiro cave has shown that the initial occupation of Europe happened during a very cold moment, where temperatures were as low as modern day Scandinavia (Pederzani et al., 2021). Outside of Europe, the IUP has been found across Eurasia from the Levant, to Turkey, and Mongolia through to China (Kuhn, 2004a, 2019; Derevianko et al., 2007, 2012; Kuhn and Zwyns, 2014, 2018; Morgan et al., 2014; Rybin, 2014). Interestingly, DNA analysis from human remains from Bacho Kiro cave shows that one individual was less than six generations removed from a Neanderthal ancestor (Hajdinjak et al., 2021). Additionally, the humans inhabiting Bacho Kiro during the IUP have no genetic connection to posterior Upper Paleolithic humans in Europe (Hajdinjak et al., 2021), supporting the hypothesis that they are indeed different populations (Hublin, 2015). Technologically, the IUP combines Levallois technological features such as direct percussion and radial reduction with UP volumetric unidirectional blade and formal tool production, some of which, would later be common in UP assemblages (e.g., endscrapers, pointed blades, etc.) (Kuhn and Zwyns, 2014; Niu et al., 2016; Kuhn, 2019; Slavinsky et al., 2019). Other aspects of this industry include bipolar technology both in lithic (bipolar knapping and wedging) and bone tools (bone wedges) (Kuhn, 2004a; Tsanova, 2006; Rybin, 2014; Niu et al., 2016; Hublin et al., 2020; Martisius et al., 2022).

Another early modern human industry in Europe is the Uluzzian (c. 45-40ka BP). The Uluzzian represents an occupation that was geographically limited with high ecological diversity and extended from the shallow marine reach of MIS3 onto the Adriatic zone (Peresani et al., 2016). Uluzzian occupations can be found throughout central, southern and northeastern Italy but not in northwestern Italy (Peresani, 2012; Douka et al., 2014; Villa et al., 2018; Collina et al., 2020). Outside of Italy, this industry has only been found in Klissoura cave in Greece (Koumouzelis et al., 2001; Kaczanowska et al., 2011). Within Italian cave sites (Fumane, Riparo del Broion, Grotta La Fabbrica, Grotta La Cala, Grotta del Cavallo, Uluzzo C and Grotta Bernardini) the Uluzzian is stratigraphically present between the Mousterian and Proto-Aurignacian industries (Villa et al., 2018). It is considered that the replacement of these populations at these sites was not gradual but instead occurred rapidly as sites were often abandoned (possibly due to ecological and climactic reasons, such as the Campanian Ignimbrite eruption) and later occupied by other populations (Villa et al., 2018). Technologically, the Uluzzian industry is characterized by high frequencies of unipolar, bipolar and occasional centripetal flake production (Peresani, 2012; Villa et al., 2018). Other aspects of this industry are limited blade production, prevalence of crescent backed pieces (microliths), high frequencies of splintered pieces, bone tools and personal ornaments(d'Errico et al., 2012; Peresani, 2012; Peresani et al., 2016; Villa et al., 2018).

The human population that ended up settling and colonizing Europe was the Aurignacian. Evidence for the passage of Aurignacian populations can be found across Europe, from the easternmost Balkans all the way to Portugal in westernmost Europe (Chiotti, 1999; Bar-Yosef and Zilhão, 2006; Banks et al., 2013; Chu and Richter, 2019; Cortés-Sánchez et al., 2019; Haws et al., 2020). This group represents a consistent wave of human migrations in western Eurasia represented by the Early Ahmarian (in the Near East), Kozarnikian (Eastern Europe), and Protoaurignacian (Southern Europe) industries (Hublin, 2015). Within Europe, both the Kozarnikian and the Protoaurignacian are geographically and chronologically limited industries. The Kozarnikian has been only identified in Bulgaria, with dates ranging from 39-36ka cal BP (Guadelli et al., 2005). The Protoaurignacian represents an older occupation (42-40ka cal BP) and has been identified only in southern Europe, specifically in France and Italy (Szmidt et al., 2010; Douka et al., 2012; Banks et al., 2013; Barshay-Szmidt et al., 2018; Villa et al., 2018). Technologically the Protoaurignacian marks the earliest bladelet industry in Europe (Kuhn, 2002; Le Brun-Ricalens et al., 2009; Falcucci et al., 2017; Riel-Salvatore and Negrino, 2018). Bladelets are produced from unidirectional prismatic cores, carinated cores, and alternating bilateral reduction, producing Dufour bladelets (Riel-Salvatore and Negrino, 2018). Additionally, notches, denticulates, sidescrapers, and splintered pieces can also be found in this industry (Kuhn, 2002; Le Brun-Ricalens et al., 2009; Falcucci et al., 2017; Riel-Salvatore and Negrino, 2018).

Contemperraneous, and in some regions immediately following the Protoaurignacian comes the Early Aurignacian (42-38 ka cal BP) (Teyssandier, 2007; T. Higham et al., 2011). While the previous is geographically restricted to southern Europe, evidence for the Early Aurignacian can be found in western, central and eastern Europe (Higham et al., 2012; Nigst and Haesaerts, 2012). The spread of this technocomplex is attributed to a wave of humans moving westward from the Danube, as there is no evidence of Protoaurignacian in this region (Hublin, 2015). The dates for the Early Aurignacian in the Danube are contemporary with the Protoaurignacian in western Europe, which supports this hypothesis (Douka et al., 2012; Higham et al., 2012; Nigst and Haesaerts, 2012). While it has been considered that the Early Aurignacian is simply an evolution of the Protoaurignacian (Banks et al., 2013), in Italy, evidence shows that the Early Aurignacian population replaced the previous (Villa et al., 2018). Furthermore, this replacement happened during the HE4 event, where cold and dry climate conditions led to semi-desert vegetation in southwestern Europe and the expansion of open grassland environments in other parts of Europe (Goñi et al., 2008; Fletcher et al., 2010), suitable for human migrations. The adaptive strategies through technology suggest some differences in this period. Innovations in the Early Aurignacian include bladelet production from carinated endscrapers, split-based bone points, and a wider range of bone tools and ornamentation (Vanhaeren and d'Errico, 2006; Banks et al., 2013). Still, similarities, such as blade production from prismatic cores and the presence of splintered pieces, remain in this industry (Chiotti, 2005; Banks et al., 2013).

The final industry and culture to appear in Europe within this period (45-30ka BP) is the Gravettian (35-26ka BP) (Douka et al., 2020). The Gravettian industry can be found across Europe and northern Asia (Germonpré et al., 2012; Bicho et al., 2015; Kozłowski, 2015; Reynolds et al., 2015; Calvo et al., 2016). Debate exists on whether this industry is developed in situ as an adaption to the sharp climate changes in Europe or is the result of migrations across Eurasia in still ongoing (Bicho et al., 2017; Douka et al., 2020). Genetic evidence (Fu et al., 2016) suggests that at least two Gravettian populations were living in Europe: one in western Europe and another directly related to Aurignacian populations in central and eastern Europe. Evidence suggests that Aurignacian groups were inhabiting westernmost Europe between 43-40ka cal BP (Cortés-Sánchez et al., 2019; Haws et al., 2020). However, based on current evidence, Gravettian groups were the first human colonists of the southwestern peak of Iberia (Bicho et al., 2012). In terms of adaptation the Gravettian is marked by an increased presence of mobile art, changes in landscape use, and large frequencies of backed bladelet production (Marreiros and Bicho, 2013; Kozłowski, 2015; Calvo et al., 2016; Kononenko, 2021). Another aspect of this industry is the significant use of bipolar technology (de la Peña Alonso and Toscano, 2013; Bernaldo de Quirós et al., 2015; Bradtmöller et al., 2016; Horta et al., 2019).

With the arrival and settlement of modern humans slowly spreading across Europe, Neanderthals, who were until that moment in time stable in their adaptations, started to shift and adapt their technology and behaviors as a result of contact (whether direct or indirect) with the humans (Hublin et al., 1996; d'Errico et al., 1998; Bar-Yosef and Bordes, 2010; Flas, 2011; Soressi et al., 2013; Soressi and Roussel, 2014). So far, only two industries have been linked with general consensus to the contact of Neanderthals and humans the Châtelperronian in western Europe and the Lincombian-Ranisian-Jerzmanowician (LRJ) in Central Europe (Bar-Yosef and Bordes, 2010; Flas, 2011; Soressi and Roussel, 2014; Ruebens et al., 2015). Some also consider the Szeletian in Czech Republic and Hungary as one such industry. However, there is still no consensus on who created this industry (e.g., (Hauck et al., 2016)).

The Châtelperronian (44-40 ka cal BP) is an industry that emerges during a warm period preceding GIS 11 and is known by high rates (up to 60%) of backed blades, produced with a specific *chaîne operatoire* on cores at the intersection of a narrow and wide surface, known as Châtelperronian points (Roussel, 2011; Soressi and Roussel, 2014). This industry includes high frequencies of UP-like tools, such as backed flakes, blades, bladelet production, endscrapers, and burins (Soressi and Roussel, 2014). In addition, there is occasional production of ornaments and bone tools (Soressi et al., 2013; Soressi and Roussel, 2014). The similarities between this industry and the Proto-Aurignacian have led to the argument that contact between the two species had to exist in order for them to be so similar (Soressi and Roussel, 2014). Still, there is no evidence of bipolar elements linked with this industry, unlike in the contemporaneous IUP and Uluzzian (Hublin et al. 2020; Villa et al. 2018).

The LRJ (43-40ka cal BP) is an industry that is contemporaneous with the Châtelperronean and geographically limited to northern Europe (Flas, 2011). Technologically the LRJ is known for its index fossil, the Jerzmanowice points, bifacial points made on large thick blades (Flas 2006, 2015). Blade production is typically bidirectional using soft hammer percussion. Interestingly no flake production methods have been found in the LRJ. A small diversity of tool types include leaf-shaped points, endscrapers, pointed blades, and burins (Flas, 2006, 2011). According to Flas (2011), splintered pieces are rarely found in LRJ assemblages.

Despite the differences in adaptive strategies and technological patterns between 45-30ka BP, one pattern is common: the presence or absence of bipolar technology. Interestingly, all modern human industries include bipolar methods, some in high frequencies (IUP, Uluzzian, and Gravettian) and some with less (Aurignacian). Still, these methods are quite rare in both classic Middle Paleolithic assemblages and virtually non-existent in the transitional industries attributed to the Neanderthals (Châtelperronian and LRJ) (Flas, 2011; Moncel et al., 2012; Márquez et al., 2013; Van Kolfschoten et al., 2015a; Ravon et al., 2016). The reason why *Homo sapiens* recurrently used these methods and Neanderthals did not is a question that is virtually unexplored in the literature. Furthermore, the role of this technology in human adaptive strategies and whether its use impacted how *Homo sapiens* out-competed Neanderthals during this period of climatic instability also remains unexplored in the literature.

1.2. Objectives

The main goal of this thesis is to contribute to filling the gaps in the literature and knowledge, that have been previously mentioned. Namely, in exploring the role that bipolar methods played in the adaptive strategies of the first *Homo sapiens* that colonized Europe. This will be done in three parts: (1) through the use of metanalytic methods to review the occurrence and understand patterns in the use of bipolar methods throughout Human Evolution; and (2) through the analysis of 3 assemblages marking the first modern human occupations of three key regions in Europe (Easternmost Europe, Southwestern France, and Southwestern Iberia); and lastly (3), through the combination and comparison of the data gathered in the previous points and using these results as a proxy for understanding the how bipolar methods shaped the adaptive strategies of these groups. Additionally, this work offers a critical assessment of the literature in both the anthropological and methodological sense. Interpretations of bipolar methods will go beyond the technology and functionality into cultural, adaptive, and cognitive aspects. By developing and using novel methods to analyze artifacts, this work also provides a blueprint into bipolar artifact analysis in all its facets (Knapping and Wedging) by answering questions about artifacts: function, use and reduction rate/sequences, raw material use, efficiency evaluation, among others. Through the combination of these contributions, this thesis provides an innovative way of accessing and understanding how bipolar methods helped shape the adaptation of the first *Homo sapiens* in Europe.

1.2. Thesis structure

This thesis was done following the so-called hybrid method. It combines published, under review, and ready to be submitted papers and chapters. The thesis is divided into five sections. Following this initial introductory section to the topic at hand, section 2 (chapter 2, namely the paper "Lithic bipolar methods as an adaptive strategy through space and time") includes: a) a literature review and critical reflection on the classification, methodology, and interpretation of bipolar methods in the literature is presented; and b) data from 167 Paleolithic sites are combined into one database and explored from the point of view of adaptation, cultural traditions, knowledge transmission and efficiency evaluation in the use of bipolar methods from the earliest Pliocene stone tool assemblages to the end of the Pleistocene. The third section (chapters 3, 4 and 5) includes the analysis of three Paleolithic sites, each representing the first *Homo sapiens* occupation of their region, these are: Vale Boi in westernmost Europe (the paper *The role of lithic bipolar technology in Western Iberia's Upper Paleolithic: the case of Vale Boi (southern Portugal*); Abri Pataud in France (the paper *Intensive and expedient resource extraction strategies through the flexible use of lithic bipolar methods in the Early Aurignacian of Abri Pataud*); and Bacho Kiro cave in Bulgaria (*Intensive re-use of stone tools as bipolar* *implements in the Initial Upper Paleolithic of Bacho Kiro Cave*). The fourth section (chapter 6) includes the results of the comparison between the three assemblages of the previous section. The fifth and final section (chapters 7 and 8) provide a discussion on the results of the thesis, discusses the role of bipolar methods in the adaptation of the first *Homo sapiens* in Europe, as well as the final conclusions of this thesis and avenues for future work.

1.3 Site choice and paper status

Chronologically, the most significant shift in bipolar method representation in Europe happens at the onset of the Upper Paleolithic (see, e.g., Zilhão 1997; de la Peña 2011; Sano 2012; Douka et al. 2014; Villa et al. 2018; Horta et al. 2019; Arrighi et al. 2020; Kolobova et al. 2021). The arrival of *Homo sapiens* in Europe is marked by a rise in the use of these methods. Therefore, this period (post 45ka) provides a unique opportunity to understand how bipolar methods impact adaptive strategies as *Homo sapiens* gradually spread across Europe. Since adaptability is one of the central questions explored in this work, a decision was made to study sites that represented the earliest occupations of *Homo sapiens* in different regions. In turn, this would allow for exploring questions of adaptability to different ecological settings.

Vale Boi currently represents the oldest *Homo sapiens* occupation in Southwestern Iberia (Bicho et al., 2012; Cascalheira et al., 2017) containing bipolar technology. Recent data (Cortés-Sánchez et al., 2019; Haws et al., 2020) from western and southern Iberia suggests that these areas were occupied earlier by Aurignacian groups, specifically in the Bajondillo and Lapa do Picareiro sites between 43-40ka years ago. In both cases, there is currently no evidence of substantial use of bipolar methods, and the fact that the dating of these occupations is currently being debated (Haws et al., 2021; Zilhão, 2021, 2022). For this reason and its large bipolar assemblage, Vale Boi was chosen as the case study in this region. The second site, Abri Pataud, represents one of the oldest Aurignacian occupations of Western Europe (Higham et al., 2011) containing bipolar technology (Chiotti, 2005). The site is located in the iconic region of the Dordogne, known for its large amount of Middle and Upper Paleolithic occupations (Movius Jr, 1966; Movius Jr and David, 1970; Chiotti et al., 2003; Chiotti, 2005; T. Higham et al., 2011; Douka et al., 2020). Lastly, Bacho Kiro is another iconic site famous for its Bachokirian industry (now IUP) and is currently the oldest occupation of *Homo sapiens* in Europe, dated to c. 45ka

(Hublin et al., 2020). Based on current evidence Bacho Kiro has the highest representation of bipolar technology out of any IUP occupation (Kozlowski, 1982; Tsanova, 2006). Unfortunately, and due to the collections already being under study, access to Uluzzian occupation in Italy, an industry famous for its bipolar technology and attributed to the earliest *Homo sapiens* occupations in Italy (Peresani et al., 2016, 2019; Moroni et al., 2018; Villa et al., 2018; Arrighi et al., 2020; Collina et al., 2020) was denied.

In order to avoid repletion, this thesis does not include a methodology chapter since every paper included in this work includes a methodological section. In fact, due to this work providing new methodologies for analyzing bipolar technology, each paper's methods build upon the previous. Still, the slight methodological improvements made in the final papers have little to no impact on the results of this work. For instance, in chapter 3 (Horta et al., 2019), a multivariate statistical analysis was conducted to access patterns in functional scars. This resulted in a negative result, where the variability in functional scars is too high, making this approach impractical. Recent works (Kolobova et al., 2021) have had similar results. For this reason, this approach was not followed in the remaining papers. Additionally, this thesis does not include a traditional literature review chapter as this was done and replaced by the meta-analysis and review in chapter 2.

Another point where the papers diverge is the nomenclature of splintered or scaled pieces. Chapters 2 and 3 both refer to these artifacts as scaled pieces, and chapters 4-7 use the terminology splintered piece. While this topic is explored in Chapter 2, the main reason for this change is the different nomenclature adopted in each team and project (Vale Boi's project has referred to these artifacts as scaled pieces and Abri Pataud's and Bacho Kiro as splintered pieces). Still, in the final chapters of this thesis (6 and 7), these artifacts are referred to as splintered pieces which is the most used terminology in modern literature (de la Peña, 2011; Peresani et al., 2016; Falcucci et al., 2017; Riel-Salvatore and Negrino, 2018; Hublin et al., 2020; Kolobova et al., 2021). Bellow, a summary description of each paper included in this thesis is provided and their current publishing status and contributions to the literature.

The first paper included in this thesis, *Lithic bipolar methods as an adaptive strategy through space and time* (Chapter 2), is a meta-analysis of lithic bipolar technology through space and time and proposes its importance as an adaptive strategy for hominin survival and migration strategies during the Paleolithic. It compiles data from 167 published paleolithic occupations in the Old World containing bipolar technology and explores the technological, functional, cultural, and ecological contexts that led to its use. It also presents a critical review of the interpretations of this technology in the literature. Importantly, it highlights the importance of bipolar methods as markers of variability and evolution of resource exploitation strategies, their dynamic in the Paleolithic archaeological record, and their implications for human adaptability. This paper provided an essential contribution to both Human Evolution studies and the thesis. While its scope went beyond the Upper Paleolithic, it explores for the first time in bipolar studies themes such as adaptation and efficiency evaluation, which are vital for this thesis. This paper has been published in the Journal of Archaeological Science: Reports (Horta et al., 2022).

Chapter three (*The role of lithic bipolar technology in Western Iberia's Upper Paleolithic: the case of Vale Boi (southern Portugal)*) explores the role of bipolar technology throughout the Upper Paleolithic at the site of Vale Boi. Its results go beyond the scope of the site and expand into all of westernmost Iberia by including data from over 30 Upper paleolithic occupations in Portugal. This paper built upon data gathered in a previous study (Horta, 2016) and included elements of regionality. The paper introduces a new methodology to analyze splintered pieces. This methodology separates artifact analysis into two sections: technological and functional traces (see chapter 3). This approach allowed for the exploration of technological patterns such as tool selection and their role in the site's technological sequences and tool functional patterns originated from their use in speciffic tasks. Additionally this chapter provided (for the first time) statistical testing of functional traces (the results of which impacted the following chapters). In addition to its methodological contributions, this paper solidified and further expanded upon the idea of the importance of bipolar methods in resource intensification strategies (Manne and Bicho, 2009; Pargeter et al., 2019). This paper was published in 2019 in the Journal of Paleolithic Archaeology (Horta et al., 2019).

The paper *Intensive and expedient resource extraction strategies through the flexible use of lithic bipolar methods in the Early Aurignacian of Abri Pataud* (Chapter 4) explores for the first time the role of bipolar technology in an Aurignacian occupation, particularly in the Abri Pataud site. This paper built upon the previous chapter's (Horta et al., 2019) methodology and explores new questions related to efficacy, use intensity, and bipolar knapping. Methodologically, this paper includes the analysis of bipolar cores and blanks and fracture patterns, and reduction indexes of splintered pieces. The inclusion of bipolar knapping allowed us to explore questions beyond the scope of splintered piece use patterns, namely the question related to blank production strategies. Regarding splintered pieces, it introduced new variables to assess the degree use of these morphotypes as wedges (fracture patterns and reduction index). The paper is currently *under review* in the journal Plos One.

The final paper to be included in this work, *Intensive re-use of stone tools as bipolar implements in the Initial Upper Paleolithic of Bacho Kiro Cave* (Chapter 5), analyzes bipolar technology in the Initial Upper Paleolithic (IUP) occupation of Bacho Kiro Cave. This is the first comprehensive study of bipolar technology in an IUP context and the oldest *Homo sapiens* occupation in Europe (Fewlass et al., 2020; Hublin et al., 2020). Bacho Kiro's assemblage provided a unique opportunity to assess and analyze bipolar technology in all its typological spectrum (including anvils and bipolar split pebbles). The combination of data led to understanding how dependent humans at the site were on bipolar methods for their adaptation. Bipolar methods were used to maximize resource exploitation through (1) bipolar knapping for raw material conservation and maximization of core to blank conversion; and (2) wedging for carcass processing for obtaining bone marrow, production of bone tools and ornaments, and wood and hide processing. Due to pandemic related issues mostly related to travel restrictions this chapter is lacking photographic evidence akin to the previous chapter. This paper is currently in the final stages of preparation for co-author revision and subsequent submission.

1.4. Data availability

This thesis follows the growing movement of open science in Archaeology. Each paper included in this thesis was published or will publish all of the data and analyses conducted. Additionally, links and all of the raw data (including the databases and high quality versions of figures) of each publication and chapter of this thesis can be freely accessed in the following public online repository: https://github.com/pehorta/The-role-of-bipolar-technology-in-the-adaptation-of-the-first-humans-in-Europe. For this reason, the complete databases were not included as Appendixes in this thesis.

Chapter II

LITHIC BIPOLAR METHODS AS AN ADAPTIVE STRATEGY THROUGH SPACE AND TIME

Pedro Horta*, Nuno Bicho, João Cascalheira

ICArEHB, Universidade do Algarve, Faro, Portugal

*corresponding author | email: pehorta@ualg.pt | phone: +351 911 005 506| ORCID ID: 0000-0001-7313-338X

DOI: *https://doi.org/10.1016/j.jasrep.2021.103263*

Abstract

The use of bipolar (on anvil) methods for resource exploitation has been identified in the archaeological record from the late Pliocene through to the Holocene. During all phases of human evolution, bipolar knapping and wedging were applied by different hominin species in a wide range of ecological settings. Studies on lithic bipolar methods have mainly focused on understanding the functional aspects of this technology. This paper explores the variability of the application of these methods during the Paleolithic on a macro scale. Through the meta-analysis of published data from 167 sites, it is posited that the use of bipolar methods may have had a significant impact on hominin expansion, adaptation, and survival strategies. Furthermore, the recurrent use of bipolar methods is not only an indicator of its success as an adaptive strategy, but also of how hominins were able to evaluate different types of efficiency through time.

Keywords

Stone tools; Bipolar methods; Paleolithic; Meta-analysis

Highlights

- Bipolar methods were used to achieve higher efficiency in resource exploitation;
- Bipolar knapping reoccurred as latent solution through evolutionary convergence;
- Data is lacking to link wedging with cultural diffusion or evolutionary convergence;

- Bipolar methods provide insights into hominin survival and adaptation strategies;

2.1 Introduction

The ability to strategically modify their environment through tool creation and manipulation as a means of adaptation is one of the many behaviors that drove hominin expansion and survival. Several strategies were used by hominins to increase their adaptability to different settings, including the production, modification, and use of tools. More precisely, it is becoming increasingly evident in archaeological research that stone technologies were essential for resource exploitation (Stout, 2011; Rezek et al., 2018)**.**

Among all kinds of lithic techniques, bipolar methods (on anvil) can be recurrently found in prehistoric assemblages all over the world (White, 1968; Barham, 1987; Diez-Martin et al., 2009; de Lombera-Hermida et al., 2016; Pargeter and de la Peña, 2017; Horta et al., 2019)**.** Most research on bipolar methods has been dedicated to understanding reduction strategies and functional patterns. As a result, we currently have a clear understanding of how these methods were applied in several chronological and ecological contexts (e.g. (Bader et al., 2015; Flood, 1980; Langejans, 2012; Shott, 1989; Paloma de la Peña, 2015a). However, further research is required to better understand the technological and adaptational aspects that led to their use.

Since its initial identification by Bardon et al. (1906), lithic bipolar methods have been surrounded by debate. This century-long controversy has ranged from a descriptive typological definition level to a functional level. One of the most important factors about bipolar methods is that they are not restricted geographically or chronologically. Whether used as a means of blank production (bipolar knapping), or organic resource exploitation (wedging), these methods are constantly present in the archaeological record. Consequently, the bipolar method has not been labeled as an Age or Industry (de la Peña and Wadley, 2014).

This paper highlights the importance of bipolar methods as markers of variability and evolution of resource exploitation strategies, their dynamic in the Paleolithic archaeological record, and their implications for human adaptability. In addition, this paper also presents a short reflection on the definition, classification, interpretation, and analytical challenges linked with bipolar methods. To understand and explore these questions on a macroscale, a metanalysis was carried out by extracting, reviewing, and analyzing information from published data on bipolar technology.

2.2. Background

2.2.1 Defining bipolar methods: classification

Classifying and determining the function of artifacts related to the application of bipolar methods have proven to be problematic in the past. This is because the identification of bipolar methods is not limited to on-anvil knapping activities, but also include the use of the so-called “splintered” or “scaled” pieces as tools for other types of activities. The main feature that defines bipolar artifacts is that they are crushed in at least two opposite poles. This damage is the result of opposite forces applied to the artifact during its use or production.

Two objectives can be reached by using bipolar methods: flaking the artifact itself or splitting the object on which it is resting (i.e., wedging/chiseling) (e.g de la Peña, 2015; Hayden, 1980; Hiscock, 2015a; Horta et al., 2019; Leaf, 1979; Octobon, 1938; Shott, 1989). The two activities have different goals, but the scars that are created on the “main artifact” (core or wedge) are often similar. Due to the artifact resting on a hard surface, the force produced by the percussion propagates downward reflecting on the anvil, causing flaking or damage to both ends due to the compression of forces. While the main striking (active) platform is identical to other direct hard-hammer percussion knapping techniques, the opposed/secondary (passive) platform often flakes in a random manner producing chips and small flakes (Octobon, 1938; Andrefsky, 1998). Consequently, it sometimes acquires the characteristics of the resting surface (de la Peña, 2011). What further complicates identification is that both cores and wedges may have been rotated. In addition, there is little to no control in the flaking of the passive platform due to it resting on the anvil. In other words, damage is often not diagnostic of function. Bipolar artifact shape is influenced by several variables (e.g., raw material type and hardness, angle of use, etc.), including some not controlled by the knapper (e.g., force application and the resulting contact with the anvil). The combination of these factors increases the level of difficulty to accurately identify the type and function of bipolar artifacts.

The functional identification of bipolar artifacts presents various degrees of difficulty. In general, some bipolar artifacts can be easily identified as cores; however, the same cannot be said for scaled pieces, which could have had different functions that left behind similar marks. A bipolar core is simply a nodule that was reduced using a bipolar method to extract blanks, often referred to as bipolar flakes (Octobon, 1938; Andrefsky, 1998). A scaled piece can be either a blank (used as a core for bipolar flaking) or as an intermediate piece or wedge (used for working hard materials, most frequently organic). It is this equifinality that led to the century long debate surrounding bipolar methods (Binford and Quimby, 1963; Tixier, 1963; Flood, 1980; LeBlanc, 1992; Shott, 1999; Lucas and Hays, 2004; de la Peña, 2011; Igreja and Porraz, 2013).

The first definition of a scaled or splintered piece was proposed by Bardon et al. (1906), who described it as the result of the bipolar knapping of flint through direct percussion. He further elaborates that the “core” will have been rested on a hard surface, causing splintering at both ends of the artifact. Since then, several other definitions were adopted and adapted by researchers in a variety of contexts (e.g., de Sonneville-Bordes and Perrot, 1956; Hayden, 1980; Knight, 2016; MacDonald, 1968; Octobon, 1938; Shott, 1989). As a result, this exact morphotype can be found throughout the literature with several different typological labels, such as: *pièce esquillée*, *outil esquillé*, *outil écaillé*, *gouge*, *chasse-lame*, *punch*, *éclateur*, bipolar, chisel, wedge, splintered piece, and scaled piece (Brun-Ricalens, 2006). This turned the scaled piece morphotype into a murky category that are often clustered with bipolar cores.

Beyond the classification debate, the biggest issue with the scaled piece morphotype comes from a functional diagnostic standpoint. In 1938, Octobon (1938) suggested that these pieces may have been used as wedges to work hard materials or as flake cores. This has also been quite debated, with researchers often defending one function over the other (see e.g., (Binford and Quimby, 1963; Tixier, 1963; Flood, 1980; LeBlanc, 1992; Shott, 1999; Lucas and Hays, 2004; de la Peña, 2011; Igreja and Porraz, 2013).

Recent literature has tried to tackle the matter of functional identification through both micro and macroscopic analysis (e.g. Bader et al., 2015; Bao et al., 2007; Bosinski et al., 2007; de la Peña, 2015, 2011; Igreja and Porraz, 2013; Lucas and Hays, 2004; Sano, 2012; Vaughan, 2002). Overall, the focus of these studies is on the identification of use-wear patterned scars and, in some cases, their comparison with experimental assemblages. Despite this, some studies frequently conclude that scaled pieces are intermediate elements to work hard organic raw materials, while others interpret them as cores for small blank production. Lastly, it has become increasingly clear that these attributions should be considered in their technological context on a site-to-site basis (Horta et al., 2019).

2.2.2 Perspectives on the occurrence of bipolar methods

The occurrence of the use of bipolar technology through time is a longstanding question, leading researchers to hypothesize on its technological and adaptational pros and cons. The presence of bipolar methods in the archaeological record has been linked to several factors, such as raw material stress (Gurtov and Eren, 2014), expediency (Horta et al., 2019), time efficiency (Eren et al., 2013), raw material size and lithic miniaturization (Pargeter and de la Peña, 2017), resource intensification strategies (Horta et al., 2019; Pargeter et al., 2019), knapping skill levels (Duke and Pargeter, 2015), core to blank conversion efficiency (B. Morgan et al., 2015; Pargeter and de la Peña, 2017; Pargeter and Eren, 2017), and mobility patterns (Eren, 2010).

One of the points that is often raised as an advantage to these methods is that—even at low levels of knapping skills—bipolar reduction can be successfully performed as a lower cost solution for obtaining sharp edges (Hiscock, 1996; B. Morgan et al., 2015; Duke and Pargeter, 2015; Gurtov et al., 2015, 2015; Pargeter and de la Peña, 2017). Duke and Pargeter (2015) noted that while experts outperform novices in bipolar cobble splitting, the latter are often still successful. Likewise, Morgan et al. (2015) noted that different skill levels do impact the outcome when it comes to bipolar reduction. In addition, the capability of teaching and employing bipolar methods on the go is considered one of its biggest advantages, especially in cases where there is high population mobility (e.g., Eren, 2010; Will et al., 2013).

Another factor to consider is time efficiency, as bipolar knapping can be taught within short periods of time (Shea, 2015) and, therefore, can be transmitted without the need for preexisting skill. Furthermore, it provides a fast and expedient manner of core reduction, while still being able to maximize blank extraction (Pargeter and de la Peña, 2017). Likewise, expediency is often referred to as a reason for the use of bipolar methods, whether in situations of time constraint and lower knapping skill. Interestingly, expediency and raw material conservation have been observed when it comes to the application of bipolar methods in both knapping (see Gurtov and Eren, 2014) and wedging activities (Horta et al., 2019). Gurtov and Eren (2014) observed different raw material curation methods in the use of bipolar reduction for different raw materials in Olduvai Gorge (see Gurtov and Eren, 2014 for a discussion). Similarly, Horta et. al (2019) observed in the Upper Paleolithic site of Vale Boi (southwestern Iberia) that the treatment of flint and quartz wedges were different. Quartz was used in an expedient way, being abandoned early on in the wedge's "use life" or reduction, while flint wedges were conserved and used until extinction, often being rotated to maximize their use potential. In this particular case, quartz was readily available at the site, while flint sources were up to one day of walking distance (Bicho et al., 2012).

Considering raw material stress, the advantages of bipolar opposed to free-hand methods for small raw material volumes is a topic that has often been considered (Hiscock, 2015a; Pargeter and de la Peña, 2017; Pargeter et al., 2019). According to Pargeter and de la Peña (2017), bipolar reduction played an incremental role in the expansion of lithic miniaturization strategies of milky quartz during the African Late Stone Age. Their data suggests that bipolar reduction shows higher efficiency in the core mass to blank conversion ratio in milky quartz, opposing previous studies that considered bipolar methods as wasteful (e.g., Diez-Martín et. al 2011). Morgan et al. (2015) and Diez-Martín et al. (2011) found that, for chert and quartz, free-hand methods were more efficient than bipolar methods for extracting flakes with larger amounts of cutting edge from small cores. Hiscock (2015) noted that bipolar reduction was more efficient than freehand methods when cores had steep platforms, or required larger amounts of force, since these constraints are neglectable when using bipolar reduction. The author added that these methods could be employed at any stage of reduction to extend the capability of reduction, making it so smaller raw material volumes could be continuously reduced and recycled.

Following this idea, Pargeter et. al, (2019) considered the possibility that increased lithic miniaturization and bipolar reduction may be linked to resource intensification and increasing population densities. The link between resource intensification and bipolar knapping, as well as with wedging, have been recognized due to their considerable representation in modern human expansion events (de la Peña, 2011; Pargeter and de la Peña, 2017). It is often in these cases that the advantages of wedging are referenced (e.g. Horta et al., 2019; LeBlanc, 1992; Manne and Bicho, 2009). Wedging is frequently used to intensify organic resource extraction by enabling higher efficiency in processing carcasses, producing bone tools, and working organic materials (Manne and Bicho, 2009;

Bicho et al., 2013; Manne, 2014; Cascalheira et al., 2017; Horta et al., 2019). Coupled with the advantages of bipolar knapping for raw material conservation and reduction intensification, it is undeniable that bipolar methods likely impacted hominin expansion and survival strategies.

2.3 Materials and Methods

This paper presents a detailed review of published data on the use of lithic bipolar methods across the Paleolithic record in the Old World. To gather the data, we searched the two major electronic databases of publishers (see below for the sampling methodology). Data was extracted from the sample of publications and used to build a comparable dataset (see below for the database and variables analyzed).

2.3.1 Sampling methodology and categorization

Electronic databases of publishers including Elsevier, Springer, and others (Plos, Taylor and Francis) were manually searched using the following terms: *bipolar*, *pièce esquillée*, *splintered piece*, and *scaled piece*. In addition, several synthesis papers encompassed the analysis of several sites based on older references, including monographs. Some of these were also included in the sample (see Fig. 1 for the Sampling Process and Appendix I for the full list of references and papers used). In total, 167 sites were identified and included in our analysis (Table 2.1).

Table 2.1. Sites included in this study. The ID matches the numbers used in Figure 2.2.

ID	Site	Chronology	Relative chronology as in reference	Reference
1	A.L.666 Hadar	Late Pliocene and Early Pleistocene	2,36 Ma	Goldman-Neuman and Hovers, 2012
2	Abri Blanchard	Late Pleistocene	33ka	Bourrillon et al., 2018
3	Abri Pataud	Late Pleistocene	40-27ka	Chiotti, 1999 Douka et al., 2020; Higham et al., 2011
4	Aghitu-3 Cave	Late Pleistocene	32-24ka cal BP	Kandel et al., 2017
5	Ambrona	Middle to Mid-Late Pleistocene	366-314ka	Terradillos-Bernal and Rodríguez, 2012
6	Apollo 11	Late Pleistocene	28-17ka	Bousman and Brink, 2017; Vogelsang et al., 2010
7	Arago cave	Middle to Mid-Late Pleistocene	+ 350ka	Byrne, 2004
8	Arbo	Middle to Mid-Late Pleistocene	MIS 7-5	Méndez-Quintas et al., 2019
9	Armiña cave	Late Pleistocene	14-12ka	Rios-Garaizar et al., 2020
10	Bacho Kiro	Late Pleistocene	~45ka	Hublin et. al 2020 Tsanova, 2006
11	Bailong Cave	Late Pliocene and Early Pleistocene	Early Middle Pleistocene	Li et al., 2014
12	Baıraki	Middle to Mid-Late Pleistocene	800-450k	Anissutkine et al., 2019
13	Barranco Leon	Late Pliocene and Early Pleistocene	1,4-1,2 Ma	Moyano et al., 2011

14	Batadomba-lena	Late Pleistocene	~36-20ka cal BP	Lewis et al., 2014; Perera et al., 2011
15	Benzú Rockshelter	Middle to Mid-Late Pleistocene	250-70ka	Ramos-Munoz et al., 2016
16	Bizat Ruhama	Late Pliocene and Early Pleistocene	1,6-1,2 Ma	Zaidner, 2013
17	Bois Laiterie	Late Pleistocene	12k cal BP	Sano et al., 2011
18	Bolinkoba	Late Pleistocene	30-14ka	Iriarte-Chiapusso and Arrizabalaga, 2015, 2011
19	Bone Cave	Late Pleistocene	29-post 18k	Cosgrove, 1999
20	Boomplaas	Late Pleistocene	37-12ka	Bousman and Brink, 2017; Pargeter et al., 2018
21	Border Cave	Late Pleistocene	46-28k a	Bousman and Brink, 2017; Villa et al., 2012
22	Bordes-Fitte rockshelter	Late Pleistocene	47-39ka	Aubry et al., 2014
23	Buiryokbastau-Bulak-1	Late Pleistocene	32-31ka	Kunitake and Taimagambetov, 2021
24	Bushman Rock Shelter	Middle to Mid-Late Pleistocene	97-73ka	Porraz et al., 2018
25	Cá Belvedere di Monte Poggiolo	Late Pliocene and Early Pleistocene	1 Ma	Arzarello et al., 2016
26	Chaminade I	Late Pleistocene	~41 ka	Nightingale et al., 2019
27	Combe Brune 2	Middle to Mid-Late Pleistocene	MIS 7-6	Mathias et al., 2020
28	Cova de les Malladetes	Late Pleistocene	23-26k cal BP	Villaverde et al., 2021
29	Cretone Basin	Middle to Mid-Late Pleistocene	600-500k	Ceruleo et al., 2015
30	Crvena Stijena	Late Pleistocene	MIS 3	Mihailović and Whallon, 2017
31	Cuesta de la Bajada	Middle to Mid-Late Pleistocene	MIS 9-8	Santonja et al., 2014
32	Cueva el Castillo	Late Pleistocene	34K	Maíllo-Fernández and de Quirós, 2010
33	Cueva Morín	Late Pleistocene	36-20k	Bradtmöller et al., 2016; Maíllo Fernández, 2003; Maíllo-Fernández and de Quirós, 2010
34	Cueva Negra	Late Pliocene and Early Pleistocene	990–772k	Walker et al., 2020
35	Danjiangkou Reservoir Region	Middle to Mid-Late Pleistocene	Middle Pleistocene	Li et al., 2017
36	Diepkloof Rock Shelter	Middle to Mid-Late Pleistocene	100-70,9k	Igreja and Porraz, 2013
37	Dingcun - Lushi Basin	Middle to Mid-Late Pleistocene	620-600k	Lu et al., 2011
38	Dmanisi	Late Pliocene and Early Pleistocene	1,8-1,7 Ma	Mgeladze et al., 2011
39	Donggutuo	Late Pliocene and Early Pleistocene	1,1Ma	Liu et al., 2013
40	Dursunlu	Late Pliocene and Early Pleistocene	Middle Pleistocene	Slimak et al., 2008
41	Egerbakta	Late Pleistocene	Aurignacian and Gravettian	Kozłowski et al., 2009
42	El Cierro	Late Pleistocene	19-12k cal BP	Álvarez-Fernández et al., 2016
43	El Horno Cave	Late Pleistocene	13-12k	Fano et al., 2020
44	El Palomar	Late Pleistocene	31-25k	de la Peña Alonso and Toscano, 2013; de la Peña, 2013
45	Elands Bay	Late Pleistocene	20-18k	Bousman and Brink, 2017; Porraz Guillaume et al., 2016
46	Esquicho-Grapaou	Late Pleistocene	~ 41.9-38.7 ka cal BP	Barshay-Szmidt et al., 2020
47	Fengshudao	Late Pliocene and Early Pleistocene	803k	Wang et al., 2014
48	Fonte Santa	Late Pleistocene	~24k	Zilhão, 1997
49	Foz Côa	Late Pleistocene	~25k	Aubry, 1998
50	Fuente Nueva 3	Late Pliocene and Early Pleistocene	1,4-1,2 Ma	Moyano et al., 2011
51	Gadeb	Late Pliocene and Early Pleistocene	1,45-700k	de la Torre, 2011
52	Garm Roud 2	Late Pleistocene	28-12ka Cal BP	Berillon et al., 2007

53	Givat Rabi	Middle to Mid-Late Pleistocene	198-95ka	Yaroshevich et al., 2018
54	Gorham's Cave	Late Pleistocene	33-24ka	Pacheco et al., 2012
55	Grotta di Castelcivita	Late Pleistocene	48-40ka	Arrighi et al., 2020
56	Grotta di Fumane	Late Pleistocene	46-40ka	Peresani et al., 2016
57	Grotta di Sant' Agostino	Middle to Mid-Late Pleistocene	55-43ka	Kuhn, 1991
58	Heuningneskrans	Late Pleistocene	~29-16k	Bousman and Brink, 2017
59	Hoedjiespunt 1	Middle to Mid-Late Pleistocene	130-119k	Will et al., 2013
60	Houfang	Middle to Mid-Late Pleistocene	Middle Pleistocene	Li et al., 2014
61	Howieson's Poort Shelter	Middle to Mid-Late Pleistocene	MSA	Tabrett, 2017
62	Huanglong Cave	Middle to Mid-Late Pleistocene	~100-40k	Li et al., 2014; Shen et al., 2016
63	Huayang	Late Pleistocene	14k cal BP	Yue et al., 2020
64	Isernia la Pineta	Middle to Mid-Late Pleistocene	610ka	Arzarello and Peretto, 2010
65	Isturitz	Late Pleistocene	~42ka	Barshay-Szmidt et al., 2018
66	Jarama VI rock shelter	Middle to Mid-Late Pleistocene	~58-49ka	Ruiz et al., 2020
67	Jebel Gharbi	Middle to Mid-Late Pleistocene	Aterian/MSA	Spinapolice and Garcea, 2014
68	Jerimalai	Late Pleistocene	Post 42k	Marwick et al., 2016
69	Kalavan 1	Late Pleistocene	14ka	Montoya et al., 2013
70	Kanjera South	Late Pliocene and Early Pleistocene	~2 Ma	Lemorini et al., 2014
71	Karungu	Middle to Mid-Late Pleistocene	94-45k	Faith et al., 2015
	Karungu	Late Pleistocene	94-45k	
72	Kashafrud Basin	Middle to Mid-Late Pleistocene	Pre-Acheulean	Biglari and Shidrang, 2006
73	Kilwa	Middle to Mid-Late Pleistocene	MSA	Beyin and Ryano, 2020
74	Klasies River Cave 1A	Middle to Mid-Late Pleistocene	68-59ka	Villa et al., 2010
75	Klipdrift Shelter	Middle to Mid-Late Pleistocene	65,5-59,4k	Henshilwood et al., 2014
76	Klipfonteinrand	Late Pleistocene	22-13ka	Mackay et al., 2020
77	Klissoura	Middle to Mid-Late Pleistocene	62-53ka	Darlas, 2007; Starkovich, 2017
78	Koobi Fora	Late Pliocene and Early Pleistocene	1,9 Ma	delaTorre et al., 2004
79	Kostenki 1	Late Pleistocene	43-35ka	Dinnis et al., 2021
80	Kozarnika Cave	Middle to Mid-Late Pleistocene	200-120ka	Tillier et al., 2017
81	La Boella	Late Pliocene and Early Pleistocene	1Ma-800ka	Mosquera et al., 2016
82	La Cansaladeta	Middle to Mid-Late Pleistocene	395-370ka	Rodríguez-Álvarez, 2016
83	La Noira	Middle to Mid-Late Pleistocene	700-600ka	Moncel et al., 2020
84	Lagar Velho	Late Pleistocene	24,5ka	Carvalho, 2011
85	Le Grand Abri aux Puces	Middle to Mid-Late Pleistocene	MIS 5e	Slimak et al., 2010
86	Leba Cave	Middle to Mid-Late Pleistocene	MSA	de Matos and Pereira, 2020
87	Les Fieux	Middle to Mid-Late Pleistocene	MIS 5-3	Faivre et al., 2017
88	Liang Bua	Middle to Mid-Late Pleistocene	95-17ka	Moore et al., 2009
	Liang Bua	Late Pleistocene	95-17ka	Moore et al., 2009
89	Liangshan	Middle to Mid-Late Pleistocene	600kA	Li et al., 2014
90	Lingjing	Middle to Mid-Late Pleistocene	125-90ka	Li et al., 2019
91	Llonin Cave	Middle to Mid-Late Pleistocene	MIS 3	Sanchis et al., 2019
92	Lomekwi 3	Late Pliocene and Early Pleistocene	3,3 Ma	Harmand et al. 2015
93	Longgupo	Late Pliocene and Early Pleistocene	1,77-1 Ma	Wei et. al, 2014 Wei et al., 2014
94	Manzi River	Late Pliocene and Early Pleistocene	Oldowan	Barham et al., 2011
95	Matupi	Late Pleistocene	40-12ka	Cornelissen, 2002
96	Melikane Rockshelter	Late Pleistocene	~post 40k	Mackay et al., 2014
97	Melka Kunture	Late Pliocene and Early Pleistocene	1,5 Ma	Gallotti, 2013
98	Menez-Dregan I	Middle to Mid-Late Pleistocene	223k	Ravon et al., 2016
99	Mochena Borago Rockshelter	Late Pleistocene	~43ka cal BP	Brandt et al., 2012
100	Mohelno-Plevovce site	Late Pleistocene	23-22ka cal BP	Rios-Garaizar et al., 2019
101	Mpila	Middle to Mid-Late Pleistocene	MSA	Demayumba, 2021
102	Mugharet el-Zuttiyeh	Middle to Mid-Late Pleistocene	~260-106ka	Malinsky-Buller, 2016
103	Mughr el-Hamamah	Late Pleistocene	45-39 ka cal BP	Stutz et al., 2015
104	Mumba Rockshelter	Late Pleistocene	~40-20ka	Marks and Conard, 2008

105	Nasera	Middle to Mid-Late Pleistocene	~56ka	Clark, 1988
106	Ngalue Cave	Middle to Mid-Late Pleistocene	105-42ka	Mercader et al., 2009
	Ngalue Cave	Late Pleistocene	105-42ka	Mercader et al., 2009
107	Notarchirico	Middle to Mid-Late Pleistocene	670–610ka	Santagata et al., 2020
108	Oelknitz 3	Late Pleistocene	~12ka	Gaudzinski-Windheuser, 2015
109	Olduvai Gorge	Late Pliocene and Early Pleistocene	1,8 Ma	Arroyo and de la Torre, 2017; Diez-Martín, 2010
110	Omo Shungura	Late Pliocene and Early Pleistocene	Early Pleistocene	Diez-Martín, 2010; Ludwig et al., 1998
111	Orgnac 3	Middle to Mid-Late Pleistocene	MIS9-MIS7	Moncel et al., 2012, 2005
112	Pech-de-l'Azé II	Middle to Mid-Late Pleistocene	180-140ka	Mathias et al., 2020
113	Peninj	Late Pliocene and Early Pleistocene	1,6-1,4 Ma	de la Torre et al., 2003
114	Petersfels	Late Pleistocene	20-14k	Maier et al., 2020
115	Petit-Bost	Middle to Mid-Late Pleistocene	340-270ka	Mathias et al., 2020
116	Pinilla de Valle	Middle to Mid-Late Pleistocene	77-71k	Márquez et al., 2013
117	Pirro Nord	Late Pliocene and Early Pleistocene	1,5-1,2 Ma	Arzarello et al., 2016
118	Pockenbank	Late Pleistocene	25-19k	Bousman and Brink, 2017
119	Pont de Lavaud	Late Pliocene and Early Pleistocene	~1Ma	de Lombera-Hermida et al., 2016
120	Prince Cave	Middle to Mid-Late Pleistocene	220ka	Rossoni-Notter et al., 2016
121	Puig d'en Roca	Middle to Mid-Late Pleistocene	MIS12-MIS11	Rodríguez-Álvarez, 2016
122	Putslaagte 8	Middle to Mid-Late Pleistocene and Late Pleistocene	76-50ka	Bousman and Brink, 2017; Mackay et al., 2015
	Putslaagte 8	Late Pleistocene	50-17ka	Bousman and Brink, 2017; Mackay et al., 2015
123	Qiaojiayao	Middle to Mid-Late Pleistocene	620-600ka	Lu et al., 2011
124	Radomyshl I	Late Pleistocene	24-22ka cal BP	Kononenko, 2021
125	Reception Rockshelter	Late Pleistocene	~24ka	Bousman and Brink, 2017; Orton Jayson et al., 2011
126	Remetea Somos I	Late Pleistocene	Gravettian	Dobrescu et al., 2018
127	Revadim	Middle to Mid-Late Pleistocene	780-460ka	Malinsky-Buller, 2016
128	Rhone Valley	Middle to Mid-Late Pleistocene	MIS 5-4	Daujeard and Moncel, 2010
129	Rietputs 15	Late Pliocene and Early Pleistocene	1,7-1,2 Ma	Kuman and Gibbon, 2017
130	Riparo Broion	Late Pleistocene	44-42ka	Peresani et al., 2019
131	Rose Cottage Cave	Late Pleistocene	29-17ka cal BP	Bousman and Brink, 2017; Lewis et al., 2014
132	Schöningen	Middle to Mid-Late Pleistocene	478-424k	Van Kolfschoten et al., 2015
133	Sehonghong	Late Pleistocene	26-20k	Bousman and Brink, 2017
134	Senga	Late Pliocene and Early Pleistocene	Early Pleistocene	Diez-Martín et al., 2011; Ludwig et al., 1998
135	Shangchen	Late Pliocene and Early Pleistocene	2,12 Ma	Zhu et al., 2018
136	Shlyakh	Late Pleistocene	41-34ka	Hoffecker et al., 2019
137	Shuidonggou 2	Late Pleistocene	32-20k cal BP	Niu et al., 2016
138	Shuidonggou locality 7	Late Pleistocene	30-23k cal BP	Niu et al., 2016
139	Sima del Elefante Atapuerca	Late Pliocene and Early Pleistocene	1,22 Ma	de Lombera-Hermida et al., 2015
140	Son valley – Rampur and Patpara	Late Pleistocene	Upper Paleolithic	Jones and Pal, 2009
141	Sterkfontein	Late Pliocene and Early Pleistocene	2-1,7 Ma	McNabb and Kuman, 2015
142	Tabun Cave	Middle to Mid-Late Pleistocene	~263ka	Malinsky-Buller, 2016
143	Teixoneres Cave	Late Pleistocene	~ >51-33ka	Picin et al., 2020
144	Ter River basin	Middle to Mid-Late Pleistocene	~350-90ka	Garcia, 2015
145	Thomas Quarry Hominid Cave	Middle to Mid-Late Pleistocene	500-360k	Raynal et al., 2010
146	Tian Shan Mountains	Late Pleistocene	~32-27ka	Kolobova et al., 2021
147	Toka	Middle to Mid-Late Pleistocene	Middle Pleistocene	Chauhan, 2007
148	Transbaikal Region Sites	Late Pleistocene	~33-16ka cal BP	Terry et al., 2016
149	Txina Txina	Late Pleistocene	14k cal BP	Bicho et al., 2018; Raja, 2021

150	Uçagızlı Cave	Late Pleistocene	42-29ka	Kuhn, 2004; Kuhn et al., 2009
151	Umbeli Belli Rock Shelter	Middle to Mid-Late Pleistocene	40-29ka	Bader et al., 2016
152	Umhlatuzana	Late Pleistocene	38-27ka	Bousman and Brink, 2017
153	Untermassfeld	Late Pliocene and Early Pleistocene	Early Pleistocene	Roebroeks et al., 2018
154	Urtiaga cave	Late Pleistocene	17-16ka	Fontes 2016 Fontes, 2016
155	Ushboulak	Late Pleistocene	45-44ka cal BP	Shunkov et al., 2017
156	Vale Boi	Late Pleistocene	32-11ka cal BP	Horta et al., 2019
157	Vallparadís	Late Pliocene and Early Pleistocene	1Ma-600ka	Garcia et al., 2012
158	Warwasi Rockshelter	Late Pleistocene	Upper Paleolithic/ Baradostian	Tsanova, 2013
159	Xiaochangliang	Late Pliocene and Early Pleistocene	1,36 Ma	Ma et al., 2020; Yang et al., 2016
160	Xuchang Man	Late Pleistocene	13k	Li and Ma, 2016
161	Yafteh Cave	Late Pleistocene	35-24ka	Tsanova 2013
162	Yarımburgaz Cave	Middle to Mid-Late Pleistocene	Middle Pleistocene	Slimack, 2008
163	Yenisey Valley	Late Pleistocene	13-12k	Kolobova et. al, 2021
164	Yujiagou	Late Pleistocene	11k	Liu et al., 2013
165	Zaozer'e	Late Pleistocene	UP	Pavlov, 2002
166	Zhiyu	Late Pleistocene	33-28k	Liu et. al 2013
167	Zhoukoudian 1	Middle to Mid-Late Pleistocene	770-240k	Li, 2016; Shen et al., 2016

The literature sample is comprised of a mixture of both general and specific papers on bipolar methods dating from 1963 to 2021. The first group (general papers) is comprised of studies that were not dedicated to bipolar methods (e.g., lithic technology papers, site monographs, etc.), but mentioned the presence, context, and other variables used in the analysis of those methods at archaeological sites.

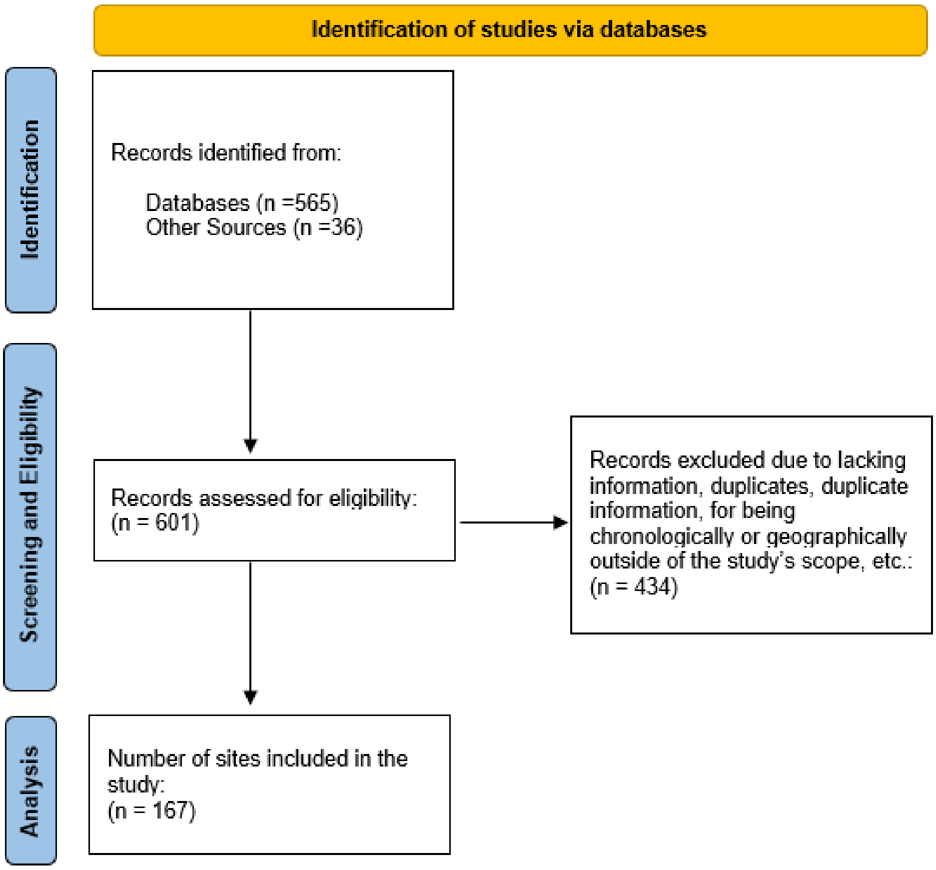


Figure 2.1: Flow chart of the sampling process

2.3.2 Recorded variables

With the goal of only including variables that would be consistently present in interpretations of the application of bipolar methods, the following group of variables were considered: chronology, site location, function attributed to bipolar artifacts at the site, raw materials, artifact type, and the size of blanks extracted (see Table 2.2 for variables and Supplementary Information for the full database). Due to the variation in the amount of data and its quality in the literature, some harmonization was needed to provide a comparable view of data from different studies.

Table 2.2. Variables recorded from the analysis of lithic bipolar methods literature used in this study.

Variable	Attributes	Observations
Site Name		

Coordinates	Latitude and Longitude	Due to the lack of precision in the literature, several sites show coordinates of the nearby settlements. Due to minor representation Oceania was merged with Asia.
Chronology	Late Pliocene and Early Pleistocene	Between 3.3 and 0.78 million of years ago
	Middle to mid-Late Pleistocene	Between 780 and 50 thousand years ago
	Late Pleistocene	Between 50 and 12 thousand years ago
Function	Blank Production	On anvil knapping for blank extraction
	Tool use	Wedging, chiseling, and others
	Not Available	No interpretation is given in the study
Artifact Type	Bipolar Cores	Any core reduced on anvil
	Scaled Pieces	Any artifact in the scaled piece category
	Bipolar Cores and Scaled pieces	Both categories of artifacts are present at the site
	Bipolar Blank	Only bipolar blanks are present at the site
	Others	Non-specified artifacts with bipolar damage or with very low representation (e.g., split cobbles, bipolar fragments, or tools with bipolar damage)
Raw Material	Chert	Includes flint and chalcedony
	Quartz	Includes all types of quartz
	Quartzite	
	Limestone	
	Obsidian	
	Others	
Blank Size	Large	According to the literature
	Medium	According to the literature
	Small	According to the literature

The sample covers all regions throughout the Old World (Fig 2). Chronologically, and due to the large time span of the sample, the sites were grouped following an adaptation of the methods by Rezek et. al, (2018). We added the Late Pliocene to the Early Pleistocene group to include the Lomekwian industry where bipolar methods have also been identified (Harmand et. al, [2015]). This resulted in sites being grouped into the following chronological phases: Late Pliocene and Early Pleistocene (3.3-0.78 million years ago [Ma]), Middle to mid-Late Pleistocene industries (780-50 thousand years ago [ka]), and Final Late Pleistocene (50-12 ka). The chronological attribution of each site in the sample was made based on the published data for the site (see SOM for the database and the full reference list). The quality and resolution of each site is far from homogeneous and absolute. Despite this we consider that due to the macro scope of this study, this problem is neglectable, posing little to no impact on the overall results.

Chronology was recorded to explore trends across time. This variable is especially important, as the sample encompasses 3.3 million of years of stone tool technology that was created and used by multiple species of hominins.

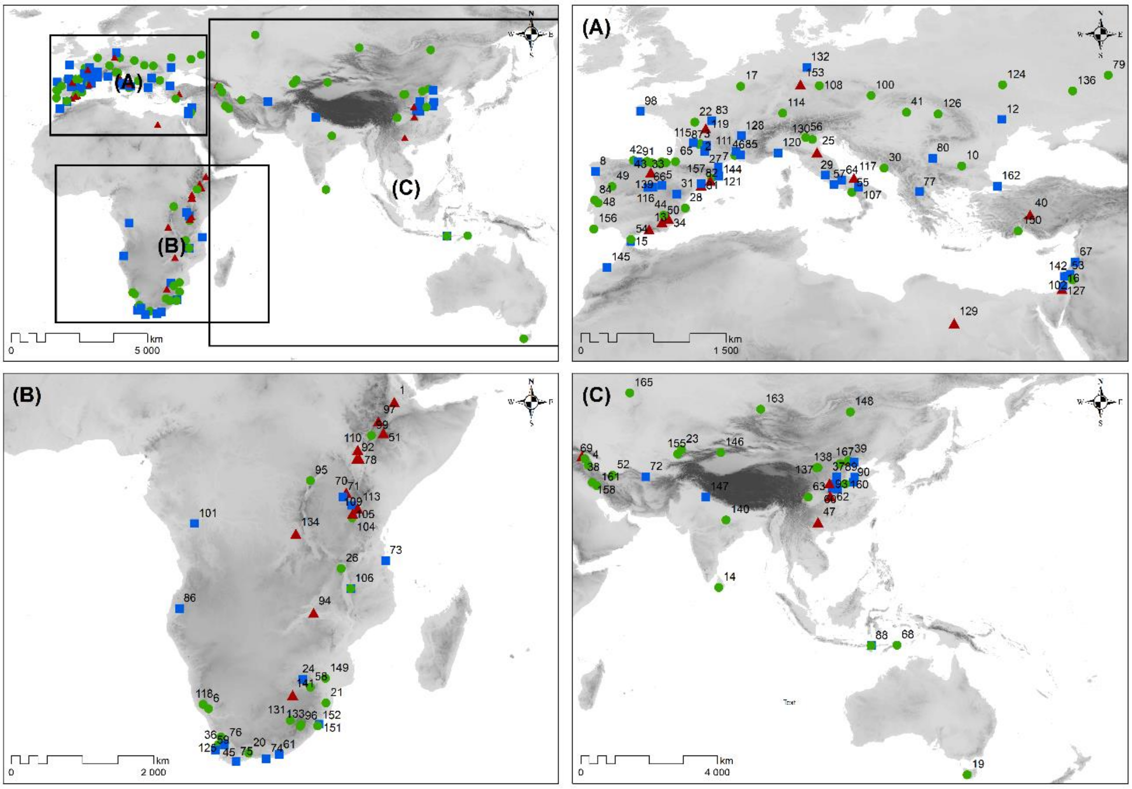


Figure 2.2. Location of sites considered in this study. Late Pliocene and Early Pleistocene sites marked in red triangles; Middle to mid-Late Pleistocene sites marked in blue squares; and Final Late Pleistocene sites marked in green circles. Numbers match the ID

As for the variable of functional attribution, the sample was separated into three main groups: Blank Production, Tool Use, and Not Available. These were mostly based on the function attributed in the original publication. For instance, several publications only mention the presence of bipolar cores in their assemblages; in these cases, the function attributed was Blank Production. Due to the previously mentioned problems with functional attributions, all functions not related to blank production in this group (wedging, etc.) were clustered into the Tool Use category. This variable was included as it has had major relevance in bipolar studies (see previous section).

