Università degli Studi di Ferrara

DOCTORAL COURSE IN
"SCIENZE UMANE"

CYCLE XXXVI

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Close Encounters of the Stone Kind – The lithic assemblages of Notarchirico and Isernia La Pineta within the chrono-cultural framework of the Middle Pleistocene Revolution: production methods, debitage technique, and behavioural implications

Scientific/Disciplinary Sector (SDS) L-ANT/01

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Years 2020/2023

Abstract

The aim of this Ph. D. thesis is to enrich the state of the art and the scientific knowledge of the archaeological contexts belonging to the European Lower Palaeolithic during the first half of the Middle Pleistocene. Such purpose will be addressed through the analysis (*i.e.*, technological approach) of the stone tools realised by the hominins of two key-sites of the Italian Peninsula: Notarchirico and Isernia La Pineta, both located in Southern Italy and chronologically placed during the first half of the Middle Pleistocene.

Within the present state of the art, the Middle Pleistocene – whose beginning has been globally set to approximately 773 ka, corresponding to the glacial stage 19 – is considered a fundamental chronological phase for the impactful environmental and climatic changes witnessed on a global scale that will cause a substantial revolution within the faunistic, floristic, and human communities. Such changes occurred over a significant amount of time and with different intensities according to the geographical areas, which is why the timeframe between 1.2 Ma to 0.8 Ma has been defined as a transitional phase between the Lower and the Middle Pleistocene named Middle Pleistocene Revolution, to emphasise the extent of these changes.

These abrupt modifications – which can be summed up in the change in the amplitude of the glacial/interglacial intervals from 41 ka to 100 ka, determining increased duration of glacial periods with expansion of continental ice caps, lowered sea levels, and aridification processes – forced species (plants, animals, and humans) to adapt rapidly to changing environments, thus enhancing evolution, selection and speciation phenomena. The significant environmental discontinuity driven by the climatic instability led human groups to constantly expand over new, formerly inaccessible territories and then retreat to refugial areas describing an occupation pattern often referred to by the authors, as the "ebb and flow" process. These refugial areas would witness a semi-continuous occupation over time, favouring the development of localised culture and group cohesion while also providing for the repopulation of formerly inhabited areas, thus generating an increased knowledge exchange and gene flow events.

Within this chronological framework, the emergence of bifacial and LCTs industries among European sites, is at the centre of a delicate and heated debate from the scientific community. The appearance of handaxes in Europe is commonly associated with the Acheulean cultural complex, which marks a moment of significant cultural and technical renovation related to the arrival of a new human species (*Homo heidelbergensis*) from the African and Asian continents. The origin and modalities of the arrival of the Acheulean over Europe, not to mention *what exactly* the Acheulean *is* – a site without bifaces can be considered an Acheulean site? – and, to a greater extent, what is the definition and perception of complexity and culture within archaeology, are among the object of this ongoing debate. Within the present state of the art, a dual case scenario is usually assumed for the "Acheulean dilemma", concerning either a local origin due to the evolution from previous occupations or an allochthonous introduction (whether episodical or continuous) of new populations alongside the diffusion of new technical traditions.

From this perspective, the Italian peninsula is a crucial spot for tracking down human dispersal across the European continent, the behavioural responses eventually adopted by the hominins to a changin environment, and the arrival/development of innovative behaviours. It shows a consistent

range of contexts spanning from the end of marine isotope stage 17 onwards, offering one of the earliest evidence of bifacial tools (680 ka, Notarchirico) and providing at the same time, contexts without bifaces (Isernia La Pineta, Ficoncella, Loreto and Atella). Additionally, it is also a “shelter” zone during the severe climatic crises of the Middle Pleistocene, making it an ideal territory for human occupation during glacial phases and for prolonged periods – as witnessed by the stratigraphic sequence of Notarchirico, documenting almost 100 ka of continuous human frequentation. Moreover, its role as the possible starting area for the recolonisation of the northern portions of Europe, together with its proximity to Sub-Saharan Africa, makes up for its crucial role within the European peopling during the Middle Pleistocene Revolution.

For these reasons, the choice of studying the lithic industries of the sites of Notarchirico and Isernia La Pineta might grant an enhanced and a more accurate perspective within the development of the European Lower Palaeolithic, starting from the evaluation of knapped tools, which, for this chronological phase, represent one of the most adequate proxies for the comprehension of human behaviour’s evolution.

Acknowledgements

First and foremost, I would like to express my sincerest thanks to my supervisors. Thanks to Marta Arzarello for the constant human and scientific support throughout these three years of my PhD and the two years of my Master's degree. She has been my guide, motivating and pushing me to become a better researcher and archaeologist, and I would like to thank her for the time and energy devoted to my professional and personal growth. Thanks also to Marie-Hélène Moncel for the insightful comments and discussions that significantly improved this work and my approach to scientific research. I want to thank her for her trust and for believing in me by allowing me to cooperate in the excavation and organisation of the Notarchirico site. It has been, is, and will be a wonderful and challenging experience for which I am grateful and from which I am learning a lot.

Thank Rosalia Gallotti and Paula Garcia Medrano for agreeing to review my thesis. Their valuable comments and suggestions improved this work and, hopefully, my future ones. I also want to thank the members of the committee: Robert Sala, Roxanne Rocca, and Marco Peresani. You have all been part of this process, and I sincerely thank you for that.

A questo punto, vorrei passare alla lingua che mi è più familiare per poter esprimere al meglio quello che questi anni hanno rappresentato per me. È opinione comune che i ringraziamenti siano la parte più divertente (?) da scrivere di una tesi perché sono quella più personale e libera di tutte, oltre che, auspicabilmente, la più breve. Ho, colpevolmente e intenzionalmente, mancato di scrivere la sezione dei ringraziamenti per la mia tesi magistrale e di conseguenza, ho accumulato un po' di "grazie" da distribuire in giro, non solo a persone, ma anche a cose inanimate – è ufficiale, questa non sarà la sezione più breve di questa tesi – che, in vario modo, hanno contributito a rendere più lieve il tutto.

Innanzitutto, e in ordine sparso, vorrei ringraziare tutte le persone incontrate all'Università di Ferrara e che, in maniera diversa, mi sono state vicine o comunque sono state parte di questo lungo percorso. Vorrei ringraziare il gruppo di ricerca di cui ho fatto parte in questi anni: Gabbro, Sara e Julie. La vostra esperienza e i vostri consigli mi sono stati utili per affrontare quest'esperienza. Grazie anche a tutte quelle persone che, tramite voi, ho incontrato sugli scavi e non: Riccardo, Claudio, Roberto, Sandro, Giovanna, Davide Bertè (specifico il cognome perché la quantità di Davide passati per l'Università di Ferrara e specializzati in archeologia preistorica è un dato che sarebbe meritevole di un'adeguata indagine statistica), Rosamaria, Maurizio, Federica, l'Arte di Luciano, Umberto e così via. In particolare, vorrei ringraziare il mio compagno di ufficio Gabbro, grazie per avermi accolto in quella stanza, grazie anche da parte delle innumerevoli bucce di mele e banane. È stato un piacere collaborare con te e nonostante l'esperienza che ci separa mi hai sempre fatto sentire come se fossimo allo stesso livello e questo mi ha aiutato molto per dedicarmi con tranquillità a questo lavoro.

Grazie ai miei "compagni di sassi" Davide Delpiano e Nicolò Fasser, avete reso tutto questo molto più divertente e allo stesso tempo professionale di quanto mi aspettassi. Parlando e discutendo con voi ho imparato e mi sono appassionato ancora di più a questo mondo e, nei momenti più stressanti, mi è stato di grande aiuto per motivarmi a continuare. Davide, sono abbastanza convinto che la tua vera vocazione sia la provincia di Reggio, intesa come entità territoriale, culturale e spirituale che si manifesta nella tua persona quando non sei impegnato a combattere con la tecnologia moderna o le malattie. Nicolò, posso affermare con relativa certezza, che in una vita non troppo lontana sei sicuramente stato una punta a dorso a ritocco erto realizzata su supporto laminre ottenuto per percussione indiretta. Il resto del tempo probabilmente ti arrampicavi su, letteralmente, qualunque tipo di superficie. Cari Davide e Nicolò, mi dispiace solamente che vi siate focalizzati, rispettivamente, su periodi come il Paleolitico Medio e il Paleolitico Superiore e Mesolitico. Un giorno riuscirete ad apprezzare il Paleolitico Inferiore in tutta la sua oscura bellezza, credo in voi – anche nel caso non dovesse accadere.

Grazie ai miei colleghi Andrea, Alessandra, Gloria, Matteo, Giorgia, e Lisa. Vi ho conosciuto durante quest'ultimo anno e mezzo di dottorato e siete stati una piacevole costante nei giorni passati in università, condividendo le cose più disparate (Top 3 degli snack da aperitivo subito), positive e negative. Mi avrebbe fatto piacere passare più tempo con voi e spero che in futuro, in un modo nell'altro, accadrà. Nel mentre vi abbraccio e vi auguro buona fortuna per il futuro. Grazie anche a Davide Margaritora, Davide Visentin, e Klaus.

Ovviamente, grazie anche alla gang di studenti del master QPA che mi hanno tenuto compagnia in questi anni e che mi hanno fatto assaggiare dei cibi incredibili e che spero di aver aiutato durante il loro soggiorno italiano. Grazie a Shantanu, Tannistha, Thomas, Mirabello e, in particolare a Trishia, la prima persona che abbia mai conosciuto *born and raised in* Manila e che parla con un perfetto accento romano pur non essendo mai passata per Roma, francamente unica e incredibile. Grazie anche a tutti i miei colleghi della laurea magistrale, in particolare a Giorgio Piazzalunga e Giorgio Puggioni con i quali sono riuscito a condividere molto nonostante il poco tempo passato insieme.

Grazie anche alle persone che ho conosciuto a Ferrara, ma al di fuori dell'università. Piz, sei chiaramente il numero uno di questa lista nonché, letteralmente, la prima persona che ho conosciuto quando sono arrivato a Ferrara e che mi ha catapultato in una cena con 8 sconosciuti svoltasi nel corridoio della mia prima casa la sera stessa che sono arrivato da Roma. Grazie per la tua leggerezza e serenità. Hai da poco preso la patente e potrai finalmente guidare l'unico mezzo di locomozione che veramente ti rappresenta: la nuvola speedy. Grazie anche a Martina, siete una super coppia, vi voglio bene e vi auguro un sacco di belle cose. Vorrei ringraziare anche Matilde e il suo cane Jango. Sono un duo pazzesco e il più sano del team è chiaramente il cane, e sono sicuro che lo sappiano entrambi. Grazie anche al mio ex coinquilino Andrea, ammiro e invidio la sensibilità e tranquillità con cui approcci, bene o male, qualunque cosa o persona. Grazie Alberto, Giacomo, Francesco, Mic, Stefano, e Boscolo, avete reso Ferrara un posto accogliente, opponendovi ad un clima meteorologico, e non solo, inesorabilmente grigio e piatto.

Grazie anche a Marzio, inzialmente compagno di studi, poi amico e coinquilino. Abbiamo condiviso parecchie cose in questi anni e un giorno finiremo di vedere la top ten degli insetti più pericolosi di una non precisata foresta pluviale sudamericana.

Cambiando stato – mi sto solamente scaldando – vorrei ringraziare anche tutte le persone incontrate nel mio breve ma intenso soggiorno parigino. Innanzitutto grazie Paula, per avermi portato in giro per Parigi, per avermi invitato alla mia prima festa messicana e per avermi fatto conoscere Five Guys (chiaramente uno dei miglior hamburger mai mangiati nella mia vita, e no questo non è un caso di pubblicità indiretta/*product placement* ma la mia sincera opinione), anche se non ringrazio per niente il fumogeno che l'educatissima polizia parigina ha ritenuto opportuno tirare all'ingresso del suddetto posto rendendo l'esperienza del pranzo estremamente più complicata e dolorosa a circa un centinaio di persone. Grazie a Dael e Julia, siete stati degli incredibili compagni di studio e di dottorato e vi auguro in futuro di poter continuare a fare quello che vi piace, ovunque sarete. Grazie anche a Gaetano e Pierre. Grazie anche a tutte le persone che ho incontrato all'IPH, è stata un'esperienza davvero stimolante.

Ci sono anche diverse persone che vorrei ringraziare e che ho conosciuto in una città che, oggi, è molto speciale per me: Lisbona. Grazie a Mariana e Victor, spero che l'infame mondo della ricerca vi permetta, in futuro, di riunirvi geograficamente. Nel frattempo tenete duro, mi mancate un sacco e grazie per tutti i consigli e il tempo passati insieme. Grazie anche a Fabia, sei ufficialmente la mia nuova coinquilina e non vedo l'ora di vederci una tonnellata di episodi di RuPaul, io te e Chiara. Grazie, ma soprattutto daje, ad Arianna – che in questo momento in cui scrivo questi ringraziamenti ha appena consegnato la sua tesi di dottorato – quando penso a te mi vengono in mente, non necessariamente in quest'ordine, Tony Soprano, l'AS Roma, la Francesinha, i Castelli Romani e qualcuno che si addormenta durante un film, insomma una serie di cose di cui non vedo (troppi) lati negativi. Grazie anche a Marija, Thomas e la piccola Sarah, la vostra energia e approccio alla vita è invidiabile e contagioso, spero di tornare a cena da voi il più presto possibile. Grazie anche a tutta la crew del Tecnico (in ordine sparso: Zahra, Diogo, Bernardo M., Bernardo B., Robert, Patricia, Miguel, Anthonie, Thales, Oscar, Pablo, Lucas & Giucas, Antoine, Bertrand, Josè, Rui, Joan, Saby, Matteo e Giorgio), che mi ha accolto e ospitato come se fossi uno di loro e senza minimanete porsi alcun problema quando un tizio che guarda un mucchio di sassi ha occupato un ufficio di fisica teorica. Grazie anche a Martina.

È il momento di tornare dentro il Grande Raccordo Anulare "che circonda la Capitale", a casa, e ringraziare tutte quelle persone che ne fanno parte, incluse quelle che vivono a Roma, pur stando fuori dal raccordo (per questo, io vi perdono), e che dicono in giro che sono di Roma (per questo, io *non* vi perdono). Chiaramente non posso ringraziare tutti per motivi di tempo e spazio, anche se questi, dopotutto, sono comunque i miei ringraziamenti e godo di una discreta libertà creativa nel redigerli.

Innazittutto ringrazio il Paradiso di Holden, sia i membri del gruppo (Nicco, Riccardo, Luca, Lorenzo, Ernesto e, modestamente, il sottoscritto) che il simbolo che ha rappresentato e rappresenta tutt'ora. Il mio arrivo a Ferrara nel Febbraio del 2018 è coinciso con la fine di quel gruppo ed ogni giorno un po' rimpiango questa scelta e un po' ne vado fiero. Senza il Paradiso di Holden non avrei trovato i motivi per andarmene e, probabilmente, ora avrei molti meno motivi per tornare. Grazie a quel gruppo di pazzi che rappresentano la mia famiglia allargata romana, un coacervo di adolescenza, nostalgia, creatività, paura per il futuro, amore, libertà e nevrosi: Alberto (una carriera incredibile che ha toccato i vertici del ping pong, la neurobiologia, gli allucinogeni, Mario Kart, Zelda, Villa Pamphilij, le scarpe barefoot e la cucina siciliana), Dario (un fisico teorico che vive chiaramente su un piano spirituale diverso dal nostro ma è nato sotto ad un vulcano), Matteo Cillario (questa persona gestisce un racket di corse dei carri di Age of Empires II dalla sua stanzetta nei Colli Portuensi, fa lo speaker radiofonico, ha un cane incredibile e un talento musicale altrettanto pazzesco), Niccolò Cerulli (celeberrimo cantante del Paradiso di Holden, nonché motociclista, sex symbol, fan di One Piece e unica persona in grado di imitare alla perfezione le voci del suo intero gruppo di amici e, allo stesso tempo, gonfiare a dismisura il proprio ventre), Giacomo Mieli (grazie per aver condiviso la mia nevrosi e per saper fare, bene o male, qualunque cosa di pratico nel campo dell'edilizia, della cinematografia, dell'elettronica e dell'arte culinaria), Jonny (fa Kung Fu, guida una Kawasaki, ha gli occhi azzurri, adora i Radiohead, tira su muri negli appartamenti, ha un'anima pura, e fa delle battute incredibili, scusatemi ma se non vogliamo ringraziare una persona con questa combo di caratteristiche chi vogliamo davvero ringraziare?), Riccardo (mi hai fatto conoscere i Pavement, abbiamo suonato insieme e mi manca da morire la libertà che avevamo nel comunicare), e Francesco Valeri (squalo fiuta ostacolo e si ammala e non penso ci sia bisogno di dire altro). Grazie davvero ragazzi, vorrei riempirvi di botte e abbracciarvi allo stesso tempo. Grazie anche a Virginia, Claudia, Giuliana, e Chiara. Oggi più di ieri capisco molte più cose e vi voglio ancora più bene.

Grazie anche ad Emanuele Cancellieri, forse più di tutti sei il responsabile per avermi infettato con questa febbre dell'età della pietra, ed il primo, sicuramente ad avermi indirizzato verso Ferrara. Grazie per tutti i consigli, la pazienza e la fiducia. Ogni volta che leggo o sento "Microbulino di Krukowski" penso a te. Non so bene se sia un complimento o una nevrosi.

Grazie a Pipo, fra tutti questi nomi sei sicuramente quello che conosco da più tempo e non te ne sei mai andato.

Grazie anche al signor Luga (nessun refuso) Romiti, non ci sono davvero altri modi per dire quanto ti voglia bene aldilà di queste stesse parole. Sei una persona incredibile.

Grazie al Nibe, a Lorenzo Fortissimo, a Micante, a Masci, a Sarli, a Bosio, a Camilla e a Clotilde, siete tutti ugualmente speciali. Grazie in particolare a Orl e a Tom, vi ammiro e vi stimo in tutte le vostre peculiarità e le vostre incongruenze. Grazie anche alla crew malatissima di Genova: Matte, Second, Lorena, Giulio (incredibile pazzesco).

Grazie anche a te Frè. Grazie per tutti i questi anni in cui ci siamo stati vicini e per la leggerezza che ritroviamo ogni volta che ci rivediamo.

Grazie a quel gruppo di persone che mi è stato introdotto da una persona particolarmente speciale e alle quali mi sono molto legato in questi anni (Federica, Somon, Alessio, Lorenzo). Grazie in particolare ad Elena e Farshid, anche a voi auguro di ritrovarvi tra i meandri del mondo della ricerca, possibilmente in un posto dove ci sia dell'ottimo cibo, birra incredibile e un campo da basket. Vi voglio bene e vi ringrazio per tutti quei giorni passati a Tarquinia. Sono stati davvero un momento di serenità e pace incredibile.

Un ringraziamento speciale va a Caterina, Pietro, Valeriana e Fabrizio. Grazie per avermi accolto e fatto sentire parte di casa vostra. Grazie anche al Piccolo Cane, non so se si capisce ma è molto piccolo e molto speciale.

Grazie anche a Liben, Fabrizio, Michele, Emanuele, Valerio, Bruno e Andrea, lo zoccolo duro del lunedì sera. Le nostre cene hanno scandito i miei anni universitari romani e mi hanno dato la forza – sottoforma di cene tardissime con acqua che non bolliva mai, video spazzatura, film improbabili, videogiochi e citazioni di cultura pop – per cominciare ogni settimana con un po' più di serenità e ingenuità.

Stiamo arrivando sul fondo di questa sequenza stratigrafica di ringraziamenti e, come ci insegna la stratigrafia, sul fondo ci sono le cose più antiche, la roccia madre, le fondamenta di tutto il riempimento che sono stati questi anni.

Prima di arrivare alla base vera e propria vorrei ringraziare una persona che è stata comunque alla base di questo percorso in tanti modi diversi e che ne è stata anche parte integrante in altrettanti modi, altrettanto diversi. Vorrei ringraziare la mia compagna, Chiara, alla quale va il mio amore e gratitudine di questi anni e negli anni a venire, per avermi insegnato cosa significa davvero la condivisione, che sia di un sentimento, di uno spazio, di un periodo o di un'idea. Ti ringrazio, Chiara, perché mi sei stata vicino, perché sono potuto sprofondare in questo dottorato con la garanzia che ci saresti stata per aiutarmi a tornare a galla, nel bene e nel male, ricordandomi che tutto ha un peso e un equilibrio. Ti ringrazio perché la tua non è stata solo vicinanza, pazienza, costanza e gentilezza ma perché è stata soprattutto partecipazione, gioia, divertimento, dolore, sofferenza, serenità, paura, unione e amore. In questo senso, uno può riuscire davvero a costruire qualcosa e io sono più che felice, e ti ringrazio, di poterlo fare e averlo fatto insieme a te. (Vorrei che fosse messo agli atti che ci tengo a "ringraziare" anche quella pandemia mondiale cominciata tra fine Febbraio e inizio Marzo 2020 e senza la quale, molto probabilmente, non ti avrei re-incontrata, rendendo tutta questa sezione un po' più corta e sicuramente meno sdolcinata).

Il ringraziamento finale va ovviamente a mia madre e mio padre. La roccia madre sulla quale ho potuto appoggiarmi per cominciare a costruirmi il futuro, e senza la quale questo percorso sarebbe stato francamente improbabile. Grazie per avermi donato quella spensieratezza e consapevolezza che solo un genitore può garantire con quella sorta di presenza-ombra e che mi ha permesso di affrontare tutte queste scelte e intraprendere tutti questi percorsi con totale libertà, e allo stesso tempo, serietà. Grazie mamma e papà perché questi tre anni e mezzo sono stati elettrici, e se sono fiero di questo percorso, il merito è tanto mio quanto vostro.

Forza Roma, sempre.

Prima di lasciarvi alla lettura di questo manoscritto incredibile vorrei fare un elenco sparso e assolutamente non esaustivo di tutte quelle cose che mi hanno aiutato in questi anni e, spero, potranno essere di aiuto a letteralmente chiunque altro decida di intraprendere un percorso di dottorato o qualunque altro tipo di percorso. Ci tengo a ringraziare: Brian Eno, il Gorgonzola, la Poang della mia stanza di Ferrara, la Nintendo Switch, l'Ultimo Uomo, Pendolino, Emanuele Atturo-Dario Saltari-Marco d'Ottavi non come gruppo distinto di persone ma come un'unica entità sonora senza volto, la pizza di Peppe, Stremio, i proiettori, i Pavement, Bill Hicks, Daniel Sloss, la mia playlist di Spotify, almeno un centinaio di film tra i quali mi vengono in mente il Petroliere, the Beginners, tutti i film di Ken Loach e Mad Max, l'oceano, la psicoterapia, gli hamburger, la Champions League, il Bello del Giovedì Sera, il mio giradischi, i miei vinili, i miei CD, il risotto alla zucca, il basket, i Talking Heads, Billy Bragg, Eric Andre, Fallout: New Vegas, Michelo, due agricoltori lucani, qualunque power ranking, la colazione del sabato e della domenica mattina, David Foster Wallace, i film al cinema, Iosonouncane, Steve Albini, le mie scarpe da corsa, Lonesome Dove, l'arrampicata, i tappi per le orecchie, una teiera cinese in ghisa, la mascherina in seta per dormire, il Pão de deus, Lisbona e il calcio bottiglia.

Infine, grazie anche a me.

È stata una cosa divertente che (forse) non farò mai più.

Summary

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“L’unica linea di resistenza è fare bene le cose”

Elio Petri

Chapter 1 Introduction

1.1. The earliest peopling in Europe – a chronological framework

Within the present state of the art, it is widely accepted that hominins colonised Western Europe during the late Early Pleistocene, starting from 1.5 – 1.3 Ma and then gradually increasing approaching the Middle Pleistocene boundary (i.e., 0.78 Ma Agustí et al., 2009; Garcia et al., 2013b; Martínez et al., 2014; López-García et al., 2015; Arzarello et al., 2016a; Lozano-Fernández et al., 2019; Palmqvist et al., 2022). The occupation of Europe occurred considerably later than the Levant and Asian region (Fig .1), where traces of hominins are now dated to 2.5 Ma (e.g., Longgupo Cave, Siwalik, and Xihoudu; Dambricourt Malassé et al., 2016; Han et al., 2017; Shen et al., 2020; Michel et al., 2021; Sun et al., 2022). This gap further increases if we consider that the earliest human traces in Europe are restricted to the Mediterranean basin (Spain and Italy), while evidence of anthropisation into more northern regions (*i.e.* Germany, France, England) is currently set to around 1.1 – 1.0 Ma (Parfitt et al., 2010; Garcia et al., 2013a; Landeck and Garcia Garriga, 2016; Roebroeks et al., 2017; Despriée et al., 2018; Lewis et al., 2019). The available data do not explain the reasons for this prolonged delay between Europe and Asia. The presence of hostile environmental conditions over the European continent acting as the primary obstructing agents for human groups has often been proposed (Blain et al., 2013; 2014; 2019; Bellucci et al., 2014; Hosfield and Cole, 2018; Sardella et al., 2018; Martínez-Monzón et al., 2022), though taphonomic and erosion factors should also be considered as possible causes for this chronological gap. On top of that, the cluster of sites recorded in Southern Europe compared to the Northern and Central portions represents an additional, more local issue (Candy et al., 2015; Moncel et al., 2018c).

Given the scarcity of sites and human remains for this chronological phase, it is still uncertain to establish the exact origin and modalities for the earliest occupation of Europe. The site of Dmanisi (1.85 Ma; Georgia) is located at the gates of Europe (Fig.1) and, so far, represents the closest connection between the Asian and the European region – other than formally symbolising the first Out of Africa's migration towards Eurasia - suggesting that hominins could have moved along the South Caucasus as one of the possible entry routes to reach Europe from Asia (Bar-Yosef, 1994; Mgeladze et al., 2011; Blain et al., 2014; Timmermann et al., 2022). On the other hand, a passage through the Levant Corridor (evidence from Ubeidiya, 1.6 – 1.4 Ma) or the Gibraltar Strait from the African region (Ain Hanech, 1.8 Ma) is also a valid alternative if we consider the current European data (N Goren-Inbar, 1993; Bar-Yosef, 1994; Belmaker et al., 2002; Barash et al., 2022; Duval et al., 2023). Additionally, the possibility of multiple waves of hominins dispersal from different continents during different chronological periods, matching the high variability recorded within the Lower Pleistocene European lithic assemblages, makes up for a further complicated scenario (Abbate and Sagri, 2012; Maslin et al., 2014; Potts and Faith, 2015; Palombo, 2016; Timmermann and Friedrich, 2016; Scardia et al., 2019; Lupien et al., 2020; Timmermann et al., 2022).

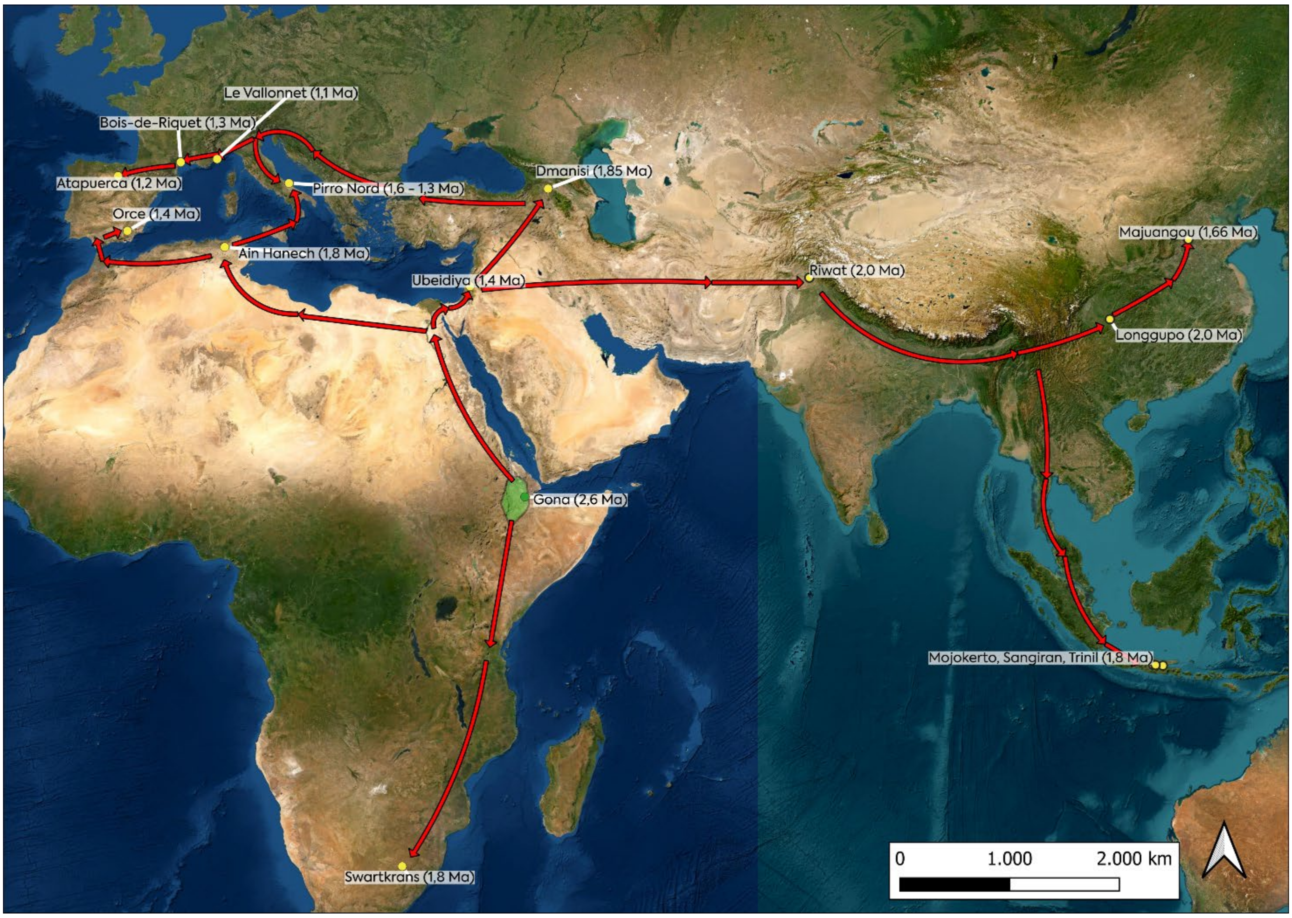

Figure 1.1 Schematic representation of the first Out of Africa.

1.1.1. The European archaeological evidence during the Lower Pleistocene

As previously mentioned, the earliest evidence of human occupation in Western Europe is currently found in the Iberian and Italian peninsulas (Fig. 1.2), respectively, in the sites of Orce's complex - Fuente Nueva 3 and Barranco León (hereafter also referred to as FN3 and BL) – and the fissure 13 of Pirro Nord (henceforth referred to as PN13) where lithic tools in association with faunal remains have been uncovered (Arzarello et al., 2007; 2015; 2016a; Moyano et al., 2011; Toro-Moyano et al., 2013; Martínez et al., 2014; Espigares et al., 2019). FN3 and BL are located in southeastern Spain in the Guadix-Baza depression, where a relatively complete Plio-Pleistocene sedimentary record is well preserved. According to Palmqvist and colleagues (2023 and reference therein), the most parsimonious age for BL and FN3 is ~1.4 – 1.2 Ma, based on the combination of biostratigraphy, magnetostratigraphy, and U-series/electron spin resonance (ESR) analysis conducted. The site of PN13, located in SE Italy, is a karstic fissure near the Gargano promontory. Despite the absence of radiometric dates, the chronological affiliation of the context has been established to ~1.6 – 1.3 Ma based on biochronological data (presence of the arvicolid *Allohaiomys ruffoi*) plus the correlation with palaeontological remains (López-García et al., 2015).

Recent work from Gabarda and colleagues (2016) revealed the existence of another Lower Pleistocene site in the Iberian peninsula: Alto de las Picazaras (Fig. 1.2). This context, located in the Valencia region, comprises a group of karst cavities containing Lower and Middle Pleistocene deposits. The analysis of the faunal remains (presence of *Allohaiomys ruffoi* and *Soergelia minor*) and the palaeomagnetic data suggest an Early Pleistocene chronology between 1.5 and 1.4 Ma. Evidence for human occupation has been established by the presence of seven lithic pieces plus butchery marks on some mammal bones.

The site of Sima del Elefante (Fig. 1.2), belonging to the Atapuerca complex, is also one of the most crucial pieces of evidence for the earliest peopling of Europe where faunal, human remains and lithic tools have been found in association. The level TE9 of the cavity of Sima del Elefante has been chronologically dated between 1.3 and 1.1 Ma (Huguet et al., 2017) through a combination of palaeomagnetism, cosmogenic nuclides and biostratigraphic markers (Carbonell et al., 2008).

Around 1.2 – 1.0 Ma, evidence for human occupation within the European continent increases even outside the Mediterranean basin - including northward human colonisation - after a “short” gap (Muttoni et al., 2010; Parfitt et al., 2010; Garcia et al., 2013a). The reasons for this “global” growth and expansion in archaeological evidence are due to significant climatic, vegetational and faunal changes that started to occur around 1.2 million years ago and that the scientific community identified as the onset of the Middle Pleistocene Revolution (henceforth referred to also as the MPR, or EMPT: Early Middle Pleistocene Transition; Cuenca-Bescós et al., 2005; Head and Gibbard, 2005; Manzi et al., 2011; Railsback et al., 2015; Palombo, 2016; Cohen and Gibbard, 2019). Although this topic will be adequately addressed in the following chapters, it is crucial to point out that the 1.2 Ma boundary marks the beginning of essential climatic shifts all over the European continent – *i.e.,* the change of periodicity in the alternation of glacial/interglacial phases from 41 ka to 100 ka being the most significant one - eventually leading to renovations and mass extinction events in the faunal communities (*i.e.,* beginning of the Epivillafranchian) and ultimately affecting human migration and triggering the development of new behavioural strategies (Manzi, 2004; 2016; Dennell et al., 2011; Profico et al., 2016; Navarro, 2018; Pope et al., 2018; Moncel et al., 2022; Hu et al., 2023; Margari et al., 2023; Ollé et al., 2023).

Among the Spanish sites placed after 1.2 Ma is the site of Vallparadís (Fig. 1.2), dated between 0.98 and 0.95 Ma (during the Jaramillo subchron), combining ESR-U/series, OSL and biochronology of macro- and micromammals (Martínez et al., 2014). Moving back to Atapuerca, at the site of Gran Dolina (Fig. 1.2), the palaeomagnetic analysis of the layer TD6 shows a pre-Matuyama negative polarity (>0.78 Ma, MIS 21) while thermoluminescence and direct ESR on human remains provided ranges of 960 ± 120 ka and 772-949 ka, leading to an overall chronology of the site to around 0.85 Ma, during MIS 22 and 21 (Duval et al., 2018). Another context witnessing a late Early Pleistocene human occupation of the Spanish peninsula is Barranc de la Boella (Tarragona; Fig. 1.2), where three main localities (La Mina, El Forn and Pit 1) yielded a rich archaeo-palaeontological assemblage. The palaeomagnetic, cosmogenic and palaeontological analysis placed the chronological frame of Barranc de la Boella between 0.99 and 0.78 Ma (Vallverdú et al., 2014; Ollé et al., 2023). Ultimately, the sites of Cueva Negra and Solana del Zamborino – positioned in SW Spain - originally dated to the late Lower Pleistocene (Walker et al., 2020), are now considered younger than anticipated and can no longer be included within the earlier peopling of this region (Moncel et al., 2022).

The archaeological evidence of the late Lower Pleistocene in the Italian Peninsula features one site: Cà Belvedere di Montepoggiolo (NE Italy; Fig. 1.2), where numerous lithic tools have been found.

The correlation with palaeontological remains from a locality surrounding the site and the palaeomagnetic and ESR analysis *in situ* led the chronological frame of this context to ~ 0.85 Ma (Peretto et al., 1998; Falguères, 2003; Muttoni et al., 2011).

As previously mentioned, several sites in France, Germany and England have provided proof of human occupation in more northern regions during the final stages of the Lower Pleistocene. In Southern France, a rich paleontological and lithic assemblage has been discovered at the cave of Le Vallonnet (located between the Maritimes Alps and the Mediterranean Sea; Fig. 1.2) with evidence of lithic tools associated with cut marks on some large mammal bones. The most recent radiometric analysis of Michel and colleagues (2017) using the U-Pb series combined with the palaeomagnetic measurements provided a new chronological framework of ~ 1.2 Ma for the human occupation of the cave during the glacial period MIS 36. These results are consistent with the current palynological data and the palaeontological correlations obtained from other European sites (Michel et al., 2017; Lozano-Fernández et al., 2019), making Le Vallonnet contemporaneous to Sima del Elefante and suggesting a possible *"synchronous Hominin activity around the Northern Mediterranean and Southern Europe."* (Michel et al., 2017, p. 5). Another significant piece of evidence comes from the site of Bois-de-Riquet (Lézignan-la-Cébe, Hérault; Fig. 1.2), always located along the southern French coast by the Mediterranean Sea, further west of Le Vallonnet. The site is in an abandoned basalt quarry where several stone artefacts realised on basalt and numerous faunal remains were discovered. The site's chronology has been initially established on biostratigraphical interpretation to an age of around 1.3 – 1.1 Ma (Bourguignon et al., 2016a), although more recent works, after a revaluation of all the data, proposed a chronology of 1.0 – 0.9 Ma, which is nowadays widely accepted by the scientific community (Lozano-Fernández et al., 2019).

Moving further North are the sites of Pont de Lavaud (district of Eguzon-Chantôme, Indre; Fig. 1.2), located in the centre of France on the western slope of the Creuse Valley and the site of Lunery-la Terre-des-Sablons (Cher Valley, Middle Loire Catchment; Fig. 1.2). The archaeological investigations at Pont de Lavaud were conducted on an area of 130 m² where a rich lithic assemblage realised on local quartz was discovered. The radiometric analysis realised through ESR yielded a chronological frame of 1.055 ± 0.055 Ma (Despriée et al., 2018). The site of Lunery corresponds to a former sand quarry where several lithic artefacts were recovered from a stratigraphic sequence. The ESR technique established the deposit age to about 1.1-1.2 and 0.9 Ma (Despriée et al., 2017). A recent re-analysis of the chronological frame of Lunery conducted by Duval and colleagues (2020) with new techniques obtained only a minimum age of ~ 710 ka. However, Duval and colleagues pointed out that an Early Pleistocene Chronology of the site cannot be excluded since the stratigraphical and technological evidence is in accordance with the previous data (Duval et al., 2020).

Lastly, the site of Pradayrol, located in Southwestern France in the Aquitaine Basin (Fig. 1.2), is a large rock shelter with prolonged human frequentation. Although a rich archaeological deposit was uncovered, no radiometric dates are available. The biostratigraphical analysis placed the oldest frequentation of the site at around 0.9 Ma (Guadelli et al., 2012).

Concerning Germany, recent investigations conducted along the Rhine basin (Fiedler et al., 2019) revealed the existence of several localities – including some well-known ones such as Mauer and

Mosbach - that might indicate an earlier human occupation of this region already from 1.3 Ma and through the final stages of the Lower Pleistocene (Fig. 1.2). Despite the low number of lithic tools recovered and the need for further analysis to confirm these data eventually, they represent a valuable step for the Lower Palaeolithic of this region. At Münster-Sarmsheim, in the Lower Nahe Valley, several fluvial terraces containing Quarternary levels have been unearthed through a large test pit. Seven lithic artefacts were recovered from the deposit, including some retouched tools (Fiedler et al., 2019). New geomorphological analyses of the sequence by Preuss and colleagues (2015) allowed the correlation of the deposit with the Belgian terraces of Maas River and with different Marine Isotope Stages, leading to a chronological estimation of 1.33 Ma (Cobb Mountain Event). At Dorn-Dürkheim 3, in the Rhineland-Palatinate region, a well-preserved Lower Pleistocene faunal concentration was unearthed during fieldwork in 1989 (Fiedler et al., 2019 and reference therein). The biostratigraphical analysis of the micro-mammals assigned the assemblage to the late Matuyama Chron (MIS 21-19) with a chronology of ca. 0.82 – 0.78 Ma. The small lithic assemblage consists of ten pieces. Along the Lower Middle Rhine and Moselle region, a system of fluvial terraces has been identified and initially correlated to the beginning of the Middle Pleistocene, even though Preuss and colleagues' analysis suggested an older age of around 1.3 Ma (Preuss et al., 2015). A few lithic artefacts have been reported but are still unpublished (Fiedler et al., 2019).

The most important site for the Lower Palaeolithic of Germany is Untermassfeld (Garcia et al., 2013a; Landeck and Garcia Garriga, 2016; Reumer and Kahlke, 2022). The context, situated on a high river terrace along the course of the Werra (Thuringia region, Central Germany; Fig. 1.2), is well known for its rich Epivillafranchian fauna. Recent fieldwork yielded several lithic artefacts attesting to human occupation, including some butchery marks (Landeck and Garcia Garriga, 2016), though some doubts have been cast on their validity. The chronology for the human occupation has been placed to approximately 1.07 Ma (Jaramillo Subchron) through palaeomagnetic and biostratigraphic investigations (Garcia et al., 2013a).

To conclude, this section is the archaeological evidence from Britain, which, within the present state of the art, provides the highest latitudinal presence of hominins during the Lower Pleistocene in the world. The site of Happisburgh 3, located on the eastern coast of England (Norfolk region, UK; Fig. 1.2), exhibits traces of human occupation of approximately 0.9 Ma (Parfitt et al., 2005; 2010; Ashton et al., 2014; Key and Ashton, 2022). The presence of well-known Early and Middle Pleistocene sediments rich in flora and faunal remains characterises the context, which has only yielded traces of anthropisation in the last decade. The lithic assemblage features 78 lithic artefacts discovered in 2005 and realised on local chert, including some retouched flakes. Additionally, during the 2013 investigation, several human footprints – belonging to both juvenile and adult individuals - were unearthed, further confirming the stable hominins' presence at this locality (Ashton et al., 2014). The site's chronology has been the object of numerous analyses, mainly combining palaeomagnetism and biostratigraphy and leading to an age between 0.99 and 0.78 Ma during the end of the Matuyama chron (Parfitt et al., 2010). The correlation of these data with the vegetational succession is consistent with an interglacial cycle further constraining human occupation to the end of either MIS 21 (866 – 814 ka) or MIS 25 (970 - 936 ka; Parfitt et al., 2010; Preece and Parfitt, 2012; Candy et al., 2015; Farjon et al., 2020; Key and Ashton, 2022).

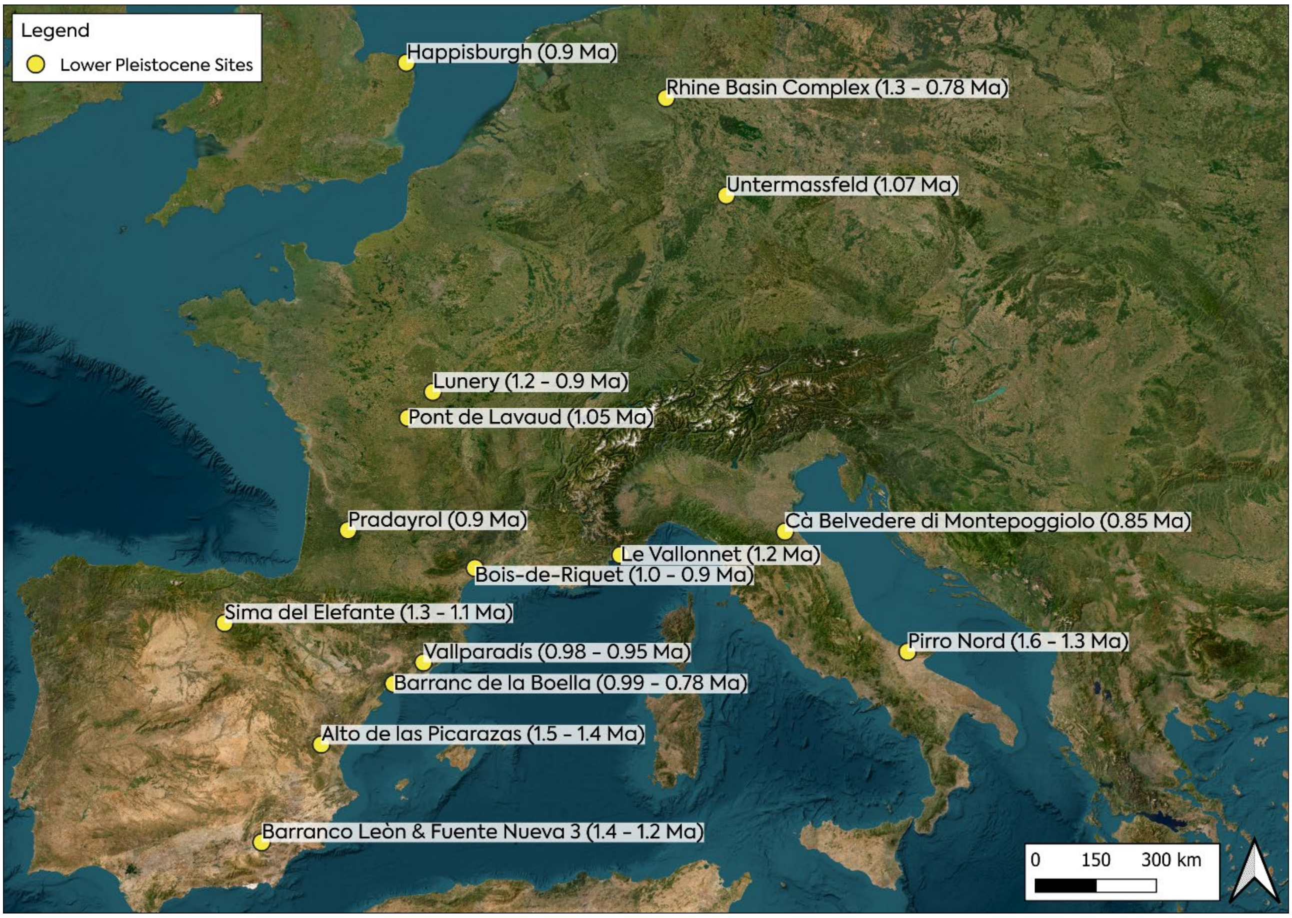

Figure 1.2. List of Lower Pleistocene sites mentioned in the text with their chronological attribution indicated in brackets.

1.1.2. The palaeoenvironmental context in Europe during the Lower Pleistocene and hominins' subsistence strategies

So far, according to the available data, we have observed a pattern of human peopling during the Lower Pleistocene, which includes a gradual expansion in the archaeological evidence as we approach the Middle Pleistocene boundary both spatially - from Southern to Northern Europe – and quantitatively (Muttoni et al., 2010; Garcia et al., 2013a; Blain et al., 2014; Agustí et al., 2015). Nevertheless, what environmental context characterises the European Lower Palaeolithic evidence? As previously mentioned, Europe features hostile environmental and geographical conditions, which seemingly affected the process of human expansion and most likely account for the delayed occupation of the more northern regions (Parfitt et al., 2010; Kahlke et al., 2011; Preece and Parfitt, 2012; Garcia et al., 2013a; Cohen and Gibbard, 2019; Gibbard et al., 2019; Moncel et al., 2022). Moreover, the high diversity of Europe from an environmental perspective should be considered, ranging from dry and continental climates in the East to wetter and temperate in the West. On top of that, the last portion of the Lower Pleistocene, which covers the European peopling (1.5 – 0.8 Ma), witnesses a progressive deterioration of the environmental conditions with less uniform climate cycles – varying in both duration and intensity – and a general shift from a wooded forest dominated ecosystem to more open landscapes (Kahlke et al., 2011; Messager et al., 2011;

Railsback et al., 2015; Palombo, 2016; Moncel et al., 2018c; Sardella et al., 2018). This gradual impoverishment of the environmental conditions is a crucial factor in the faunal and floristic turnovers that will take place in Europe already during the Jaramillo subchron (Martínez et al., 2010; Garcia et al., 2013a), strongly affecting the subsistence strategies of the human groups who seemingly faced a more hostile and changing environment. Within this scenario, it has often been suggested that the Mediterranean area (*i.e.,* the Iberian and the Italian peninsulas and the Southern French coast) could have functioned as refugia areas since their geographical position would grant milder climatic conditions, thus explaining an older and possibly continuous occupation by hominins. On the other hand, the human occupation of more northern areas would have happened more gradually and during favourable climatic phases, which - given the change in the periodicity of the glacial/interglacial cycles – were considerably longer, granting to the hominins wider windows of opportunity to expand into the North.

From this perspective, a recent study on the analyses of marine and terrestrial proxies from a deep-sea core on the Portugese margin revealed the presence of a pronounced climatic instability event between ~1.15 Ma and ~1.12 Ma, which ultimately culminated in a glacial stage (MIS 34) comparable, for cooling intensity, to the most extreme glacial events of the last 400 ka years (Margari et al., 2023). According to the authors, these extreme conditions led to Europe's global and massive depopulation through subsequent glacial-interglacial cycles. They further state that, before 1.15 Ma, European climatic conditions were more stable with short glacial events, granting hominins "easier" and prolonged occupation, while after MIS 34, the recorded climatic instability *"would have placed hominin populations under considerable stress. The likely much-lower carrying capacity of the environment would have challenged small hunter-gatherer bands, compounded by the likelihood that early hominins lacked sufficient fat insulation and the means to make fire, effective clothing, or shelters, leading to much-lower population resilience."* (Margari et al., 2023, p. 5). These data confirm the previously mentioned archaeological hiatus that affected the European region around 1.2 Ma and further enhance the hypothesis that Southern Europe was depopulated at least once during the Lower Pleistocene.

In any case, comprehending the climatic and environmental conditions grants essential insights into the range of behavioural, cultural and physiological adaptations the hominins might have undergone in facing adverse and challenging ecosystems.

According to the precipitation rate, the environmental data from the Guadix Basin Area (sites of Orce) during the Lower Pleistocene shows an alternation in the vegetation between dry steppes and open forests or woodland (Altolaguirre et al., 2020; 2021). This area was described as an endorheic basin with a saline-like system surrounded by mountains >2000 m high, exhibiting a high diversification of biomes, including freshwater, areas of lower latitudes with Mediterranean woodland and shrubland and mountainous areas with higher arboreal cover. During glacial phases, temperatures were relatively mild and similar to modern ones - suggesting that hominins could have endured in this region - while interglacial phases recorded warmer temperatures if compared to present ones. The herpetofauna analysis further validates these data (Agustí et al., 2015). The environmental reconstruction through the pollen record shows that herbs, grasses and xerophilous plants (*Artemisia, Ephedra*) were prevalent during the dry phases (Arzarello et al., 2023). As a consequence, open spaces such as steppes and grasslands were predominant. During humid phases, arboreal taxa were more frequent in the basin, covering a significant percentage of the environment, with deciduous and conifer forests (*Quercus, Pinus, Picea* and *Abies*). The high number of gazers' remains among the faunal assemblage, such as *Equus, Bison, Mammuthus meridionalis,* and *Hemitragus*, suggests that these deciduous forests were relatively open while the presence of *Praemegaceros* confirms a higher arboreal cover in the mountainous areas. Recent studies on the herpetofauna record recovered from the archaeological layers of Barranco León 5 and Fuente Nueva 3 indicate that seemingly hominins occupied this area during glacial (dry) and interglacial (humid) cycles (Sánchez-Bandera et al., 2020).

The palaeoenvironmental data (palaeontological and palaeobotanical) from level TE9c at Sima del Elefante (Huguet et al., 2017) indicates that the presence of evergreen *Quercus, Pinus* spp., and *Cupressaceae* is consistent with a typical Mediterranean climatic context, seemingly wetter and rainier than the present days. The percentage of micro-charcoal remains detected was interpreted as an occurrence of fire, suggesting a dry season or periods of drought typical of the Mediterranean area. The analysis of the herpetofauna assemblage hints at warm climatic conditions, given the presence of species associated with high rainfall, permanent rivers or ponds and wet meadows (Huguet et al., 2017). The large mammal assemblage involves the presence of woodland and woodland edge fauna, such as cervids (*Eucladoceros giulli* and *Dama valonnetensis*), together with open-land taxa like horses (*Equus altidens*), rhinos (*Stephanorhinus* sp.) and bovids (*Bison* cf. *menneri*) which portraits a patchy landscape formed by grasslands and forested areas surrounded by wet areas. The archaeological remains recovered from the cave of Sima del Elefante also shed some light on the subsistence strategies of the early hominins. The study of the faunal remains indicated that primary and early access to the carcasses – regardless of the size of the animals - was granted to the hominins through hunting and scavenging. According to the researchers, this type of strategy would be possible only if human groups shared social cooperation, thus implying a degree of complexity in their relationships. The presence of carnivores in the faunal assemblage and carnivores' marks on the bones suggest that the competition between humans and carnivores was nonetheless high, but *"hominins did not depend on the remains left by the carnivores for food"* (Huguet et al., 2017, p. 18), confirming the efficiency of the strategies employed (Huguet et al., 2013; Saladié et al., 2014).

Concerning the climate and landscape reconstruction of Pirro Nord, most of the data comes from the study of the herpetofauna assemblage recovered from 24 karstic fissures (Blain et al., 2019). The results show slightly more continental climatic conditions than present, with a predominance of open-dry biotopes and a higher winter rainfall corresponding to a cold period during the Lower Pleistocene. The small mammals and bird species detected confirm a context characterised by an open landscape with an arid climate. Some fissures recorded a closer, more humid landscape, similar to today, with forests or wetlands placed in the surroundings of watercourses and swamps. Blain and colleagues explain these differences as *"a short time difference in accordance with some Lower Pleistocene glacial-interglacial dynamic."* (Blain et al., 2019, p. 831). It is generally acknowledged that a transition toward globally colder and drier conditions became gradually more frequent all over Europe – consisting of a higher frequency of open landscapes during glacial cycles that were not immediately replaced during the subsequent interglacials - with the approach of the 1.2 Ma boundary (Leroy et al., 2011). This global trend should have seemingly favoured the dispersal of large herbivores species from the East to the West through the opening of new corridors, such as *Equus altidens, Bison degiulii,* and *Xenocyon lycaonides* which have all been recorded at the site of Pirro Nord (Cheheb et al., 2019). A similar pattern, where a worsening of the climatic and environmental conditions was recorded over time, has been witnessed at the sites of Dmanisi and Barranco León. In the case of the basin of Orce, gradual aridification affecting the arboreal diversity and the water resources was reported at the onset of the Middle Pleistocene Transition (Manzi et al., 2011; Magri et al., 2017; Altolaguirre et al., 2020; 2021).

The available data from Le Vallonnet also depicts a transitional environment along the stratigraphic sequence, witnessing a shift from a more temperate humid context at the bottom of the deposit (Ensemble I and II) to a cold and dry climate in the levels associated with the human occupation (Ensemble III, MIS 36; Michel et al., 2017; Blain et al., 2021; Cauche, 2022). During the humid phases of Ensemble I and II, the palynological data highlights a landscape with an arboreal cover composed of large deciduous trees, Mediterranean taxa and *Pinus*. Ensemble III shows a substantial marine regression and is associated with climate cooling, even though summers are reported to be relatively long and warm. The landscape during this phase seems to be more steppe-like with less arboreal cover.

Moving to the site of Bois-de-Riquet, the micro-mammals and herpetofauna data provided for level US2 (oldest of the sequence) shows that an open and humid meadow landscape dominated the area along with patches of humid forest, woodland margin and water edges (Bourguignon et al., 2016a; Lozano-Fernández et al., 2019). The palaeontological analysis further confirms this information, given the abundance of large herbivores typical of open landscapes (savanna-like and woodlands), such as *Praemegaceros* sp., *Equus altidens, Equus* cf. *suessenbornensis,* and *Dama*-like cervid, and the presence of *Stephanorhinus etruscus* which is typically associated with lacustrine environments exhibiting a high degree of humidity (Lozano-Fernández et al., 2019).

After the Jaramillo subchron, the palaeoenvironmental data available for the last portion of the Lower Pleistocene consists of different sites on a wide geographical area.

At Barranc de la Boella, the paleoecological data for this site are still the object of ongoing studies. The correlation of the sedimentological analysis with the palaeontological record (presence of hippopotamus and water voles) has allowed the researchers to establish the presence of a flooded habitat (Vallverdú et al., 2014; Mosquera et al., 2015). At Vallparadìs, the association of micro-mammals of unit EVT7 (MIS 27) revealed the existence of a Mediterranean-type landscape dominated by water edge and open humid meadows, with small areas of woodland and woodland margin and open-dry meadow (Martínez et al., 2014). The palynological results available for the unit EVT4 (Matuyama – Brunhes boundary, MIS 19) show that the arboreal cover was composed of *Pinus,* evergreen *Quercus* and *Corylus,* suggesting a temperate climate (semi-cool and semi-humid) (Leroy et al., 2011; Martínez et al., 2014). According to Martìnez and colleagues (2014), who integrated the chronological and environmental (pollen, herpetofauna and rodents) data of Vallparadìs with the ones coming from the sites of Gran Dolina and Cal Guardiola – covering a chronological frame that spans from the Jaramillo subchron to the Brunhes/Matuyama boundary – an evolution from a Mediterranean climate and an open landscape to a semi-cool and drier context with a predominance of coniferous tree cover took place in all the mentioned sites. However, this global impoverishment of the environmental conditions did not prevent hominins from occupying the Iberian peninsula (Agustí et al., 2010; Martínez et al., 2010).

From the French sites of Pont de Lavaud, several pollen and phytolith analyses have been performed to reconstruct the environmental context of the Paris basin around 1.0 Ma (Messager et al., 2011). The results indicate a closed temperate environment characterised by a deciduous temperate forest dominated by *Quercus* and *Castanea* trees and a herbaceous component of temperate *Poaceae*. According to the authors, the deciduous forest of the site developed during warm and wet climatic conditions, corresponding to an interglacial cycle – seemingly MIS 31 - during which human occupation of the site is witnessed (Despriée et al., 2018). The very scarce presence at the site of relict taxa such as Pterocarya and Carya is a sign of the cooling trend that characterises the final portion of the Lower Pleistocene with colder and drier glacial cycles (Messager et al., 2011) which, especially at higher latitudes, most likely prevented human from enduring in this areas during glacial periods.

The site of Untermassfeld provides crucial information on the palaeoenvironmental context of the European temperate regions between 1.2 and 0.9 Ma (Kahlke et al., 2011; Reumer and Kahlke, 2022). According to the site's lithological, palaeomagnetic and biostratigraphic characteristics, the assemblage formation occurred during the warm interglacial MIS 31. The climate was warmer than the present – described as a temperate, warm-humid one without particular seasonal fluctuations - with higher summer temperatures – confirmed by freshwater turtles and the numerous remains of Hippopotamus – and mild winters (Garcia et al., 2013a). The composition of the faunal assemblage, which is the most emblematic of the Epivillafranchian period, also suggests warm conditions with temperate and thermophilous taxa (*Bison menneri, Hippopotamus antiquus, Stephanorhinus hundsheimensis, Pantera onca gombaszoegensis, Acicnonyx pardinensis pleistocaenicus, Puma pardoides, Megantereon cultridens, Homotherium crenatidens,* and *Lycaon lycaonoides* being the most characteristics of this type of climate). The landscape comprises a mosaic of environments including wet, humid and relatively dry habitats with the predominance of dry grasslands, shrubs, and, in minor portions, woodlands (Kahlke et al., 2011). The presence of permanent freshwater has also been established. It should be underlined that, despite a humid climate warmer than today, the temperatures during winters would still fall below 0 °C proving that hominins could adapt and endure in a different ecosystem from the Mediterranean area, thus implying efficient ways to exploit the environment and outrun the carnivores' competition (Garcia et al., 2013a; Landeck and Garcia Garriga, 2016; Roebroeks et al., 2017).

The sites of Gran Dolina yielded a rich herpetofauna and palynological assemblage, which allowed an accurate reconstruction of the environment at the Brunhes–Matuyama transition (Blain et al., 2013; Cuenca-Bescós et al., 2013). The climate of the level TD6-2 is described as Mediterranean temperate, with cold winters, temperate summers and abundant rainfalls throughout the year. Compared with the modern climate, during the Lower Pleistocene at Grand Dolina, it was warmer and rainier than today. In particular, the duration of the dry period during summer is absent, while today, it consists of two months (July and August). Humid meadows and woody habitats characterised the landscape. The pollen spectra recorded the presence of common Mediterranean taxa such as *Quercus* type, *Ilex-coccifera, Olea, Celtis, Pistacia* and *Coriaria,* indicating an open forest cover typical of Mediterranean conditions. The faunal remains confirm a warm, relatively wooded landscape with significant open-landscape areas (*Mammuthus* sp.). The authors correlated this landscape reconstruction to a transitional phase of forest development during a shift from a cold to a warm climate, seemingly corresponding to the MIS 22/21 transition. In the upper layers (TD6-3 and TD5), a switch to colder conditions and a more open landscape seem to occur.

According to the authors, *"the reconstructed landscape for the level TD6 of Gran Dolina is very similar to those reconstructed for other Iberian Early Pleistocene sites that have yielded strong evidence of a hominin presence, such as Sima del Elefante, Barranco León D and Fuente Nueva 3, having a good representation of woodland and water-edge areas in common"* (Blain et al., 2013, p. 316). Following this line of thought, we could add to this list the previously mentioned sites of Pirro Nord, Bois-de-Riquet and Le Vallonnet, fitting within this environmental context and all located in the Mediterranean area. The scientific community agrees that a clear association during the Plio-Pleistocene exists between *Homo* and ecologically rich semi-open savannah-type and mosaic landscapes – showing warm-humid climate - where wetlands and coastal habitats are recurrent traits. Such conditions should correspond to a wide range of resources available for human groups, such as plants, freshwater, large mammals and raw materials. On top of that, these semi-open landscapes have also been considered one of the most valuable routes for humans and animals to follow during their dispersals (*i.e.,* to arrive in Europe but also to move into higher latitudes), often coinciding with the transition from glacial to interglacial periods. According to the hypothesis proposed by Leroy *et al.* (2011), there is a solid correlation between the presence of warm climatic conditions and the not fully developed forests– defined by Blain and colleagues as "*the lag of the vegetation optimum behind the climatic optimum"* (Blain et al., 2013, p. 317) – which is only possible during a transition from a glacial cycle to an interglacial one and that should grant hominins and animals the most favourable circumstances to diffuse over the territory.

The environmental reconstruction conducted at Montepoggiolo indicates the presence of an open landscape during the human occupation with coniferous forest (*Pinus* and *Abies*) and steppic herbaceous taxa (Poaceae, Chenopodiaceae and *Artemisia*) developed under cold and dry climatic conditions. The complete pollen sequence analysed in 2004 covers a period from 1.4 to 1.07 Ma, preceding the human occupation and witnessing several interglacial/glacial cycles (Messager et al., 2011). According to the available results, the glacial periods are considered mild, given the absence of a steppic environment and the continuous presence of trees, allowing the permanence of the human groups even during these cold phases.

Regarding the climatic and ecological context of Happisburgh 3 – witnessing human occupation during an interglacial phase - the available data suggest similar environmental conditions to the site of Untermassfeld (Parfitt et al., 2010; Kahlke et al., 2011; Garcia et al., 2013a), though Farjon et al. (2020) challenges this statement by advocating for a cooler climate. The initial environmental interpretations (Parfitt et al., 2010) suggested a climate analogous to southern Scandinavia at the boundary between the temperate and boreal vegetation zones with a conifer-dominated landscape. Recent analyses by Farjon et al. (2020) led to more accurate climate and landscape reconstruction results. Besides the former known taxa such as Pinus, Picea and Abies, the conifer assemblage comprises the discovery of *Tsuga, Juniperus, Larix, Taxus* and *Sequoia.* These new data indicate a coniferous woodland of greater diversity compared to modern northern and central Europe, with summers similar to today but winters apparently colder by at least 5° C. This information stresses the presence of a continental climate with strong seasonality at Happisburgh 3, with hominins that faced sub-zero temperatures (lower than previously expected) during winters.