Regarding Artifact Types, all cores mentioned in the literature that were knapped on anvil were considered “bipolar cores”. This category includes all types of cores regardless of their main reduction scheme (e.g., Levallois cores knapped on anvil were considered bipolar cores). For the “scaled pieces” group, all artifacts were considered and grouped regardless of the nomenclature originally used (see previous section for a list terms) or their use as cores or tools. As it is highly linked to function, this variable sheds light on what activities were being conducted at the site with bipolar methods.

In the Raw Material variable, only the raw materials that were used for bipolar technology were recorded. The goal here was to look for patterns in the application of bipolar methods to specific types of raw material across space and time. Due to the large variation within this variable, all types of quartz mentioned in the literature were compiled into the Quartz category. Likewise, all types of flint, chert, and chalcedony were compiled into the Chert category, and so on. This variable was considered due to the fact that several studies link raw material availability, quality, and hardness to the use of bipolar technology (e.g. Gurtov and Eren, 2014; Diez-Martín et. al, 2011).

Lastly, a Blank Size variable was created to understand, whether bipolar methods were used to reduce small or large cores with the goal of producing small or large blanks. This variable was included to see if there were any trends in the use of bipolar methods for artifacts of different sizes (see previous section for the links between bipolar technology and lithic miniaturization and others). Due to the highly subjective nature of size, and as only a handful of papers present quantitative data on size, the respective authors’ labels as being small or large blanks were followed.

Overall, the choice to consider these variables was made to understand large generic patterns in the use of bipolar methods through space and time. Naturally, given the diversity of consulted sources, some degree of subjectivity is inherent to the classification of the selected attributes. We argue that, despite this, the broad harmonization of the data has little impact on the large-scale results and interpretations of our study.

2.3.3 Data availability

Analyses and data processing were accomplished in R. Following recent concerns on the reproducibility and transparency of archaeological analysis we include the R code used for all the analysis contained in this paper as well as the raw database in our online research compendium which can be accessed at: www.doi.org/10.17605/OSF.IO/2KXDP.

2.4. Results

Bipolar methods and technology have been identified and described across different chronological and ecological contexts. The analyzed sample is comprised of a total of 167 sites of which 18.8% have Late Pliocene to Early Pleistocene occupations, 35.9% have Middle to Mid-Late Pleistocene occupations, and 45.3% have Late Pleistocene occupations, as shown in Table 2.3.

Table 2.3. Site distribution across region and time frame. Percentages shown in parenthesis

Chronology	Africa	Asia	Europe	Total
Late Pliocene and Early Pleistocene	13 (40.6)	9 (28.1)	10 (31.3)	32(100)
Middle to Mi-Late Pleistocene	17 (27.9)	15 (24.6)	29 (47.5)	61 (100)
Final Late Pleistocene	17 (22)	22 (28.6)	38 (49.4)	77 (100)

Currently, the end of the Pliocene marks the earliest evidence for the use of stone tools in the archaeological record, corresponding to the oldest evidence for the use of bipolar methods dating to c. 3.3 Ma (Harmand et. al, 2015). Site concentration in this phase is higher in Africa (40.6%) followed by Europe (31.3%) and Asia (28.1%) (Fig 2, Table 2.3). Bipolar cores dominate the representation in all regions, with blanks and others having minor representation in Africa and Asia (Fig 3). The application of bipolar methods during this period was likely targeting blank production in a wide variety of raw materials across all regions. While small blanks tend to be more common for this period, there is evidence for the use of bipolar methods for producing large blanks in all regions.

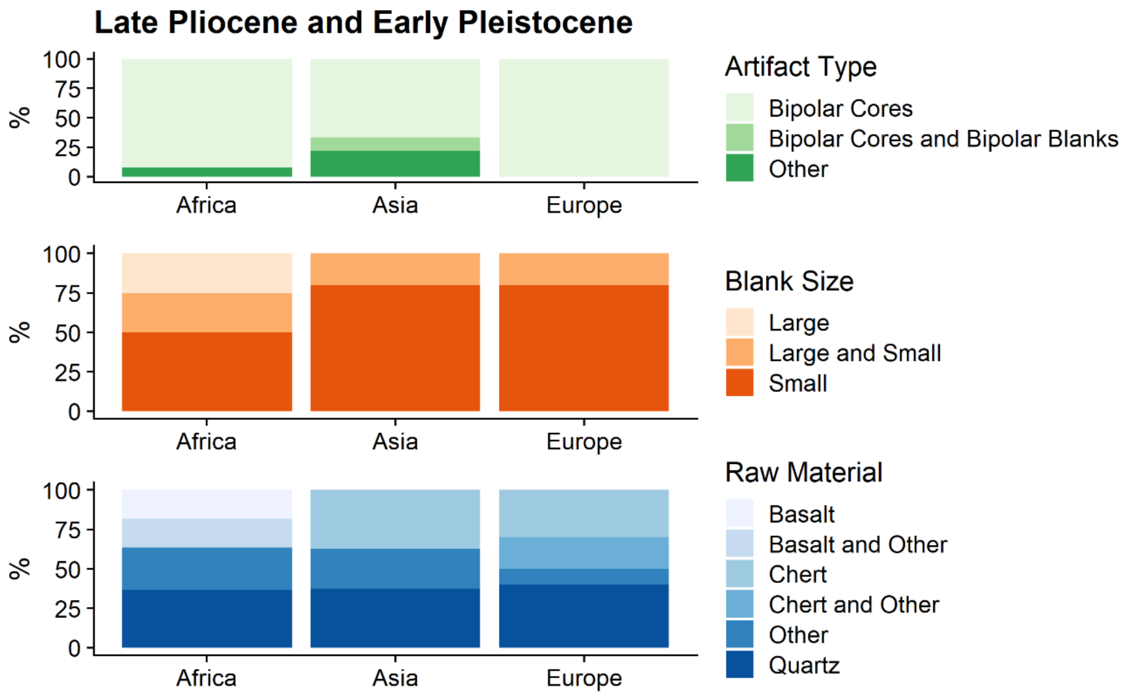


Figure 2.3. Barplots of artifact types, blank size, and raw material types by region across the Late Pliocene and Early Pleistocene. Data retrieved from 32 sites.

The Middle to Mid-Late Pleistocene period marks the expansion of Mode 2 industries, as well as the emergence of *Homo sapiens* and Mode 3 industries. During this time frame, site representation is higher in Europe (47.5%) followed by Africa (27.9%) and Asia (24.6%) (Table 2.3, Fig 2). As can be observed in Fig. 4, bipolar cores dominate representation in Europe and Asia, with minor representation of scaled pieces. In Africa, while bipolar cores are still the most represented artifact type in this period, the combination of both bipolar cores and scaled pieces shows very similar frequencies, followed by a minor representation of sites only containing scaled pieces. While small blanks tend to dominate the assemblages in all regions, there are cases of large blank production in Africa and Asia. As far as raw materials are concerned, the trend of reduction of multiple raw materials carries on from the previous period during this time frame in Africa. In Europe and Asia, there is a preference for the use of chert and quartz for bipolar reduction.

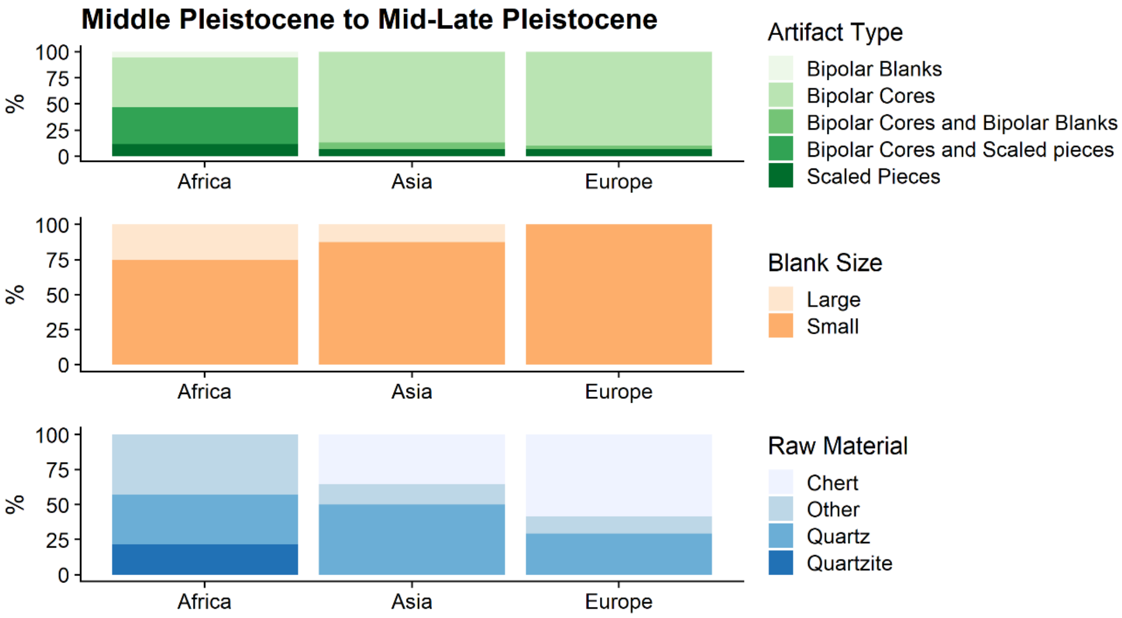


Figure 2.4. Barplots of artifact types, blank size, and raw material types by region across the Middle to Mid-Late Pleistocene. Data retrieved from 61 sites

The Final Late Pleistocene marks the definitive spread of *Homo sapiens* throughout the Old World. Site representation in this period is higher in Europe (49.4%), followed by Asia (28.6%), and lastly Africa (22%) (Fig. 2, Table 2.3). Artifact types show the highest variability during this period, with an increase in the combination of bipolar cores and scaled pieces noted across all regions (Fig. 5). As in the previous period, bipolar cores tend to dominate the sample with the combination of bipolar cores and scaled pieces rising in Africa. In Asia, while bipolar cores are the most represented artifact type, it is closely followed by sites with scaled pieces and, subsequently, the combination of both bipolar cores and bipolar blanks. In Europe, occupations with only scaled pieces show the highest representation, followed by bipolar cores and the combination of both. Small blank production can be considered the primary goal of bipolar methods across all regions. As far as raw material reduction is concerned, there are notable differences across regions. In Africa, there is a clear dominance of quartz reduction, and minor representation of other raw materials. In both Asia and Europe, a rise is noted in chert reduction, with other raw material reduction displaying lesser representation.

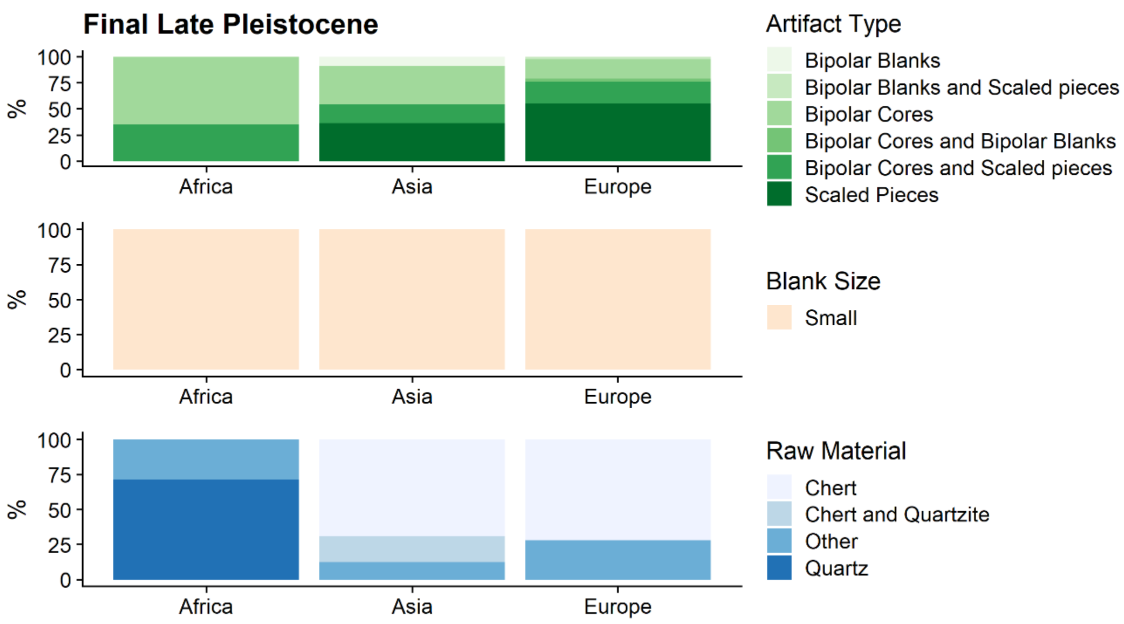


Figure 2.5. Barplots of artifact types, blank size, and raw material types by region across the Final Late Pleistocene. Data retrieved from 77 sites.

While most variables suggest similar trends across time, artifact type seems to indicate a pattern of change. As function is a variable that is directly linked to artifact type, we proceeded to run simple Correspondence Analysis on the data to confirm whether there were trends through time. As Fig. 6 suggests, there is a trend of different functionality across time. Most of the variability in the data can be explained in the first dimension of the biplot (93%). This dimension clearly separates the Late Pleistocene sample from the Late Pliocene/Early Pleistocene and Middle to Mid-Late Pleistocene samples, as the former is dominated by wedging and the combination of blank production and wedging, while the later are dominated by the use of bipolar methods to produce blanks.

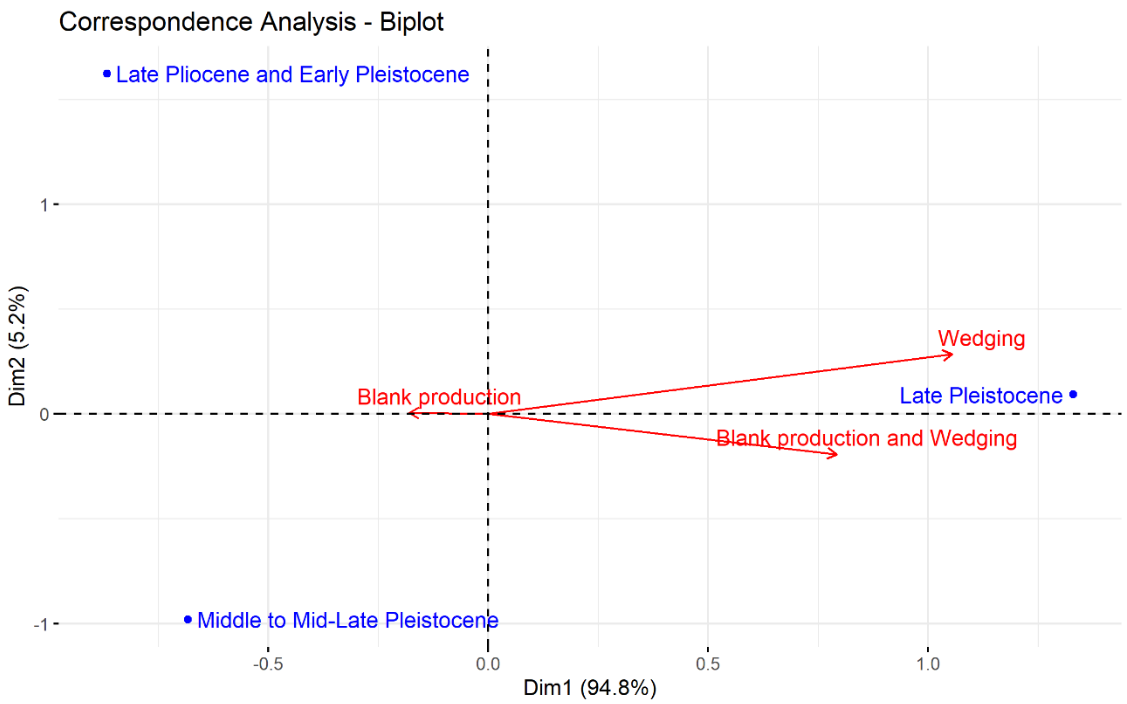


Figure 2.6. Simple Correspondence Analysis biplot summarizing the relationship between the Function and Chronology variables.

2.5. Discussion

The technological means by which hominins achieved and evaluated efficiency in the use of stone tools for adapting to different pressures in the environment remains an important question in human evolution studies. Furthering our understanding of these issues is crucial if we are to evaluate how different types of technologies and techniques structured hominin survival and expansion. While the basic principles of flaking remained the same, different techniques were applied throughout space and time, and bipolar methods were no exception. The fact that these methods are constantly present across 3.3 million years of flaking (spanning multiple hominin species and ecological settings) makes it evident that it was both a successful and impactful factor in hominin adaptations. A major focus on these questions is needed if we are to better understand hominin migrations and adaptations to different ecological settings.

Although this paper focused primarily on the Paleolithic record, bipolar methods were continuously used in Stone Age periods all around the world (Binford and Quimby, 1963; Binford, 1968; Shott, 1989; LeBlanc, 1992; Carvalho, 2007). Furthermore, modern-day chimpanzees and capuchins have been recorded using on-anvil percussion for nut-cracking activities (e.g. Fragaszy et al., 2004; Sakura and Matsuzawa, 1991). In these cases, the nut is placed on an anvil and hit with a rock. While the goal is to crack the nuts themselves, the same principles of bipolar methods are followed. These activities are very likely to have been performed by early hominins, possibly leading to the original "discovery" of bipolar knapping and its reoccurrence (e.g. Bril et al., 2015, 2012; Carvalho et al., 2009; Goren-Inbar et al., 2002).

Our results show a widespread presence of bipolar methods through space and time within our sample. Due to the large scale of the chronological groups used in this study, smaller representation patterns may be invisible in data. More in-depth regional studies addressing bipolar industries may further consolidate interpretations hypothesized in this study.

One trend that our results suggest is that the use of bipolar methods shifts through time. In the Late Pliocene and Early Pleistocene, bipolar methods were being used exclusively for raw material reduction through blank production, as bipolar cores and blanks are the only artifact types present in the assemblages. In the following period, blank production is still the dominant type of activity being performed across the Old World, albeit with a small difference: across all regions, scaled pieces start appearing in the archaeological record. In Europe and Asia, the appearance of scaled pieces (in neglectable percentages) poses no change in function, as blank production seems to be the main activity being performed. In Africa, however, the appearance of scaled pieces is linked with wedging activities in sites where bipolar knapping is still being performed (see Section 2.1 for the link between scaled pieces and wedging and/or knapping). This marks the first sighting of wedging as a—or variation of—bipolar technology. This innovation marked the subsequent artifact and function variability verified in the Late Pleistocene across all regions. Interestingly, while in Africa, a combination of bipolar blank production and wedging is present in this period. In Asia, and particularly in Europe, wedging became a rather popular activity, often out representing blank production.

This increase in functional and artifact variability in stone tool techniques perfectly aligns with the results of Rezek et al. (2018). As the authors noted that in the Late Pleistocene the variation in blank sharp edges considerably increases due to an increase in impact precision as a result of the introduction and widespread use of new flaking techniques. In turn, this raises the question of whether wedging spread through cultural diffusion or evolutionary convergence. On one hand, the widespread of this technique across the Old World happens together with Later Stone Age technologies, which could suggest cultural diffusion. On the other, other industries that have been historically considered to have been left as a trail by *Homo sapiens* migrations out of Africa (e.g. Nubian) currently point to its emergence through evolutionary convergence (Groucutt, 2020; Hallinan and Shaw, 2020). Therefore, it is difficult to argue either theory with the current data.

Regarding wedging, its mechanical concept is the same as bipolar knapping, albeit with different purposes. This technique allowed bone, stone, wood, and antler to be worked in a variety of new ways, including carcass processing, grease rendering, or organic tool production (e.g., de la Peña, 2011; Horta et al., 2019; Igreja and Porraz, 2013; LeBlanc, 1992; Shott, 1999). This new array of possibilities provided hominins with adaptational advantages that previously did not exist, allowing for a better chance of survival in new ecological settings. The current published body of evidence shows no mention of wedging activities in non-modern human occupations. While evidence for carcass processing dates as early as the Oldowan (Chazan and Horwitz, 2006; Pickering and Egeland, 2006; Niven, 2013; Arroyo and de la Torre, 2017), there is no published evidence of bone splintering through wedging that predates the late Middle Stone Age. The same pattern can be observed regarding bone tools. While there is evidence for bone tools in pre-modern human occupations (Gaudzinski, 1999; d'Errico and Backwell, 2003; Soressi et al., 2013), their frequency and complexity rises considerably in the late Middle Stone Age, Late Stone Age and the European Upper Paleolithic (Brooks et al., 1995; Backwell et al., 2008; d'Errico et al., 2012). We have no data suggesting that Neanderthals were recurrently employing bipolar methods for any other activity than knapping (Moncel et al., 2012; Márquez et al., 2013; Van Kolfschoten et al., 2015c; Tillier et al., 2017b; Villa et al., 2018).

The fact that wedging has only been identified in modern human occupations may be because it was simply invisible to lithicists who were not trained to identify it. Due to its inherently close mechanical concept with bipolar knapping (which, at this point, has been part of technological kits for a long-time span), it is unlikely that it requires a necessary cognitive structure for high-fidelity transmission. However, a hypothesis can be raised as to whether wedging may have emerged in parallel to diverse and complex technologies of the Late Pleistocene as a latent solution (Tennie et al., 2017). In other words, the concept of wedging may have been created through individual low-fidelity social learning, where specific environmental stimuli or behavior recognition expressed by others leads to its conception (Tennie et al., 2017). This is particularly interesting due to wedging's mechanical and conceptual similarity to nut cracking.

Another pattern that our results reveal is that bipolar knapping seems to have been used as means to produce small and occasionally large blanks from small cores through space and time. Data suggests that bipolar methods were used for the reduction of variable quality raw materials in different sizes, albeit these were mostly small. While previous studies have mentioned that obtaining cutting edged bipolar methods can be less efficient than freehand methods (Diez-Martín et al., 2011; B. Morgan et al., 2015), its advantages may have been enough for their recurrent use, especially when linked with highly mobile human groups raw material conservation, and time-efficient knapping of hard raw materials (Hiscock, 1996, 2015a; Gurtov et al., 2015; Shea, 2015; Pargeter and de la Peña, 2017). Lastly, free-hand knapping is often constrained by raw material size volume due to the way the materials fit into the human hand, as volumes that are too big or too small cannot be accurately gripped or hammered. This problem can be circumvented by using bipolar methods, as the core is supported on the anvil or on the ground, increasing the window of reduction of any raw material volume.

Interestingly, the data on bipolar knapping does seem not support phenomena of cultural diffusion, but possibly evolutionary convergence. Data seems to suggest that the use of bipolar knapping will vary from site-to-site, as sites in the same region have different patterns. Gurtov et al. (2015) argued that bipolar knapping appears in the archaeological record through recurrent convergent evolution, which is possibly linked to its low skill requirement. In these scenarios, it is possible that the reoccurrence of bipolar knapping is due to it being a latent solution (Tennie et al., 2017), rather than cultural or technological tradition.

In human evolution, the decision-making process of using bipolar methods opposed to freehand methods is an interesting point. Based on the evidence presented, it is clear that efficiency evaluation played a role in hominin decision-making, even in early periods. This is especially the case when both biotic and abiotic resources are scarce or of lower quality. In these moments, efficiency plays an important role, as resources need to be managed and economized. Previous studies have proposed that hominins understood the advantages of using bipolar methods by recognizing its advantages as a low-cost solution for obtaining sharp edges, its time efficiency, and lack of skill constraints (de la Torre, 2011; Diez-Martín et al., 2011; Gurtov and Eren, 2014; Jones et al., 1994; Ludwig et al., 1998; Whiten et al., 2009). Based on our results and the available data, it seems reasonable to argue that hominins showed a degree of understanding in the evaluation of efficiency to achieve specific goals early-on. This likely played a pivotal role in shaping hominin expansion, survival, and adaption strategies.

Taking all data into consideration, the application of bipolar methods through time provided a flexible way to improve the efficiency of resource exploitation. Whether for expediency or economization, hominins were better prepared for episodes of migration to new territories, rapid environmental changes, resource stress, competition and increases in demography because they were applying bipolar methods. Despite often being characterized as simple, expedient, and of low cognitive meaning, bipolar technology should be considered when attempting to understand hominin decision making and problem solving. The fact that the evaluation of stone tool efficiency was present in early periods has interesting implications for the evolution of hominin cognition. This is particularly important when the concept of wedging is introduced and apparently used by a single species. Wedging allowed for further enhancement of the effectiveness of carcass processing, bone marrow extraction, antler and woodworking, and bone/wood tool production. At the same time, it can be argued that bipolar methods for wedging allowed for a flexible and efficient resource exploration, which significantly contributed to modern humans' unique ecological plasticity (Roberts and Stewart, 2018). As such, these methods helped shape both the survival and expansion of human groups to new territories, or in periods where resources were scarce or unpredictable. Based on this body of evidence, bipolar methods can be considered both a technological and cognitive response to problem solving. This is particularly evident when considering that these methods allowed hominins to achieve higher efficiency levels when performing a single task, whether it is for expedient solutions, raw material conservation, or exploiting other organic resources. The continuous evolution of how these methods were employed through time can also be considered an important marker for understanding technological innovation and adaptation strategies.

2.6 Conclusions

Our data suggests that hominins recognized the advantages of applying bipolar methods in a wide array of contexts through time. While the concept of putting a stone tool on a hard surface to break or flake it by applying a bipolar force could be considered an expedient low-cost strategy of little cultural significance, it can alternatively be understood as a behavioral response regarding the use of lithic materials to better achieve a specific goal. By recognizing the advantages of applying these techniques, hominins would theoretically be better prepared to face periods of economic stress, environmental pressure, high mobility, and limited understanding of new territories.

This paper presents a contribution to a growing realization that this often-neglected method for hominin survival and adaptation is important. While recent literature has gone beyond understanding functional advantages, we still need to further explore the cognitive, technological, and cultural contexts of these applications through space and time. By doing this, we will be able to further reconstruct how bipolar methods structured hominin survival and expansion.

Chapter III

THE ROLE OF LITHIC BIPOLAR TECHNOLOGY IN WESTERN IBERIA'S UPPER PALEOLITHIC: THE CASE OF VALE BOI (SOUTHERN PORTUGAL)

Pedro Horta* (ICArEHB, University of Algarve, Faro, Portugal)

João Cascalheira (ICArEHB, University of Algarve, Faro, Portugal)

Nuno Bicho (ICArEHB, University of Algarve, Faro, Portugal)

*corresponding author | email: *pedroehorta@gmail.com* | phone: +351 911 005 506| ORCID ID: 0000-0001-7313-338X

DOI:10.1007/s41982-019-0022-5

Abstract

Scaled or splintered pieces are one of the most common lithic artifacts type in Upper Paleolithic assemblages throughout Europe, especially in its westernmost regions. Despite this, and even after one century of being identified there is still no consensus on how to define, analyze or interpret these tools. In western Iberia there is a clear lack of comprehensive studies regarding this type of artifacts at a regional scale. In this paper we present a first techno-morphological analysis of a sample of scaled pieces from the Upper Paleolithic site of Vale Boi. Our first aim was to build upon existing analytical models in order to identify function and possible reduction strategies for these artifacts. Our second goal was to critically evaluate the role of these artifacts within western Iberia's Upper Paleolithic. Our results showed that functional identification of scaled pieces is still not clear. By comparing our data with other author's we found that current models could not be applied to the archaeological record, as the attribute variability is too high. Furthermore, in this region we found that higher frequencies of bipolar technology can be found related to residential sites due to both functional and cultural patterns. While we still cannot define a specific function for these artifacts (intermediate pieces or wedges for working hard raw materials or cores for the extraction of chips and small bladelets), it is clear that they had a major role in the variability and intensification of resource exploitation during the Upper Paleolithic in western Iberia.

Keywords

Stone tools; Bipolar technology; Upper Paleolithic; Western Europe

3.1 Introduction

Bipolar technology is generically classified into two types of lithic artifacts - bipolar cores and scaled pieces (also known as splintered pieces or *pièce esquilée*), this latter being the main focus of this paper. Their distinction, however, has not always been consensual (Hayden 1980). Besides the fact that bipolar cores are often confused or lumped with scaled pieces (de la Peña 2011; Villa et al. 2018), the definition of scaled piece has suffered significant changes ever since its initial identification in the early 20th century and, to this day, there still seems to be no world-wide accepted clear definition for this type of artifact. The first definition of scaled pieces was proposed by Bardon and Bouyssonie (1906), describing them as a result of bipolar knapping through direct percussion, with the "core" resting on a hard surface, originating splintering in both ends of the tool. Since then, several other definitions were adopted and adapted by researchers for a very diverse set of contexts across the world (e.g. Hayden 1980; MacDonald 1985; Octobon 1938; Shott 1989; Sonneville-Bordes and Perrot 1956).

Beyond the classification debate, the biggest issue with this type of tools comes from a functional standpoint, a problem that has also been largely debated (e.g. Binford and Quimby 1963; de la Peña 2011; Flood 1980; Igreja and Porraz 2013; LeBlanc 1992; Lucas and Hays 2004; Shott 1999; Tixier 1963). The issue surrounding this problem lies within the functional equifinality of these artifacts. Contrary to bipolar cores that are exclusively part of a technological reduction sequence with the goal of blank extraction (e.g. Binford and Quimby 1963; Crabtree 1972; Leaf, 1979), scaled pieces have been associated with two distinct types of activities: (1) as intermediate pieces or wedges for working hard organic raw materials (e.g. bone, ivory, antler); and (2) as cores for the extraction of chips, small flakes and bladelets (Brantingham et al. 2004). Although largely debated, the ambiguity of this classification has, however, been ignored in some of the most recent literature, with some authors not acknowledging that bipolar evidence in stone tools might also result from other activities other than only reduction strategies (see e.g. Hiscock 2015a).

Many current studies on scaled pieces apply use-wear methods (e.g. Bader et al. 2015; de la Peña 2011, 2015a, 2015b; de la Peña and Wadley 2014; Gibaja et al. 2007; Igreja and Porraz 2013; Lucas and Hays 2004; Sano 2012), focusing on the identification of polishes and use-wear patterned stigmas, through both micro and macroscopic analysis of splintered surfaces and its comparison with experimental assemblages. Frequently, these studies coincide in interpreting scaled pieces as intermediate elements for the work of hard organic raw materials. The study by P. de la Peña (2011, 2015b) is one of the most recent and relevant references in this regard. The author presents the results of an experimental program aiming to identify specific wear patterns in the use of bipolar techniques that allow the distinction between different types of activities and worked materials. Results indicate that while no visible differences can be identified in the percussion area, significant variation can be observed in the morphology of the areas in contact with the worked material.

As in many other regions and Stone Age periods across the world (e.g. Diez-Martín et al. 2009; Igreja and Porraz 2013; Langejans 2012; White 1968), evidence of bipolar technologies are quite ubiquitous in European Upper Paleolithic contexts. In many sites, bipolar elements classified as scaled pieces have been associated with different functionalities (see e.g. de la Peña 2011; Sano 2012; Zilhão 1997).

In the case of the westernmost regions of Iberia, scaled pieces are commonly found in archaeological contexts ranging from the Upper Paleolithic to the Neolithic (e.g. Bicho 2000; Carvalho 1998; Zilhão 1997). While scarce, the majority of Portuguese Paleolithic studies (e.g. Almeida 2000; Gonçalves 2012) have not presented, so far, any context-specific interpretations for the presence of scaled pieces. Most references broadly interpret these as bipolar cores for the extraction of small flakes, bladelets and chips to be used in composite tools (e.g. Zilhão 1997), or as intermediate pieces for working hard materials (Gibaja et al. 2007; Marreiros 2009). Zilhão (1997), for example, argues that the presence of scaled pieces throughout the Upper Paleolithic sequence of central Portugal is inversely proportional to the presence of "carinated cores", and thus it is likely that the former should have worked as a flexible substitute for the latter. Carvalho (1998) agrees with this interpretation and considers it also valid for the Portuguese early Neolithic.

While we agree that some of the elements might have been used as cores, these interpretations seem simplistic, and those studies seem to have little to no analytical evidence to back those hypotheses, other than the inverse relationship mentioned above. This results, in part, from the lack of comprehensive studies regarding this type of artifacts at a regional scale. Additionally, the contexts from where most of these artifacts were recovered did not have good organic preservation or dedicated use-wear studies and, thus, no direct association between these tools and the exploitation of hard organic raw materials is possible, and, in face of the nonexistence of any absolute dates, their precise chronological attribution is also, frequently, unreliable.

In this paper, we present a first approach to the characterization of the morpho-technological variability and consequent role of scaled pieces during the Upper Paleolithic of the westernmost regions of Iberia (c. 32–10 ka cal BP). Using data from the multi-component, thoroughly dated, site of Vale Boi, located in southern Portugal, we present the analysis of a series of technological and morpho-functional attributes of a relatively large set of scaled pieces coming from one of the areas of the site. Using these data as a starting point, we then explore the relationship between the variability detected in the production and use of these artifacts with inter-site lithic technological patterns, and with the striking evidence for an intensification and diversification of faunal resources exploitation during the time-span under consideration.

3.2 Vale Boi

The archaeological site of Vale Boi is located in the western edge of the Algarve region (southern Portugal) (Fig. 1). The site can be found in a small valley following a river north-south for 2 km, until it reaches the Atlantic Ocean. Archaeological deposits occupy an estimated area of over 10 000 sq. meters across a stepped slope, marked at the top by a 10 meter-high limestone cliff face (Bicho et al. 2010, 2012).

A rather complete Upper Paleolithic sequence has been identified at Vale Boi, with all the traditionally-defined techno-complexes (Gravettian, Proto-Solutrean, Solutrean and Magdalenian) being identified across the three main excavation areas: the Terrace, the Rockshelter, and the Slope.

The Terrace area is located in the lower part of the hill. In this area, the longest archaeological sequence of the site can be found, including the complete Upper Paleolithic sequence but also three Holocene horizons, corresponding to Neolithic, Mesolithic and Epipaleolithic occupations (Bicho et al. 2012; Cascalheira et al. 2017). From within the lower levels of this area, an Early Gravettian occupation was discovered, dated to c. 32 ka cal BP, being one of the earliest radiocarbon dates for anatomically modern humans in Southern Iberia (Bicho et al. 2013; Marreiros et al. 2015).

The Rockshelter area is a collapsed rock shelter located in the upper part of the slope, a couple of meters below the limestone cliff. This collapse would have occurred after the Last Glacial Maximum, since below the collapsed debris, several Solutrean occupations can be found, overlaying a sequence of very ephemeral Gravettian horizons (Cascalheira et al. 2012; Manne et al. 2012; Marreiros 2009). The Solutrean is dated to between c. 20 ka and 25 ka cal BP (Cascalheira and Bicho 2015), while the Gravettian is dated between 26 ka and 32 ka cal BP (Marreiros et al. 2015).

Finally, the Slope section, from where the assemblage here presented is coming from, is composed of a series of excavation areas opened across the mid-hill sector of the site. These areas exhibit heterogeneous conditions in terms of site formation processes and archaeological preservation (Manne et al. 2012), but all revealed the presence of occupations attributed to the Gravettian, Proto-Solutrean, Solutrean and Magdalenian. Like in the previous areas, remains are well preserved, and high frequencies of lithic artifacts, malacological and mammalogical fauna and bone tools were recovered. No habitation features were identified in this area and based on the conditions and type of artifacts found, it has been suggested that this area would have mostly functioned as a midden deposit (Bicho et al. 2012, 2010).

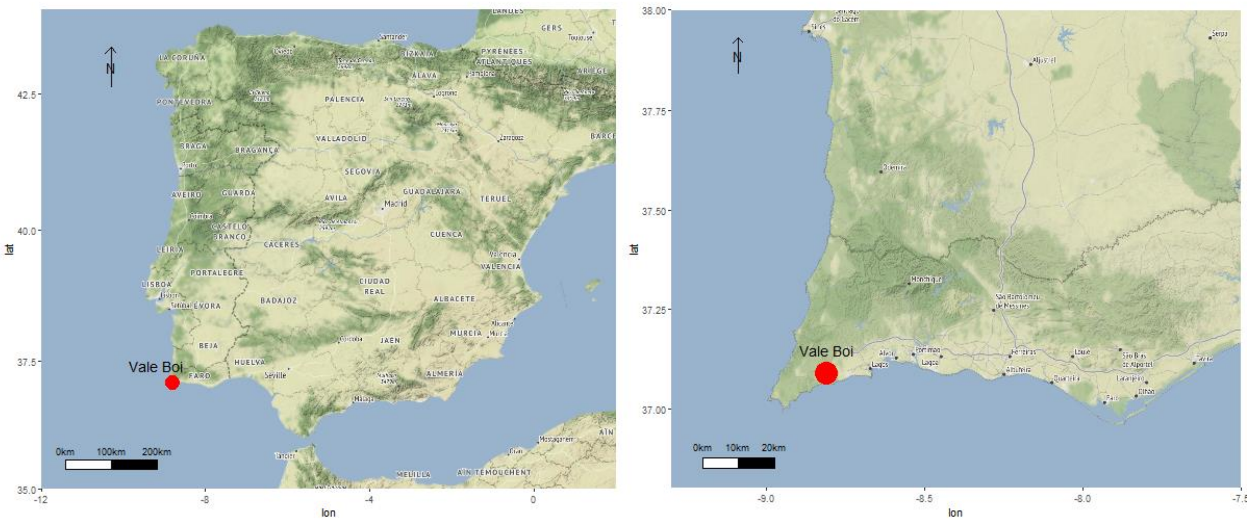


Figure 3.1. Location of the site of Vale Boi. Map data are from Stamenmap (http://maps.stamen.com), using the ggmap package Kahle and Wickham (2013).

3.2.1 Lithic technology

Vale Boi's lithic studies have revealed a general tendency for stable technological and functional patterns throughout the Upper Paleolithic (e.g. Bicho et al. 2012; Bradtmöller et al. 2016; Cascalheira 2013; Cascalheira et al. 2017, 2012; Gibaja and Bicho 2011; Marreiros and Bicho 2013; Marreiros et al. 2015, 2018; Marreiros 2009). This can be explained, partially, by raw material availability. Most raw materials were procured locally, or regionally from deposits located at no more than 20 km away from the site (Bicho et al. 2010). Chert was the most used rock type for more complex retouched tools production, while quartz and greywacke were mostly used for flake extraction and simple retouched tools production. Other raw materials can be found at the site, but much more restricted, both diachronically and functionally, within each techno-complex. Schist, for instance, shows up in some occupations almost exclusively connected to mobile art. Dolerite is only found in the Proto-Solutrean levels (Belmiro et al. 2017), while chalcedony is mostly limited to the Proto-Solutrean and Solutrean levels (Cascalheira et al. 2012).

Chert is the most abundant knapped rock type in Vale Boi. Throughout the several occupations, chert was considered the preferred rock type for knapping, which is evident by the way it was explored with much more complex strategies than either greywacke or quartz. While it can be said that chert exploration strategies were more elaborate, the most common strategies were still simple unidirectional or bidirectional reduction sequences, producing mostly flakes (Marreiros et al. 2012). Elongated products are found at low frequencies across all chronologies. When present, retouched tools are mostly notches, denticulates, end-scrapers, and, although not retouched artifacts *per se* scaled pieces. One possible reason for these simplistic strategies seems to be an overall low knapping quality, since nodules are quite small, and frequently show a high degree of tectonically derived fractures (Pereira et al. 2016).

Two distinct types of quartz were identified at the site. The first is a thick grain, low-quality type, mostly inadequate for knapping. Still, this kind of quartz is present in large quantities and is most likely associated with stone boiling and grease rendering activities (Bicho et al. 2012; Manne 2010, 2014; Manne and Bicho 2009; Manne et al. 2012). The second type of quartz is characterized by finer-grain small pebbles with yellowish cortex. This type of quartz was knapped using rather simple strategies, mostly for small flake production, which in turn were used to produce simple and versatile tools.

Greywacke is the third most frequent raw material at Vale Boi, showing up in the site mostly in the form of large slabs, in which the identification of concavely shaped impact marks is thought to result from their use as anvils. The importance of greywacke anvils is indicated by its high frequency, with hundreds of slabs found in many levels throughout all occupations (Bicho et al. 2012; Manne et al. 2012). Greywacke was also knapped for flake extraction, using expedient unidirectional reduction strategies (Cascalheira 2013; Marreiros 2009).

3.2.1 Subsistence patterns

Organic preservation is fairly good at Vale Boi. Faunal remains can be frequently found in all occupations, both of terrestrial and marine resources. Marine fauna at the site is marked by the presence of mollusks, crustaceans, some fish vertebrae and, in rare occasions, marine mammal remains (Manne 2010). Regarding terrestrial fauna, three species dominate the vertebrate group: rabbit (*Oryctolagus cuniculus*), red deer (*Cervus elaphus*) and horse (*Equus caballus*). Smaller amounts of wild ass (*Equus hydruntinus*), aurochs (*Bos primigenius*), ibex (*Capra pyrenaica*) and wild boar (*Sus scrofa*) are also present (Manne 2010, 2014; Manne et al. 2012). One of the most interesting patterns within the faunal assemblages is that a large portion of ungulate remains present specific types of fracture that have been associated with bone marrow extraction activities. Red deer and horse remains frequently show evidence of opposed cone fractures, trituration and smashing (Manne 2010, 2014; Manne and Bicho 2009; Manne et al. 2012).

Ungulates would have been hunted and processed in a similar fashion throughout the Upper Paleolithic. While there were conditions for the whole bones to be preserved, these bones are frequently anthropically broken. These fragmentation patterns seem to be linked to grease rendering activities (Manne 2010, 2014; Manne et al. 2012). The main goal of grease rendering is to obtain grease, through heat exposure from animal bones, as it has a very high caloric value. Other than this, this grease could have many uses with the addition of being easily stored and transported (Manne et al. 2012). The spongeous bone parts would be fragmented and deposited in a hole, covered with animal pelts full of water, after which, pre-heated rock fragments were added. The high temperature of the rocks would make the water boil and therefore separate the grease from the spongeous bones creating a highly nutritional stew. After being cooled the grease would accumulate at the top where it could be easily removed, transported and stored. Unlike simple bone marrow extraction, this method involved large preparation, including water transport, fire, and heat production, rock heating, and finally the storing of the grease (Manne 2014).

These grease rendering techniques are thought to be quite common at the site since the parts of the bones with higher amounts of fat are missing despite the good preservation of the rest of the remains. Fragmented ungulate remains show up in the site connected to large amounts of thermo-altered quartz, anvils, hard hammers and scaled pieces. This suggests that red deer and horse bones were processed and afterward intensively grease rendered. To confirm this, a single scaled piece was found stuck to a cracked phalanx in a Gravettian horizon (Manne 2010, 2014; Manne and Bicho 2009; Manne et al. 2012).

3.3 Methods

3.3.1 Scaled pieces attribute analysis

Based on previous works (e.g., Hayden 1980) here we define scaled pieces as artifacts of variable size and morphology, showing traces of crushing and splintering of edges at opposite ends, caused by direct percussion at one end, and subsequent crushing of the other for being rested on a hard surface. Scaled pieces present always two opposite surfaces, just like a flake or blade would, but at least one of them shows signs of crushing. Crushing traces can be bifacially or unifacially distributed. Some scaled pieces do not present crushing in opposed platforms, but are still classified as scaled pieces here. This detail has been previously referred by Villa et al. (2018) who noted that some edges may present a flat (instead of intensively shattered) platform. Our criteria does not include a particular type of blank because, as we will show in later sections of the paper, these artifacts can originate from flakes, blades or debris.

On the contrary, following mostly Hayden (1980) and Leaf (1979), bipolar cores are not marked by bifacially opposed surfaces. Their shape is more blocky and angular, showing evidence of, at least, one flaking surface with two opposed platforms (the striking platform and the base) with typical crushing and flake removal on one or both ends. The striking platform is the surface that is struck with a hammerstone to produce blanks. Typically, it exhibits little crushing except near the point of impact. Large flake scars tend to originate at the striking platform. The base is the surface that rests on the anvil, from where small flake scars can also originate.

All lithic artifacts recovered from the Slope area of Vale Boi that fit the scaled piece definition presented above were considered for this study, independent of raw material or technological class.

Attribute analysis was split into two main groups, each corresponding to two distinct types of features: (1) technological attributes (Table 3.1) and (2) morpho-functional attributes (Table 3.2). In the first group, a series of variables traditionally used in lithic studies (e.g. Andrefsky Jr 2005; Inizan et al. 1999) were recorded, aiming to characterize patterns of blank choice for the application of bipolar technology. For the second group of variables, a macroscopic approach building upon the work of de la Peña (2011) and Fischer et. al (1984) was adopted. Studies by Sano (2012), and Gibaja et al. (2007) indicate that, since use-wear traces are formed before the splintering, the removal of small chips removes most of the polishes and use-wear traces left by the contact with the static element (either a stone anvil or hard-organic materials). This, together with the large presence of quartz artifacts in our sample, prevented us to pursue a microscopic use-wear approach for this study in particular.

Table 3.1. Technological attributes used for the analysis of scaled pieces included in this study.

Variable	**Variable name in database**	**Values**	**Observations**
Raw Material	RawMaterial	Quartz	
		Chert	
		Greywacke	
		Chalcedony	
		Others	
Type of blank	Blank	Blade	
		BladeFragment	
		Bladelet	
		BladeletFragment	
		Core	
		Flake	
		FlakeFragment	
		Nodule	
		Non_Identifiable	
Length of the typological axis	TypologicalAxisLength	mm	Typological axis is defined as a vector that proceeds perpendicular to the two opposed damaged platforms, bisecting them
Length of the technological axis	TechnologicalAxisLength	mm	Same as axis of flaking in Debénath and Dibble (1994)
Width of the typological axis	TypologicalAxisWidth	mm	Distance at a mid-point between two edges of the artifact, as measured perpendicularly to the typological length
Width of the technological axis	TechnologicalAxisWidth	mm	Distance at a mid-point between two edges of the artifact, as measured perpendicularly to the technological length
Thickness	Thickness	mm	Measured at the intersection of the typological length and width
Axes coincidence	AxisCoincident	Yes	Coincidence between the typological and technological axes
Retouch presence	Retouch	Absent	Presence of retouch in artifact's edges
		Present	

Percentage of cortex	Cortex	No_Cortex	
		>25%	
		25-50%	
		50-95%	
		>95%	
Platform type	Butt	Absent	See Inizan et al (1999) for description of each value
		Cortical	
		Dihedral	
		Faceted	
		Pointed	
		Flat	
Profile	Profile	Straight	
		Curved	
		Irregular	
		Twisted	
Cross-section morphology	CrossSection	Other	
		Irregular	
		Rectangular	
		Trapezoidal	
		Triangular	
Longitudinal section morphology	SideSection	Elliptical	
		Irregular	
		Other	
		Rectangular	
		Semicircular	
		Trapezoidal	
		Triangular	
Blank edge morphology	BlankShape	Biconvex	
		Circular	
		Converging	

		Diverging	
		Irregular	
		Others	
		Parallel	
Scar dorsal pattern	DorsalScars	Bidirectional-Alternating	
		Bidirectional-Parallel	
		Bidirectional-Perpendicular	
		Non_Identifiable	
		Parallel-Distal	
		Parallel-Proximal	
		Parallel-One-Side	
		Radial	
		Other	
Fire traces	Fire	Burnt	
		No_traces	
		Thermal-Treatment	

Table 3.2. Morpho-functional attributes used for the analysis of each damaged platform of scaled pieces included in this study. *Adapted from Gonzalez-Urquijo and Ibanez-Estévez (1994). **Adapted from de la Peña (2011).

Variable	**Variable name in database**	**Values**	**Observations**
Number of damaged platforms	DamagePlatforms	1	
		2	
		3	
		4_or_more	
Platform Width	Width	mm	
Number of scars	NScars	N	
Platform Angle	Angle	<45º	
		>45º	
		Platform	>90º angle

Platform Delineation*	ScarEdgeDelineation	Concave	
		Convex	
		Irregular	
		Oblique	
		Pointed	
		Straight	
Degree of damage**	DamageDegree	High	No traces of the original platform are visible
		Medium	Some traces of the original platform are visible
		Low	Original platform is visible
Scars Shape**	ScarShape	Half-Moon	
		Irregular	
		Mixed	
		Quadrangular	
		Semicircular	
		Trapezoidal	
		Triangular	
Scar Distribution*	ScarDistribution	Central	Scars are limited to the central area of the platform
		Lateral	Scars are limited to one of the sides of the platform
		Total	Scars completely cover the platform
Scar Disposition*	ScarArrangement	Aligned	Scars are parallel and next to each other without overlapping
		Isolated	Scars are isolated
		Overlapped	Scars overlap
Scar Extension**	ScarExtension	Invasive	Scars extent to a maximum of 49% of the typological axis length
		Marginal	Scars extent to a maximum of 20% of the typological axis length
		Mixed	Scar extension is both invasive and marginal
Scar Facial Distribution**	ScarFacialDistribution	Bifacial	Scars are present in both faces of the platform
		Unifacial	Scars are present in only one face of the platform

Macroscopic morpho-functional attributes were separately analyzed for each damaged platform, aiming to detect patterns of morphological change that occurred in artifacts during use. Following the work of de la Peña (2011, 2015b) and Gonzalez-Urquijo and Ibanez-Estévez (1994), we expected that these attributes would be indicative of which function the artifacts had. For instance, according to de la Peña (2011, 2015b), for pieces used as wedges the delineation of the damaged platforms are constantly asymmetrical and only the hammered edge clearly shows the typical *écaille* retouch. Furthermore, these pieces would have irregular shapes, variable scar size, and irregular scar distribution. On the other hand, pieces used as bipolar cores would have squared or rectangular shapes, symmetric straight damaged platforms, and a higher frequency of scars on the hammered edge than on the opposed edge. The addition of other attributes drawing upon the work by Gonzalez-Urquijo and Ibanez-Estévez (1994) was made following the same reasoning. We expected, thus, to be able to differentiate pieces used as wedges from pieces used as cores, as both groups would show distinct combinations of attributes. To assist us with this differentiation we tested the presence of the referred patterns within our assemblage using descriptive and multivariate statistical analysis and comparing it with the data described by the referred authors.

3.3.2 Analysis, reproducibility and open source materials

All analyses and data processing were accomplished in R (version 3.5.1) (*R* 2013). Following recent concerns on the reproducibility of archaeological analysis we include the entire R code used for all the analysis and visualizations contained in this paper in our online research compendium at *https://dx.doi.org/10.17605/OSF.IO/WPXGH*. To produce those files we followed the procedures described by Marwick et al. (2017) for the creation of research compendiums to enhance the reproducibility of research. The files provided contain all the raw data used in our analysis as well as a custom R package (Wickham 2015) holding the code used for all analysis and to produce all tables and figures. To enable maximum re-use, our code is released under the MIT license, our data as CC-0, and our figures as CC-BY, (for more information see Marwick 2016).

3.4 Results

A total of 139 scaled pieces were analyzed, of which 42.45% come from Gravettian, and 45.32% from Solutrean levels, as shown in Table 3.3). In terms of raw materials, the great majority of pieces were either made on quartz or chert, with chalcedony being represented only by 5 artifacts.

Table 3.3. Frequencies of scaled pieces used in this study, by raw material and chronological period. Percentages are shown in parentheses.

	Chert	**Quartz**	**Chalcedony**	**Total**
Gravettian	20 (32.8)	39 (53.4)	0 (0.0)	59 (42.4)
Proto-Solutrean	6 (9.8)	4 (5.5)	1 (20.0)	11 (7.9)
Solutrean	32 (52.5)	27 (37.0)	4 (80.0)	63 (45.3)
Magdalenian	3 (4.9)	3 (4.1)	0 (0.0)	6 (4.3)

As previously mentioned, concerning technological data, one of our main objectives was to characterize the choice of blanks involved in bipolar technology. Overall, the technological analysis revealed some trends that lasted throughout the Upper Paleolithic, in agreement with the general patterns of lithic technology recorded for the site. Across all techno-complexes, blanks used were either flakes (based on the recognition of dorsal and ventral surfaces) or unclassifiable fragments, but the choice seems to be different for each raw material. For quartz, in the Gravettian assemblage, the blank types are almost equally split between flakes and unclassifiable pieces (Table 3.4). In other periods, flakes were the preferred type of blank (Tables 3.6, 3.5 and 3.7). Regarding chert, in every occupation flakes dominate the assemblages, followed by a reduced number (n = 12) of unclassifiable blanks. The small sample of chalcedony blanks is exclusively represented by flakes.

Technological and morphological characteristics of the flake blanks present very similar patterns across time and among raw materials. The blanks sought after would have straight profiles, parallel edges, no cortical surfaces and trapezoidal or triangular shaped cross-sections.

Other characteristics of the assemblage are the low frequency of retouch found in the non-damaged edges (n = 2), fire alterations (n = 4), and the presence of original striking platforms (n = 8). Still, when present, retouch is located in the lateral part of the artifacts, similar to what would define a side-scraper. In a very small number of cases, when striking platforms are present, these are mostly flat. The absence of the original blank platforms is to be expected in this type of artifact, mostly due to the functional use of the pieces, and consequent removal of the platform, rather than an actual choice. The large absence of platforms may, also, be the result of the use of the technological axis as main functional axis. In fact, when identifiable, technological and typological axes coincide in 50.5% of the cases. The longitudinal sections show a large variability of shapes, independent of raw materials or chronologies. Similarly, the dorsal pattern of previous removals was rarely identified, although this, like with the case of platform absence, might occur due to the functional stigmas and be dependent on the intensity of use for each artifact.

Table 3.4. Technological attributes frequencies by raw materials for the Gravettian sample. Percentages are shown in parentheses.

	Chert	**Quartz**	**Total**
Blank			
CompleteFlake	6 (33.3)	7 (30.4)	13 (31.7)
FlakeFragment	12 (66.7)	15 (65.2)	27 (65.9)
Non_identifiable	0 (0.0)	1 (4.3)	1 (2.4)
AxisCoincident			
No	9 (50.0)	7 (30.4)	16 (39.0)
Yes	9 (50.0)	16 (69.6)	25 (61.0)
CrossSection			
Other	0 (0.0)	0 (0.0)	0 (0.0)
Rectangular	1 (5.6)	3 (13.0)	4 (9.8)
Trapezoidal	10 (55.6)	15 (65.2)	25 (61.0)
Triangular	7 (38.9)	5 (21.7)	12 (29.3)
SideSection			
Elliptical	4 (22.2)	5 (21.7)	9 (22.0)
Irregular	1 (5.6)	1 (4.3)	2 (4.9)
Other	2 (11.1)	0 (0.0)	2 (4.9)
Rectangular	1 (5.6)	0 (0.0)	1 (2.4)
Semi_Circular	1 (5.6)	6 (26.1)	7 (17.1)
Trapezoidal	8 (44.4)	7 (30.4)	15 (36.6)
Triangular	1 (5.6)	4 (17.4)	5 (12.2)
Profile			
Curved	2 (11.1)	0 (0.0)	2 (4.9)
Straight	16 (88.9)	23 (100.0)	39 (95.1)
BlankShape			

Biconvex	0 (0.0)	2 (8.7)	2 (4.9)
Circular	2 (11.1)	2 (8.7)	4 (9.8)
Converging	0 (0.0)	0 (0.0)	0 (0.0)
Irregular	2 (11.1)	2 (8.7)	4 (9.8)
Other	1 (5.6)	1 (4.3)	2 (4.9)
Parallel	13 (72.2)	16 (69.6)	29 (70.7)
Cortex			
<25%	2 (11.1)	1 (4.3)	3 (7.3)
>95%	0 (0.0)	1 (4.3)	1 (2.4)
25-50%	2 (11.1)	0 (0.0)	2 (4.9)
50-95%	2 (11.1)	0 (0.0)	2 (4.9)
No_Cortex	12 (66.7)	21 (91.3)	33 (80.5)
ButtType			
Absent	14 (77.8)	23 (100.0)	37 (90.2)
Flat	4 (22.2)	0 (0.0)	4 (9.8)
Retouch			
No	17 (94.4)	23 (100.0)	40 (97.6)
Yes	1 (5.6)	0 (0.0)	1 (2.4)
Fire			
Burnt	1 (5.6)	0 (0.0)	1 (2.4)
No_Traces	17 (94.4)	23 (100.0)	40 (97.6)

Table 3.5. Technological attributes frequencies by raw materials for the Proto-Solutrean sample. Percentages are shown in parentheses.

	Chert	**Quartz**	**Chalcedony**	**Total**
Blank				
CompleteFlake	3 (60.0)	2 (50.0)	0 (0.0)	5 (50.0)
FlakeFragment	2 (40.0)	2 (50.0)	1 (100.0)	5 (50.0)
Non_identifiable	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
AxisCoincident				
No	3 (60.0)	1 (25.0)	1 (100.0)	5 (50.0)
Yes	2 (40.0)	3 (75.0)	0 (0.0)	5 (50.0)
CrossSection				
Other	1 (20.0)	0 (0.0)	0 (0.0)	1 (10.0)

Trapezoidal	4 (80.0)	4 (100.0)	1 (100.0)	9 (90.0)
Triangular	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
SideSection				
Semi_Circular	0 (0.0)	1 (25.0)	0 (0.0)	1 (10.0)
Trapezoidal	5 (100.0)	2 (50.0)	1 (100.0)	8 (80.0)
Triangular	0 (0.0)	1 (25.0)	0 (0.0)	1 (10.0)
Profile				
Straight	5 (100.0)	4 (100.0)	1 (100.0)	10 (100.0)
BlankShape				
Circular	1 (20.0)	0 (0.0)	0 (0.0)	1 (10.0)
Irregular	1 (20.0)	1 (25.0)	1 (100.0)	3 (30.0)
Other	1 (20.0)	0 (0.0)	0 (0.0)	1 (10.0)
Parallel	2 (40.0)	3 (75.0)	0 (0.0)	5 (50.0)
Cortex				
<25%	1 (20.0)	0 (0.0)	0 (0.0)	1 (10.0)
No_Cortex	4 (80.0)	4 (100.0)	1 (100.0)	9 (90.0)
ButtType				
Absent	5 (100.0)	3 (75.0)	1 (100.0)	9 (90.0)
Flat	0 (0.0)	1 (25.0)	0 (0.0)	1 (10.0)
Retouch				
No	5 (100.0)	4 (100.0)	1 (100.0)	10 (100.0)
Fire				
No_Traces	5 (100.0)	4 (100.0)	1 (100.0)	10 (100.0)

Table 3.6. Technological attributes frequencies by raw materials for the Solutrean sample. Percentages are shown in parentheses.

	Chert	**Quartz**	**Chalcedony**	**Total**
Blank				
CompleteFlake	4 (16.7)	7 (33.3)	2 (50.0)	13 (26.5)
FlakeFragment	20 (83.3)	14 (66.7)	2 (50.0)	36 (73.5)
Non_identifiable	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
AxisCoincident				
No	15 (62.5)	12 (57.1)	2 (50.0)	29 (59.2)
Yes	9 (37.5)	9 (42.9)	2 (50.0)	20 (40.8)

CrossSection				
Other	1 (4.2)	1 (4.8)	0 (0.0)	2 (4.1)
Rectangular	4 (16.7)	3 (14.3)	0 (0.0)	7 (14.3)
Trapezoidal	8 (33.3)	12 (57.1)	3 (75.0)	23 (46.9)
Triangular	11 (45.8)	5 (23.8)	1 (25.0)	17 (34.7)
SideSection				
Elliptical	3 (12.5)	4 (19.0)	0 (0.0)	7 (14.3)
Irregular	3 (12.5)	1 (4.8)	1 (25.0)	5 (10.2)
Rectangular	2 (8.3)	4 (19.0)	1 (25.0)	7 (14.3)
Semi_Circular	2 (8.3)	5 (23.8)	0 (0.0)	7 (14.3)
Trapezoidal	9 (37.5)	3 (14.3)	2 (50.0)	14 (28.6)
Triangular	5 (20.8)	4 (19.0)	0 (0.0)	9 (18.4)
Profile				
Straight	24 (100.0)	21 (100.0)	4 (100.0)	49 (100.0)
BlankShape				
Biconvex	0 (0.0)	1 (4.8)	0 (0.0)	1 (2.0)
Circular	2 (8.3)	1 (4.8)	0 (0.0)	3 (6.1)
Converging	1 (4.2)	3 (14.3)	1 (25.0)	5 (10.2)
Irregular	6 (25.0)	3 (14.3)	1 (25.0)	10 (20.4)
Other	2 (8.3)	0 (0.0)	0 (0.0)	2 (4.1)
Parallel	13 (54.2)	13 (61.9)	2 (50.0)	28 (57.1)
Cortex				
<25%	1 (4.2)	0 (0.0)	0 (0.0)	1 (2.0)
>95%	1 (4.2)	1 (4.8)	0 (0.0)	2 (4.1)
25-50%	4 (16.7)	0 (0.0)	0 (0.0)	4 (8.2)
No_Cortex	18 (75.0)	20 (95.2)	4 (100.0)	42 (85.7)
ButtType				
Absent	22 (91.7)	21 (100.0)	4 (100.0)	47 (95.9)
Flat	2 (8.3)	0 (0.0)	0 (0.0)	2 (4.1)
Retouch				
No	23 (95.8)	21 (100.0)	4 (100.0)	48 (98.0)
Yes	1 (4.2)	0 (0.0)	0 (0.0)	1 (2.0)
Fire				
Burnt	1 (4.2)	0 (0.0)	1 (25.0)	2 (4.1)
No_Traces	23 (95.8)	21 (100.0)	3 (75.0)	47 (95.9)

Table 3.7. Technological attributes frequencies by raw materials for the Magdalenian sample. Percentages are shown in parentheses.