The scientific community agrees that the severe cold, reduced growing season, fewer edible plants, scarcer mammalian prey and shorter daylight hours represent the most challenging aspects of such environments, but which solutions could have been adopted by the hominins? The evidence from Happisburgh 3 raises essential questions regarding which strategies the hominins could have used to cope with such harsh climatic conditions (Ashton and Lewis, 2012; Hosfield and Cole, 2018; Rodríguez et al., 2021; Scott and Hosfield, 2021; Moncel et al., 2022). Aside from using controlled fire, excluded for lack of evidence, MacDonald (2018) and Hosfield and Cole (2018) propose two main plausible strategies. The first one involves that hominins should have been able to increase the animal food contributions to their diet (*i.e.,* more meat) and store a surplus of food resources, implying a greater knowledge of the landscape, higher mobility and social group organisation. The second one includes enhanced insulation, which could have been physiological (elevated basal metabolic rate, increased muscle mass, more body hair or subcutaneous fat) and/or technological (clothing and shelter).

Even though the material evidence for the latter strategy is scarce, the data from Happisburgh 3, Untermassfeld, and Pont de Lavaud indicates that around 1.0 Ma hominins, while more or less continuously occupying Southern Europe, were able to reach the northernmost regions during interglacial intervals – whereas abandoning them at the onset of the subsequent glacial cycles – enduring in below-zero temperatures, in what has been defined by Hosfield and Cole as a *"fragmented multi-phased hominin occupation"* or (building on the modified theory of the short chronology of Dennell and Roebroeks, 1996) *"punctuated long chronology (PLC), whereby cycles of population crashes and increases align with MIS stages"* (Hosfield and Cole, 2018, pp. 156–157). Following this line of thoughts, recent work from Key et al. (2022) postulated that hominins could have occupied Britain, or more, in general, the northern regions of Europe with prohibitive climatic conditions, even before 1.0 Ma using predictive software (*i.e.,* OLE models: optimal linear estimation models) that interpolated palaeoclimatic, palaeobotanical, faunistic and archaeological data from all Europe. Despite this work being a simulation of the current data - also speculating on the afore-mentioned taphonomic issues that could have erased the archaeological evidence of the northern regions – it is contributing to the homogenisation of the current view of an earlier and prolonged peopling of Europe during the Lower Pleistocene characterised by multiple waves of hominin dispersal (Hosfield and Cole, 2018; Key and Ashton, 2022).

1.1.3. The anthropological evidence of Europe during the Lower Pleistocene

From an anthropological perspective, three localities yielded human remains related to the Lower Pleistocene: Barranco León, Sima del Elefante and Gran Dolina TD6 (Carbonell et al., 2008; Bermúdez de Castro et al., 2010; 2017a; 2017b; Toro-Moyano et al., 2013; Lorenzo et al., 2015; Hardy et al., 2017; Duval et al., 2018; García-Martínez et al., 2021). At Barranco León, a first deciduous molar attributed to *Homo* sp. has been found in association with lithic tools and faunal remains. The tooth (specimen BL02-J54-100) comes from level BL D (also referred to as BL 5), which makes it the oldest human evidence of Europe, given the site's age (1.4 – 1.2 Ma).

Two human remains, assigned to *Homo* sp., were discovered at Sima del Elefante: a mandible (Carbonell et al., 2008) and a left-hand phalanx (Lorenzo et al., 2015). The mandible (specimen

ATE9-1), consisting of a fragment of the symphyseal region, was recovered along with an isolated tooth belonging to the same individual from the level TE9c, dated to around 1.2 Ma. A study on the dental calculus preserved on the mandible (Hardy et al., 2017) allowed us to gain some basic information about the diet and the environment of the earliest inhabitants of Europe. The results showed that hominins consumed plants (grass-type, seemingly of the family of *Poaceae*) acquired in the site's proximity, while several types of vegetal fibres – including non-edible wood debris – also suggest using plants as raw materials. Other fibrous remains have been associated with meat consumption (*i.e.,* connective tissue like tendons or ligaments). Concerning the landscape, coniferous pollens indicated the individual's proximity to a forested environment. Their presence has been related to the consumption of the plant as food since conifer trees have edible needles, nuts and inner bark, rather than woodworking. The authors also remarked that the high concentration of pollen grains recorded on the dental calculus contrasts with the scarcity of pollen in the sediment, demonstrating how valuable these analyses are for environmental reconstructions (Hardy et al., 2017). The mandible's dental wear was considered heavy, suggesting prolonged para-masticatory (*i.e.,* that does not involve just chewing) or masticatory behaviours. The current data does not support the use of controlled fire, which, on the other hand, provides evidence for the consumption of raw food for plants and meat. The left-hand phalanx (specimen ATE9-2) was found at the same level, depth, and less than 2m from the human mandible. It belongs to an adult individual and is probably part of the fifth finger. The studies revealed that the hand morphology remained stable in the genus *Homo* over the past 1.4 Ma (Lorenzo et al., 2015).

The richest record comes from the unit TD6 of Atapuerca Gran Dolina, where, over the last 25 years, more than 170 hominin fossil remains were found and assigned to a minimum number of 8 individuals (Bermúdez de Castro et al., 2017a; 2017b; García-Martínez et al., 2021). As previously mentioned, the chronology of the TD6 unit has been the object of several studies and analyses, leading to a consensus around an age of 0.9 – 0.8 Ma (772 – 949 ka) before the Middle Pleistocene transition (Parés et al., 2013; Martínez et al., 2014; Duval et al., 2018). All the human remains have been attributed to *Homo antecessor* (Bermúdez De Castro et al., 1997), representing the earliest known hominin species identified in Western Europe. The human remains have been found in association with more than 831 lithic instruments and several thousand fossil remains of different species of micro and macro mammals. Their state of preservation is good even though at least two cannibalism events have altered the sample (Fernández-Jalvo et al., 1999; Carbonell et al., 2010a; Saladié et al., 2012). The reasons for these cannibalism events have been the object of several works which tried to establish the nature and the purpose of such actions. According to Saladié et al. (2012, p. 693), *"the cannibalism evidenced at the site can only be explained by the consumption of the bodies for nutritional reasons".*

The analyses of human fossils, which comprise the presence of many cranial and postcranial remains, revealed unique combinations of cranial, mandibular and dental traits characterised by overall mosaicism of the anatomical features (*i.e.,* the combination of primitive and derived features regarding the *Homo* clade) which led to the 1997's proposal of naming a new human species *(i.e., H. antecessor*; for a detailed explanation see Bermúdez de Castro et al., 2017a; 2017b). According to numerous studies realised throughout the years, including the most recent one on the enamel proteins recovered from a molar fragment (Welker et al., 2020), *Homo antecessor* is "*a closely related sister taxon of the last common ancestor of H. sapiens, H. neanderthalensis and*

Denisovans" (García-Martínez et al., 2021, p. 1). Furthermore, its postcranial morphology shares several similarities and derived traits with modern humans and the Middle Pleistocene human remains from China.

Given the proximity of the remains of Gran Dolina with the ones from Sima del Elefante (about 500 m), it has been speculated whether they could represent an *in-loco* evolution of the same population. However, a comparison based on the anatomical traits of the two assemblages is currently impossible, mainly because of the scarcity of human remains from Sima del Elefante. According to the different technological behaviours highlighted in the knapping strategies of the two contexts, the hypothesis of two different hominin migrations into Western Europe has been proposed and accepted by the scientific community. On the other hand, the richness of the sample from Gran Dolina provided crucial evidence regarding the origin of *H. antecessor* and, more globally, of the human dispersal in Europe after 1.0 Ma. *H. antecessor* distinguishes itself for its anatomical mosaicism, sharing similarities with Neandertals and modern humans, being cladistically "distant" from its African ancestors and the Dmanisi hominins, and showing comparable derived features with Middle and Late Pleistocene Eurasian populations (Dennell et al., 2011; Bermúdez de Castro and Martinón-Torres, 2013; Bermúdez de Castro et al., 2013; 2017b). That said, the idea of *H. antecessor* being the last common ancestor of both Neandertal and Sapiens lineages has been rejected from an anthropological, genetic, geographical and climatical perspective. However, it is generally acknowledged that *H. antecessor* and the last common ancestor belong to the same clade and, therefore, are very close from a genetic point of view. The most recent model (Dennell et al., 2011; MacDonald et al., 2012) proposed to explain such peculiarities builds on the idea of the existence of a Eurasian clade – originating from a Lower Pleistocene's Out of Africa seemingly at 1.8 Ma – which evolved locally and subsequently originated several waves of hominin's dispersal into Europe across the Lower and Middle Pleistocene. The European region's hostile environmental context further complicated the hominins' settlement, favouring the isolation of the populations over time and eventually leading to *in-loco* hybridisations of the first residents, thus explaining the substantial diversity observed in the European human fossil record during the Middle Pleistocene (e.g., Ceprano, Caune de l'Arago, Sima de los Huesos; Manzi, 2004; 2016; Manzi et al., 2011; Bermúdez de Castro et al., 2017a).

To sum up, during the Lower Pleistocene, Europe would represent the last part of a hypothetical journey of the human species, which originated in Africa and then moved towards Western Asia, where it was subject to a local evolution and spread afterwards into Europe through multiple dispersal events. In this scenario, the Levantine corridor, identified as a solid biodiversity hotspot and the geographical crossroads of Africa, Asia and, ultimately, Europe, would represent a route of continuous connection between the African and Asian region and *"a source of phylogenetic diversity, inducing speciation and reduced extinction rates"* (Bermúdez de Castro et al., 2017a, p. 28). The additional climatic similarities of these two regions, especially when compared to Europe, strengthen this connection, and the faunal evidence of the Lower Pleistocene aims for a scenario where Asiatic taxa – originated from Africa - gradually migrated into Europe. Ultimately, different authors have proposed and supported the genetic connection between Africa and Asia – and then between Asia and Europe - through the Levantine corridor during the Lower Pleistocene. A subsequent genetic flow from Asia to Europe would explain the similarities between these two regions and the divergences observed between the African and European taxa (*i.e., Homo* *antecessor*). Despite the remains of *H. antecessor* being dated shortly before the Middle Pleistocene boundary and the ones from Sima del Elefante, which do not allow for a reliable genetic attribution, it is plausible that *H. antecessor* entered Europe earlier than expected. On the other hand, the recent work by Margari and colleagues (2023) postulated that if the European and Eurasian region underwent a massive depopulation around 1.2 – 1.1 Ma, as the climatic data seem to suggest, the reoccupation of Europe could have been delayed until MIS25, or, most likely, after the end of the disruptive glacial stage 22. These data would match the chronology of the level TD6 of Gran Dolina, with *H. antecessor* being a more resilient species capable of thriving under the increasing intensity of glacial conditions but only entering later in Europe. Within the present state of the art, it seems more accepted by the scientific community that European peopling during the Lower Pleistocene happened discontinuously. The current analyses and data are helping to enrich this framework, and future works will be fundamental in clarifying these dynamics. The focus of the debate is, as pointed out in the works of Dennel (2011) and Margari (2023): how often was Europe uninhabited after hominins first entered it? And for how long?

1.1.4. The European lithic assemblage during the Lower Pleistocene

Now that the chronological, environmental, and anthropological context of the Lower Pleistocene has been defined, the mentioned sites' material culture and its behavioural implications should be considered to provide the global archaeological frame in which the European Lower Palaeolithic developed. Within the present state of the art, lithic artefacts represent the closest connection the archaeologists have to try grasping hominins' behaviours, including the concept and the evolution of behavioural complexity and the required cognitive abilities to produce stone tools. As the privileged markers of the Palaeolithic material culture, lithic artefacts have taken on tremendous informative potential over the years, even exceeding the "classic" technological boundary and often leading to a possible overestimation of the importance of the lithic technology itself in the understanding of hominins' lives (Sillitoe and Hardy, 2003; Stout, 2011). Aside from these more theoretical issues, it is undeniable that lithic artefacts grew into archaeological proxies to follow the steps of human evolution concerning tools' manufacture. On top of that, the development of disciplines such as use-wear or residues analysis - applied to lithic assemblages - together with the technological approach, allowed researchers to increase the degree of resolution within the investigation of the Palaeolithic's sites which would be otherwise lost, given the antiquity of the context mentioned above and the erosive and taphonomical processes that might occur.

Generally speaking, the European lithic assemblages of the Lower Pleistocene feature the exploitation of several lithologies (*i.e.,* different types of chert and limestone, basalt, quartzite) morphologically and qualitatively diversified and always locally collected (0 – 3 km of radius from the site). Though encompassing a substantial variability, seemingly matching an already diversified environmental and chronological context, the European lithic record of the Lower Pleistocene is characterised by some common traits. Cores are usually exploited according to the existing natural convexities through multiple debitage strategies ranging from unifacial to multifacial knapping without including a structured organisation of the knapping surfaces. The privileged technique is freehand percussion, even though the bipolar on anvil technique has witnessed a substantial increase in evidence during recent years, being frequently employed by the hominins throughout the Lower

Pleistocene (de Lombera-Hermida et al., 2016; Horta et al., 2022). Massive production of morphologically non-standardised flakes is the primary goal of the short-reduction sequences with an absence, or very low percentages, of retouched tools and sometimes including different morphotypes of pebble tools. Another often-mentioned aspect is the low number of lithic pieces recovered from the sites. This would not be a characterising aspect *per se* but is somewhat indicative of the Lower Pleistocene's type of contexts the archaeologists have to deal with. Aside from the incidence of secondary-origin deposits, where the number of lithic artefacts is affected by sedimentological and post-depositional dynamics and the recurrent taphonomical issues that may alter the nature of an archaeological site, Lower Pleistocene's contexts often comprise short-sized lithic corpus that diverges from the richer palimpsests which start to appear during the Middle Pleistocene. It has often been suggested that the cause behind these low numbers could be the effective scarcity of the human population that characterises this chronological frame. After all, it coincides with the sparse archaeological evidence we observed in the previous paragraphs and may be an accurate marker of the hominins' diffusion and status in Europe.

From a technological, methodological, and often cultural perspective, it is generally acknowledged to ascribe these lithic assemblages to the Olduvaian techno-complex, or Mode 1 industries, thus indicating – and often inducing - a similarity, on a technological and methodological basis, with the Lower Pleistocene African sites. Despite the frequent debates over terminologies that have always affected lithic technology, it is essential to emphasise how the methodological and cultural attribution of European sites to African industries should not be made too lightly, given the broad chronological context taken into consideration, not to mention the differences that characterise these two continents from a chronological, geographical, and anthropological perspective. For these reasons, several works have focused on the implications and usefulness of using these terms in relation to European contexts. In this work, we will refrain from using such terminologies and try to discuss this argument in a detailed way in the Materials and Methods chapter.

In the Orce's basin, the lithic industry from the sites of Fuente Nueva 3 and Barranco León represents only 5% of the archaeological material (with 95% being faunal remains) and has been accurately studied in the last decade (Moyano et al., 2011; Barsky et al., 2015a; 2015b). The exploited raw materials include chert and limestone obtained from local alluvial sources. The lithic corpus comprises small-sized flakes, choppers, heavy-duty tools (realised on limestone cobbles) and very few retouched pieces. The techniques used feature freehand percussion and bipolar on anvil. The analyses of the lithic assemblage highlighted that hominins selected and knapped raw materials according to specific functional and production goals (Barsky et al., 2015a; 2018). Chert was used to realise small-sized cutting-oriented flakes, while limestone was selected to obtain percussive tools and heavy-duty scrapers. Evidence for *in situ* recycling of some debitage products has been detected, while the analysis of the reduction sequences witnessed that hominins might have carried different knapping activities outside of the site and then transported already-worked blocks at the site (Barsky et al., 2015a; 2015b). According to the authors, these data provide insights into the degree of behavioural complexity displayed by the hominins gravitating in the Orce's basin, indicating a range of complex processes within the operative schemes (Moyano et al., 2011; Barsky et al., 2015b).

The lithic assemblage of Pirro Nord 13 roughly comprises 340 pieces between flakes, cores and debris recovered in a secondary position (Arzarello et al., 2015; Cheheb et al., 2019; Carpentieri and Arzarello, 2022). The artefacts were realised from local raw materials, consisting of high-quality chert pebbles and cobbles collected in riverbeds or slope deposits. The analysis of the reduction sequences revealed that, according to the selected morphologies, the smallest and rounder pebbles were knapped through centripetal debitage, while on larger volumes, a multifacial knapping was applied. The aim was the realisation of small-sized flakes, while the presence of retouching has been documented on four pieces (Cheheb et al., 2019). The use-wear analyses of flakes revealed mixed butchery-related actions resulting from contact with different animal tissues (Cheheb et al., 2019; Berruti and Arzarello, 2020). Although the primary use of freehand percussion has been assessed, pebbles could have been opened by bipolar on anvil technique to speed up the production process.

From Sima del Elefante, 110 lithic artefacts realised on chert, limestone and, in minor percentages, quartz have been recovered (Ollé et al., 2013a; Huguet et al., 2017; Terradillos-Bernal et al., 2022). The lithic corpus mainly consists of small-sized flakes with suitable cutting edges and a couple of cores exhibiting short reduction sequences. The presence of retouching has been detected on four flakes. The raw materials were collected near the sites and seemingly knapped outside and inside the cave. According to the most recent work (Terradillos-Bernal et al., 2022), hominins selected rounder blocks with sub-rounded edges and irregular quadrangular blocks detached from the walls and roof of the cave to be knapped through freehand percussion. It is essential to remark that the relevance of limestones industries (such as the ones from Barranco León, Fuente Nueva 3 or Sima del Elefante), formerly considered of lesser importance – even from a human behavioural perspective – due to their classification as a qualitatively inferior raw material, has been increasing over the years thanks to the improvements made in their identification within lithic assemblages, primarily through several experimental activities. These works enabled a broader view of the hominins' technical behaviour, highlighting an even greater diversification of the European evidence throughout the Lower Pleistocene.

The lithic assemblage from Vallparadìs counts more than 10,000 pieces featuring cores, flakes, retouched flakes, cobble tools, anvils, hammerstones and manuports, but of which 70% are mainly debris (Garcia et al., 2013b). Different raw materials were exploited, predominating quartz (80%), followed by chert (13%) and lydite (7%). Several products obtained from quartzite, limestone, sandstone, granite, hornfels and jasper were recovered, even if they represent roughly 1.5% of the whole assemblage. The raw materials were collected locally, being all present in the sedimentary matrix of the archaeological levels. Quartz, chert and lydite were used to realise small-sized flakes and retouched implements; sandstone blocks were exploited as anvils and for shaping choppers, while quartzite was used as percussive material. Extensive use of the bipolar on anvil technique (98 % of the cores, thus explaining the high number of debris) and freehand percussion (Sánchez-Yustos et al., 2017) have been used. A significantly high number of retouched flakes (529 pieces, *i.e.,* 5%) was also documented, comprising scrapers, denticulates, notches and beaks. Given the relative abundance of these pieces, they represent an essential technological aspect that differentiates the site of Vallparadìs from the other Lower Pleistocene contexts, being more similar to the lithic assemblages of the Middle Pleistocene (Martínez et al., 2010; Garcia et al., 2013b; Landeck and Garcia Garriga, 2016; Sánchez-Yustos et al., 2017).

Moving to Barranc de la Boella, the three localities (La Mina, El Forn and Pit 1) yielded a diversified lithic corpus of percussion cobbles, choppers, chopper-cores, cores, flakes and retouched flakes (denticulates and notches; Mosquera et al., 2016; Ollé et al., 2023). La Mina contains 80 lithic artefacts, El Forn 100 and Pit 1 125. The lithic artefacts indicate different activities performed at the sites, while the reduction sequences are generally short and straightforward. The assemblage from Pit 1 includes several refitting associated with the remains of a young adult of *Mammuthus meridionalis*, providing evidence for one of the oldest butchery sites in Europe (Mosquera et al., 2015). While the analyses of the lithic artefacts from the three sites are still in progress, the following raw materials gathered around the area have been identified: chert, schist, sandstone, quartz, porphyr, quartzite and granite. The discovery of two large cutting tools from El Forn and Pit 1 – a cleaver-like tool and a pick – led many authors to question whether these instruments could be an earlier attestation of the Acheulean techno-complex (Vallverdú et al., 2014; Martínez and Garcia Garriga, 2016; Mosquera et al., 2016; Ollé et al., 2023). The debate between a local development of this technology over the hypothesis of an African intrusion seems now polarised towards the former option (Moncel et al., 2022), even though a proper contextualisation of this context and the spread of the Acheulean over Europe will be made in the following chapter. Whichever the case, Barran de la Boella represents a crucial context for its lithic corpus and its chronology halfway in between the final Lower Pleistocene and the beginning of the Middle Pleistocene.

The lithic evidence from Atapuerca Gran Dolina Unit TD6 (and relative sub-units) consists of 1,046 pieces (Mosquera et al., 2018; Lombao et al., 2022a). Two main stages of human occupation have been identified: the oldest one (sub-unit TD6.3) seems to correspond to a short and brief hominin occupation of the cave, which gradually increases towards the top of the unit, the data from the occupation of TD6.2 and TD6.1 are richer and points to a prolonged and more intense occupation of the cave, seemingly by a larger hominin group. Despite this occupation distinction, the lithic assemblage characteristics are rather homogeneous (Mosquera et al., 2018; Lombao et al., 2022a). The hominins knapped five primary raw materials: chert, quartzite, sandstone, quartz and limestone, acquired no further than 3 km from the site. Chert is the most exploited raw material, given its abundance compared to the other types. Unit TD6.3 contains 84 lithic pieces, mainly pebbles used as percussive elements, some unretouched flakes, three cores and one denticulate. Freehand percussion and bipolar on-anvil techniques have been identified for this unit. The remaining lithic artefacts are stored in the upper unit of Gran Dolina, featuring more than 900 pieces and witnessing more complex and diversified reduction sequences, including a greater diversity of the exploited raw materials. According to Mosquera et al. (2018), chert was mainly selected to make small-sized flakes and retouched flakes, constituting the predominant raw material within the unit. The high number of cores indicates sustainable hominin presence at the site over time. Percussive activities were still practised, given the massive presence of quartzite pebbles (the hardest raw material at Atapuerca) with percussion marks. Cores were knapped through different debitage strategies, including unipolar (applied to all raw materials), multifacial orthogonal and centripetal (restricted to chert).

A connection between the knapping strategies and specific morphologies of the blocks – which seemingly dictated the operative schemes – was also detected (Mosquera et al., 2018). Related to this matter is the increased presence of centripetal chert cores and flakes obtained through this debitage. According to the authors, given the prolonged occupation of the site over time, the systematic hominins' adaptation to the natural volumes of the available raw materials may have led to habitual knapping behaviours, which could translate into a sort of methodological substratum.

High-quality, large-sized chert cores with little knapping throughout the site denote a degree of planning for the cave's occupation – notably in its duration - suggesting that hominins would require larger quantities of raw material over time, implying the existence of possible storage activities. This behaviour has been related to episodes of more frequent cannibalism. The bipolar on-anvil technique persists in the upper layers but is restricted to quartz cores. Retouched tools feature the presence of several morphotypes highlighting great variability: denticulates, notches, scrapers, beaks and pointed tools. The lithic assemblage of Gran Dolina TD6 presents archaic and derived features within the Lower Pleistocene's archaeological background. The recurrence of unipolar debitage – defined by Mosquera et al. as *"the use of a single flake-production method"* (2018, p. 41) – and diversification of the operative schemes (orthogonal and centripetal debitage; use of the bipolar on-anvil technique) without structured organisations were identified as the main "archaic" criteria.

On the other hand, diversification in the exploitation of raw materials, the increased rate of retouched tools, their diversity, and hints to systematic knapping behaviours have been defined as derived features, pointing to possible behavioural changes. Being closer to the Middle Pleistocene Transition and presenting the previously mentioned innovations, the authors speculated whether the lithic assemblage of TD6 and its technology might evolve into the Acheulean industry or could represent an incipient Acheulean complex. The relevance assumed by centripetal debitage and a systematic adaptation to the original raw materials' morphologies - which might lead to a better knowledge of the knapping process, translating into complete control of the knapped volumes and standardisation of the products – are considered by many authors as fundamental features for the development of the bifacial concept (Martínez and Garcia Garriga, 2016; Moncel and Ashton, 2018; Moncel et al., 2018d; Davis and Ashton, 2019).

At the site of Cà Belvedere di Montepoggiolo, another rich lithic assemblage was discovered comprising 1319 lithic objects, consisting of 1166 flakes and 153 cores (Peretto et al., 1998; Arzarello et al., 2016a; Carpentieri and Arzarello, 2022). The presence of 76 refits confirms the primary position of the deposit. The lithic assemblage was realised entirely on chert marine pebbles of high-quality collected in the marine deposits surrounding the site. The presence of limestone pebbles was also recorded and associated with their use as hammers. The chert pebbles exhibit two distinct morphologies: elongated and ovally shaped or smaller and rounded-shape. The hominins adapted to these morphologies through 1) unipolar-semitournant or multifacial exploitation (corresponding to longer reduction sequences) when larger and more oval volumes were available or 2) orthogonal/centripetal exploitation of one knapping surface on rounder morphologies (corresponding to shorter reduction sequence) after opening the pebbles through a split-fracture technique. These operative schemes produced longer convergent and elongated flakes or small-sized quadrangular flakes. Freehand percussion was the privileged technique for both debitage strategies. Significantly few retouched flakes have been recovered. Similar to the case of Atapuerca Gran Dolina at Montepoggiolo, the massive exploitation of identical morphologies through distinct knapping strategies might have produced systematic behaviours in the hominins, leading to the development of a possible methodological process. As proposed in a recent work, such behaviours *"when systematically and constantly applied, might eventually standardise the technical gestures, which generate greater awareness during the flaking activity. This being the case, technical expedients can become systemised choices assimilated within a steady mental scheme, thus* *expanding the possible methodological responses"* and, in a broader diachronic perspective, *"the process of subordination to morphological criteria can be gradually reversed, and the morphology itself becomes subordinated to the technical criteria for the production of predetermined products."* (Carpentieri and Arzarello, 2022, pp. 36–38).

Moving to the French lithic assemblages, at Le Vallonnet, 104 lithic pieces were discovered in the cave, associated with faunal remains (Michel et al., 2017; Cauche, 2022). The lithic corpus consists of pebbles used as percussion tools, roughly shaped pebbles, cores, flakes and retouched flakes. Hominins predominantly knapped limestone pebbles (72%) and, to a lesser extent, sandstone, quartzite, chert and quartz. Except for the chert, whose origin seems more than 7 km from the cave, the other lithologies were locally collected on the cave's massif. Shaped limestone pebbles are described as in between core and chopping tools, exhibiting few removals without a systematic organisation (Cauche, 2022). The retouched flakes are very few and exclusively obtained on chert. The reduction sequences were described as short, with most cores and chopping cores displaying a single removal. The few chert flakes and cores recovered document seemingly longer knapping processes, and it is interesting to note that this raw material was collected particularly far from the site. The identified techniques are freehand percussion and bipolar on-anvil.

At Bois-de-Riquet, despite the rich faunal assemblage uncovered (more than 2000 remains), only 23 lithic artefacts have been recovered, among which are 10 manuports (defined as unmodified basalt pebbles) and 13 debitage products (Bourguignon et al., 2016a; 2021). The only raw material the hominins exploited was basalt (volcanic rock), acquired in the site's proximity and constituting the archaeological deposit's sedimentary matrix. The researchers required a massive experimental program to properly distinguish the anthropogenic basalt artefacts from the naturally detached fragments. The hominins purposely carried the unmodified basalt pebbles to the site as the archaeological layer they have been found in (US2 C) is uniquely composed of angular basalt blocks, while their origin has been established as alluvial. These pebbles show similar morphological dimensions and density, thus suggesting a selective process at the place of acquisition by the hominins and are associated with a level where the evidence of fracture on fresh bone is relatively elevated. This evidence, along with the presence of crush marks on the extremities of the pebbles, led the authors to hypothesise their use as hammerstones. The 13 debitage products consist of 12 flakes and one core. One refitting between the core and one flake was documented. Flakes are of medium size (50 mm) and are characterised by a natural back opposed to a convex cutting edge. Freehand percussion has been suggested, even though the bipolar on-anvil technique should also be considered. In the end, the evidence from Bois-de-Riquet features the first basalt lithic assemblage in Europe. Exploiting this raw material by the hominins is relatively common in the Lower Pleistocene contexts from Africa and Eurasia, allowing some interesting future comparisons and contributing to the expansion of the European Palaeolithic variability (Barsky, 2009).

Pont de Lavaud provides one of the richest lithic assemblages in Europe, with around 8000 artefacts made exclusively on quartz pebbles and subangular vein quartz fragments of alluvial origin and locally collected, including 4000 broken pebbles (Despriée et al., 2010; 2018). According to the most recent works, 1321 lithic pieces have been identified and selected as anthropically modified (de Lombera-Hermida et al., 2016; Despriée et al., 2018). One of the most peculiar aspects of this site is the use of the bipolar on-anvil technique by the hominins as the primary knapping technique, followed by freehand percussion. Hominins' technique choice was affected by the morphological and petrographic characteristics of the quartz assemblage. A detailed study of the reduction sequences identified several knapping methods concerning each technique (de Lombera-Hermida et al., 2016; Despriée et al., 2018). Cores knapped by freehand percussion show three primary methods: unipolar-longitudinal - referred to by the author as Unipolar Longitudinal method, cf. SSDA (Forestier, 1993) – centripetal and orthogonal. Concerning the bipolar on-anvil technique, five different methods were identified according to the position of the pebble, the morphology of the knapped segment and the type of reduction sequence (for a detailed explanation, see de Lombera-Hermida et al., 2016). Flakes exhibit low morphological standardisation, and retouched flakes are only four. Reduction sequences are short, with cores that are never rotated or intensively exploited in what has been described as: *"no attempt to exercise volumetric control during knapping sequences"* (de Lombera-Hermida et al., 2016, p. 173). Despite this, authors also stated that at Pont de Lavaud: *"although complexity does not seem to be a characteristic of the core technology at the site, there are some trends in terms of pebble selection and knapping methods that reinforce the idea that the technological behaviours belong to a same concept"* (de Lombera-Hermida et al., 2016, p. 173).

At Lunery, two archaeological horizons (Unit 1 and Unit 2) have yielded lithic artefacts (Despriée et al., 2010; 2011; 2017; Duval et al., 2020). Unit 2 comprises several flakes realised through unidirectional debitage along some unifacial and bifacial cores. The artefacts are realised on local chert and rarely on oolithic silicified limestone. In Unit 3, more than 500 lithic objects have been recovered. Local chert and millstone represent the predominant raw materials. The short reduction sequences are characterised by parallel unidirectional removals producing elongated flakes. Two retouched flakes were documented from Unit 3, consisting of a *pointe déjetée* and a scraper.

From central Europe, the data from Untermassfeld represents the most crucial evidence for this region. Up to today, 256 lithic artefacts associated with faunal remains have been uncovered, including hammerstones, anvils, cobble tools, cores, flakes and retouched flakes (Garcia et al., 2013a; Landeck and Garcia Garriga, 2016). Local chert is the most exploited raw material, followed by minor silicified limestone and rhyolite percentages. Bipolar on-anvil is the primary technique adopted by hominins to produce, through short reduction sequences, morphologically non-standardised flakes with sharp edges. Freehand percussion's cores were knapped through different operative schemes, including centripetal debitage. The retouched flakes consist of notches, scrapers and denticulates and the fragment of a specimen exhibiting bifacial retouching (Garcia et al., 2013a). The percentage of retouched tools found at Untermassfeld (11.3%) is significantly higher than other penecontemporaneous sites, even though the low number of recovered artefacts does not allow for further implications concerning the possible presence of innovative traits.

Lastly is the lithic corpus from Happisburgh 3, composed of 78 high-quality chert artefacts, including cores, flakes and retouched flakes (Parfitt et al., 2010). The assemblage is characterised by the predominance of large flakes (up to 145 mm) realised with freehand percussion and exhibiting a cortical back opposed to a cutting edge. The retouched flakes toolkit features the presence of notches and denticulates. The high ratio of retouched flakes has led the authors to postulate that the lithic assemblage of Happisburgh 3 might be the outcome of an accurate selection by the hominins, who seemingly brought the end products into the site, knapping them elsewhere. The occurrence of flakes and tools along different levels might be a sign of repeated visits to the site. Ongoing excavations will seemingly enlarge the lithic assemblage of Happisburgh 3, which, so far, represents the northernmost human occupation of the world during the Lower Pleistocene. The associated human footprints discovered contributed to strengthening the consistency of human occupation of Britain during the Lower Pleistocene, shedding light on the behavioural implications that allowed hominins to arrive and endure in such harsh environments (Parfitt et al., 2010; Ashton et al., 2014).

1.2. The Middle Pleistocene Transition

The beginning of the Middle Pleistocene has been globally set to approximately 773 ka (MIS 19), coinciding with the inversion of the earth's magnetic field (*i.e.*, shift from the Matuyama to the Brunhes chron; Cohen and Gibbard, 2019). This chronological boundary is of fundamental importance for the environmental and climatic changes witnessed on a global scale. As mentioned in the previous paragraphs, such changes did not occur abruptly but over a significant amount of time and with different intensities according to the geographical areas. Therefore, the timeframe spanning from 1.2 Ma – during which the significant first climatic oscillations were documented – to 0.8 Ma (or 0.4 in its broadest definition) has been defined as a transitional phase between the Lower and Middle Pleistocene, often referred to as the Early Middle Pleistocene Revolution (EMPR) or Early Middle Pleistocene Transition (EMPT; Head and Gibbard, 2005; Manzi et al., 2011; Palombo, 2016; Moncel et al., 2018c).

Approaching the range of climatic, environmental, floristic, faunal and anthropic changes that this period encompasses should be done by first explaining what is considered the triggering factor: the change in the obliquity of the Earth’s axis rotation. Before moving into any detail, the change in the obliquity produced a gradual increase in the duration of the glacial/interglacial cycles, which, prior to MIS 36, had a rhythmicity of about 41 ka and then progressively ended in having a duration close to 100 ka (also meaning longer and drier glacial periods). At the base of these results is the work of Milankovitch, who hypothesised that the major factors affecting Earth’s climate cyclicity were the variations and alternations of three orbital movements influencing Earth’s position relative to the Sun. These parameters include obliquity, eccentricity and precession.

The angle of rotation of Earth’s axis in respect to its orbital plane as it travels around the sun is called obliquity and is why Earth has seasons. The greater the value of this angle (oscillating between 22° and 25°), the more accentuated the seasons are. Changes in the obliquity occur with a rhythmicity of about 41 ka. The shape in the Earth’s orbit around the Sun is called eccentricity, and since it is not perfectly circular due to other planets’ gravitational forces, eccentricity measures how much the shape of the Earth’s orbit diverges from a perfect circle. These variations in the orbit affect the distance between the Earth and the Sun and are one of the main factors influencing the seasons’ length. The eccentricity regulates itself through 96, 125 and 413 ka cycles. Lastly, precession is the oscillations in the Earth’s axis rotation direction. This parameter is controlled by the Sun and the Moon's gravitational forces, and precession changes directly control the seasonal contrasts between the Earth’s hemispheres.

The combined effect of these three cyclical orbital movements, known today as “Milankovitch Cycles”, directly affect the quantity and position of solar radiation (*i.e.,* insolation) reaching the

Earth, therefore being responsible for climate's oscillations and intensity. Despite a great debate over the real influence of orbital forcing on climate cycles, the effects on the Earth's flora, fauna and human evolution have been widely documented. Before describing them, it should be mentioned that the EMPR changes, despite acting on a global scale, exhibit local geographical and chronological differences. For instance, it has been verified that the EMPR effects on the Mediterranean basin were less pronounced than in Central and Northern Europe. Therefore, an approach including a global and local scale of what happened in Europe during this timeframe is essential to contextualise the archaeological evidence properly (Messager et al., 2011; Orain et al., 2013; Palombo, 2014; Combourieu-Nebout et al., 2015; Moncel et al., 2018c).

The change in the amplitude of the glacial/interglacial intervals from 41 ka to 100 ka has been first detected around 1.2 Ma (MIS 36), leading to significant environmental changes. The increased duration of glacial periods led to the aridification of many areas, expanding open landscapes, such as savannahs and grasslands, and reducing more wooded environments. The subsequent expansion of continental ice caps, accumulating large amounts of water, lowered the sea level, thus generating prolonged periods of droughts and opening land areas previously covered by water. This dual process – aridification and ice caps expansion – led to a depopulation of high-latitude territories in Central and Northern Europe (freezing winters, reduced growth season, loss of arboreal cover, decreasing the size of territories over an expansion of the ice sheets) and of tropical and dry areas such as Sub-Saharan African, Northern Africa, the Arabian peninsula and Eurasia (advance of desert areas, a massive decrease of water-dominated ecosystems, progressive shallowing), producing mass extinction events but also allowing the opening of formerly inaccessible migratory routes for large-mammals communities and human groups that needed to escape hostile environments. All these climatic perturbations, where a trend of "*increasing opening-up of the landscape*" (Palombo, 2014, p. 18) is generally recognised, also led to an environmental fragmentation (*i.e.,* regional diversification) with the development of several ecological niches further pushing to specialisation and competition within the micro and macro mammal communities (Masini and Sala, 2007; Sala and Masini, 2007; Bertini et al., 2010; Palombo, 2016; Ashton, 2017).

According to several authors, these abrupt modifications forced species (animals and humans) to move and adapt rapidly to changing environments, thus enhancing the evolution, selection and speciation processes (Muttoni et al., 2010; 2018; Stewart and Stringer, 2012; Maslin et al., 2014; Timmermann and Friedrich, 2016; Timmermann et al., 2022). These processes, considered to be fundamental for the earliest human migrations outside of Africa with *Homo erectus* that shifted from *"regional dweller to early global wanderer"* (Timmermann et al., 2022, p. 6), have also been proposed for *Homo heidelbergensis* (the human species that is supposed to colonise Europe during the Middle Pleistocene), which, in order to face harsher climatic conditions, should have acquired new adaptation skills, *"strengthening their ability to further expand their geographical range"* (Timmermann et al., 2022, p. 6). On top of that, the structural changes that large mammal communities undergo during the EMPT resulted in an enlarged prey spectrum for the hominins, further facilitating their dispersal in a pattern of predators' dependency on the migration of their prey. The development of ecological niches and the increased habitat heterogeneity allowed predators to diversify in specific niches, reducing the inter-specific competition and thus offering hominins several opportunities to fill in the gaps left in a more flexible environment with a broader spectrum of accessible resources and reduced species competition (Dennell et al., 2011; Manzi et al., 2011; Rodríguez et al., 2012; Palombo, 2014; Saladié et al., 2014; Rodríguez-Gómez et al., 2016; 2017; Palmqvist et al., 2023).

The impact of the EMPT on the floral assemblage has also been relevant (Combourieu-Nebout et al., 2015; Magri et al., 2017). During the Lower Pleistocene, a progressive pattern of impoverishment characterised by decreased arboreal vegetation and increased herbaceous and steppe environment, simultaneously with the amplitude of climatic cycles, was documented in the Mediterranean region and Southern France. The 40 ka cyclicity established at the transition between the Pliocene and the Lower Pleistocene already drove an alternation of forest and steppe vegetation mirroring the glacial/interglacial intervals and leading to a massive reduction of the Pliocene sub-tropical forests, favouring oak-dominated vegetations and conifer forests. The subsequent shift to a 100 ka periodicity affected the forested taxa with an additional spread of steppe-like landscapes. Climatic data from several European regions indicates a global decline in winter temperatures and annual precipitation. A massive decline in water-dominated environments such as flooded ground habitats, damp woodlands, and swamps also led to more pronounced droughts during the warm seasons, particularly in the Mediterranean. Despite a general impoverishment trend globally recorded, regional trends increased during the EMPT, producing a mosaic of geographic and climatic situations that often prevented identifying clear dominant vegetation types and turnover events, if not on a local scale (Messager et al., 2011; Combourieu-Nebout et al., 2015; Magri et al., 2017; Moncel et al., 2018c).

Regarding the palaeontological record, a progressive transition in the European faunal communities was witnessed by the arrival of new taxa - seemingly migrated from the Eurasian region – typical of open environments (grazers, large herbivores such as bovids, caprines inhabiting rocky environments) along reductions of the biomass of forested dwellers species (Palombo, 2014). To describe this phenomenon of faunal renovation associated with the climatic transition of the EMPT, the term Epivillafranchian was proposed to cover the chronological frame between 1.2 and 0.9 Ma (also referred to as late Early Pleistocene), embodying the passage from the faunal units of the Villafranchian to the Galerian ones (Sardella et al., 2006; 2018; Muttoni et al., 2010; 2018; Kahlke et al., 2011; Palombo, 2014; 2016; Iannucci et al., 2021). Such chronological frame coincides with the most intense cooling period and increased aridity recorded between the Jaramillo subchron (1.07 Ma ca.) and MIS 22 (0.87 Ma), which is considered, together with MIS 16 and 12, the harshest glacial event of the EMPT.

According to Kahlke et al. (2011) and Palombo (2014), the late Early Pleistocene (1.2 – 0.9 Ma), being a phase of less uniform climate cycles – during which the 100 ka periodicity was not yet established – is associated with the most intense migration of mammal communities, along with an increase in the ecological varieties of the European habitats, and persistence of relatively mild and humid conditions, especially in the Mediterranean region. For instance, MIS 31 (between 1.1 and 1.07) is considered an exceptionally long period with warm conditions, marked by notable faunal renewal (Palombo, 2014). These conditions would seemingly favour human occupation over Europe, as witnessed in Barranco León, Sima del Elefante, Pont de Lavaud, Montepoggiolo, Le Vallonnet, Vallparadìs, Untermassfeld and Happisburgh 3. On the other hand, starting from 0.9 Ma (MIS 24 and 22), the 100 ka stability of the periodicity produced longer and stabler climatic periods but also a progressive deterioration of the temperatures, increasing aridity, greater seasonality contrast, drastic decrease in forest vegetation, and more open-landscape specialised mammal communities with solid sub-regional diversification (Manzi et al., 2011; Palombo, 2014; Magri et al., 2017). This phase would coincide with a break in the human occupation all over Europe and a substantial period of isolation for both faunal and human communities.

Among the new faunal species that homogenously characterise the European faunal assemblage starting from 1.2, Ma is *Cervus elaphus* (introduced from the Asian region) and two carnivores of African origin, *Panthera pardus* (typical of forested and savannah/grassland landscape) and *Crocuta crocuta* (inhabiting mainly open environments). The arrivals of *Megaloceros savini* from Spain and/or France and *"Hemibos" galerianus* from Asia in Italy have been reported as significant of this climatic transition. Seemingly, the several remains of the *Palaeoloxodon* (= *Mammuthus*) representatives should indicate a faunal dispersal from the Levantine region. At the same time, the diffusion from Southern Europe towards the French basin of *Gulo, Mammuthus trogontherii* and *Stephanorhinus kirchbergensis* (corresponding to open and forest inhabitants) suggest a change in the ecosystems, with several taxa enlarging their territorial range (Palombo, 2014; 2016).

A subsequent phase of faunal renewal over Western Europe – again mirroring the vegetation changes – seems to characterise the final portion of the EMPT after the end of the glacial stage 16, around 600 ka, concluding the transition to the Galerian faunal assemblage of the Middle Pleistocene and following the moment of climatic and archaeological break begun during MIS 22 (Manzi, 2004; Manzi et al., 2011; Palombo, 2014). This renewal is often associated with the dispersal of *Homo heidelbergensis*. The progressive deterioration of the climate witnessed at the end of the Lower Pleistocene persists in this chronological phase, with a global decline of the most thermophilous arboreal taxa and an even more pronounced habitat fragmentation (Combourieu-Nebout et al., 2015; Magri et al., 2017). The diffusion of taxa typical of open landscapes, such as *Bos primigenius, Panthera leo fossilis,* and *Equus mosbachensis,* is significant. By contrast, the presence of *Hippopotamus amphibius* only in Italy and *Bison priscus* and *Rangifer tarandus* in France perfectly portrays the regionalisation begun at the end of the Epivillafranchian. The Italian peninsula characterises itself as the *refugial area* for more warm and humid-related taxa, while Central Europe started to witness the sporadic arrival and persistence of cold-related and steppe-dominant taxa (Palombo, 2014).

Before concluding this section, Palombo (2014) argues that although the palaeontological evidence from Europe suggests that during the Lower and Middle Pleistocene, large mammals frequently reacted to climate stimuli by *"expanding, contracting, shifting or creeping their range. [...] Pleistocene mammals did not generally move in multi-species waves of dispersal, rather each species changed its range depending on the suitability of environmental conditions in respect to its own environmental tolerances and ecological flexibility"* (Palombo, 2014, p. 17). For these reasons, the triggering factors driving faunal dispersal may have differed geographically from species to species, but also, most importantly, chronologically, producing asynchronicity in the first arrivals and/or disappearances. This aspect is essential when analysing such chronological frames as the presence or absence of specific taxa are now commonly used as biochronological markers to date archaeological deposits.

1.2.1. The archaeological framework during the Middle Pleistocene Transition

The available data on human occupation from the Middle Pleistocene reflects the environmental discontinuity and fragmentation witnessed during the Middle Pleistocene Revolution, alternating expansion and contraction patterns and mirroring the increased climatic oscillations trend (McNabb, 2005; Manzi et al., 2011; Palombo, 2014; 2016; Stringer, 2016; Magri et al., 2017; Ashton and Davis, 2021; Blain et al., 2021; Moncel et al., 2021b; 2022; Timmermann et al., 2022). Many authors have often used the "ebb and flow" or "source and sink" models to describe the human occupation during and after the transition between the Lower and Middle Pleistocene (Dennell, 2003; Manzi, 2004; Parfitt et al., 2010; Dennell et al., 2011; Bermúdez de Castro and Martinón-Torres, 2013; Bermúdez de Castro et al., 2013). The significant environmental discontinuity driven by the climatic instability led human groups to constantly expand (*i.e.,* flow) over new, formerly inaccessible territories (*i.e.* sink areas) and then retreat (*i.e.,* ebb) to refugial areas (*i.e.,* source areas; warm spots as the Mediterranean). These source areas would witness a semi-continuous occupation over time, favouring the development of localised culture and group cohesion while also providing for the repopulation of sink areas (defined as a *cul-de-sac* and often subjected to local extinction events), thus generating an increased knowledge exchange and gene flow events (García-Medrano et al., 2015; 2019; Ashton, 2017; Davis and Ashton, 2019; Ashton and Davis, 2021).

That being said, a gradual increase in the archaeological evidence – from a geographical and chronological perspective – is documented by a significant number of contexts, especially when approaching MIS 11 (*i.e.,* the beginning of the Holsteinian period; 400 ka), which represents the transition to the Middle Palaeolithic, being a crucial cultural and evolutive turnover for entire Europe (Manzi, 2016; Moncel and Schreve, 2016; Moncel et al., 2016b; 2020c; Connet et al., 2020; Ashton and Davis, 2021; Blain et al., 2021). The reasons behind this increase are what make the Middle Pleistocene a critical phase for human evolution, technology and culture. According to many authors, the development of innovative behaviours, including more complex land-use patterns, raw materials management, the spread of handaxe technology, bone and wooden tool manufacturing, more efficient hunting techniques, larger group size, better cooperation, use of fire, and the rise of regional cultural aspects, constitutes the key aspects (Stout, 2011; Vaesen and Houkes, 2017; Davis and Ashton, 2019; Moncel et al., 2021a; 2021c). Before presenting the most important sites, it should be noted that since the chronological boundaries of this work lie at the transition between the Lower and Middle Pleistocene, evaluating the possible innovations detected within the material culture analysis during this time frame, only the first part of the Middle Pleistocene before the onset of the Middle Palaeolithic transition (MIS 11) will be addressed.

The archaeological evidence in Western Europe during the Middle Pleistocene features a gap of around 200 ka between the interglacial MIS 21 and MIS 17, with the first contexts chronologically dated to around 700 ka. The reasons behind this gap, aside from the loss of evidence due to possible erosive and taphonomic processes, seemingly lie within the glacial intervals 22, 20 and 18, which were particularly harsh and could have acted as an environmental barrier for human groups. In a recently published work focused on the demographic estimation of the Late Lower Pleistocene African and non-African population through the analyses of genetic samples, it was discovered that a massive bottleneck event took place during the final stages of the Lower Pleistocene, shortly before the transition with the Middle Pleistocene, and severely affecting our ancestors (Hu et al., 2023). According to the available data, this bottleneck occurred between 930 and 813 ka, lasting for about 117 ka, causing the extinction of 98.7% of the human population. The causes behind this disruptive event have been connected with the severe climatic transition brought about by the Middle Pleistocene Revolution. The existence of this ancient bottleneck might explain, on one side, the scarcity of human remains in Africa, Europe and Eurasia between 950 and 650 ka, but also, on the other side, the archaeological gap witnessed in Europe (Hu et al., 2023).

The Middle Pleistocene archaeological evidence from Europe features two main groups of sites according to their chronology. The first group (700 – 650 ka) is related to the interstadial 17 and comprises few sites, while the second group takes place after the end of the glacial stage 16 (650 - 620 ka) – considered as one of the coldest during the EMPT – and covers MIS 15 and 13 (with MIS 14 being relatively warm) showing an abrupt increase in the archaeological evidence throughout Europe. Some areas, such as the Italian and Iberian peninsulas, provide evidence for prolonged human occupation even during the glacial events – milder in these regions - and have therefore considered refugial areas. The subsequent glacial stage 12 represents a major prolonged climatic crisis for the whole continent, coinciding with gaps and hiatuses in many archaeological sequences and abandonments of high-latitude territories. During these disruptive events, the innovative behaviours previously mentioned might have been locally developed – or externally introduced - by the hominins as an adaptive response to external environmental pressures. It is generally acknowledged that the Acheulean techno-complex is the major cultural and behavioural break that took place in Europe during the Early Middle Pleistocene (García-Medrano et al., 2015; Moncel et al., 2015; 2020a; 2020e; Davis and Ashton, 2019; Key, 2023).

1.2.2. The Acheulean and the European perspective

The Acheulean is considered the first and longest-lived cultural complex of prehistory and is associated with hominins' acquisition of new impactful cognitive abilities, establishing a crucial evolutionary shift before and after its diffusion (Diez-Martín et al., 2015; Moncel and Schreve, 2016). The Acheulean is universally related to the appearance of bifaces – becoming its archaeological marker – consisting of lithic tools symmetrically worked on two faces from which the term “biface” was initially created by Vayson de Pradenne in 1920 and then globally adopted. The term “Acheulean” comes from the French Palaeolithic site of Saint Acheul, located in the Somme region near Amiens, where several bifacial tools and other lithic pieces were discovered in the XIXth century. The head of the excavations at Saint Acheul, Gabriel de Mortillet, hypothesised a chronological classification of the Palaeolithic industry, proposing four cultural and chronological periods: the Chelléen (later renamed Abbevillien), the Mousterian, the Solutrean, and the Magdalenian. The term Acheulean was subsequently introduced to describe the transition between the Chelléen (absence of bifaces) and the Mousterian (Middle Palaeolithic, Levallois method), characterised by the production of bifacial tools, and has therefore used ever since to describe industries featuring these artefacts in Africa, Europe and Asia.

The origin of this cultural complex took place in Eastern Africa, where a substantial transition from the Mode 1 (*i.e.,* Oldowan) industries, characterised by the production of choppers, chopping tools and flake, to Mode 2 industries (*i.e.,* Acheulean), featuring the realisation of handaxes, occurred

(Clark, 1964; Clark and Kleindienst, 1974; Carbonell et al., 2009). Within the present state of the art, the earliest evidence of the Acheulean is in the African site of Kokiselei 4 (Nachukui formation, West Turkana, Kenya), dated to 1.76 Ma (Duke et al., 2021). Kokiselei 4 comprise Mode 1 and Mode 2 industries, suggesting that these techno-complexes are not mutually exclusive – or the outcome of a single evolving cultural lineage - and that the Acheulean possibly originated elsewhere and was then imported to the site (Duke et al., 2021). Examples of transitional industries between Mode 1 and Mode 2 have been proposed for the site of Olorgesailie (Kenya), where instruments exhibiting partial bifacial faconnage have been found (Potts et al., 1999).

The technological and evolutionary implications represented by the appearance of bifaces have always been considered ground-breaking. Bifaces are realised through predetermined and codified gestures that imply the presence of a solid mental scheme beneath them, capable of subordinating the morphology of the raw materials to a predefined object even before its knapping. The concept of symmetry developed in bifaces has also been the object of numerous studies as it was previously unseen in tool manufacture and was, therefore, associated with increased behavioural capabilities of the hominins. Several factors have been proposed as triggering for bifaces' symmetry: functional reasons, development of perception and aesthetics skills, and the possibility of passing the knowledge in their realisation to future generations (presence of human bonding) are considered the most discriminating. According to the most recent data, a direct association between bifaces and *Homo* was witnessed in the Ethiopian sites of Gombore Iγ (1.4 Ma) and Gombore Iδ (1.3), where Mode 2 artefacts and *Homo erectus/ergaster* remains have been found (Mussi et al., 2021). A global consensus exists over considering *Homo erectus* as the maker of the first Acheulean techno-complex. Despite this, the African continent during 1.8 Ma was inhabited by different species of *Australopithecus* (*A. boisei, A. aethiopicus, A. garhi, A. africanus*) and *Homo* (*H. rudolfensis, H. habilis, H. erectus*).

The evolution and mode of dispersal of the Acheulean are also the objects of great debates from the scientific community. After developing over the African continent, it is generally acknowledged that the Acheulean subsequently spread in Asia and Europe over a million years, considered as a single unified cultural tradition (Moncel et al., 2018d; Ashton and Davis, 2021; Key, 2023). Evidence for bifacial industries outside Africa has been found in the Levantine area at the site of Ubeidiya (Israel), dated to 1.5 Ma, a region that has long been considered crucial for the hominin dispersal outside Africa during the Lower and Middle Pleistocene (Bar-Yosef, 1994; Moncel et al., 2018b; 2018a; 2018d). However, the earliest evidence of bifaces over the European region occurs almost a million years later than in Africa, dated between the end of the Lower and the beginning of the Middle Pleistocene. Following these lines of thought, several works speculated that, given the considerable chronological frame during which this culture spread, cultural convergence could be responsible for the independent presence of bifacial industries in different portions of Asia and Europe. Key et al. (2023) argue that the lack of temporal cohesion within the Acheulean may represent the actual absence of cultural information that otherwise would be needed to continuously transmit this type of potential (Stout, 2011; Pope et al., 2018; Davis and Ashton, 2019).

This argument is tightly connected with the current European evidence (Moncel and Schreve, 2016). The earliest presence of bifaces in Europe was placed during the end of the Lower Pleistocene at the Spanish site of Barranc de La Boella (1.0 – 0.9 Ma) and the French site of Bois de Riquet (US4, 0.8 Ma). In these sites, crudely made bifacial tools were discovered (Bourguignon et al., 2016b; Ollé et al., 2023). Then, a gap of around 200 ka exists before the simultaneous appearance of more elaborated bifacial industries in the sites of La Noira (stratum a, 700 ka), Moulin Quignon (650-670 ka) and Notarchirico (680 ka) during MIS 17-16 (Moncel et al., 2016a; 2020e; Antoine et al., 2019). From this chronological phase onward, a progressive increase of Acheulean industries over Europe can be witnessed (600 – 400 ka) along with sites bearing the absence of such tools (core-and-flake assemblages), portraying a significantly diversified archaeological scenario (Barsky and de Lumley, 2010; Barsky, 2013; Stout et al., 2014; Gallotti and Peretto, 2015; Moncel and Ashton, 2018; Moncel et al., 2018d). Questions regarding whether the evidence from La Boella and Bois de Riquet might be a local independent evolution from Lower Pleistocene European industries have been raised and compared to an allochthonous introduction – seemingly from the African or Eurasian region – of ideas and human groups carrying innovative behavioural capabilities (Moncel et al., 2022; Key, 2023; Ollé et al., 2023). The massive climatic instability characterising the transition between the Lower and the Middle Pleistocene is at the centre of this delicate matter. The dispersal events caused by the environmental crisis might have introduced new species and technologies over the European regions through multiple waves of migrations, producing an evolutionary turnover that was initially sporadic (La Boella, Bois de Riquet) and then gradually more frequent (abrupt spread of bifacial tools in France and Italy around 650-700 ka). On the other hand, the prolonged glacial periods established by the change of periodicity might have caused isolation and local evolution (both genetic and technological) of human groups retreated to warmer spots (*i.e., the* Mediterranean basin), thus inducing the development of behavioural adaptation (cultural and evolutional convergence) (Ollé et al., 2013a; Moncel et al., 2021a; Rineau et al., 2022).

An additional aspect of this matter is what precisely the notion of "Acheulean" – and more, in general, the notion of culture – implies (Baena et al., 2010; Stout, 2011; Rocca, 2013; Moncel et al., 2015; 2020d; Vaesen and Houkes, 2017; Davis and Ashton, 2019; Stout et al., 2019; Ashton and Davis, 2021). The classic Acheulean paradigm features bifacial tools as discriminating proxies of its presence (or absence). The European archaeological context of the Early Middle Pleistocene comprises sites with bifaces and sites without bifaces, producing a dichotomy between Acheulean sites and non-Acheulean sites (often described as Mode 1 industries). The recent re-contextualisation of important Lower Palaeolithic sites showing the absence of bifaces, such as Isernia La Pineta, Pakefield, Gran Dolina TD6, Ficoncella, and Korolevo, has revealed that significant innovation within lithic industries – increased frequency of retouched flakes and centripetal debitage, development of discoidal reduction sequences, structured and planned management of the raw materials – also detected on bifaces bearing contexts, took place (Parfitt et al., 2005; Koulakovska et al., 2010; Gallotti and Peretto, 2015; Aureli et al., 2016; Rocca et al., 2016; Lombao et al., 2022a; Carpentieri et al., 2023a). This produced a gradual shift from "the presence of bifaces as exclusive markers of the Acheulean" paradigm to a package of diversified behavioural innovations falling under the umbrella of the Acheulean culture. Along this line of thought, the term Acheulean itself has been considered obsolete, leading several authors to propose using the plural version "Acheuleans" (Rocca et al., 2016; Gallotti and Mussi, 2017; Moncel, 2017; Arzarello and Moncel, 2021; Moncel et al., 2021a).

To conclude, it is undeniable that a cognitive shift during the transition between the Lower and the Middle Pleistocene took place over Europe in different times and modalities. It is generally agreed that such a shift goes under the name of the first cultural complex of the Palaeolithic, Acheulean. The sites with or without bifaces prove that hominins improved their ability to adapt to more hostiles and changing environments. However, which *Homo* species lies behind these revolutionary changes witnessed in Europe?

1.2.3. The palaeoanthropological context of the Middle Pleistocene

The human remains associated with the European Middle Pleistocene (700 – 250 ka) are ascribed to *Homo heidelbergensis*, which may have originated in Africa and spread over Europe after the end of the Lower Pleistocene (Stewart and Stringer, 2012; Stringer, 2012; Manzi, 2016; Profico et al., 2016). Despite exhibiting a huge morphological variability (leading to the proposal of several subspecies), the remains of *Homo heidelbergensis* show a larger cranial volume compared to *Homo antecessor* and are considered the ancestors of the Neanderthal and Sapiens lineages. *Homo heidelbergensis* is considered the carrier of the aforementioned behavioural innovations, including the capability of producing bifaces and the behavioural plasticity to endure in colder climates. This species was first identified in 1907 at the site of Mauer, near the village of Heidelberg (Western Germany), where a human mandible was found in association with several faunal remains attributed to the Galerian or Cromerian period (*i.e.,* Early Middle Pleistocene). Otto Schoetensack, in charge of the excavation at Mauer, noted unseen mosaicism of primitive and derived features on the mandible from Mauer and decided to define a new species in 1908: *Homo heidelbergensis*. The mandible has been recently dated to 609 ± 40 ka through the combination of ESR-U/Th techniques, corresponding to the glacial stage 16 (Wagner et al., 2010), and is nowadays the holotype for this species.

The number of European sites which yielded human remains attributed to this species is relatively high, with contexts located in Italy (Ceprano, Saccopastore, Notarchirico, Isernia La Pineta, Visogliano), Spain (Atapuerca Sima de los Huesos), France (Caune de l'Arago), England (Swanscombe), Germain (Mauer, Bilzingsleben, Steinheim), and Greece (Petralona), and spanning between 600 and 200 ka (Fig. 1.3). The record from Africa (Bodo, Kabwe, Elandsfontein, Florisbad, Ngaloba, Omo Kibish II, Eliye Springs, Djebel Irhoud) and Asia (Narmada, Dali, and Jinniushan) is also rich with *Homo heidelbergensis* displaying substantial similarities with many taxa chronologically close to the emergence of *Homo sapiens* (Manzi, 2016). The human fossil samples comprise a significant cranial variability, and various hypotheses have been proposed to explain this species' origin, diffusion and diversification. Manzi (2016) observes that the African hominin record from the beginning of the Middle Pleistocene is distinct from the late Lower Pleistocene individuals (*i.e., Homo ergaster, Homo erectus, Homo antecessor*), suggesting that a taxonomic and phylogenic discontinuity occurred during the transition with the Middle Pleistocene. The existence of the massive bottleneck between 930 and 813 ka led the authors to identify this event as the possible taxonomic and phylogenic discontinuity phenomenon (Hu et al., 2023). The genetic analyses performed by Hu et al. (2023) and by Poszewiecka et al. (2022) revealed that two ancestral chromosomes fused to form chromosome 2 in humans around 900 to 740 ka, in coincidence with the bottleneck event, further enhancing the presence of an intense speciation event during this timeframe. Additionally, a "rapid" population recovery was documented after 813 ka, seemingly suggesting the presence of several behavioural innovations, among which the use of controlled fire – documented in the site of Gesher Benot Ya'aqov and dated to about 790 ka (Zohar et al., 2022) – is considered as one of the most relevant for this population recovery (Hu et al., 2023).

After 780 ka, many remains of the same species (*i.e. Homo heidelbergensis*) are distributed over a broad geographical area, seemingly originating from the African continent. The considerable amount of variability displayed by the cranial morphologies suggests that a subsequent regionalisation of different populations of *Homo heidelbergensis* took place locally, recalling the phenomenon of “isolation by distance” (Manzi, 2016). This process was seemingly “favoured” by the prolonged climatic instability during the MPR (especially during its harsher phase between 800 and 400 ka), which may have led to the progressive genetic selection of specific morphological and/or cognitive traits as well as to the extinction of other populations. The significant phenotypic variations observed on a local and global scale represent the starting point for the speciations of *Homo neanderthalensis* in Europe and *Homo sapiens* in Africa, with which *Homo heidelbergensis* share significant morphological similarities.

Manzi (2016) proposed four sub-species that should partially express the geographical variability of *Homo heidelbergensis* but also its genetical link with subsequent *Homo* species: *Homo heidelbergensis heidelbergensis* (exhibiting the most archaic traits, and it is chronologically placed to 600-500 ka), *Homo heidelbergensis daliensis* (referred to the Asian non-*erectus* specimens, representing a possible link with the Denisova population), *Homo heidelbergensis rhodesiensis* (corresponding to the Middle Pleistocene African specimens preceding *Homo sapiens,* but also including those referred to as “archaic *Homo sapiens*”), and *Homo heidelbergensis steinhemensis* (the European lineage of *H. heidelbergensis* that will lead to the Neanderthals).