	Chert	**Quartz**	**Total**
Blank			
FlakeFragment	2 (100.0)	3 (100.0)	5 (100.0)
Non_identifiable	0 (0.0)	0 (0.0)	0 (0.0)
AxisCoincident			
No	0 (0.0)	2 (66.7)	2 (40.0)
Yes	2 (100.0)	1 (33.3)	3 (60.0)
CrossSection			
Rectangular	0 (0.0)	2 (66.7)	2 (40.0)
Trapezoidal	1 (50.0)	0 (0.0)	1 (20.0)
Triangular	1 (50.0)	1 (33.3)	2 (40.0)
SideSection			
Elliptical	1 (50.0)	0 (0.0)	1 (20.0)
Semi_Circular	0 (0.0)	1 (33.3)	1 (20.0)
Trapezoidal	0 (0.0)	1 (33.3)	1 (20.0)
Triangular	1 (50.0)	1 (33.3)	2 (40.0)
Profile			
Straight	2 (100.0)	3 (100.0)	5 (100.0)
BlankShape			
Circular	0 (0.0)	1 (33.3)	1 (20.0)
Converging	0 (0.0)	1 (33.3)	1 (20.0)
Irregular	1 (50.0)	0 (0.0)	1 (20.0)
Parallel	1 (50.0)	1 (33.3)	2 (40.0)
Cortex			
No_Cortex	2 (100.0)	3 (100.0)	5 (100.0)
ButtType			
Absent	2 (100.0)	3 (100.0)	5 (100.0)
Retouch			
No	2 (100.0)	3 (100.0)	5 (100.0)
Fire			
No_Traces	2 (100.0)	3 (100.0)	5 (100.0)

As in other classes of stone tools, scaled pieces' metric attributes are impacted by both the initial blank size as well as by the intensity of their use. Specifically, because some scaled pieces are used in multiple axes, direct comparisons for length and width of the typological axes cannot be straightforwardly performed. Since the majority of the analyzed pieces presented a rectangular outline, we use the area of a rectangle (i.e. typological Length x Width) as an approximation for the overall dimensions of the artifacts. Area calculations revealed a maximum of 1082.03 mm^2 and a minimum of 94.86 mm^2. For thickness the maximum is 28.81 mm and the minimum is 2.79 mm. In general, mean values tend to be similar between raw materials, with some differences occurring within the Proto-Solutrean and Magdalenian assemblages, most certainly as a result of the small samples analyzed for each of these periods (Fig. 2). Across techno-complexes, however, no significant statistical differences were detected when using an ANOVA test for both Area (F (3, 132) = 1.1761119, p = 0.3213952, d = 0.1634926), and Thickness (F (3, 134) = 1.6205801, p = 0.1875711, d = 0.1904774).

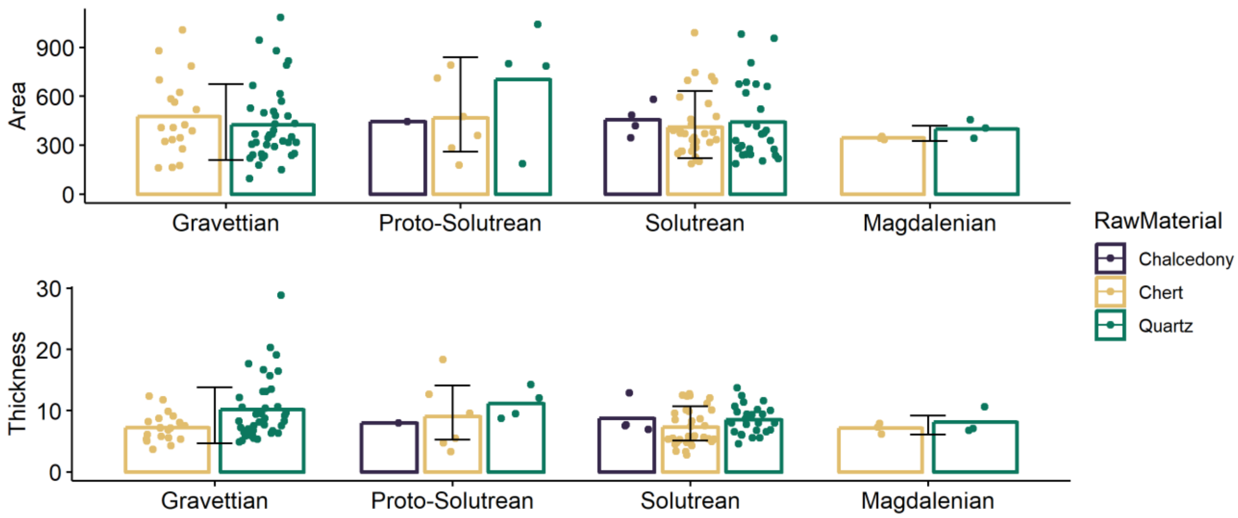


Figure 3.2. Barplots of means for Area (Length x Width) and Thickness of scaled pieces, by raw material and across the four chronological phases. Error bars represent standard deviations.

The patterns of use and rotation of damaged platforms seem to be the same across all chronologies. In every assemblage quartz pieces were exclusively used in one single axis, exhibiting only two damaged platforms. On the other end, a small number of chert and chalcedony artifacts (n = 12) exhibit multiple functional axis, with three or four damaged platforms (Fig. 3). This seems to indicate different strategies of curation for coarse (quartz) and fine grain (chert and chalcedony) raw materials, with fine grain materials being rotated when the first used axis becomes too small and/or the edges get useless for that specific activity. However, when plotted against metric data (Fig. 4), results for the Area variable reveal that pieces with four damaged platforms are among the largest in all assemblages, and that there is not a visible difference between the thicknesses of the pieces comprising each group. This seems to attest that the use of several axes in the same piece is not correlated with curation occurring in later phases of artifact use, but instead to a probable difference in raw material performance.

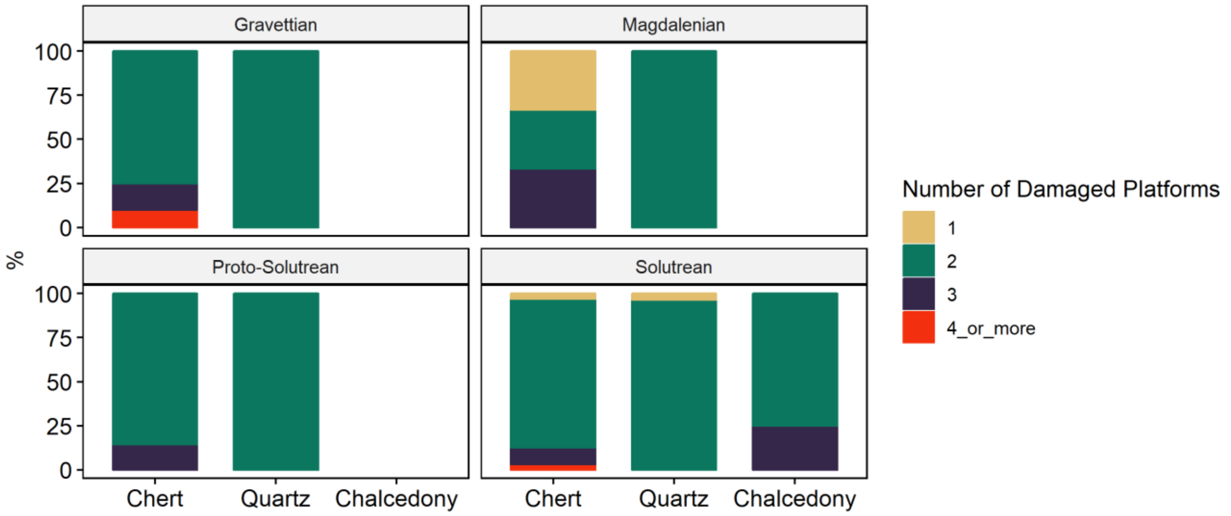


Figure 3.3. Number of damaged platforms by raw material and chronology.

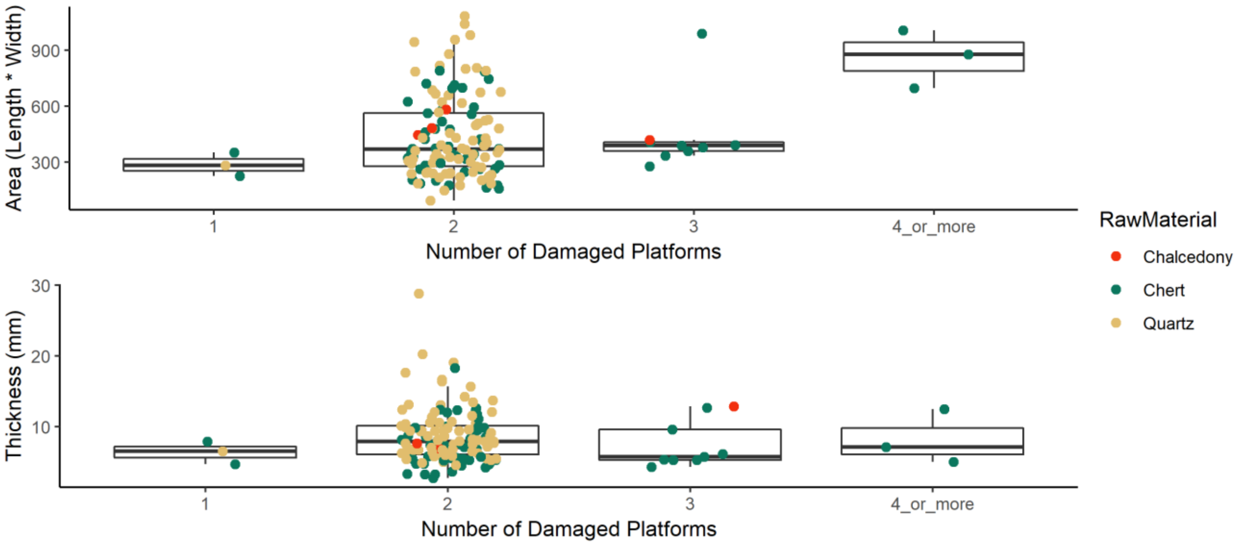


Figure 3.4. Boxplot of Area (Length x Width) and Thickness distribution for each raw material.

With few exceptions, most morpho-functional attributes show a fairly high degree of variability. Similarly to what was registered for the technological attributes, most differences occur between raw materials rather than between chronologies. For this reason the results presented below focus only on overall and between raw materials variability. Fig. 5 shows the relative frequencies of all qualitative variables recorded for each damaged platform. To simplify representation, and to avoid wrong comparisons between hammered and active platforms, opposed damaged platforms were grouped into pairwise categories. When present, the category 'Other' represents the cluster of attributes which frequency was less than 10% within each variable.

In three (Scar Arrangement, Scar Extension and Edge Delineation) of the six represented variables, the category 'Other' is one of the most frequent (above 35%) for both quartz and chert, revealing a very high variability for the combination of attributes within each variable. A chi-square test with modified alpha level (Bonferroni correction) to adjust for multiple testing and reduce type-I error, shows significant differences in the quartz and chert Scar Arrangement categories (X^2 [4, N = 127] = 22.94, p = < 0.001, *phi* = 0.43), and in Scar Faciality categories (X^2 [2, N = 127] = 11.94, p = 0.003, *phi* = 0.31). The effect size statistic (Phi) suggests, however, a medium practical significance for both variables.

For quartz artifacts the most common patterns are the combination of central/total scar distributions, both platforms with angles wider than 45º, and a combination of either unifacial/unifacial or unifacial/bifacial scar distribution. Chert pieces, on the other hand, more typically present opposed platforms with damage occupying the whole platform width, and a weaker presence of unifacial/unifacial scar edge facial distribution. Still, with exception of Angle and Scar Facial Distribution, the overall trend for the morpho-functional variables is one of high variability, with a very large set of combinations appearing at very low frequencies.

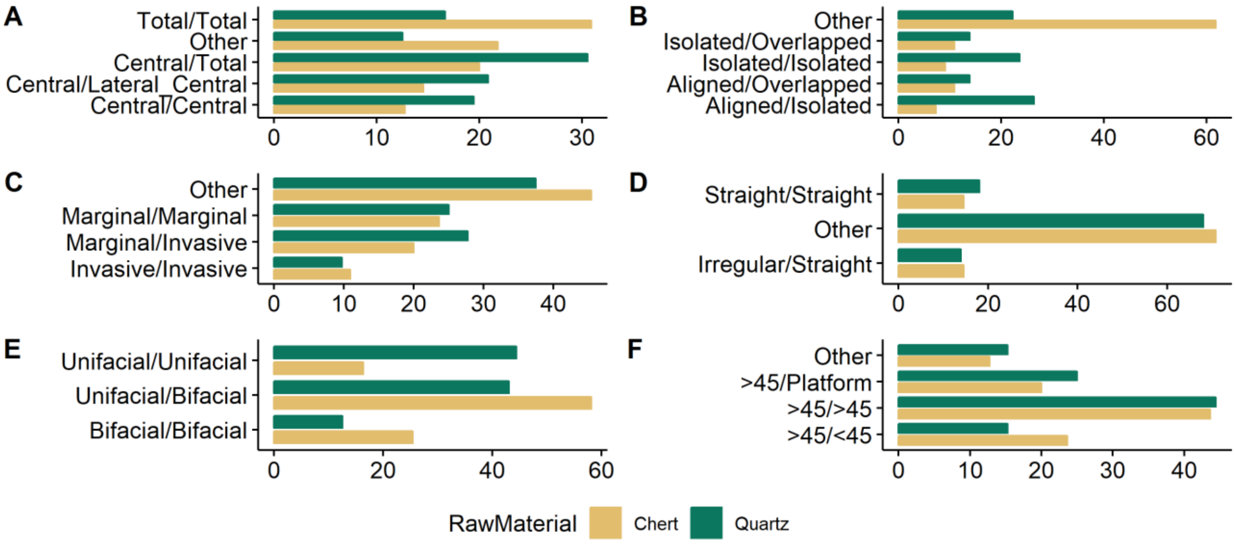


Figure. 3.5 Frequency of morphological attributes for each raw material. Opposed damaged platforms were grouped so that each artifact was only counted once and to avoid wrong comparisons between active *and* hammered platforms. A - Distribution of damage; B - Arrangement of scars; C - Extension of scars; D - Delineation of damaged platforms; E - Facial distribution of scars; F - Angle of damaged platforms.

To identify possible patterns of association among the qualitative variables used in our analysis, a Multiple Correspondence Analysis (MCA) was performed. In this analysis, raw material was used as a qualitative supplementary variable.

The first two dimensions of the MCA express 20.92% of the total dataset inertia, meaning that only that percentage of the total variability is explained by the plane combining the first two dimensions. An inspection of the screenplot presented in Fig. 6 suggests restricting the analysis to the description of the first 4 dimensions. These dimensions present an amount of inertia slightly greater than that obtained by the 0.95-quantile of random distributions (37.74% against 34.37%). Still, it is a rather small percentage, somehow attesting the high variability suggested by our interpretation of Fig. 5, and suggesting that patterns identified by previous studies (e.g. de la Peña 2015b, 2011), in which certain combinations of attributes were used to discriminate scaled pieces functionalities, are difficult to apply to the assemblage used in this study.

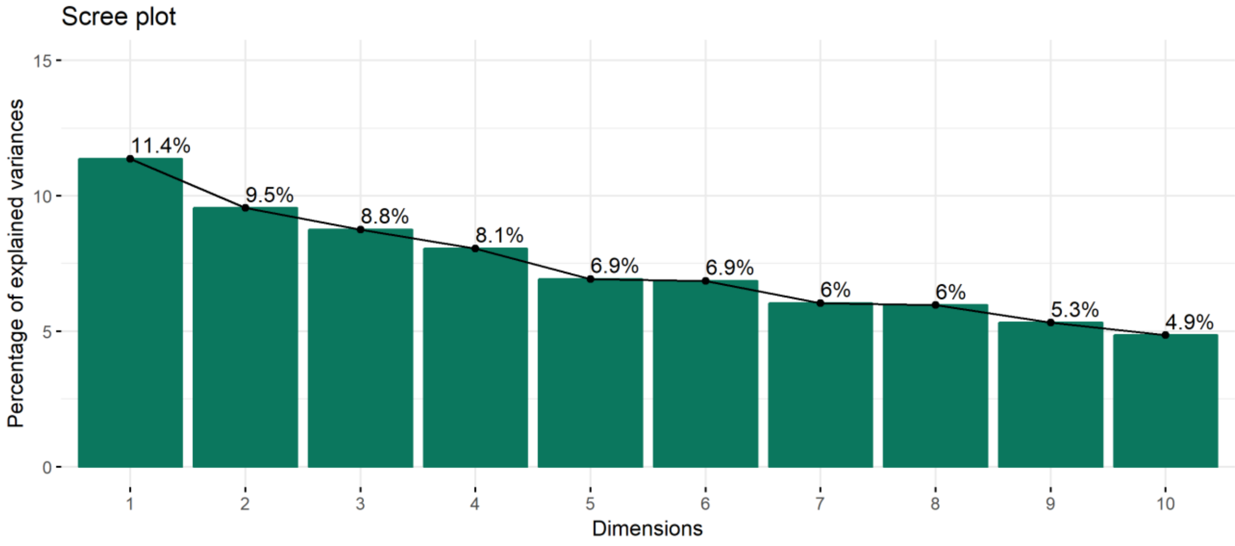


Figure 3.6. Multiple Correspondence Analysis screenplot.

3.5 Discussion and conclusions

Bipolar technology clearly had an important role on the adaptive systems of the first modern humans in Western Iberia, as well as in other European regions (see e.g. Villa et al. 2018; de la Peña 2011; Sano 2012; Zilhão 1997). In Europe there is a considerable rise in the use of bipolar technologies after the Middle to Upper Paleolithic transition, and some authors consider scaled pieces as one of the most common lithic morphotypes in European Upper Paleolithic assemblages (de la Peña 2011). A rise in bipolar technologies cannot be dissociated from the diverse set of factors that made Anatomically Modern Humans thrive. Changes in mobility patterns (Shott and Tostevin 2015), or the development of a "generalist specialist" ecological approach (Roberts and Stewart 2018), with particular emphasis on the diversification and intensification of resources use, are among some of those traits. It is in the context of this latter point that bipolar technology may have played a major role. In Vale Boi, since the earliest occupations at c. 32 ka cal BP, scaled pieces show up in the archaeological record connected to evidence related to an intensification and diversification of resource exploration, particularly the aforementioned grease/marrow obtention techniques. These have been shown by the constant presence of impact fractures in ungulate bones, low percentage of bone areas related to higher amounts of grease, and the presence of red deer bone fragments from bones with considerably higher marrow and grease contents (Manne 2010, 2014; Manne and Bicho 2009; Manne et al. 2012). Other indicators are both the constant presence of thermally altered quartz fragments that might be linked to stone boiling activities, and a large number of greywacke slabs with impact marks revealing their use as anvils (Cascalheira et al. 2017). For carcass processing and bone marrow extraction the use of scaled pieces would allow for a better control of bone fracture. In fact, this should be significantly better than using a hard hammer directly on the bone, since the latter technique may either over fracture the bone or even crush it due to the lack of precision. The use of a wedge for these activities provides more control, avoiding complete crushing of the bone, making it much easier to cleanly extract bone marrow.

In addition, scaled pieces in Vale Boi may also be associated to bone tool production, given that Vale Boi is one of the Portuguese Upper Paleolithic sites with significant evidence for onsite production and use of bone tools (Évora 2013). According to both Leblanc (1992) and Shott (1999) wedges are needed to work bone, antler, and wood, and stone wedges are preferable than other types of material. For hunter-gatherers, these artifacts would provide multifunctionality from a single piece that could be continuously used until losing their optimal morphological characteristics.

Importantly, our results show that the use of scale pieces at Vale Boi reveals techno-functional patterns that seem to stay fairly similar across all Upper Paleolithic horizons. One relevant trend is the fact that while quartz pieces were only explored in a single axis, chert pieces were, sometimes, explored in multiple axes. One possible reason for these patterns might be the fact that quartz would be more easily available than chert, and thus tool economy would have been different between both materials. Another possibility for this is the difference in the physical properties of each raw material. While with quartz it may be possible to continuously use a single axis in a piece, reducing it in only one axis without losing its efficiency, with chert it may be necessary to rotate it more often in order to continue obtaining usable edges. On the other hand, the higher number of axis could simply suggest that chert was differently managed and economized. Nevertheless, the simple fact that most of the pieces with multiple axes are on average larger than the rest, suggests that this hypothesis is likely incorrect. From an economic standpoint, the ideal would be to continuously use the same piece without any risk of loss of the features that made it ideal for this kind of use. Throughout the use of these pieces, they suffer successive violent blows, even the platform that rests on a surface suffers some sort of heavy impact. In this specific case, we argue that there is little to no control on how the piece's features change over its lifetime use.

Several researchers argued that scaled pieces were used as cores for the extraction of chips or small bladelets (e.g. Carvalho 1998; de la Peña 2011; LeBlanc 1992; Shott 1989, 1999; Zilhão 1997). Based on our data we find that this concept does not seem to fit in Vale Boi. First, with the single exception of the early Gravettian (during which very small backed bladelets are present - see Marreiros et al. 2018), the site's technology shows no evidence of manufacture or use of tools with such small dimensions as the ones recorded from the scars of scaled pieces (5-8 mm). Second, although the most common interpretation is that these chips/bladelets would be inserted in composite throwing tools, there is no evidence of bone or antler tools with grooves that might be used for the insertion of stone implements even though Vale Boi has a very rich assemblage of organic tools (Évora 2013). However, we still do not discard the hypothesis that these may have been made from perishable organic materials. Third, although previous ethnographic studies(e.g. Flenniken 1981; Shott 1989) support the use of small flakes, bladelets and chips for these types of implements and other activities such as scraping, boring and cutting, we currently have no data that can support this hypothesis at the site. Finally, as previously mentioned, Vale Boi stone tool technological analyses revealed that every phase of the chaîne operatoire is present, which means that knapping was mostly occurring at the site, which is attested by the high number of chips found. Considering that most knapping activities originate chipage, the need of a specific tool for the sole purpose of extracting them does not seem viable. By putting all these factors in context, the hypothesis that these pieces were used for carcass processing, bone marrow extracting (Manne et al. 2012) and other similar activities, such as working hard, organic materials with the goal of producing tools seems, thus far, to be the most reasonable interpretation. The use of scaled pieces as wedges would allow for further enhancement of the effectiveness of these activities and has been identified in modern human occupations all over the world (Igreja and Porraz 2013; Langejans 2012; LeBlanc 1992; Sano 2012; Shott 1989). In fact, this technique would be extremely useful in periods of greater environmental stress and in periods when communities needed higher mobility. Despite this, we do not discard the possibility that some scaled pieces might have been used for bipolar reduction strategies. In addition to the amount of stone anvils at the site, bipolar cores are also present across all techno-complexes (Cascalheira 2010; Marreiros 2009). There may even be the case that blanks from bipolar cores were transformed into scaled pieces by using them for further bipolar or wedging activities. Unfortunately, due to the nature of the damage present in scaled pieces this is a very hard point to prove. Still, open hypotheses clearly attest the value and versatility of bipolar technologies for early modern human groups in the region.

Taking this into consideration, in Table 3.8 we present current data on Upper Paleolithic bipolar technology in Portugal. It is important to note that aside from Vale Boi, all scaled pieces and bipolar cores counts in this table were made according to each author's typological definitions and classifications, and not the ones we propose for this paper. Although the number of scaled pieces and bipolar cores is considerably low in most of the sites, a significant number of *loci* present some kind of bipolar technology evidence. Moreover, it is clear a discrepancy when comparing the presence of scaled pieces versus bipolar cores, the latter being well under represented than the first. It is also clear that scaled pieces show on average a higher representation in Vale Boi's assemblages than on most other sites. Further, of the three bipolar cores in all sites, two of these come from Vale Boi. While currently there are no definitive data on the representation of scaled pieces within the retouched tool assemblage of the Slope area, it is fairly safe to assume that it should be a particularly high value.

Table 3.8. Frequencies of scaled pieces and bipolar cores in Portuguese Upper Paleolithic sites.

Chronology	**Sites**	**Scaled Pieces (N)**	**Scaled Pieces (%)**	**Bipolar Cores (N)**	**Bipolar Cores (%)**	**Total (%)**	**Source**
Gravettian	Casal do Felipe	12	5.91	0	0.0	2.33	Zilhão (1997)
Gravettian	CPM III	1	0.81	0	0.0	0.19	Zilhão (1997)
Gravettian	Fonte Santa	105	12.49	0	0.0	20.43	Zilhão (1997)
Gravettian	Gato Preto	3	3.13	0	0.0	0.58	Zilhão (1997)
Gravettian	Gruta do Caldeirão	1	11.11	0	0.0	0.00	Zilhão (1997)
Gravettian	Salto do Boi – Cardina I	1	2.7	0	0.0	0.19	Zilhão (1997)
Gravettian	Vale Boi - Terrace	12	37.5	1	0.0	2.33	Cascalheira (2009); Marreiros (2009)
Gravettian	Vale Boi – Slope	59	NA	0	0.0	11.48	Horta, 2016
Gravettian	Vale Comprido - Barraca	10	2.6	0	0.0	1.95	Zilhão (1997)

Gravettian	Vales da Senhora da Luz	1	0.32	0	0.0	0.19	Zilhão (1997)
Proto-Solutrean	Terra do José Pereira	4	1.91	0	0.0	0.78	Zilhão (1997)
Proto-Solutrean	Terra do Manuel (1940-1942)	9	1.03	0	0.0	1.75	Zilhão (1997)
Proto-Solutrean	Terra do Manuel (1988-1989)	1	2.13	0	0.0	0.19	Zilhão (1997)
Proto-Solutrean	Vale Boi Slope	13	?	0	0.0	2.53	Horta (2016)
Proto-Solutrean	Vale Comprido - Encosta	9	0.9	0	0.0	1.75	Zilhão (1997)
Solutrean	Casal do Cepo	6	1.43	0	0.0	1.17	Zilhão (1997)
Solutrean	Gruta de Salemas II	1	1.69	0	0.0	0.19	Zilhão (1997)
Solutrean	Gruta de Salemas UP Mixed	1	1.16	0	0.0	0.19	Zilhão (1997)
Solutrean	Lagar Velho 09	1	3.45	0	0.0	0.19	Zilhão (1997)
Solutrean	Vale Almoinha	26	5.9	0	0.0	5.05	Zilhão (1997)
Solutrean	Vale Boi Rockshelter	24	11.7	1	2.3	4.67	Marreiros (2009)
Solutrean	Vale Boi Terrace	5	13.51	0	0.0	0.97	Cascalheira (2009)
Solutrean	Vale Boi Slope	66	NA	0	0.0	12.84	Horta (2016)
Magdalenian	Areeiro I	8	4	0	0.0	1.56	Bicho (2000)
Magdalenian	Areeiro III área 1	16	2.9	0	0.0	3.11	Bicho (2000)
Magdalenian	Areeiro III área 2	10	2.9	0	0.0	1.95	Bicho (2000)
Magdalenian	Areeiro Teste	6	1.4	0	0.0	1.17	Bicho (2000)
Magdalenian	Carneira I	2	0.35	0	0.0	0.39	Zilhão (1997)
Magdalenian	Carneira II	17	9.9	1	4.3	3.31	Bicho (2000)
Magdalenian	Cerrado Novo	5	0.93	0	0.0	0.97	Bicho (2000)
Magdalenian	CPM I Inferior	1	0.5	0	0.0	0.19	Zilhão (1997)

Magdalenian	CPM I Superior	18	1.2	0	0.0	3.50	Bicho (2000)
Magdalenian	CPM II Middle	4	3.4	0	0.0	0.78	Bicho (2000)
Magdalenian	CPM II Superior	2	1.1	0	0.0	0.39	Zilhão (1997)
Magdalenian	CPM IIIS	5	1.3	0	0.0	0.97	Bicho (2000)
Magdalenian	CPM III Superior	2	1.1	0	0.0	0.39	Bicho (2000)
Magdalenian	CPM V	2	1.3	0	0.0	0.39	Bicho (2000)
Magdalenian	Olival da Carneira	3	1.11	0	0.0	0.58	Zilhão (1997)
Magdalenian	Pinhal da Carneira	2	1	0	0.0	0.39	Bicho (2000)
Magdalenian	Quinta da Barca	9	10.23	0	0.0	1.75	Bicho (2000)
Magdalenian	Quinta da Barca Sul	22	42.31	0	0.0	4.28	Bicho (2000)
Magdalenian	Quinta da Granja	3	13.04	0	0.0	0.58	Bicho (2000)
Magdalenian	Rossio do Cabo	1	1.14	0	0.0	0.19	Zilhão (1997)
Magdalenian	Vale da Mata	6	0.45	0	0.0	1.17	Zilhão (1997)

Bipolar technology is quite common in Upper Paleolithic contexts of Western Iberia, but current interpretations are based on empirical observations, rather than on more solid analytical evidence. This, of course, stems in part from the lack of dedicated studies on bipolar technology in the region, an issue that can be also argued to be true for all of the European Upper Paleolithic. We argue that all factors mentioned in this study must be considered while interpreting each site in this region. While in Vale Boi there is clear evidence that the use of these artifacts would not be primarily for bipolar knapping, in other sites the picture may be different.

As our results show, the low presence of bipolar cores is quite evident in these sites, while scaled pieces are more often present. It can also be argued that the number of pieces in the overall picture is also low, although presenting an accurate picture for each site since most of these sites have been extensively studied.

Higher degrees of representation of scaled pieces in sites can be originated by factors such as site function, but also by cultural patterns. Regarding site functionality, if we look at the *loci* with higher counts of scaled pieces (Vale Boi's Terrace and Slope and Fonte Santa), all are open-air residential sites. One example outside of this region is the Magdalenian site of Gönnersdorf in Southwestern Germany, where according to Sano (2012) scaled pieces were the second most frequent tool types within the site's retouched tools assemblage (257 from a total of 1501 utensils, corresponding to c. 17,12%). This frequency is as high as both Vale Boi's and Fonte Santa's, and like both of these sites Gönnersdorf is an open-air residential site. However, these data can be misleading, as Casal do Felipe (5,91%), Terra do Manuel 1940-42 (1,03%), Terra do Manuel 1988-89 (2,13%) and Vale Comprido – Encosta (0,9%) are also open-air multifunctional sites with much smaller representations of scaled pieces.

It seems reasonable that scaled pieces should be linked mostly with residential sites since the activities for which they are applied are conducted in a residential scenario rather than a hunting station, quarry, workshop or temporary shelter. While we cannot fully discard the fact that scaled pieces can be used as a single representation of site functionality, they can be a tool for such ends, as argued by Jeske and Sterner-Miller (2015). We, thus, argue that in this region, bipolar technology in the Upper Paleolithic may be also linked to cultural traditions rather than just simply functional ones. By considering that most sites aforementioned show similarities from a functional, chronological, faunal, floral and climate standpoints, there is no clear reason for the presence of different relative numbers of scaled pieces at each site other than a combination of both cultural and functional patterns.

Chapter IV

INTENSIVE AND EXPEDIENT RESOURCE EXTRACTION STRATEGIES THROUGH THE FLEXIBLE USE OF LITHIC BIPOLAR METHODS IN EARLY AURIGNACIAN OF ABRI PATAUD

Pedro Horta[a] & Laurent Chiotti[b]

[a] *Interdisciplinary Centre for Archaeology and the Evolution of Human Behaviour, Universidade do Algarve, Faro, Portugal*

[b] *Muséum National d'Histoire Naturelle, Département Homme et Environnement, UMR 7194 HNHP du CNRS, Abri Pataud, 20 Rue Du Moyen-âge, Les Eyzies-de-Tayac, FR-24620, France*

Corresponding author: Pedro Horta (*pehorta@ualg.pt*)

Abstract

The strategies that drove *Homo sapiens'* successful survival and settlement in Europe have been a longstanding question in Human Evolution studies. The appearance of the Aurignacian industry is considered to be one of the first manifestations of these groups' settlement in Western Europe. One particularity that the Aurignacian shares with all other Upper Paleolithic industries is the considerable representation of lithic bipolar technology compared to prior industries in this region.

In this paper we analyze the bipolar technology of the Aurignacian occupations of Abri Pataud. By exploring the technological, functional and cultural use of bipolar technology during the Aurignacian occupations of the site, we aim to provide new data on how this technology contributed to the adaptation and settlement of *Homo sapiens* in this region.

Our results show that *Homo sapiens* were flexibly using bipolar methods as means of resource extraction at the site. While bipolar methods were mostly used for wedging, for working hard organic materials these were used in different levels of intensity. In the earliest occupation there is a clear choice and intensive use of wedges until depletion, with the goal of maximizing both each tool's potential and resource extraction. On the other hand, in later occupations, When the shelter used as a short-term camp, bipolar methods were used as a quick and expedient way of working organic materials or even

producing flakes. Tools were chosen, used and abandoned early on. While bipolar methods are often linked to contexts of: (1) raw material conservation, intensive resource extraction strategies, etc.; (2) or even expedient resource extraction strategies; our results suggest the understanding of the flexible advantages of these methods was present in technological traditions of Aurignacian groups. This work presents insights on how the understanding of the flexibility of the use of bipolar methods played a strategic role on the adaptation and settlement of *Homo sapiens* across Western Europe.

4.1. Introduction

The successful dispersal of *Homo sapiens* across Western Europe is accompanied by the emergence of the Aurignacian industry (Chu and Richter, 2019). A predecessor to the Gravettian and a successor to transitional industries like the Châtelperronian and the Middle Paleolithic Mousterian industries the Aurignacian marks some of the earliest blade technologies in this region (Bar-Yosef and Zilhão, 2006; Chu and Richter, 2019). In addition, this industry is well known for its art, personal ornamentation and bone technology (e.g. Hahn 1986; White 1995; Conard 2009; Tartar 2012). One particularity that early upper Paleolithic industries including the Aurignacian share is a considerable representation of bipolar technology compared to prior industries (e.g. Chiotti 2005; Tsanova 2006; de la Peña 2011; Peresani et al. 2016, 2019; Villa et al. 2018; Horta et al. 2019; Haws et al. 2020).

The term bipolar technology refers to two possible activities/techniques these are: bipolar knapping (meaning core reductions on an anvil) or wedging/chiseling activities (using stone tools as intermediate tools for working organic materials, such as bone, wood and antler) (Octobon, 1938; Leaf, 1979; Hayden, 1980; Shott, 1989, 1999; LeBlanc, 1992; de la Peña, 2011; Langejans, 2012; Bader et al., 2015; Horta et al., 2019). Both of these activities due to compression of forces originate damage in two opposite ends of stone tools, the one that is hammered (active) and the one (passive) that is supported on the anvil (regardless of which it is a stone anvil or an organic surface) (Paloma de la Peña, 2015b). While mechanically both activities lead to similar damage on stone tools their goal is completely distinct. In bipolar knapping the goal is to extract blanks from a core and in the wedging/chiseling the goal is to work the “anvil” material by controlling its shape and fracturing (e.g., rib splitting, bone marrow extraction, bone shaping, wood splitting, etc.(Shott, 1989; LeBlanc, 1992; de la Peña, 2011; Horta et al., 2019).

In assemblages, bipolar knapping can be found in the form of bipolar cores and bipolar blanks, while wedging is often attributed to splintered pieces (also referred to as scaled pieces or *pièces esquillées*). However, it has been argued that splintered pieces in addition to being used as wedges could also have been used as cores for small flakes and bladelets (Hayden, 1980a; Shott, 1989; LeBlanc, 1992; Paloma de la Peña, 2015c). Recent studies and the current body of evidence seems to suggest that either functional attribution can vary from site to site and should therefore be considered in the context of the site and its technology (LeBlanc, 1992; Lucas and Hays, 2004; Gilabert et al., 2015; Horta et al., 2019a; Kolobova et al., 2021).

Bipolar technology can be found in a wide array of chronological and ecological settings, making it so it's not considered an Age or industry (de la Peña and Wadley, 2014b). While bipolar technology was present in hominin toolkits as early as the Pliocene (Harmand et al., 2015a), in Europe this technology first emerges in Acheulean occupations (Arzarello and Peretto, 2010; Garcia et al., 2012; de Lombera-Hermida et al., 2015, 2016; Arzarello et al., 2016). Despite being present in several Acheulean and late Acheulean industries, the transition to the Middle Paleolithic is marked by a decline in the use of this technology. This is evident by the low number of Middle Paleolithic occupations with bipolar technology(e.g. (Moncel et al., 2005; Moncel and Daujeard, 2012; Márquez et al., 2013; Van Kolfschoten et al., 2015b; Ravon et al., 2016)), compared to the previous periods and the Upper Paleolithic (Tsanova, 2006; Gibaja and Bicho, 2011; Sano, 2012; de la Peña Alonso and Toscano, 2013; Bradtmöller et al., 2016; Peresani et al., 2016; Kandel et al., 2017; Villa et al., 2018; Horta et al., 2019). However, this data can be deceiving as per what types of bipolar technologies were present in these three chronological periods. While the lower and middle paleolithic bipolar technology is represented solely by bipolar knapping, the Upper Paleolithic combines bipolar knapping with wedging activities.

It has often been argued that splintered pieces are one of the most common artifact types found in Upper Paleolithic occupations in Europe (de la Peña, 2011). This is the case from the earliest Initial Upper Paleolithic occupations in Eastern Europe (Tsanova, 2006; Hublin et al., 2020) and across the Upper Paleolithic to the Holocene (Gibaja and Bicho, 2011; Gilabert et al., 2015; Horta et al., 2019). To an extent, bipolar cores are likewise common in Upper Paleolithic assemblages however in much lesser representation (Horta et al., 2019). In Western Europe particularly, bipolar technology has been argued to have had an important role in *Homo sapiens* adaptations through the intensification of resource exploitation strategies (Bicho et al., 2012; Cascalheira et al., 2017; Horta et al., 2019).

The Vézère valley of the Dordogne in southwestern France can be considered an important region to understand the arrival, settlement, survival and differences and similarities in adaptation strategies used by Neanderthals and *Homo sapiens*. Particularly due to the significant amount of Middle and Upper Paleolithic occupations found in this region. In this paper we analyze the bipolar technology of the Aurignacian occupations of Abri Pataud a site well known for its Aurignacian and Gravettian occupations (Movius Jr, 1966; Movius Jr and David, 1970; Chiotti et al., 2003; Chiotti, 2005; T. Higham et al., 2011; Douka et al., 2020). In this paper our goal is to explore the technological, functional and cultural use of bipolar technology during the Aurignacian occupations at the site and to provide new data on how this technology contributed to the adaptation and settlement of the first *Homo sapiens* in this region.

4.1.1 The site

Abri Pataud or the Pataud rock shelter is located in the Vézère valley of the Dordogne in southwestern France (Fig. 1). Situated in the village of Les Eyzies-de-Tayac, the site can be found at the base of a thirty-meter-high cliff, along the Vézère river between the famous Cro-Magnon rock shelter and the town’s medieval castle that currently houses the National Museum of Prehistory (Chiotti, 1999). The rockshelter is currently at approx. 75m above sea level and 20m from the bottom of the Vézère valley.

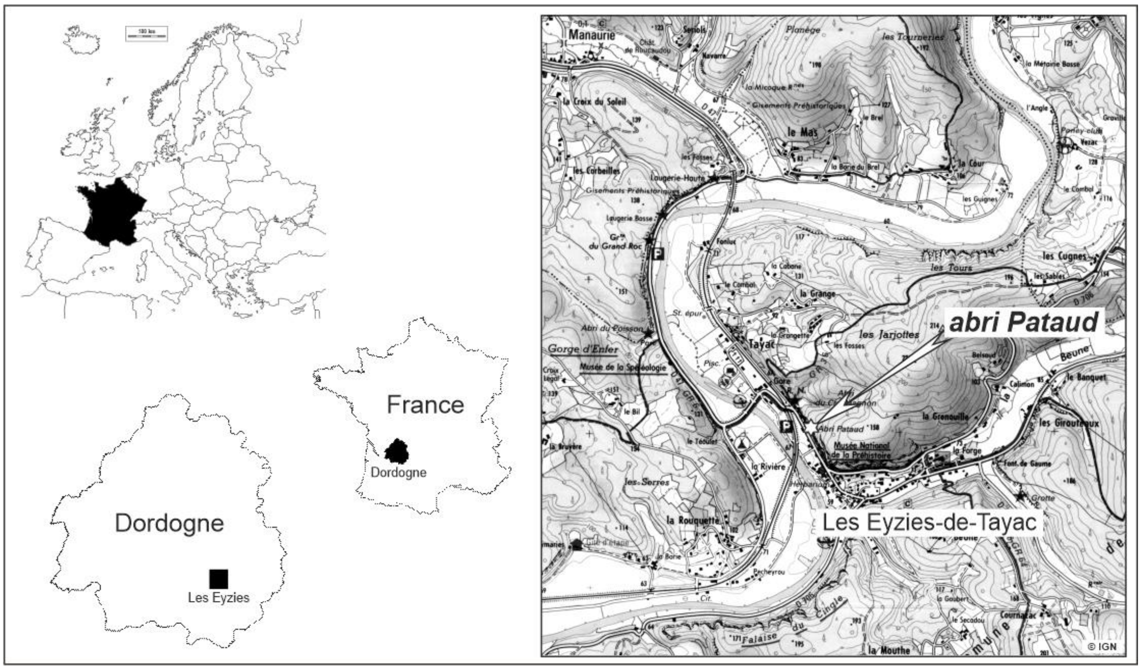


Figure 4.1. Site Location

Abri Pataud was initially discovered in the late ninetieth century, however the first excavation project would be later undertaken between 1958 and 1964 by Movius (Movius Jr, 1977). These excavations were carried out in a meticulous manner and uncovered a complete Upper Paleolithic sequence comprised of Aurignacian, Gravettian and Solutrean levels. The Aurignacian sequence includes a total of 9 levels ranging from level 14 to level 6. Levels 14 to 9 have been attributed to the Early Aurignacian (EA) or Aurignacian I dating to c. 40-38 ka cal BP (Chiotti, 2005; T. Higham et al., 2011). Levels 8-6 have been attributed to the Evolved Aurignacian (EvA) or Aurignacian II with dates ranging from c. 37.5 to35k cal BP (Chiotti, 2005; T. Higham et al., 2011).

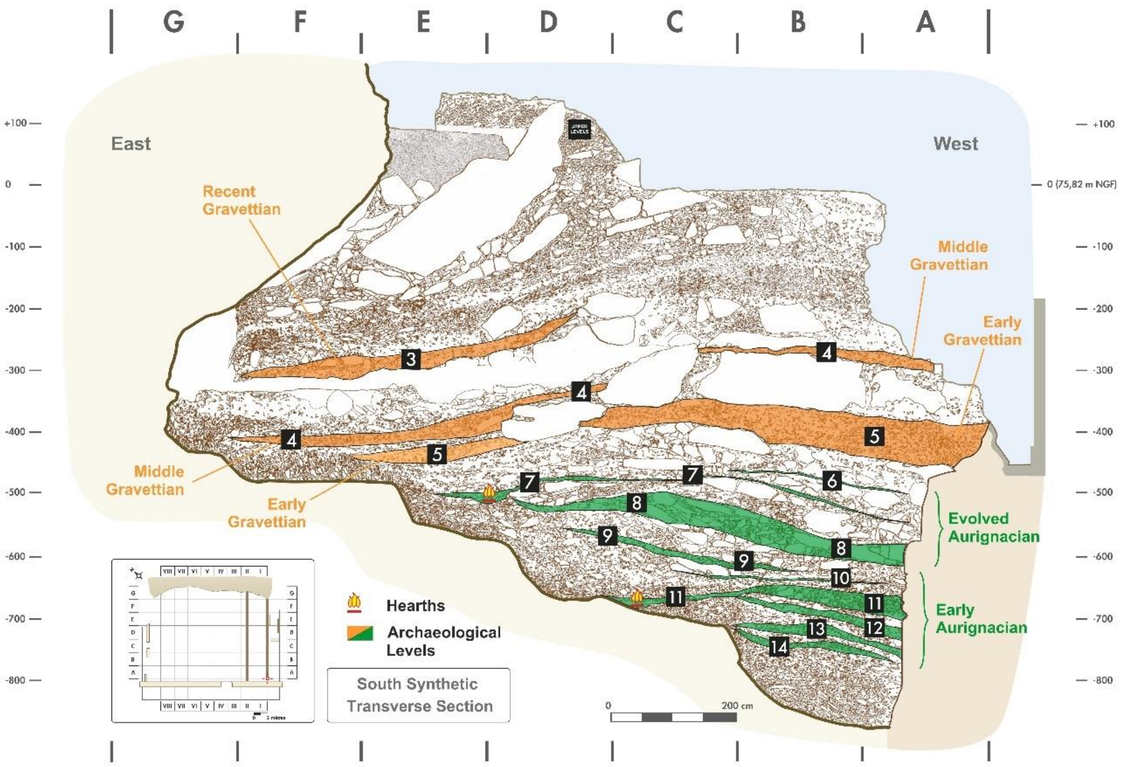


Figure 4.2. Abri Pataud's southern section stratigraphy.

The EA initial occupation (Level 14) seems to have occurred during a cold moment in which reindeer dominate in the faunal spectrum (percentages ranging from 98.7%) (Chiotti, 2005; Agsous, 2008; T. Higham et al., 2011). Subsequent levels (13-11) and occupations seem to have occurred during H4 climactic event a period also dominated by reindeer representation (98.7-71%) (Chiotti, 2005; Agsous, 2008; T. Higham et al., 2011). The final moments of the EA (10-9) seem to be linked to the GIS8 with very poor faunal preservation (Chiotti, 2005; Agsous, 2008; T. Higham et al., 2011). Technologically, this period is marked by high proportions of flake debitage through a variety of reduction sequences from locally sourced flint (Chiotti, 1999, 2005). These range from prismatic, globular, and irregular cores to the less frequent discoidal, non-typical Levallois and cores-on-flakes (Chiotti, 2002, 2005, 2012). The goal seems to have been the production of flakes as tool blanks, as this period is marked by a predominance of carinated scrapers and retouched blades (including Aurignacian blades). Level 14, is particular due to its high ratio of laminar tools compared to all the levels altough the on-site debitage is directed towards flake production (Chiotti, 2005). It is hypothesized that this period is marked initially by a longer occupation in level 14 due to the technological variety of the occupation containing all the characteristic tool types of the Early

Aurignacian phase (Chiotti, 2005). However, in the remaining levels there seems to be a succession of short-term occupations (Chiotti et al., 2003), evident due to isolated finds of blades produced off-site, low tool laminar indexes and predominant flake production. Percentages of the presence of bipolar technology in this period range from 8.27-2.3% of formal tools with an average of 5.4% of representation.

The beginning of the EvA is marked by GIS 8 and a wide variety of species being represented in the fauna assemblages (T. Higham et al., 2011). Small mammals, birds, and amphibians, seem to be most common, with a lower representation of large mammals. When present, these include red deer, reindeer, wild boar, bison and horse (T. Higham et al., 2011). Technologically, as with the EA the EvA is marked by the predominance of flake production with representations ranging from 82-70.93% of blanks from locally sourced flint (Chiotti, 1999, 2005). Core reduction strategies are similar to the EA with the predominance of prismatic cores. A far as formal tools are concerned level 8 is dominated by scrappers with the presence of Dufour bladelets of the Roc de Combe subtype (Chiotti, 2005). Level 7 is comprised by the dominance of burins busqués (Chiotti, 2005), and level 6 is attributed to the Aurignacian III and IV technocomplexes (Chiotti, 2005). Percentages of the presence of bipolar technology in this period range from 2.5-1% of formal tools with an average of 1.6% of representation.

4.2 Materials and Methods

All lithic artifacts recovered from the Aurignacian levels of Abri Pataud that fit the definitions of splintered piece and bipolar core (see Horta et al. 2019) were considered for this study, independent of raw material or technological class. A total of 163 artifacts were separated and analyzed by adapting Horta et al. (2019) methods. In addition to splintered pieces, both bipolar cores and blanks (often called bipolar flakes) were also identified and analyzed. Due to their different nature these three groups were analyzed in a different matter although with some overlap.

Bipolar cores (Table 4.1) and blanks, were analyzed based on attributes recorded in traditional lithic studies (Tixier and Inizian, 1983; Andrefsky, 1998). Splintered piece attribute analysis was carried out adapting Horta et. al, (2019) by splitting variables into two main groups, each corresponding to two distinct types of features present on the tools: (1) technological attributes and (3) morpho-functional attributes. Technological attributes analyzed were a series of variables traditionally used in lithic studies (Tixier and Inizian, 1983; Andrefsky, 1998). Likewise, for the morpho-functional attributes, a macroscopic approach was used adapting (de la Peña, 2011; Horta et al., 2019). For this group specifically, we added the "fracture" variable due to the constant presence of fractured artifacts. Despite fragmentation patterns at the site having been previously discussed (Chiotti, 1999, 2005) we found recurring types of fractures that are only present in these artifacts. Previous studies have suggested that these fractures represent the final stage of reduction of wedging activities (Tixier, 1963; Kolobova et al., 2021).

As in Horta et. al, (2019) in addition to these analyses our approach hoped to find patterns in the combination of attributes in some artifacts that would point to splintered piece's function. Theoretically and following previous authors (de la Peña, 2011; Paloma de la Peña, 2015b) artifacts used as cores would have different combinations of attributes than artifacts used as wedges. For this they recurred to descriptive and multivariate statistical analysis. However, due to the extremely high variability in attributes they could not find such patterns. In similar fashion, in a recent publication Kolobova et al. (Kolobova et al., 2021), used Shapiro-Wilk tests, Pearson's correlation coefficient, Spearman's rank correlation coefficient (for abnormally distributed samples) in addition to calculating the coefficient of determination (r2), in order to understand splintered piece reduction sequences. Likewise, they found high variability and little to no patterning in different stages of reduction sequences. Their results showed that experimental splintered pieces who suffered a larger number of blows would be consistently smaller in length and width than others. This of course, is a pattern that is to be expected and of difficult application when translated onto the archaeological data where the original size of the blanks is unknown. For these reasons and the low number of artifacts per occupation we opted not to pursue statistical approaches and use traditional descriptive analyses.

Overall and following our methodology we expected to identify patterns depending on the type of artifact. For splintered pieces we expected to find patterns in blank choice, insights into the type of use and possible reduction sequences. For the bipolar cores and blanks we expected to find patterns in technological attributes that would point to the importance or expediency of this type of reduction strategy at the site.

Table 4.1. Technological attributes used for the analysis of bipolar cores included in this study.

Variable	**Variable name in database**	**Values**	**Observations**
Raw Material	RawMaterial	Flint	
Type of blank	Blank	Nodule	
		Free-hand Core	
		Flake	
		Pebble	
		Other	
		Non_Identifiable	
Length of the technological axis	TechnologicalAxisLength	mm	Same as axis of flaking in Debénath and Dibble (1994)
Width of the technological axis	TechnologicalAxisWidth	mm	Distance at a mid-point between two edges of the artifact, as measured perpendicularly to the technological length
Thickness	Thickness	mm	Measured at the intersection of the typological length and width
Weight		g	
Percentage of cortex	Cortex	No_Cortex	
		>25%	
		25-50%	
		50-95%	
		>95%	
Fire traces	Fire	Burnt	
		No_traces	
		Thermal-Treatment	
Bipolar reduction type	CoreType	Typical	Anvil Damage is visible on the main scarred faces
		Rested on anvil	Anvil damage is not visible on the main scarred face
Number of Core Faces	NumberCoreFaces	One	
		Two	
		Three	
		Four	
		MoreThanFour	
Core Platform Type	CorePlatform	Plain	
		Dihedral	
		Faceted	
		Cortical	
		Crushed	
		Other	

Core Abandonment	CoreAbandon	Hinge	
		Crushed Platform	
		Natural Imperfection	
		Fracture	
		Angle Loss	
		No Reason	
Type of Byproduct extracted	ByproductType	Flakes	
		Bladelets	
		Chips	
		Mixed	
Number of extracted Blanks	NumberByproduct	N	Number of blank scars
Maximum length of extracted Blanks	ByproductMAXLenght	mm	
Maximum width of extracted Blanks	ByproductMAXWidth	mm	

4.3 Results

From the combined Aurignacian levels of Abri Pataud, a total of 163 stone tools were identified as bipolar. Of which, 83.6% come from the EA levels and the remaining 16.4% from the EvA levels, as shown in Figure 4.3. Regarding artifact type representation in the EA sample, splintered pieces are the most common artifact type in both periods representing 78.8% of the assemblage, followed by bipolar blanks (11%), bipolar fragments (8%) and bipolar cores (2.2%). In the EvA sample only splintered pieces and bipolar blanks were identified of which the first represents a total of 96.2% of the sample while the latter is represented by a single artifact corresponding to 3.8% of the total sample. As seen in Figure 3, artifact representation also fluctuates in each period. During the EA artifact peaks coincide with the probably longer occupation of level 14 and subsequently levels 11 and 12, being lower in levels 13, 10 and 9. In the EvA there is a steady rise in artifact frequency from levels 8 through to level 6.

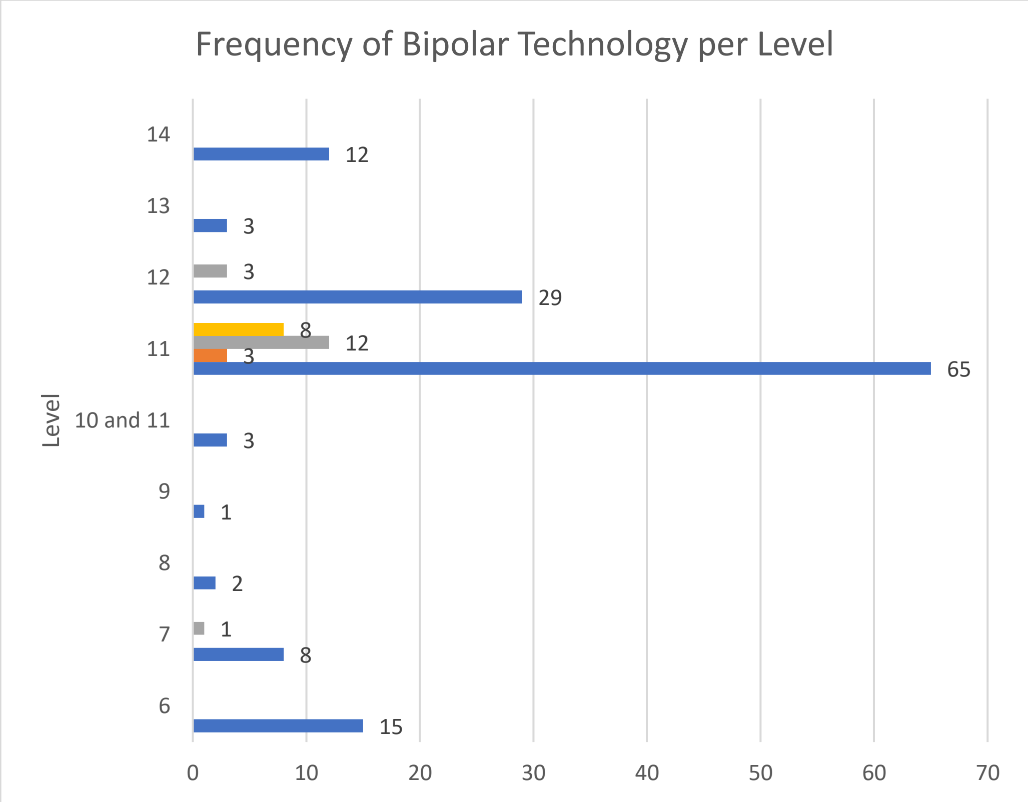


Figure 4.3. Frequency of bipolar technology per level

4.3.1 Bipolar Cores

Following Horta et al., (2019), we analyzed the technological data in order to understand the reduction sequences of bipolar cores and the subsequent attributes of bipolar blanks extracted from bipolar cores (Fig 4.4). Only 3 cores are present in the assemblage all recovered from the EA (Level 11, Fig 4.4). Two cores were formerly likely a nodule while the remaining core was a pebble. All cores are typical bipolar cores with evidence of being reduced on anvil with a 90º angle with traces of extraction of 4 or more flakes and some bladelets in the striking faces (Table 4.2). As seen in Table 4.2 two cores have cortical surfaces covering under 25% of the cores surface in one case and between 25-50% on the other. In addition, while two cores exhibit plain platform the other presents a crushed platform. Furthermore, two cores were reduced on only one striking platform, exhibiting a single core face while the other has two faces. Regarding metrics, the cores have lengths between 35-50mm (Fig 4.5A), widths between 24-38mm (Fig 4.5A), and thicknesses ranging between 14-21mm (Fig 4.5A). Regarding the blank scars observed in each core, their largest extractions ranged between 25-45mm in length and 14-31mm in width (Fig 5B). Lastly, the cores weight ranges from 30-44g (Fig 5C).

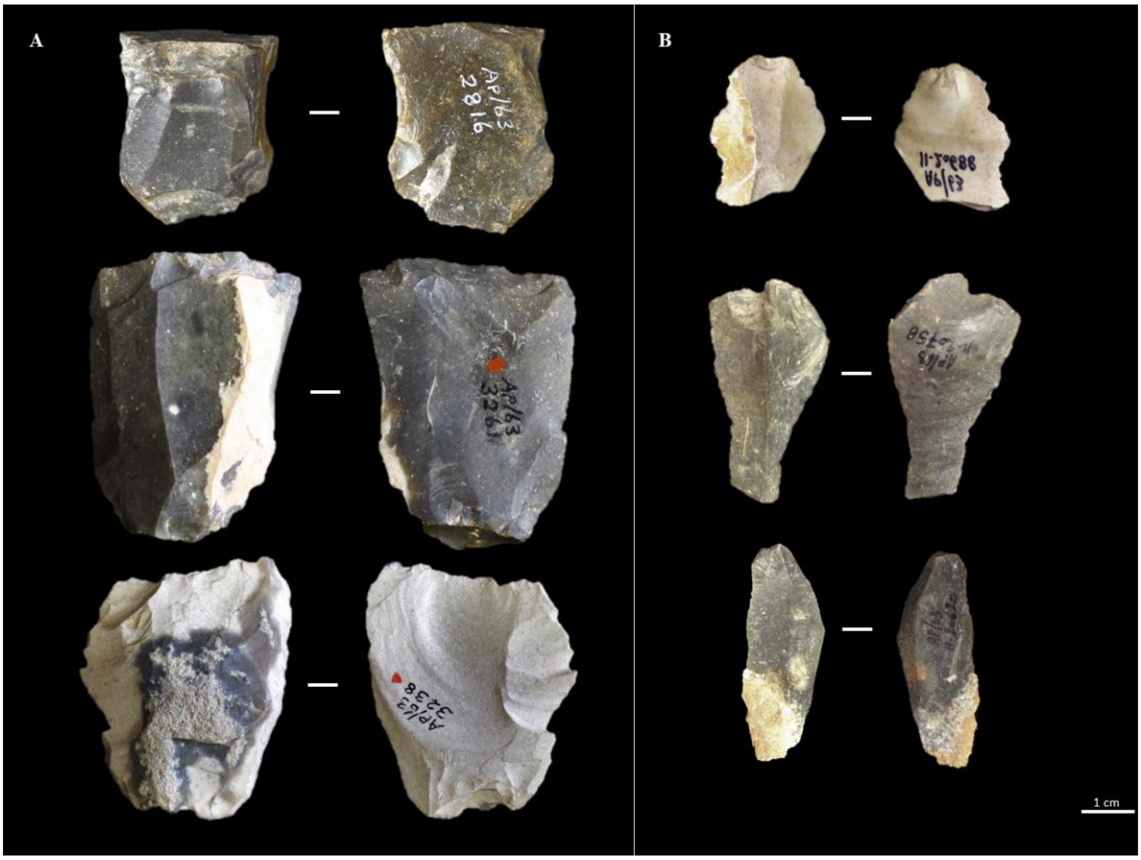


Figure 4.4. Bipolar cores and blanks from levels (12-9) of the Early Aurignacian. A – Bipolar cores. B – Bipolar Blanks.

Table 4.2. Bipolar core technological data

Attributes	**Total**
Blank Type	
Nodule	2 (67)
Pebble	1 (33)
Cortex	
<25%	1 (33)
25-50%	1 (33)
No_Cortex	1 (33)
Number of Core faces	
One	2 (67)
Two	1 (33)
Core Type	
Typical	3 (100)
Platform type	
Crushed	2 (67)
Plain	1 (33)

Type of blanks extracted	
Mixed	3 (100)
Number of Scars	
4 or more	3 (100)

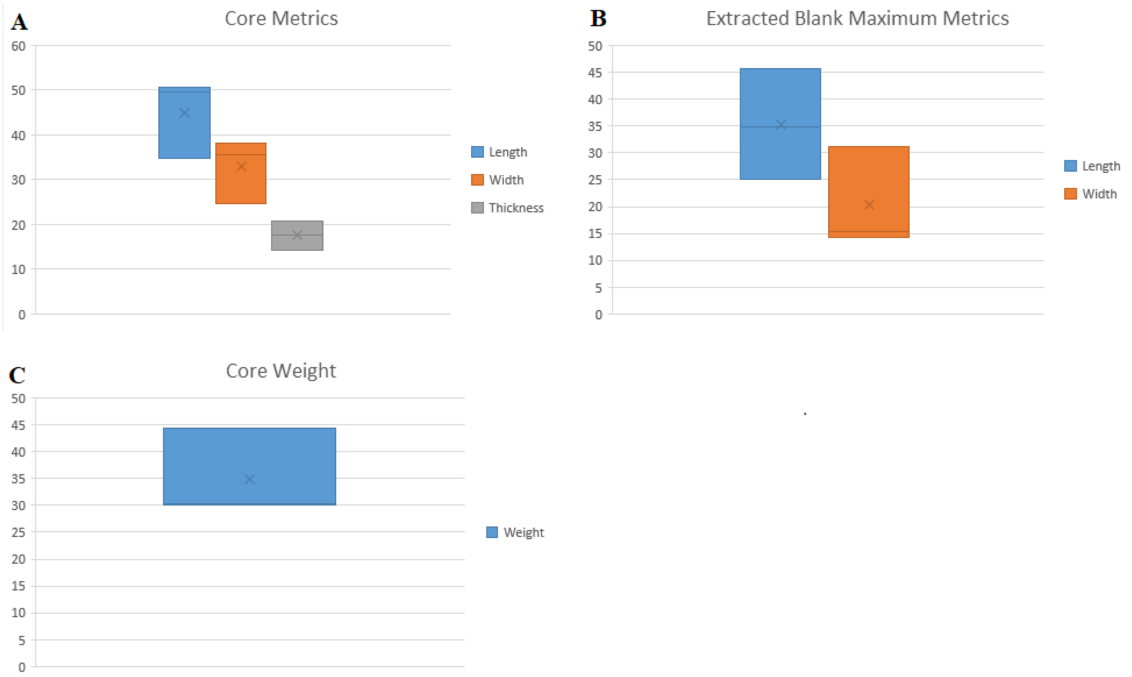


Figure 4.5. Core Metrics. Full data available in the SOM.

4.3.2 Bipolar Blanks

Regarding bipolar blanks in the assemblage most of them (N=15) come from the EA levels (level 11, Fig 4.3), with a single blank found in the EvA (level 7). Overall, all blanks found can be considered flakes. These can be described as small unmodified non-cortical flakes (Fig 4.6A, 4.6B) with unidirectional parallel-proximal dorsal patterns, no retouch or fire traces. In the EA flakes, crushed butts (Fig 4.6C) dominate the sample (66.7%), followed by flat (13.3%), absent (13.3%), and other types of butts (6.7%). Blank shapes (Fig 4.6D) are typically either parallel (40%) or other types (40%), followed by irregular, converging and circular shapes (6.7% each). Cross sections (Fig 4.6E) are also varied, with trapezoidal section being more common (40%), followed by triangular (26%), other (20%) and rectangular (13.3%). Side sections (Fig 4.6F) show some variance as well with other types representing (40%) of the sample followed by irregular, rectangular, trapezoidal and triangular shapes with 13.3% of representation each and lastly elliptical (6.7%). Blank tips or terminations show the most diversity with even representation of feather, hinged and stepped terminations (Fig 4.6G). Regarding metrics, these flakes' lengths range from 12-41mm (Fig 4.7A), widths from 7-29mm, thicknesses range between 2-11mm and their respective weights from 0.1-13g. The EvA flake can be described as having a flat butt, triangular sections, parallel edges and a hinged termination (Fig. 4.6), it measures 27.8x31x8.21mm and weighs 6.1g (Fig 4.7).

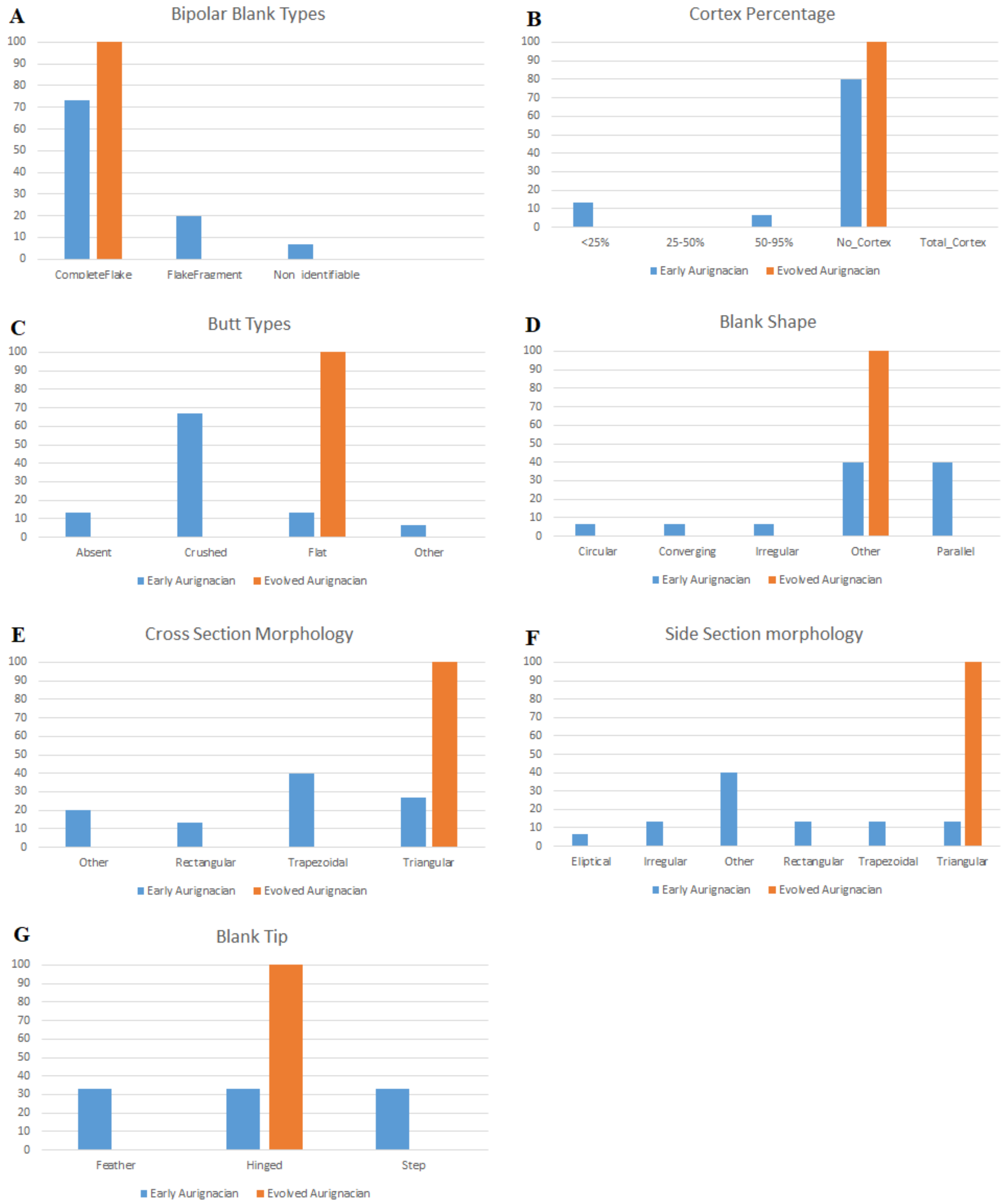


Figure 4.6. Bipolar Blank technological attributes. Full data available in the SOM.

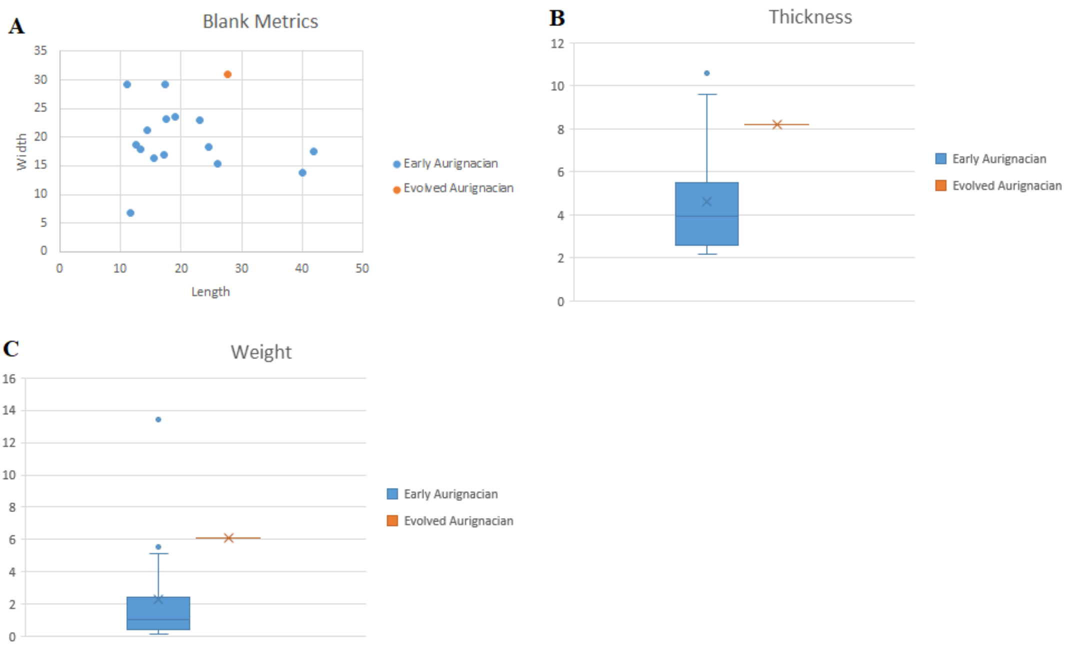


Figure. 4.7 Bipolar Blank metrics. Full data available in the SOM.

4.3.3 Splintered pieces

Technology: Technological analysis was aimed at characterizing the choice of blanks for splintered pieces. This can suggest a specific type of use (wedge or core), efficiency evaluation (if there is a preferred choice in the morphology of the original stone tool to be used), but also expediency in the choice of the blanks for the task at hand. Since splintered pieces are the only artifact type that is present throughout the entire Aurignacian sequence, we subdivided the analysis to include the different types of occupations during the EA into EAL (Early Aurignacian probably longer occupation of level 14) and EAS (Early Aurignacian short occupations of levels 13-9).

Due to the degree of damage and intensity of use observed in splintered pieces during the EAL, blanks were only securely identifiable in 45% of cases. Of these, splintered pieces were chosen from unmodified blades (n=3) and former retouched tools (n=2) (Fig. 4.8 and 8A). None of non-identifiable cases (55%) exhibit any presence of retouch along the edges, so these were most likely former unmodified flakes or blades (Fig 4.8A). Splintered pieces in the EAS were chosen from a diverse set of blanks, with former formal tools (Fig 4.8B) having the largest representation (n=34), followed unmodified flakes (n=28) and blades (n=14). Still, blanks were identifiable in 80% of cases during this time period (Fig. 4.9A). Like in the EAS, in most cases (76%), blank choice was identifiable in the EvA (Fig. 4.9A). In this chronology flakes were the clear preferred choice for blanks representing up to 60% of the assemblage (n=15), followed a mixture of retouched blanks (n=1), blades (n=1) and the remaining types (Fig. 8A).

Figure 4.8. Splintered Pieces. A – Splintered pieces on flakes and blades (left and right) or unidentifiable (center). B – Splintered pieces on retouched tools.

The remaining technological attributes of splintered pieces reveal an intentional choice in the morphology of blanks throughout the entire sequence, which suggests the same functional use. Specifically, and with little variance the blanks used had little to no cortical surfaces, coinciding axis (the bipolar main axis followed the technological axis), varied shaped cross and side-sections and straight profiles with parallel edges and no fire traces (Fig. 4.9).

Figure 4.9. Splintered Piece technological data. Full data available in the SOM

<u>Morpho-functional traits</u> As previously mentioned, it was our goal with the morpho-functional analysis to look for morphological changes in each artifact created by its use. Our main goal was to understand the type of use and the degree to which artifact was used. As observed in the technological data, similarities can be seen throughout the

sequence. This attests to the fact that splintered pieces were likely used in a very similar manner.

Throughout the sequence a high degree of fracturing is observable regardless of each tool's size. Unlike regular (bipolar) splintering that occurs in the platforms of this type of artifacts, these are large fractures that cross the tool. This is most likely the reason for the abandonment these tools, since these fractures makes them virtually unusable. In the EAL, these large fractures are present in 82% of the cases (n=9), and in the EAS (n=50) and EvA (n= 13) in 52% of the tools. The pattern of fracture is the same throughout the sequence, in that these are either large transversal or longitudinal fractures. Most transversal fractures tend to occur in what appears to be a snaping motion as only portions of the original tool remain. These fractures tend to happen close to the passive platform (the one in contact with the "anvil") and what remains is either the distal portion (containing the passive platform, see Fig 4.10A), or most of the tool with that portion missing (Fig 9B). These types of fractures are the most common throughout the sequence representing 66% of fractures in the EAL (n=6) and 61.5% in the EAS (n=32) and EvA (n=8). In a couple of cases, we were able to do some refits (Fig. 4.10C), in which the fractures occurred as described above. The longitudinal fractures seem to happen akin to a Siret accident where the tool splits in the middle, or a Burin blow where a portion of the artifact splits (Fig. 10). This has been previously reported by Tixier (1963), who described it as being the final part of splintered piece's reduction sequence, in which the tool shatters in several longitudinal fragments (see Fig 4.11A for a refit). In some cases, the active (hammered) platform is missing (Fig. 4.11B). These fractures are less frequent, yet represent 33% of all fractures in the EAL (n=3) and 38.5% in the EAS (n=20) and EvA (n=5).

Figure 4.10. Splintered pieces with transversal fractures (Fractures are in the bottom portion of the artifact). A – Only a small portion of the artifact is present. B – Most of the artifact is present. C – Refits of 2 splintered pieces with transversal fractures.

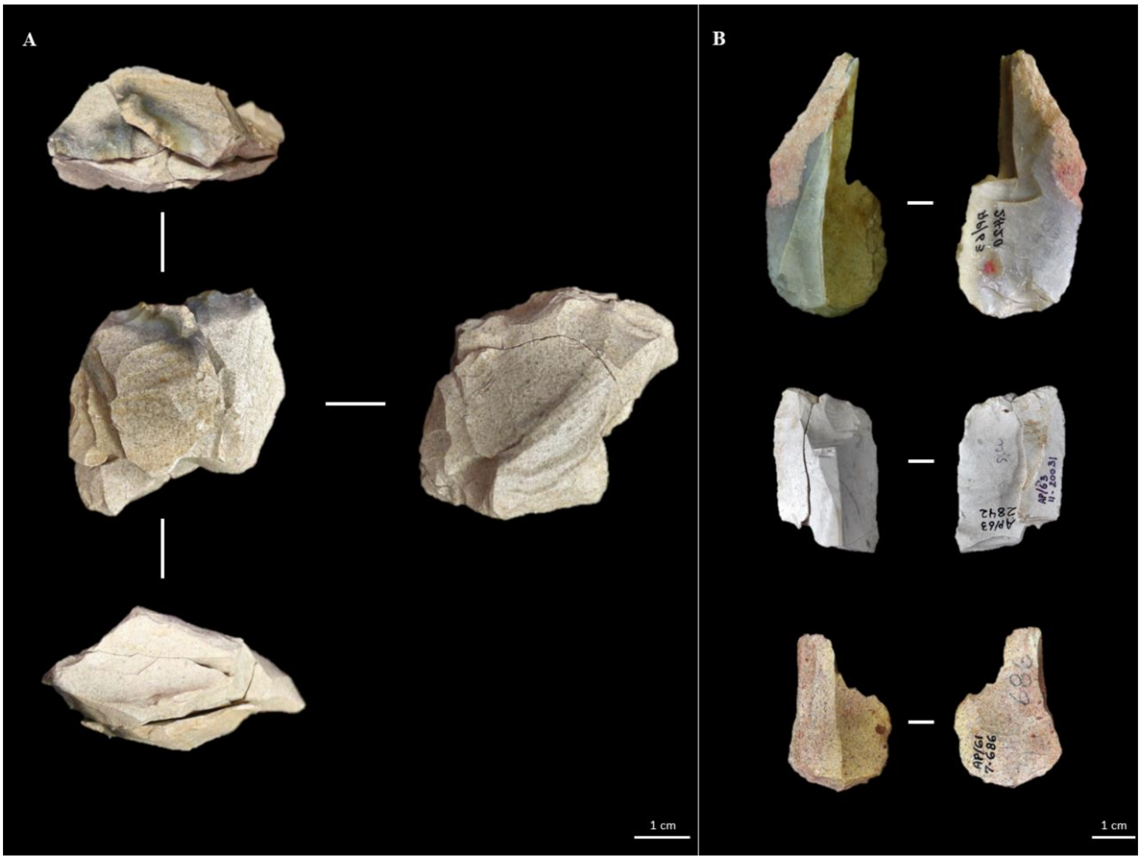


Figure 4.11. Splintered Pieces with longitudinal fractures. A – Refit of a splintered piece in a final phase of reduction as described by Tixier (1963). B – Splintered pieces with longitudinal fractures, where the active (hammered) portion of the artifact is missing (top and bottom) and a refit where the tool fractured near the middle (center).

With few exceptions, most morpho-functional attributes show a similar degree of variability (Fig. 4.12). Likewise, to what was registered for the technological attributes, most differences tend to occur between the EAL and the latter two chronologies. Throughout the sequence, splintered pieces tend to have 2 damaged opposing platforms, which means they were used in one single axis (Fig 4.12A). In both the EAS and the EvA a singular tool has 3 and another has 4 damaged platforms. In these cases, the splintered pieces with 3 damaged platforms these were used in two axes, sharing one damaged platform and the pieces with 4 damaged platforms were used in two opposing perpendicular axes (e.g., see Fig 4.13A). In all chronologies splintered pieces tend to have different damage degrees in each opposing platform, most commonly high damage in one and subsequently low or medium damage in the other (Fig 4.13A). Previous research (Lucas and Hays, 2004; de la Peña, 2011; Kolobova et al., 2021) has shown that the hammered platform tends to be the one where most damage occurs, so in cases where the damage is high in both platforms or even high and medium, the tool was likely rotated

180º and continued to be used. The remaining attributes show little variance throughout the sequence: scar extension tends to be marginal, with aligned or overlapped dispositions, distributed throughout the entire platform, typically bifacially and one platform tends to be thicker than the other (Fig 4.12).

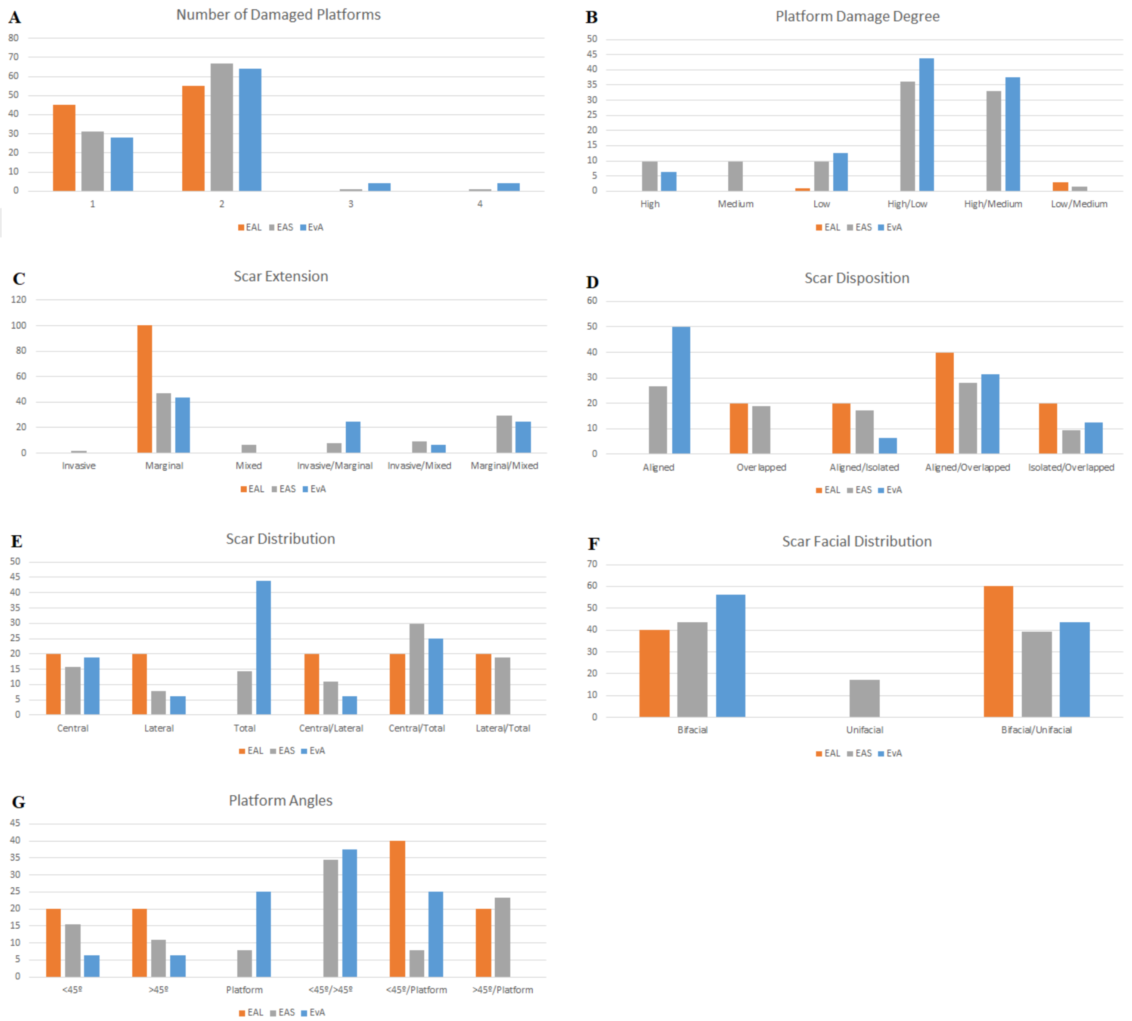


Figure 4.12. Splintered Piece morpho-functional data. Full data available in the SOM.

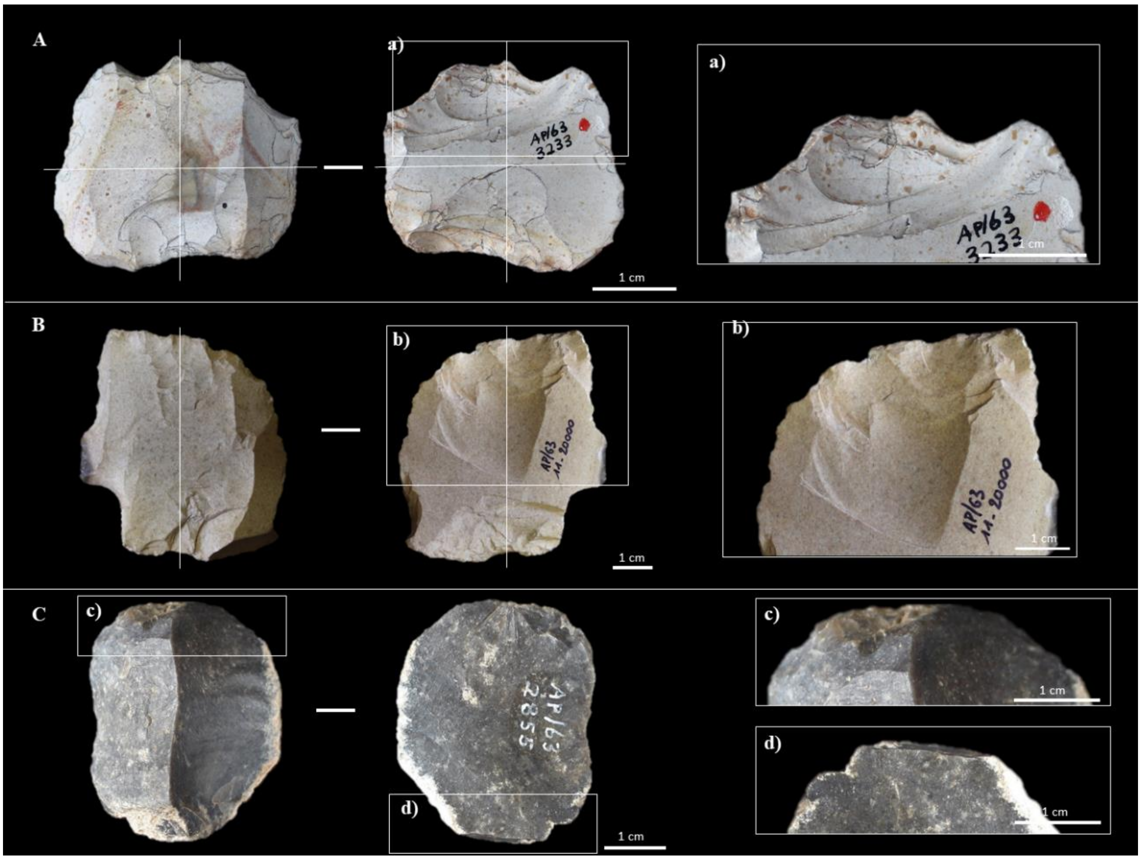


Figure 4.13. Splintered Pieces with differing degrees of damage. Reduction axes represented by white lines that cross the artifact. A – Splintered piece with 4 damaged platforms and highly damaged platforms; a) platform with high degree of damage, scars overlapping disposition and distributed across the platform (total). B – Splintered piece with 2 damaged platforms (one axis of reduction); b) platform with medium damage and overlapped, invasive scarring. C – Splintered piece with 2 damaged platforms; c) platform with low damage, marginal scars and scars with aligned disposition, central/lateral distribution; d) platform with no visible damage (the damaged was formed unifacially, in the dorsal face.

Regarding metrics, there are slight differences amongst the occupations, most likely due to the original blank choice and possibility use intensity. EAL splintered pieces tend to be slightly thinner and narrower than the ones in the subsequent periods (Fig 4.14A, 4.13B). This coincides with the pattern of blank choice, since blade blanks were more common during this time-period *(Chiotti, 1999, 2005)*. Several studies refer to splintered pieces also being used as bipolar cores and the difficult distinction between activities*[9,13,23,60–61]*. To confirm our hypothesis supported by the previously shown data, we compared the maximum and average scar extension of splintered pieces against those of bipolar cores, as well as their weight. As seen in figure 4.14 (C and D), splintered pieces tend to be lighter and have much smaller scars than the cores. The splinters removed from splintered pieces are mostly chips or rather small flakes (Figure 13C), even if there are other sites where these have been used *(Flenniken, 1981)*. When combining all our functional data with these data we reaffirm our hypothesis that splintered pieces were used as wedges and not cores for the extraction of small products.

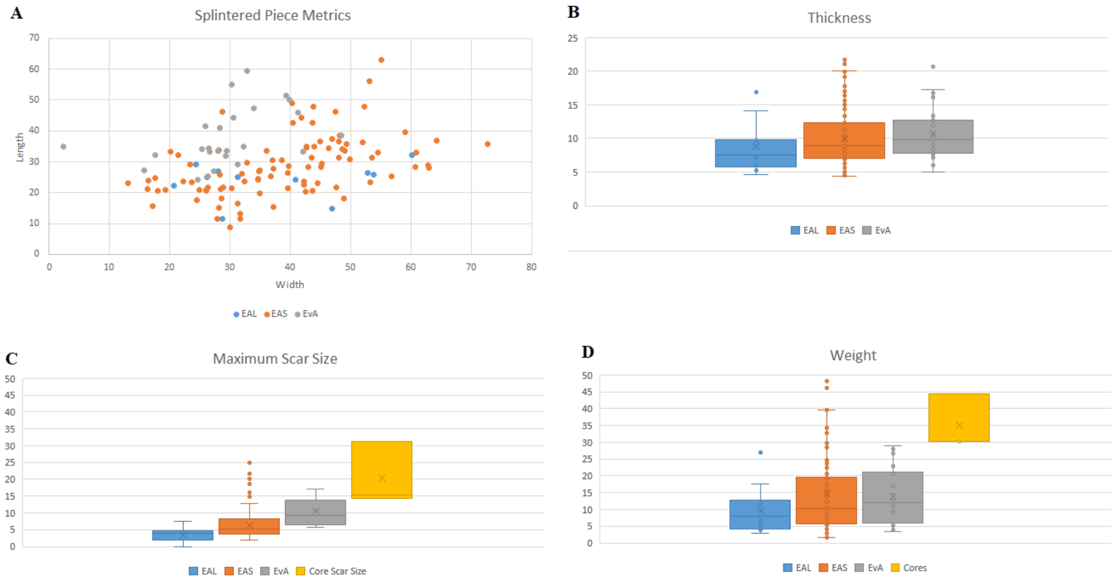


Figure 4.14. Splintered Piece metric data. Full data available in the SOM.

Overall, our data suggests that these tools were used in the same manner throughout time as wedges for working hard organic materials. The thickest platform (coinciding in most cases with the butt of a blank) was the one being hammered, therefore exhibiting a higher degree of damage. In some cases, tools were rotated to maximize their efficiency. The fracture patterns combined with the rest of the data suggest different intensity in the use of splintered pieces through time. Data suggests that during the EAL splintered pieces had a more intense use than in the following occupations, due to splintered being abandoned when the damage made them unusable (due to the occurrence of large fractures). On the other hand, during the EAS and EvA, splintered pieces were used in a more expedient manner, being chosen from a wider range of blanks and abandoned in earlier stages of reduction, being often still usable when discarded.

4.4 Discussion and Conclusions

Bipolar technology has often been described as an expedient answer to problem solving, namely as a method requiring low levels of cognitive or technological complexity (Hiscock, 1996; B. Morgan et al., 2015; Duke and Pargeter, 2015; Gurtov et al., 2015, 2015; Pargeter and de la Peña, 2017). The term itself is quite vague as it encompasses two differing activities each with its own goal (wedging and knapping). The distinction between both activities has been a matter of debate for over one century (see the discussion in (Horta et al., 2019). Nevertheless, both applications share a mechanical similarity, that is the use of an anvil as support. For knapping the goal is to extract blanks from a core, using the anvil as support, whereas for wedging the goal is to crack or shape the anvil itself (in most cases organic materials). This distinction is important when discussing the application of these methods because each activity answers a different problem. Which is especially relevant when discussing their role in adaptive strategies. The use of bipolar knapping has often been described as an answer to raw material constraints, including: raw material shortage, of lower quality, higher hardness levels, etc. Likewise, expediency, as it provides a quick solution for obtaining sharp edges that is both time and skill efficient (Eren et al., 2013; Duke and Pargeter, 2015; Shea, 2015; Pargeter and de la Peña, 2017). Wedging has been linked with diversification and intensification strategies (Manne, 2014; Cascalheira et al., 2017; Horta et al., 2019), through its advantages in carcass processing, organic tool production and organic material shaping (LeBlanc, 1992; Lucas and Hays, 2004; de la Peña, 2011; Langejans, 2012; Horta et al., 2019). Unlike other tools wedges do not require any complex retouch, shaping or preparation in order to be used. In addition to its advantages as quick and expedient solution, that requires little to no preparation (LeBlanc, 1992; Lucas and Hays, 2004b; Horta et al., 2019).

Evidence for the use of these methods has been found throughout pre-history in diverse chronological and ecological settings (Octobon, 1938; Leaf, 1979; Hayden, 1980; Shott, 1989; LeBlanc, 1992; de la Torre et al., 2003; Arzarello and Peretto, 2010; de la Torre, 2011; Langejans, 2012; Bader et al., 2015; Harmand et al., 2015a; Paloma de la Peña, 2015a; Arzarello et al., 2016; Arroyo and de la Torre, 2017; Pargeter and Tweedie, 2018). Europe in particular has evidence for the use of bipolar methods ranging from its earliest occupations through to the Holocene (de la Peña Alonso and Toscano, 2013; Márquez et al., 2013; Gilabert et al., 2015; Van Kolfschoten et al., 2015a; de Lombera-Hermida et al., 2016; Ravon et al., 2016; Horta et al., 2019, 2020; Arrighi et al., 2020). The arrival of *Homo sapiens* in Europe is marked by a considerable rise in the use of these methods when compared to Middle Paleolithic assemblages. Evidence suggests that this rise might be linked to its importance in adaptational strategies as bipolar technology is constantly present in the earliest *Homo sapiens* occupations of Europe (Peresani et al., 2016, 2019; Villa et al., 2018; Horta et al., 2020; Hublin et al., 2020). Despite this, the number of dedicated studies to this technology in this region remains scarce (Horta et al., 2019).

Our results show that *Homo sapiens* in Abri Pataud were flexibly using bipolar methods as means of resource extraction during the Aurignacian. Firstly, as far as artifact function goes our data suggests that splintered pieces were used as wedges for working organic materials and not cores. These tools represent the bulk of the bipolar technology of the sequence, nevertheless, we also found evidence for bipolar knapping through the presence of bipolar cores and blanks. Despite being present in the entire sequence, bipolar technology played a different role through time.

The earliest occupation of the site (level 14) occurs during a cool moment at around 40k cal BP (T. Higham et al., 2011). This occupation is marked by an intensive use of wedges (splintered pieces), not in terms of having a large frequency in the overall assemblage (around 5%) but the extent of which tool was used. The wedging in this level is connected with bone tool creation and probably carcass processing activities, as evidence for both has been found (Chiotti, 1999). The wedges in question were being used until exhaustion. Nearly all wedges were only abandoned after a major fracture that rendered them unusable occurred. In addition, in most cases the damage is such that the original blank used as a wedge could not be identified. In the remaining cases they seem to have been blades which follows the exact same pattern as the blank choice for the majority of retouched tools during this occupation (Chiotti, 1999, 2005). Interestingly, this occupation is marked by a mostly flake production and only occasionally blade production(Chiotti, 1999). In turn this may suggest that the choice to use blades as wedges is purely functional, due to these having the desired morphological attributes for the task (parallel edges, straights profiles, etc.). Since raw material is abundant locally and these tools are being used to the maximum of their efficiency rather than being easily replaced, this also suggests that there is preoccupation with maximizing efficiency in both the use and maintenance of these tools. This suggests the importance these tools may have had in the adaptive strategies of *Homo sapiens* as a means to increase efficiency in organic resource extraction.

In the rest of the sequence, the site seems to have had a succession of short-term occupations. This includes not only the remainder of the early Aurignacian but the subsequent evolved Aurignacian, a sequence marked by technological shifts. Levels 13, 12 and 11 are marked by harsh cold and arid climate (~39-38k cal BP (T. Higham et al., 2011)), where the environments likely to have been steppic with few trees (Chiotti, 2005). While it is expected that during these harsher environmental conditions a need for organic resource exploitation would have been great, level 13 is marked by a drop in both carcass processing activities and wedges. Although it is possible that these activities were occurring offsite. Despite this the site seems to have had a residential function (Chiotti, 1999) where these activities are expected to be conducted (Horta et al., 2019).

Subsequent levels (12 and 11) on the other hand mark a considerable rise in the use of bipolar technology, *in situ* carcass processing activities and bone tool and ornament production (Chiotti, 1999, 2005; Chiotti et al., 2003). During this time period wedges played an important role not only in carcass processing, but probably also in ornament and bone tool production. However, process of use and choice of wedges is different from the long occupation of level 14. In particular, most wedges were chosen from former tools (Fig. 7 – B) and in lesser extent unmodified flakes, showing that there was no particular care for the morphology of the tool as long as it was usable. Interestingly, a care for tool efficiency is still noted. In most cases the active (hammered) platform of the artifact was the thickest, coinciding often with the original platform (butt). Despite this, wedges were discarded earlier on their use life, as most original blanks are still identifiable, and a half showed no major fractures and therefore were still usable at the time of abandonment. Evidence seems to suggest that wedges were used in a much more expedient manner than in level 14 despite appearing in larger frequencies. It can also be noted, that the high frequency is also directly related to the expediency of use. Wedging is an activity that tends to create significant damage to the tools as they are violently hammered, and data suggests that lesser damage is formed in the passive platform (Lucas and Hays, 2004; de la Peña, 2011). Still if the tool isn't intensively used it may still be usable for other activities such as scrapping or boring. End-scrappers that were used for instance, typically show low damage in their "scrapper head" and mostly in their ventral face, so they usability as a core or tool is not compromised. Still in some cases these suffered wedging fractures, which likely led to their immediate abandonment, also supporting our hypothesis of expedient usage.

During these occupations we also observed evidence for expedient bipolar knapping. As shown in our results, a small number of bipolar cores were found and most likely played a small role in the technological kit of *Homo sapiens* at the time. These cores were likely used as an expedient, on the go, method of flake production. This is evident not only by the small number of cores but also of bipolar blanks present in the assemblage. It is also of note that none of the bipolar blanks show evidence of being retouched. However, this does not exclude their probable use as informal tools. The final moments of the Early Aurignacian (levels 10 and 9) show very poor faunal preservation (T. Higham et al., 2011) and a large drop in the number of wedges (3 in total). However, it is important to note that flint quantity is very low in these levels since only the laterals parts were excavated, still we hypothesize that their use and care follow the same expedient pattern as the previous occupation.

The beginning of the Evolved Aurignacian (37,550-36,960 cal BP) occurs during a period of wooded environment with birch, pine, oak and a variety of herbaceous plants locally present (Donner, 1975; T. Higham et al., 2011). During this period the faunal diversity increases with large mammals being rare and the diverse consumption of birds, small mammals and aquatic species being prevalent at the site (Bouchud, 1975; Sekhr, 1998; Chiotti, 1999). Likewise, we can observe a large drop in wedge frequency (n=1) as well as bone tool production (n=4) (Chiotti, 1999), which is likely directly related to drop in the consumption of large mammals. The subsequent and final occupations of this time-period (levels 7 and 6) occur in a cooler environment. These occupations are marked by a rise in the consumption of larger mammals namely reindeer (Bouchud, 1975; Sekhr, 1998). This rise is directly proportional with a rise in the bone industry and bipolar technology. During this period, we can observe this exact same pattern of use and curation of tools observed in levels 11 and 12 of the Early Aurignacian. Wedges were being used in an expedient manner, often abandoned while still usable. The only recorded difference is in the blank choice as flake blanks were more prevalent in the sequence. Furthermore, we found evidence for the presence of a single bipolar flake, possibly extracted from a bipolar core offsite or it simply hasn’t been found yet.

Overall, the functional application of bipolar methods was the same throughout the sequence. Wedging served as a means of enhancing carcass processing through controlled fracturing and possibly even bone marrow extraction. Furthermore, it enabled the shaping of bone and antler for the production of osseous tools and ornaments. The possibility that these tools may have played a role in the extraction and working of plant and wood resources is also present, as it has been observed in other cases (LeBlanc, 1992; de la Peña, 2011; Langejans, 2012; Igreja and Porraz, 2013). Overall, wedging can be considered one of the significant lithic technological breakthroughs that is unambiguously linked with increasing efficiency of faunal resource exploitation, described by Hovers and Belfer-Cohen (2020). It would have served as a significant advantage in cases where there is a need to maximize organic resource extraction. As suggested by the data, we do find a higher presence of this technique during periods of harsher environmental conditions, likely due to the need of maximizing organic resources. On the other hand, bipolar knapping provided a quick, alternative, least cost solution method for obtaining blanks, when needed. This expedient use of bipolar knapping has been observed in other regions of western Europe (Horta et al., 2019) and its time-efficient advantages (Shea, 2015; Pargeter and de la Peña, 2017) were likely the reason for its use at the site as there is no shortage of high quality raw material.

Our results show that bipolar technology may have played a strategic role in the settlement of *Homo sapiens* at the site and subsequently the region. This is shown not only by: (1) the constant presence of this technology throughout the Aurignacian, persisting through technological adaptations and changes; (2) the flexibility in its use, both intensively and expediently; (3) the understanding of how to achieve higher efficiency in resource extraction; and most importantly (4) the understanding of how the advantages in the strategical implementation of these methods in different scenarios. Our data suggests that this technology was used in a per need basis as its peaks in frequency coincide with periods of harsher environmental conditions, through the need to enhance carcass processing, enabling peaks in osseous industry, ornamentation or as a quick solution for problem solving. Future studies should further investigate the connection between bipolar technology, environmental conditions and the production of bone tools and ornaments, to understand if this is a large-scale phenomenon. Based on our data and previous studies on the subject (Cascalheira et al., 2017; Horta et al., 2019, 2020), we do suspect as such.

It is becoming increasingly clear that the understanding of the technological and adaptational advantages of the use of bipolar methods played a role in the settlement and survival of *Homo sapiens* in Europe. Our work highlights the importance of understanding the entire spectrum of tool use as a means of resource extraction in adaptational strategies. By focusing on a technology considered to be of low technological or cultural value we were able to further expand on this subject. Lastly, we argue that it is the combined understanding of the strategic meaning being tool production and use in a larger scale that will help us understand the settlement and survival of *Homo sapiens* in the region.

Chapter V

INTENSIVE RE-USE OF STONE TOOLS AS BIPOLAR IMPLEMENTS IN THE INITIAL UPPER PALEOLITHIC OF BACHO KIRO CAVE

5.1 Introduction

The Middle to Upper Paleolithic transition in Europe and the Levant (post 50ka) is marked by a shift in adaptative strategies (Bar-Yosef, 2002; Hublin, 2015; Mellars, 2005; Teyssandier, 2008; Zilhão, 2013). As successive waves of *Homo sapiens* enter Europe, Neanderthals adapted to the new competition by innovating their adaptive strategies. The earliest manifestations of this shift come in the form of new industries such as the Châtelperronian, the Lincombien-Ranisien-Jerzmanowicien (LRJ), and the so-called Initial Upper Paleolithic (IUP) (Flas, 2011; Kuhn and Zwyns, 2014; Soressi and Roussel, 2014; Ruebens et al., 2015; Kuhn, 2019). Contacts between *Homo sapiens* and Neanderthals are reflected in aDNA sequences (Compton et al., 2021; Hajdinjak et al., 2021; Lalueza-Fox, 2021; Prüfer et al., 2021) but nuanced in the archaeological record. The general consensus is that the Châtelperronian is a Neanderthal industry that combines Levallois technology with blade production and emerges in Western Europe at the same time as *Homo sapiens* starts settling in Europe (Bar-Yosef and Bordes, 2010). Another Neanderthal industry that emerged during this period is the LRJ, geographically limited to northern Europe (Flas, 2011). An industry known for its index fossil the Jerzmanowice points, which are bifacial points made on large thick blades (Flas 2006, 2015).

The IUP represents dispersal events by *Homo sapiens* migrating out of Africa and into Eurasia (Hublin, 2015; Kuhn and Zwyns, 2014; Zwyns et al., 2019). The term IUP was initially described by Marks and Volkman (1986) to describe layer 4 of Boker Tachtit in the Negev Desert, Israel. According to the authors, the technology gradually evolved from bidirectional Levallois point production to volumetric unidirectional blade production (as seen in the UP). Several researchers have expanded on the term ever since, resulting in general knowledge of its most common features (Kuhn, 2004a, 2019; Derevianko et al., 2007, 2012; Kuhn and Zwyns, 2014, 2018; Morgan et al., 2014; Rybin, 2014). In general terms, IUP industries combine features from MP Levallois technology, such as direct percussion and radial reduction, with UP volumetric unidirectional blade and formal tool production, some of which would later be common in UP assemblages (e.g., end-scrappers, pointed blades) (Kuhn and Zwyns, 2014; Niu et al., 2016; Kuhn, 2019; Slavinsky et al., 2019).

Little to no attention has been paid to the presence or role of bipolar technologies in these industries (Kuhn, 2004a; Tsanova, 2006, 2013; Kuhn et al., 2009; Niu et al., 2016). This is especially relevant considering that bipolar technology appears sporadically in the MP (Márquez et al., 2013; Moncel et al., 2005; Van Kolfschoten et al., 2015) but is quite common across the UP (Kozlowski, 1982; Zilhão, 1997; Almeida, 2000; Tsanova, 2006, 2013; de la Peña, 2011; d'Errico et al., 2012; de la Peña Alonso and Toscano, 2013; Villa et al., 2018; Horta et al., 2019; Kolobova et al., 2021). Recent works have highlighted the importance of this type of technology as an adaptive strategy, namely in periods of high mobility, environmental pressure, and raw material scarcity (Cascalheira et al., 2017; Horta et al., 2019, 2022; Horta and Chiotti, Submitted). Therefore, the importance of understanding the role that bipolar technology played in *Homo sapiens* dispersal and settlement strategies in Europe cannot be understated.

Bacho Kiro cave's Layers I and J (IUP) currently stands as the oldest *Homo sapiens* occupation in Europe (Fewlass et al., 2020; Hublin et al., 2020). Previous studies have shown that this occupation contains many bipolar artifacts (Kozlowski, 1982; Tsanova, 2006; Hublin et al., 2020). This paper explores the role that bipolar technology played in the adaptational strategies of the first *Homo sapiens* groups in Europe. By identifying reduction strategies, tool function, and economization strategies in combination with subsistence patterns, this study sheds light on the importance of bipolar methods for the settlement and success of early *Homo sapiens* in Europe.

5.1.1 The site

Bacho Kiro cave stands as a key site to understand the arrival of *Homo sapiens* in Europe. Located on the northern slope of the Balkan Mountain range in Bulgaria, the site has a rich chrono-stratigraphic sequence spanning from the Middle Paleolithic to the Upper Paleolithic (Kozlowski, 1982; Tsanova, 2006; Hublin et al., 2020). The site was initially excavated in 1920 by Popov, whose sections were later extended by Garrod in the 1930s, who described the technology as an "unknown UP industry" (Garrod et al., 1939). Later excavations, led by Kozlowski and B. Ginter, were conducted between 1971 and 1976

(Kozlowski, 1982). These focused on expanding previous excavation areas throughout what is now known as the Main sector (Kozlowski, 1982; Hublin et al., 2020). Kozlowski would later describe the site's technology as an Upper Paleolithic industry with an early date and some morphological traits resembling the Aurignacian, labeling it the Bachokirian (Kozlowski, 1982, 2004). The Bachokirian, according to Kozlowski, was an early migration of *Homo sapiens* into Europe coming from the Levant (Kozlowski, 2004).

Excavations would later resume in 2015 through a joint project by the National Archaeological Institute with the Museum of the Bulgarian Academy of Sciences (NAIM-BAS) in Sofia and the Max Planck Institute for Evolutionary Anthropology (MPI-EVA). These new excavations aimed at refining the site's chronology and confirming the previously reported stratigraphy. Excavations occurred in two sections of the cave, the Main Sector and the Niche 1 (Figure 5.1). The new data shows that while previously excavated deposits separate these two areas, many of the analogous layers have been correlated (Fewlass et al., 2020). Additionally, the previously reported stratigraphy of the Main Sector (Kozłowski, 1982) was confirmed (Hublin et al., 2020), and the nomenclature changed (e.g., Layer 11 is now layer I). The archaeological sequence of the Niche 1 (Figure 5.1C), however, only preserves the lower part of the sequence, including the IUP (Layers I and J) and MP (Layer K) deposits.

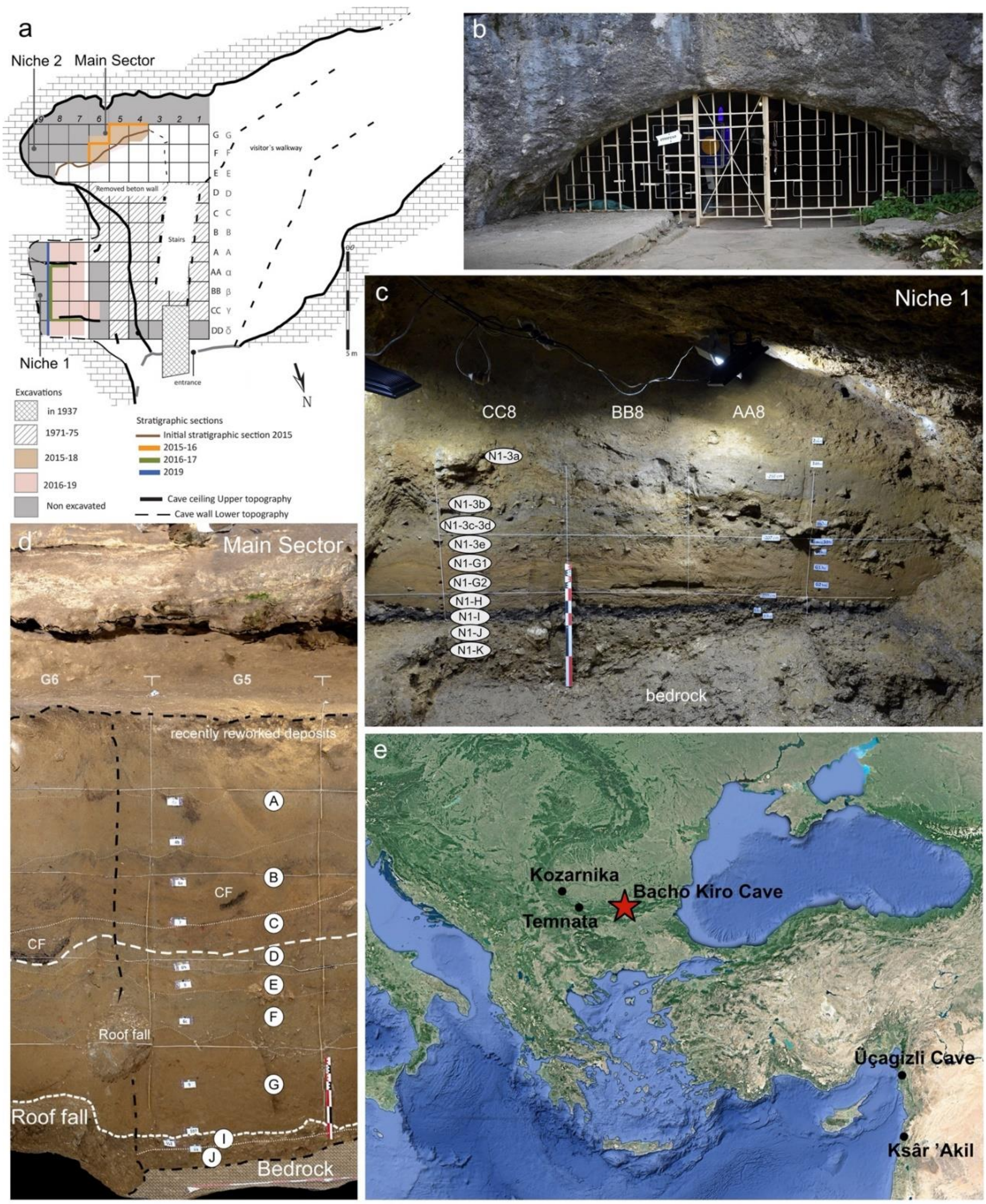


Figure 5.1. Figure adapted from Martisius et. al, (2022). (a) Site plan with location of 1970-75 excavations and recent excavations (2015-2019), Main Sector (top) and Niche 1 (left). (b) Photograph of cave entrance taken by N. Zahariev. (c) Stratigraphic sequence of the Niche 1 and Main Sector (d). (e). Location of Initial Upper Paleolithic sites close to Bacho Kiro cave.

Layer I has the largest concentration of lithic and faunal remains at the site (Hublin et al., 2020). This layer has a distinct dark color that results from a large portion of organic remains, including charcoal, burned bone, and plant matter (Hublin et al., 2020). Human remains belonging to the same individual were found within layer I in the Niche 1 and the upper part of layer J in the Main Sector, in addition to others. (Hajdinjak et al., 2021; Hublin et al., 2020). aDNA analysis suggests that one individual had a Neanderthal ancestor less than six generations away (Hajdinjak et al., 2021). Furthermore, there is no evidence that these humans were genetically connected to posterior UP humans but are related to later Asian populations (Hajdinjak et al., 2021). Archaeology in the Niche 1 suggests that Layer J accumulated slowly over a period of low cave occupation intensity compared to Layer I (Fewlass et al., 2020) and that the same population inhabited the cave during the formation of Layer J and intensified their stay and use during the deposition of Layer I (Martisius et al., 2022). Recent C14 dates place the start of the upper part of Layer J at around 45,990 cal BP and Layer I into the period from 45,040 to 43,280 cal BP (Fewlass et al., 2020; Smith et al., 2021). High resolution oxygen stable isotope analysis suggests temperatures were 10-15∘C below modern-day in Layers J and I (Pederzani et al., 2021). Still, seasonality indicators illustrate human occupation within Layer I throughout all seasons of the year despite the cold climate (Smith et al., 2021).

The fauna found in layers I and J is characteristic of Marine Isotope Stage 3 (MIS 3) throughout southeast Europe. This includes a mix of cold and more temperate adapted species with a broad range of climatic/ecological tolerances (Hublin et al., 2020; Smith et al., 2021). The most common species found in these layers are *Bos/Bison*, cave bear, and red deer. There is also evidence for other carnivores (cave lion, leopard, cave hyena, red fox, wolf, and brown bear), medium-sized herbivores (horse, European ass, giant deer, ibex, chamois), and megafauna (mammoth and rhino) (Smith et al., 2021). While carnivore modifications are not uncommon, human surface modifications are persistent across the layers (cut marks, bone marrow extraction, and scrapping). These data also suggests the selective transport of limb bone elements to the site and subsequent *in situ* processing (Hublin et al., 2020; Smith et al., 2021). While these human-made modifications are constant in *Bos/Bison* and cervids, they are observed in similar proportions in cave bear remains. Ursidae remains, in particular, show increased modifications on cranium and foot portions, indicative of skinning and the first stages of fur removal (Smith et al., 2021).

In addition, Layer I includes the use of a range of animal carcasses as raw material both for bone tools (n = 92) and personal ornaments (n = 29) (Smith et al., 2021). Formal tools (n=19) include awls and lissoirs, while informal bone tool types (n=48) include retouchers and intermediate tools (used as wedges) (Smith et al., 2021). Ornaments consist mainly of teeth pendants and pendant fragments (n = 27) produced mainly on cave bear teeth, wolf, and fewer herbivore taxa (Hublin et al., 2020).

Lithic technological data from Layer I and the upper part of Layer J shows patterns that combine MP and UP techno-typological elements (Tsanova, 2008), typical for IUP assemblages (Marks and Volkman, 1986; Kuhn, 2004a; Kuhn and Zwyns, 2014, 2018; Niu et al., 2016). Typology in these layers is characterized by retouched blades, endscrapers, and splintered pieces (Kozłowski, 1982; Tsanova, 2008, 2012). In addition to these tools typical of the Upper Palaeolithic, there is a combination with Levallois forms, faceted platforms, and hard-hammer percussion and techniques reminiscent of the preceding Middle Palaeolithic African Middle Stone Age (Kuhn and Zwyns, 2014; Hublin et al., 2020). Overall the technology found in layers I and J is similar to Üçağızlı Cave in Turkey (Kuhn et al., 2009; Hublin et al., 2020). Raw materials in these layers consist mostly of different types of flint and residual percentages of other raw materials (Tsanova, 2006). Preliminary data on raw material sourcing shows that different flint types were collected from sources 80-150km away from the site (Hublin et al., 2020).

5.2 Methods

All lithic artifacts recovered from layers I and J of the new excavations were screened, and those which fit the definitions of splintered piece, bipolar core, bipolar blank, and anvil, were included in this study (see Horta et al. 2019 and Horta and Chiotti, under review). It is important to note that we only considered the final use of each artifact for classification purposes. This means that a splintered piece used as a bipolar core (e.g., if knapping scars overlap the typically much smaller wedging scars), then this splintered piece was considered a bipolar core and vice versa. Due to the uncertainty in the boundaries of the layers, artifacts from the contact zones between layers H/I and I/J were also included in the sample. This resulted in the inclusion of a total of 260 artifacts. Artifacts were analyzed in different manners according to their typology.

Splintered piece analysis was done adapting Horta et al. (2019), Horta and Chiotti (under review) and Kolobova et. al, (2021). This methodology separates technological and functional variables in order to answer different questions. Technological data is registered to understand general patterns of blank choice for splintered pieces. In turn, functional data is registered to understand artifact use, possible stages of usage, and cause for abandonment. As mentioned by Horta and Chiotti (under review), so far, no studies have successfully shown statistical approaches in order to answer these questions. This stems from the fact that the morphology of these artifacts is highly variable because their shape ultimately results from their use and damage that fall outside of the knapper/user's control. Due to the combination of these reasons, in addition to the low number of artifacts in the sequence that a choice was made not to pursue statistical approaches and to use already proven to be successful traditional descriptive analyses for these types of artifacts e (de la Peña, 2011; Horta et al. 2019; Horta and Chiotti, Under review).

Bipolar core and bipolar blanks were analyzed based on their technological attributes recorded in traditional lithic studies (Tixier and Inizian, 1983; Andrefsky, 1998). In addition to these, we added the variables "External Platform Angle" (EPA) and "Damage Location" to the analysis of bipolar blanks. EPA was recorded to understand patterns of intention in the prediction of blank shape and size during extraction (Rezek et al., 2018) and allow for comparison with free-hand blanks. The damage location variable was added to understand whether the blank crossed the entire surface of the bipolar core when extracted (therefore exhibiting distal damage due to the contact with an anvil) or if simply the damage was located in the proximal portion. In the latter case, in combination with size, this allows for understanding whether the blank came from a regular bipolar core or a splintered piece (in this case, from wedge splintering). We recorded their raw material type, metrics, and evidence of further use for split pebbles.

Anvils were analyzed following their surface modifications (Arrighi et al., 2020; Paixao et al., 2021). In addition to regular metric analysis, type, number, and location of use features were recorded as possible reasons for their abandonment. Regarding the type of features, three types of surface modifications were observed and recorded: impact features, grinding features, traces of residue, and a combination of the previous. This variable is expected to show the primary type of activity the anvil was used for. The feature location along the surface of the anvil was also recorded through the following attributes: central, extremities or a combination. From a stability standpoint, it is expected that most anvil use would occur in the central portion, where the propagation of force would not impact its stability. The choice of different zones of use in combination with the number of features present in the anvil surface may indicate efficiency evaluation by suggesting expedient or intensive use of the anvil. Lastly, several anvils shown signs of large fractures, which were recorded in order to understand whether these may have led to their abandonment.

5.3 Results

A total of 260 artifacts were analyzed from Layers I and J and their subsequent contact zones, excavated in the Niche and the site's Main section. All currently identified types of bipolar artifacts are present in the assemblage (Table 5.1). Most bipolar artifacts were made on yellow flint, despite all other types of flint being presented in smaller percentages (Table 5.1). Anvils were made exclusively on sandstone and split pebbles on quartz and other raw materials (Table 5.1). Most artifacts (74,6%) were found in Layer I in the Niche, with lesser representation in Layer J and the contact zones between both layers and Layer H and I (Figure 5.2). Only 14 artifacts were found in the main section of the site, and 7 (50%) of these from Layer I (Figure 5.2). While not included in the analysis for this paper, it is important to mention that bipolar technology was also found in other layers of the site, specifically 7 artifacts in layer H of the Niche and 10 artifacts from layer B of the main section.

Table 5.1. Frequency of bipolar artifacts per raw material type.

Raw Material	**Artifact Types**													
	Splintered Pieces		**Bipolar Cores**		**Split Pebbles**		**Bipolar Blank**		**Fragment**		**Anvil**		**Total**	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Brown Flint	8	6,2	-	-	-	-	2	3,2	1	4,5	-	-	11	4,2
Coarse Grey Flint	4	3,1	1	11,1	-	-	1	1,6	1	4,5	-	-	7	2,7
Grey Flint	2	1,6	-	-	-	-	2	3,2	2	9	-	-	6	2,3
Quartz	1	0,8	1	11,1	2	14,3	-	-	-	-	-	-	4	1,5
Sandstone	-	-	-	-	2	14,3	-	-	1	4,5	28	96,6	31	11,9
Spotted Flint	20	15,5	3	33,3	-	-	1	1,6	4	18,2	-	-	28	10,8
Yellow Flint	92	71,3	3	33,3	-	-	55	88,7	13	59,1	-	-	163	62,7
Other	2	1,6	1	11,1	5	71,4	1	1,6	-	-	1	3,4	10	3,8
Total	129	100	9	100	9	100	62	100	22	100	29	100	260	100

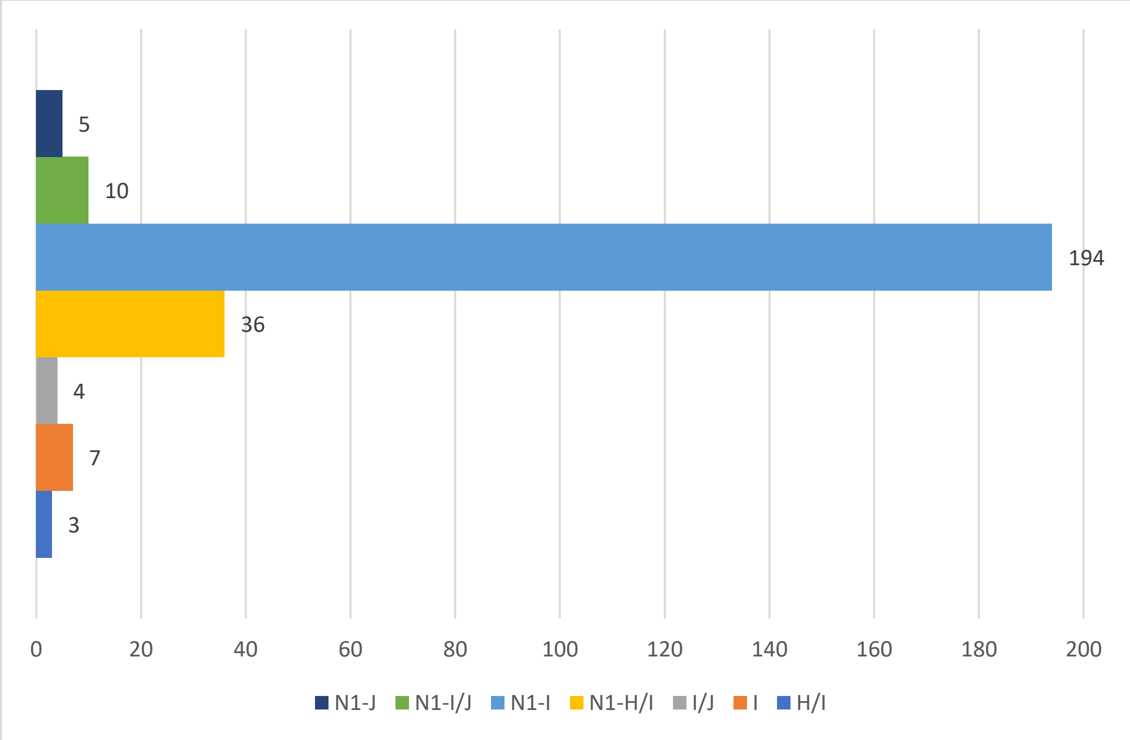


Figure 5.2. Artifact frequency per layer.

Bipolar cores in the sequence (n=9) were all made on flint. Three cores (33%) are made on yellow flint, another 3 on spotted flint, and one core in coarse-grained grey flint (Figure 5.3B). Two cores (28.6%) were made on flakes, 2 (28.6%) were too reduced and damaged to be able to be identified (Figure 5.3A). The remaining 3 were made on a previous core (initially reduced with freehand methods and posteriorly on an anvil), a flint nodule, and the last one on a splintered piece (in this case, the knapping scars overlap the "wedging" scars). Regarding cortex (Figure 5.3C), 4 cores have no cortical surfaces, 2 have less than 25% of cortical surface and the remaining core has between 25 and 50% of its surface covered in cortex. All but one core have plain platforms, while the other core has a crushed platform (Figure 5.3E). Likewise, 6 cores have evidence of striking on a single face, while the remaining one was reduced in 2 (Figure 5.3D). Overall, all cores are flake cores. However, 3 cores have a single bladelet-like removal (Figure 5.3F). Previous studies (Peresani et al., 2019) have proposed that these removals are likely accidental. All cores seem to have been heavily reduced because only 1 of the 7 cores was made on a possibly unmodified nodule, but most of these exhibit up to 10 removal scars (Figure 5.3G). Lastly, despite each core's damage and reduction rate, only one core seems to have been abandoned due to a large fracture occurring during knapping (Figure 5.3H).