Lastly, the modalities of the arrival of this species over Europe go hand in hand with the faunal dispersal theories during the Middle Pleistocene Transition, favouring the arrival from Eurasia rather than directly from Africa (McNabb, 2005; Muttoni et al., 2010; 2018; Manzi et al., 2011; Abbate and Sagri, 2012; Palombo, 2014; 2016; Timmermann and Friedrich, 2016; Scardia et al., 2019). The most valid hypotheses currently support a sporadic and gradual arrival of *Homo heidelbergensis* from the East through Central Europe. The data from contexts dated to around 500 ka in this region is increasing (Doronichev and Golovanova, 2010; Koulakovska et al., 2010; Rocca, 2013; 2016; Rocca et al., 2016; Golovanova and Doronichev, 2017). Furthermore, the 700 – 650 ka cluster of sites from Northern France (La Noira, Moulin Quignon) may indicate an earlier arrival through this passage. From this perspective, the absence of bifaces – seemingly “brought” by *H. heidelbergensis* groups – within East, Central Europe and Western Eurasia contexts has led some scholars to consider this region aside from the migratory routes for these human groups (Doronichev and Golovanova, 2010; Golovanova and Doronichev, 2017; Burdukiewicz, 2021). An out-of-Africa migration, following the Nile’s course and the Levantine corridor, is also often proposed and strengthened by the presence of the site of Gesher Benot Ya’aqov (Jordan Valley, 0.8 Ma), which also features some Acheulean-type traits (Muttoni et al., 2010; 2018; Sharon et al., 2011; Moncel et al., 2018d). The passage through Gibraltar’s Strait or Sicily during the lowering of the sea level due to the glacial periods is controversial, even though the Spanish and Italian sites of La Boella, Notarchirico and Atapuerca Gran Dolina may indicate it as a viable route (Abbate and Sagri, 2012; Rolland, 2013).

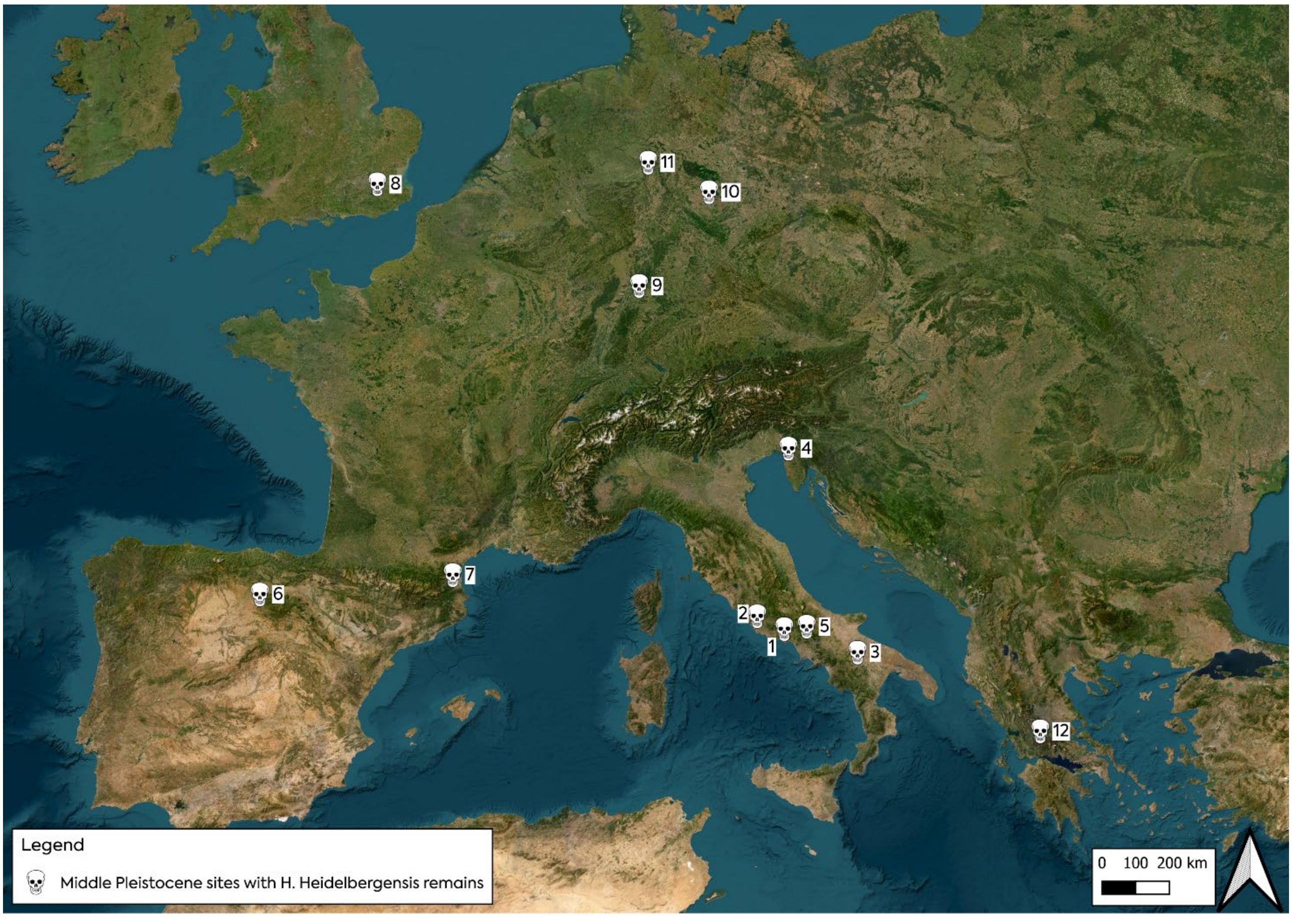

Figure 1.3 List of European Middle Pleistocene sites (700 – 250 ka) with H. heidelbergensis remains cited in the text. 1. Ceprano; 2. Saccopastore; 3. Notarchirico; 4. Visogliano; 5. Isernia La Pineta (?, Homo cf. heidelbergensis); 6. Sima de los Huesos; 7. Caune de l'Arago; 8. Swanscombe; 9. Mauer; 10. Bilzingsleben; 11. Steineheim; 12. Petralona. Data modified from Manzi (2016).

1.2.4. The archaeological evidence during MIS 17 and 16

The MIS 17's related sites are in England, France and Italy and include the earliest evidence of the Acheulean techno-complex during the Middle Pleistocene (Fig. 1.4). The site of Pakefield is located in Suffolk (UK; Fig. 1.4) along the North Sea Coast, and it belongs to the Cromer Forest-bed Formation (CF-bF), which has been long famous for its Early Middle Pleistocene fossiliferous deposits (Parfitt et al., 2005; Preece and Parfitt, 2012). The CF-bf was originally a massive floodplain of rivers extending over Central and Eastern England before getting covered by ice sheets during MIS 12 (around 450 ka). Before that, South-Eastern England was connected to Central Europe, offering a swift passage for hominins that wanted to reach or move along this region (Rose et al., 2001; Moncel et al., 2022). The discovery of 32 chert artefacts represents the first clear signs of anthropisation ever detected in this formation. These lithic objects consist of one core, one retouched and several unretouched flakes and debris and have been described by the authors as *"consistent with Mode 1 technology"* (Parfitt et al., 2005, p. 1). They are obtained from a high-quality black chert collected in an adjacent fluvial deposit. Lithostratigraphic, palaeomagnetic, palaeontological and palaeoenvironmental analyses indicate that the sediments containing artefacts belong to an interglacial interval. Thus, the site's age has been estimated to be 680 ka (MIS 17) at the very youngest or 750 ka (last part of MIS 19) at the very maximum (Parfitt et al., 2005). The environmental reconstruction points to a local climate described as a warm, seasonally dry Mediterranean climate with strong seasonal precipitations. The arboreal taxa feature thermophilous trees, which no longer exist in Britain, while the *Hippopotamus* remains indicate warmer summers and mild winters. The landscape was a meandering river context with marshy grounds rich in reedy vegetation, shallow and pools. The presence of oak woodland pollen suggests the existence of open grasslands in the surrounding of the site, confirmed by the presence of large herbivore remains (*Mammuthus trogontherii, Stephanorhinus hundsheimensis, Megaloceros savini, Bison* cf. *schoetensacki*) and the related carnivore guild (*Homotherium* sp., *Panthera leo, Canis lupus* and *Crocuta crocuta*). The availability of high-quality chert makes the environment of Pakefield perfect for human groups with access to diversified resources (water, plants, meats) and ecosystems (fluvial and grassland) within a small range during a climatic optimum.

The evidence from France consists of two sites: Moulin Quignon and La Noira (Fig. 1.4). Moulin Quignon is located in the Somme Valley in the Northwest of France and is a former sand and gravel quarry excavated during the XIX century. The old fieldwork led to the discovery of several handaxes, large mammal remains and a human mandible. Recent investigations (2016-2019) led to new geological and archaeological data, along with the discovery of several lithic artefacts, confirming the previous findings and providing a chronological and cultural frame for Moulin Quignon (Antoine et al., 2019; Bahain and Antoine, 2021; Moncel et al., 2021b; 2021c; 2022; Vialet and Hurel, 2021). The chronology of the glacial, fluvial deposit from where the artefacts were recovered has been established through the ESR technique between 709 ± 55 ka and 650 ± 37 ka. The chronological data and the malacofauna and palaeontological analyses suggest an interglacial period for the occupation of the site during the end of MIS17 and, possibly, part of the glacial stage 16, though a human occupation at the beginning of MIS 16 is more accepted (Antoine et al., 2019; Bahain and Antoine, 2021; Moncel et al., 2022). The lithic corpus from the new excavations features 254 flakes (31 retouched), 15 cores, five bifaces, and four shaped tools, all discovered *in situ*. The artefacts are realised from a fined-texture chert collected from a secondary deposit. Cores mostly exhibit short reduction sequences with unipolar or centripetal removals with efficient management of the convexities. A few cores display more structured debitage, with partial preparation of the striking platforms and bifacial or multifacial knapping indicating independence from the natural shapes. Flakes are large-sized (40-80 mm in length) and often present a natural back opposed to a cutting edge. The retouched flakes consist of scrapers and end scrapers with irregular retouches on one or more edges. The five bifaces exhibit diversified shapes (from crudely made to oval and symmetrical) and shaping sequences, ranging from short sequences of removals to longer ones, including a resharpening phase. Hard and soft hammers were seemingly employed during the handaxes' shaping. These data show that the hominins at Moulin Quignon had skilled knowledge and control of the bifacial concept. No environmental information is available for Moulin Quignon, but the data so far seems to point to a short-time occupation by the hominins, seemingly at the beginning of MIS 16, during a punctual warmer phase (Moncel et al., 2022). As for the case of Happisburgh 3 and Pakefield, questions and hypotheses regarding the capability of hominins to thrive in hostile environments at high latitudes have been raised (Ashton, 2017; Hosfield and Cole, 2018; MacDonald, 2018; Rodríguez et al., 2021). Moulin Quignon's evidence may suggest that humans established around watercourses and moved along rivers and coastal lines. The strategic position of this context (Somme Valley) in relation to a northern route that would have led to England (connected to Mainland Europe until MIS 12) is worthy of note, especially considering the British archaeological evidence (Fig. 1.4).

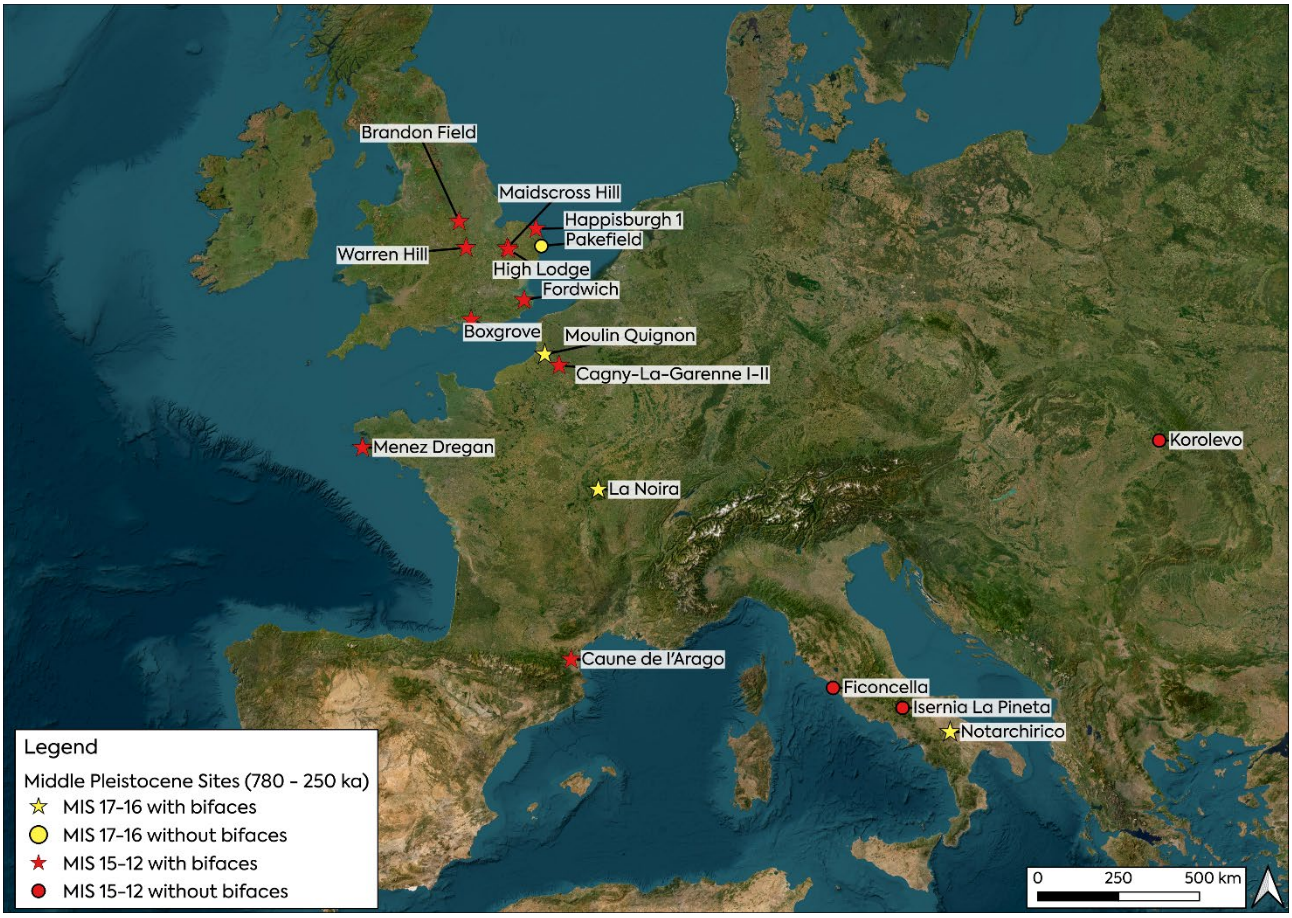

Figure 1.4 List of Early Middle Pleistocene sites mentioned in the text.

The site of La Noira is located in the Middle Loire Basin (Centre Region, France; Fig. 1.4). Excavations between 2010 and 2018 unearthed a complex stratigraphy with four successive strata (a, b, c, and d) within a fluvial formation (Fougères Formation; Brinay). The basal layer (stratum a) is the older of the sequence and bears traces of human occupation; it is a coarse slope deposit lying on the limestone bedrock, deposited at the beginning of a glacial stage. The overlying stratum (b) was dated through the ESR technique on the fluvial sands at 655 ± 55 ka (Despriée et al., 2017; Duval et al., 2020), constraining the age of the human occupation of stratum a around 700 – 670 ka, between the end of MIS 17 and the beginning of MIS 16. Evidence of human occupation was also found in stratum c, dated through the ESR technique at 449 ± 45 ka, indicating a frequentation at the end of MIS 12 or in the first part of MIS 11 (Moncel et al., 2016a; 2020a; 2021a; Duval et al., 2020).

The lithic corpus from stratum a comprises 915 pieces, including flakes, cores, retouched flakes, hammers, bifaces, bifacial tools and cleavers realised on large slabs of millstone locally collected. Cores (50 – 120 mm) show structured organisation, with unifacial and bifacial knapping exhibiting hierarchical reduction sequences (maintenance of the same knapping surface and striking platform until the end of the core's exploitation) and preparation of the striking platforms. Debitage was mainly centripetal and orthogonal, showing affinities with discoidal-type reduction sequences. Flakes are often elongated and cortical, showing a natural back. The ratio of retouched flakes within the lithic assemblage from stratum a is relatively high (23.4% of the flakes). They show a continuous and abrupt retouch, resulting in scrapers, denticulates and beaks. The handaxes and heavy-duty tools component display skilful management of the bifacial volumes and discrete morphological heterogeneity. The bifacial shaping was realised mainly with a hard hammer, with the soft hammer used to regularise tips and edges. Bifaces are obtained from the thinnest millstone slabs, suggesting an accurate selective process of the raw material from the hominins (Moncel et al., 2020a). According to the recent residues and use wear analyses (Hardy et al., 2018), several activities were conducted at the site, including domestic (plant and wood treatment) and butchery-related. Bifaces showed interaction with different materials and were seemingly conceived as multi-functional tools. The data from the site of La Noira show significant behavioural innovations compared to the Lower Pleistocene's contexts and are mainly related to the bifaces' introduction. The evidence from stratum a indicates that hominins occupied this region during a warm phase around 700 ka, abandoning it at the onset of MIS 16. The site re-occupation witnessed in stratum c shows that hominins re-entered this region between MIS 12 and MIS 11 following milder climatic conditions. A further technological and cognitive shift is witnessed in the lithic assemblage from stratum c and was associated with the demographic and cultural expansion of the MIS 11 climatic optimum.

The last site of this Early Middle Pleistocene group is Notarchirico, which, together with La Noira and Moulin Quignon, provides the earliest appearance of the Acheulean techno-complex in Europe. The site of Notarchirico is located in South-Eastern Italy (Basilicata; Fig. 1.4) and lies within the fluvial-lacustrine basin of Venosa. Like La Noira, it is an open-air site featuring a long stratigraphic sequence (11 archaeological layers) with multiple evidence of human occupations. Recent analyses of the stratigraphic sequence using 40Ar/39Ar and ESR methodologies constrained the chronology of Notarchirico between 610 (layer α) and 695 ka (layer I2), corresponding to the end of MIS 17 and the entire MIS 16 (Pereira et al., 2015; Moncel et al., 2020e). The sites comprise a rich palaeontological assemblage with many remains of large herbivores (*Palaeoloxodon antiquus, Bison schoetensacki and Megaloceros solhilacus*), lithic tools (cores, flakes, retouched, flakes, bifaces, pebble tools, LCTs and retouched nodules) and a fragment of human femur – recovered from layer α - assigned to *Homo heidelbergensis* (Belli et al., 1991; Piperno, 1999). The environmental reconstruction indicates an open landscape with shallow paleochannels, and lakeshore remains dominated by grassland and herbaceous taxa (Poaceae meadows) and the limited presence of trees (Moncel et al., 2023). The lowermost portion of the sequence, corresponding to the interglacial phase, shows warmer climatic conditions, confirmed by the presence of *Hippopotamus antiquus* and *Macaca sylvanus* (Mecozzi et al., 2021)*,* while in the higher-most layers, a colder climate corresponding to the glacial stage was documented (Sala, 1999; Moncel et al., 2023). The lithic assemblage is realised on small chert nodules and limestone pebbles locally collected in secondary deposits (fluvial and lacustrine). Cores and flakes indicate short and simple reduction sequences with scarce evidence of discoidal-type cores in the top layers. The retouched tools (flakes and nodules) are relatively frequent, showing different morphologies such as scrapers, denticulates, notches, beaks and pointed implements (Moncel et al., 2020e; Rineau et al., 2022; Carpentieri et al., 2023b). Bifaces are attested from layer G (680 ka) and then are alternatively documented in the higher-most levels of the sequence. They show limited peripherical removals, often preserving the original shape of the selected nodules, and are realised through hard hammer percussion. The current use-wear and residues analyses indicate similarity between Notarchirico and La Noira, indicating that the site was used for multiple activities ranging from butchery-related to processing plants and wood implements.

The recurrent presence of hominins at the site of Notarchirico, particularly during a glacial stage, over a prolonged chronological frame confirms the status of the warm spot held by the Mediterranean area during the Lower and the Middle Pleistocene. As witnessed by other sites, the presence of water, raw materials, large herbivores, and arboreal cover were discriminating factors for human frequentation. The presence of bifacial tools at Notarchirico, La Noira and Moulin Quignon, along with an increased ratio of retouched flakes and raw materials management, suggests that a simultaneous, possibly behavioural, shift occurred between 700 and 650 ka in Western Europe. The scientific community proposes that this shift is related to the spread of the Acheulean cultural complex and the arrival of *Homo heidelbergensis*. Within the present state of the art, two main scenarios have been proposed to explain this phenomenon's origin and diffusion over Europe. In the first case, an *in situ* evolution has been advanced, implying that human groups living in Europe developed new strategies to cope with the changing environments of the MPR. Supporting this scenario is the evidence from Barranc de la Boella and Bois-de-Riquet (layer US4), which yielded earlier proof of bifacial tools during the Lower Pleistocene and has been considered by the authors as the outcome of a local convergent evolution case (Vallverdú et al., 2014; Bourguignon et al., 2016a; Mosquera et al., 2016; Ollé et al., 2023). The second scenario proposes an allochthonous introduction of human groups or an influx of new ideas that spread over Europe as a consequence of the human dispersal during the transition to the Middle Pleistocene from the African and Eurasian regions. This hypothesis also builds on the evidence provided by the origin of *Homo heidelbergensis* (Dennell et al., 2011; Stringer, 2012; Manzi, 2016; Vialet and Hurel, 2021) and the abrupt and homogeneous appearance of handaxe technology and other behavioural innovations, around 700 ka (*i.e.,* La Noira, Moulin Quignon and Notarchirico).

1.2.5. The archaeological evidence between MIS 15 and 12

The archaeological evidence from MIS 15 onwards features a global increase in the number of sites, geographically and chronologically, including richer lithic assemblages (Fig. 1.4). This expansion has been correlated with the last faunal turnover of the MPR, which corresponds to the final transition from the Villafranchian to the Galerian faunal units (Sardella et al., 2006; Muttoni et al., 2010; 2018; Palombo, 2014; 2016; Bermúdez de Castro et al., 2016). During MIS 15, crucial evidence comes from the sites of Isernia La Pineta (Italy), Brandon Fields, Maidscross Hill, Warren Hill, Fordwich (all located in England) and Caune de l'Arago (France; Fig. 1.4).

Isernia La Pineta is located near the site of Notarchirico in southeastern Italy (Fig. 1.4). It is an open-air site comprising five sedimentary units of fluvial origin, of which Unit 3 bears evidence of human occupation (sub-units t.3c, t.3a, and t.3coll). The identified archaeological layers yielded an exceptional number of lithic pieces (more than 20,000) associated with several faunal remains (mostly large herbivores carcasses) and, among other things, a human deciduous tooth attributed to *Homo heidelbergensis* found in layer t.3coll (Coltorti et al., 2005; Gallotti and Peretto, 2015; Peretto et al., 2015; Arnaud et al., 2016; Carpentieri et al., 2023a). Recent datings of the archaeological layers realised through the 40Ar/39Ar laser fusion method yielded a chronological range of approximately 583 ka, corresponding to the final portion of the interglacial 15 (Peretto et al., 2015). The faunal assemblage is dominated by large herbivores typical of an open woodland landscape, such as *Elephas (Palaeoloxodon) antiquus, Hippopotamus* cf. *antiquus, Stephanorhinus hundsheimensis, Bison schoetensacki, Praemegaceros solilacus, Cervus elaphus cf. acoronatus, Dama* cf. *roberti, Capreolus sp., Sus scrofa, Hemitragus* cf. *bonali*. The documented carnivores remains are from *Panthera leo fossilis, Panthera pardus,* and *Ursus deningeri*. The hominins' intensive exploitation of the herbivores' carcasses is confirmed by cut marks and intentional fresh bone fractures, pointing to systematic butchering activities over a wide area (Pineda et al., 2020). The environmental reconstruction indicates the presence of an open arboreal steppe environment with the fluctuating presence of ephemeral watercourses and ponds with a cold and arid climate (Messager et al., 2011; Orain et al., 2013; Zanazzi et al., 2022). The lithic corpus is realised on local chert and limestone collected from fluvial deposits. Hominins exploited limestone to obtain percussive tools and some large flakes, while chert was selected to produce small-sized flakes through the intense use of hard hammer percussion and bipolar on anvil technique. Cores exhibit different types of debitage, including structured discoid reduction sequences (Gallotti and Peretto, 2015). The retouched flakes represent a discrete percentage of the lithic corpus, including scrapers, denticulates, notches, beaks and pointed tools. Despite the absence of bifacial tools, the site of Isernia La Pineta has been reconsidered as evidence of the innovative behaviours spread over Europe after the Middle Pleistocene Transition.

The British evidence from the Middle Pleistocene is clustered within the fluvial deposits of the Bytham River (West Midlands, Suffolk; Fig. 1.4). This area has been long known for its rich Lower Palaeolithic evidence – including at least eight archaeological sites - explored during decades of research (Davis et al., 2021). Recent re-analyses of the old lithic collections, along with new fieldwork and datations, vastly improved the chronological framework of this region, providing evidence of human occupation spanning between MIS 18 and MIS 12 (Davis et al., 2021 and reference therein). Several flakes, retouched flakes and bifacial tools were recovered at the sites of Brandon Fields, Maidscross Hill and Warren Hill. The dating of the associated sediments through the ESR technique from these localities suggested an age of 600 – 550 ka during the MIS 15 and 14, representing the earliest evidence of bifaces in England, while the microfaunal data proposes a younger age, around MIS 13 – 12 (Candy et al., 2015).

The bifaces from Brandon Fields include crudely shaped hard hammer ones and more refined ovate and thin handaxes worked by soft hammers. These artefacts are realised on cobbles of local, high-quality chert. Bifacial tools from Warren Hill are similar to the ones from Brandon Fields, except ovate and more intensively-worked handaxes prevail. Several large scrapers realised on chert flakes with unifacial scalar retouch were also recovered from Warren Hill. Crudely-made bifaces dominate the lithic corpus from Maidscross Hill, even though some thin and ovate ones have also been attested. The Acheulean artefacts from these British localities exhibit several affinities with the La Noira and Moulin Quignon bifaces, reinforcing the "cultural" connection between these regions during MIS 15. The exceptional regularity of the ovate and cordate handaxes from Brandon Fields, Maidscross Hill and Warren Hill is found within several MIS 13 contexts of the same area, such as High Lodge (where many scrapers similar to the one from Warren Hill have been found), Boxgrove, and Rampart Field. Such similarities led the authors to postulate a regionalisation of the technological aspects of the British Acheulean, hypothesising a continuum in the human occupation of the Bytham River during MIS 15, 14 and 13. Strengthening this perspective are the available environmental data that indicate the glacial stage 14 as milder than the others, facilitating the persistence of human groups over time (Candy et al., 2015; Voinchet et al., 2015; Ashton and Davis, 2021; Key et al., 2022).

Following this recent revitalisation of the British archaeological collections from the XIXth and XXth centuries is the new data coming from the site of Fordwich (Kent; Fig. 1.4; Key et al., 2022). The site of Fordwich is a former industrial quarry where, during the 1920s, over 330 bifaces were discovered. The bifaces are described as narrow, thick and of *"ovate tradition"* (Key et al., 2022, p. 4), although several of them retain a substantial portion of the cortex and the original shape of the blocks. The new investigations conducted in recent years included new excavation and datings in the quarry and re-examinations of the old collections. The new fieldwork led to the discovery of 238 flakes, 7 cores and 7 retouched flakes *in situ*. The Infrared-radiofluorescence (IR-RF) technique was used to date the feldspar within the level-bearing chert artefacts, yielding a chronological range between 570 ± 36 ka and 513 ± 30 ka and corresponding to MIS 15. According to Key et al. (2022), an MIS 15 age should also be valid for the bifacial tools recovered during old excavations, further enlarging the sample of sites witnessing handaxe technology during this chronological frame.

The site of Caune de l'Arago is one of the best-documented contexts of the Middle Pleistocene. The site is located in the southern portion of France, near the town of Tautavel (Eastern Pyrenees; Fig. 1.4), and is a karstic fissure carved within a limestone cliff. The excavations conducted since the 1980s unearthed a 10m thick sedimentary sequence rich in lithic, faunal and human remains deposited during the alternation of several humid-temperate and dry-cold phases of the Middle Pleistocene (Barsky and de Lumley, 2010; Barsky et al., 2010; 2019; Barsky, 2013; Falguères et al., 2015). The bottom of the sequence (level P-Q) has recently been dated to 532 ± 106 ka through ESR/U-series techniques and represents the first evidence of human occupation of the cave. According to the sedimentological analyses, level P-Q can be correlated with MIS 14, while the middle part of the sequence (level F) belongs to MIS 12, and the summit level D should represent the transition to MIS 11. The rich faunal assemblage includes *Ursus deningeri, Cuon priscus, Vulpes vulpes, Lynx spelaeus, Panthera cf. pardus, Equus mosbachensis, Stephanorhinus hemitoechus, Bison sp., Ovis ammon antiqua, Hemitragus bonali, Rangifer tarandus and Cervus elaphus*. The high quantity of reindeer, horse and bear remains within levels P-Q confirms the existence of a cold and dry climate with a steppic landscape. The cave was alternatively a shelter for human groups during short-term occupations and a carnivores' den.

The lithic assemblage features more than 100,000 artefacts realised on diversified lithologies, including quartz, schist, chert, sandstone, limestone, jasper and gneiss (Barsky and de Lumley, 2010; Barsky et al., 2010). The technological analysis over the years revealed significant differences between the layers, confirming the hominins' erratic occupation of the cave between MIS 14 and 12/11. Percussive tools, pebble tools, handaxes, cores, flakes, and retouched flakes were recovered across the entire stratigraphic sequence. Elaborated reduction sequences have been documented in the lowest levels (levels P-K), with discoid reduction sequences being the predominant knapping strategy. Cores are small-sized due to intense and prolonged exploitation. The percentage of retouched flakes is relatively high and seems focused on obtaining small-sized pointed tools and notches, perhaps suggesting a task-related role. Some retouched tools show dedicated reduction sequences, such as the pointed flakes, mainly obtained through discoid debitage. Handaxes show a high level of standardisation, being retouched through a soft hammer to regularise the tips and edges. Regular use of freehand percussion and bipolar on anvil technique was documented in relation to distinct reduction sequences, indicating a high level of specialisation of the cave's inhabitants. Despite the predominance in the exploitation of local raw materials, some exotic lithologies were identified, seemingly suggesting a high mobility of the human groups over the territory.

The intermediate levels of the sequence (J-H) are characterised by the absence of bifacial tools, more selective employment of raw materials and a higher ratio of retouched tools. Bifacial discoid reduction sequences are still the preferential knapping strategy, even though an increase in the unidirectional debitage can be witnessed from level H. The largest flakes were selected to be transformed into lateral, double or converging-edge scrapers. The raw materials exhibiting a finer quality were exploited exclusively through centripetal debitage. The scarcity of cortical flakes and a lower ratio of cores to flake may suggest that the initial phases of the knapping process were carried outside the cave.

The higher levels (G-D) show increased exploitation of local raw materials (quartz, jasper, and chert). Discoid reduction sequences become more structured than lower levels, and cores are asymmetrical, exhibiting surfaces' hierarchisation with massive preparation of the striking platforms. According to the authors, the increased notion of predetermination within the discoid knapping strategies could be related to the Levallois method, which started to spread over Europe from MIS 11 (Barsky, 2013). Aside from this, the presence of giant cores (defined as Clactonian-type) unidirectionally or orthogonally knapped was also detected in layer G, which witnessed a general increase in the size of the end products. Retouched flakes show an additional increase in frequency, even though their diversification is similar to layers J-H, comprising side scrapers, end scrapers, and notches. Bifacial tools reappear within the lithic corpus but are more irregular and asymmetrical than those from layers P-Q. The abandonment of the soft hammer to shape edges and tips has also been documented. Level D is considered to record a gradual transition to the Middle Palaeolithic at the site of l'Arago. The progressive miniaturisation of the lithic products with tiny discoid and multidirectional-type cores and the exclusive use of freehand percussion related to quartz are the most emblematic traits of this layer. Sings of more specialised behaviours by the hominins, such as reduced variability in the exploitation of the raw materials and preferential hunting of small to middle-sized herbivores, have been considered as proofs of innovations within human communities and have been related to the onset of the Middle Palaeolithic during the MIS 11 climatic optimum.