Figure 5.3. Bipolar core attributes. A: Blank type; B: Raw material type; C: Cortex percentage; D: Number of striking platforms; E: Platform type; F: Type of products extracted G: Number of removals (n represented by bars and the trend by the line); H: Apparent reason for abandonment. Full data available in the SOM.

Bipolar cores (pebble cores included) have lengths between 22-40mm, widths between 18-39mm, thicknesses between 8-22mm, and weigh between 8-17g. As seen in Figure

5.4A, bipolar cores have, on average, similar lengths and widths as free-hand cores, with only 2 free-hand cores being significantly larger. When it comes to thickness, free-hand cores are typically thicker than bipolar cores (Figure 5.4C). Interestingly as shown in figure 5.4D, and likely due to being heavily re-used, bipolar cores are lighter than free-hand blanks (unfortunately, we currently have no data for the weights of FH cores for comparison).

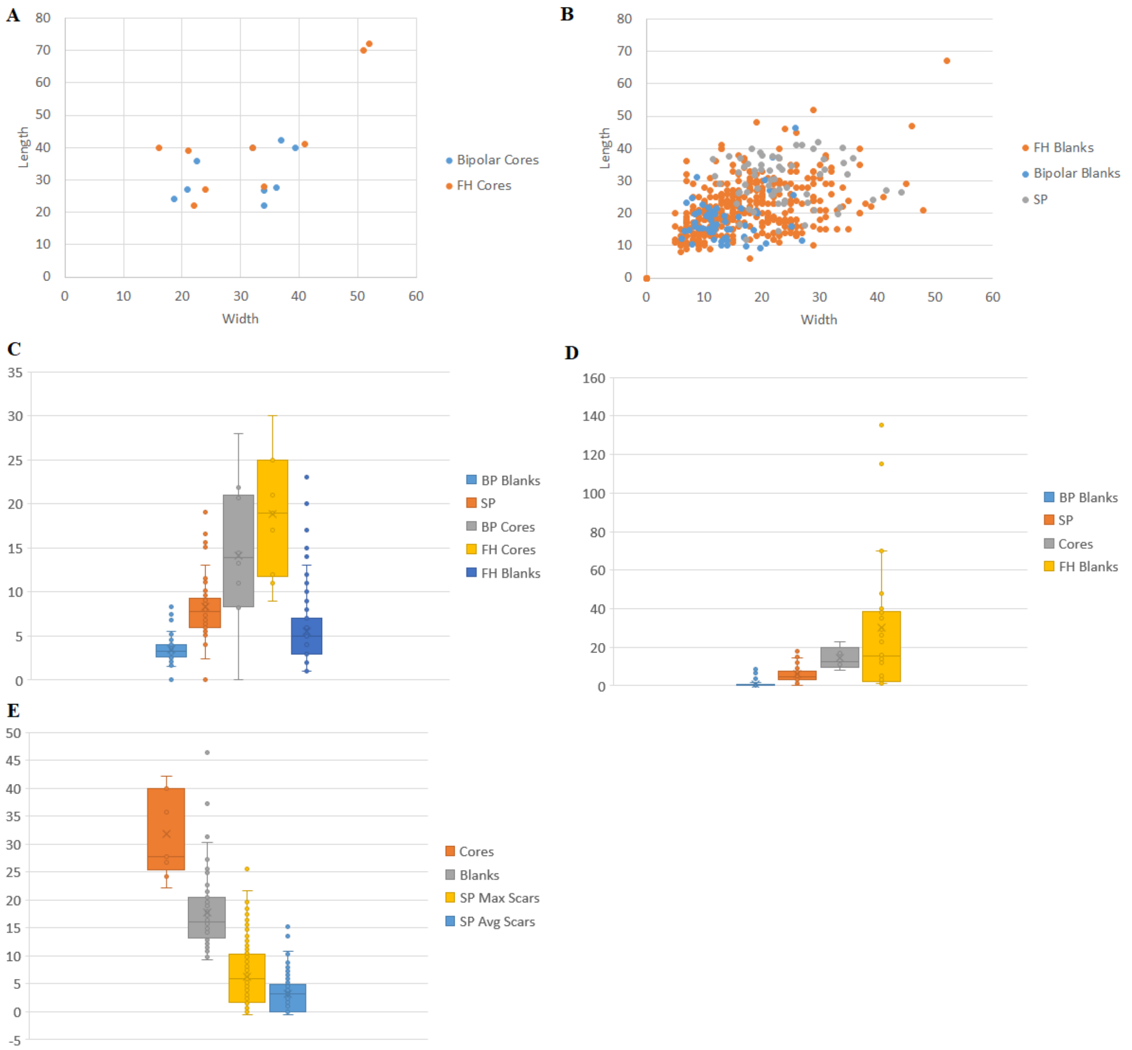


Figure 4. Metric data. FH: Free-hand; SP: splintered pieces; BP: bipolar. Full data available in the SOM.

<u>Split pebbles and split pebble cores</u> A total of 11 split pebbles were found in the IUP sequence, including two posteriorly used as bipolar cores. These pebbles were most likely collected as complete pebbles then split on an anvil, and two were used as a core (on

anvil) to extract flakes. The 2 cores are made on quartz and a quartzite like raw material whose identification is still under study. These cores have large cortical surfaces (50-90%), plain or cortical platforms, a single striking face, only 2 removals each and no apparent reason for abandonment. Interestingly, the blanks extracted from these cores are not currently present in the assemblage. In addition, no formal tools seem to have been made in these raw materials, so pebble use may be expedient. The remaining split pebbles show no evidence of being used after being split. Since we could not refit any of them, it is possible that the "missing halves" have been used, and these were discarded instead. Two of these are sandstone pebbles, another two are in quartz, and the remaining are in other raw materials. All of these have fully cortical dorsal faces. Split pebbles in the sequence have lengths between 19-61mm, widths between 19-42mm, thicknesses between 9-20mm, and weigh 10-12g.

<u>Bipolar Blanks</u> A total of 64 blanks extracted from bipolar methods have been identified in the IUP levels of the sequence. Bipolar blanks share some similarities and some differences from free-hand blanks. Bipolar blanks are 75% (n=48) flakes, 15,6% (n=10) elongated products and the remaining 9,4% (6) are flake fragments (Figure 5.5A). In this case, they are similar to free-hand blanks as the majority of the latter are also flakes (Figure 5.5A). As shown in Figure 5.5B, most blanks (90%) are made on yellow flint, with the other types of flint having similar residual representations (1-3%), following a similar pattern as free-hand blanks. Overall, other similarities between both types of blanks are the following: no cortex (90%), straight profiles (90%), parallel edges (42%), and triangular (60%) cross-sections (Figures 5.5C, 5.5E, 5.5F and 5.5G). Regarding their platforms, the blanks typically have crushed (56%), flat (23%), and smaller percentages of the remaining types (Figure 5.5D). In this case, they are quite different from free-hand blanks since these have a majority of flat platforms. In addition, 24 (42%) of the blanks have stepped tips, 17 (26%) have natural, feather-shaped tips and the remainder have hinged (14%) or other types of terminations (Figure 5.4H). Regarding their EPA, bipolar blanks are highly variable, as opposed to free-hand blanks, which have angles between 75 º and 100º as seen in Figure 5.5I. Of the bipolar blank group, 24 (37,5%) have EPAs between 25º and 50º, 18 (28.1%) have between 50º and 75º EPAs, 14 (21.4%) have between 75º and 100º and with smaller representations less than 25º and over 100º. This variability is likely due to the lesser degree of control that the knapper has used this reduction method, resulting in unpredictable EPAs. Lastly, the main diagnostic feature of

a blank extracted through bipolar methods is its damage. In this manner the damage can be located in the proximal portion in the form of crushing due to the hammering and in the distal portion (passive damage caused by the rebound contact with the anvil). However, distal damage is not always present in these artifacts because the removal does not often cross the whole face of the core. Following this, of the bipolar blanks present in the sequence 75% (n=48) have damage only in the proximal end, 20% (n=13) in both the proximal and distal ends and the remaining 3% (n=2) in the distal end (Figure 5.5J).

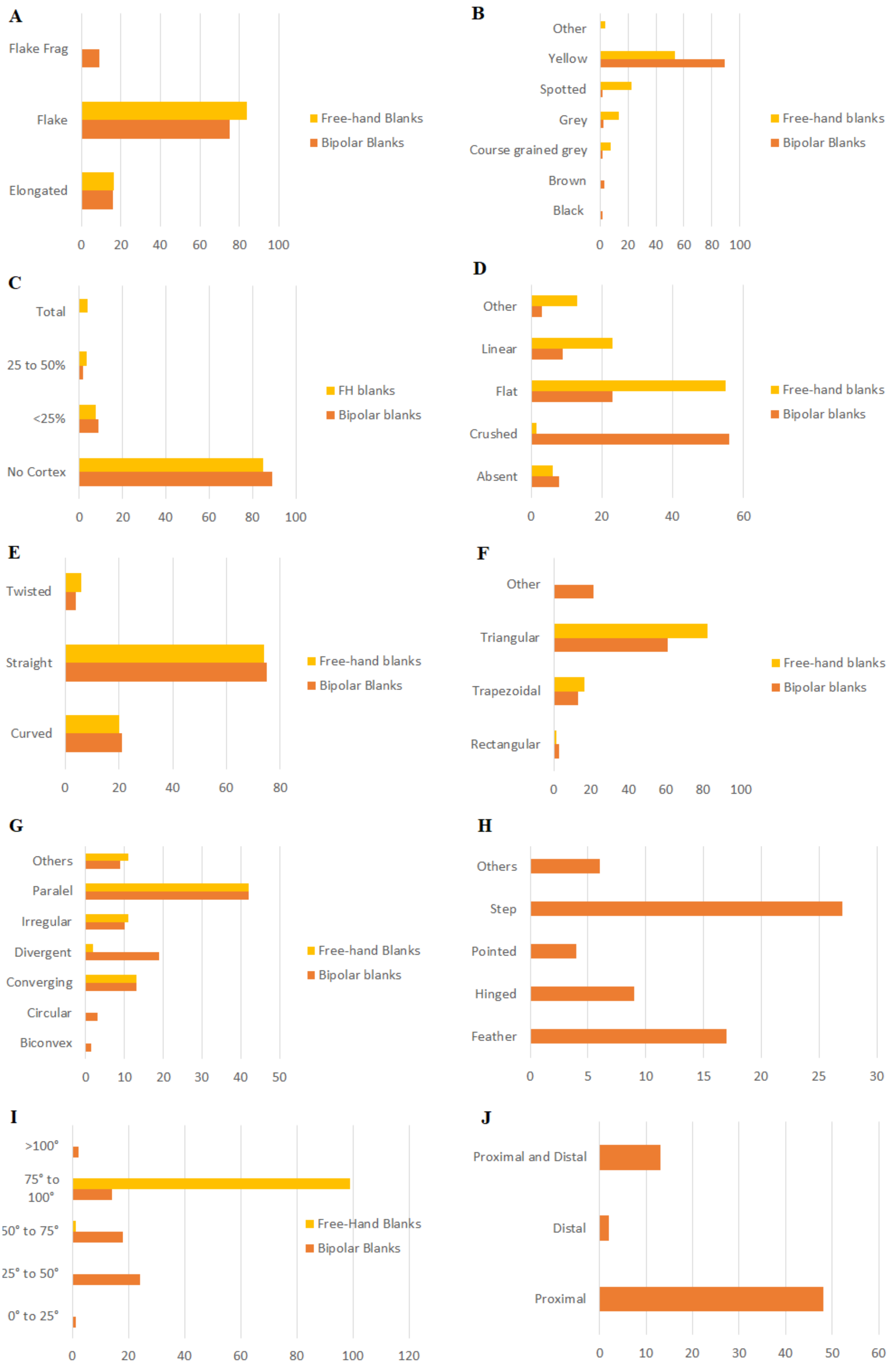

A
Flake Frag
Flake
Elongated
0 20 40 60 80 100
Free-hand Blanks
Bipolar Blanks
B
Other
Yellow
Spotted
Grey
Course grained grey
Brown
Black
0 20 40 60 80 100
Free-hand blanks
Bipolar Blanks
C
Total
25 to 50%
<25%
No Cortex
0 20 40 60 80 100
FH blanks
Bipolar blanks
D
Other
Linear
Flat
Crushed
Absent
0 20 40 60
Free-hand blanks
Bipolar blanks
E
Twisted
Straight
Curved
0 20 40 60 80
Free-hand blanks
Bipolar Blanks
F
Other
Triangular
Trapezoidal
Rectangular
0 20 40 60 80 100
Free-hand blanks
Bipolar blanks
G
Others
Paralel
Irregular
Divergent
Converging
Circular
Biconvex
0 10 20 30 40 50
Free-hand Blanks
Bipolar blanks
H
Others
Step
Pointed
Hinged
Feather
0 5 10 15 20 25 30
I
>100°
75° to 100°
50° to 75°
25° to 50°
0° to 25°
0 20 40 60 80 100 120
Free-Hand Blanks
Bipolar Blanks
J
Proximal and Distal
Distal
Proximal
0 10 20 30 40 50 60

Figure 5.5. Bipolar Blank technological attributes. A: Blank type; B: Raw material type; C: Cortex percentage; D: Butt type; E: Profile; F: Cross-section shape; G: Blank shape; H: Blank termination; I: EPA; J: Damage Location. Full data available in the SOM.

Bipolar blanks are typically smaller than free-hand blanks, splintered pieces, and bipolar cores (Figure 5.4C). Their lengths are between 9-46mm, widths between 6-25mm, thickness between 3-7mm, and weight between 0.3-15g (Figure 5.9B and 5.9D). They are both lighter and thinner than free-hand blanks (Figure 5.4C). In order to understand whether these blanks come from bipolar cores or splintered pieces, we compared their length to the average scar length of splintered pieces and the maximum scar length of both bipolar cores and splintered pieces. As shown in figure 5.4E, bipolar blanks fall in between bipolar core scars and splintered pieces maximum scar lengths. As a result, we conclude that they come from bipolar cores and, on rare occasions, splintered pieces.

<u>Splintered pieces</u> A total of 129 (49.6% of the total sample) splintered pieces were analyzed from the IUP levels of Bacho Kiro. Of these, 92 (71.3%) were made in yellow flint, followed by 20 (15.5%) in spotted flint and minor frequencies of the remaining raw materials (Figure 5.5A). Due to the high degree of damage and reduction observed, the original blank is not identifiable in one third of cases. In the remainder of the cases these artifacts were originally flakes (28.2%), indistinguishable between blade and flakes (17.7%), former blank fragments (8%), and others. Most splintered pieces exhibit no cortex, straight profiles, parallel edges, and cross-sections that are quadrangular, triangular, or trapezoidal (Figure 5.5).

Figure 5.6. Splintered pieces technological attributes: Blank type; B: Raw material type; C: Cortex percentage; D: Butt type; E: Profile; F: Cross-section shape; G: Blank shape. Full data available in the SOM.

Splintered pieces show high fracturing rates, which is typical when these artifacts are used as wedges *(Tixier, 1963; Kolobova et al., 2021; Horta and Chiotti, Submitted)*. Specifically, only 64 (49.6%) splintered pieces are complete (Figure 5.6A). The remaining (n=65) exhibit large fractures that might have led to their abandonment. In these cases, large transversal fractures (49%) and longitudinal fractures (26%) are more frequent (Figure 5.6B). In addition, 6 (9.2%) splintered pieces exhibit oblique, and another 6 show split fractures (when the tool breaks in half, akin to a Siret accident).

The use of these tools was done following their technological axis (85% of cases), with most likely the striking platform being used as the active (hammered) platform of the tool and the distal end as the passive (in contact with the organic or stone anvil). Recent experimental work has suggested that the damage mainly occurs on the active platform of each tool (de la Peña, 2011; Kolobova et al., 2021). Considering this, it is not surprising that the platform of blanks is used as the active platform since it is usually thicker and can withstand more blows. Still, up to 89% of these tools were rotated (180º) during use, perpendicularly to their technological axis, resulting in 2 damaged platforms. Several other tools (7.8%) were rotated both vertically and at other angles multiple times (exhibiting 3, 4, or more damaged platforms), and only in 3% of cases these tools were used unidirectionally (Figure 5.6C). The rotation was likely to maximize each artifact's potential as a tool. As a result of this rotation and the intensity of use, most tools have highly or medium damaged platforms, with little to no traces left of the original platforms (Figure 5.6E). When it comes to scars, splintered pieces have: aligned (54%) or aligned/overlapped (32%) scar dispositions (Figure 5.6D); scars are distributed throughout the entirety of the platforms (28%) (Figure 5.6F); marginal scar extension (Figure 5.6G); and bifacial scar distribution (Figure 5.6H).

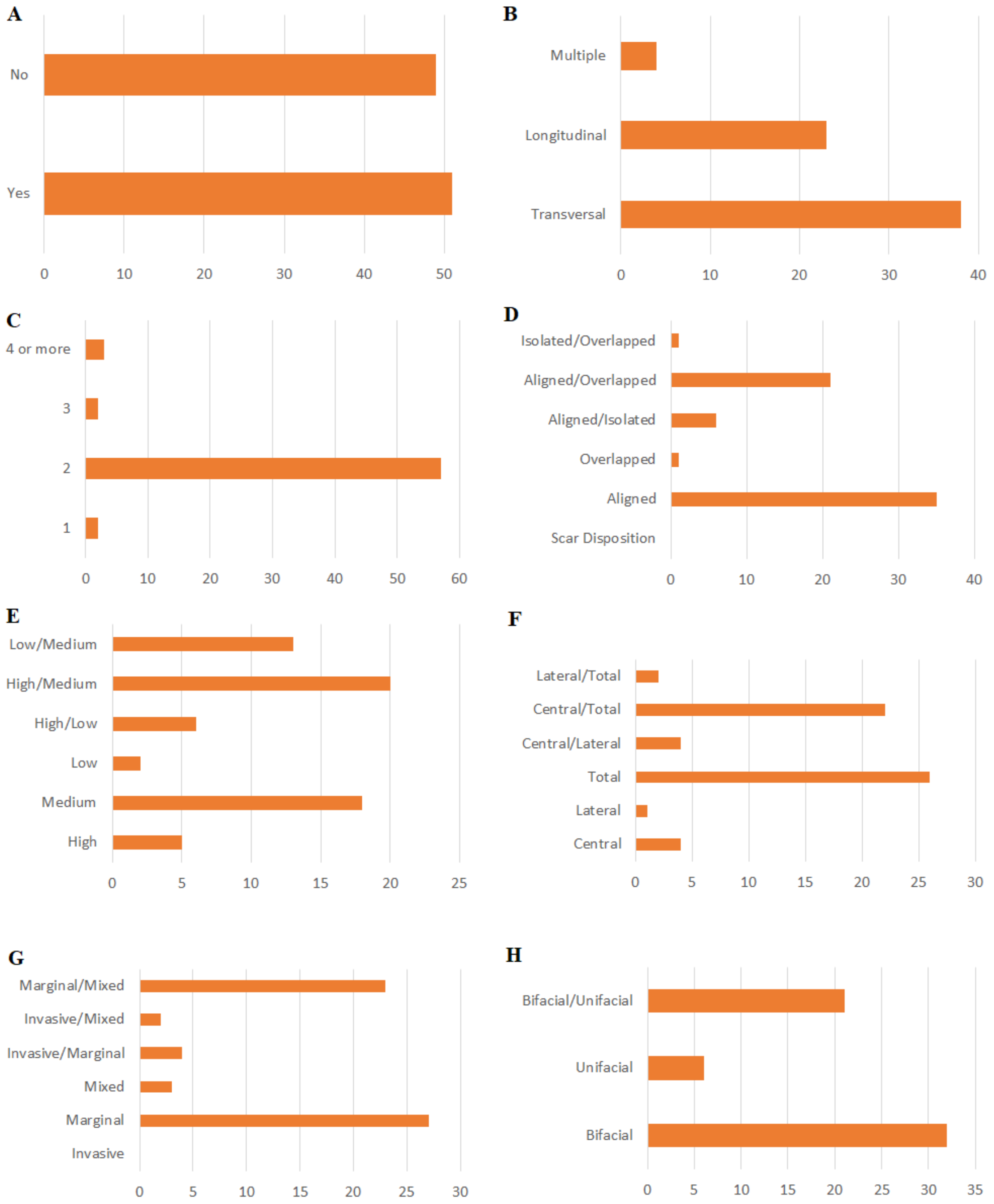


Figure 5.7. Splintered piece morpho-functional attributes. A: Fracture Presence; B: Fracture Type; C: Number of damaged platforms; D: Scar Disposition: E: Platform Damage Degree; F: Scar Distribution; G: Scar extension; H: Scar Facial Distribution. Full data available in the SOM.

Splintered piece lengths are between 11-41mm, widths between 11-44mm, thickness between 2-19mm and weight between 2-17g (Figures 5.4B, 5.4C and 5.4D). On average, they have similar sizes to bipolar cores, except for being lighter and thinner (Figures 5.4C and 5.4D). Most of them are re-used free-hand blanks, their compared sizes (Figure 5.4B) are similar (with splintered pieces being slightly smaller on average). Regarding scar size, most splintered piece scars have between 1-5mm of length and maximum sizes of 5-10mm, occasionally having up to 25mm (Figure 5.7). Therefore, the byproducts splintering from these tools were primarily chips or very small flakes. Previous studies (Kolobova et al., 2021) have identified reduction sequences using length and width, namely through an index of reduction. Following these methods, we found that most splintered pieces (80%) were abandoned either when the length was reduced to the same size as the width or very close to it (Figure 5.8). When combining this reduction index with our quantitative and qualitative data, we conclude that complete splintered pieces were abandoned either at the exhaustion point or close.

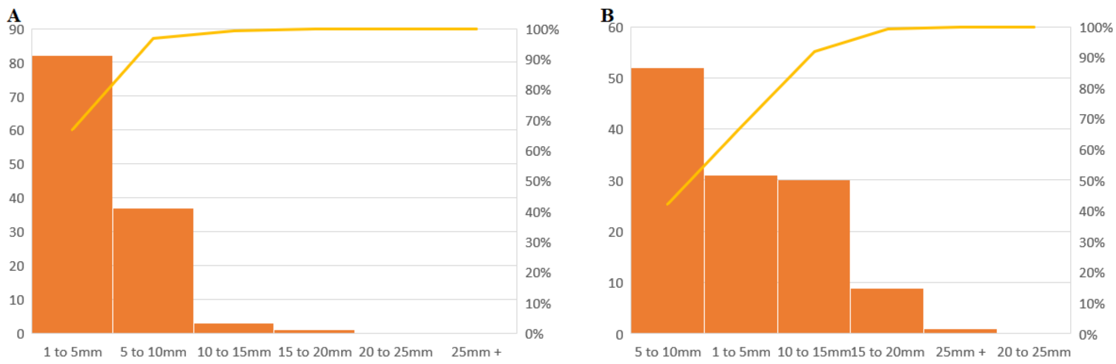


Figure 5.8. Metric data for splintered pieces. Full data available in the SOM.

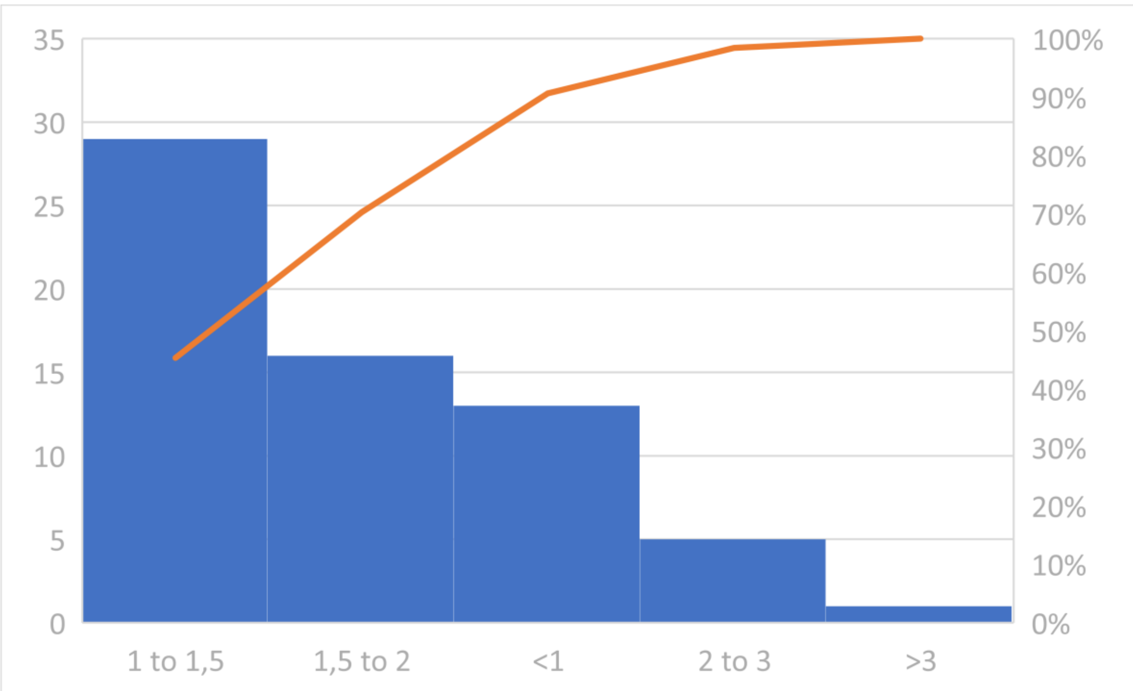


Figure 5.9. Splintered piece reduction index. Full data available in the SOM.

Additionally, we found 4 artifacts that had several identifiable stages of use. We considered them splintered pieces for methodological reasons since this was their last use. However, these artifacts had up to 3 stages of use, with wedging always being the final stage (see Figure 5.9). This, due to the highly destructive nature of wedging, is not surprising. Still, these data reaffirm the intensive nature of reducing and maximizing efficacy in resource exploitation at the site.

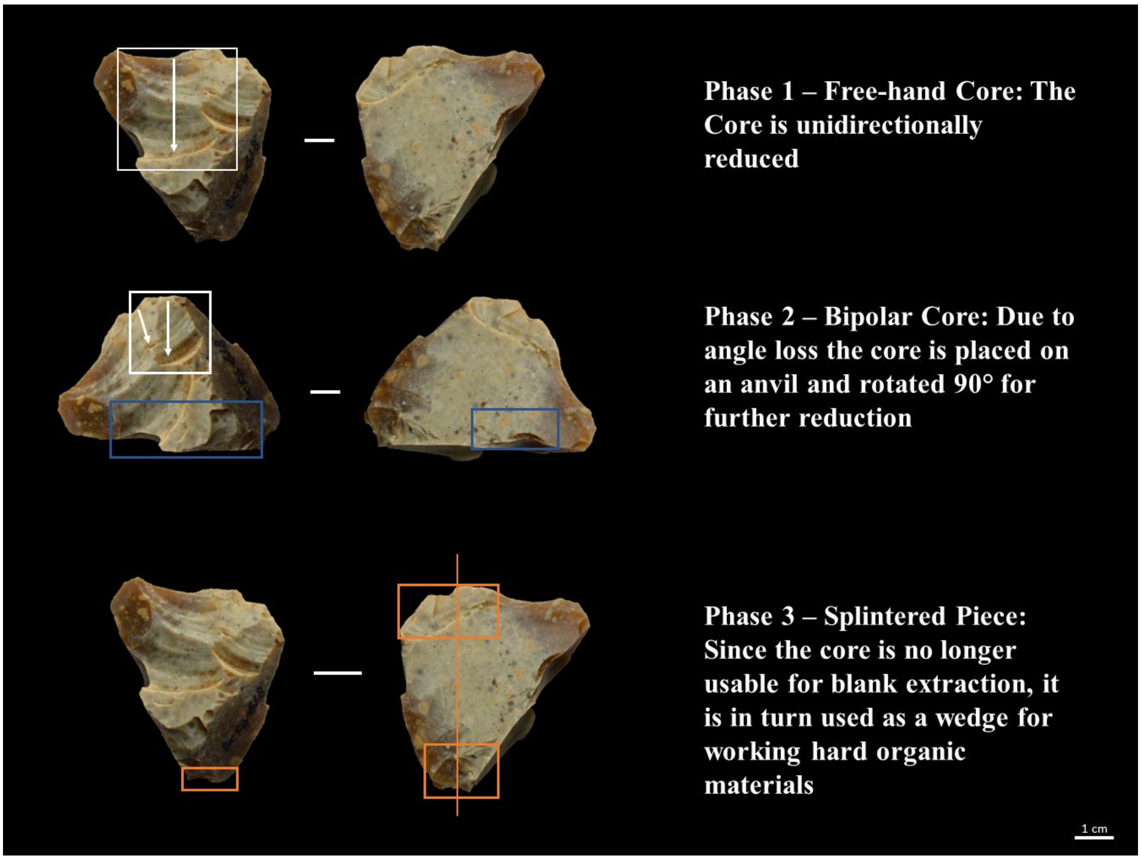


Figure 5.10. Artifacts with several phases of reduction. White represents the direction of percussion; blue squares represent the anvil damage; orange squares represent wedging damage.

Anvils Throughout the sequence, we found 29 stone slabs in which we were able to identify a range of surface alterations congruent with their use as anvils. Interestingly, all of the anvils found come from the IUP levels. Anvils were also identified by Kowsloski (1982) in previous excavations. As observed in the materials collected in the 70s, nearly all anvils (96%) were "made" on sandstone slabs, with one other in a raw material akin to quartzite. Sandstone slabs are quite common around the site and especially on the plateau above the cave, so these were most likely locally sourced. Three types of features were identified on the anvils: (1) impact features likely caused by bipolar knapping (possibly even wedging activities, although this remains to be tested), (2) grinding features, and (3) traces of residue (Figure 5.10A). In terms of traces, impact features are most common (51%), and with slightly lesser representation (44.9%), the combination of impact and grinding features, and less common are anvils with only residue traces (3.4%). As shown in Figure 5.10B, most anvils have between 1 to 5 impact features present on the surface, followed by 6 to 10 (24%) and with lesser representation 11 to 15 (7%) and 16 to 20 (10%). Traces are distributed either in the central portion of the anvil (48% of cases), near the extremities (31%) or a mixture of both (20.7%) (Figure 5.10C). From a stability standpoint, it is expected that the central area would be preferred for knapping. Still since impact features are found near the extremities and in some cases in the extremity itself this may have led to the fracturing of the slab itself. It is important to note that the slabs are also fragments of larger slabs and whether they are simply collected as is, purposely broken to be transported, or fractured during use, remains to be tested. Still, 44% of the anvils (n=13) the remaining seem to have been abandoned to a large fracture that split the anvil, possibly due to use, while the remaining (55%) show no apparent reason for abandonment (Figure 5.10D).

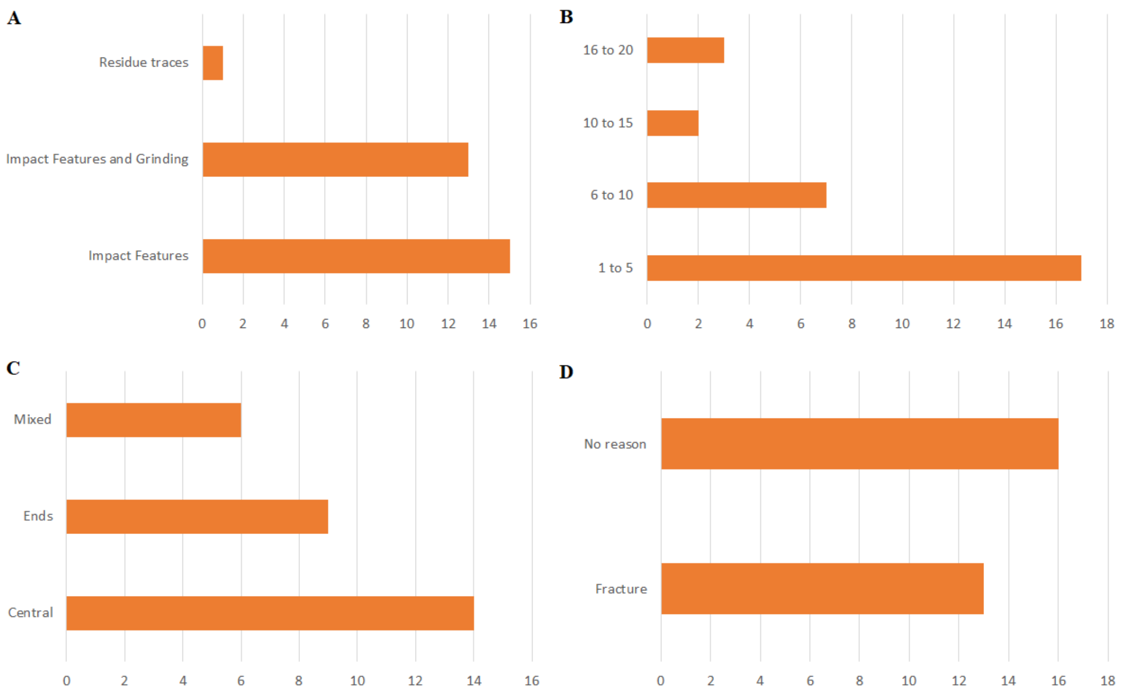


Figure 5.10. Anvil attributes. A: Type of Surface Traces; B: Number of Features; C: Feature Distribution; D: Reason for Abandonment. Full data available in the SOM.

As shown in Figures 5.11 and 5.12, anvils are, as expected, larger and heavier than the rest of the assemblage. We considered the longest morphological axis as length and the following as width for these artifacts. Anvils have lengths between 75-154mm, widths between 62-143mm, thicknesses between 12-57mm, and weights between 200-1000g.

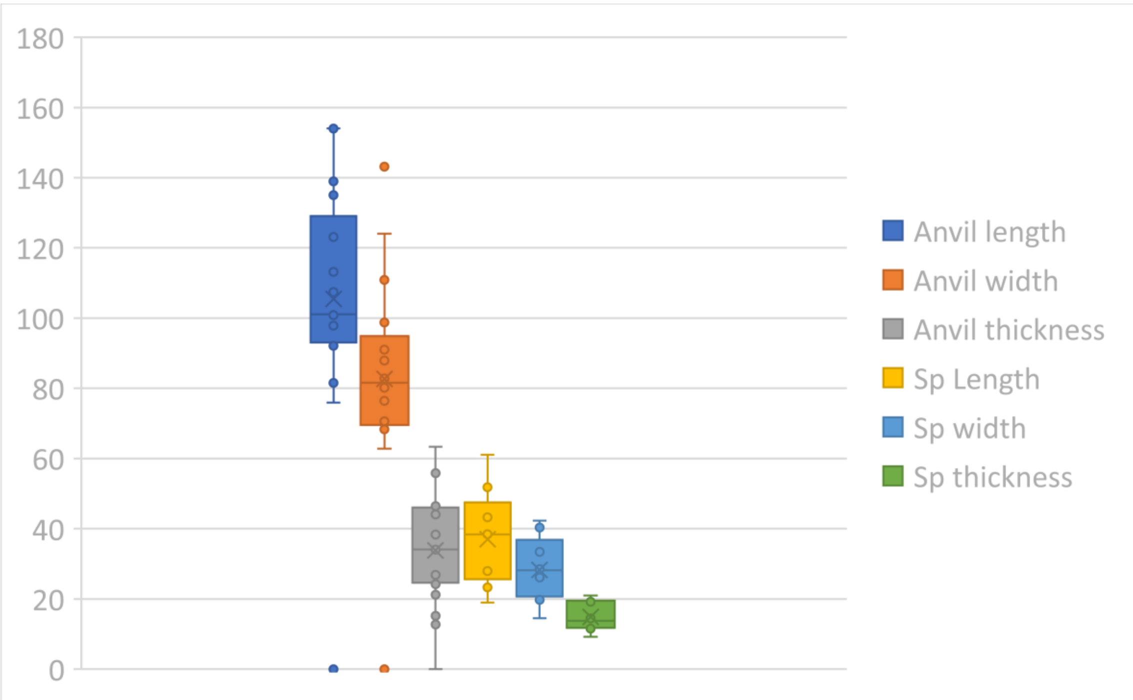


Figure 5.11. Anvil and split pebble metrics. Full data available in the SOM.

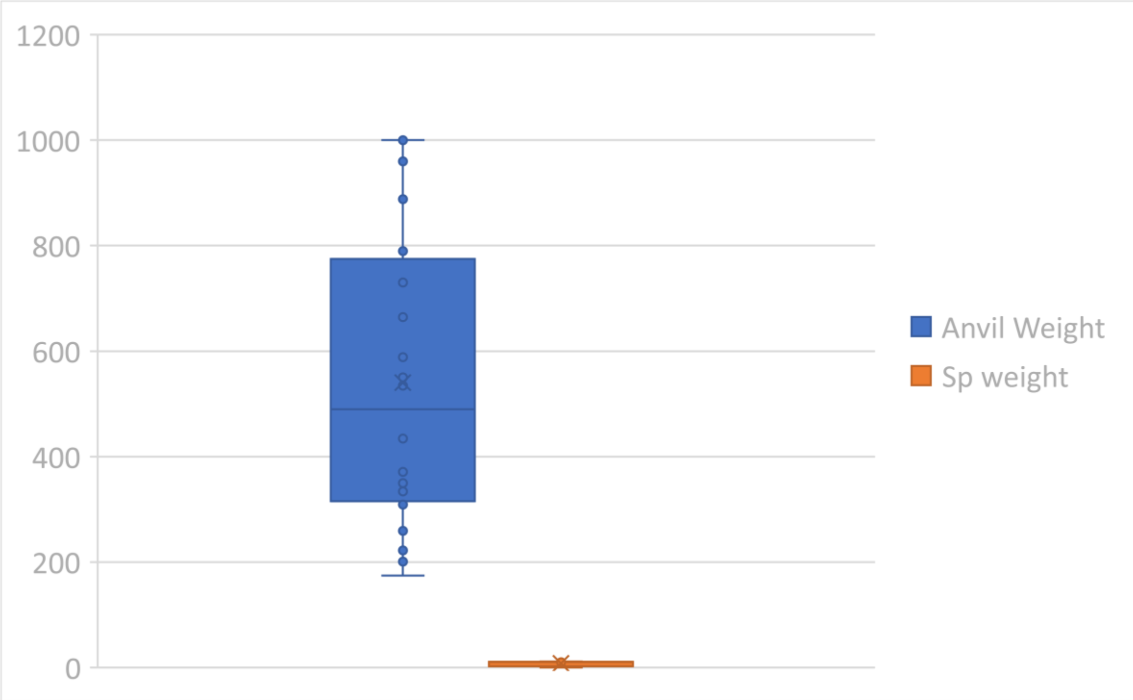


Figure 5.12. Anvil and split pebble weight. Full data available in the SOM.

5.4 Discussion and Conclusions

This paper and the results presented here represent the first in-depth analysis of bipolar technology in Bacho Kiro cave and IUP contexts. It is important to note that bipolar technology is present in other IUP occupations, namely in sites in Central Mongolia, China, and Turkey (Kuhn, 2004a; Rybin, 2014; Niu et al., 2016). In these sites, bipolar knapping seems relatively expedient, having low representations in their assemblages. The same can be noted when referring to splintered piece representation. As a result, little attention has been paid to understanding the effective role this strategy may have had in these occupations.

Our results show that Bacho Kiro Cave's IUP is a unique case for the use and understanding of bipolar techniques. The assemblage includes the current spectrum of bipolar artifacts types (bipolar cores, bipolar blanks, anvils, splintered pieces, and bipolar split pebbles). In terms of representation, bipolar cores currently represent 50% of all cores in the IUP, and splintered pieces present 31% of all tool types. In turn, this represents some of the highest frequency and representation of this technology in Europe outside of the Uluzzian (Gambassini and Napoleone, 1997; Kaczanowska et al., 2011; De

Stefani et al., 2012; Dini and Tozzi, 2012; Peresani, 2012; Peresani et al., 2016, 2019; Villa et al., 2018).

Our results suggest that several activities were carried out at the site with bipolar methods: knapping, wedging, and bone grinding. Bipolar knapping is present in the form of bipolar cores and blanks, splintered pieces were used as wedges for working hard organic materials, and anvils were used as bases for these activities. Our data aligns with Kozlowsky’s (1982), who recognized the use of sandstone slabs as anvils through impact features and indentations caused by grinding. Sandstone slabs would be collected locally to be used as anvils for these activities. Sandstone slabs are numerous in the Dryanovo river (less than 200m from the site) and the plateau above the cave in regular rectangular shapes. These would be the natural choice for anvils as their size and morphology allow for stable surfaces for indirect percussion. Another advantage is their rugged surface, which would be optimal for bone grinding (see Martisius et al., 2022) and core stability. Several of the anvils are fractured, and the reason for this is yet to be explored. These fractures could have occurred during use due to the constant violent blow they indirectly received, or these could have happened during the moment of collection. In the latter, larger slabs could have been purposely split or fractured to make them smaller and more mobile for transportation to the site. Nevertheless, it is clear that these played an incremental role by enabling the use of bipolar methods at the site.

In Europe, bipolar knapping is not a rare occurrence in Upper Paleolithic assemblages (Zilhão, 1997; Peresani, 2012; de la Peña Alonso and Toscano, 2013; Peresani et al., 2016, 2016b; Kandel et al., 2017; Horta et al., 2019; Arrighi et al., 2020; Horta and Chiotti, Submitted) and to a lesser extent in Middle Paleolithic assemblages (Moncel et al., 2012; Márquez et al., 2013; Van Kolfschoten et al., 2015; Tillier et al., 2017; Villa et al., 2018). In the IUP, this technique is noted in the Tolbor sites in Mongolia (Derevianko et al., 2007; Rybin, 2014) and Üçağızlı Cave in Turkey (Kuhn, 2004a) as a means of blade production. However, this does not appear to be the case in Bacho Kiro, where most bipolar cores are flake cores. Since the cores themselves have a high degree of reuse, it is possible that bipolar blade production happened in earlier stages of reduction, although we currently have no evidence to support this hypothesis. Bacho Kiro is similar to Shuidonggou locality 7 and Northern China (Zhang, 2002; Niu et al., 2016) in this regard, where both bipolar and free-hand methods are used for flake production. The main difference is the higher frequency of this technique in Bacho Kiro compared to any of the other IUP sites.

Our results show that bipolar knapping seems to have been a recurrent practice in Bacho Kiro. Interestingly, bipolar reduction seems to happen as a final phase of a reduction sequence rather than a primary means of reducing unmodified raw material volumes. Previous studies (Hublin et al., 2020; Tsanova et al., 2020) have suggested that the raw materials were sourced between 80 and 150km away from the site. Raw material conservation has often been one of bipolar knapping's advantages (Gurtov and Eren, 2014a; Hiscock, 2015a; Shea, 2015; Pargeter and de la Peña, 2017; Pargeter et al., 2019; Horta et al., Under review). Previous studies (Kozlowski, 1982; Tsanova, 2006) noted a high degree of re-debitage happening at the site, which our results reaffirm. All but one flint bipolar core in the assemblage had previous reduction stages, including cores-on-flakes. Cores (and even large flakes or fragments) would initially be reduced through free-hand methods and then placed on an anvil for continuous reduction and used as wedges afterward.

While this is the case for all flint types, the quartz and quartzite cores were primarily reduced on anvil for blank extraction. These cores were originally pebbles likely sourced locally from the nearby Dryanovo river. Raw material conservation is likely not a factor since these cores have a relatively low number of scars, and blanks in these raw materials are rare. Additionally, we found that small pebbles of variant knapping quality were split on anvil to be later used for other activities. These mostly have no flaking scars, unlike the cores, so their use is currently unknown. In Africa, the use of bipolar methods as a means of splitting and reducing pebbles is a common occurrence in assemblages from the Early, Middle, and Later Stone Age through to the Holocene (Barham, 1987; de la Torre et al., 2003; Villa et al., 2010; Barham et al., 2011; de la Torre, 2011; Gurtov and Eren, 2014a; Arroyo and de la Torre, 2017; Pargeter and de la Peña, 2017). For bipolar reduction, constraints such as small core sizes, raw material hardness, and quality, irregular shapes, steep platforms, or the requirement of larger amounts of force are neglectable since the core is supported on a surface and not hand-held (Hiscock, 2015b, 2015a; Horta et al., Under review). Therefore, it is an efficient method to continuously reduce cores of any shape or raw material and/or even tools and blanks such as large flakes or blades.

Additionally, it offers high productivity of various blank types characterized by different size, morphology and edge delineation, and rectilinear profiles (Moroni et al., 2018; Arrighi et al., 2020; Collina et al., 2020). Considering this, it is not surprising that the IUP *Homo sapiens* at Bacho Kiro would frequently use bipolar methods. High-quality raw material was scarce, and there was a clear need to economize and maximize the efficiency in its use. Bipolar knapping allowed for maximizing blank production as a means of high-quality (flint) raw material conservation. In addition, it provided a fast, least cost, and more effective solution for expedient reduction of local pebbles.

Our results conclude that splintered pieces were used as wedges for working organic materials and therefore are not bipolar cores. Splintered pieces were intensively used as wedges for working hard organic materials during the IUP in Bacho Kiro. However, we do not discard the possibility that byproducts removed from splintered pieces during wedging were not used. In fact, due to the high degree of raw material conservation at the site, it is a possibility. It is important to remember that there is no control on what "splinters" from the wedge during use, so blanks cannot be predicted. This high degree of uncertainty in blank prediction does not match all other technological and economic traits observed in the assemblage. As shown in Figure 5.9, cores were occasionally re-used as wedges, but never the other way around. As a result, we find the hypothesis that splintered pieces could have been used as cores themselves not valid at the site.

Wedging was an important recurrent activity at the site, as there is recurring evidence of intensive re-use of artifacts as wedges. Flakes, blades, cores, former tools, and fragments were all used as wedges, turning them into splintered pieces. Any stone tool with usable morphology (straight edges) was used as a wedge. This activity was intensively performed until the tool was no longer usable. Over half of the wedges were abandoned after a large fracture occurred, and the remaining show high degrees of reduction. These tools were either being used to exhaustion or close to it. Often, one-third of them are so modified that no traces of the original blank can be found. The maximization of each tool's potential was likely a concern as several wedges were rotated at a variety of different angles in order to be still efficient for use. Our results align with use wear data that suggests (Marreiros et al., 2019) that splintered pieces have been highly modified and show intensive development of microwear and were used for bone, wood, and hide working. In addition to splintered pieces, we found evidence at the site for bone wedges (Smith et al., 2021; Martisius et al., 2022). These follow the same type and intensity of use pattern that we observed in stone wedges. Stone wedges were used for processing bone, wood, antler, and hide. Being a softer material, bone wedges mainly were used for processing wood and hide (Martisius et al., 2022). As in stone wedges, these were intensively used as they seem to have been abandoned only after suffering fractures that compromised their use as tools. Bone wedges were chosen from long bone diaphyseal fragments of medium to large mammals, and like stone wedges, are extremely variable (Martisius et al., 2022). Interestingly, several bone wedges show evidence of being initially shaped through wedging themselves. Being a rarer raw material, these tools were likely used as a compliment to stone wedges that were more numerous and “harder”.

Wedging evidence is also widely present at the site, from carcass processing to bone tool and ornament production (Smith et al., 2021; Martisius et al., 2022). Carcass modifications (deliberate impact features (Lyman, 1994; Fisher, 1995) produced by wedging for bone marrow extraction are persistent in *Bos/Bison*, cervids, and cave bear remains (Smith et al., 2021). The link between wedging and carcass processing (including bone marrow extraction) as resource intensification strategies has been noted in other UP assemblages (Horta et al., 2019; Manne, 2014, 2010). Likewise, wedging evidence is commonly found in bone tools, as these were often shaped prior to their use (Martisius et al., Under review). These modifications include, as previously stated, shaping bone as wedges. The use of wedges to fracture hard animal tissues allows for more control during the fracturing process and is a crucial method in developing osseous technologies (Horta et al., 2019, Under review; LeBlanc, 1992). Wedging also played a role in ornament production. While this relation is still to be explored in detail, few studies have explored this possibility, including finding direct evidence in the Uluzzian (di Cesnola, 1993; Horta et al., Under review; Martisius et al., 2022). Martisius et al. (2022) state that grooving techniques are most common for pendants and notched pieces. However, there is little evidence that they grooved bone prior to inserting a wedge for splitting.

Little evidence has been found for wedging in the IUP other than the presence of splintered pieces in low frequencies (Kuhn, 2004a; Niu et al., 2016). This technique seems unique to *Homo sapiens*, with little to no evidence being found in Neanderthal occupations (Horta et al., 2022). Evidence for splintered pieces has been reported in Italian Middle Paleolithic occupations (Peresani, 2012; Villa et al., 2018). However, there is no evidence that these were used as wedges. Evidence for wedging activities has been reported in late MSA occupations in Southern Africa and is common in LSA and Upper

Paleolithic assemblages (Langejans, 2012; de la Peña Alonso and Toscano, 2013; Igreja and Porraz, 2013; Bader et al., 2015; Kandel et al., 2017; Horta et al., 2019, Under review; Kolobova et al., 2021; Horta and Chiotti, Submitted).

Overall, our results show that the Bacho Kiro assemblage and the use of bipolar methods make it stand out as a unique case during the IUP. *Homo sapiens* were strategically using bipolar methods to maximize their adaptability to the environment. High-quality raw material sources were far from the site, so bipolar knapping was recurrently used as a means of raw material conservation. This was done by continuously reducing former cores, blanks, and tools to keep producing blanks. In addition, local pebbles of coarser raw materials were also efficiently reduced with bipolar methods. In these cases, bipolar methods provided a more efficient way of reduction for maximizing high-quality raw material conservation and a fast, least-cost solution for expediently obtaining sharp edges by reducing coarser raw materials (Hayden, 1980; Duke and Pargeter, 2015; Hiscock, 2015b, 2015a). The cave occupation during the IUP, happened during a very cold moment (Pederzani et al., 2021). Wedging was turned to in order to combat economic scarcity by enhancing carcass processing activities. This, in turn, allowed for efficient limb splitting and bone marrow extraction (which provided important caloric value). Wedging further enabled efficient bone tool and ornament manufacture, turning carcasses into raw material and enhancing wood and hide processing.

Bipolar methods were used as a means to enhance resource extraction strategies, allowing *Homo sapiens* to be able to survive during adverse environmental pressures. While Bacho Kiro currently represents the oldest *Homo sapiens* in Europe, it represents a unique case of adaptation strategies through bipolar methods. Primarily through the level to which efficacy was considered in every adaptation aspect. The use of bipolar methods as an answer to maximize adaptability shows a clear and deep understanding of the advantages of these methods. *Homo sapiens* combined IUP technology with recurring use of bipolar technology akin to Uluzzian or LSA occupations, resulting in a unique technology catered to maximize adaptability to hostile environments. Whether these methods are a latent solution (Tennie et al., 2016, 2017) for problem-solving remains to be confirmed. However, the adaptive advantages of using these methods cannot be underestimated. Lastly, as the differences and similarities between Neanderthals and *Homo sapiens* continue to be debated, it is imperative to understand how both groups evaluated and achieved efficiency by using stone resources for mediating environmental pressure and the use of bipolar methods provides such comparison.

Chapter VI

RESULTS – SITE COMPARISON

In combination, all four papers included in this thesis provide a unique insight into how the different early *Homo sapiens* groups adapted across Europe to different ecological settings. The first paper (chapter 2) explores questions related to hominin mobility and survival, proving vital for understanding bipolar technology beyond its technological aspects in each site. Chapters 3-5 provided unique case studies to explore how humans used bipolar methods to adapt across Europe. Based on the data previously shown, it is safe to say that bipolar technology was an essential part of adaptive strategies during the onset of the Upper Paleolithic. In order to understand how different variables (e.g., distance to raw material sources, bipolar tool function, and blank production) impacted the way bipolar methods were used, this chapter combines aspects from these previous chapters by comparing the data extracted from the three sites.

Bacho Kiro (BK), Abri Pataud (AP), and Vale Boi (VB) represent the earliest human occupations containing bipolar technology in each respective region (T. Higham et al., 2011; Bicho et al., 2012; Fewlass et al., 2020). Despite this, there is a clear chronological, populational, and technological gap between each site. Bacho Kiro Cave's earliest human occupation occurs between c. 45-43ka cal BP (Fewlass et al., 2020). Abri Pataud's earliest occupation is dated to c. 40-38k cal BP and the subsequent from c. 37.5 to 35ka cal BP (T. Higham et al., 2011). Vale Boi's earliest occupation is dated to c. 32 ka cal BP and the site was continuously occupied throughout the Upper Paleolithic. Technologically, Bacho Kiro's analyzed assemblage is attributed to the IUP industry (Tsanova, 2006; Hublin et al., 2020), Abri Pataud's to the Aurignacian industry (Chiotti, 2005), and Vale Boi's to the Gravettian, Solutrean, Proto-Solutrean and Magdalenian industries. All of these industries have differences among them; however, the presence of bipolar technology is a connecting factor. While there is currently no data available for aDNA on either Vale Boi or Abri Pataud, the first humans who occupied Europe and, therefore, Bacho Kiro cave are not genetically connected to either the Aurignacian people who settled across Europe (Hajdinjak et al., 2021) or (hypothetically) the Gravettian population who occupied Vale Boi (Fu et al., 2016). So not only were these sites spread chronologically, technologically, and culturally, but they also had different (genetic) populations occupying them. Still, since bipolar technology was used in each site and they all encompass episodes of early human adaptation, comparisons can still be made.

As shown in previous chapters, all three sites have different frequencies and types of bipolar artifacts. As a result, only splintered pieces and bipolar cores are found in all three assemblages. Therefore, split pebbles and anvils will not be considered. For direct comparison purposes, all Vale Boi's splintered pieces will be considered because they have no functional or technological differences throughout the sequence. In Abri Pataud, each single occupation will be considered because splintered pieces had differences in their frequency and use degree. Because both Abri Pataud and Bacho Kiro's assemblages are made on flint, only the flint Vale Boi's splintered pieces will be considered for direct comparison. A single exception is made when calculating splintered piece frequency amongst the tools in Vale Boi, in which case the quartz splintered pieces are also considered. Since access to an Uluzzian occupation was not possible, data from Riparo Broin (RB) and Grotta di Fumane (GF) (Peresani et al., 2016, 2019) was adapted and included for comparison providing comparable data from Italy during this timeframe (particularly, between c. 45-40ka BP).

According to the data from Chapter 2 (Horta et al., 2022), during the Final Late Pleistocene (after 50ka BP), occupations across the globe tended to have either splintered pieces or a mixture of splintered pieces and bipolar cores, as observed in the sites mentioned above. Table 6.1 shows the frequencies of bipolar technology in each site. Regarding splintered pieces frequency, Riparo Broin (RB) has the highest frequency of all occupations with this morphotype, representing 75.58% of the tools in the assemblage, followed by BK with 31% and GF with 29.51%. Vale Boi has the fourth-highest frequency with 19%, and then Abri Pataud's Early Aurignacian short occupations (APEAs) with 6.2%. Abri Pataud's Early Aurignacian long occupation (APEAl) and the Evolved Aurignacian occupations also have low representation of 7% and 1.6%, respectively.

Regarding the presence of bipolar cores, BK has the highest representation with 51% of bipolar cores. To a lesser extent, bipolar cores represent 2.5% of cores in VB and 2% APEAs. Notably, bipolar cores are not present in either of Uluzzian occupations (Peresani et al., 2016, 2019), neither in APEAl nor APEvA. However, it is important to note that in both Uluzzian occupations, splintered pieces have been interpreted as cores (Peresani et al., 2016, 2019), while in the APEAl and APEvA, there are simply no bipolar cores. If one considers the splintered pieces in the Ulluzian occupations as bipolar cores, then RB would have the highest representation of 97.35% and GF 38.75% being lower than BK and following the same trend seen in splintered pieces frequency.

In terms of representation, all sites have more splintered pieces than bipolar cores, which is not surprising considering cores are less common than tools in most assemblages. Still, as shown in Table 6.1, BK has the closest splintered piece to core ratio (16:1) followed by APEAs and VB. Neither of the Uluzzian occupations was considered since it would be a 1:1 ratio as splintered pieces were all considered as cores. BK has the highest bipolar blank to core ratio (8:1) when compared to APEAs (5:1) or (if including the Ulluzian data) GF (~3:1) and RB (~11:6).

Table 6.1. Frequency of bipolar artifacts per raw material type. TI – Typological Index; VB's TI was calculated based on chapter 3's frequency table (Cascalheira 2013, Marreiros 2013). It does not include the data presented in the rest of the chapter because the site area has no data on the retouched tools' frequency. Meanwhile, the N does include the analyzed splintered pieces.

	Splintered pieces (SP)		**Bipolar Cores (BC)**		**Bipolar Blanks**		**SP to BC Ratio**	**Blank to BC ratio**
	N	**TI**	**N**	**%**	**N**	**%**		
APEAl	14	7	-	-	-	-	-	-
APEAs	98	6,22	3	2	15	0,2	~33:1	5:1
APEvA	25	1,6	-	-	1	0,03	-	-
BK	129	31	8	51	62	6,6	16:1	~8:1
VB	182	19	5	2.5	-	-	~37:1	-
RB	294	75,58	**294***	**97.35***	544	89	-	~116
GF	31	29,52	**31***	**38.75***	91	11,14	-	~3:1

*SPs were interpreted as BC and no pure typologically BCs were identified at the sites.

Regarding the analyzed bipolar cores, as shown in Figures 6.1, 6.2, and 6.3 APEAs cores are generally larger, wider, thicker, and heavier than BK's or VB's, which are relatively similar when it comes to metrics. The main difference being VB's are typically smaller and lighter. Regarding the number of extracted blanks (Figure 6.4), BK's cores have more scars than the other two occupations. Still, VB has the largest blank scars (Figure 6.5), despite being the smallest cores. Interestingly, APEAs' cores have the smallest scars while being the largest, most likely linked to core reduction intensity. Considering the combination of number of blank scars and size, BK's cores show the most intensive reduction, followed by VB and finally APEAs.

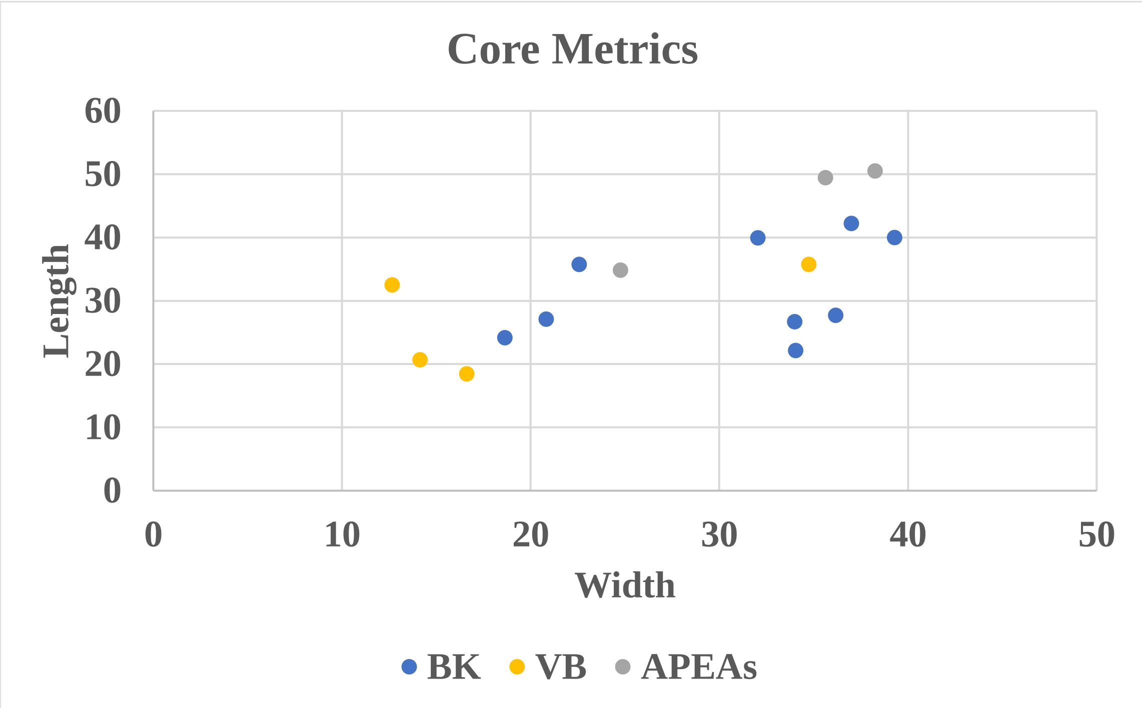


Figure 6.1. Core metric comparison.

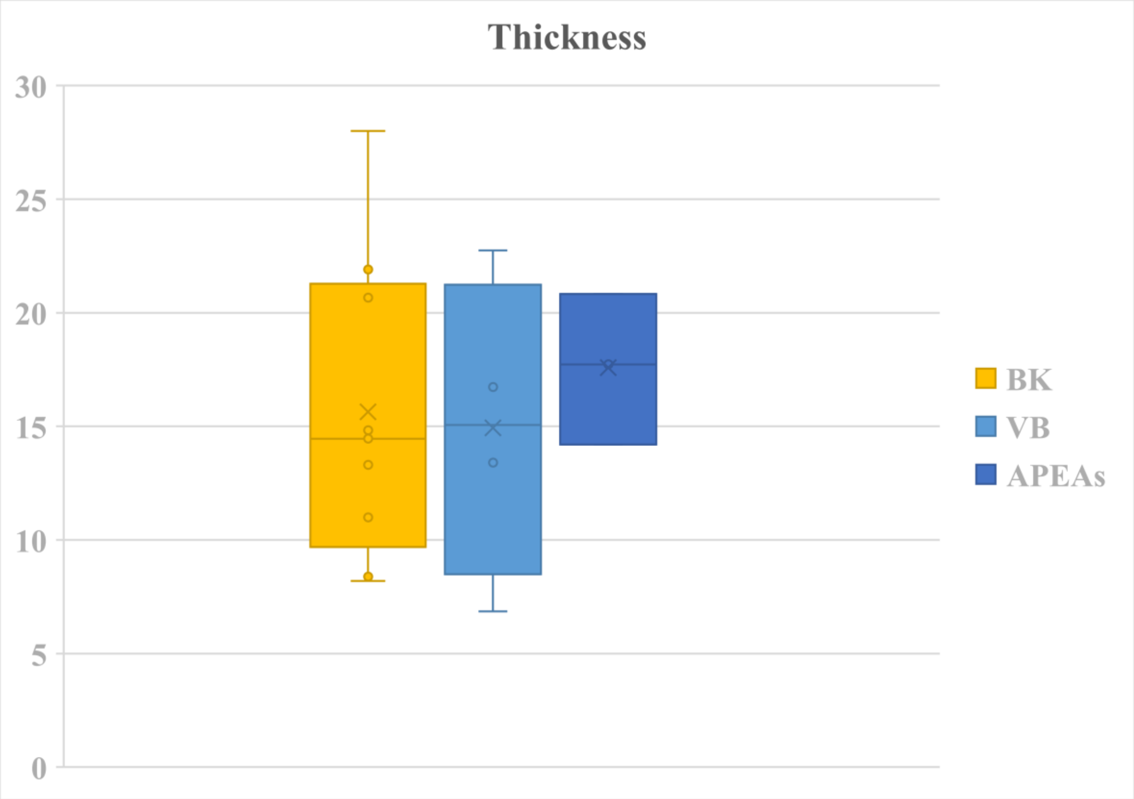


Figure 6.2. Core thickness comparison.

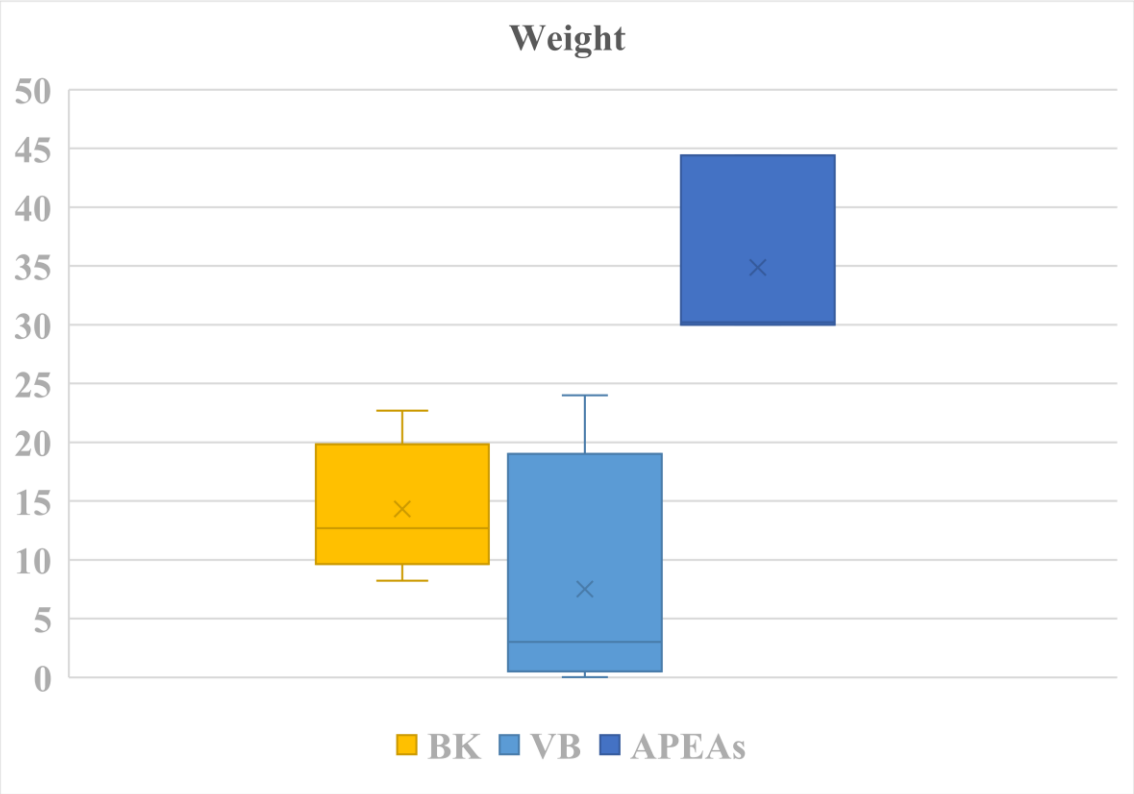


Figure 6.3. Core weight comparison.

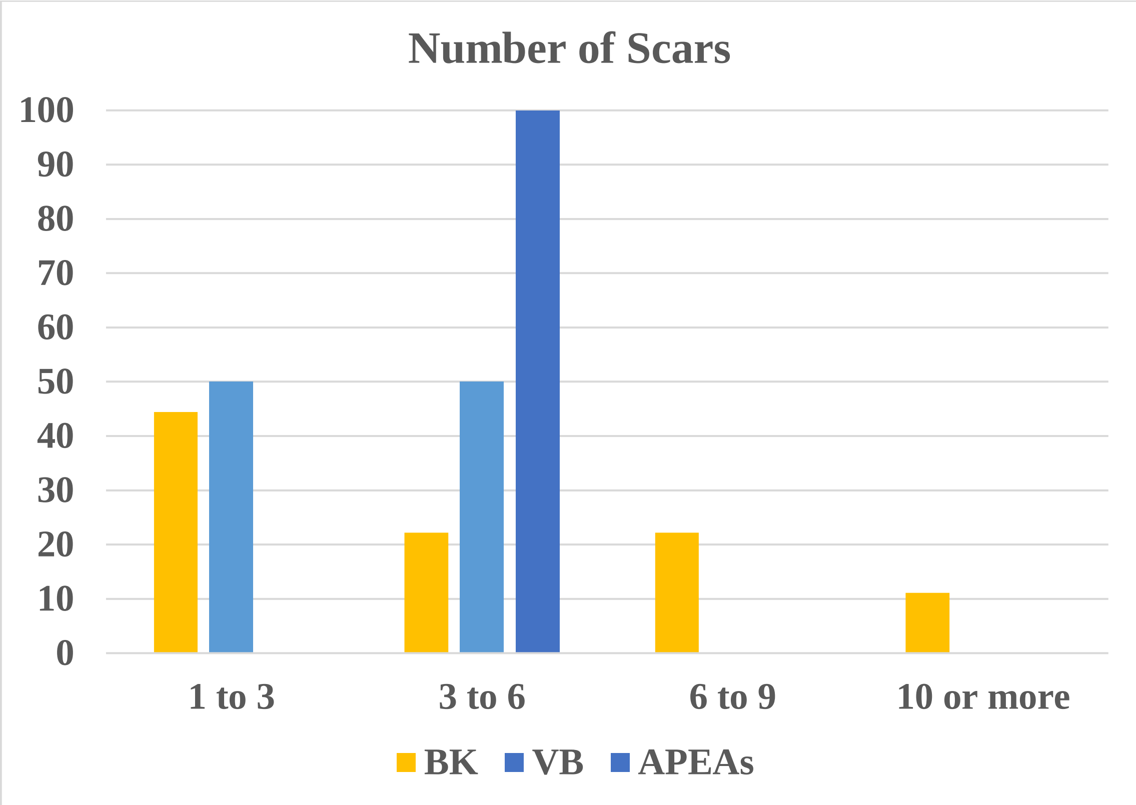


Figure 6.4. Comparison of number of scars in cores.

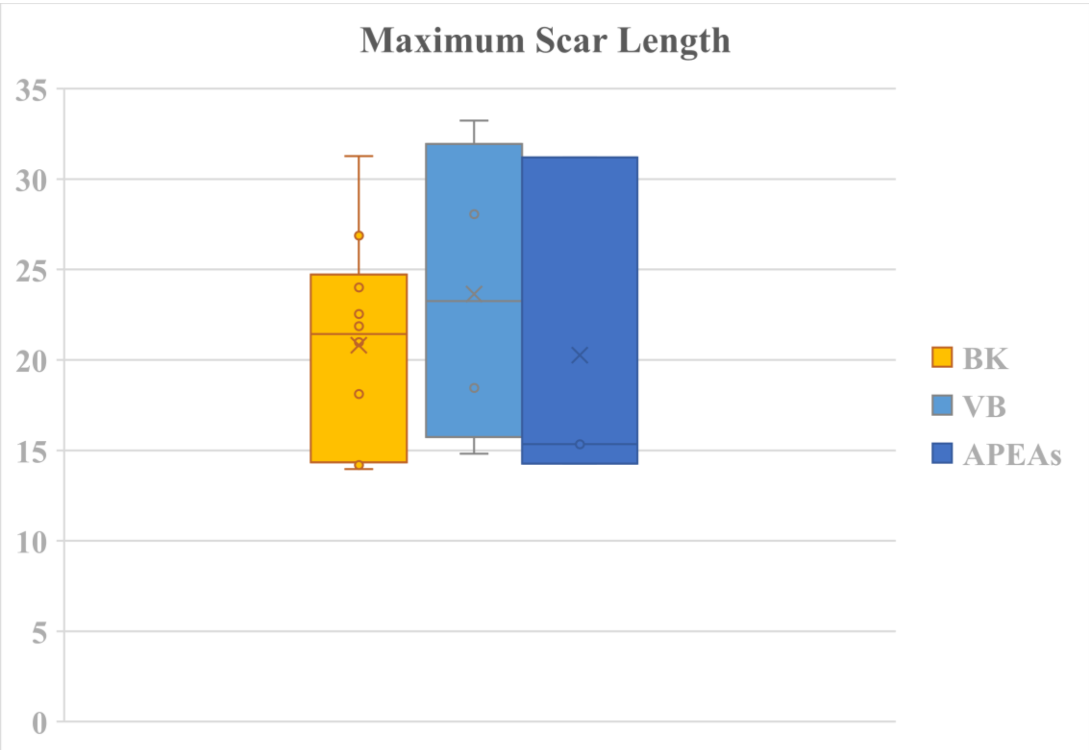


Figure 6.5. Comparison of maximum scar length in cores.

Splintered pieces are the most typical artifact type in all occupations. According to the results of the previous chapters, they were used as wedges for working organic materials and not bipolar cores as in they were interpreted in the Uluzzian occupations (Peresani et al., 2016, 2019). As shown in Figure 6.6, splintered pieces from AP's occupations are larger than the rest. Still, APEAs splintered pieces are quite variable in size. BK's are typically smaller than AP's and larger than VB's.

Interestingly, there seems to be an almost directly proportional relation between length and width. Most of these differences most likely come from the original size of available blanks. For comparison, RB's splintered pieces have between 10-40mm lengths, 5-30mm widths, and thicknesses between 3-15mm, while GF's have means of 36.6, 28.3, and 8.6 mm and maximums of 60, 41, and 14 mm respectively.

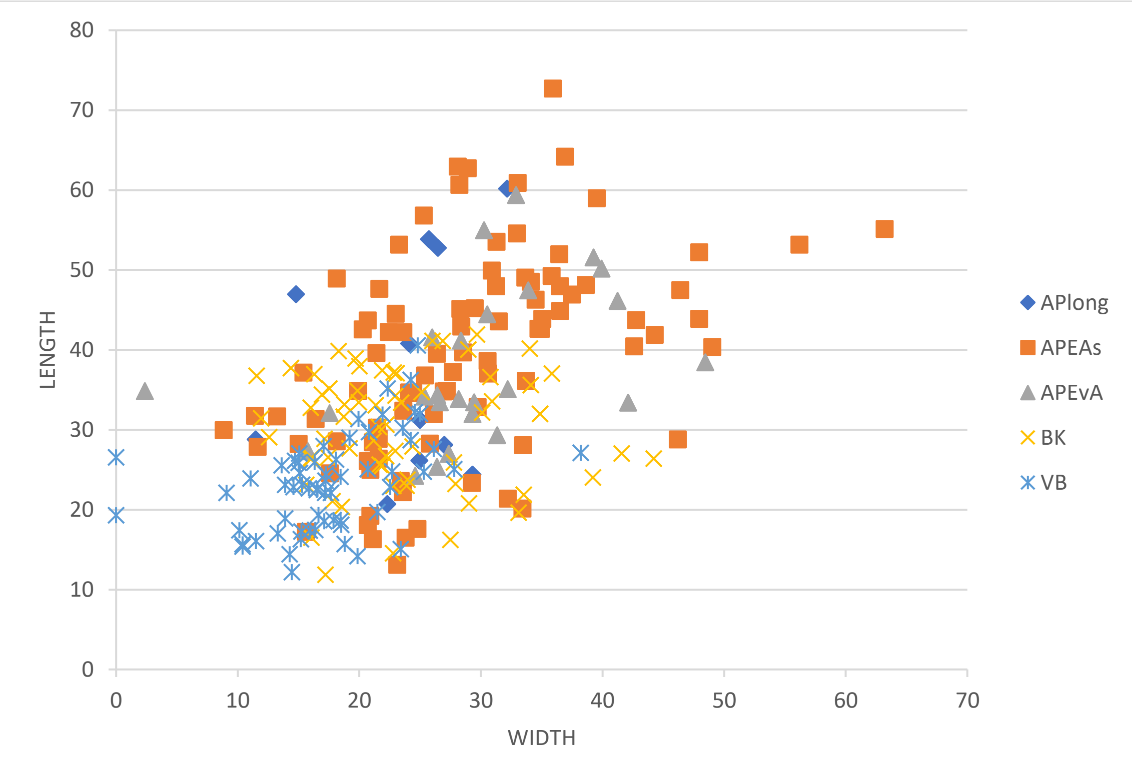


Figure 6.6. Comparison of splintered piece metrics.

There are differences amongst occupations regarding the blanks for splintered pieces as shown in Figure 6.7. In APEvA, Bacho Kiro and Vale Boi most splintered pieces were originally a flake or a blade. In APEAs and APEAl this is also the case but with higher use of retouched tools which tend to be less used in other occupations. In the Ulluzian occupations, the authors consider that most splintered pieces were originally flakes and in RB 12% were formerly retouched tools (similar to BK or APEAl). Bacho Kiro and APEAs are unique in that cores were reused as splintered pieces, however, in mostly rare cases. Especially in later stages of use/reduction (Tixier, 1963), splintered pieces' original blank is no longer recognizable, often to a point where a dorsal and ventral face cannot be distinguished. In this sense, APEAl shows the highest percentage of these tools (55%), followed by Bacho Kiro (31%), VB and APEvA (25 and 45%) and finally APEAs.

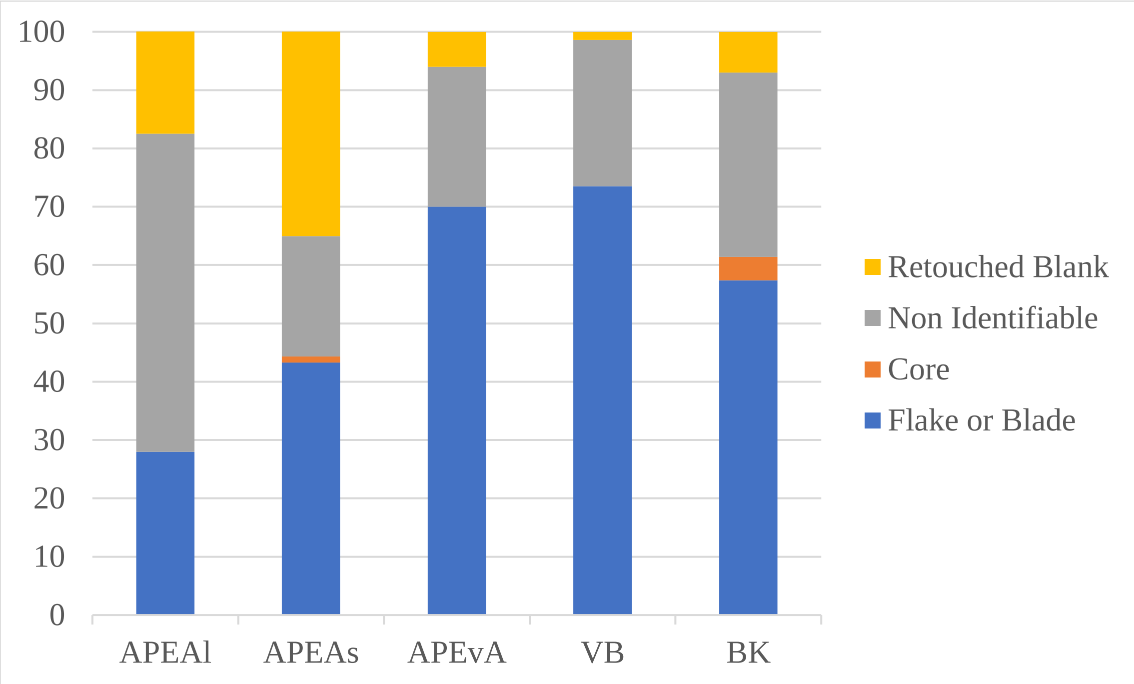


Figure 6.7. Comparison of splintered piece original blanks. Data from the Uluzzian sites were not included due to lacking information.

Similarly, and in the final stages of use (Tixier, 1963; Kolobova et al., 2021), splintered pieces tend to fracture, making them unusable (see the results section in Chapter 4). As shown in Figure 6.8, the pattern of use/reduction is similar. APEAl shows by far the highest percentage of broken splintered pieces (80%), followed by BK, the remaining AP occupations (51 and 50% respectively) and finally VB (20%). Despite the authors' interpretation of splintered pieces in the Uluzzian occupations as cores, RB splintered pieces in this stage of use or reduction represent 16.3% of the total (Peresani et al., 2019). Despite this value being lower than any of the other occupations, it is of note that the authors refer that the majority of splintered pieces in RB were discarded when they were no longer usable (Peresani et al., 2019).

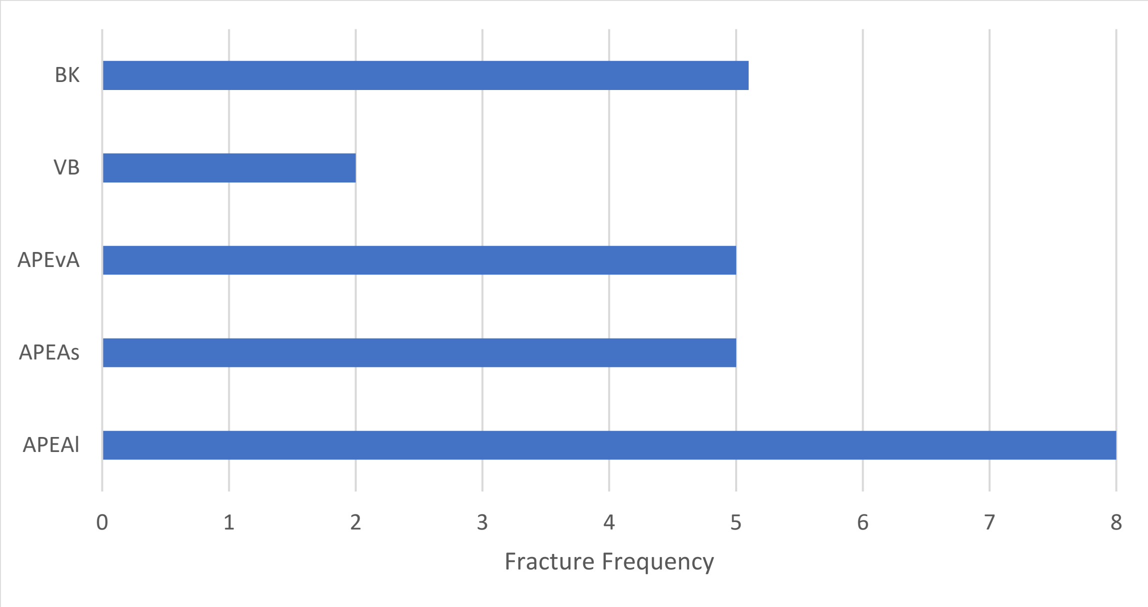


Figure.6.8. Comparison of splintered pieces' fracture frequency (percentage).

One of the essential questions revealed and highlighted in chapter 2 (Horta et al., 2022) was "expediency *vs.* intensity" in bipolar methods. According to the previously presented results, BK and APEAl would be occupations where the use of bipolar methods was more intensive and in APEAs, APEvA and, to a lesser extent, VB, the use would be more used expedient.

Table 6.2 exhibits the values for each variable related to use intensity in both bipolar cores and splintered pieces and variables related to the raw material sources (distance, quality, and size). As explored in chapter 2, raw material conservation is often one of the main reasons to use bipolar methods, notably in cases where raw materials are small, scarce, and of variant quality. For this reason, the following attributes were considered: distance to the nearest raw material source (RMsd); the size of the nodules, pebbles at the raw material source (RMsi); and the knapping quality of the raw material. Regarding the RMsd, the values were included in the original references (Kozlowski, 1982; Chiotti, 1999, 2005; Bicho et al., 2012; Peresani et al., 2016, 2019; Hublin et al., 2020). RMsi and Rmq are nuanced categories, as explained in Chapter 2, since no actual metric or quantitative data is available. Still, and based on the preceding chapters' information, RMsi was split into three attributes: large, medium, and small (based on the original authors' interpretation). Likewise, the quality of raw material has been split between low, medium, and high based on the grain size (e.g., coarse grain raw materials are considered low, and fine grain raw materials are considered high).

Table 6.2. Data regarding the use of bipolar methods in relation to raw material variables per occupation

	Core freq	**Core Size***	**SP freq**	**SPb**	**SPf**	**RMsd**	**RMsi**	**RMq**
APEAl	0	Smaller	7	50	80	<5km	Large	High
APEAs	2	Smaller	6	20	50	<5km	Large	High
APEvA	0	Smaller	0,1	20	50	<5km	Large	High
VB	3	Smaller	20	25	25	>15km	Small	Low
BK	50	Smaller	30	33	51	>100km	Large	High
RB	97.35**	-	75	-	16	5-40km	-	-
GF	38.75**	-	29	-	-	5-10km	-	-

*Core Size compared to Free-hand Cores

**If the splintered pieces are considered cores as hypothesized by the authors

The presence of bipolar blanks, anvils, or split pebbles was not considered because these were not yet identified in all occupations. Regarding bipolar cores, only their frequency (Core freq) amongst all core types within each occupation and their size (Core size) compared to the rest of the cores in each assemblage was considered. Several extracted blanks were not added because this variable is somewhat subjective as it only regards the number of scars at the point of abandonment. For instance, a core could have 6 scars, and a final extraction removes traces of the previous, leaving only 1 large scar and vice versa. In this case, both cores have had the exact same reduction rate, but the one with the most scars would be mistakenly considered to have a higher reduction rate. For the same reason, the size of the scars was not considered.

For splintered pieces, the following attributes were considered: their frequency amongst all tool types (SPfreq), the frequency of tools that were reduced to a point where the original blanks are not identifiable (SPb), and lastly, the percentage of tools that were used until exhaustion and therefore, abandoned due to large fractures (SPf). These attributes are consistently present in all occupations and are directly linked to the extent that these tools were used. As explained before, the remaining functional attributes of splintered pieces are too variable to be considered.

Data reaffirm the preexisting hypothesis that BK had a higher frequency of use of bipolar methods than the other occupations due to having higher frequencies of both cores and

splintered pieces and high degrees of intensive use of splintered pieces. Additionally, and despite raw materials at the source being large and of high quality, the source is the furthest away from any occupation. This is most likely why bipolar methods are intensively used at the site. Comparatively, RB raw materials can be found closer to the site, but in terms of frequency, bipolar methods dominate the assemblage and according to the authors, splintered pieces were often used to exhaustion (Peresani et al., 2019). APEAl was also considered an occupation where the use of bipolar methods was intense despite no cores, low frequency of splintered pieces, and raw materials being local, large, and of high quality.
Interestingly, most splintered pieces were intensively used until they broke. APEA is an occupation that shows a more expedient use of bipolar methods. Frequencies are low and similar to APEAl, however, there seems to be less intensive use of splintered pieces.

VB seems to have a more expedient use of bipolar methods. Cores are rare, and splintered pieces are occasionally (ca. 25%) intensively used. Raw materials are not as close to the site as in AP or the Ulluzzian occupations. They are small, and of low quality, so it would be expected for there to be more intensive use of bipolar methods related to raw material conservation. However, it is still of note that many splintered pieces used in VB were made in locally sourced quartz and used more expediently than the ones in flint. APEvA had the most expedient use of bipolar methods as bipolar frequencies are very low and splintered pieces were less intensively explored compared to APEAl. Not much data is available from GF to hypothesize whether the use of bipolar methods was either expedient or intensive. Still, it is of note that it is similar frequency-wise to BK.

Overall, the data presented in this chapter illustrate differences in bipolar methods in each occupation and support previously suggested hypotheses. Bipolar methods were used on a per-need basis with different degrees of intensity but for similar functions. Bipolar knapping allowed for the continuous reduction of small and large raw material volumes for blank production. In BK (and theoretically RB), it allowed for maximizing raw material conservation, while at VB and APEAs it provided an expedient fast solution for obtaining flakes. Splintered pieces were used in all occupations to process organic materials, however, with different degrees of intensity. In BK and APEAl they were intensively used either to or close to exhaustion. In VB, APEAs and APEvA were often discarded in earlier stages of use while still being usable. As a result, and despite differences in chronological, climate, and ecological settings, bipolar methods provided a means of efficient resource exploitation as a means of adaptation throughout these occupations.

Chapter VII

DISCUSSION: THE ROLE OF BIPOLAR TECHNOLOGY IN THE ADAPTATION OF THE FIRST HUMANS IN EUROPE

7.1 Bipolar technology in Human Evolution

The presence and occurrence of bipolar methods throughout Human evolution were, to an extent, explored in Chapter 2 (Horta et al., 2022), in which the take-away message was that bipolar technology played the role of an adaptive strategy. Here some of the questions and results that were not included or were briefly presented in that section are discussed. One of these questions is the origin of bipolar methods, a question that is understandably often avoided by researchers. Like most things in the archaeological record pinpointing the origin of a technique, method and/or culture is virtually impossible. In the case of bipolar methods, these are present in the archaeological record since at least 3.3 million years ago in the oldest known stone tool assemblage, now referred to as the Lomekwian (Harmand et al., 2015a; Lombard et al., 2019). Similarly, bipolar methods have also been identified around 2.1 million years ago in Shangchen, central China (Zhu et al., 2018), the oldest evidence of hominin occupation outside Africa.

Like these, many examples can be made for the presence of bipolar technology during the Late Pliocene and Early Pleistocene, a critical period in Human Evolution prior to the emergence of the genus *Homo*. Mechanically, the use of bipolar methods, as in supporting something on an anvil and applying a direct force through pressure or percussion, is likely even older. For instance, the mechanics of chewing (Osborn, 1987; Williams et al., 2009) operate similarly as two opposing forces are applied to the “object” that is being chewed. In nature, several species use bipolar methods for problem-solving. For instance, otters often support shells on their torso and hit them with a pebble to open them (Mann and Patterson, 2013). Famously and of greater importance to this topic, both monkeys and apes often resort to using anvils and hard hammers in nut-cracking activities (Sakura and Matsuzawa, 1991b; Bril et al., 2012, 2015; Coelho et al., 2015). When chimpanzees use bipolar methods for cracking large nuts, they occasionally produce flakes (Mercader et al., 2002), even if inadvertently. Even if chimpanzees end up discarding and not using these flakes, hominins may have seen this as an opportunity to obtain tools with sharp edges. Hayden (2015) pointed out that due to the probable nut-cracking abilities of early hominins bipolar reduction would have the easiest reduction technique to master. In fact, Hayden (2015) hypothesizes that several of the Dikika bones that contain the oldest known cutmarks (McPherron et al., 2010) may have originated from bipolar flakes, since there is extensive evidence of this in the ethnographic record. Combining this theory with the data from Chapter 2, it can be hypothesized that bipolar methods may be intrinsically linked with the origins of stone flaking. Of course, much more data is required in order to explore these avenues, but these questions should be heavily considered in the future.

Apart from the innovation of the wedging method and unlike free-hand methods, the evolution of bipolar methods is practically invisible in the archaeological record. It can be argued that since bipolar methods are simple and effective, there was simply no need to innovate. Bipolar knapping in the Late Pliocene follows the same mechanical and cognitive principles as in the Holocene. As a result, activities observed in Ethnography and the Paleolithic record look identical regarding the resulting artifact shape. This is another reason bipolar technology has never been perceived as a marker of evolution. However, the opposite view is firmly defended throughout this work, as the data discussed here point to the significance of this technology as a marker of hominin adaptation. Arguably, it is relatively safe to speculate that these methods likely also evolved through time, and this is where the question of efficiency evaluation comes into play (Horta et al., 2022). Bipolar methods have been considered an efficient answer in the following scenarios: raw material stress (Gurtov and Eren, 2014), expediency (Horta et al., 2019), time efficiency (Eren et al., 2013), small raw material size and lithic miniaturization (Hiscock, 2015b; Pargeter and de la Peña, 2017), resource intensification strategies (Horta et al., 2019; Pargeter et al., 2019), lower knapping skill levels (Duke and Pargeter, 2015), core to blank conversion ratios (B. Morgan et al., 2015; Pargeter and de la Peña, 2017; Pargeter and Eren, 2017), and mobility patterns (Eren, 2010).

The evolution of bipolar methods, per se, may have come in the realization of what is more efficient and in which circumstances. In order words the “how” it operates and “what it is used for” likely remained the same since there is no evolution in the technique nor the resulting artifact shape and the major difference would come in the “why” and “when”. Bipolar technology might have been used as an answer to raw material restrictions, lower cognition and knapping skill in early stages in human evolution, and later with developments in hominin cognition and technological skill it became multipurpose way of achieving higher efficiency in tasks, whether in the aforementioned cases of skill and raw materials restrictions, in cases of severe environmental pressure, in scenarios on high mobility, time constraints, as means of enabling and supplementing other technologies, etc. As a result, as the Pleistocene progressed homnins may have perceived a new array of avantages provided by this technology, increasing the sceneraios in which they applied. For this reason, it is important to build an understanding of how bipolar technology was used on a chronological and regional basis. This ultimately allows us as researchers to better understand its constant presence and importance in each stage of Human Evolution.

Bipolar reduction may have been a familiar (like nut-cracking) low-cost solution for obtaining flakes with sharp edges (Diez-Martín et al., 2011) for early hominins. Its evolution would later come to realize its advantages (circumventing skill, for instance) for reducing hard raw materials such as quartz and quartzite (de la Torre, 2011; Gurtov and Eren, 2014a; Arroyo and de la Torre, 2017). In subsequent stages of the Early Pleistocene, it would be applied to different types of varying quality raw materials volumes that would come in the shape of nodules or pebbles (de la Torre, 2011). Later in the Acheulean, it would be used for reducing small and large volumes of varying quality raw materials across the Old World that were too small or too large to hand-hold effectively (Arzarello and Peretto, 2010; Gallotti and Peretto, 2015; Arzarello et al., 2016; Li, 2016; Li et al., 2017).

Following this train of thought and speculation based on the available data with the emergence of Mode 3 (500-100 ka) technologies across the Old World, there seems to be a drop in the use of bipolar in Africa (Horta et al., 2022). For some reason, Middle Stone Age *Homo sapiens* groups seem to have opted not to use this technology as it was only identified in Mumba, Sibudu, and possibly Diekploof during this period (Igreja and Porraz, 2013; Marks and Conard, 2008; Tabrett, 2016)(Marks and Conard, 2008). At the same time, in Europe, only a handful of Neanderthal sites have evidence of bipolar methods during this period (Byrne, 2004; Garcia, 2015; Ravon et al., 2016; Mathias et al., 2020). This may be simply a technological choice as in these assemblages bipolar technology has a small representation. However, the hypothesis that these methods are present in more assemblages and were simply not identified in the archaeological record cannot be discarded. Moore (1997) argued that archaeologists can fail to recognize up to 90% of bipolar products. At the same time, it can be argued that this results from the fact that the number of early dated *Homo sapiens* sites (500-100 ka) in Africa is not exceptionally high compared to other periods. However, the same cannot be said for Neanderthal sites in Eurasia or *Homo erectus* sites in Asia, which were extensively studied for more than a century. Regardless there is not enough data at this point to draw conclusions. Still, the inverse proportion between Levallois reduction and bipolar methods should be considered in future studies. Hominins during this period would have been exposed to the same scenarios of adaptation as in previous (Early Stone age and Lower Paleolithic) or posterior periods (Later Stone Age, Upper Paleolithic, and the Holocene) where bipolar methods were consistently used. Again, this may have been a question of technological choice since the know-how was very likely present in the technological kits of these hominins. It is this difference in representation that is evident in Europe during the Middle to Upper Paleolithic transition, as one species (*Homo sapiens*) often used bipolar methods and the other (Neanderthals) rarely did (See the dedicated section in Chapter 1).

Overall, the evolution of bipolar technology likely came with the realization and understanding of its advantages and disadvantages in multiple scenarios throughout Human Evolution. If we are to understand its evolution and role in adaptive strategies of hominins through time, we need to combine dedicated studies in specific regional and chronological settings such as the one explored in this work. Below is one such discussion in the arrival and settlement of *Homo sapiens* in Europe.

7.2. The Role of Bipolar technology in the adaptation of the first humans in Europe

Between 45 and 30ka, several waves of human groups came into Europe from the East and competed for resources amongst themselves and the local Neanderthals. These populations came with different adaptive strategies, giving them an upper hand in an ever-changing climatic and environmental landscape. Temperatures fluctuated between extremely cold and warm, while environments often switched from open forest biomes to dry steppe or tundra biomes and vice-versa, which in turn implied changes in flora and fauna (Goñi et al., 2000; van Andel, 2002; Cadwell et al., 2003; Van Andel et al., 2003; Müller et al., 2011; Cacho et al., 2012). While climacteric adversity was ultimately not a deterrent for human migrations (see Chapter 1.1.2-3), employing efficient adaptive strategies was crucial for these populations' persistence. As previously noted, one of the differences between Neanderthals' and *Homo sapiens*' adaptive strategies regards the use of bipolar methods, which has remained unexplored in the literature. While Neanderthals only occasionally used these methods, they are a staple in *Homo sapiens* occupations throughout the world (see Chapter 1). Therefore, understanding the role of this technology in Homo sapiens' expansions during this period (45-30ka) in Europe may help shed light on what made them thrive over Neanderthals.

This dissertation aimed to provide a step forward by approaching this topic in a novel manner. Exploring concepts such as expediency and intensity as a proxy for efficiency evaluation in different environmental, ecological, and cultural scenarios suggests that efficiency played a significant role in the choice of when to apply bipolar methods for resource exploitation. Additionally, its results reinforce a growing realization of the importance of understanding bipolar technology in all its aspects (Duke and Pargeter, 2015; Paloma de la Peña, 2015a; Horta et al., 2019, 2022; Arrighi et al., 2020), particularly in hominin survival and expansion strategies (Horta et al., 2022). The meta-analysis of bipolar technology through space and time (Chapter 2) provided for the first time insight into how this technology impacted hominin adaptation strategies. Analyzing three European early *Homo sapiens* occupations (Chapters 3,4, and 5) and their comparison (Chapter 6) allowed for the direct application of the hypothesis explored in Chapter 2. This approach revealed differences and similarities in bipolar methods between the analyzed sites and occupations. These are particularly important because each site and occupation have significant differences that range from environmental and ecological to the culture and genetics of its settlers. Differences were found in the frequency and the degree to which bipolar methods were used.

The oldest human occupation of Europe (Bacho Kiro cave) occurred during a very cold moment (Fewlass et al., 2020; Pederzani et al., 2021). Raw materials were scarce and sourced from 80-150km away from the site (Hublin et al., 2020). As a result, resources were not widely available, and there was a clear need to economize and exploit what was available efficiently. Bipolar methods played an important role in answering the harsh environment pressure. Bipolar knapping was used to conserve raw material by enabling the continuous reduction of raw materials by using flakes, blades, and tools and reusing cores as volumes for flake production. Likewise, wedging enabled efficient organic material processing. Wedges were likely used to extract bone marrow and split limbs of carcasses; produce a wide array of bone tools; produce ornaments; and processing wood and hide (Horta et al., 2020; Smith et al., 2021; Martisius et al., 2022). Both of these activities (bipolar knapping and wedging) were recurrent and intensive as bipolar artifacts were often re-used until exhaustion to maximize their potential. Overall, in Bacho Kiro, bipolar methods were intensively used to maximize abiotic (raw material) and biotic (organic) resource exploitation. Therefore, playing an integral role in the adaptation strategy allowed these humans to survive and settle in a new territory full of environmental adversity.

In Abri Pataud, the use and frequency of bipolar methods were different as time went on. Unlike in Bacho Kiro and Vale Boi, high-quality raw material is locally available (Chiotti, 1999), so raw material quality and availability are not an issue. This is particularly evident in how much larger the bipolar artifacts found in all levels are compared to Bacho Kiro's or Vale Boi's. The rock shelter was likely occupied in different manners throughout the Aurignacian. The first occupation is hypothesized to be a long-term residential occupation, while the following tend to be short-term logistic occupations (Chiotti, 2002, 2005, 2012). Overall, the frequency of bipolar artifacts is also low compared to Bacho Kiro and Vale Boi, with a maximum of 7% representation. Still, bipolar technology is present throughout the sequence. The first occupation of the site attributed to the Early Aurignacian occurred during c. 40-38 ka cal BP is a particularly cold moment (Chiotti, 2005; T. Higham et al., 2011). During this occupation, wedging activities occurred at the site to process organic materials, most likely for carcass processing and bone tool production. Despite the very low frequency (7%), wedges were used intensively until exhaustion. This pattern would change as time went on and the function of the rock shelter changed.

In the following short-term occupations, wedging and bipolar knapping occurred at the site. These, however, come in a much more expedient manner, with both lower frequencies and artifacts exhibiting lower degrees of use. In these occupations, bipolar knapping likely served as a means of fast and expedient blank production. Likewise, wedges were chosen from various blanks and were often abandoned while still usable. Interestingly, peaks in bipolar technology coincide with both colder moments and peaks in bone tool and ornamentation across the Aurignacian sequence at the site. Therefore, bipolar methods played a much more expedient role in Abri Pataud during the Aurignacian than in the IUP of Bacho Kiro. Despite not having a high representation, bipolar technology played a role in efficiency maximization for organic resource exploitation during the first occupation of the site, enabling efficient and controlled carcass processing and likely bone tool and ornament production. In the subsequent short-term occupations, it played a lesser role as a means to produce blanks or process organic resources expediently. However, since the site changed functionality during these periods (Late Early Aurignacian and Evolved Aurignacian), there is the possibility that the activities that involved bipolar methods were conducted off-site.

In Vale Boi, the use and frequency of bipolar technology were similar across time. Vale Boi is particular in regards to raw material availability. Flint is available approximately 15km away from the site, yet nodules are typically small and fractured (Marreiros, 2009; Cascalheira, 2010, 2013; Bicho et al., 2012; Marreiros and Bicho, 2013; Cascalheira et al., 2017). However, quartz is readily available around the site (Cascalheira, 2013; Marreiros and Bicho, 2013; Horta et al., 2019). Bipolar knapping, which served as an essential means of raw material conservation in Bacho Kiro, has little expression in Vale Boi, as shown in Chapter 3 (Horta et al., 2019). The same seems to be the case for most of western Iberia during this period. This is likely due to the local quartz's high availability, which provides a fast and low-cost solution for obtaining sharp edges (Cascalheira, 2013; Marreiros and Bicho, 2013; Horta et al., 2019). Wedging, however, was a recurrent practice at the site. Wedges were used for bone tool production and resource intensification through bone marrow exploitation and grease rendering (Manne and Bicho, 2009; Manne, 2010; Évora, 2016; Horta et al., 2019). Interestingly, wedging may not be connected with ornament production at the site. Most ornaments found in Vale Boi are made from shells (Tátá et al., 2014), so any pointed object could have been used for piercing the shells. Furthermore, the use of wedges was likely not intensive, as observed in Bacho Kiro and the first occupation of Abri Pataud, as only 25% of wedges were used to or close to exhaustion. Overall, bipolar methods played an essential role in Vale Boi (and western Iberia) as a means of resource intensification for the processing of organic materials and a minor role in technological traditions and raw material reduction.

Whether the use was expedient or intensive, bipolar methods provided a means of efficient resource exploitation. The understanding of the adaptational advantages of using these methods was present early on in *Homo sapiens*' adaptive strategies. In scenarios where there were significant environmental pressure and resource scarcity, bipolar methods were used to enhance resource exploitation. On the other hand, in high mobility scenarios and abundant resources, bipolar methods served as a fast and expedient way of producing sharp edges or processing organic materials. Both points have been observed to an extent in the ethnographical record.

In ethnography, the use of bipolar methods related to achieving higher efficiency in resource exploitation has been observed in Papua New Guinea, Australia, Africa, and North America (MacCalman and Grobbelaar, 1965; White, 1968; Hayden, 1980; Shott, 1989; Hiscock, 2015a). Australian Aboriginals' most efficient manner for removing slabs of wood for creating shields or spear throwers was through wedging. They would insert large thin pieces of stone into cuts in trees and hammer them to create splits in the wood in order to extract large portions of bark (Hayden, 2015), producing inadvertedly, splintered pieces. Bipolar knapping is prevalent in these contexts due to the small size of quartz nodules and pebbles. In these cases, bipolar reduction allows for the continuous reduction of very small cores, and the products have very sharp cutting edges (Hayden, 2015; Hiscock, 2015b). Similarly, the Ova Tjimba in Southwest Africa often resorts to bipolar methods to obtain sharp flakes for butchering activities (MacCalman and Grobbelaar, 1965). In North America, bipolar reduction served as an expedient manner of obtaining sharp edges for organic resource processing, including butchering and hide extraction (Binford, 1978). While a one-to-one comparison cannot be made, it can be argued that similar scenarios of thought processes in picking "a more efficient method for X activity" led to the recurrent use of bipolar methods by early *Homo sapiens* settlers in Europe.

One relatively unexplored point is how bipolar methods vary during this period. In the earliest occupations (Bacho Kiro and the Uluzzian), bipolar knapping seems to have a more important expression when compared to later occupations where it is residual (see Chapter 6). On the other hand, wedging remains a significant activity throughout the Upper Paleolithic in Europe (see Chapters 2-6 for discussions). This may be related to several factors, including the different cultural and technological contexts of the various groups of humans that came into Europe. Still, the high prevalence of wedging and the inversely proportional decline of bipolar knapping may be a regional pattern. Unfortunately, the current literature does not allow for head-to-head comparisons with other regions except for South Africa during this time frame. In South Africa in this period (post 50ka), bipolar knapping seems to have been the dominant bipolar activity compared to wedging (Barham, 1987; Paloma de la Peña, 2015a; Bousman and Brink, 2017; Pargeter and de la Peña, 2017). One reason for this may be as simple as the availability of raw material coupled with the popular lithic miniaturization strategies observed in this region (Paloma de la Peña, 2015a; Pargeter and de la Peña, 2017). Overall, no accurate concrete conclusions can be drawn from this data. However, it does open an interesting avenue to be explored in the future: the inter-regional variations and adaptations of the use of bipolar methods by the same species. If anything, this further solidifies the hypothesis that the versatility of bipolar methods provides in adaptation scenarios.

In Chapter 2 the question of the occurrence of bipolar methods was explored (Horta et al., 2022). As for bipolar knapping, it has been hypothesized that it reappears throughout the Paleolithic record through evolutionary convergence (Duke and Pargeter, 2015; Horta et al., 2022), whereas for wedging, there simply is not enough data (Horta et al., 2022). During this period (45-30ka BP), both bipolar knapping and wedging can be observed in Europe. Both activities reappear with diverging representation and possibly also through evolutionary convergence as a latent solution for resource exploitation problems (Tennie et al., 2016, 2017). Bipolar methods can be transmitted in short periods through low-fidelity social learning (Shea, 2015), where "the behavior is latently present in the individual and is expressed in the context of specific stimuli or when one recognizes the behavior (or its effects on the environment) expressed by others" (Tennie et al., 2016). At the same this, this advantage in transmission would also facilitate scenarios of dispersal of cultural diffusion (Whiten et al., 2009, 2016).

Interestingly, this knowledge may not have been passed through the contact and assimilation between humans and Neanderthals. This is particularly interesting as the Neanderthal transitional industries show little to no evidence of bipolar use (Flas, 2006, 2011; Soressi and Roussel, 2014). Notably, the fact that these methods were recurrently used by the different waves of human populations is evidence of the successful adaptational advantages that they provide. Especially as this use persisted throughout all of the Upper Paleolithic, long after the Neanderthals demise, and into the Holocene. The data suggest that this understanding helped *Homo sapiens* time and time again to adapt to the shifting climate, the unstable environment, the availability of resources, and their competition. And this nuance may have been another factor that tipped the scales in favor of our species against all other hominins, especially the Neanderthals. As the differences between *Homo sapiens* and Neanderthals become murkier in the archaeological record, it is imperative to look at their adaptive strategies if we are to understand what made *Homo sapiens* thrive. Understanding how they evaluated and achieved efficiency in the use of stone resources for mediating environmental pressure through techniques like bipolar, support the notion of the human adaptive specialist (Wells and Stock, 2007; Roberts and Stewart, 2018). Through the understanding of each species' adaptive strategies, we will be able to understand what made humans successful in settling all over the Old World, when no other species did so.

Overall, this thesis and the papers included here significantly contribute to the literature regarding the perception of bipolar technology. This work invalidates the long-lasting idea that bipolar methods had little cognitive, technological and cultural significance. It is a behavioral response regarding the use of stone tools for problem-solving and mediating environmental pressure. Importantly, it constitutes a marker of how hominins evaluated efficiency in resource mediation. Bipolar technology, in all its different applications, should be regarded as a latent solution in stone tool technologies (Tennie et al., 2016). Whether it was used as a more efficient knapping technique in specific circumstances or for processing organic resources with different intensities, it is an interesting marker for the evolution of stone tool use and efficiency evaluation by hominins. However, it is clear that we still require more comprehensive perspectives to evaluate its role as a cultural and cognitive marker in the definition of technological traditions. Understanding its role in hominin expansion and survival strategies will allow us to understand better how this technology helped shape Human Evolution.

Chapter VIII

CONCLUSIONS AND FUTURE RESEARCH

8.1 General Conclusions

The hybrid nature of this dissertation made it, so the main conclusions were presented throughout each section of this work. This section aims to compile the main conclusions of this research, expand upon its limitations and explore avenues for future work. The results of this research brought a combination of answers and questions that are relevant to: the broad scope of Human Evolution; providing methodological advances into how to analyze and interpret bipolar technology; and its main goal of understanding how bipolar technology impacted the arrival and settlement of *Homo sapiens* across Europe.

Regarding the main objective of this thesis, the following conclusions can be made:

1. The presence and use of bipolar methods is one technological feature that was not shared (in general) between *Homo sapiens* and Neanderthals;
2. Bipolar technology played an important role in the adaptation of early *Homo sapiens* across Europe by providing them with a versatile and efficient mechanism to exploit both biotic and abiotic resources;
3. Through bipolar knapping, these groups were able to efficiently conserve and maximize raw material by continuously being able to reduce raw material volumes too small or too irregular to be held in hand;
4. Bipolar knapping further allowed for them to expediently produce blanks with sharp edges in short periods regardless of the knapper's skill level;
5. Wedging allowed for these groups to increase their efficiency in exploiting organic materials, including carcass processing, bone shaping, bone tool production, ornament production, and wood and antler shaping and processing;
6. Its adaptive advantages and knowhow could be transmitted in short periods through low-fidelity social learning;
7. This technology's adaptive advantages are reflected in its continuous use throughout the Upper Paleolithic regardless of cultural, technological, or even environmental context;

8. The understanding of all of the aforementioned advantages may have been one of many reasons that tipped the scales into our species over the Neanderthals when it came to mediating environmental pressure;

Beyond these conclusions, the results of this work led to further advancements in understanding bipolar technology in Human Evolution and in how to analyze it. The following conclusions were drawn:

1. Bipolar methods have been present in hominin technological kits since the earliest stone tools assemblages, and their use was re-occurring throughout Human Evolution;
2. Bipolar technology played the role of an adaptive strategy that shaped hominin's ability to adapt, survive and migrate by providing an often more efficient manner to explore biotic and abiotic resources;
3. Its recurrent use can be considered an essential indicator of how hominins were able to evaluate different types of efficiency through time;
4. Bipolar knapping reoccurred as a latent solution through evolutionary convergence;
5. More data is required in order to link the spread of the wedging technique with either cultural diffusion or evolutionary convergence;
6. Wedging seems to be an activity only used by *Homo sapiens*;
7. The use of meta-analytics was invaluable for exploring macroscale patterns in bipolar methods through time. Several questions raised by the use of this methodology proved essential for the discussion and understanding of the results;
8. The macroscopic approach to analyzing bipolar technology proved to be successful in answering questions of artifact typology, function, reduction, and use sequences;
9. More work needs to be done in accurately assessing specific types of use for each artifact. Namely, the methods developed throughout this work were only able to assess whether artifacts were used as cores or wedges generally and not for a particular use (e.g., soft or hard organic material processing);

In conclusion, this work provided new perspectives on how to regard bipolar methods as a tool for understanding how our ancestors adapted to different environmental pressures throughout time. It is clear that a lot more work still needs to be done in this field. Still, the presented work provided a step forward for studies on human adaptation and bipolar technology. Lastly, what role did bipolar technology play in the adaptation of the first humans in Europe? That of an adaptive strategy that was simple, complicated, and versatile, used to enhance biotic and abiotic resource exploitation. While its use is likely not a critical factor that led to the assimilation and replacement of Neanderthals, it is clear that its use helped shape the success of the expansion and adaptation of humans in Europe.

8.2 Research limitations and future research

Despite over one century of research, the understanding of the role of bipolar methods in Stone Age contexts is still not clear (see, e.g., Barham, 1987; de la Peña, 2015; Duke and Pargeter, 2015; Hayden, 1980; Horta et al., 2022; LeBlanc, 1992; Shott, 1999, 1989; Toth, 1985). Several of these issues have been mentioned and addressed (e.g., classification, function, ubiquity). Still, one of the most significant barriers to overcome is understanding what is bipolar, what is not, and what answers it can give us about the archaeological record. As keenly pointed out by Moore (Moore, 1997) and Hayden (Hayden, 2015), lithic analysts cannot recognize up to 85-90% of bipolar products. Of course, this is an issue that cannot be easily fixed. Still, the definitions of bipolar core and splintered provided in Chapter 3 (Horta et al., 2019) and methods of macroscopic analysis devolved throughout this work are a step forward in standardizing bipolar analysis moving forward.

As all scientific studies, this dissertation has its fair share of issues and limitations. These issues and limitations affected the results presented here. However, they do not demean the overarching success of this work. As in every aspect of life, things do not always go according to plan. The original plan was to conduct mechanically assisted experiments (Dibble and Rezek, 2009; Rezek et al., 2011; Magnani et al., 2014; Lin et al., 2018) and apply it to an archaeological assemblage. This experimental program would differ from previous works which were manually conducted and lack statistic verification (de la Peña, 2011; Kolobova et al., 2021; Lucas and Hays, 2004; Morgan et al., 2015). Through precise variable control through the use of a machine (Dibble and Rezek, 2009; Lin et al., 2018; Rezek et al., 2011) and its application in bipolar scenarios (knapping and wedging), it would be possible to assert the physical modification of stone tools through their use/reduction sequence. These results would later be compared through statistical and morphological verification (Archer and Braun, 2010; Buchanan and Collard, 2010; Cardillo, 2010; Caruana et al., 2014; Herzlinger et al., 2017) in order to establish whether reduction sequences and types of use could be macroscopically diagnosed. Ultimately, the data would be compared to the previously mentioned manual experimentations, reassessing the validity of each approach.

Several issues made this approach unviable. Firstly, full access to a knapping machine would be required, as it is possible that the experiment had to be run several times, and currently, only two of these machines exist (one in Pennsylvania and another in Wollongong); secondly, in order to collect accurately reproducible data, it would be required to use standardized forms (replacing cores and wedges), which posed many economic and travel restraints. Randomized blanks were another choice; however, this would introduce a degree of variability that goes against the experiment's controlled nature. There is also the case that the final morphology of each artifact is highly variable and therefore is not means of statistically diagnosing function with precision (as argued in chapters 3,4, and 5). Overall, this would mean that if the experiment were successful and proved that no function could be accurately diagnosed, these results would not be of much use when applied to an archaeological assemblage. Combining these factors made it clear that the decision to pursue this approach would be risky and viable for a publication but not a thesis.

From this point onwards, a decision was made to pursue a different approach. This would be made building upon previous work by the author (Horta et al., 2015, 2017; Horta, 2016). The goal was to correct the previously found shortcomings and expand on their successes. As a result, a decision was made to build upon these methods and apply them to several archaeological contexts. Two approaches were possible to take from this point onwards, either to opt for a regional study (Clark, 1988; Daujeard and Moncel, 2010; Montoya et al., 2013; Calvo et al., 2016; Ruebens, 2013) or a macro approach where sites were chosen in different geographical areas. Since the goal of this thesis was to understand the adaptive nature of the use of bipolar methods, a decision was made to go for the latter while still incorporating elements of regional studies. In essence, this became this work’s main strength and weakness.

The combined results of Chapters 3-6 allowed for a general understanding of the variability of bipolar methods in different contexts. The data came from 3 sites across a whole continent and with completely distinct cultural, ecological, and chronological contexts. Arguably, the only way of understanding the role of bipolar methods for the first humans in Europe would be to access a large sample of sites, which is not feasible in a Ph.D. dissertation context. One of the workarounds that were tested was to use comparable data from other sites, which proved a major challenge. As shown in Chapter 2, the data are far from homogenous across the literature, which means any attempt to compare the data on a macro-scale automatically involves a process of "homogenization," which inserts a bias into the study. Likewise, as tested in Chapter 2, the sampling process will exclude data that is simply outside the sampling scope, ultimately affecting the outcome of the research.

Additionally, in Chapter 3, data from sites across a large region (in this case, several regions of Portugal) were included to compare bipolar methods on a regional scale. The same was not possible in Chapters 4 and 5. In Chapter 4, for instance, despite Abri Pataud being located in a region well studied, there is very little data on the use of bipolar methods with the addition that are no dedicated papers on bipolar technology for the Aurignacian. Chapter 5 and Bacho Kiro are similar in that while there are no dedicated studies on bipolar methods for the IUP, there is very little regional data. Remarkably, there are mentions of bipolar methods in Temnata cave (Tsanova, 2006), but these need to be reassessed.

Future studies should focus on the following methods of analysis that provide comparable data. Likewise, one cannot emphasize enough the need for open science if we are to continue to unravel the puzzle that is human evolution. More dedicated studies are needed regarding bipolar technology, especially at a regional level. This is especially the case regarding hominin expansion events as most studies often only refer to elements of bipolar technology (e.g., one bipolar core) and provide no empirical data on the artifacts themselves or often the context. Furthermore, there is a clear need for both manual and controlled experimentation. Together these approaches can provide data that can directly be compared to the archaeological record while incorporating macro and microscopic analysis. One of the limitations of the methods explored in this work is the inability to accurately assert a use for an artifact (e.g., woodworking). Of course, these use-wear approaches come with their share of problems. One of them, mainly when applied to splintered pieces, is the concept that one tool was one for one purpose. Despite this, a good combination of manual and controlled experimental work with micro and macroscopic analysis can direct research on what methods to apply to archaeological material. With this data combined with metanalytic approaches, it will allow us to understand how bipolar technology shaped the several stages of human evolution.

REFERENCES

Agsous, S., 2008. Stratigraphie et sédimentologie de l'abri Pataud (Les Eyzies de Tayac, Dordogne, France): contribution à l'étude des paléoenvironnements des cultures du paléolithique supérieur ancien du Périgord.

Almeida, F., 2000. The terminal Gravettian of Portuguese estremadura: technological variability of the lithic industries. S. M. U.

Álvarez-Fernández, E., Álvarez-Alonso, D., Bécares, J., Carral, P., Carriol, R.-P., Chauvin, A., Cubas, M., Cueto, M., Domingo, R., Douka, K., Elorza, M., Jordá-Pardo, J.F., Murelaga, X., Portero, R., Rivero, O., Tapia, J., Tarriño, A., Teira, L.C., 2016. Nouvelles données sur le Magdalénien inférieur de la Région Cantabrique : le Niveau F de la grotte de El Cierro (Ribadesella, Asturies, Espagne). Paléolithique supérieur. 120, 537–567.

Andrefsky, W., 1998. Lithics. Cambridge University Press.

Andrefsky, W., 2008. The Analysis of Stone Tool Procurement, Production, and Maintenance. Journal of Archaeological Research. 17, 65–103.

Andrefsky, W., 2010. Human land-use strategies and projectile point damage, resharpening and disccard patterns. Human Evolution. 25, 13–30.

Anissutkine, N.K., Tchepalyga, A.L., Kolavenko, S.I., 2019. Baïraki – un site du Paléolithique inférieur sur le territoire de la Plaine d'Europe orientale. Préhistoire de la Russie. 123, 233–256.

Archer, W., Braun, D.R., 2010. Variability in bifacial technology at Elandsfontein, Western cape, South Africa: a geometric morphometric approach. Journal of Archaeological Science. 37, 201–209.

Archer, W., Gunz, P., van Niekerk, K.L., Henshilwood, C.S., McPherron, S.P., 2015. Diachronic Change within the Still Bay at Blombos Cave, South Africa. PLoS One. 10, e0132428.

Arrighi, S., Marciani, G., Rossini, M., Santos, M.C.P., Fiorini, A., Martini, I., Aureli, D., Badino, F., Bortolini, E., Figus, C., 2020. Between the hammerstone and the anvil: bipolar knapping and other percussive activities in the late Mousterian and the Uluzzian of Grotta di Castelcivita (Italy). Archaeological and Anthropological Sciences. 12, 1–39.

Arroyo, A., de la Torre, I., 2017a. Pounding tools in HWK EE and EF-HR (Olduvai Gorge, Tanzania): Percussive activities in the Oldowan-Acheulean transition. Journal of human evolution.

Arroyo, A., de la Torre, I., 2017b. Pounding tools in HWK EE and EF-HR (Olduvai Gorge, Tanzania): Percussive activities in the Oldowan-Acheulean transition. Journal of human evolution.

Arzarello, M., De Weyer, L., Peretto, C., 2016a. The first European peopling and the Italian case: Peculiarities and “opportunism.” Quaternary International. 393, 41–50.

Arzarello, M., De Weyer, L., Peretto, C., 2016b. The first European peopling and the Italian case: Peculiarities and “opportunism.” Quaternary International. 393, 41–50.

Arzarello, M., Peretto, C., 2010. Out of Africa: the first evidence of Italian peninsula occupation. Quaternary International. 223, 65–70.

Aubry, T., 1998. Olga Grande 4 : uma sequência do Paleolítico superior no planalto entre o Rio Côa e a Ribeira de Aguiar. Revista Portuguesa de Arqueologia. 1, 5–26.

Aubry, T., Dimuccio, L.A., Buylaert, J.-P., Liard, M., Murray, A.S., Thomsen, K.J., Walter, B., 2014. Middle-to-Upper Palaeolithic site formation processes at the Bordes-Fitte rockshelter (Central France). Journal of Archaeological Science. 52, 436–457.

Backwell, L., d’Errico, F., Wadley, L., 2008a. Middle Stone Age bone tools from the Howiesons Poort layers, Sibudu Cave, South Africa. Journal of Archaeological Science. 35, 1566–1580.

Backwell, L., d’Errico, F., Wadley, L., 2008b. Middle Stone Age bone tools from the Howiesons Poort layers, Sibudu Cave, South Africa. Journal of Archaeological Science. 35, 1566–1580.

Bacon, A.-M., Bourgon, N., Welker, F., Cappellini, E., Fiorillo, D., Tombret, O., Thi Mai Huong, N., Anh Tuan, N., Sayavonkhamdy, T., Souksavatdy, V., Sichanthongtip, P., Antoine, P.-O., Duringer, P., Ponche, J.-L., Westaway, K., Joannes-Boyau, R., Boesch, Q., Suzzoni, E., Frangeul, S., Patole-Edoumba, E., Zachwieja, A., Shackelford, L., Demeter, F., Hublin, J.-J., Dufour, É., 2021. A multi-proxy approach to exploring Homo sapiens’ arrival, environments and adaptations in Southeast Asia. Scientific Reports. 11, 21080.

Bader, G.D., Cable, C., Lentfer, C., Conard, N.J., 2016. Umbeli Belli Rock Shelter, a forgotten piece from the puzzle of the Middle Stone Age in KwaZulu-Natal, South Africa. Journal of Archaeological Science: Reports. 9, 608–622.

Bader, G.D., Will, M., Conard, N.J., 2015. The lithic technology of Holley Shelter, KwaZulu-Natal, and its place within the MSA of southern Africa. The South African Archaeological Bulletin. 149–165.

Bae, C.J., Douka, K., Petraglia, M.D., 2017. On the origin of modern humans: Asian perspectives. Science. 358.

Banks, W.E., d'Errico, F., Zilhao, J., 2013. Revisiting the chronology of the Proto-Aurignacian and the Early Aurignacian in Europe: a reply to Higham et al.'s comments on Banks et al. (2013). J Hum Evol. 65, 810–7.

Bao, J.F.G., Palomo, A., Bicho, N., Batlle, X.T., 2007. Tecnología y función de los" útiles astillados": programa experimental para contextos prehistóricos de la Península Ibérica. Presented at the Arqueología experimental en la Península Ibérica: Investigación, didáctica y patrimonio, pp. 157–164.

Bardon, L., Bouyssonie, J., Bouyssonie, A., 1906. Outils écaillés par percussion. F. Alcan.

Barham, L., Phillips, W.M., Maher, B.A., Karloukovski, V., Duller, G.A., Jain, M., Wintle, A.G., 2011. The dating and interpretation of a Mode 1 site in the Luangwa Valley, Zambia. Journal of human evolution. 60, 549–570.

Barham, L.S., 1987a. The bipolar technique in southern Africa: a replication experiment. The South African Archaeological Bulletin. 45–50.

Barham, L.S., 1987b. The bipolar technique in southern Africa: a replication experiment. The South African Archaeological Bulletin. 45–50.

Barshay-Szmidt, C., Bazile, F., Brugal, J.-P., 2020. First AMS 14C dates on the Protoaurignacian in Mediterranean France: The site of Esquicho-Grapaou (Russan-Ste-Anastasie, Gard). Journal of Archaeological Science: Reports. 33, 102474.