The archaeological evidence across MIS 14, 13 and 12 is characterised by either the absence of the handaxe technology or its consolidation. The British sites of Boxgrove, Happisburgh 1 and High Lodge are all dated to MIS 13, around 500 ka, through stratigraphic correlation and biostratigraphy, and are located in eastern England (Fig. 1.4; Ashton et al., 1992a; Roberts and Parfitt, 1999; Gibbard et al., 2019). These sites yielded an impressive number of well-worked ovate bifaces and, in minor percentages, debitage products (cores, flakes and retouched flakes) realised through unipolar, orthogonal and centripetal knapping. The bifaces are generally symmetrical in shape and cross-section and exhibit evidence of resharpening, suggesting a high degree of standardisation within the reduction sequences and the end products, not to mention a seemingly long life. Hard and soft hammers were used for their realisation.

From Eastern Europe is the Ukrainian site of Korolevo (Fig. 1.4), which features a multi-layered stratigraphy with lithic industry belonging to the Lower and Middle Palaeolithic. Recent re-examination of this site led to the attribution of the Lower Palaeolithic industry (levels VI and VII) to the glacial stage 14 (Koulakovska et al., 2010; Rocca et al., 2016). The lithic corpus is realised on local volcanic rocks (andesite) with the sporadic presence of quartzite, sandstone and jasper. Cores show simple reduction sequences, mainly unidirectional and, more rarely, bidirectional or orthogonal. Side-scrapers unifacially retouched dominate the tool assemblage, showing a certain degree of standardisation within the retouch (associated with the Quina or semi-Quina retouch). A second category of tools comprises denticulates and notches. According to the authors, two bifacially worked tools show similarities with the Middle Palaeolithic complexes of Eastern Europe (Keilmesser and Charentian; Koulakovska et al., 2010).

In Central Italy, the site of Ficoncella (Latium; Fig. 1.4) has been dated to the MIS 13. The site is characterised by a single layer attesting to a single human frequentation to exploit the carcass of a *Palaeoloxodon antiquus* (Aureli et al., 2016). The related lithic corpus features exclusively small unretouched and retouched flakes realised on chert pebbles collected in the fluvial deposits surrounding the site. Since the hominins' main goal was the exploitation of the herbivore's carcass, the assemblage is dominated by cutting-oriented, and pointed-tools end products realised through short yet complex reduction sequences.

Approaching the MIS 12 boundary, only two sites are witnessing human occupation during this harsh glacial phase, and they are both located in Northern France and characterised by the handaxe technology: Menez-Dregan and Cagny La Garenne I-II (Fig. 1.4; Tuffreau et al., 2008; Moncel et al., 2015; Ravon et al., 2016a; 2016b; 2022). These sites feature a human occupation mostly related to MIS 11 for Cagny La Garenne and MIS 11, 10, 9 and 8 for Menez-Dregan. However, it has been proposed that short incursions during summers could have occurred during the end of MIS 12. According to several authors, after 424 ka (*i.e.,* termination of MIS 12), the human occupation of Northern Europe exhibits a substantial increase, especially by biface-bearing lithic assemblages: La Grande Vallée and Saint-Pierre-lès-Elbeuf in France (Leroyer and Cliquet, 2010; Hérisson et al., 2016), Swanscombe and Barnham in England (Conway et al., 1996; Ashton et al., 1998; Connet et al., 2020). The use of controlled fire by human groups has often been advanced as the most solid hypothesis to explain this phenomenon, especially considering the spread over the Central and Northern Europe of steppic landscape (Davis and Ashton, 2019; Scott and Hosfield, 2021). Currently, the earliest accepted European evidence of the use of fire lies within the Hungarian site Vértesszőlős, dated to MIS 13 (Kretzoi and Dobosi, 1989), followed by the MIS 11 sites of Menez-Dregan (Northern France), Beeches Pit (England) and Terra Amata (Southern France; de Lumley, 2006; Preece et al., 2006; Ravon et al., 2016a). As previously mentioned, with the beginning of MIS 11 and through MIS 9, a global renewal in the site of Europe, along with the first arrival of the Levallois method, the development of regional cultures specialised in handaxes manufacture, and massive change in the hominins' subsistence strategies, introduce the Middle Palaeolithic transition (Moncel et al., 2016b; 2020c). That being said, the archaeological evidence from these regions still encompasses significant geographical and chronological variability. The range of sites, aside from the ones already mentioned, spanning between MIS 11 and 9, is quite impressive and depicts a progressive demographic expansion that affects the whole European region "simultaneously". From Italy: Fontana Ranuccio, Guado San Nicola, Torre in Pietra, Visogliano, Cave dall'Olio, La

Polledrara, and Castel di Guido; from France: Soucy, Cagny l'Epinette, Orgnac 3, Colombiers, Londigny, Saint-Illiers-la-Ville, Etricourt-Manancourt, Artenac, Gouzeaucourt, and La-Celle-Sur-Seine; from Spain: Ambrona-Torralba, Atapuerca Gran Dolina, and La Cansaladeta; from Germany: Kärlich, and Schöningen (Lhomme, 2007; Tuffreau et al., 2008; Ollé et al., 2013a; 2016; Boschian and Saccà, 2015; García-Medrano et al., 2015; Peretto et al., 2016; Hérisson et al., 2016; Arnaud et al., 2017; Golovanova and Doronichev, 2017; Mathias et al., 2020; Moncel et al., 2020c; Connet et al., 2020; Grimaldi et al., 2020; Muttillo et al., 2021a; Burdukiewicz, 2021; Lemorini et al., 2022).

As witnessed for the transition from the Lower to the Middle Pleistocene related to the spread of the Acheulean cultural complex, environmental stresses foster adaptation and migration mechanisms within human communities. Back-and-forth patterns characterise the diffusion of human groups over different territories, alternating moments of stasis and isolation to dynamic phases, favouring genetic fluxes and ideas' circulation. The subsequent transitions to interglacial and climatic optimums phases allow for a proliferation of all these elements in what can be defined as an acculturation process. Regions became occupied for prolonged periods, and over broader geographical areas (*i.e.* the process of transition to the Middle Palaeolithic that characterises entire Europe), the newly acquired techniques, behaviours, and ideas that enabled overcoming environmental crises and granted social and group cohesion may now further develop, leading to a progressive specialisation and local diversification.

Chapter 2 Site's presentation

2.1. The archaeological site of Notarchirico

2.1.1. History of the site (1979 – 1995)

The site of Notarchirico lies within the fluvial-lacustrine basin of Venosa (Piano Region sedimentary formation), a few kilometres outside the village of Venosa (PZ, Basilicata) in southeastern Italy. It is an open-air site discovered during surveying activities conducted in 1979 by the *Istituto Italiano di Paleontologia Umana* (IIPU), represented by A. G. Segre, E. Segre-Naldini, and I. Biddittu, and the *Soprintendenza Speciale al Museo Nazionale Preistorico ed Etnografico "L. Pigorini"*, represented by P. F. Cassoli and M. Piperno (Fig. 2.1; Piperno, 1999). Afterwards, from 1980 to 1995, the site was extensively excavated on a surface of approximately 275 m² and divided into four main areas covering the whole stratigraphic sequence of Notarchirico (SE, SI1, SI2, AE), of which SI1, SI2 and AE have been museumised (Fig. 2.2; Piperno, 1999).

1) *Scavo Esterno* (SE, 156 m²): layers B, C, D, E, F; excavated from 1980 to 1984;
2) *Scavo Interno* 1 (SI1, 131 m²): layers Alfa (α) and B; excavated from 1985 to 1995;
3) *Scavo Interno* 2 (SI2, 120 m²): layers A, B, C, D, E, E1, F; excavated from 1985 to 1995;
4) *Area dell'elefante* (AE, 24m²; Elephant Area): layers: A, A1, B; excavated from 1985 to 1995;

During the 1995 fieldwork, a new area near SE was excavated (SE95), over 50 m², to investigate the bottom part of the sequence. Additionally, several test pits were opened between 1981 and 1992, leading to the identification of layers G and G1 (*Sondaggio 1*, S1, 16 m²), layer H (*Sondaggio 2*, S2, 9 m²) and layer I (*Sondaggio 3,* S3, 4 m²; Fig. 2.2).

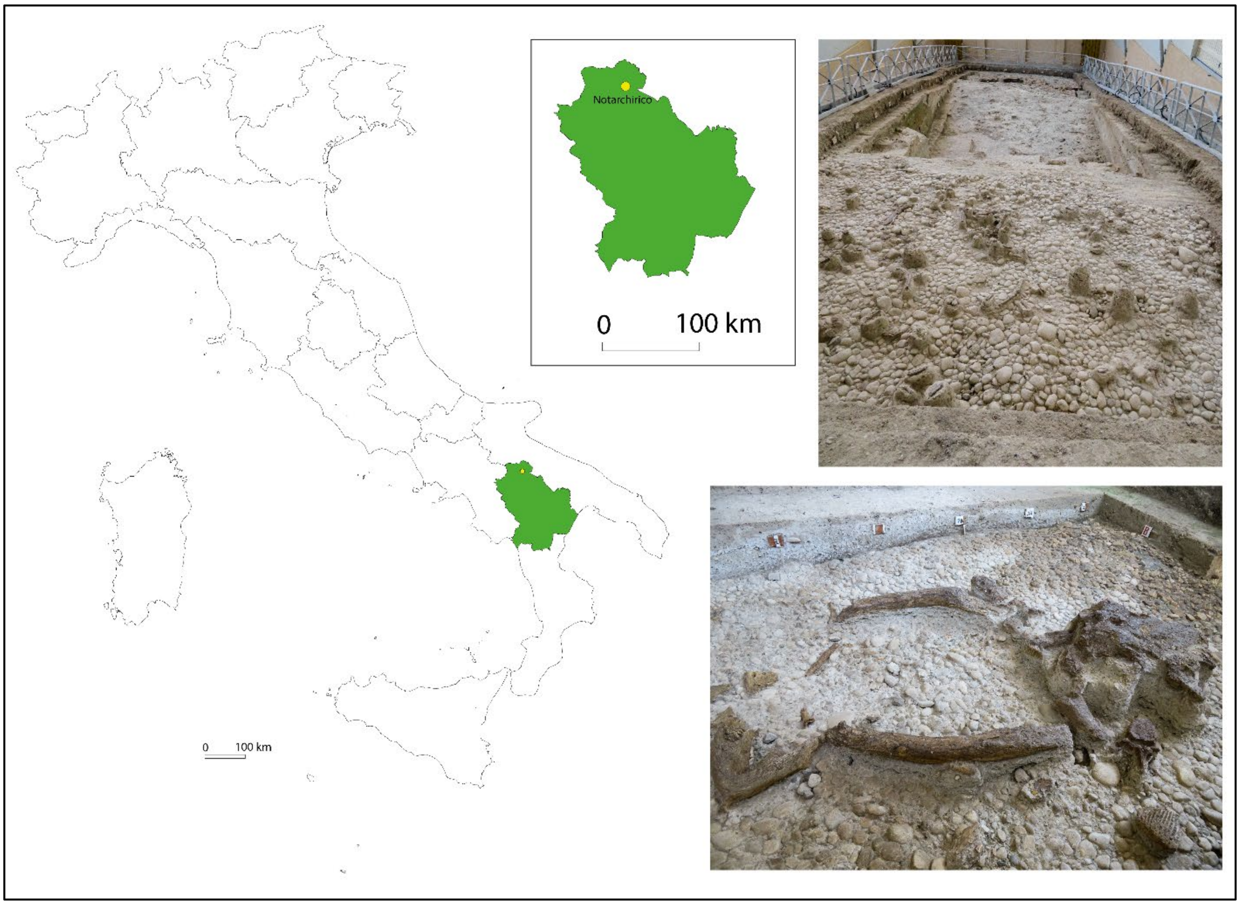

Figure 2.1 Location of the site of Notarchirico (left). Museumised paleosurfaces (right).

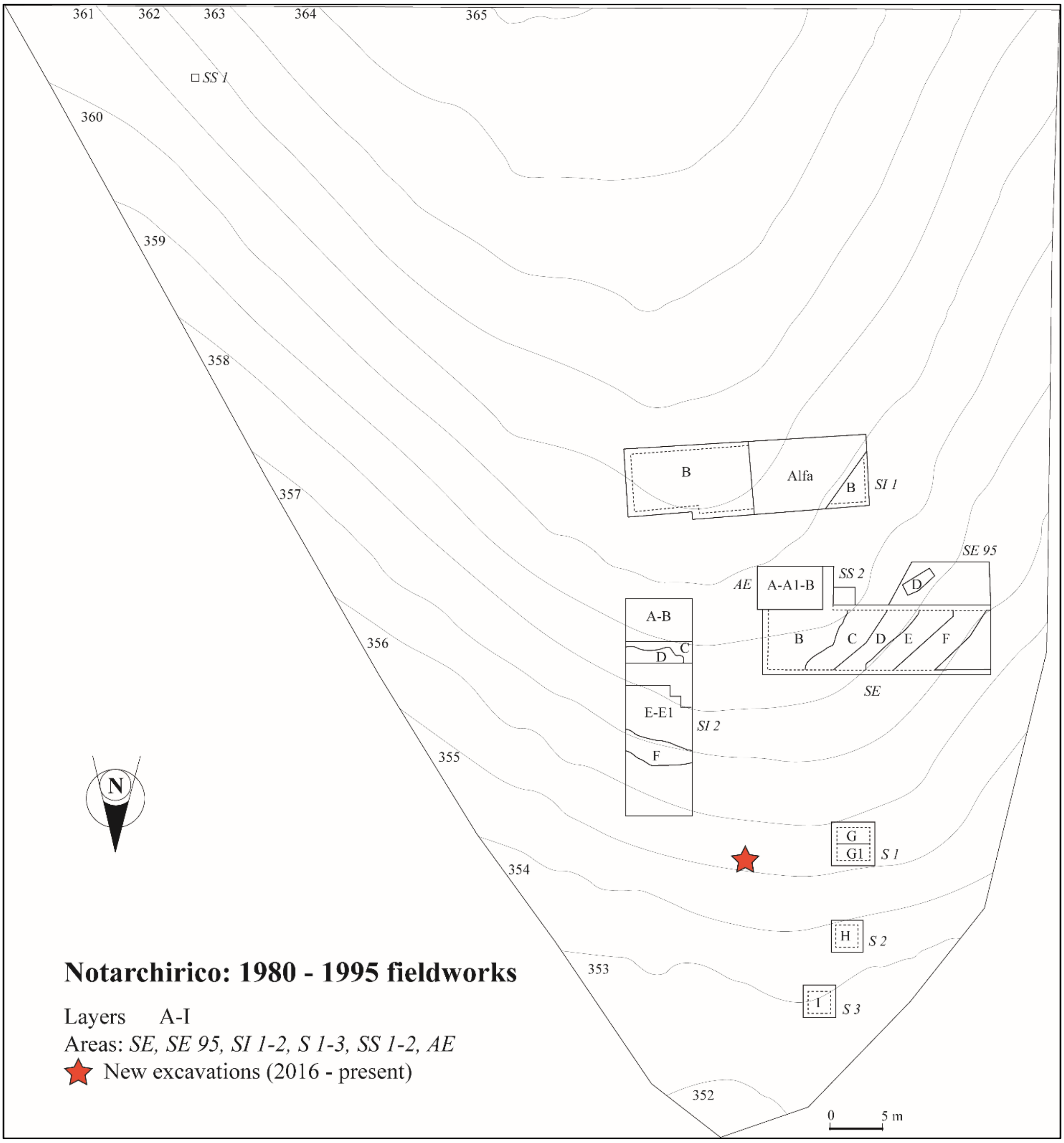

Figure 2.2 The Notarchirico Hill and fieldworks conducted by M. Piperno and his èquipe between 1980 and 1995, and the location of the 2016's new trench (red star) (modified from Piperno, 1999).

From a geological perspective, the Venosa region belongs to the Adriatic Foredeep or Fossa Bradanica system of Southern Italy. The Adriatic Foredeep extends across several basins from the Adriatic Sea to the Ionian Sea. It is flanked by two structural units, the Apulian Foreland to the East and the Appennine Chain to the West. The sedimentary filling of the foredeep is composed of a thick series of clayed siltstone, primarily turbidites (*Argille subappenine* or *Argille di Gravina*), sometimes alternated with flysch nappes, which are covered first by shelly coastal sands (*Sabbie di Monte Marano*), and by conglomerates with interbedded sands (*Conglomerato d'Irsina*) later, deposited either in a coastal environment or in an epicontinental shallow sea (Piperno, 1999; Raynal et al., 1999).

During the final portion of the Lower Pleistocene, a general uplift raised the different structural units, causing several deformations across the Adriatic Foredeep and re-directing the organisation of the massive hydrographic system from the Appennine Chain to the Ionic Sea and through the Venosa region. The progressive erosion of one of the rivers within the Venosa region generated a deep and large fluvial valley with massive conglomerate deposits (Fonte del Comune Formation), named Venosa Basin.

The Venosa Basin, where the archaeological site of Notarchirico lies, extends for approximately 60 km at the feet of the Volcanic complex of the Monte Vulture and represents an exceptional volcano-sedimentary record. Monte Vulture's volcanic activity – which peaked during the first half of the Middle Pleistocene, between 0.78 and 0.48 Ma – massively impacted and shaped the surrounding basin, including the site's stratigraphic sequence (Raynal et al., 1999; Lefèvre et al., 2010). Consequently, the Venosa Basin's morpho-sedimentary system includes three lithostratigraphic units: the Fonte del Comune Formation, of fluvial origin at the base, and two volcano-sedimentary units, the Piano Region Formation in the middle and the Tufarelle Formation at the top.

The Fonte del Comune Formation shows reverse magnetic polarity and is contemporary with the initial volcanic activity phase during the Lower Pleistocene's final phase. On the other hand, the Piano Region Formation and the Tufarelle Formation are contemporaneous with the most intense phase of the volcanic activity of Monte Vulture during the Early Middle Pleistocene, between 740 and 600 ka (Piperno, 1999; Raynal et al., 1999; Lefèvre et al., 2010). Subsequent inundations of the basin by shallow lakes and marshes, during which human activity flourished (Notarchirico and Loreto), and the persistent volcanic activity progressively filled the basin during the Late Middle Pleistocene. Further tectonic activity alongside the latest phase of eruptions of the Monte Vulture during the Upper Pleistocene, modified the basin, generating a new drainage pattern (Fiumara di Venosa) which eroded the older formations, thus exposing the Middle Pleistocene deposits as terraces where the archaeological site of Notarchirico was found.

The stratigraphic sequence of Notarchirico, which rests on the Piano Region Formation, features four stratigraphic units (1-4; Fig. 2.3). Unit 4, which lies at the bottom of the sequence, was identified above layer G and below layer F on a small area and was not intensively described and analysed. Unit 3 is described as a coarse volcanic sediment about 0,5 m thick which, from the bottom to the top, consists of cross-bedded sands, flat-bedded sands and an unstratified gravel-rich sediment, whose top is made up of continuous pebbles bed (archaeological layer F) indicative of base deposition load from slow flowing water in a channel. The analysis of the sands revealed that they were emitted as coarse volcanic ash, which was later reworked and resorted to a low-flow drainage regime.

Unit 2 comprises volcanic sediments with an average thickness of 2.50 m and ten sub-units (2.1 – 2.10; Fig. 2.3):

- Sub-unit 2.1 presents coarse to fine sands without any structure indicative of water reworking and a poor sorting of the particles.
- Sub-unit 2.2 consists of compact sediment not calcified from accumulated volcanic glass herds (particles 25 to 100 mm) mixed with rare minerals. It results from a fine, direct distal ash fall into still water.

- Sub-unit 2.3 is similar to 2.2, a compact sandy lamina not calcified and composed of accumulated volcanic glass and rare minerals.
- Sub-unit 2.4 is described as a 0.20 m thick compact white micaceous layer with the consistency of a talc. An accumulation of unaltered volcanic glass herds with occasional minerals can also be observed. The pumice sherds indicate an initial, relatively viscous magma dispersion by a Plinian eruption. The ash of Unit 2.4 is known as the Notarchirico Tephra.
- Sub-unit 2.5 is a 0.10 m thick layer of light grey volcanic sands, cemented by carbonates, with lenses of coarse reworked tephras. At its bottom, there are traces of biological activity after its deposition. Numerous pebbles, lithic industries, and faunal remains from archaeological layers E and E1 are at its top. The pebbles and sands derived from basal sediment load deposited in a slightly braided channel.
- Sub-unit 2.6 consists of volcanic sediments accumulated in a 1 m thickness. The granulometry of this sub-unit indicates a progressive increase in activity at the beginning, followed by a cessation of activity. This is followed by archaeological layer D, which comprises base load sediments partially reworked by the erosion and removal of the fine fraction, causing the localised formation of jointed cobble paving.
- Sub-unit 2.7 comprises a layer of silty sands, clayey silts and pumices in a 0.4 m thickness.
- Sub-unit 2.8 presents fine green sands, interspersed with clayey lamina, with an overall thickness of 0.45 m.
- Sub-unit 2.9 is a narrow channel, incising unit 2.8 and filling it with fine sands. The range of clay minerals indicates an input of volcanic material.
- At its base, sub-unit 2.10 incorporates the archaeological layer C and, at its top, layer B. The thickness of this sub-unit is 0.7 m and comprises relatively coarse sand beds containing volcanic structures. Layer B is an undulating bed of jointed pebbles forming a pavement across the top of coarse sands and gravels of unit 2.10.

Unit 1 is the upper complex of volcanic sediments with a thickness of 2.5 m and is composed of six sub-units, all of which are slightly calcified (Fig. 2.3):

- Sub-unit 1.1 incorporates the archaeological layers B and A, consisting of a bank of gravels and bedded sands passing up into clayey silts with an overall thickness of 0.3 m. Layer A is composed of faunal remains, pebbles and lithic industry. The bones do not show any preferred orientation, and this sub-unit is considered to originate from a mass flow event.
- Sub-unit 1.2 rests on layer B and has a thickness of 0.5 m. It is a shallow channel feature of variable dimensions within sub-unit 1.1, composed of brown silts and incorporates mud sands of black silts rich in organic matter. Traces of altered volcanic materials were found in the sands.
- Sub-unit 1.3 consists of superimposed levels of fine to coarse sediments of green-grey colour with an overall thickness of 0.8 m. At the top of this sub-unit are accretionary lapilli, indicating that the original material was derived from a pyroclastic flow subsequently contaminated with exotic sediments.
- Sub-unit 1.4 has a maximum thickness of 0.5 m. The sedimentological composition features coarsely stratified sands, gravels and pebbles. At the top of this sub-unit is an initial clast-supported gravel overlayed by another gravelly deposit and well-sorted coarse sands. The

archaeological material associated with the upper part of the deposit constitutes the archaeological layer alfa.

- Sub-unit 1.5 forms a massive channel with an undulating base (1.25 m thick), which has eroded sub-unit 1.4 and partially sub-unit 1.3. It comprises several layers of reworked tephras passing into fine sandy sediments with alternate beds of fine detritus and calcified layers.
- Sub-unit 1.6 includes tephric material with some pebbles within a thickness of 0.5 m. The granulometry indicates volcanic falls occurring and subsequently reworked by currents.

At the top of these Units is Unit 0, which consists of recent deposits exposed at the top of the section and partially disturbed.

The stratigraphic sequence unearthed during Piperno's excavations features a 7 m thick deposit of fluvial and volcanic sediments, including, from the top, 11 archaeological layers: Alfa, A, B, C, D, E, E1, F, G, and I (Fig. 2.3). The archaeological material consists of lithic implements and large herbivores' carcasses laying on beds of pebbles and cobbles corresponding to shallow paleochannels and lakeshore remains. Additionally, a fragment of a hominin femur was found in layer Alfa and dated, in 1990, to 359 ± 154 ka through U-series (Belli et al., 1991). Recent geochronological dating (ESR, 40Ar/39Ar) established the chronological limits of the sequence excavated by Piperno between 610 ka (layer α) and 675 ka (layer F), corresponding to the glacial stage 16 (Pereira et al., 2015; Pereira, 2017; Moncel et al., 2020e). The monography published in 1999 comprises the multidisciplinary analysis of the archaeological material from layers Alfa and A, with the remaining layers being partially described and studied (Piperno, 1999). Nowadays, the entire sequence is the object of an ongoing investigation to provide an exhaustive analysis of Piperno's archaeological material (Moncel et al., 2019; 2020e; 2023; Mecozzi et al., 2021).

The faunal assemblage from layer Alfa, described by Cassoli et al. (1999), includes 2400 faunal remains (Tab. 2.1), of which 827 were paleontologically analysed. The palaeontological record comprises mammals, reptiles and birds. Among the reptiles, the European pond turtle (Emys orbicularis) was the only species identified. At the same time, the avifauna includes remains of bean goose (*Anser fabalis*) and pintail (*Anas acuta*), indicating a lacustrine environment. The mammalian record is characterised by the presence of the straight-tusked elephant (*Palaeoloxodon antiquus*), fallow deer (*Dama clactoniana*), red deer (*Cervus elaphus*), aurochs (*Bos primigenius*), Pleistocene woodland bison (*Bison schoetensacki*) and brown hare (*Lepus* cf. *europaeus*). Layer A features a broader spectrum of species identified despite the minor number of identifiable remains (n=544). *Emys orbicularis* was the only reptile found, while among the avifaunal specimens, *Anser fabalis, Anas acuta,* Eurasian wigeon (*Mareca penelope*), garganey (*Anas querquedula*), and the northern shoveler (*Anas clypeata*) were identified. The large mammal assemblage is similar to layer alfa, with *Palaeoloxodon antiquus, Dama clactoniana, Cervus elaphus, Bos primigenius, Bison schoetensacki, Lepus* cf. *europaeus,* and, additionally, wild boar (*Sus scrofa*), and giant deer (*Megaceroides sp.*).

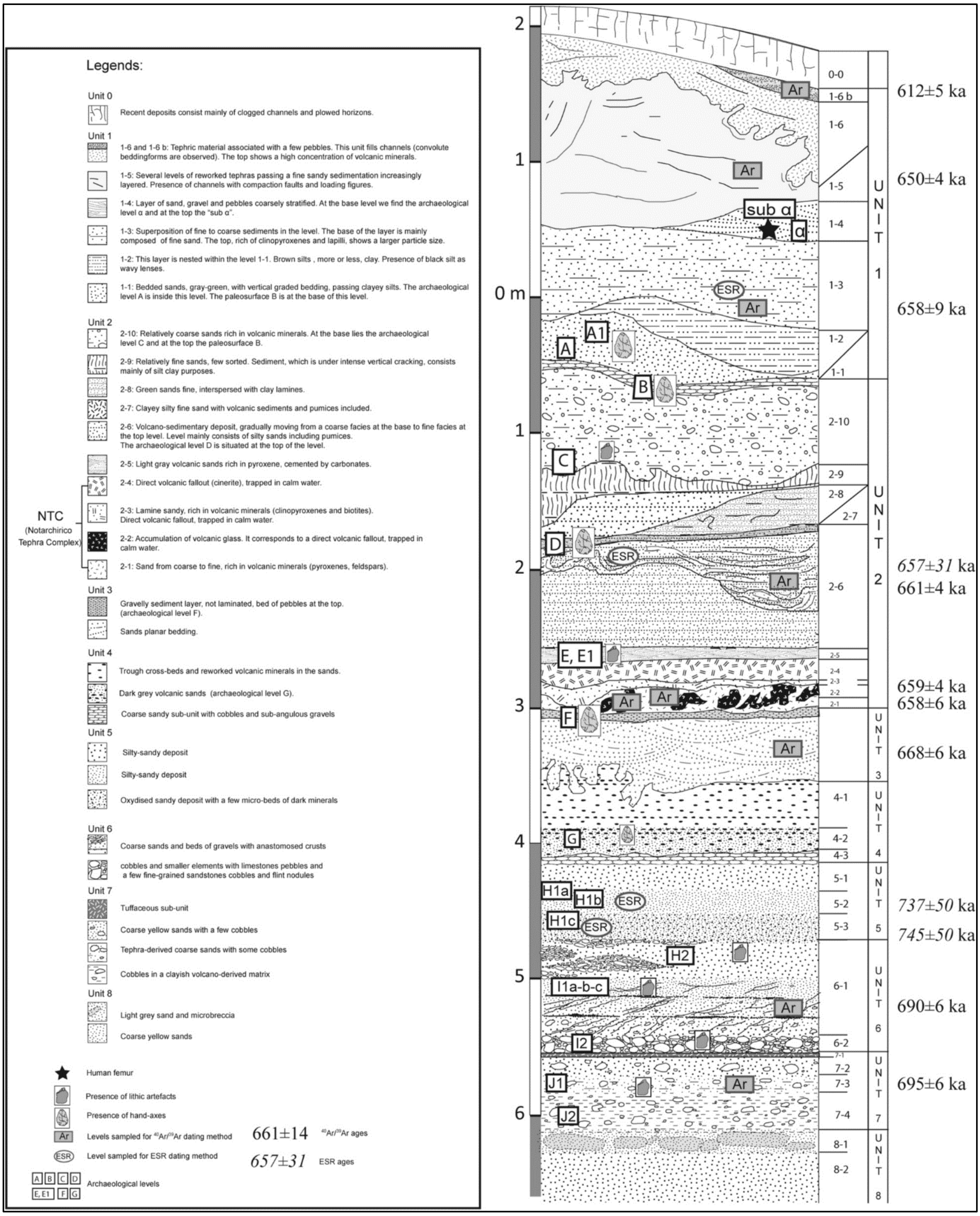

Figure 2.3 Stratigraphic log of the sequence of Notarchirico. This section includes the old excavations (up to Unit 4) and new excavations (from Unit 4 to Unit 8). (modified from Raynal et al. and Moncel et al., 1999; 2020e).

Table 2.1 Faunal remains and lithic objects from Notarchirico (1980 – 1995) (modified from Piperno, 1999).

Piperno's excavation			
Layer	Limestone Industry	Chert Industry	Faunal Remains
Alfa			2400
A	283	33	544
A1	30	11	85
B	312	39	26
C	74	4	5
D	256	44	26
E	66	89	207
E1	124	161	143
F	-	-	-
G	-	-	-
H	-	-	-
I	-	-	-

The faunal assemblage from the remaining portion of the sequence – layers A1, B, C, D, E, E1, F, G, I – is similar to layers Alfa and A, suggesting a global homogeneity for the entire stratigraphy of Notarchirico. According to the authors, the most abundant remains across all the levels belong to *Palaeoloxon antiquus, Dama clactoniana, Cervus elaphus* and *Bison schoetensacki,* followed by *Sus scrofa* (layers E, I) and *Megaceroides sp.* (layer I) attested in very low percentages. Sporadic evidence of *Stephanorhinus sp.* was also found in layers C, E1, and I, alongside a lower molar of *Castor fiber* from layer E1.