Barshay-Szmidt, C., Normand, C., Flas, D., Soulier, M.-C., 2018. Radiocarbon dating the Aurignacian sequence at Isturitz (France): Implications for the timing and development of the Protoaurignacian and Early Aurignacian in western Europe. Journal of Archaeological Science: Reports. 17, 809–838.

Bartov, Y., Stein, M., Enzel, Y., Agnon, A., Reches, Z., 2002. Lake levels and sequence stratigraphy of Lake Lisan, the late Pleistocene precursor of the Dead Sea. Quaternary Research. 57, 9–21.

Bar-Yosef, O., Bordes, J.G., 2010. Who were the makers of the Chatelperronian culture? J Hum Evol. 59, 586–93.

Bar-Yosef, O., Zilhão, J., 2006. Towards a definition of the Aurignacian: proceedings of the symposium held in Lisbon, Portugal, June 25-30, 2002. Instituto Português de Arqueologia.

Bennett, T., 2011. Middle Stone Age Lithic Technology at Mvumu, Niassa, Mozambique. Master's thesis. Department of Archaeology. University of Calgary, Calgary, Canada.

Berillon, G., Khaneghah, A.A., Antoine, P., Bahain, J.-J., Chevrier, B., Zeitoun, V., Aminzadeh, N., Beheshti, M., Chanzanagh, H.E., Nochadi, S., 2007. Discovery of new open-air Paleolithic localities in Central Alborz, Northern Iran. Journal of human evolution. 52, 380–387.

Bernaldo de Quirós, F., Maíllo-Fernández, J.-M., Castaños, P., Neira, A., 2015. The Gravettian of El Castillo revisited (Cantabria, Spain). World of Gravettian Hunters. 359–360, 462–478.

Beyin, A., Ryano, K.P., 2020. Filling the Void: a Study of Sites Characterized by Levallois and Blade Technologies in the Kilwa Basin, Coastal Tanzania. Journal of Paleolithic Archaeology. 1–47.

Bicho, N., Cascalheira, J., André, L., Haws, J., Gomes, A., Gonçalves, C., Raja, M., Benedetti, M., 2018. Portable art and personal ornaments from Txina-Txina: a new Later Stone Age site in the Limpopo River Valley, southern Mozambique. Antiquity. 92.

Bicho, N., Cascalheira, J., Gonçalves, C., 2017. Early Upper Paleolithic colonization across Europe: Time and mode of the Gravettian diffusion. PLoS One. 12, e0178506.

Bicho, N., Cascalheira, J., Marreiros, J., 2012. On the (L)edge: The Case of Vale Boi Rockshelter (Algarve, Southern Portugal). In: Bergsvik, K.A., Skeates, R. (Eds.), Caves in Context - The Cultural Significance of Caves and Rockshelters in Europe. Oxbow Books.

Bicho, N., Manne, T., Marreiros, J., Cascalheira, J., Pereira, T., Tátá, F., Évora, M., Gonçalves, C., Infantini, L., 2013. The ecodynamics of the first modern humans in Southwestern Iberia: The case of Vale Boi, Portugal. Quaternary International. 318, 102–116.

Bicho, N., Marreiros, J., Cascalheira, J., Pereira, T., Haws, J., 2015. Bayesian modeling and the chronology of the Portuguese Gravettian. Quaternary International. 359–360, 499–509.

Biglari, F., Shidrang, S., 2006. The Lower Paleolithic Occupation of Iran. Near Eastern Archaeology. 69, 160–168.

Binford, L.R., 1978. Nunamiut ethnoarchaeology, null.

Binford, L.R., Quimby, G.I., 1963. Indian sites and chipped stone materials: In the northern Lake Michigan area. Fieldiana Anthropology. 36, 277.

Binford, S., 1968. Early Upper Pleistocene Adaptations in the Levant. American Anthropologist. 70, 707–717.

Blinkhorn, J., Achyuthan, H., Ajithprasad, P., 2015. Middle Palaeolithic point technologies in the Thar Desert, India. Quaternary International.

Blome, M.W., Cohen, A.S., Tryon, C.A., Brooks, A.S., Russell, J., 2012. The environmental context for the origins of modern human diversity: A synthesis of regional variability in African climate 150,000–30,000 years ago. J Hum Evol. 62, 563–592.

Bond, G., Broecker, W., Johnsen, S., McManus, J., Labeyrie, L., Jouzel, J., Bonani, G., 1993. Correlations between climate records from North Atlantic sediments and Greenland ice. Nature. 365, 143–147.

Bosinski, G., Bosinski, H., Gesellschaft für Archäologie an Mittelrhein und Mosel, 2007. Gönnersdorf und Andernach-Martinsberg: Späteiszeitliche Siedlungsplätze am Mittelrhein. Ges. für Archäologie an Mittelrhein und Mosel.

Bouchud, J., 1975. Etude de la faune de l’abri Pataud, les Eyzies, Dordogne. Movius HL. Excavation of the Abri Pataud, Les Eyzies (Dordogne). Contributors. Cambridge: American School of Prehistoric Research. 65–153.

Bourrillon, R., White, R., Tartar, E., Chiotti, L., Mensan, R., Clark, A., Castel, J.-C., Cretin, C., Higham, T., Morala, A., 2018. A new Aurignacian engraving from Abri Blanchard, France: Implications for understanding Aurignacian graphic expression in Western and Central Europe. Quaternary International. 491, 46–64.

Bousman, C.B., Brink, J.S., 2017. The emergence, spread, and termination of the Early Later Stone Age event in South Africa and southern Namibia. Quaternary International.

Bradtmöller, M., Marreiros, J., Pereira, T., Bicho, N., 2016. Lithic technological adaptation within the Gravettian of the Iberian Atlantic region: Results from two case studies. Quaternary International. 406, 3–24.

Brandt, S.A., Fisher, E.C., Hildebrand, E.A., Vogelsang, R., Ambrose, S.H., Lesur, J., Wang, H., 2012. Early MIS 3 occupation of Mochena Borago Rockshelter, Southwest Ethiopian Highlands: implications for Late Pleistocene archaeology, paleoenvironments and modern human dispersals. Quaternary International. 274, 38–54.

Breeze, P.S., Drake, N.A., Groucutt, H.S., Parton, A., Jennings, R.P., White, T.S., Clark-Balzan, L., Shipton, C., Scerri, E.M., Stimpson, C.M., 2015. Remote sensing and GIS techniques for reconstructing Arabian palaeohydrology and identifying archaeological sites. Quaternary International. 382, 98–119.

Bril, B., Parry, R., Dietrich, G., 2015. How similar are nut-cracking and stone-flaking? A functional approach to percussive technology. Philosophical Transactions of the Royal Society B: Biological Sciences. 370, 20140355.

Bril, B., Smaers, J., Steele, J., Rein, R., Nonaka, T., Dietrich, G., Biryukova, E., Hirata, S., Roux, V., 2012. Functional mastery of percussive technology in nut-cracking and stone-flaking actions: experimental comparison and implications for the evolution of the human brain. Philosophical Transactions of the Royal Society B: Biological Sciences. 367, 59–74.

Brooks, A., Helgren, D., Cramer, J., Franklin, A., Hornyak, W., Keating, J., Klein, R., Rink, W., Schwarcz, H., Smith, J., et, al., 1995. Dating and context of three middle stone age sites with bone points in the Upper Semliki Valley, Zaire. Science. 268, 548–553.

Brun-Ricalens, F.L., 2006. Les pièces esquillées: état des connaissances après un siècle de reconnaissance. PALEO. Revue d’archéologie préhistorique. 95–114.

Buchanan, B., Collard, M., 2010. A geometric morphometrics-based assessment of blade shape differences among Paleoindian projectile point types from western North America. Journal of Archaeological Science. 37, 350–359.

Buck, L.T., De Groote, I., Hamada, Y., Hassett, B.R., Ito, T., Stock, J.T., 2019. Evidence of different climatic adaptation strategies in humans and non-human primates. Scientific Reports. 9, 11025.

Byrne, L., 2004. Lithic tools from Arago cave, Tautavel (Pyrénées-Orientales, France): behavioural continuity or raw material determinism during the Middle Pleistocene? Journal of Archaeological Science. 31, 351–364.

Cacho, C., Martos, J.A., Jordá-Pardo, J., Yravedra, J., Sesé, C., Zapata, L., Avezuela, B., Valdivia, J., Ruiz, M., Marquer, L., Martín-Lerma, I., Tejero, J.M., 2012. Human landscapes of the Late Glacial Period in the interior of the Iberian Peninsula: La Peña de Estebanvela (Segovia, Spain). Quaternary International. 272–273, 42–54.

Cadwell, D.H., Muller, E.H., Fleisher, P.J., Cremens, D.L., Hart, J.P., 2003. Geoarchaeology of Landscapes in the Glaciated Northeast, null.

Calvo, A., Bradtmöller, M., Martínez, L., Arrizabalaga, Á., 2016. Lithic cultural variability during the Gravettian in the Cantabrian Region and the western Pyrenees: State of the art. Quaternary International. 406, 25–43.

Cardillo, M., 2010. Some applications of geometric morphometrics to archaeology. In: Morphometrics for Nonmorphometricians. Springer, pp. 325–341.

Caruana, M.V., Carvalho, S., Braun, D.R., Presnyakova, D., Haslam, M., Archer, W., Bobe, R., Harris, J.W., 2014. Quantifying traces of tool use: a novel morphometric analysis of damage patterns on percussive tools. PLoS One. 9, e113856.

Carvalho, A.F., 2007. A neolitização do Portugal meridional: os exemplos do Maciço calcário estremenho e do Algarve ocidental. Universidade do Algarve.

Carvalho, S., Biro, D., McGrew, W.C., Matsuzawa, T., 2009. Tool-composite reuse in wild chimpanzees (Pan troglodytes): archaeologically invisible steps in the technological evolution of early hominins? Animal Cognition. 12, 103–114.

Carvalho, V.C.M., 2011. O Abrigo do Lagar Velho e o Paleolítico Superior em Leiria, Portugal: análise dos dados arqueológicos no actual contexto da evolução humana.

Cascalheira, J., 2010. Tecnologia lítica do abrigo Solutrense de Vale Boi, Cadernos da Uniarq 5. UNIARQ, Lisbon.

Cascalheira, J., 2013. A influência mediterrânica nas redes sociais do Solutrense final peninsular (Unpublished Ph.D. thesis). Universidade do Algarve, Faro.

Cascalheira, J., Bicho, N., Manne, T., Horta, P., 2017. Cross-scale adaptive behaviors during the Upper Paleolithic in Iberia: the example of Vale Boi (Southwestern Portugal). Quaternary International. In press.

Ceruleo, P., Marra, F., Pandolfi, L., Petronio, C., Salari, L., 2015. The archaic Acheulean lithic industry of the Cretone basin (Latium, central Italy). Journal of Archaeological Science: Reports. 3, 480–492.

Chauhan, P.R., 2007. Soanian cores and core-tools from Toka, Northern India: Towards a new typo-technological organization. Journal of Anthropological Archaeology. 26, 412–441.

Chazan, M., Horwitz, L.K., 2006. Finding the message in intricacy: The association of lithics and fauna on Lower Paleolithic Multiple Carcass Sites. Journal of Anthropological Archaeology. 25, 436–447.

Chiotti, L., 1999. Les industries lithiques des niveaux aurignaciens de l'abri Pataud, Les Eyzies-de-Tayac (Dordogne): étude technologique et typologique.

Chiotti, L., 2002. La production d'éclats dans l'Aurignacien ancien de l'abri Pataud, les Eyzies-de-Tayac, Dordogne. Espacio Tiempo y Forma. Serie I, Prehistoria y Arqueología.

Chiotti, L., 2005. Les industries lithiques aurignaciennes de l'abri Pataud, Dordogne, France: les fouilles de Hallam L. Movius, Jr. British Archaeological Reports Limited.

Chiotti, L., 2012. Some evidence for flake production in the early aurignacian: examples from the Pataud and Castanet rock shelters (France). In: In : Pastoors, A., Peresani M. (Eds), Flakes Not Blades: The Role of Flake Production at the Onset of the Upper Palaeolithic in Europe. Presented at the Workshop du Musée de Neanderthal, Mettmann.

Chiotti, L., Patou-Mathis, M., Vercoutère, C., 2003. Comportements techniques et de subsistance à l'Aurignacien ancien: la couche 11 de l'abri Pataud (Dordogne). Gallia Préhistoire–Archéologie de la France préhistorique. 45, 157–203.

Chu, W., Richter, J., 2019. Aurignacian Cultural Unit. In: Encyclopedia of Global Archaeology. Springer International Publishing, Cham, pp. 1–10.

Clark, J.D., 1959. The prehistory of southern Africa. Harmondsworth, England.

Clark, J.D., 1988. The Middle Stone Age of East Africa and the beginnings of regional identity. Journal of World Prehistory. 2, 235–305.

Clark, J.D., Beyene, Y., WoldeGabriel, G., Hart, W.K., Renne, P.R., Gilbert, H., Defleur, A., Suwa, G., Katoh, S., Ludwig, K.R., 2003. Stratigraphic, chronological and behavioural contexts of Pleistocene Homo sapiens from Middle Awash, Ethiopia. Nature. 423, 747–752.

Clarkson, C., Jacobs, Z., Marwick, B., Fullagar, R., Wallis, L., Smith, M., Roberts, R.G., Hayes, E., Lowe, K., Carah, X., Florin, S.A., McNeil, J., Cox, D., Arnold, L.J., Hua, Q., Huntley, J., Brand, H.E.A., Manne, T., Fairbairn, A., Shulmeister, J., Lyle, L., Salinas, M., Page, M., Connell, K., Park, G., Norman, K., Murphy, T., Pardoe, C., 2017. Human occupation of northern Australia by 65,000 years ago. Nature. 547, 306–310.

Coelho, C., Falótico, T., Izar, P., Mannu, M., Resende, B. de, Siqueira, J., Ottoni, E., 2015. Social learning strategies for nut-cracking by tufted capuchin monkeys (Sapajus spp.). Animal cognition. 18, 911–919.

Collina, C., Marciani, G., Martini, I., Donadio, C., Repola, L., Bortolini, E., Arrighi, S., Badino, F., Figus, C., Lugli, F., 2020. Refining the Uluzzian through a new lithic assemblage from Roccia san Sebastiano (Mondragone, southern Italy). Quaternary International. 551, 150–168.

Compton, T., Skinner, M.M., Humphrey, L., Pope, M., Bates, M., Davies, T.W., Parfitt, S.A., Plummer, W.P., Scott, B., Shaw, A., Stringer, C., 2021. The morphology of the Late Pleistocene hominin remains from the site of La Cotte de St Brelade, Jersey (Channel Islands). Journal of Human Evolution. 152, 102939.

Conard, N.J., 2009. A female figurine from the basal Aurignacian of Hohle Fels Cave in southwestern Germany. Nature. 459, 248–252.

Cornelissen, E., 2002. Human Responses to Changing Environments in Central Africa Between 40,000 and 12,000 B.P. Journal of World Prehistory. 16, 197–235.

Cortés-Sánchez, M., Jiménez-Espejo, F.J., Simón-Vallejo, M.D., Stringer, C., Lozano Francisco, M.C., García-Alix, A., Vera Peláez, J.L., Odriozola, C.P., Riquelme-Cantal, J.A., Parrilla Giráldez, R., Maestro González, A., Ohkouchi, N., Morales-Muñiz, A., 2019. An early Aurignacian arrival in southwestern Europe. Nature Ecology & Evolution. 3, 207–212.

Cosgrove, R., 1999. Forty-Two Degrees South: The Archaeology of Late Pleistocene Tasmania. Journal of World Prehistory. 13, 357–402.

Curtoni, R.P., 1996. Experimentando con bipolares: indicadores e implicancias arqueológicas. Relaciones de la Sociedad Argentina de Antropología. 21.

d'Errico, F., Backwell, L.R., 2003. Possible evidence of bone tool shaping by Swartkrans early hominids. Journal of Archaeological Science. 30, 1559–1576.

d'Errico, F., Borgia, V., Ronchitelli, A., 2012. Uluzzian bone technology and its implications for the origin of behavioural modernity. Quaternary International. 259, 59–71.

d'Errico, F., Zilhão, J., Julien, M., Baffier, D., Pelegrin, J., 1998. Neanderthal Acculturation in Western Europe? A Critical Review of the Evidence and Its Interpretation 1. Current Anthropology. 39, S1–S44.

Darlas, A., 2007. Le Moustérien de Grèce à la lumière des récentes recherches. Moustérien. 111, 346–366.

Daujeard, C., Moncel, M.-H., 2010. On Neanderthal subsistence strategies and land use: A regional focus on the Rhone Valley area in southeastern France. Journal of Anthropological Archaeology. 29, 368–391.

de la Peña Alonso, P., Toscano, L.G.V., 2013. Bipolar Knapping in Gravettian Occupations at El Palomar Rockshelter (Yeste, Southeastern Spain). Journal of Anthropological Research. 69, 33–64.

de la Peña, P., 2011. Sobre la identificación macroscópica de las piezas astilladas: propuesta experimental. Trabajos de Prehistoria. 68, 79–98.

de la Peña, P., 2013. The beginning of the Upper Paleolithic in the Baetic Mountain area (Spain). Paleolithic Ecodynamics in southern Iberia. 318, 69–89.

de la Peña, Paloma, 2015a. The interpretation of bipolar knapping in African Stone Age studies. Current Anthropology. 56, 911–923.

de la Peña, Paloma, 2015b. A qualitative guide to recognize bipolar knapping for flint and quartz. Lithic Technology. 40, 316–331.

de la Peña, P., Wadley, L., 2014a. . Quaternary International. 350, 26.

de la Peña, P., Wadley, L., 2014b. . PLoS ONE. 9, 1.

de la Torre, I., 2011. The Early Stone Age lithic assemblages of Gadeb (Ethiopia) and the Developed Oldowan/early Acheulean in East Africa. J Hum Evol. 60, 768–812.

de la Torre, I., Mora, R., Domínguez-Rodrigo, M., de Luque, L., Alcalá, L., 2003. The Oldowan industry of Peninj and its bearing on the reconstruction of the technological skills of LowerPleistocene hominids. J Hum Evol. 44, 203–224.

de Lombera-Hermida, A., Bargalló, A., Terradillos-Bernal, M., Huguet, R., Vallverdú, J., García-Antón, M.-D., Mosquera, M., Ollé, A., Sala, R., Carbonell, E., Rodríguez-Álvarez, X.-P., 2015. The lithic industry of Sima del Elefante (Atapuerca, Burgos, Spain) in the context of Early and Middle Pleistocene technology in Europe. Journal of Human Evolution. 82, 95–106.

de Lombera-Hermida, A., Rodríguez-Álvarez, X.P., Peña, L., Sala-Ramos, R., Despriée, J., Moncel, M.-H., Gourcimault, G., Voinchet, P., Falguères, C., 2016. The lithic assemblage from Pont-de-Lavaud (Indre, France) and the role of the bipolar-on-anvil technique in the Lower and Early Middle Pleistocene technology. Journal of Anthropological Archaeology. 41, 159–184.

de Matos, D., Pereira, T., 2020. Middle Stone Age lithic assemblages from Leba Cave (Southwest Angola). Journal of Archaeological Science: Reports. 32, 102413.

de Sonneville-Bordes, D., Perrot, J., 1956. Lexique typologique du Paléolithique supérieur: Outillage lithique. Bulletin de la Société préhistorique de France. 53, 547–559.

De Stefani, M., Dini, M., Klempererova, H., Peresani, M., Ranaldo, F., Ronchitelli, A., Ziggiotti, S., 2012. Continuity and replacement in flake production across the Middle-Upper Palaeolithic transition: a view over the Italian Peninsula. Flakes Not Bl Role Flake Prod Onset Up Palaeolithic Eur Mettmann. 135–151.

delaTorre, I., deBeaune, S., Davidson, I., Gowlett, J., Hovers, E., Kimura, Y., Mercader, J., delaTorre, I., 2004. Omo revisited: evaluating the technological skills of Pliocene hominids. Current Anthropology. 45, 439–465.

Demayumba, N., 2021. Contribution à l'étude du Middle Stone Age (MSA) d'Afrique Centrale. Étude typo-technologique des industries lithiques du site préhistorique de Mpila, Brazzaville, République du Congo. L'Anthropologie. 125, 102851.

Dennell, R., Martinón-Torres, M., de Castro, J.-M.B., Xing, G., 2020. A demographic history of Late Pleistocene China. Quaternary International. 559, 4–13.

Dennell, R., Roebroeks, W., 2005. An Asian perspective on early human dispersal from Africa. Nature. 438, 1099–1104.

Derevianko, A., Xing, G., Olsen, J., Rybin, E., 2012. The Paleolithic of Dzungaria (Xinjiang, northwest China) based on materials from the Luotuoshi site. Archaeology, Ethnology and Anthropology of Eurasia. 40, 2–18.

Derevianko, A., Zenin, A., Rybin, E., Gladyshev, S., Tsybankov, A., Olsen, J., Tseveendorj, D., Gunchinsuren, B., 2007. The technology of early Upper Paleolithic lithic reduction in Northern Mongolia: The Tolbor-4 site. Archaeology, Ethnology and Anthropology of Eurasia. 29, 16–38.

di Cesnola, A.P., 1993. Il Paleolitico superiore in Italia: introduzione allo studio. Garlatti e Razzai.

Dibble, H.L., Rezek, Z., 2009. Introducing a new experimental design for controlled studies of flake formation: results for exterior platform angle, platform depth, angle of blow, velocity, and force. Journal of Archaeological Science. 36, 1945–1954.

Diez-Martín, F., 2010. Evaluating the effect of plowing on the archaeological record: The early middle palaeolithic in the river Duero basin plateaus (north-central Spain). Quaternary International. 214, 30–43.

Diez-Martin, F., Yustos, P., Dominguez-Rodrigo, M., Mabulla, A., Barba, R., 2009. . Journal of Anthropological Archaeology. 28, 274.

Diez-Martín, F., Yustos, P.S., Domínguez-Rodrigo, M., Prendergast, M.E., 2011. An experimental study of bipolar and freehand knapping of Naibor Soit quartz from Olduvai Gorge (Tanzania). American Antiquity. 76, 690–708.

Dini, M., Tozzi, C., 2012. La transizione paleolitico Medio-paleolitico superiore nella grotta La Fabbrica (Grosseto-Toscana). Atti Societa Toscana Nat. Mem Serie A. 117–119.

Dinnis, R., Bessudnov, A., Reynolds, N., Devièse, T., Dudin, A., Pate, A., Sablin, M., Sinitsyn, A., Higham, T., 2021. Eastern Europe's "Transitional Industry"?: Deconstructing the Early Streletskian. Journal of Paleolithic Archaeology. 4, 6.

Dobrescu, R., Tuffreau, A., Bonsall, C., 2018. L'utilisation de l'obsidienne au Paléolithique supérieur dans le nord-ouest de la Roumanie. L'Anthropologie. 122, 111–128.

Dominguez-Rodrigo, M., Pickering, T.R., Semaw, S., Rogers, M.J., 2005. Cutmarked bones from Pliocene archaeological sites at Gona, Afar, Ethiopia: implications for the function of the world's oldest stone tools. J Hum Evol. 48, 109–21.

Donner, J.J., 1975. Pollen composition of the Abri Pataud sediments. MOVIUS HL, Excavation of the Abri Pataud, Les Eyzies (Dordogne). Contributors, American School of Prehistoric Research, Peabody Museum, Harvard University, Cambridge, Massachusetts, bull. 160–173.

Douka, K., Chiotti, L., Nespoulet, R., Higham, T., 2020. A refined chronology for the Gravettian sequence of Abri Pataud. Journal of human evolution. 141, 102730.

Douka, K., Grimaldi, S., Boschian, G., del Lucchese, A., Higham, T.F., 2012. A new chronostratigraphic framework for the Upper Palaeolithic of Riparo Mochi (Italy). J Hum Evol. 62, 286–99.

Douka, K., Higham, T.F., Wood, R., Boscato, P., Gambassini, P., Karkanas, P., Peresani, M., Ronchitelli, A.M., 2014. On the chronology of the Uluzzian. J Hum Evol. 68, 1–13.

Duke, H., Pargeter, J., 2015. Weaving Simple Solutions to Complex Problems: An Experimental Study of Skill in Bipolar Cobble-Splitting. Lithic Technology. 40, 349–365.

Dunbar, R.I., Shultz, S., 2007. Evolution in the social brain. science. 317, 1344–1347.

Eren, M.I., 2010. Anvil reduction at the early paleoindian site of paleo Crossing (33ME274), Northeast Ohio. Current Research in the Pleistocene. 27, 75–77.

Eren, M.I., Diez-Martin, F., Dominguez-Rodrigo, M., 2013. An empirical test of the relative frequency of bipolar reduction in Beds VI, V, and III at Mumba Rockshelter, Tanzania: implications for the East African Middle to Late Stone Age transition. Journal of Archaeological Science. 40, 248–256.

Évora, G.M.S. de A., 2016. A indústria óssea do Paleolítico Superior do sul da Península Ibérica: a gestão do risco e da incerteza.

Faith, J.T., Tryon, C.A., Peppe, D.J., Beverly, E.J., Blegen, N., Blumenthal, S., Chritz, K.L., Driese, S.G., Patterson, D., 2015. Paleoenvironmental context of the Middle Stone Age record from Karungu, Lake Victoria Basin, Kenya, and its implications for human and faunal dispersals in East Africa. Journal of Human Evolution. 83, 28–45.

Faivre, J.-Ph., Gravina, B., Bourguignon, L., Discamps, E., Turq, A., 2017. Late Middle Palaeolithic lithic technocomplexes (MIS 5–3) in the northeastern Aquitaine Basin: Advances and challenges. Cleaning up a Messy Mousterian: How to describe and interpret Late Middle Palaeolithic chrono-cultural variability in Atlantic Europe. 433, 116–131.

Falcucci, 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, e0189241.

Fano, M.Á., Chauvin Grandela, A., Clemente-Conte, I., Tarriño, A., Teira, L.C., 2020. Magdalenian knappers in the Asón Valley: Level 2 at El Horno Cave (Ramales de la Victoria, Cantabria, Spain). Journal of Archaeological Science: Reports. 30, 102230.

Fewlass, H., Talamo, S., Wacker, L., Kromer, B., Tuna, T., Fagault, Y., Bard, E., McPherron, S.P., Aldeias, V., Maria, R., 2020. A 14 C chronology for the Middle to Upper Palaeolithic transition at Bacho Kiro cave, Bulgaria. Nature ecology & evolution. 4, 794–801.

Fisher, J.W., 1995. Bone surface modifications in zooarchaeology. Journal of Archaeological method and theory. 2, 7–68.

Flas, D., 2006. La transition du Paléolithique moyen au supérieur dans la plaine septentrionale de l'Europe. Les problématiques du Lincombien-Ranisien-Jerzmanowicien.

Flas, D., 2011. The Middle to Upper Paleolithic transition in Northern Europe: the Lincombian-Ranisian-Jerzmanowician and the issue of acculturation of the last Neanderthals. World Archaeology. 43, 605–627.

Flas, D., 2015. La fin du Paléolithique moyen dans le Nord de l'Europe: la question des origines du Lincombien-Ranisien-Jerzmanowicien. Les plaines du Nord-Ouest: carrefour de l'Europe au Paléolithique moyen? 259–280.

Flenniken, J.J., 1981. Replicative Systems Analysis: A Model Applied to The Vein Quartz Artifacts From The Hoko River Site, null.

Fletcher, W.J., Sánchez Goñi, M.F., Allen, J.R.M., Cheddadi, R., Combourieu-Nebout, N., Huntley, B., Lawson, I., Londeix, L., Magri, D., Margari, V., Müller, U.C., Naughton, F., Novenko, E., Roucoux, K., Tzedakis, P.C., 2010. Millennial-scale variability during the last glacial in vegetation records from Europe. Quaternary Science Reviews. 29, 2839–2864.

Flood, J., 1980. The moth hunters: Aboriginal prehistory of the Australian Alps. Australian Institute of Aboriginal Studies.

Fontes, L.M., 2016. The Initial Magdalenian mosaic: New evidence from Urtiaga cave, Guipúzcoa, Spain. Journal of Anthropological Archaeology. 41, 109–131.

Fragaszy, D., Izar, P., Visalberghi, E., Ottoni, E.B., de Oliveira, M.G., 2004. Wild capuchin monkeys (Cebus libidinosus) use anvils and stone pounding tools. American Journal of Primatology. 64, 359–366.

Fu, Q., Posth, C., Hajdinjak, M., Petr, M., Mallick, S., Fernandes, D., Furtwängler, A., Haak, W., Meyer, M., Mittnik, A., 2016. The genetic history of ice age Europe. Nature. 534, 200–205.

Gallotti, R., 2013. An older origin for the Acheulean at Melka Kunture (Upper Awash, Ethiopia): techno-economic behaviours at Garba IVD. Journal of Human Evolution. 65, 594–620.

Gallotti, R., Peretto, C., 2015. The Lower/early middle Pleistocene small débitage productions in western Europe: new data from Isernia La Pineta t. 3c (Upper Volturno Basin, Italy). Quaternary International. 357, 264–281.

Gambassini, P., Napoleone, G., 1997. Il Paleolitico di Castelcivita: culture e ambiente. Electa Napoli.

Garcea, E.A., 2016. Dispersals out of Africa and back to Africa: Modern origins in North Africa. Quaternary International. 408, 79–89.

Garcia, J., 2015. Long-term hominin occupation during the Middle and early Late Pleistocene: Chronostratigraphy of the Ter River basin (Girona, North-eastern Spain). Journal of Archaeological Science: Reports. 3, 493–512.

Garcia, J., Martínez, K., Carbonell, E., Agustí, J., Burjachs, F., 2012. Defending the early human occupation of Vallparadís (Barcelona, Iberian Peninsula): a reply to Madurell-Malapeira et al.(2012). Journal of Human Evolution. 63, 568–575.

Garrod, D.A., Howe, B., Gaul, J., 1939. Excavations in the cave of Bacho Kiro, north-east Bulgaria. Bulletin of the American School of Prehistoric research. 15, 46–76.

Gaudzinski, S., 1999. Middle Palaeolithic Bone Tools from the Open-Air Site Salzgitter-Lebenstedt (Germany). Journal of Archaeological Science. 26, 125–141.

Gaudzinski-Windheuser, S., 2015. The public and private use of space in Magdalenian societies: Evidence from Oelknitz 3, LOP (Thuringia, Germany). Journal of Anthropological Archaeology. 40, 361–375.

Germonpré, M., Lázničková-Galetová, M., Sablin, M.V., 2012. Palaeolithic dog skulls at the Gravettian Předmostí site, the Czech Republic. Journal of Archaeological Science. 39, 184–202.

Gibaja, J.F., Bicho, N.F., 2011. La función de los instrumentos líticos en el asentamiento de Vale Boi (Algarve, Portugal) Estudio del utillaje gravetiense y solutrense. SAGVNTVM. Papeles del Laboratorio de Arqueología de Valencia. 38, 9–21.

Gilabert, X.R., Mora, R., Martínez-Moreno, J., 2015. Identifying bipolar knapping in the Mesolithic site of Font del Ros (northeast Iberia). Phil. Trans. R. Soc. B. 370, 20140354.

Goldman-Neuman, T., Hovers, E., 2012. Raw material selectivity in Late Pliocene Oldowan sites in the Makaamitalu Basin, Hadar, Ethiopia. Journal of Human Evolution. 62, 353–366.

Goñi, M.F.S., Landais, A., Fletcher, W.J., Naughton, F., Desprat, S., Duprat, J., 2008. Contrasting impacts of Dansgaard–Oeschger events over a western European latitudinal transect modulated by orbital parameters. Quaternary Science Reviews. 27, 1136–1151.

Goñi, M.F.S., Turon, J.-L., Eynaud, F., Gendreau, S., 2000. European Climatic Response to Millennial-Scale Changes in the Atmosphere–Ocean System during the Last Glacial Period. Quaternary Research. 54, 394–403.

Goñi, M.S., Cacho, I., Turon, J.-L., Guiot, J., Sierro, F., Peypouquet, J., Grimalt, J., Shackleton, N., 2002. Synchroneity between marine and terrestrial responses to millennial scale climatic variability during the last glacial period in the Mediterranean region. Climate dynamics. 19, 95–105.

Goren-Inbar, N., Sharon, G., Melamed, Y., Kislev, M., 2002. Nuts, nut cracking, and pitted stones at Gesher Benot Ya ‘aqov, Israel. Proceedings of the National Academy of Sciences. 99, 2455–2460.

Groucutt, H.S., 2020. Culture and convergence: The curious case of the Nubian Complex. In: Culture History and Convergent Evolution. Springer, pp. 55–86.

Groucutt, H.S., Petraglia, M.D., 2012. The prehistory of the Arabian peninsula: deserts, dispersals, and demography. Evolutionary Anthropology: Issues, News, and Reviews. 21, 113–125.

Groucutt, H.S., Petraglia, M.D., Bailey, G., Scerri, E.M., Parton, A., Clark-Balzan, L., Jennings, R.P., Lewis, L., Blinkhorn, J., Drake, N.A., 2015. Rethinking the dispersal of Homo sapiens out of Africa. Evolutionary Anthropology: Issues, News, and Reviews. 24, 149–164.

Guadelli, J.-L., Sirakov, N., Ivanova, S., Sirakova, S., Anastassova, E., Courtaud, P., Dimitrova, I., Djabarska, N., Fernandez, P., Ferrier, C., 2005. Une séquence du Paléolithique inférieur au Paléolithique récent dans les Balkans: la grotte Kozarnika à Orechets (nord-ouest de la Bulgarie). In: Les Premiers Peuplements En Europe. British Archaeological Reports, pp. 87–103.

Gurtov, A.N., Buchanan, B., Eren, M.I., 2015. “Dissecting” quartzite and basalt bipolar flake shape: a morphometric comparison of experimental replications from Olduvai Gorge, Tanzania. Lithic Technology. 40, 332–341.

Gurtov, A.N., Eren, M.I., 2014a. Lower Paleolithic bipolar reduction and hominin selection of quartz at Olduvai Gorge, Tanzania: What’s the connection? Quaternary International. 322–323, 285–291.

Gurtov, A.N., Eren, M.I., 2014b. Lower Paleolithic bipolar reduction and hominin selection of quartz at Olduvai Gorge, Tanzania: What’s the connection? Quaternary International. 322–323, 285–291.

Hahn, J., 1986. Kraft und Aggression: die Botschaft der Eiszeitkunst im Aurignacien Süddeutschlands? Archaeologica Venatoria.

Hajdinjak, M., Mafessoni, F., Skov, L., Vernot, B., Hübner, A., Fu, Q., Essel, E., Nagel, S., Nickel, B., Richter, J., 2021. Initial Upper Palaeolithic humans in Europe had recent Neanderthal ancestry. Nature. 592, 253–257.

Hallinan, E., Shaw, M., 2020. Nubian Levallois reduction strategies in the Tankwa Karoo, South Africa. Plos one. 15, e0241068.

Harmand, S., Lewis, J.E., Feibel, C.S., Lepre, C.J., Prat, S., Lenoble, A., Boes, X., Quinn, R.L., Brenet, M., Arroyo, A., Taylor, N., Clement, S., Daver, G., Brugal, J.P., Leakey, L., Mortlock, R.A., Wright, J.D., Lokorodi, S., Kirwa, C., Kent, D.V., Roche, H., 2015a. 3.3-million-year-old stone tools from Lomekwi 3, West Turkana, Kenya. Nature. 521, 310–5.

Harmand, S., Lewis, J.E., Feibel, C.S., Lepre, C.J., Prat, S., Lenoble, A., Boes, X., Quinn, R.L., Brenet, M., Arroyo, A., Taylor, N., Clement, S., Daver, G., Brugal, J.P., Leakey, L., Mortlock, R.A., Wright, J.D., Lokorodi, S., Kirwa, C., Kent, D.V., Roche, H., 2015b. 3.3-million-year-old stone tools from Lomekwi 3, West Turkana, Kenya. Nature. 521, 310–5.

Harrison, R., 2004. Kimberley points and colonial preference: new insights into the chronology of pressure flaked point forms from the southeast Kimberley, Western Australia. Archaeology in Oceania. 39, 1–11.

Hauck, T., Rethemeyer, J., Rentzel, P., Schulte, P., Heinze, S., Ringer, A., Richter, J., Chu, W., Lehmkuhl, F., Vogels, O., 2016. Neanderthals or early modern humans? A revised 14C chronology and geoarchaeological study of the Szeletian sequence in Szeleta Cave (Kom. Borsod-Abaúj-Zemplén) in Hungary. Archäologisches Korrespondezblatt. 46, 271–290.

Haws, J.A., Benedetti, M.M., Bicho, N.F., Cascalheira, J., Ellis, M.G., Carvalho, M.M., Friedl, L., Pereira, T., Talamo, S., 2021. The early Aurignacian at Lapa do Picareiro really is that old: A comment on'The late persistence of the Middle Palaeolithic and Neandertals in Iberia: A review of the evidence for and against the" Ebro Frontier" model'. Quaternary Science Reviews. 274, 107261.

Haws, J.A., Benedetti, M.M., Talamo, S., Bicho, N., Cascalheira, J., Ellis, M.G., Carvalho, M.M., Friedl, L., Pereira, T., Zinsious, B.K., 2020. The early Aurignacian dispersal of modern humans into westernmost Eurasia. Proceedings of the National Academy of Sciences. 117, 25414–25422.

Hayden, B., 1980a. Confusion in the bipolar world: bashed pebbles and splintered pieces. Lithic Technology. 9, 2–7.

Hayden, B., 1980b. Confusion in the bipolar world: bashed pebbles and splintered pieces. Lithic Technology. 9, 2–7.

Hayden, B., 1980c. Confusion in the bipolar world: bashed pebbles and splintered pieces. Lithic Technology. 9, 2–7.

Hayden, B., 2015. Insights into early lithic technologies from ethnography. Philosophical Transactions of the Royal Society B: Biological Sciences. 370, 20140356.

Henshilwood, C.S., d'Errico, F., Marean, C.W., Milo, R.G., Yates, R., 2001. An early bone tool industry from the Middle Stone Age at Blombos Cave, South Africa: implications for the origins of modern human behaviour, symbolism and language. J Hum Evol. 41, 631–78.

Henshilwood, C.S., Dubreuil, B., 2011. The Still Bay and Howiesons Poort, 77–59 ka: symbolic material culture and the evolution of the mind during the African Middle Stone Age. Current anthropology. 52, 361–400.

Henshilwood, C.S., van Niekerk, K.L., Wurz, S., Delagnes, A., Armitage, S.J., Rifkin, R.F., Douze, K., Keene, P., Haaland, M.M., Reynard, J., Discamps, E., Mienies, S.S., 2014. Klipdrift Shelter, southern Cape, South Africa: preliminary report on the Howiesons Poort layers. Journal of Archaeological Science. 45, 284–303.

Hershkovitz, I., Weber, G.W., Quam, R., Duval, M., Grün, R., Kinsley, L., Ayalon, A., Bar-Matthews, M., Valladas, H., Mercier, N., 2018. The earliest modern humans outside Africa. Science. 359, 456–459.

Herzlinger, G., Goren-Inbar, N., Grosman, L., 2017. A new method for 3D geometric morphometric shape analysis: The case study of handaxe knapping skill. Journal of Archaeological Science: Reports. 14, 163–173.

Higham, T., Basell, L., Jacobi, R., Wood, R., Ramsey, C.B., Conard, N.J., 2012. Testing models for the beginnings of the Aurignacian and the advent of figurative art and music: The radiocarbon chronology of Geißenklösterle. Journal of human evolution. 62, 664–676.

Higham, T., Jacobi, R., Basell, L., Ramsey, C.B., Chiotti, L., Nespoulet, R., 2011. Precision dating of the Palaeolithic: a new radiocarbon chronology for the Abri Pataud (France), a key Aurignacian sequence. J Hum Evol. 61, 549–63.

Higham, Thomas, Jacobi, R., Basell, L., Ramsey, C.B., Chiotti, L., Nespoulet, R., 2011. Precision dating of the Palaeolithic: A new radiocarbon chronology for the Abri Pataud (France), a key Aurignacian sequence. Journal of human evolution. 61, 549–563.

Hiscock, P., 1996. Mobility and technology in the Kakadu coastal wetlands. Bulletin of the Indo-Pacific Prehistory Association. 15, 151–157.

Hiscock, P., 2015a. Dynamics of knapping with bipolar techniques: modeling transitions and the implications of variability. Lithic Technology. 40, 342–348.

Hiscock, P., 2015b. Making it small in the Palaeolithic: bipolar stone-working, miniature artefacts and models of core recycling. World Archaeology. 47, 158–169.

Hiscock, P., 2015c. Dynamics of knapping with bipolar techniques: modeling transitions and the implications of variability. Lithic Technology. 40, 342–348.

Hoffecker, J.F., Holliday, V.T., Nehoroshev, P., Vishnyatsky, L., Otcherednoy, A., Salnaya, N., Goldberg, P., Southon, J., Lehman, S.J., Cappa, P.J., 2019. The dating of a middle paleolithic blade Industry in southern Russia and its relationship to the initial upper paleolithic. Journal of Paleolithic Archaeology. 2, 381–417.

Horta, P., 2016. Tecnologia e Funcionalidade das Peças esquiroladas do Paleolítico Superior de Vale Boi, Vila do Bispo (Master's Thesis). Universidade do Algarve, Faro.

Horta, P., Bicho, N., Cascalheira, J., 2022. Lithic bipolar methods as an adaptive strategy through space and time. Journal of Archaeological Science: Reports. 41, 103263.

Horta, P., Cascalheira, J., Bicho, N., 2015. Expedient tools for intensive practices: the bipolar implements from the Upper Paleolithic site of Vale Boi (Southwestern Iberia). In: Proceedings of the European Society for the Study of Human Evolution, 4: 124. Presented at the 4th Meeting of the European Society for the study of Human Evolution, London.

Horta, P., Cascalheira, J., Bicho, N., 2017. Sobre a definição e interpretação das tecnologias líticas bipolares em contextos pré-históricos. In: Estado Da Questão. Presented at the II Congresso da Associação dos Arqueólogos Portugueses, Lisboa, pp. 385–392.

Horta, P., Cascalheira, J., Bicho, N., 2019. The Role of Lithic Bipolar Technology in Western Iberia's Upper Paleolithic: the Case of Vale Boi (Southern Portugal). Journal of Paleolithic Archaeology. 2, 134–159.

Horta, P., Chiotti, L., Submitted. Intensive and expedient resource extraction strategies through the flexible use of lithic bipolar methods in the Early Aurignacian of Abri Pataud. Archaeological and Anthropological Sciences.

Horta, P., Tsanova, T., Sirakov, N., Marreiros, J., Svoboda, S., Delvigne, V., McPherron, S., Hublin, J.-J., 2020. Intensive re-use of stone tools as bipolar implements in the Initial Upper Paleolithic of Bacho Kiro Cave. In: Paper Presented at the 10th Annual Meeting of the European Society for the Study of Human Evolution Abstract Book.

Hovers, E., Belfer-Cohen, A., 2020. Are Lithics and Fauna a Match Made in (Prehistoric) Heaven? Journal of Paleolithic Archaeology. 3, 108–125.

Hublin, J.-J., 2015. The modern human colonization of western Eurasia: when and where? Quaternary Science Reviews. 118, 194–210.

Hublin, J.-J., Ben-Ncer, A., Bailey, S.E., Freidline, S.E., Neubauer, S., Skinner, M.M., Bergmann, I., Le Cabec, A., Benazzi, S., Harvati, K., 2017. New fossils from Jebel Irhoud, Morocco and the pan-African origin of Homo sapiens. Nature. 546, 289–292.

Hublin, J.-J., Sirakov, N., Aldeias, V., Bailey, S., Bard, E., Delvigne, V., Endarova, E., Fagault, Y., Fewlass, H., Hajdinjak, M., 2020. Initial upper palaeolithic homo sapiens from bacho kiro cave, Bulgaria. Nature. 581, 299–302.

Hublin, J.-J., Spoor, F., Braun, M., Zonneveld, F., Condemi, S., 1996. A late Neanderthal associated with Upper Palaeolithic artefacts. Nature. 381, 224–226.

Igreja, M., Porraz, G., 2013. Functional insights into the innovative Early Howiesons Poort technology at Diepkloof Rock Shelter (Western Cape, South Africa). Journal of Archaeological Science. 40, 3475–3491.

Iriarte-Chiapusso, M., Arrizabalaga, A., 2015. Bolinkoba (Abadiño) y su yacimiento arqueológico. Arqueología de la Arqueología para la puesta en valor de su depósito, a la luz de las excavaciones antiguas y recientes. Spite of Paleoantropología, Bizkaiko Arkeologia Indusketak. 6, 1–192.

Iriarte-Chiapusso, M.J., Arrizabalaga, A., 2011. El Gravetiense de Bolinkoba (Bizkaia) a la luz de las excavaciones antiguas y recientes. Pensando el Gravetiense: nuevos datos para la región cantábrica en su contexto peninsular y pirenaico. Monografías del Museo Nacional y Centro de Investigación de Altamira. 23, 205–215.

Jerardino, A., Marean, C.W., 2010. Shellfish gathering, marine paleoecology and modern human behavior: perspectives from cave PP13B, Pinnacle Point, South Africa. J Hum Evol. 59, 412–24.

Jones, P., Leakey, M., Roe, D., 1994. Olduvai Gorge, Excavations in Beds III, IV, and the Masek Beds, 1968–1971, null.

Jones, S.C., Pal, J.N., 2009. The Palaeolithic of the Middle Son valley, north-central India: Changes in hominin lithic technology and behaviour during the Upper Pleistocene. Journal of Anthropological Archaeology. 28, 323–341.

Kaczanowska, M., Kozłowski, J., Sobczyk, K., 2011. Upper Palaeolithic human occupations and material culture at Klissoura Cave 1. Eurasian Prehistory. 7.

Kandel, A.W., Gasparyan, B., Allué, E., Bigga, G., Bruch, A.A., Cullen, V.L., Frahm, E., Ghukasyan, R., Gruwier, B., Jabbour, F., 2017. The earliest evidence for Upper Paleolithic occupation in the Armenian Highlands at Aghitu-3 Cave. Journal of human evolution. 110, 37–68.

Knight, J., 2016. Technological analysis of the anvil (bipolar) technique. Lithics–The Journal of the Lithic Studies Society. 57.

Kolobova, K.A., Kharevich, V.M., Kharevich, A.V., Fedorchenko, A.Yu., Bocharova, E.N., Kurbanov, R., Flas, D., Krivoshapkin, A.I., Olsen, J.W., 2021. Archaeological and experimental studies of splintered pieces in the Central Asian Upper Paleolithic. Archaeological and Anthropological Sciences. 13, 28.

Kononenko, O., 2021. The Upper Palaeolithic site Radomyshl I (Ukraine): Another phenomenon of the gravettian technocomplex? Quaternary International. 587, 251–276.

Koumouzelis, M., Ginter, B., Kozlowski, J.K., Pawlikowski, M., Bar-Yosef, O., Albert, R.M., Litynska-Zajac, M., Stworzewicz, E., Wojtal, P., Lipecki, G., Tomek, T., Bochenski, Z.M., Pazdur, A., 2001. The Early Upper Palaeolithic in Greece: The Excavations in Klisoura Cave. Journal of Archaeological Science. 28, 515–539.

Kozlowski, J., 1982. Excavation of the Bacho Kiro Cave. Final report. Pol. Sci. Publ., Warszawa.

Kozlowski, J.K., 2004. Early Upper Paleolithic Levallois-derived industries in the Balkans and in the Middle Danube basin. Anthropologie (1962-). 42, 263–280.

Kozłowski, J.K., 2015. The origin of the Gravettian. Quaternary international. 359, 3–18.

Kozłowski, J.K., Mester, Z., Zandler, K., Budek, A., Kalicki, T., Moskal, M., Ringer, Á., 2009. Le Paléolithique moyen et supérieur de la Hongrie du nord: nouvelles investigations dans la région d'Eger. L'Anthropologie. 113, 399–453.

Kuhn, S.L., 1991. "Unpacking" reduction: Lithic raw material economy in the mousterian of west-central Italy. Journal of Anthropological Archaeology. 10, 76–106.

Kuhn, S.L., 2002. Pioneers of Microlithization: The "Proto-Aurignacian" of Southern Europe. Archeological Papers of the American Anthropological Association. 12, 83–93.

Kuhn, S.L., 2004a. From Initial Upper Paleolithic to Ahmarian at Üçağizli Cave, Turkey. Anthropologie (1962-). 42, 249–262.

Kuhn, S.L., 2004b. Upper Paleolithic raw material economies at Üçağızlı cave, Turkey. Journal of Anthropological Archaeology. 23, 431–448.

Kuhn, S.L., 2019. Initial Upper Paleolithic: A (near) global problem and a global opportunity. Archaeological Research in Asia. 17, 2–8.

Kuhn, S.L., Stiner, M.C., Güleç, E., Özer, I., Yılmaz, H., Baykara, I., Açıkkol, A., Goldberg, P., Molina, K.M., Ünay, E., Suata-Alpaslan, F., 2009. The early Upper Paleolithic occupations at Üçağızlı Cave (Hatay, Turkey). Journal of Human Evolution. 56, 87–113.

Kuhn, S.L., Zwyns, N., 2014. Rethinking the initial Upper Paleolithic. Quaternary International. 347, 29–38.

Kuhn, S.L., Zwyns, N., 2018. Convergence and continuity in the initial upper Paleolithic of Eurasia. Convergent evolution in stone-tool technology. 131–152.

Kuman, K., Gibbon, R.J., 2017. The Rietputs 15 site and Early Acheulean in South Africa. Quaternary International.

Kunitake, S., Taimagambetov, Z.K., 2021. Bladelet industries of the Early Upper Palaeolithic in southern Kazakhstan: A detailed analysis of carinated bladelet cores excavated from the newly discovered Buiryokbastau-Bulak-1 site in the Karatau mountains. Quaternary International.

Lalueza-Fox, C., 2021. Neanderthal assimilation? Nature Ecology & Evolution. 5, 711–712.

Langejans, G.H.J., 2012. Middle Stone Age pièces esquillées from Sibudu Cave, South Africa: an initial micro-residue study. Journal of Archaeological Science. 39, 1694–1704.

Le Brun-Ricalens, F., Bordes, J.-G., Eizenberg, L., 2009. A crossed-glance between southern European and Middle-Near Eastern early Upper Palaeolithic lithic technocomplexes. Existing models, new perspectives. The Mediterranean from. 50, 11–33.

Leaf, G.R., 1979. Variation in the form of bipolar cores. The Plains Anthropologist. 39–50.

LeBlanc, R., 1992. Wedges, pièces esquillées, bipolar cores, and other things: An alternative to Shott's view of bipolar industries. North American Archaeologist. 13, 1–14.

Lemorini, C., Plummer, T.W., Braun, D.R., Crittenden, A.N., Ditchfield, P.W., Bishop, L.C., Hertel, F., Oliver, J.S., Marlowe, F.W., Schoeninger, M.J., Potts, R., 2014. Old stones' song: Use-wear experiments and analysis of the Oldowan quartz and quartzite assemblage from Kanjera South (Kenya). Journal of Human Evolution. 72, 10–25.

Lewis, L., Perera, N., Petraglia, M., 2014. First technological comparison of Southern African Howiesons Poort and South Asian Microlithic industries: An exploration of inter-regional variability in microlithic assemblages. Lithics of the Late Middle Palaeolithic: Post MIS 5 technological variability and its implications. 350, 7–25.

Li, F., 2016. An experimental study of bipolar reduction at Zhoukoudian locality 1, north China. Quaternary International. 400, 23–29.

Li, H., Li, C., Sherwood, N.L., Kuman, K., 2017. Experimental flaking in the Danjiangkou Reservoir Region (central China): A rare case of bipolar blanks in the Acheulean. Journal of Archaeological Science: Reports. 13, 26–35.

Li, H., Li, Z., Gao, X., Kuman, K., Sumner, A., 2019. Technological behavior of the early Late Pleistocene archaic humans at Lingjing (Xuchang, China). Archaeological and Anthropological Sciences. 11, 3477–3490.

Li, Y., Sun, X., Bodin, E., 2014. A macroscopic technological perspective on lithic production from the Early to Late Pleistocene in the Hanshui River Valley, central China. Quaternary International. 347, 148–162.

Li, Z., Ma, H., 2016. Techno-typological analysis of the microlithic assemblage at the Xuchang Man site, Lingjing, central China. Quaternary International. 400, 120–129.

Lin, S.C., Rezek, Z., Dibble, H.L., 2018. Experimental design and experimental inference in stone artifact archaeology. Journal of Archaeological Method and Theory. 25, 663–688.

Lisiecki, L.E., Raymo, M.E., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic δ18O records. Paleoceanography. 20.

Liu, Y., Hu, Y., Wei, Q., 2013. Early to Late Pleistocene human settlements and the evolution of lithic technology in the Nihewan Basin, North China: a macroscopic perspective. Quaternary international. 295, 204–214.

Lombard, M., Högberg, A., Haidle, M.N., 2019. Cognition: From Capuchin rock pounding to Lomekwian flake production. Cambridge Archaeological Journal. 29, 201–231.

Lombard, M., Wadley, L., 2016. Hunting Technologies During the Howiesons Poort at Sibudu Cave: What They Reveal About Human Cognition in KwaZulu-Natal, South Africa, Between~ 65 and 62 ka. In: Multidisciplinary Approaches to the Study of Stone Age Weaponry. Springer, pp. 273–286.

Lothrop, J.C., Gramly, R.M., 1982. Pieces esquillees from the Vail site. Archaeology of Eastern North America. 10, 1–22.

Louys, J., Roberts, P., 2020. Environmental drivers of megafauna and hominin extinction in Southeast Asia. Nature. 586, 402–406.

Lu, H., Sun, X., Wang, S., Cosgrove, R., Zhang, H., Yi, S., Ma, X., Wei, M., Yang, Z., 2011. Ages for hominin occupation in Lushi Basin, middle of South Luo River, central China. Journal of Human Evolution. 60, 612–617.

Lucas, G., Hays, M., 2004. Les pièces esquillées du site paléolithique du Flageolet I (Dordogne): outils ou nucléus. XXV Congrès Préhistorique de France. Approches fonctionnelles en Préhistoire (Nanterre, 2000), Paris. 107–120.

Ludwig, B., Harris, J., Petraglia, M., Korisettar, R., 1998. Early Human Behavior in Global Context, null.

Lyman, R.L., 1994. Vertebrate taphonomy. Cambridge University Press.

Ma, D., Pei, S., de la Torre, I., Xu, Z., Li, H., 2020. Technological adaptations of early humans at the Lower Pleistocene Nihewan Basin, North China: the case of the bipolar technique. Archaeological and Anthropological Sciences. 12, 1–17.

MacCalman, H.R., Grobbelaar, B., 1965. Preliminary Report of Two Stone-Working Ovatjimba Groups in the Northern Koakoveld [sic] of South West Africa.

MacDonald, G., 1968. Debert: A Palaeo-Indian Site in Central Nova Scotia, National Museum of Canada, Anthropology Papers 16. Google Scholar.

Mackay, A., Cartwright, C.R., Heinrich, S., Low, M.A., Stahlschmidt, M.C., Steele, T.E., 2020. Excavations at Klipfonteinrand Reveal Local and Regional Patterns of Adaptation and Interaction Through MIS 2 in Southern Africa. Journal of Paleolithic Archaeology. 3, 362–397.

Mackay, A., Jacobs, Z., Steele, T.E., Orton, J., 2015. . Journal of African Archaeology. 13, 71.

Mackay, A., Stewart, B.A., Chase, B.M., 2014. Coalescence and fragmentation in the late Pleistocene archaeology of southernmost Africa. Journal of human evolution. 72, 26–51.

Madsen, D.B., Haizhou, M., Brantingham, P.J., Xing, G., Rhode, D., Haiying, Z., Olsen, J.W., 2006. The late Upper Paleolithic occupation of the northern Tibetan Plateau margin. Journal of Archaeological Science. 33, 1433–1444.

Magnani, M., Rezek, Z., Lin, S.C., Chan, A., Dibble, H.L., 2014. Flake variation in relation to the application of force. Journal of Archaeological Science. 46, 37–49.

Maier, A., Liebermann, C., Pfeifer, S.J., 2020. Beyond the Alps and Tatra Mountains—the 20–14 ka Repopulation of the Northern Mid-latitudes as Inferred from Palimpsests Deciphered with Keys from Western and Central Europe. Journal of Paleolithic Archaeology. 3, 398–452.

Maíllo Fernández, J., 2003. La Transición Paleolítico Medio-Superior en Cantabria: análisis tecnológico de la industria lítica de Cueva Morín. Madrid: UNED University.

Maíllo-Fernández, J.M., de Quirós, F.B., 2010. L'Aurignacien archaïque de la grotte El Castillo (Espagne) : caractérisation technologique et typologique. L'Anthropologie. 114, 1–25.

Malinsky-Buller, A., 2016. The Muddle in the Middle Pleistocene: The Lower–Middle Paleolithic Transition from the Levantine Perspective. Journal of World Prehistory. 29, 1–78.

Mann, J., Patterson, E.M., 2013. Tool use by aquatic animals. Philosophical Transactions of the Royal Society B: Biological Sciences. 368, 20120424.

Manne, T., 2010. Upper Paleolithic foraging decisions and early economic intensification at Vale Boi, Southwestern Portugal (PhD Thesis). University of Arizona, Ph.D.

Manne, T., 2014. Early Upper Paleolithic bone processing and insights into small-scale storage of fats at Vale Boi, southern Iberia. Journal of Archaeological Science. 43, 111–123.

Manne, T., Bicho, N., 2009. Vale Boi: rendering new understandings of resource intensification & diversification in southwestern Iberia. Before Farming. 2009, 1–21.

Marks, A., Volkman, P., 1986. The Mousterian of Ksar Akil: Levels XXVIA through XXVIIIB. Paléorient. 5–20.

Marks, A.E., Conard, N.J., 2008. Technology vs. typology: the case for and against a transition from the MSA to the LSA at Mumba Cave, Tanzania. Space and time: which diachronies, which synchronies, which scales. 123–131.

Márquez, B., Mosquera, M., Pérez-González, A., Arsuaga, J.L., Baquedano, E., Panera, J., Espinosa, J.A., Gómez, J., 2013. Evidence of a Neanderthal-Made Quartz-Based Technology at Navalmaíllo Rockshelter (Pinilla Del Valle, Madrid Region, Spain). Journal of Anthropological Research. 69, 373–395.

Marreiros, J., 2009. As primeiras comunidades do Homem moderno no Algarve Ocidental: Caracterização paleotecnológica e paleoetnográfica das comunidades gravetenses e proto-solutrenses de Vale Boi (Algarve, Portugal). University of Algarve, Faro.

Marreiros, J., Bicho, N., 2013. Lithic technology variability and human ecodynamics during the Early Gravettian of Southern Iberian Peninsula. Quaternary International. 318, 90–101.

Marreiros, J., Martisius, N.L., Tsanova, T., McPherron, S.P., Sirakov, N., Hublin, J.-J., 2019. Functional analysis on the lithic assemblage from Layer I (the Bachokirian) at the onset of the Upper Palaeolithic in Bacho Kiro cave, Bulgaria. In: Paper Presented at the 9th Annual Meeting of the European Society for the Study of Human Evolution 19th-21st September, Abstract Book. Liège, Belgium.

Martínez-Navarro, B., 2010. Early Pleistocene faunas of Eurasia and hominin dispersals. In: Out of Africa I. Springer, pp. 207–224.

Martisius, N.L., Spasov, R., Smith, G.M., Endarova, E., Sinet-Mathiot, V., Welker, F., Aldeias, V., Horta, P., Marreiros, J., Rezek, Z., McPherron, S., Sirakov, N., Sirakova, S., Tsanova, T., Hublin, J.-J., 2022. Initial Upper Paleolithic bone technology and personal ornaments at Bacho Kiro Cave (Bulgaria). Journal of Human Evolution.

Marwick, B., Clarkson, C., O'Connor, S., Collins, S., 2016. Early modern human lithic technology from Jerimalai, East Timor. Journal of human evolution. 101, 45–64.

Mathias, C., Bourguignon, L., Brenet, M., Grégoire, S., Moncel, M.-H., 2020. Between new and inherited technical behaviours: a case study from the Early Middle Palaeolithic of Southern France. Archaeological and Anthropological Sciences. 12, 1–39.

McCall, G.S., Marks, T.P., Thomas, J.T., Eller, M., Horn, S., Horowitz, R.A., Kettles, K., Taylor-Perryman, R., 2011. Erb tanks: a middle and later stone age rockshelter in the central Namib Desert, western Namibia. PaleoAnthropology. 2011, 398–421.

McNabb, J., Kuman, K., 2015. Experimental stone tool replication at the Early Stone Age site of Sterkfontein, Gauteng, South Africa. Journal of Archaeological Science: Reports. 4, 44–53.

McPherron, S.P., Alemseged, Z., Marean, C.W., Wynn, J.G., Reed, D., Geraads, D., Bobe, R., Bearat, H.A., 2010. Evidence for stone-tool-assisted consumption of animal tissues before 3.39 million years ago at Dikika, Ethiopia. Nature. 466, 857–60.

Méndez-Quintas, E., Demuro, M., Arnold, L.J., Duval, M., Pérez-González, A., Santonja, M., 2019. Insights into the late stages of the Acheulean technocomplex of Western Iberia from the Arbo site (Galicia, Spain). Journal of Archaeological Science: Reports. 27, 101934.

Mercader, J., Asmerom, Y., Bennett, T., Raja, M., Skinner, A., 2009. Initial excavation and dating of Ngalue Cave: a Middle Stone Age site along the Niassa Rift, Mozambique. J Hum Evol. 57, 63–74.

Mercader, J., Panger, M., Boesch, C., 2002. Excavation of a chimpanzee stone tool site in the African rainforest. Science. 296, 1452–1455.

Mgeladze, A., Lordkipanidze, D., Moncel, M.-H., Despriee, J., Chagelishvili, R., Nioradze, M., Nioradze, G., 2011. Hominin occupations at the Dmanisi site, Georgia, Southern Caucasus: Raw materials and technical behaviours of Europe’s first hominins. Journal of Human Evolution. 60, 571–596.

Mihailović, D., Whallon, R., 2017. Crvena Stijena revisited: The Late Mousterian assemblages. Prehistoric hunter-gatherers and farmers in the Adriatic and neighboring regions. 450, 36–49.

Moncel, M., Daujeard, C., 2012. The variability of the Middle Palaeolithic on the right bank of the Middle Rhône Valley (southeast France): Technical traditions or functional choices? Quaternary International. 247, 103–124.

Moncel, M.-H., Despriée, J., Courcimaut, G., Voinchet, P., Bahain, J.-J., 2020. La Noira site (Centre, France) and the technological behaviours and skills of the earliest Acheulean in Western Europe between 700 and 600 ka. Journal of Paleolithic Archaeology. 1–47.

Moncel, M.-H., Moigne, A.-M., Combier, J., 2005. Pre-Neandertal behaviour during isotopic stage 9 and the beginning of stage 8. New data concerning fauna and lithics in the different occupation levels of orgnac 3 (Ardèche, South-East France): occupation types. Journal of Archaeological Science. 32, 1283–1301.

Moncel, M.-H., Moigne, A.-M., Combier, J., 2012. Towards the Middle Palaeolithic in Western Europe: The case of Orgnac 3 (southeastern France).

Montoya, C., Balasescu, A., Joannin, S., Ollivier, V., Liagre, J., Nahapetyan, S., Ghukasyan, R., Colonge, D., Gasparyan, B., Chataigner, C., 2013. The Upper Palaeolithic site of Kalavan 1 (Armenia): An Epigravettian settlement in the Lesser Caucasus. Journal of Human Evolution. 65, 621–640.

Moore, M.W., 1997. Aboriginal Archaeology of Dry Sclerophyll Forest Conservation Reserves in Eastern Tasmania: A Study of Tasmanian Lithic Technology: A Report to Forestry Tasmania. Forestry Tasmania.

Moore, M.W., Sutikna, T., Morwood, M., Brumm, A., 2009. Continuities in stone flaking technology at Liang Bua, Flores, Indonesia. Journal of Human Evolution. 57, 503–526.

Morgan, B., Eren, M.I., Khreisheh, N., Hill, G., Bradley, B., Jennings, T., Smallwood, A., Thomas, J., Ashley, S., 2015. Clovis: Current perspectives on technology, chronology, and adaptations, null.

Morgan, C., Barton, L., Yi, M., Bettinger, R.L., Gao, X., Peng, F., 2014. Redating Shuidonggou locality 1 and implications for the initial upper Paleolithic in east asia. Radiocarbon. 56, 165–179.

Moroni, A., Ronchitelli, A., Arrighi, S., Aureli, D., Bailey, S., Boscato, P., Boschin, F., Capecchi, G., Crezzini, J., Douka, K., 2018. Grotta del Cavallo (Apulia–southern Italy). The Uluzzian in the mirror. J Anthropol Sci 96: 1–36.

Mosquera, M., Ollé, A., Saladie, P., Cáceres, I., Huguet, R., Rosas, A., Villalaín, J., Carrancho, A., Bourlčs, D., Braucher, R., 2016. The Early Acheulean technology of Barranc de la Boella (Catalonia, Spain). Quaternary International. 393, 95–111.

Mourre, V., Villa, P., Henshilwood, C.S., 2010. Early use of pressure flaking on lithic artifacts at Blombos Cave, South Africa. Science. 330, 659–62.

Movius Jr, H.L., 1966. The hearths of the Upper Perigordian and Aurignacian horizons at the Abri Pataud, Les Eyzies (Dordogne), and their possible significance. American Anthropologist. 296–325.

Movius Jr, H.L., 1977. Excavation of the Abri Pataud, Les Eyzies (Dordogne). Stratigraphy. American School of Prehistoric Research. Bulletin Cambridge, Mass. 1–167.

Movius Jr, H.L., David, N.C., 1970. Burins avec modification tertiaire du biseau, burins-pointe et burins du Raysse à l'Abri Pataud, Les Eyzies (Dordogne). Bulletin de la Société préhistorique française. Études et travaux. 445–455.

Moyano, I.T., Barsky, D., Cauche, D., Celiberti, V., Grégoire, S., Lebegue, F., Moncel, M.H., de Lumley, H., 2011. The archaic stone tool industry from Barranco León and Fuente Nueva 3, (Orce, Spain): Evidence of the earliest hominin presence in southern Europe. Quaternary International. 243, 80–91.

Müller, U.C., Pross, J., Tzedakis, P.C., Gamble, C., Kotthoff, U., Schmiedl, G., Wulf, S., Christanis, K., 2011. The role of climate in the spread of modern humans into Europe. Quaternary Science Reviews. 30, 273–279.

Nightingale, S., Schilt, F., Thompson, J.C., Wright, D.K., Forman, S., Mercader, J., Moss, P., Clarke, S., Itambu, M., Gomani-Chindebvu, E., 2019. Late middle stone age behavior and environments at Chaminade I (Karonga, Malawi). Journal of Paleolithic Archaeology. 2, 258–297.

Nigst, P.R., Haesaerts, P., 2012. L'Aurignacien en Basse Autriche: résultats préliminaires de l'analyse technologique de la couche culturelle 3 de Willendorf II et ses implications pour la chronologie du Paléolithique supérieur ancien en Europe centrale. l'Anthropologie. 116, 575–608.

Niu, D., Pei, S., Zhang, S., Zhou, Z., Wang, H., Gao, X., 2016. The Initial Upper Palaeolithic in Northwest China: New evidence of cultural variability and change from Shuidonggou locality 7. Quaternary International. 400, 111–119.

Niven, L., 2013. A Diachronic Evaluation of Neanderthal Cervid Exploitation and Site Use at Pech de l'Azé IV, France. In: Clark, J.L., Speth, J.D. (Eds.), Zooarchaeology and Modern Human Origins: Human Hunting Behavior during the Later Pleistocene. Springer Netherlands, Dordrecht, pp. 151–161.

Octobon, C., 1938. Contribution à l'étude des outillages. Ciseaux et pièces esquillées. Bulletin de la Société Préhistorique Française. 25, 409–412.

Oestmo, S., Schoville, B.J., Wilkins, J., 2012. Preliminary taphonomic and technological analysis of two Middle Stone Age (MSA) open-air lithic assemblages at Vleesbay, Western Cape, South Africa. Memphis, USA.

Orton Jayson, Klein Richard G., Mackay Alex, Schwortz Steve, Steele Teresa E., 2011. Two Holocene rock shelter deposits from the Knersvlakte, southern Namaqualand, South Africa. Southern African Humanities. 23, 109–150.

Osborn, J., 1987. Relationship between the mandibular condyle and the occlusal plane during hominid evolution: some of its effects on jaw mechanics. American Journal of Physical Anthropology. 73, 193–207.

Pacheco, F.G., Giles Guzmán, F.J., Gutiérrez López, J.M., Pérez, A.S., Finlayson, C., Rodríguez Vidal, J., Finlayson, G., Fa, D.A., 2012. The tools of the last Neanderthals: Morphotechnical characterisation of the lithic industry at level IV of Gorham's Cave, Gibraltar. Quaternary International. 247, 151–161.

Paixao, E., Pedergnana, A., Marreiros, J., Dubreuil, L., Prevost, M., Zaidner, Y., Carver, G., Gneisinger, W., 2021. Using mechanical experiments to study ground stone tool use: exploring the formation of percussive and grinding wear traces on limestone tools. Journal of Archaeological Science: Reports. 37, 102971.

Pargeter, J., de la Peña, P., 2017. Milky Quartz Bipolar Reduction and Lithic Miniaturization: Experimental Results and Archaeological Implications. Journal of Field Archaeology. 42, 551–565.

Pargeter, J., de la Peña, P., Eren, M.I., 2019. Assessing raw material’s role in bipolar and freehand miniaturized flake shape, technological structure, and fragmentation rates. Archaeological and Anthropological Sciences. 11, 5893–5907.

Pargeter, J., Eren, M.I., 2017. Quantifying and Comparing Bipolar Versus Freehand Flake Morphologies, Production Currencies, and Reduction Energetics During Lithic Miniaturization. Lithic Technology. 42, 90–108.

Pargeter, J., Loftus, E., Mackay, A., Mitchell, P., Stewart, B., 2018. New ages from Boomplaas Cave, South Africa, provide increased resolution on late/terminal Pleistocene human behavioural variability.

Pargeter, J., Peña, P., 2017. Milky Quartz Bipolar Reduction and Lithic Miniaturization: Experimental Results and Archaeological Implications. Journal of Field Archaeology. 1–15.

Pargeter, J., Tweedie, M.S., 2018. Bipolar Reduction and Behavioral Variability During the Mid-Late Holocene at Eagle’s Nest, Mount Sinai Harbor, New York. The Journal of Island and Coastal Archaeology. 1–20.

Pavlov, P.Y., 2002. Zaozer’e, un nouveau site du Paléolithique supérieur ancien dans le nord-est de l’Europe. Rapport préliminaire. L’Anthropologie. 106, 731–743.

Pederzani, S., Britton, K., Aldeias, V., Bourgon, N., Fewlass, H., Lauer, T., McPherron, S.P., Rezek, Z., Sirakov, N., Smith, G.M., 2021. Subarctic climate for the earliest Homo sapiens in Europe. Science advances. 7, eabi4642.

Perera, N., Kourampas, N., Simpson, I.A., Deraniyagala, S.U., Bulbeck, D., Kamminga, J., Perera, J., Fuller, D.Q., Szabo, K., Oliveira, N.V., 2011. People of the ancient rainforest: Late Pleistocene foragers at the Batadomba-lena rockshelter, Sri Lanka. Journal of human evolution. 61, 254–269.

Peresani, M., 2012. Fifty thousand years of flint knapping and tool shaping across the Mousterian and Uluzzian sequence of Fumane cave. Quaternary International. 247, 125–150.

Peresani, M., Bertola, S., Delpiano, D., Benazzi, S., Romandini, M., 2019. The Uluzzian in the north of Italy: insights around the new evidence at Riparo Broion. Archaeological and Anthropological Sciences. 11, 3503–3536.

Peresani, M., Cristiani, E., Romandini, M., 2016. The Uluzzian technology of Grotta di Fumane and its implication for reconstructing cultural dynamics in the Middle–Upper Palaeolithic transition of Western Eurasia. Journal of Human Evolution. 91, 36–56.

Picin, A., Chacón, M.G., Gómez de Soler, B., Blasco, R., Rivals, F., Rosell, J., 2020. Neanderthal mobile toolkit in short-term occupations at Teixoneres Cave (Moia, Spain). Journal of Archaeological Science: Reports. 29, 102165.

Pickering, T.R., Egeland, C.P., 2006. Experimental patterns of hammerstone percussion damage on bones: implications for inferences of carcass processing by humans. Journal of Archaeological Science. 33, 459–469.

Pitulko, V.V., Tikhonov, A.N., Pavlova, E.Y., Nikolskiy, P.A., Kuper, K.E., Polozov, R.N., 2016. Early human presence in the Arctic: Evidence from 45,000-year-old mammoth remains. Science. 351, 260–263.

Porraz, G., Val, A., Tribolo, C., Mercier, N., de la Peña, P., Haaland, M.M., Igreja, M., Miller, C.E., Schmid, V.C., 2018. The MIS5 Pietersburg at '28' Bushman Rock Shelter, Limpopo Province, South Africa. PLOS ONE. 13, e0202853.

Porraz Guillaume, Igreja Marina, Schmidt Patrick, Parkington John E., 2016. A shape to the microlithic Robberg from Elands Bay Cave (South Africa). Southern African Humanities. 29, 203–247.

Potts, R., 2013. Hominin evolution in settings of strong environmental variability. Quaternary Science Reviews. 73, 1–13.

Prüfer, K., Posth, C., Yu, H., Stoessel, A., Spyrou, M.A., Deviese, T., Mattonai, M., Ribechini, E., Higham, T., Velemínský, P., 2021. A genome sequence from a modern human skull over 45,000 years old from Zlatý kůň in Czechia. Nature ecology & evolution. 5, 820–825.

Raja, M.I.M., 2021. A geoarqueologia da jazida da idade da pedra superior de Txina-Txina, Massingir, Moçambique.

Ramos-Munoz, J., Bernal-Casasola, D., Barrena-Tocino, A., Domínguez-Bella, S., Clemente-Conte, I., Vijande-Vila, E., Cantillo-Duarte, J.J., Almisas-Cruz, S., 2016. Middle Palaeolithic Mode 3 lithic technology in the rock-shelter of Benzú (North Africa) and its immediate environmental relationships. Quaternary International. 413, 21–35.

Ravon, A.-L., Monnier, J.-L., Laforge, M., 2016. Menez-Dregan I, layer 4: A transitional layer between the Lower and Middle Palaeolithic in Brittany. Quaternary International. 409, 92–103.

Raynal, J.-P., Sbihi-Alaoui, F.-Z., Mohib, A., El Graoui, M., Lefèvre, D., Texier, J.-P., Geraads, D., Hublin, J.-J., Smith, T., Tafforeau, P., 2010. Hominid Cave at Thomas Quarry I (Casablanca, Morocco): recent findings and their context. Quaternary International. 223, 369–382.

Reynolds, N., Lisitsyn, S.N., Sablin, M.V., Barton, N., Higham, T.F., 2015. Chronology of the European Russian Gravettian: new radiocarbon dating results and interpretation: Die Chronologie des Europäisch-Russischen Gravettien: neue Radiokarbon-Ergebnisse und deren Interpretation. Quartär–Internationales Jahrbuch zur Erforschung des Eiszeitalters und der Steinzeit. 62, 121–132.

Rezek, Z., Dibble, H., Mcpherron, S., Braun, D., Lin, S., 2018. Two million years of flaking stone and the evolutionary efficiency of stone tool technology.

Rezek, Z., Lin, S., Iovita, R., Dibble, H.L., 2011. The relative effects of core surface morphology on flake shape and other attributes. Journal of Archaeological Science. 38, 1346–1359.

Richter, D., Grün, R., Joannes-Boyau, R., Steele, T.E., Amani, F., Rué, M., Fernandes, P., Raynal, J.-P., Geraads, D., Ben-Ncer, A., Hublin, J.-J., McPherron, S.P., 2017. The age of the hominin fossils from Jebel Irhoud, Morocco, and the origins of the Middle Stone Age. Nature. 546, 293–296.

Riel-Salvatore, J., Negrino, F., 2018. Proto-Aurignacian Lithic Technology, Mobility, and Human Niche Construction: A Case Study from Riparo Bombrini, Italy. In: Robinson, E., Sellet, F. (Eds.), Lithic Technological Organization and Paleoenvironmental Change: Global and Diachronic Perspectives. Springer International Publishing, Cham, pp. 163–187.

Rios-Garaizar, J., San Emeterio, A., Arriolabengoa, M., Aranbarri, J., Rofes, J., Marín-Arroyo, A.B., Rivero, O., Intxaurbe, I., Arranz-Otaegui, A., Salazar, S., Medina-Alcaide, M.Á., Garate, D., 2020. Sporadic occupation in Armiña cave during the

Upper Magdalenian: What for? Journal of Archaeological Science: Reports. 30, 102271.

Rios-Garaizar, J., Škrdla, P., Demidenko, Y.E., 2019. Use-wear analysis of the lithic assemblage from LGM Mohelno-Plevovce site (southern Moravia, Czech Republic). Comptes Rendus Palevol. 18, 353–366.

Robbins, L.H., Brook, G.A., Murphy, M.L., Ivester, A.H., Campbell, A.C., 2016. The Kalahari during MIS 6-2 (190–12 ka): archaeology, paleoenvironment, and population dynamics. In: Africa from MIS 6-2. Springer, pp. 175–193.

Roberts, P., Stewart, B.A., 2018. Defining the 'generalist specialist' niche for Pleistocene Homo sapiens. Nature Human Behaviour. 2, 542–550.

Rodríguez-Álvarez, X.P., 2016. The use of quartz during the Lower Palaeolithic in northeastern Iberia. New approaches to the study of Quartz lithic industries. 424, 69–83.

Roebroeks, W., Gaudzinski-Windheuser, S., Baales, M., Kahlke, R.-D., 2018. Uneven data quality and the earliest occupation of Europe—the case of Untermassfeld (Germany). Journal of Paleolithic Archaeology. 1, 5–31.

Rossoni-Notter, E., Notter, O., Simone, S., Simon, P., 2016. Acheulean breccias of Prince cave (Liguria, Italy): New insights and regional issues. The Acheulean in Europe: origins, evolution and dispersal. 411, 236–253.

Roussel, M., 2011. Normes et variations de la production lithique durant le Châtelperronien: la séquence de la Grande-Roche-de-la-Plématrie à Quinçay (Vienne).

Ruebens, K., McPherron, S.J.P., Hublin, J.-J., 2015. On the local Mousterian origin of the Châtelperronian: Integrating typo-technological, chronostratigraphic and contextual data. Journal of Human Evolution. 86, 55–91.

Ruiz, M.N., Jordá Pardo, J.F., Burow, C., Kehl, M., Pastoors, A., Weniger, G.-C., Wood, R., 2020. Last Neanderthal occupations at Central Iberia: the lithic industry of Jarama VI rock shelter (Valdesotos, Guadalajara, Spain). Archaeological and Anthropological Sciences. 12, 45.

Rybin, E.P., 2014. Tools, beads, and migrations: Specific cultural traits in the Initial Upper Paleolithic of Southern Siberia and Central Asia. Quaternary International. 347, 39–52.

Sakura, O., Matsuzawa, T., 1991a. Flexibility of wild chimpanzee nut-cracking behavior using stone hammers and anvils: An experimental analysis. Ethology. 87, 237–248.

Sakura, O., Matsuzawa, T., 1991b. Flexibility of wild chimpanzee nut-cracking behavior using stone hammers and anvils: An experimental analysis. Ethology. 87, 237–248.

Sanchis, A., Real, C., Sauqué, V., Núnez-Lahuerta, C., Égüez, N., Tormo, C., Ripoll, M.P., Marco, Y.C., Duarte, E., de la Rasilla, M., 2019. Neanderthal and carnivore activities at Llonin Cave, Asturias, northern Iberian Peninsula: Faunal study of Mousterian levels (MIS 3). Comptes Rendus Palevol. 18, 113–141.

Sano, K., 2012. Functional Variability in the Late Upper Palaeolithic of North-Western Europe. Universitätsforschungen zur Prähistorischen Archäologie. 219.

Sano, K., Maier, A., Heidenreich, S.M., 2011. Bois Laiterie revisited: functional, morphological and technological analysis of a Late Glacial hunting camp in north-western Europe. Journal of Archaeological Science. 38, 1468–1484.

Santagata, C., Moncel, M.-H., Piperno, M., 2020. Bifaces or not bifaces? Role of raw materials in the Middle Pleistocene. The example of levels E-E1, B and F (610–670 ka) at Notarchirico (Italy). Journal of Archaeological Science: Reports. 33, 102544.

Santonja, M., Pérez-González, A., Domínguez-Rodrigo, M., Panera, J., Rubio-Jara, S., Sesé, C., Soto, E., Arnold, L.J., Duval, M., Demuro, M., Ortiz, J.E., de Torres, T., Mercier, N., Barba, R., Yravedra, J., 2014. The Middle Paleolithic site of Cuesta de la Bajada (Teruel, Spain): a perspective on the Acheulean and Middle Paleolithic technocomplexes in Europe. Journal of Archaeological Science. 49, 556–571.

Sekhr, A., 1998. Etude archéozoologie des niveaux aurignaciens (couches 14 à 6) et de la base des niveaux gravettiens (niveaux X à T4) de l'Abri Pataud (les Eyzies, Dordogne): Paléoécologie, taphonomie, palethnographie.

Shea, J.J., 2015. Making and using stone tools: advice for learners and teachers and insights for archaeologists. Lithic Technology. 40, 231–248.

Shea, J.J., Sisk, M.L., 2010. Complex projectile technology and Homo sapiens dispersal into western Eurasia. PaleoAnthropology. 2010, 100–122.

Shen, C., Zhang, X., Gao, X., 2016. Zhoukoudian in transition: Research history, lithic technologies, and transformation of Chinese Palaeolithic archaeology. Quaternary International. 400, 4–13.

Shott, M.J., 1989. Bipolar industries: ethnographic evidence and archaeological implications. North American Archaeologist. 10, 1–24.

Shott, M.J., 1999. On bipolar reduction and splintered pieces. North American Archaeologist. 20, 217–238.

Shunkov, M., Anoikin, A., Taimagambetov, Z., Pavlenok, K., Kharevich, V., Kozlikin, M., Pavlenok, G., 2017. Ushbulak-1: new Initial Upper Palaeolithic evidence from Central Asia. Antiquity. 91, e1.

Slavinsky, V.S., Rybin, E.P., Khatsenovich, A.M., Belousova, N.E., 2019. Intentional fragmentation of blades in the initial upper Paleolithic industries of the Kara-Bom site (Altai, Russia). Archaeological Research in Asia. 17, 50–61.

Slimak, L., Kuhn, S.L., Roche, H., Mouralis, D., Buitenhuis, H., Balkan-Atlı, N., Binder, D., Kuzucuoğlu, C., Guillou, H., 2008. Kaletepe Deresi 3 (Turkey): Archaeological evidence for early human settlement in Central Anatolia. Journal of Human Evolution. 54, 99–111.

Slimak, L., Lewis, J.E., Crégut-Bonnoure, E., Metz, L., Ollivier, V., André, P., Chrzavzez, J., Giraud, Y., Jeannet, M., Magnin, F., 2010. Le Grand Abri aux Puces, a Mousterian site from the Last Interglacial: paleogeography, paleoenvironment, and new excavation results. Journal of Archaeological Science. 37, 2747–2761.

Smith, G.M., Spasov, R., Martisius, N.L., Sinet-Mathiot, V., Aldeias, V., Rezek, Z., Ruebens, K., Pederzani, S., McPherron, S.P., Sirakova, S., 2021. Subsistence behavior during the Initial Upper Paleolithic in Europe: Site use, dietary practice, and carnivore exploitation at Bacho Kiro Cave (Bulgaria). Journal of Human Evolution. 161, 103074.

Soressi, M., McPherron, S.P., Lenoir, M., Dogandzic, T., Goldberg, P., Jacobs, Z., Maigrot, Y., Martisius, N.L., Miller, C.E., Rendu, W., Richards, M., Skinner, M.M., Steele, T.E., Talamo, S., Texier, J.P., 2013. Neandertals made the first specialized bone tools in Europe. Proc Natl Acad Sci U S A. 110, 14186–90.

Soressi, M., McPherron, S.P., Lenoir, M., Dogandzic, T., Goldberg, P., Jacobs, Z., Maigrot, Y., Martisius, N.L., Miller, C.E., Rendu, W., Richards, M., Skinner, M.M., Steele, T.E., Talamo, S., Texier, J.P., 2013. Neandertals made the first specialized bone tools in Europe. Proc Natl Acad Sci U S A. 110, 14186–90.

Soressi, M., Roussel, M., 2014. European Middle-to-Upper Palaeolithic transitional industries: Châtelperronian. In: Encyclopedia of Global Archaeology. Springer, pp. 2679–2693.

Spinapolice, E.E., Garcea, E.A., 2014. Aterian lithic technology and settlement system in the Jebel Gharbi, North-Western Libya. Quaternary International. 350, 241–253.

Spinapolice, E.E., Garcea, E.A.A., 2013. The Aterian from the Jebel Gharbi (Libya): New Technological Perspectives from North Africa. African Archaeological Review. 30, 169–194.

Starkovich, B.M., 2017. Paleolithic subsistence strategies and changes in site use at Klissoura Cave 1 (Peloponnese, Greece). Journal of Human Evolution. 111, 63–84.

Stout, D., 2011. Stone toolmaking and the evolution of human culture and cognition. Philosophical Transactions of the Royal Society B: Biological Sciences. 366, 1050–1059.

Stutz, A.J., Shea, J.J., Rech, J.A., Pigati, J.S., Wilson, J., Belmaker, M., Clark, J.L., 2015. . Journal of Human Evolution. 85, 157.

Szmidt, C.C., Normand, C., Burr, G.S., Hodgins, G.W., LaMotta, S., 2010. AMS 14C dating the Protoaurignacian/Early Aurignacian of Isturitz, France. Implications for Neanderthal–modern human interaction and the timing of technical and cultural innovations in Europe. Journal of Archaeological Science. 37, 758–768.

Tabrett, A., 2017. The detachment of Levallois flakes using bipolar percussion at Howiesons Poort Shelter, South Africa. Journal of Archaeological Science: Reports. 15, 620–629.

Tartar, E., 2012. The recognition of a new type of bone tools in Early Aurignacian assemblages: implications for understanding the appearance of osseous technology in Europe. Journal of Archaeological Science. 39, 2348–2360.

Tátá, F., Cascalheira, J., Marreiros, J., Pereira, T., Bicho, N., 2014. Shell bead production in the Upper Paleolithic of Vale Boi (SW Portugal): an experimental perspective. Journal of Archaeological Science. 42, 29–41.

Taylor, N., 2016. Across rainforests and woodlands: a systematic reappraisal of the Lupemban Middle Stone Age in Central Africa. Africa from MIS 6-2. 273–299.

Tennie, C., Braun, D.R., Premo, L.S., McPherron, S.P., 2016. The Island Test for Cumulative Culture in the Paleolithic. In: Haidle, M.N., Conard, N.J., Bolus, M. (Eds.), The Nature of Culture: Based on an Interdisciplinary Symposium 'The Nature of Culture', Tübingen, Germany. Springer Netherlands, Dordrecht, pp. 121–133.

Tennie, C., Premo, L.S., Braun, D.R., McPherron, S.P., 2017. Early stone tools and cultural transmission: Resetting the null hypothesis. Current Anthropology.

Terradillos-Bernal, M., Rodríguez, X.-P., 2012. The Lower Palaeolithic on the northern plateau of the Iberian Peninsula (Sierra de Atapuerca, Ambrona and La Maya I): a technological analysis of the cutting edge and weight of artefacts. Developing an hypothetical model. Journal of Archaeological Science. 39, 1467–1479.

Terry, K., Buvit, I., Konstantinov, M.V., 2016. Emergence of a microlithic complex in the Transbaikal Region of southern Siberia. Quaternary International. 425, 88–99.

Teyssandier, N., 2007. En route vers l'Ouest: les débuts de l'Aurignacien en Europe. John and Erica Hedges Limited.

Tillier, A., Sirakov, N., Guadelli, A., Fernandez, P., Sirakova, S., Dimitrova, I., Ferrier, C., Guérin, G., Heidari, M., Krumov, I., Leblanc, J.-C., Miteva, V., Popov, V., Taneva, S., Guadelli, J.-L., 2017a. Evidence of Neanderthals in the Balkans: The infant radius from Kozarnika Cave (Bulgaria). Journal of Human Evolution. 111, 54–62.

Tillier, A., Sirakov, N., Guadelli, A., Fernandez, P., Sirakova, S., Dimitrova, I., Ferrier, C., Guérin, G., Heidari, M., Krumov, I., Leblanc, J.-C., Miteva, V., Popov, V., Taneva, S., Guadelli, J.-L., 2017b. Evidence of Neanderthals in the Balkans: The infant radius from Kozarnika Cave (Bulgaria). Journal of Human Evolution. 111, 54–62.

Tixier, J., 1963. Typologie de l'Epipaléolithique du Maghreb. Mémoires du Centre de Recherches Anthropologiques, Préhistoriques et Ethnographiques, No 2. Paris: Arts et Métiers Graphiques.

Tixier, J., Inizian, M.-L., 1983. Préhistoire de la pierre taillée. 1. Terminologie et technologie.

Toth, N., 1985. The Oldowan reassessed: a close look at early stone artifacts. Journal of Archaeological Science. 12, 101–120.

Tsanova, T., 2006. Les débuts du Paléolithique supérieur dans l'Est des Balkans. Réflexion à partir de l'étude taphonomique et techno-économique des ensembles lithiques des sites de Bacho Kiro (couche 11), Temnata (couches VI et 4) et Kozarnika (niveau VII).

Tsanova, T., 2013. The beginning of the Upper Paleolithic in the Iranian Zagros. A taphonomic approach and techno-economic comparison of Early Baradostian assemblages from Warwasi and Yafteh (Iran). Journal of Human Evolution. 65, 39–64.

Tsanova, T., Sirakov, N., Delvigne, V., Sirakova, S., Marreiros, J., Horta, P., Zahariev, N., Krumov, I., Anastassova, E., Rezek, Z., Hublin, J.-J., McPherron, S., 2020. The Initial Upper Palaeolithic lithic assemblage from Bacho Kiro Cave (Bulgaria). In: Paper Presented at the 10th Annual Meeting of the European Society for the Study of Human Evolution 2020, Abstract Book. Online.

Vaks, A., Bar-Matthews, M., Ayalon, A., Matthews, A., Halicz, L., Frumkin, A., 2007. Desert speleothems reveal climatic window for African exodus of early modern humans. Geology. 35, 831–834.

van Andel, T.H., 2002. The Climate and Landscape of the Middle Part of the Weichselian Glaciation in Europe: The Stage 3 Project. Quaternary Research. 57, 2–8.

Van Andel, T.H., Davies, W., Weninger, B., 2003. The human presence in Europe during the last glacial period I: human migrations and the changing climate. Neanderthals and modern humans in the European landscape during the last glaciation: archaeological results of the Stage. 3, 31–57.

Van Kolfschoten, T., Parfitt, S.A., Serangeli, J., Bello, S.M., 2015a. Lower Paleolithic bone tools from the 'Spear Horizon' at Schöningen (Germany). Special Issue: Excavations at Schöningen: New Insights into Middle Pleistocene Lifeways in Northern Europe. 89, 226–263.

Van Kolfschoten, T., Parfitt, S.A., Serangeli, J., Bello, S.M., 2015b. Lower Paleolithic bone tools from the 'Spear Horizon'at Schöningen (Germany). Journal of human evolution. 89, 226–263.

Van Kolfschoten, T., Parfitt, S.A., Serangeli, J., Bello, S.M., 2015c. Lower Paleolithic bone tools from the 'Spear Horizon'at Schöningen (Germany). Journal of human evolution. 89, 226–263.

Vanhaeren, M., d'Errico, F., 2006. Aurignacian ethno-linguistic geography of Europe revealed by personal ornaments. Journal of Archaeological Science. 33, 1105–1128.

Vaughan, P., 2002. Gebrauchsspurenanalyse der Feuersteinartefakte aus der Konzentration II. Die Steinartefakte des Magdalénien von Andernach (Mittelrhein). Die Grabungen 1979e1983. Tübinger Arbeiten zur Urgeschichte. 1, 159e172.

Villa, P., Pollarolo, L., Conforti, J., Marra, F., Biagioni, C., Degano, I., Lucejko, J.J., Tozzi, C., Pennacchioni, M., Zanchetta, G., 2018. From Neandertals to modern humans: New data on the Uluzzian. PloS one. 13, e0196786.

Villa, P., Pollarolo, L., Conforti, J., Marra, F., Biagioni, C., Degano, I., Lucejko, J.J., Tozzi, C., Pennacchioni, M., Zanchetta, G., Nicosia, C., Martini, M., Sibilia, E., Panzeri, L., 2018. From Neandertals to modern humans: New data on the Uluzzian. PLOS ONE. 13, e0196786.

Villa, P., Soriano, S., Teyssandier, N., Wurz, S., 2010. The Howiesons Poort and MSA III at Klasies River main site, Cave 1A. Journal of Archaeological Science. 37, 630–655.

Villa, P., Soriano, S., Tsanova, T., Degano, I., Higham, T.F.G., d'Errico, F., Backwell, L., Lucejko, J.J., Colombini, M.P., Beaumont, P.B., 2012. Border Cave and the beginning of the Later Stone Age in South Africa. Proceedings of the National Academy of Sciences. 109, 13208.

Villaverde, V., Sanchis, A., Badal, E., Bel, M.Á., Bergadà, M.M., Eixea, A., Guillem, P.M., Martínez-Alfaro, Á., Martínez-Valle, R., Martínez-Varea, C.M., 2021. Cova de les Malladetes (Valencia, Spain): New Insights About the Early Upper Palaeolithic in the Mediterranean Basin of the Iberian Peninsula. Journal of Paleolithic Archaeology. 4, 1–65.

Vogelsang, R., Richter, J., Jacobs, Z., Eichhorn, B., Linseele, V., Roberts, R.G., 2010. New Excavations of Middle Stone Age Deposits at Apollo 11 Rockshelter, Namibia: Stratigraphy, Archaeology, Chronology and Past Environments. Journal of African Archaeology. 8, 185–218.

Wadley, L., Hodgskiss, T., Grant, M., 2009. Implications for complex cognition from the hafting of tools with compound adhesives in the Middle Stone Age, South Africa. Proceedings of the National Academy of Sciences. 106, 9590–9594.

Walker, M.J., Uriarte, M.H., Jiménez, A.L., Martínez, M.L., Lerma, I.M., Van der Made, J., Duval, M., Grün, R., 2020. Cueva Negra del Estrecho del Río Quípar: a Dated Late Early Pleistocene Palaeolithic Site in Southeastern Spain. Journal of Paleolithic Archaeology. 1–40.

Wang, W., Bae, C.J., Huang, S., Huang, X., Tian, F., Mo, J., Huang, Z., Huang, C., Xie, S., Li, D., 2014. Middle Pleistocene bifaces from Fengshudao (Bose Basin, Guangxi, China). Journal of Human Evolution. 69, 110–122.

Weber, M., Scholz, D., Schröder-Ritzrau, A., Deininger, M., Spötl, C., Lugli, F., Mertz-Kraus, R., Jochum, K.P., Fohlmeister, J., Stumpf, C.F., Riechelmann, D.F.C., 2018. Evidence of warm and humid interstadials in central Europe during early MIS 3 revealed by a multi-proxy speleothem record. Quaternary Science Reviews. 200, 276–286.

Wei, G., Huang, W., Chen, S., He, C., Pang, L., Wu, Y., 2014. Paleolithic culture of Longgupo and its creators. Quaternary International. 354, 154–161.

Wells, J.C., Stock, J.T., 2007. The biology of the colonizing ape. American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists. 134, 191–222.

Westaway, K.E., Louys, J., Awe, R.D., Morwood, M.J., Price, G.J., Zhao, J., Aubert, M., Joannes-Boyau, R., Smith, T., Skinner, M.M., 2017. An early modern human presence in Sumatra 73,000–63,000 years ago. Nature. 548, 322–325.

White, J.P., 1968. Fabricators, outils ecailles or scalar cores. Mankind. 6, 658–66.

White, R., 1995. Ivory personal ornaments of Aurignacian age: technological, social and symbolic perspectives. In: Le Travail et l’usage de l’ivoire Au Paléolithique Supérieur. Centre Universitaire Européen pour les Biens Culturels, pp. 29–62.

Whiten, A., Caldwell, C.A., Mesoudi, A., 2016. Cultural diffusion in humans and other animals. Culture. 8, 15–21.

Whiten, A., Schick, K., Toth, N., 2009. The evolution and cultural transmission of percussive technology: integrating evidence from palaeoanthropology and primatology. Journal of human evolution. 57, 420–435.

Will, M., Parkington, J.E., Kandel, A.W., Conard, N.J., 2013. Coastal adaptations and the Middle Stone Age lithic assemblages from Hoedjiespunt 1 in the Western Cape, South Africa. Journal of Human Evolution. 64, 518–537.

Williams, V.S., Barrett, P.M., Purnell, M.A., 2009. Quantitative analysis of dental microwear in hadrosaurid dinosaurs, and the implications for hypotheses of jaw mechanics and feeding. Proceedings of the National Academy of Sciences. 106, 11194–11199.

Yang, S.-X., Hou, Y.-M., Yue, J.-P., Petraglia, M.D., Deng, C.-L., Zhu, R.-X., 2016. The Lithic Assemblages of Xiaochangliang, Nihewan Basin: Implications for Early Pleistocene Hominin Behaviour in North China. PLOS ONE. 11, e0155793.

Yaroshevich, A., Shemer, M., Porat, N., Roskin, J., 2018. Flint workshop affiliation: Chronology, technology and site-formation processes at Giv'at Rabbi East, Lower Galilee, Israel. Quaternary International. 464, 58–80.

Yuan, B., Huang, W., Zhang, D., 2007. New evidence for human occupation of the northern Tibetan Plateau, China during the Late Pleistocene. Chinese Science Bulletin. 52, 2675–2679.

Yue, J.-P., Li, Y.-Q., Zhang, Y.-X., Yang, S.-X., 2020. Lithic raw material economy at the Huayang site in Northeast China: localization and diversification as adaptive strategies in the Late Glacial. Archaeological and Anthropological Sciences. 12, 107.

Zaidner, Y., 2013. Adaptive flexibility of Oldowan hominins: secondary use of flakes at Bizat Ruhama, Israel. PLoS One. 8, e66851.

Zhang, S., 2002. Advances in Chinese Paleolithic archaeology in the past 20 years and some comments. Quaternary Sciences. 22, 11–19.

Zhu, Z., Dennell, R., Huang, W., Wu, Y., Qiu, S., Yang, S., Rao, Z., Hou, Y., Xie, J., Han, J., Ouyang, T., 2018. Hominin occupation of the Chinese Loess Plateau since about 2.1 million years ago. Nature. 559, 608–612.

Zilhão, J., 1997. O Paleolítico Superior da Estremadura portuguesa. Colibri, Lisbon.

Zilhão, J., 2021. The late persistence of the Middle Palaeolithic and Neandertals in Iberia: A review of the evidence for and against the "Ebro Frontier" model. Quaternary Science Reviews. 270, 107098.

Zilhão, J., 2022. Everything you always wanted to ask about the Lapa do Picareiro Aurignacian and should not be afraid to know: A reply to'The early Aurignacian at Lapa do Picareiro really is that old'. Quaternary Science Reviews. 277, 107296.

APPENDIXES

APPENDIX I - Supplementary Materials for Chapter II “Lithic bipolar methods as an adaptive strategy through space and time”

Site	Chronology	Function	Artifact Type	Raw Material	Blank Size	Reference
A.L.666 (Hadar)	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Goldman-Neuman and Hovers, 2012
Abri Blanchard	Late Pleistocene	NA	Scaled Pieces	Chert	-	Bourrillon et al., 2018
Abri Pataud	Late Pleistocene	Wedging	Scaled pieces	Chert	-	Chiotti, 1999 Douka et al., 2020; Higham et al., 2011
Aghitu-3 Cave	Late Pleistocene	NA	Scaled pieces	Obsidian	-	Kandel et al., 2017
Ambrona	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	-	-	Terradillos-Bernal and Rodríguez, 2012
Apollo 11	Late Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Bousman and Brink, 2017; Vogelsang et al., 2010
Arago cave	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	-	Byrne, 2004
Arbo	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	-	Méndez-Quintas et al., 2019
Armiña cave	Late Pleistocene	NA	Scaled pieces	Chert	-	Rios-Garaizar et al., 2020
Bacho Kiro	Late Pleistocene	NA	Scaled pieces	Chert	-	Sirakov et. al, 2017 Hublin et. al 2020 Tsanova, 2006
Bailong Cave	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Quartz	-	Li et al., 2014
Baıraki	Middle to Mid-Late Pleistocene	NA	Scaled Pieces	Chert	-	Anissutkine et al., 2019
Barranco Leon*	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Chert and Other	Large and Small	Moyano et al., 2011
Batadomba-lena	Late Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Lewis et al., 2014; Perera et al., 2011
Benzú Rockshelter	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Other	-	Ramos-Munoz et al., 2016
Bizat Ruhama	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Chert	Small	Zaidner, 2013
Bois Laiterie	Late Pleistocene	Wedging	Scaled pieces	Chert	-	Sano et al., 2011
Bolinkoba	Late Pleistocene	NA	Bipolar Cores	Chert	-	Iriarte-Chiapusso and Arrizabalaga, 2015, 2011
Bone Cave	Late Pleistocene	Blank production	Bipolar Cores	-	Small	Cosgrove, 1999
Boomplaas	Late Pleistocene	Blank production	Bipolar Cores and Scaled pieces	Quartz	Small	Bousman and Brink, 2017; Pargeter et al., 2018
Border Cave	Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Quartz	-	Bousman and Brink, 2017; Villa et al., 2012
Bordes-Fitte rockshelter	Late Pleistocene	Blank production	Bipolar Cores and Bipolar Blanks	-	-	Aubry et al., 2014
Buiryokbastau-Bulak-1	Late Pleistocene	NA	Scaled Pieces	Chert	-	Kunitake and Taimagambetov, 2021
Bushman Rock Shelter*	Middle to Mid-Late Pleistocene	Blank production	Bipolar Blanks	Quartz	-	Porraz et al., 2018
Cá Belvedere di Monte Poggiolo	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Chert	Small	Arzarello et al., 2016

Chaminade I	Late Pleistocene	Blank production	Bipolar Cores	Quartz and Quartzite	-	Nightingale et al., 2019
Combe Brune 2	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Mathias et al., 2020
Cova de les Malladetes	Late Pleistocene	NA	Bipolar Blanks and Scaled pieces	Chert	-	Villaverde et al., 2021
Cretone Basin	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	-	-	Ceruleo et al., 2015
Crvena Stijena	Late Pleistocene	Blank production	Bipolar Cores	Chert	Small	Mihailović and Whallon, 2017
Cuesta de la Bajada	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	-	-	Santonja et al., 2014
Cueva el Castillo	Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Chert	-	Maíllo-Fernández and de Quirós, 2010
Cueva Morín	Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Chert	-	Bradtmöller et al., 2016; Maíllo Fernández, 2003; Maíllo-Fernández and de Quirós, 2010
Cueva Negra	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Chert	Small	Walker et al., 2020
Danjiangkou Reservoir Region	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	Large	Li et al., 2017
Diepkloof Rock Shelter	Middle to Mid-Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Quartz, Quartzite and Other	-	Igreja and Porraz, 2013
Dingcun - Lushi Basin	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores and Bipolar Blanks	Quartz	Small	Lu et al., 2011
Dmanisi	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Basalt	-	Mgeladze et al., 2011
Donggutuo	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Chert	Small	Liu et al., 2013
Dursunlu	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Slimak et al., 2008
Egerbakta	Late Pleistocene	NA	Scaled Pieces	Other	-	Kozłowski et al., 2009
El Cierro	Late Pleistocene	NA	Scaled Pieces	Chert and Quartzite	-	Álvarez-Fernández et al., 2016
El Horno Cave	Late Pleistocene	NA	Scaled pieces	Chert	-	Fano et al., 2020
El Palomar	Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Chert	-	de la Peña Alonso and Toscano, 2013; de la Peña, 2013
Elands Bay	Late Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Bousman and Brink, 2017; Porraz Guillaume et al., 2016
Esquicho-Grapaou	Late Pleistocene	NA	Scaled pieces	-	-	Barshay-Szmidt et al., 2020
Fengshudao	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores and Bipolar Blanks	Quartz and Quartzite	Large and Small	Wang et al., 2014
Fonte Santa	Late Pleistocene	Wedging	Scaled pieces	Chert	-	Zilhão, 1997
Foz Côa	Late Pleistocene	Wedging	Scaled pieces	Chert	-	Aubry, 1998

Fuente Nueva 3	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Chert and Other	Large and Small	Moyano et al., 2011
Gadeb	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Basalt and Other	Small	de la Torre, 2011
Garm Roud 2	Late Pleistocene	Blank production	Bipolar Blanks	Chert and Quartzite	Small	Berillon et al., 2007
Givat Rabi	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Yaroshevich et al., 2018
Gorham's Cave	Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Pacheco et al., 2012
Grotta di Castelcivita	Late Pleistocene	Blank production	Bipolar Cores	-	-	Arrighi et al., 2020
Grotta di Fumane	Late Pleistocene	Blank production	Scaled pieces	Chert	-	Peresani et al., 2016
Grotta di Sant' Agostino	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Kuhn, 1991
Heuningneskrans	Late Pleistocene	Blank production	Bipolar Cores	-	-	Bousman and Brink, 2017
Hoedjiespunt 1	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	-	Will et al., 2013
Houfang	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	-	Li et al., 2014
Howieson's Poort Shelter	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Other	-	Tabrett, 2017
Huanglong Cave	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz and Quartzite	-	Li et al., 2014; Shen et al., 2016
Huayang	Late Pleistocene	NA	Scaled pieces	Other	Small	Yue et al., 2020
Isernia la Pineta	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores and Bipolar Blanks	Chert	-	Arzarello and Peretto, 2010
Isturitz	Late Pleistocene	NA	Scaled pieces	-	-	Barshay-Szmidt et al., 2018
Jarama VI rock shelter	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartzite	-	Ruiz et al., 2020
Jebel Gharbi	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores and Scaled pieces	Chert	-	Spinapolice and Garcea, 2014
Jerimalai	Late Pleistocene	Blank production	Bipolar Cores	Chert	Small	Marwick et al., 2016
Kalavan 1	Late Pleistocene	NA	Bipolar Cores and Scaled pieces	Obsidian	-	Montoya et al., 2013
Kanjera South	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Quartzite	-	Lemorini et al., 2014
Karungu	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	-	-	Faith et al., 2015
Kashafrud Basin*	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Biglari and Shidrang, 2006
Kilwa	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores and Scaled pieces	Chert and Quartz	Large	Beyin and Ryano, 2020
Klasies River Cave 1A	Middle to Mid-Late Pleistocene	NA	Scaled Pieces	-	-	Villa et al., 2010
Klipdrift Shelter	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	-	Henshilwood et al., 2014
Klipfonteinrand	Late Pleistocene	Blank production	Bipolar Cores	Quartz	-	Mackay et al., 2020
Klissoura	Middle to Mid-Late Pleistocene	NA	Scaled Pieces	Chert	-	Darlas, 2007; Starkovich, 2017

Koobi Fora	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Basalt	-	delaTorre et al., 2004
Kostenki 1	Late Pleistocene	NA	Scaled pieces	-	-	Dinnis et al., 2021
Kozarnika Cave	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	Small	Tillier et al., 2017
La Boella	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Mosquera et al., 2016
La Cansaladeta	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	-	Rodríguez-Álvarez, 2016
La Noira	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	Small	Moncel et al., 2020
Lagar Velho	Late Pleistocene	NA	Scaled pieces	Chert	-	Carvalho, 2011
Le Grand Abri aux Puces	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Slimak et al., 2010
Leba Cave	Middle to Mid-Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Quartz	small	de Matos and Pereira, 2020
Les Fieux	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	-	Faivre et al., 2017
Liang Bua	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Moore et al., 2009
Liang Bua	Late Pleistocene	Blank production	Bipolar Cores	Chert	-	
Liangshan*	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz and Other	Small	Li et al., 2014
Lingjing	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Li et al., 2019
Llonin Cave	Middle to Mid-Late Pleistocene	NA	Scaled Pieces	Chert		Sanchis et al., 2019
Lomekwi 3	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Basalt and Other	Large	Harmand et al. 2015
Longgupo	Late Pliocene and Early Pleistocene	Wedging	Other	Quartz	-	Wei et. al, 2014 Wei et al., 2014
Manzi River	Late Pliocene and Early Pleistocene	NA	Other	Quartz	-	Barham et al., 2011
Matupi	Late Pleistocene	Blank production	Bipolar Cores	-	-	Cornelissen, 2002
Melikane Rockshelter*	Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Quartz	Small	Mackay et al., 2014
Melka Kunture	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Basalt	-	Gallotti, 2013
Menez-Dregan I	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	Small	Ravon et al., 2016
Mochena Borago Rockshelter	Late Pleistocene	Blank production	Bipolar Cores	Obsidian	Small	Brandt et al., 2012
Mohelno-Plevovce site	Late Pleistocene	Wedging	Scaled Pieces	Chert and Quartz	-	Rios-Garaizar et al., 2019
Mpila	Middle to Mid-Late Pleistocene	NA	Scaled Pieces	Quartzite	-	Demayumba, 2021
Mugharet el-Zuttiyeh	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Malinsky-Buller, 2016
Mughr el-Hamamah	Late Pleistocene	NA	Bipolar Cores and Scaled pieces	-	-	Stutz et al., 2015
Mumba Rockshelter	Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Quartz	-	Marks and Conard, 2008
Nasera	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert and Quartz	-	Clark, 1988

Ngalue Cave	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartzite	-	Mercader et al., 2009
Ngalue Cave	Late Pleistocene	Blank production	Bipolar Cores	Quartzite	-	Mercader et al., 2009
Notarchirico	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert, Quartz and Other	-	Santagata et al., 2020
Oelknitz 3	Late Pleistocene	NA	Scaled pieces	-	-	Gaudzinski-Windheuser, 2015
Olduvai Gorge	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Quartz	-	Arroyo and de la Torre, 2017; Diez-Martín, 2010
Omo Shungura	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	-	-	Diez-Martín, 2010; Ludwig et al., 1998
Orgnac 3	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Moncel et al., 2012, 2005
Pech-de-l'Azé II	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Mathias et al., 2020
Peninj	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Basalt and Quartz	-	de la Torre et al., 2003
Petersfels	Late Pleistocene	NA	Scaled pieces	-	-	Maier et al., 2020
Petit-Bost	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Mathias et al., 2020
Pinilla de Valle	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Márquez et al., 2013
Pirro Nord	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Chert	Small	Arzarello et al., 2016
Pockenbank	Late Pleistocene	Blank production	Bipolar Cores	-	-	Bousman and Brink, 2017
Pont de Lavaud	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Quartz	Small	de Lombera-Hermida et al., 2016
Prince Cave	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert, Quartzite and Other	-	Rossoni-Notter et al., 2016
Puig d'en Roca	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	-	Rodríguez-Álvarez, 2016
Putslaagte 8	Middle to Mid-Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	-	-	Bousman and Brink, 2017; Mackay et al., 2015
Putslaagte 8	Middle to Mid-Late Pleistocene and Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	-	-	Bousman and Brink, 2017; Mackay et al., 2015
Qiaojiayao	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Lu et al., 2011
Radomyshl I	Late Pleistocene	NA	Scaled Pieces	Chert	-	Kononenko, 2021
Reception Rockshelter	Late Pleistocene	Blank production	Bipolar Cores	Quartz	-	Bousman and Brink, 2017; Orton Jayson et al., 2011
Remetea Somos I	Late Pleistocene	NA	Scaled Pieces	Obsidian	-	Dobrescu et al., 2018
Revadim	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Malinsky-Buller, 2016
Rhone Valley	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	-	-	Daujeard and Moncel, 2010
Rietputs 15	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Quartz and Other	-	Kuman and Gibbon, 2017
Riparo Broion	Late Pleistocene	Blank production	Bipolar Cores and Scaled pieces	Chert	-	Peresani et al., 2019
Rose Cottage Cave	Late Pleistocene	Blank production	Bipolar Cores	Quartz	-	Bousman and Brink, 2017; Lewis et al., 2014

Schöningen	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	Small	Van Kolfschoten et al., 2015
Sehonghong	Late Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Bousman and Brink, 2017
Senga	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	-	-	Diez-Martín et al., 2011; Ludwig et al., 1998
Shangchen	Late Pliocene and Early Pleistocene	Blank production	Other	-	-	Zhu et al., 2018
Shlyakh	Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Hoffecker et al., 2019
Shuidonggou 2	Late Pleistocene	Blank production	Bipolar Cores and Scaled pieces	Chert	-	Niu et al., 2016
Shuidonggou locality 7	Late Pleistocene	Blank production	Bipolar Cores	Chert and Quartzite	-	Niu et al., 2016
Sima del Elefante Atapuerca	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Quartz	Small	de Lombera-Hermida et al., 2015
Son valley – Rampur and Patpara	Late Pleistocene	NA	Bipolar Blanks	-	-	Jones and Pal, 2009
Sterkfontein	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Quartz	Large and Small	McNabb and Kuman, 2015
Tabun Cave	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Chert	-	Malinsky-Buller, 2016
Teixoneres Cave	Late Pleistocene	Blank production	Bipolar Cores	Quartz	-	Picin et al., 2020
Ter River basin	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	-	-	Garcia, 2015
Thomas Quarry Hominid Cave	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartzite	Small	Raynal et al., 2010
Tian Shan Mountains	Late Pleistocene	Wedging	Scaled pieces	Chert and Quartzite	-	Kolobova et al., 2021
Toka	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	-	Small	Chauhan, 2007
Transbaikal Region Sites	Late Pleistocene	Blank production	Bipolar Cores	Chert and Quartzite	-	Terry et al., 2016
Txina Txina	Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Chert, Quartz and Other	Small	Bicho et al, 2018
Uçagızlı Cave	Late Pleistocene	NA	Bipolar Cores and Scaled pieces	Chert	-	Kuhn, 2004; Kuhn et al., 2009
Umbeli Belli Rock Shelter	Middle to Mid-Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Quartz	Small	Bader et al., 2016
Umhlatuzana	Late Pleistocene	NA	Scaled pieces	-	-	Bousman and Brink, 2017
Untermassfeld	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	chert	Small	Roebroeks et al., 2018
Urtiaga cave	Late Pleistocene	NA	Bipolar Cores and Scaled pieces	Chert	-	Fontes 2016 Fontes, 2016
Ushboulak	Late Pleistocene	NA	Scaled Pieces	Chert	-	Shunkov et al., 2017
Vale Boi	Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Chert and Quartz	Small	Horta et al., 2019

Vallparadís	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Garcia et al., 2012
Warwasi Rockshelter	Late Pleistocene	Blank production	Bipolar Cores	Chert	Small	Tsanova, 2013
Xiaochangliang	Late Pliocene and Early Pleistocene	Blank production	Bipolar Cores	Chert	Small	Ma et al., 2020; Yang et al., 2016
Xuchang Man	Late Pleistocene	Blank production	Bipolar Cores	Chert	Small	Li and Ma, 2016
Yafteh Cave	Late Pleistocene	NA	Scaled Pieces	Chert	-	Tsanova 2013
Yarımburgaz Cave	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Slimack, 2008
Yenisey Valley	Late Pleistocene	Wedging	Scaled pieces	Chert	-	Kolobova et. al, 2021
Yujiagou	Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Chert	Small	Liu et al., 2013
Zaozer’e	Late Pleistocene	NA	Scaled Pieces	Chert	-	Pavlov, 2002
Zhiyu	Late Pleistocene	Blank production and Wedging	Bipolar Cores and Scaled pieces	Chert	Small	Liu et. al 2013
Zhoukoudian 1	Middle to Mid-Late Pleistocene	Blank production	Bipolar Cores	Quartz	Small	Li, 2016; Shen et al., 2016

APPENDIX II - Supplementary Materials for Chapter 3 ‘The role of lithic bipolar technology in Western Iberia’s Upper Paleolithic: the case of Vale Boi (southern Portugal)”

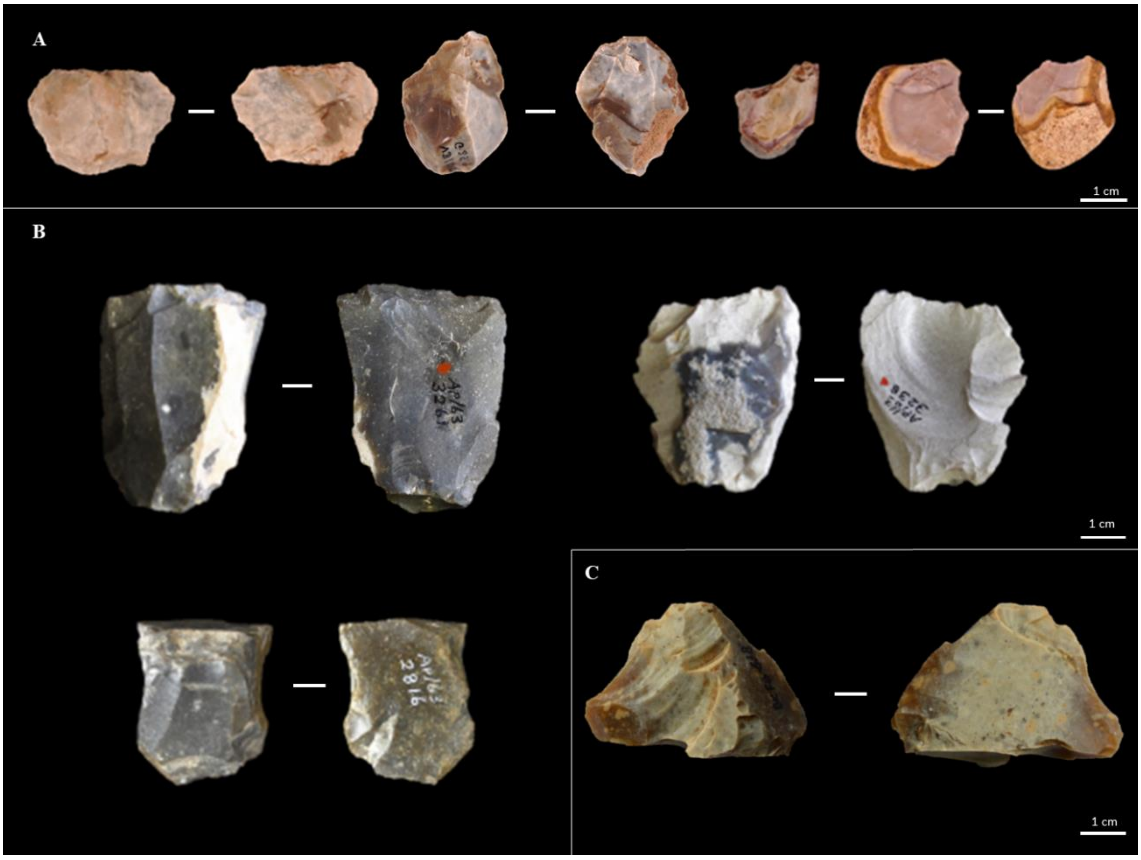
Technological attributes used for the analysis of scaled pieces included in this study

Variables	Attributes
Raw Material	Quartz
	Chert
	Greywacke
	Chalcedony
	Others
Blank	Blade
	Blade Fragment
	Bladelet
	Bladelet Fragment
	Core
	Flake
	Fragment
	Nodule
Coinciding Axis	Coinciding
	Non-Coinciding
	Unidentifiable
Retouch	Absent
	Present
Cortex %	No Cortex
	>25%
	25-50%
	50-95%
	>95%
Cortex Location	Distal
	Lateral
	Lateral Distal
	Lateral Mesial
	Lateral Proximal
	Mesial
	Proximal
Butt	Absent
	Cortical
	Dihedral
	Faceted
	Pointed
	Flat
Profile	Straight

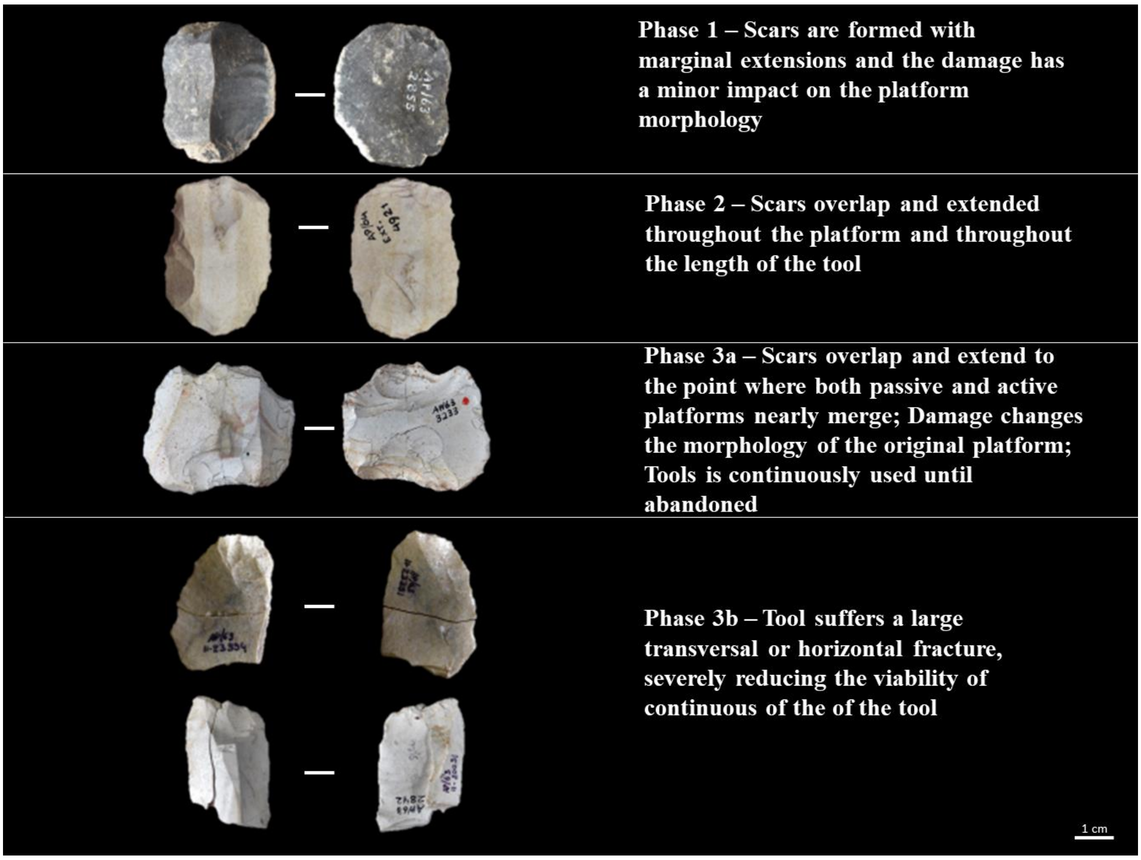
	Curved
	Irregular
	Twisted
Transversal Section Shape	Other
	Irregular
	Rectangular
	Trapezoidal
	Triangular
Longitudinal Section Shape	Elliptical
	Irregular
	Other
	Rectangular
	Semicircular
	Trapezoidal
	Triangular
Edge Shape	Biconvex
	Circular
	Converging
	Diverging
	Irregular
	Others
	Parallel
Dorsal Pattern	Bidirectional Alternating
	Bidirectional Parallel
	Bidirectional Perpendicular
	Unidentifiable
	Parallel Distal
	Parallel Proximal
	Parallel one side
	Radial
Termination	Stepped
	Natural
	Hinged
	Transversal
Fire Traces	Burnt
	No traces
	Thermal Treatment

APPENDIX III – Figures

Appendix III.1. Splintered pieces from Abri Pataud (A), Vale Boi (B) and Bacho Kiro (C).



Appendix III.2. Bipolar cores from Vale Boi (A), Abri Pataud (B) and Bacho Kiro (C).



Appendix III.3. Splintered Piece reduction sequence. Note: these data were not analytically used in this thesis as they are purely based on observed patterms and currently represent a hypothesis to be tested in the future.