The taxa's association – attributed to the Isernia La Pineta Faunal Unit – describes an open lacustrine cold environment with arboreal cover in the surrounding area. The micro-mammals assemblage, analysed by Sala, confirms the presence of a cold climate typical of a glacial stage and comprises the presence of *Microtus* aff. *arvalis* and *Microtus* sp. in layers Alfa and B, *Microtus sp.* and *Arvicola cantianas* in layers B and C, *Microtus* sp. and *Microtus* aff. *arvalis* in layer E, *Sorex* cfr. *runtonensis, Talpa* sp., *Pliomys episcopalis, Microtus* aff. *arvalis, Microtus (Terricola)* sp., *Arvicola cantianas, Chionomys nivalis* and *Apodemus* sp. in layer E1. The palynological result, elaborated by L. Cattani, represents only the top of the stratigraphic sequence and indicates the predominance of a grassland/savannah landscape (*Poaceae* meadows) with a limited presence of trees (*Pinus sylvestris, Quercus pubescens, Quercus ilex, Corylus, Carpinus, Fraxinus and Ulmus).*

The lithic corpus of Notarchirico is realised on local raw materials (limestone and chert) collected in a secondary position along the river banks/lakeshores. The technological analysis conducted by Piperno shows the production of heavy-duty tools and core and flake assemblages as the main goals of the reduction sequences along the entire stratigraphic sequence (Piperno, 1999). The heavy-duty components are primarily obtained from large limestone and, in minor portions, chert pebbles. They consist of various unifacial and bifacial tools, chopper/chopping tools, cleavers, rabots, pointed elements, and bifaces. The debitage production was realised on smaller supports of chert and, more rarely, limestone to produce small flakes (15-20 mm) through unifacial/multifacial knapping. Freehand percussion was the privileged technique employed, even though the bipolar on anvil technique was also attested. Larger flakes (50-100 mm) are rarer and mainly obtained from limestone cores. Retouched tools are also attested, consisting of scrapers, notches and denticulates. Compared to the debitage chert products, a predominance of large-sized implements realised from limestone characterises the entire stratigraphic sequence.

The distribution of the lithic material within the stratigraphic sequence is slightly richer and denser than the faunal remains (Tab. 2.1). Layer A comprises 316 lithic pieces, 283 on limestone and 33 on chert. The lithic corpus from this layer features the presence of two bifaces, choppers and percussive tools. From layer A1 were recovered 41 lithic artefacts, primarily realised on limestone and including several bifaces. Layer B presents 351 lithic pieces (312 on limestone and 39 on chert) and is characterised by many percussive implements and choppers with sporadic evidence of small-sized denticulates and notches in chert. Ten bifaces have been recovered from this layer. Layer C includes 78 pieces (74 of limestone and four of chert), mostly chopping tools and some flakes without evidence of bifaces. The lithic industry from layer D comprises 300 artefacts (256 on limestone and 44 on chert) with similar characteristics to the upper layers, including two bifaces. From layer E, 155 lithic pieces (64 on limestone and 91 on chert). The composition of the lithic assemblage from this layer highlights a predominance of debitage chert products (cores, flakes and retouched flakes) over limestone tools and an absence of bifaces. The lithic industry from layer E1 (n = 244) is similar to layer E, with a predominance of chert (n = 166) over limestone (n = 78). Flakes and retouched flakes are frequent, followed by a few choppers. The absence of bifaces was also reported from this layer. There is no quantitative data from layer F since most of the lithic material was left on the palaeosurface except for some bifaces that reappear in this layer. The raw material analysis highlighted a predominance of limestone over chert. The end of the sequence, represented by layers G, H and I, was investigated only through some test pits where significantly fewer lithic pieces, primarily on limestone, were recovered (Piperno, 1999).

2.1.2. Notarchirico – The new investigations (2016 – present)

Since 2016, new investigations have been taking place at Notarchirico by M. H. Moncel (CNRS) to explore, in a broader area, the bottom of the sequence unearthed by Piperno below layer F (Moncel et al., 2020e). A 26 m long trench was thus opened on the right side of Notarchirico hill, near Piperno's test pits, covering a surface of approximately 100 m² (Fig. 2.2, 2.4). The new excavations, which are still in progress, identified five lithostratigraphic units (3 to 8; Fig. 2.3), including six archaeosurfaces (F, G, H, I1, I2 and J). All the archaeosurfaces, except for layer J, bear evidence of human frequentation, with layers F, G, I1 and I2 witnessing recurrent and repeated occupations by the hominins. On the other hand, layer H is thought to record a sporadic/short-term site frequentation phase.

The new investigations also involved a complete re-analysis of the stratigraphic sequence unearthed by Piperno and the associated archaeological material. A multidisciplinary approach was adopted to explore the available data from the site of Notarchirico in every aspect. This included new descriptions and analyses of the stratigraphic sequence, radiometric datations (which have been previously mentioned), palaeontological and taphonomical analyses of the faunal remains (macro and micro mammals), technological and petrographical studies of the lithic industry, and spatial distribution (Santagata, 2016; Moncel et al., 2019; 2020e; 2023; Santagata et al., 2020; Rineau et al., 2022).

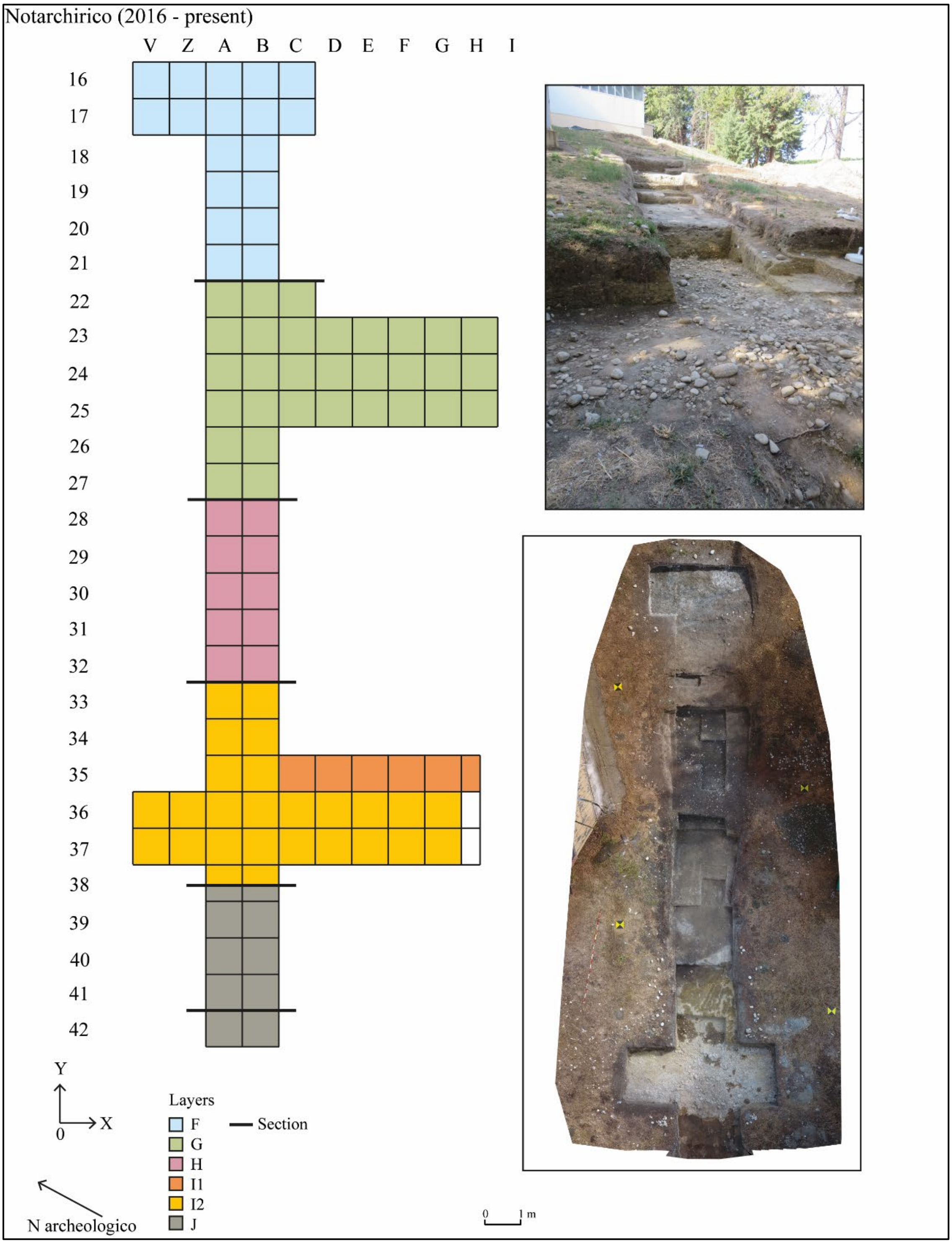

Figure 2.4 Extension of new excavations (left); general view of layer I2 (top right); general view of the excavation (bottom right; courtesy of A. d'Andrea). Graphic elaboration by the author.

The new deposit excavated in 2016 belongs to the *Notarchirico Complex* and is in geometrical continuity with the sequence established by M. Piperno (Fig. 2.3). Within the new stratigraphic sequence, Unit 3 represents the top of the deposit and is capped by the *Notarchirico Tephra complex,* recently dated to 670 ± 14 ka by 40Ar/39Ar (Pereira et al., 2015). This lithostratigraphic unit is described as a cross-bedded volcano-derived and non-volcanic sands layer, with substantial variations in grain size distribution (coarse to very coarse), and it is the equivalent of lithostratigraphic unit 3 identified by Piperno. It is described as the coarsest sediment in the new sequence, with an observed thickness of 20 cm and well-sorted sediment. According to the most recent interpretation, fluvial processes (or heavy runoff) controlled the sedimentation process, and volcaniclastics did not represent direct inputs (Moncel et al., 2020e). The archaeological layer F belongs to this unit.

Unit 4 presents three sub-units (4.1, 4.2, 4.3):

- Sub-unit 4.1 has a thickness of 1 m with a sandy composition and a compact base. Coarse iron-coated sands indicate a volcano-derived sedimentary unit. The matrix of the unit is composed of weathered volcanic glass, coarse melanocratic lavas with smoothed grains and weathered pumice, suggesting a degraded distal pyroclastic flow. A few cobbles (up to 5cm) are attested. The bottom of the sub-unit is finer and richer in silts and clays with encrusted pebbles.
- Sub-unit 4.2 presents dark-grey volcano-derived sands containing rounded quartz grains within a thickness of 30 cm. Cobbles (5-10 cm in diameter) attested at its base form the archaeological layer G, described as thick lag deposit covered by fluvial sands.
- Sub-unit 4.3 is characterised by coarse sands with cobbles, sub-angulous gravels, and microbedding underlined by heavy mineral laminas. The stratification is essentially planar, and sub-beds are barely graded, indicating fluvial deposition dynamics. The contact with the underlying unit is undulating.

Unit 5 is divided into three sub-units (5.1, 5.2 and 5.3) and is globally described as a yellowish layer with an approximate thickness of about 80 cm:

- Sub-unit 5.1 is a silty-sandy deposit with very poorly sorted sediments dominated by silts.
- Sub-unit 5.2 is a silty-sandy deposit, slightly sandier at its base. The bottom is laterally sandier and more oxidised, with a few micro-beds of dark minerals and an undulated base. This is where archaeological layer H is.

Sub-unit 5.3 also exhibits a silty-sandy composition.

Unit 6 has two sub-units:

- Sub-unit 6.1 (30 cm of thickness) is composed of coarse greyish to greenish sands and beds of more or less dense gravels, sometimes concentrated in shallow pits. At its base, cobbles appear in a sandy matrix. Pluri-millimetric anastomosed crusts cross this sub-unit and are sub-horizontal to the sand beds. The crusts form ripples in sands, constituted by carbonaceous accumulations due to post-depositional events related to vadose waters. At the top, the sediment is sandy-silty; at the bottom, the sandy matrix of the cobbled layer is richer in silts.
- Sub-unit 6.2 is a lag deposit (10 to 15 cm thick) consisting of a dense accumulation of cobbles and pebbles (1 to 10 cm). The archaeological material is inserted within the "pavement" corresponding to archaeological layer I. This layer primarily contains limestone pebbles, fine-grained sandstone cobbles, and chert nodules. The matrix of the deposit is

described as fine and sandy-silty in composition. This aspect and a lag deposit might indicate a dynamic re-equilibrium following a volcanic input.

Unit 7 has four sub-units, and its general aspect is similar to that of the distal pyroclastic flows identified in other localities of the basin, which form the Piano Reggio Formation.

- Sub-unit 7.1 is tuffaceous, pink in colour, 2-3 cm thick and with some dark grains crustified at the top. It is a direct tephra fall trapped in stagnant water and marks a discontinuity in the sedimentary process.
- Sub-unit 7.2 is 15 cm thick, composed of coarse yellow sands with rare cobbles, siltier towards the base. It might correspond to a Tephra input.
- Sub-unit 7.3 is a tephra-derived coarse sand deposit with some cobbles 10 cm thick.
- Sub-unit 7.4 exhibits cobbles in a clayish volcano-derived matric, forming archaeological layer J and overlying the crustified top of unit 8. The thickness is about 30 cm. The interface of this sub-unit with unit 8 is siltier in composition.

Unit 8 presents two sub-units and, at its top, is composed of a carbonated crust overlying the grey sands of sub-unit 8.1, subsequently changing into yellow coarse sands in sub-unit 8.2. This unit derives from a volcanic input.

- Sub-unit 8.1 is a silty-sandy sediment.
- Sub-unit 8.2 is composed of coarse yellow sands with relatively good sorting.

The sedimentary dynamics of the new stratigraphic sequence of Notarchirico can be summarised as a scenario in which from an environment submitted to regular tephra inputs (units 8 to 6), sedimentation progressively changes from low to higher energy currents (unit 5 to 3), yet remaining highly volcano-derived (Tab. 2.2). The periods of spasmodic sedimentation and those following lag deposits are connected to hominins' occupation, giving direct access to cobble materials.

The new analyses are in accordance with the conclusions made for the museumised sequence, corresponding to a relatively short accumulation period (Piperno, 1999; Moncel et al., 2020e; 2023). The different facies seemingly correspond to fills of meandering paleochannels, sometimes crossed due to the action of low-energy currents. Additionally, the original slopes of the deposits have been modified by tectonic activities since the Lower Pleistocene. The rate of the sedimentation process was heavily dependent on the periodic emission of tephra originating from the Monte Vulture. The finer fractions are derived from the alterations and reworking of the volcano-derived sediments. The layers exhibiting cobbles and gravels result from slope destabilisation processes systematically intervening after the deposition of the tephra and the release of lateral contributions from older conglomeratic deposits (debris flows, mudflows, etc.). These deposits were saturated by water at maximum flow rates, generating scouring, elutriation and the concentration of coarse materials.

The new radiometric datings realised through the 40Ar/39Ar on single grain technique and ESR on bleached quartz method included four sedimentary units (Fig. 2.2). Sub-units 5.2 and 5.3 (archaeological layer H) were dated by ESR, while sub-units 6.1 (archaeological layer I) and 7.3 (archaeological layer J) were analysed by the 40Ar/39Ar technique (Pereira et al., 2018; Moncel et al., 2020e). The results placed the chronology of the new sequence between 670 ka (layer F, lithostratigraphic unit 3) and 695 ka (layer J, lithostratigraphic unit 7), corresponding to the end of the interglacial stage 17 and the beginning of glacial stage 16. Together with the new results from the sequence excavated by M. Piperno – chronologically placed between 615 ka, layer alfa, and 670 ka, layer F – the site of Notarchirico exhibits a more or less continuous human occupation over 80 ka. The archaeological material of the new sequence consists of lithic artefacts associated with faunal remains laying within a bed of pebbles and cobbles of approximately 10-30 cm thickness, representing paleo water channels and lakeshores. Layers F and I2 show a dense bed of pebbles preserved in situ, while layers G and I1 are more disturbed.

Table 2.2 Synthesis of the stratigraphic sequence. Bold italic: archaeological layer. Italic: sterile lithostratigraphic units at the bottom or between the archaeological layers. Bold: archaeological layers. (from Moncel et al., 2023).

Lithostratigraphic unit	Archaeological layer	Sub-unit	Characteristics
3	***F***	F	Bed of cobbles-pebbles
			Cross-bedded volcano-derived and non-volcanic sands 20 cm
			Archaeological layer
3		F1	*Black volcanic sands 20 cm*
4.1			Brown with small gravel 1m
4.2	***G***	G1	Dark-grey volcanic sands 30 cm
			Archaeological layer
4.3			*Coarse sandy sub-unit with cobbles and sub-angulus gravels 30 cm.*
5.1	***H***	H1a	Silty-sandy deposit 10 cm
			Dispersed archaeological material
5.2		H1b	Silty-sandy deposit 10 cm
			Dispersed archaeological material
5.3		H1c	Silty-sandy deposit. Sandier and oxidised with a few micro-beds of dark minerals 30 cm.
			Dispersed archaeological material
6.1	***I1***	I1a-b-c	Local lenses of small pebbles 16-30 cm
			Coarse sands and beds of more or less dense gravels with pluri-millimetric anastomosed crusts 40-45 cm
			Dispersed archaeological material
6.2	***I2***	I2	Dense accumulation of cobbles and smaller elements with limestone pebbles and a few fine-grained sandstone cobbles and flint nodules 10-15 cm
			Archaeological layer
7.1			*Tuffaceous sub-unit 3 cm*
7.2			*Coarse yellow sands with a few cobbles 15 cm*
7.3		J1	Tephra-derived coarse sands with some cobbles 10 cm
			Rare artefacts non-in situ
7.4	***J***	J2	*Cobbles in a clayish volcano-derived matrix 30 cm*
8.1			*Light-grey sand and micro-breccia*
8.2			*Coarse yellow sands*

The new palaeontological analyses (Moncel et al., 2020e; 2023; Mecozzi et al., 2021) cover layers F, G, H, I1 and I2 for 4081 faunal remains (Tab. 2.3). *Palaeoloxodon antiquus, Bison schoetensacki, Cervus elaphus ssp.,* and several unidentified remains of *Bovidae sp.,* cervids and megacerine characterise layer F. Layer G features the presence of *Palaeoloxodon antiquus, Bison schoetensacki,* cervids, megacerine, *Dama*-like deer and two newly identified species: *Hippopotamus antiquus* and *Macaca sylvanus sp.* The record from layer H presents *Palaeoloxodon antiquus, Cervus elaphus ssp.,* cervids and megacerine. The faunal spectrum from layers I1 and I2 includes remains of *Palaeoloxodon antiquus, Bison schoetensacki, Bovidae sp., Hippopotamus antiquus*, *Cervus elaphus,* cervids, *Dama*-like deer and megacerine in layer I1, and *Palaeoloxodon antiquus, Bison schoetensacki*, *Bovidae sp.,* cervids and megacerine in layer I2.

Table 2.3 Large mammal taxa identified from Notarchirico (2016 – present) (modified from Moncel et al., 2023).

Layer	F	G	H	I1	I2
Species					
Palaeoloxodon antiquus (=Elephas antiquus)	x	x	x	x	x
Hippopotamus antiquus		x		x	
Bovinae indet.	x			x	x
Bison schoetensacki	x	x		x	x
Cervidae	x	x	x	x	x
Cervus elaphus ssp.	x		x	x	
Dama-like deer		x		x	
Megacerine indet	x	x	x	x	x
Macaca sp.		x			

Cervids largely dominate the faunal spectrum within layers H and I1. The large-sized megacerines are abundant, but their fragmentary preservation and the lack of antlers prevented a clear identification. The presence of *Dama*-like deer was attested through a distal metatarsal from layer G and an upper molar from layer I1, documenting for the first time the presence of fallow deer in the lower levels of Notarchirico. The anatomical representation of the cervids features an abundance of limb extremities, followed by some cranial and trunk elements. The straight-tusked elephant *Palaeoloxodon antiquus* prevails in layers F, G, and I2 but is more or less constant in all the layers. Cranial tusks, teeth fragments, trunks and girdle elements primarily represent this species. An almost complete fragment of a humerus and some indeterminate bone shaft fragments represent the appendicular skeleton. Larger bovids (Bos/Bison) are attested in all layers except for layer H. Isolated teeth, the trunk, the girdle, and long bone shaft fragments represent them. The newly identified species, *Hippopotamus antiquus* and *Macaca sylvanus sp.,* were identified, respectively, on four dental fragments and by a proximal fragment of a right ulna. The faunal list is similar to the upper part of the sequence excavated by Piperno (Alfa and A), confirming the attribution to the Isernia La Pineta Faunal Unit (Moncel et al., 2020e; 2023).

The archaeozoological and taphonomical studies (Moncel et al., 2020e; 2023) highlighted a high fragmentation rate of the faunal remains (most bones are less than 50 mm), with low identification indexes (the number of anatomically identified remains out of the total number of remains) and an abundance of isolated teeth. No anatomical connections were observed during the excavation. Dry and green bone fractures, alongside recent breakages, are the most recurrent type of fragmentation. The surfaces' preservation is very poor, with about a third of the faunal remains being illegible due to post-depositional alteration and fractures (*i.e.,* cracking, desquamation, concretion, chemical corrosion, and abrasion) that heavily modified the faunal assemblage. According to the interpretation of these data, these alterations are due to climatic and edaphic weathering, water exposition, and transport and/or trampling. The effect of water is also confirmed by the frequent presence of calcite crusts on the bones' surface. No or very scarce elements have shown carnivore marks. No clear cut marks or percussion marks could be identified in any of the excavated layers, excluding an anthropic modification of the bones – which, on the other hand, has been postulated and validated through the stone tools' use-wear analysis (Moncel et al., 2020e; Rineau et al., 2022).

The available transportable indices on the skeletal distribution of all species indicate layer F as a lag deposit, with a majority of remains of the less transportable groups and a high teeth-to-vertebrae ratio. On the other hand, data from layer I1 show a solid predominance of elements of the first group, which are usually the first to be sorted by fluvial transport, and a lower teeth-to-vertebrae ratio. This scenario seemingly matches a deltaic or lacustrine environment. For both layers, the hypothesis of fluvial sorting processes is supported, with faunal remains affected alternately by low and high-energy flows. Generally, the entire sequence provides evidence for "prolonged" exposure of the faunal remains to water and other alteration agents in a lacustrine or fluvial environment.

A preliminary taphonomical re-analysis of layer Alfa revealed that half of the faunal remains' surfaces show different degrees of abrasion due to water action from slight to strong stages (Moncel et al., 2023). The degree of legibility is low, with natural abrasion (polish and striations) and encrustations as the main natural alterations. Seemingly, the faunal remains were transported within the excavated area by water flow and bank erosion, which caused a second deposition of external elements. It is also plausible that the bone accumulation derived from the carcasses of animals that naturally died or were chased by carnivores or humans near the water stream. As for the 2016 area, the taphonomic results for layer alfa indicate that natural processes seem to be the primary agents behind the formation and subsequent modification of the bone bed. No anthropic marks have been detected so far on the faunal assemblage from this area, even though the association between lithic tools and bones persist. These results agree with the previous conclusions proposed for layer Alfa by M. Piperno's equipe: the bone accumulation from layer Alfa results from multiple accumulation events, mostly related to water flows. The skeletal distribution also points to a shore deposit or a low-energy deltaic or lacustrine environment, possibly with more violent hydraulic transport episodes. Similar environmental conditions might have occurred in layers E and J in the outside trench.

The small-mammal assemblage includes 53 remains (Tab. 2.4). Excluding layer F, where no micro-mammal remains were found, layer G features the presence of only two fragments of Lagomorpha indet. The species identified in layer H are Arvicolinae indet., Lagomorpha indet., and *Microtus (Terricola) savii*. From layer I1, the record is richer with the presence of *Talpa* sp., *Arvicola mosbachensis*, *Microtus* cf. *nivaloides, Microtus (T.)* cf. *arvalidens,* Arvicolinae indet., Rodentia indet., and Lagomorpha indet. Lastly, from layer I2 were documented *Microtus (T.)* cf. *arvalidens,* Rodentia indet., and Lagomorpha indet. *Arvicola mosbachensis* is the most represented species in the new stratigraphic sequence (MNI=6; NISP=22). The several remains of Lagomorpha indet.

might be assigned to *Lepus sp.* due to their morphologies and dimensions, though further analyses are required. The small-mammal assemblage from the new excavations is very similar to the previously published material (Sala, 1999), allowing the attribution of this portion of the stratigraphic sequence to the beginning of Early Toringian (*Arvicola-Microtus* zone, *Arvicola mosbachensis* sub-zone) (Sala and Masini, 2007).

The lithic assemblage from the new excavations consists of more than 1000 lithic objects divided into pebbles with percussion marks or broken pebbles, pebble tools, large cutting tools (LCTs, *i.e.,* bifaces, cleavers, unifacial tools, pick), cores, flakes, retouched flakes and retouched nodules (Tab. 2.5). The lithic material is always associated with the faunal remains. All the layers yielded a rich corpus of stone tools except for layer H (Tab. 2.5). The preservation of the lithic material surfaces is decent, with traces of alterations such as fractures, surface brightness (gloss), colour patina, thermal stress, and concretions (Moncel et al., 2020e; 2023). The hominins locally collected raw materials such as limestone pebbles and cobbles and different types of chert nodules, which were abundant along the paleochannels of the area in a secondary position. Four main lithotypes of chert were identified: silicified litharenites, nodular chert, vitreous chert, and radiolarite. The presence of limestone is reported as well. Such lithotypes occur in the polygenic pebbles and cobbles lags formed in the fluvial-lacustrine environment of the area of Notarchirico (Synthem of Palazzo San Gervasio) as products of the erosion of the outer geological units of the Southern Apennine formed after the evolution from late Triassic to Miocene of a deep-sea basin on passive margin (Lagronegro basin) to a foredeep basin (Irpinian basin) characterised by flyschoid sequences (Pescatore et al., 1999).

Table 2.4 Small mammal assemblage identified from Notarchirico (2016 – present) (modified from Moncel et al., 2023).

Layer	F	G	H	I1	I2
Species					
Talpa sp.				1	
Arvicola mosbachensis				22	
Microtus cf. *nivaloides*				1	
Microtus (T.) cf. *arvalidens*				1	1
*M. (T.) savii**			1		
Arvicolinae indet.			1	6	
Rodentia indet.				3	1
Lagomorpha indet.		2	1	11	
*Reworked					

A recent taphonomic analysis of the lithic tools' surface from layer F highlighted that despite weathered surfaces being the most numerous across the artefacts, well-preserved surfaces withhold a decent percentage within the assemblage, suggesting some fast-sealing episodes of tools in the palimpsest (Moncel et al., 2023). Additionally, the scarce presence of rolled artefacts shows that relatively few items were transported by high-energy water flows. Evidence of mechanical alterations is also limited, hinting that trampling activities might have only marginally affected the lithic corpus. The cutting edges are relatively fresh.

The artefacts can be divided into two main technological groups: core and flake (analysed in this work) and heavy-duty components, with the former being far more common than the latter across the entire stratigraphic sequence, except for layers F and G (Tab. 2.5). The goal of the debitage production is mainly small-sized flakes (10-20 mm) and, more rarely, larger flakes (40-120 mm) employing different types of knapping strategies (discoid, unifacial, multifacial, centripetal, etc.). Hominins showed exceptional skills in adapting to the available small-sized volumes, optimising the knapping process through short yet complex reduction sequences. Retouched tools are also attested (denticulates, scrapers and pointed tools). In addition, hominins selected small chert nodules (20-40 mm) to shape through an abrupt or denticulate retouch. Most chert nodules are cubic or slightly rounded (Moncel et al., 2020e; 2023).

Various artefacts characterise the heavy-duty component with a low morphological standardisation (unifacial, bifacial and trifacial pebble tools, diverse LCTs, rabots and chopping tools). These are mainly obtained from limestone pebbles, with only one chert implement. The bifaces, on the other hand, show complete control of the bifacial and bilateral symmetry. They are realised mainly on limestone and the few locally available chert pebbles. The shaping process covers a large portion of the periphery and surface of these tools by one or several series of removals with evidence of retouching to regularise the cutting edges. The cross-sections are symmetrical or plano-convex, often presenting a cortical base. The recent analysis also highlighted evidence of recycling on the cutting edges of one of the handaxes. A total of six bifaces were recovered from layers F and G, further postponing the rise of the Acheulean cultural complex in this region to 680 ka.

Table 2.5 Lithic components of the layers F to I2 at Notarchirico (2016 – present) (modified from Moncel et al., 2023).

Layer	E-F	F	G	H	I1	I2
Categories						
Flakes in chert (retouched flakes)	67 (10)	195(31)	223 (67)	63 (16)	255 (47)	51 (16)
Cores in chert	1	13	35		41	11
LCTs: Unifacial-bifacial, Cleavers, Bifaces		10 (3 bifaces)	9 (2 bifaces)			2
Flakes in limestone	4	50	9	1	10	4
Cores in limestone		11	2		1	
Retouched nodules in chert	1	12	77	8	39	5
Pebble tools (unifacial, bifacial, with isolated removals)	1	104	71	1	32	12
Pointed pebble tools (unifacial, bifacial)		16	7		9	1
Total	74	411	424	73	386	87

Preliminary use-wear and residue analyses have been performed on flakes and tools (Moncel et al., 2020e; 2023). The analyses revealed the presence of different post-depositional processes on the artefacts' surface: patina, gloss (a consequence of the mechanical action of the water flow), striations and mechanical alterations. Despite these processes, it was possible to observe the presence of use-wear. The results highlighted the interaction with soft to hard materials (fleshy tissue and woods have been identified so far), mainly worked by cutting and scraping and, to a lesser extent, by mixed actions like engraving. Seemingly, the debitage implements were employed for different activities and purposes, not only related to food processing. The residue analyses focused on 50 artefacts from layers H, I1 and I2, revealing traces of feather barbules, plant, and wood, often co-occurring with wear patterns suggesting they were use-related. The preservation of use-related residues suggests that some stone artefacts are in primary context and were buried relatively rapidly after being discarded. More prolonged exposure on the surface or movement by water dramatically decreases the likelihood that residues will survive. Thus, while the evidence from the surface analysis shows patination and rolling on some pieces, the residue preservation suggests that others were undisturbed (Moncel et al., 2020e; 2023).

The spatial analysis performed in 2023 revealed significant information for each layer (Moncel et al., 2023). Layer F is a dense bed of pebbles where the natural or retouched material does not show a specific orientation. The high density in the distribution of the archaeological material is possibly due to successive site occupations. Faunal remains are located on the "pavement" or between the pebbles with no specific orientation. In layer G, pebbles are dispersed among a coarse-grained deposit, corresponding to the remains of a pebble pavement. The material is primarily concentrated over a thickness of 30 cm (sub-unit G1). Post-depositional disturbances affected the vertical more than the horizontal distribution of the material. Lithic artefacts cover a larger surface than the faunal remains, with no specific distribution patterns. Layer H is the poorest in terms of quantitative archaeological material. The lithic material is lying flat around the elephant's humerus, which does not show any trace of human activity.

On top of that, the residue analysis on the lithic tools from this layer revealed exclusively plant and wood use. The material from layer H is thus seemingly disturbed in spatial distribution and patterning by fluvial and post-depositional processes. Nonetheless, the hypothesis of short-term and sporadic frequentations by hominins cannot be entirely ruled out.

Layer I1 is a 30-cm-thick bed composed mainly of yellow sands and some small and large dispersed pebbles. There is also a thin lens of small pebbles with archaeological material (I1a). The material is not vertically oriented and shows diverse orientations. Faunal remains and lithic tools are homogeneously dispersed throughout the layer, regardless of size, species and category. The vertical distribution of the material shows a higher density at the bottom of the layer, at the interface with layer I2. This could indicate a palimpsest situation with a denser occupation at the beginning of the deposit's formation, with a mixture of some material coming from I2 due to post-depositional processes. Layer I2 is a bed of pebbles preserved in situ with a random distribution of the different lithic categories and faunal remains.

2.2. The archaeological site of Isernia La Pineta

The site of Isernia La Pineta lies within the fluvial basin of the Upper Volturno Valley, a few kilometres outside the town of Isernia (Molise, Italy; Fig. 2.5). It is an extensive open-air site located at an elevation of 457 m a.s.l. and has been systematically excavated since 1979 (Crovetto et al., 1994; Peretto, 1996; 1999; 2006; Peretto et al., 2015; 2004a; Coltorti et al., 2005; Rufo et al., 2009; Gallotti and Peretto, 2015; Channarayapatna et al., 2018; Muttillo et al., 2021b; Carpentieri et al., 2023a). The site was discovered in 1978 during the works of the Napoli-Vasto highway. The present excavation area includes Sector I (250 square meters; Fig. 2.5) and Sector II (90 square meters), separated by railway tracks. Sector I lies north of the highway and was museumised in 1999 by constructing a pavilion, while Sector II was extensively excavated to facilitate the highway's construction.

The site lies inside the main fluvial-lacustrine filling of the "Le Piane basin", representing the highest and, at the same time, the oldest Pleistocene sedimentological unit described in this area. The deposits, composed of a series of fluvial terraces, comprehend a sequence of fluvial, lacustrine and volcanic sediments in which lies the archaeological deposit (Fig. 2.5). The volcanic component is mainly associated with the Plinian and ultraplinian eruptions of the Roccamonfina and the Monte Vulture volcanic complexes. "Le Piane basin" is a sub-basin within the more extensive system of the Carpino – Le Piane Basins Fault System (CLPBFS). The filling of the basin is characterised by four major unconformity stratigraphic units (UBSUs) deposited during the Pleistocene and Holocene and organised in three fluvial deposits located at progressive elevations on the valley floor (Coltorti, 1983; Coltorti et al., 2005; Peretto et al., 2015).

The oldest unit (UBSU 1), corresponding to the Lower and Middle Pleistocene, comprises a 60 m thick deposit of gravels, silts and clays covered by calcareous tufa up to 20 m thick. The gravel deposit corresponds to the distal margins of several fluvial conoids deposited at the basin's margins simultaneously with the clays. The successive unit (UBSU 2, Middle Pleistocene) features sands, gravels and silts containing many coarse-grained tephras (pumice) layers that extensively outcrop to the southwest of Isernia. In the site's proximity, the calcareous tufa outcrops are covered by alluvial deposits of sand and gravel. The top depositional surface of UBSUs 1 and 2 (alluvial deposits and tufa) is located at the same elevation and was named "main filling" or "main unit". The youngest UBSU corresponds to a Late Pleistocene terrace framed between the Holocene floodplain and the older UBSU. At the same elevation of the youngest UBSU are some alluvial fans from the lateral valleys covering the oldest UBSU. The archaeological deposit of Isernia lays 4m below the surface within the older UBSU buried under sediments from the Middle Pleistocene.

The stratigraphy of Isernia La Pineta from the base to the top consists of 5 sedimentary units (Fig. 2.5):

- Unit 5 belongs to the upper part of UBSU 1 and comprises clayey lacustrine layers alternated to thin levels of gravel and debris (maximum thickness of 70 m).
- Unit 4 also belongs to the upper of the UBSU 1 and is characterised by travertines deposited by the freshwater river (maximum thickness of 50 m) and, on its top, by a primary pyroclastic flow named Unit 4 T containing white weathered pumice (up to 1 cm in diameter).
- Unit 3 belongs to UBSU 2. It is a palustrine deposit that features sands and thin layers of gravel deposited by ephemeral rivers and is subdivided into three sedimentary sub-units (U3A, U3E, U3F). Sands are very rich in reworked volcanic material, including sanidines and clinopyroxenes. These volcanic minerals were used to obtain a 40Ar/39Ar age of 610 ± 10 ka (2σ) in the 3coll layer by Coltorti et al. (2005).

- Unit 2 belongs to UBSU 2 and includes sands and gravels deposited by ephemeral streams. The top of this unit corresponds to a highly weathered palaeosol (S2).
- Unit 1 is a colluvium sequence with sands and gravels attesting to a pyroclastic fall dated by 40Ar/39Ar at 499 ± 13 ka (2σ) and weathered at the top by a palaeosol (S1).

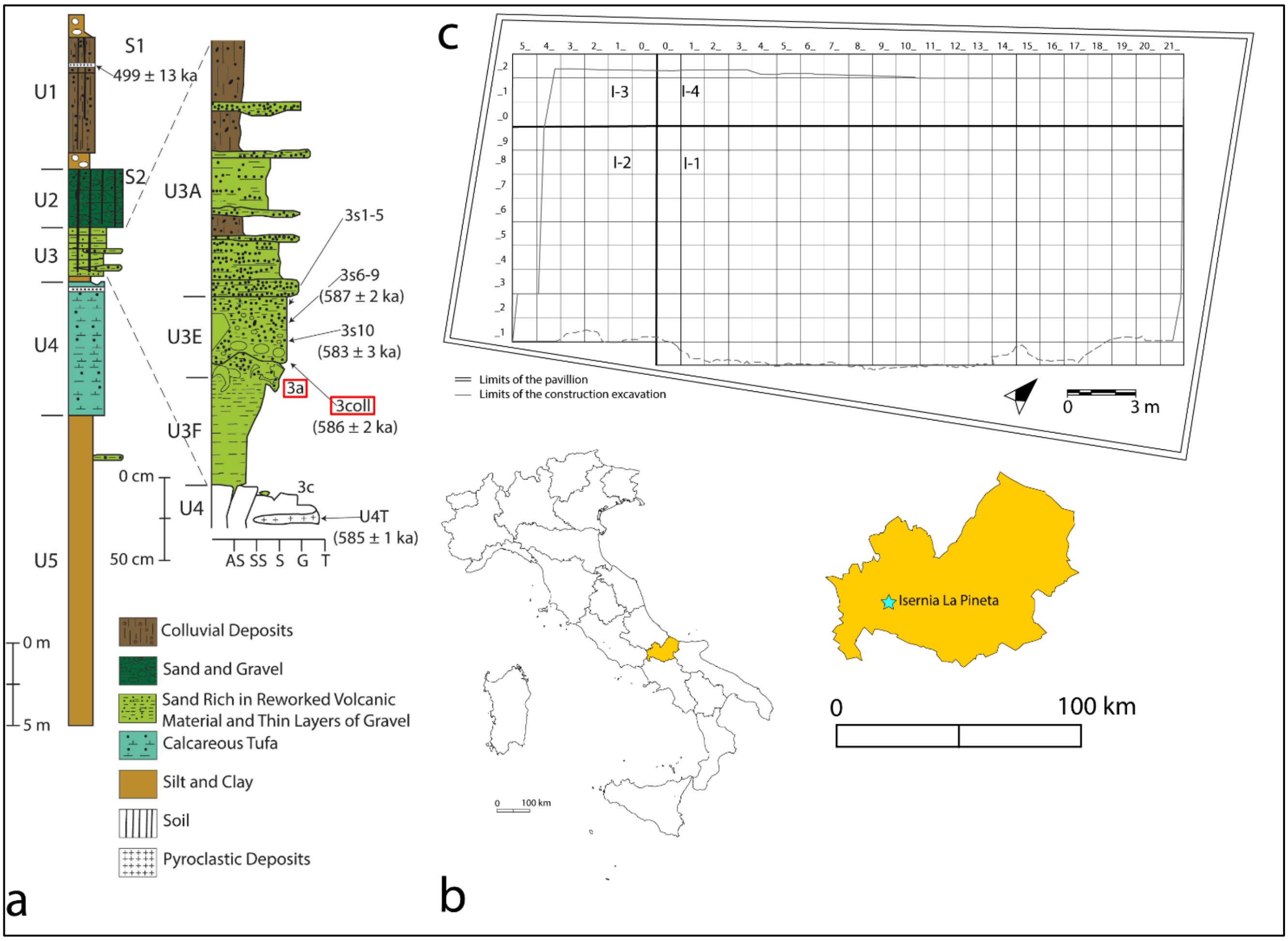

Figure 2.5 A) Stratigraphic sequence of Isernia La Pineta (modified from Zanazzi et al., 2022). B) Location of the site. C) Excavation area of Sector I (modified from Gallotti and Peretto, 2015).

The archaeosurfaces were identified in the sub-Units 3F (t.3c, t3b, t.3a) and 3E (3coll, 3s 1-5, 3s 6-9, 3s 10), with the layers t.3c, t3.a and 3coll being the richest in lithic and faunal remains. Additional datings using sanidine crystals through the 40Ar/39Ar laser fusion method were performed on the fluvial units 3coll (586 ± 2 ka), 3s10 (583 ± 3 ka) and 3s6-9 (587 ± 2 ka), right above the archaeosurface t.3a. The site's chronological constraints have been recently set approximately 583 ka, corresponding to the end of the interglacial stage 15 (Fig. 2.5; Peretto et al., 2015). In 2014 a human deciduous tooth (*Homo* cf. *heidelbergensis*) was found within layer 3coll (U3E; Peretto et al., 2015; Lugli et al., 2017). The isotopic analyses on the tooth suggest a local living location for the mother of the Isernia child, proposing a limited mobility pattern for the human groups of this chronological phase (Lugli et al., 2017).

The archaeological material from Isernia La Pineta consists of many faunal remains associated with many lithic objects. The analysed faunal assemblage (Tab. 2.6) belongs to the Isernia La Pineta Faunal Unit, ascribed to the Middle Galerian (Thun Hohenstein et al., 2009; Channarayapatna et al., 2018; Pineda et al., 2020). Large herbivores dominate the faunal spectrum. The species identified

(Tab. 2.6) feature the presence of *Elephas (Palaeoloxodon) antiquus, Hippopotamus* cf. *antiquus, Stephanorhinus hundsheimensis, Bison schoetensacki* (most represented species with the *Stephanorhinus hundsheimensis* and the cervids)*, Praemegaceros solilhacus, Cervus elaphus* cf. *acoronatus, Dama* cf. *roberti, Capreolus* sp., *Sus scrofa,* and *Hemitragus* cf. *bonali*. Among the carnivores, the most abundant remains belong to *Ursus deningeri*, even though one tooth of *Panthera leo fossilis* and one mandible of *Panthera pardus* have been recently identified. Additional data led to the identification of *Hyaena* cf. *brunnea, Castor fiber,* and *Macaca sylvanus*. The small-mammal assemblage features the presence of *Arvicola mosbachensis, Pliomys episcopalis, Microtus (Terricola) arvalidens, and Sorex* aff. *rutonensis, Talpa* sp., *Crocidura* sp., *Pliomys coronensis, Clethrionomys* sp., *Iberomys brecciensis*, and *Microtus* gr. *arvalis-agrestis*. The herpetofauna and avifauna record includes *Emys orbicularis, Anas platyhyncha* and *Tachybaptus ruficollis* (Tab. 2.6). The pollen studies revealed that herbaceous plants are dominant, primarily palustrine taxa such as *Cyperaceae* and *Typha*. Rare pollens of *Alnus*, *Salix cf.* attest the arboreal taxa. *Populus, Platanus, Quercus, Pinus* and *Cedrus*. The small-mammal assemblage is chronologically attributed to the Early Toringian Small Mammal Age (Tab. 2.6; Zanazzi et al., 2022).

The environmental data composition suggests an open arboreal steppe environment with scattered woody areas alongside the fluctuating presence of ephemeral watercourses and ponds (Zanazzi et al., 2022). The small-mammal assemblage indicates the climate as generally dry with brief rainy periods during which the rivers occasionally flood. The presence of *Macaca sylvanus* is an indicator of the onset of warmer intervals in the upper sandy layers. A recent analysis of the paleoclimate and paleoenvironment highlighted that mean annual precipitation highly decreased during the 600 – 400 ka timeframe, leading to increased aridity. Despite this, mean annual temperatures during the same chronological interval were broadly similar to present-day temperatures (~ 13 °C). The precipitation seasonality was likely low, and the temperature seasonality was moderate. These environmental conditions depict a mosaic ecosystem with an open landscape, arboreal cover, water and raw material availability suitable for large herbivores, herds, and human groups (Zanazzi et al., 2022).

Table 2.6 Faunal species documented at Isernia La Pineta .

Family		Genus and Species	Common name	3S1-9	3S10	3coll	3a	3c
REPTILIA	Emydidae	*Emys orbicularis*	European pond turtle				x	
AVES	Anatidae	*Anas platyhyncha*	Mallard/wild duck				x	
	Podicipedidae	*Tachybaptus ruficollis*	Little grebe/dabchick				x	
SORICOMORPHA	Talpidae	*Talpa* sp.	Mole				x	
	Soricidae	*Sorex* cf. *runtonensis*	Shrew				x	
		Crocidura sp.	Crocidura/musk shrew				x	
PRIMATES	Cercopithecidae	*Macaca sylvanus*	Barbary macaque	x				
CARNIVORA	Ursidae	*Ursus deningeri*	Bear	x	x	x	x	x
	Hyaenidae	*Hyaena* cf. *brunnea*	Hyena	x				
	Felidae	*Panthera leo fossilis*	Lion				x	
		Panthera pardus	Leopard			x		
PROBOSCIDAEA	Elephantidae	*Elephas (Palaeoloxodon) antiquus*	Elephant	x	x	x	x	x
PERISSODACTYLA	Rhinocerotidae	*Stephanorhinus hundsheimensis*	Rhinoceros	x	x	x	x	x
ARTIODACTYLA	Hippopotamidae	*Hippopotamus* cf. *antiquus*	Hippopotamus		x	x	x	x
	Suidae	*Sus scrofa*	Wild boar				x	
	Cervidae	*Praemegaceros solilhacus*	Megacerine	x	x	x	x	x
		Cervus elaphus cf. *acoronatus*	Red deer	x	x	x	x	
		Dama cf. *roberti*	Fallow deer	x	x		x	x
		Capreolus sp.	Roe deer				x	
	Bovidae	*Bison schoetensacki*	Bison	x	x	x	x	
		Hemitragus cf. *bonali*	Bonal tahr			x	x	
LAGOMORPHA	Leporidae	*cf. Oryctolagus*	European rabbit/coney				x	
RODENTIA	Castoridae	*Castor fiber*	Eurasian beaver	x			x	
	Microtinae	*Pliomys episcopalis*	Vole				x	
		Pliomys coronensis	Vole				x	
		Clethrionomys sp.	Slender vole				x	
		Microtus aff. *arvalis*	Meadow vole				x	
		Microtus brecciensis	Meadow vole				x	
		Microtus (Terricola) arvalidens	Meadow vole				x	
		Arvicola mosbachensis	Meadow vole				x	
		Iberomys brecciensis	Vole				x	

The archaeozoological and taphonomical studies – the most recent one focused on layer 3 coll - highlighted that bone surface abrasion affects almost half of the faunal remains, indicating that the bone accumulation of the site was massively influenced by water flows (Thun Hohenstein et al., 2009; Pineda et al., 2020). The presence of striations due to the volcanic origin of the sedimentary particles and traces of trampling on the bones' surface made identifying anthropogenic modification difficult. Signs of large carnivores' interference were also detected. Cut marks and breakages due to human activity were nonetheless identified on a small portion of the bones, hinting at butchering activities. The authors underlined that given the poor preservation of bones' surfaces and the several taphonomical alterations that the faunal assemblage of Isernia underwent, cut marks and other signs of human-animal interactions might have been masked, under-represented or even destroyed by these agents (Pineda et al., 2020). The 80% of tooth marks on limb bones and ribs were documented, suggesting a primary access to the carcasses from the carnivores. The absence of the co-occurrence of human and carnivore activities might indicate that both groups acted independently and at different, repeated times on the faunal remains, equally contributing to their accumulation.

The lithic industry of Isernia La Pineta is realised on chert slabs and limestone pebbles, with the former being the most exploited raw material. The primary deposit lies about 5 km from the site where the chert (varicoloured jaspers) occurs in strata and lenses within the Cretaceous limestone formations (Sozzi et al., 1994). Hominins collected chert (under sub-cubic/rectangular slabs of 60-100 mm) and limestone in alluvium deposits of the Carpino River near the site. Chert's slabs exhibit a fine-grained texture and quality. Still, they are characterised by many fracture planes due to the intense tectonic activity recorded in this region and many breakages due to their subsequent alluvial transport. Iron and manganese oxides are often infiltrated within the latent fracture planes, invalidating the raw material quality and morphology and causing further breakages during the knapping activities. Chert cobbles and pebbles are very rare. Given the high degree of breakage within the chert slabs, the presence of cortex is absent or minimal (Crovetto et al., 1994; Gallotti and Peretto, 2015; Carpentieri et al., 2023a).

Two lithotypes of limestone have been identified in primary and secondary sources: a micro-crystalline facies, corresponding to a high-quality limestone, compact, homogeneous and easy to knap, and a marly facies, tender, very porous and unsuitable for knapping. The limestone is available in the alluvial deposits under medium-large-sized blocks and angular fragments where the marly variety is predominant. The limestone artefacts were knapped exclusively on the micro-crystalline lithotype, indicating a strict selection process by the hominins, not to mention an excellent knowledge of the lithic resources available in the surrounding landscape.

The lithic industry realised on chert is oriented to producing morphologically non-standardised flakes of small and medium dimensions (Crovetto et al., 1994; Peretto, 1994; 2006; Peretto et al., 2004b; Gallotti and Peretto, 2015; Carpentieri et al., 2023a). Different knapping strategies were employed for the debitage, including unipolar, centripetal, and discoid (primarily in layer t.3c), some applied regardless of the slab shape and volume. The reduction sequences are short and strongly codified on the morphological and qualitative availability of the slabs. A recent review of the lithic assemblage from layers t.3c, t.3a and t.3 coll revealed the presence of more complex reduction sequences, mostly related to the use of the discoid method, suggesting the presence of a high degree of expertise and planning by the hominins (Gallotti and Peretto, 2015; Carpentieri et al., 2023a). A high ratio of retouched flakes characterises the lithic production of Isernia with denticulates, scrapers, notches, and pointed tools, while no evidence of bifacial tools or LCTs has been detected. Extensive use of freehand percussion and bipolar on anvil technique – primarily to overcome the qualitative issues of the raw material – is reported (Anconetani et al., 1992; Crovetto et al., 1994; Vergès and Ollé, 2011).

The limestone was selected to realise medium-large-sized flakes exploiting fluvial pebbles and cobbles. The reduction sequences, mainly conducted through unipolar-unifacial debitage, are short and aim to obtain medium-sized flakes sporadically retouched (Rufo et al., 2009; Gallotti and Peretto, 2015). Another goal of the limestone industry was the realisation of various pebble tools, including chopper cores, large denticulates and heavy-duty tool morphotypes (Anconetani et al., 1992). Cobbles and pebbles of medium and large dimensions were collected for their realisation. The possibility that the limestone implements were employed for battering and percussive activities cannot be discarded even though identifying clear percussion marks related to anthropic activities on this type of raw material and in an open-air context is challenging.

Use-wear analyses have been performed (Longo, 1994; Carpentieri et al., 2023a) on the chert artefacts revealing butchering-oriented activities for the site of Isernia La Pineta. The most recent work on layers t.3a and t.3coll (Carpentieri et al., 2023a) showed that chert flakes were exclusively used for carcass processing on soft and soft-medium material (meat, fresh hide and animal tissues). Flakes’ function was primarily cutting and, to a slightly lesser extent, scraping activities, although all the phases of carcass processing were identified. Minor traces of bone working were also observed. They might be related to periosteum removal required during marrow extraction, confirming a butchery-related role of the site (or at least of the chert materials).

Chapter 3 Materials and Methods

3.1. Methodologies for lithic technology: a Lower Palaeolithic overview

This work aims to analyse the debitage production (*i.e.,* cores, flakes, retouched flakes) of Notarchirico and Isernia La Pineta. In the last decades, the techno-economic approach and the concept of *chaîne opératoire* proved to be the most efficient tools to analyse a lithic corpus and address the cultural and behavioural implications of the hunter-gatherers' material culture during the Palaeolithic (Leroi-Gourhan, 1965; Tixier and Inizan, 1983; Boëda, 1995; Inizan et al., 1995; 1999; Pelegrin, 2000; Peresani, 2003; Arzarello et al., 2011; Goodale and Andrefsky, 2015). Therefore, they have also been applied in this work, further facilitating the comparison with other European sites sharing the same chronology (synchronic perspective) and allowing the observation of possible evolutions over time (diachronic perspective).

The techno-economic analysis was applied to conceive all the phases of the flaking activity as a single process, from the raw material selection through the core reduction strategies and the obtainment of flakes until their abandonment. This approach joins the classical technological analysis with the economy (*i.e.,* management of available resources) of the raw materials employed by the hominins: spatio-temporal dimension of the *chaîne opératoire*. The goal is to establish the provisioning modalities, from primary outcrops to secondary deposits (streams, alluvial fans, paleosols, recycled old patinated artefacts), and the morphology of the exploited raw materials to provide a more accurate framework to the knapping process and the land-use management. Ultimately, the reconstruction of the *chaîne opératoire* itself is fundamental to understanding the production's goals and the modalities (operative schemes, knapping strategies, knapping methods, techniques, etc.) applied to pursue such goals.

From this perspective, one of the primary objectives of the technological analysis is the identification of a knapping method whose concept – what is and means - has changed through the years, adjusting to the evolution of the technological approach and the different chrono-cultural frameworks considered. A knapping method is a planned sequence of reasoned actions to achieve a goal by applying a more or less complex mental scheme (Tixier, 1965; Inizan et al., 1995). In the last 30 years, it has been established that a knapping method implies a codified mental prefiguration at its base, granting extreme flexibility and versatility over space and time (Boëda et al., 1990; Boëda, 1993; 1994; Forestier, 1993; Bourguignon, 1997). On a practical/knapping-wise level, this translates into specific volumetric conceptions of cores and flakes corresponding to morphological standardised productions. Because of this, concepts such as "standardisation", "hierarchisation", and "predetermination" were tightly connected with the definition of a knapping method.

On the other hand, the existence of these specific volumetric conceptions that different knapping methods can share or have at their origin – *e.g.* the centripetal conception – led to the adoption of the word "concept/conception" (*i.e.,* nowadays, we often refer to the Levallois as a "concept"; we often refer to the bifacial shaping has a versatile concept) to express this common and yet diversified substratum (Boëda, 1994; Peresani, 2003). Eventually, a knapping method became such because it was being transmitted and passed on in terms of precise concepts and ideas while still retaining specific characteristics that would make it technologically and morphologically identifiable.

What happens when we attempt to apply these notions to a chronological framework during which the concept of what a knapping method is might not be present? As underlined in the Introduction chapter, the European Lower Palaeolithic is a long-lasting and rich chronological phase during which the development of behavioural complexity is thought to arise in many aspects (Manzi et al., 2011; Stout, 2011; Stewart and Stringer, 2012). The lithic industries of this period encompass a substantial variability, ranging from "simple" to more "complex" assemblage – seemingly following the development of the human behavioural complexity – but always being connoted as somehow "unstructured" and "chaotic" (Vaquero and Romagnoli, 2018). Because of this, pattern recognition within such lithic industries became more challenging, while the lack of an apparent structure and standardisation has often led the scientific community to question the existence of - or at least the impossibility of identifying – a knapping method during the Lower Palaeolithic. The ambivalence in the concept of façonnage and debitage has also been considered a sign of a chronological and anthropological phase of turmoil during which a methodological substratum has not yet consolidated properly.

As an outcome, most works focusing on European Lower Palaeolithic lithic assemblages feature a diversified and often inhomogeneous range of terms to describe hominins' technical behaviours. The addressed matter in lithic technology became tracking the development of complexity within a chronological phase (*i.e.,* the Lower Palaeolithic), during which the shift from a complexity-free situation (level 0) to a progressively emerging one (level 1) was seemingly witnessed (Clark, 1969; Carbonell et al., 2009; 2016). As a side note, this process also generated a superimposition between the notion of "knapping method" and "complexity", where contexts lacking any trace of standardisation, predetermination or hierarchisation – often considered as the main features of a knapping method – in their lithic corpus were also deemed complexity-free. Ultimately, the importance of the notion of culture (how to define it, whether it is more or less detectable, etc.) represented a further challenge for lithic technology. The shift to the quest for complexity also corresponded to a shift to the quest for the evolution of human groups as culture-makers – affecting in different manners African, Asian and European archaeology. It is the case of the cultural complex of the Acheulean, which started as a lithic facies and nowadays comprises a multitude of technical behaviours identified within the lithic industries, whose implications are beyond the knapping method paradigm (Diez-Martín et al., 2015; Moncel et al., 2018d; Pope et al., 2018; Duke et al., 2021). The same concept regarding bifaces and bifacial shaping has vastly impacted our perception of the Lower Palaeolithic.

In the present state of the art, many recent works focused on re-evaluating old sites. At the same time, new data significantly improved our knowledge of the Lower Palaeolithic, leading to a global consensus around the degree of complexity displayed by the earliest lithic assemblages of Europe. Nonetheless, terminologies and methodological issues persisted, and the scientific community is attempting to find efficient means to bring consistency within this broad chrono-cultural phase. To overcome these debates, several authors proposed to use the same terminology adopted for the African Lower Palaeolithic (*i.e.,* Early Stone Age), where Mode 1 and Mode 2 (Clark, 1977) correspond to the shift between core and flake-oriented assemblages to the appearance of handaxes – and more in general to the development of the Acheulean package – also in Europe. The idea is to offer an easier terminological comparison and somehow propose a technological and methodological affiliation between the two continents. Despite this attempt, the employment of the "Mode" terminology may fail at including the massive variety that encompasses the lithic assemblages over such prolonged chronologies, which is also why, for the Early Stone Age, these terms are seeing their efficiency decreasing over the years, if not for a scientific convention.

Following this trend, we tried to tackle the topic of the methodological attribution of European Lower Palaeolithic lithic industries in a recent work (Carpentieri and Arzarello, 2022), which will represent the methodological groundwork of the present work.

3.1.1. The opportunistic debitage

As previously mentioned, the quest for complexity became the leitmotif of lithic technology during the Lower Palaeolithic, shifting from the "knapping method" paradigm characterising more recent periods. Because of this, more than in other chronologies, lithic artefacts grew into essential proxies to track the evolution of human behaviours and their material culture. Some authors argued that along this process, an actual overestimation of the importance of lithic technology for prehistoric people was taking place. In this scenario, ancient knappers were devoting most of their time, energy, and cognitive abilities to manufacturing stone tools. Hence, the involved mental processes in knapping were allegedly driven by well-defined concepts reflected in structured and standardised procedures. Since its beginning, but mostly over the last 30 years, the technological approach has emphasised the importance of mental constructs in lithic productions. This tendency, simplified in a recent statement, "*allowed some researchers to maximise the use of the predetermination concept in the interpretation of lithic technologies"* (Vaquero and Romagnoli, 2018, p. 337), resulting in a gradual loss of interest in the contexts lacking any, or showing very low, degree of predetermination. Additionally, given that pattern recognition is facilitated in morphologically standardised assemblages, the "appeal" of unstructured and chaotic strategies, such as the one characterising the Lower Palaeolithic, decreased even more. Vaquero and Romagnoli (2018) further state that the same debate regarding the appearance of human complexity, together with the recurrent idea of a linear technological evolution from "simple formal" to "complex formal" productions, might have caused an underestimation of the concept of a low degree of predetermination in lithic assemblages.

In this perspective, the distinction between complexity and simplicity developed into several dichotomies in archaeological research (i.e. curation/expediency, expediency/opportunism, etc.), mainly when the amount of time and energy invested in tool manufacturing was considered. Simultaneously, in lithic technology, notions such as predetermination, hierarchisation, and standardisation became the mirror image of these dichotomies, often standing as the boundary between simple and complex in prehistoric contexts. The methodological assumption at the base of this work and the related papers (Arzarello, 2003; Carpentieri and Arzarello, 2022) is not to erase the concept of simplicity from human technical behaviours but rather to question the methodological implications of assemblages considered as complex- and planning-free.

The definition of opportunistic debitage has its origin in the work of Arzarello (2003), in which by analysing the Mousterian sequence of Riparo Tagliente, the issue concerning the analysis – and methodological attribution – of debitage productions not falling within the methodological paradigm of Levallois-Discoid-Laminar was addressed. In the case of Riparo Tagliente, these productions represented the majority of the entire lithic assemblage and were undeniably a critical component of the hominins' material culture, even more than other well-known reduction methods (Arzarello, 2003). Through technological analysis and extensive experimental activity, the study of this category of lithic artefacts (including cores, flakes, and retouched flakes) revealed several common traits:

- a massive subordination to the morphological criteria of the available raw materials;
- highly flexible and variable reduction sequences (unipolar, orthogonal, bipolar, and centripetal);
- length of the reduction sequences influenced and adjusted to the raw material volume/morphology;
- reduction sequences related to specific morphologies to speed the production process and optimise volumes' exploitation;
- production of morphologically non-standardised flakes (which, as a side note, were primarily selected for retouching activities way more than Discoid, Levallois or Laminar flakes, also increasing their "time and energy" value);
- high replicability of the technical gestures;
- absence of surfaces' preparation or hierarchisation;
- low degree, or absence, of predetermination.

Building on these assumptions and starting from the structure of the debitage method S.S.D.A. (Système par Surface de Débitage Alterné; Ashton et al., 1992b; Forestier, 1993), which was documented within the Riparo Tagliente's lithic assemblage, Arzarello developed the concept of opportunistic debitage. It comprises the algorithm and the fundamentals of S.S.D.A. (*i.e.,* morphological and volume conception) but unlike the latter, it also implies the presence of a mental scheme and capacity of abstraction which Forestier did not consider as a requirement for the S.S.D.A. makers: *"L'approche du tailleur clactonien n'est pas une approche qui engendre une stratégie issue d'un schéma mental nécessitant, comme dans le Levallois des fac- ultés d'abstraction très développées"* (Forestier, 1993, p. 59). The introduction of the mental scheme notion – which, as witnessed by the evolution of the lithic technology over the years, became a crucial component of knapping methods – was meant to highlight and include the variability and versatility of the opportunistic debitage and, at the same time the presence of a precise methodological substratum beneath it.

Therefore, opportunistic debitage was defined as *"a flaking method oriented to massive exploitation of raw materials, not implying the preparation of any core or surface. The striking platforms and knapping surfaces are created as far as the flaking activity continues. [...] The opportunistic debitage includes an infinite range of variants deriving from the same common operative scheme."* (translated from Arzarello, 2003, p. 6; and modified from Carpentieri and Arzarello, 2022, pp. 11–12). The term opportunism was not applied negatively but referred to its original semantic definition: "a behaviour in which someone adapts his actions to each context to gain the most advantage from it" (The Oxford English Dictionary, O.E.D.). In the recent work of Carpentieri and Arzarello (2022), the purpose of the opportunism/opportunistic term has been further addressed to provide a more accurate contextualisation of its meaning as a debitage method.

The history of the term opportunism in archaeological and ethnographical research goes back to the concept of expedient and curated technology formulated by Binford (1977; 1979). These concepts structure themselves on the degree of technological investment (i.e., time and energy) required to manufacture stone tools. According to Binford, curation and expediency refer to different forms of technological organisation. Curated technologies imply a high level of investment, being very organised in artefact manufacture and maintenance. On the other hand, expedient technologies have poorly organised manufacturing procedures without any long-term planning regarding the artefact's life. Over the years, the concept of expediency has often been used to characterise unstructured and chaotic technical behaviours ("simple formal"), in contrast to more complex ones associated with curated technologies. Even though this might be an oversimplification, the dichotomy between high- and low-cost technical behaviours has been steadily present, whether implicit or not, in archaeological research and has been highly debated ever since its definition to postulate the presence of complex thinking.

Initially, even if the debate extensively focused on the definition and characterisation of curated technologies within lithic assemblages, the notion of expediency has witnessed an expansion of its original theoretical boundaries, being declined under many aspects. For instance, Nelson (1991) stated that expedient behaviours comprised a degree of planning consisting of scheduled and predictable activities. This allowed him to introduce the distinction between expedient and opportunistic technologies, defining the latter as technical behaviours responding to immediate, unanticipated conditions, hence lacking any planning. Within the present state of the art, the framework of expedient technologies has been significantly reconsidered as an attitude applied to lithic industries' analyses, in which concepts as complexity might still coexist, albeit with an apparent lack of time, energy and predetermination invested for their realisation (Nicoud et al., 2016; Daffara et al., 2018; 2021; Romagnoli et al., 2018; Vaquero and Romagnoli, 2018). On the other hand, opportunistic behaviours remained as notions designating the complete absence of complexity and planning in lithic assemblages, even describing rudimental and primitive knapping activities (Crovetto et al., 1994; Rodríguez et al., 2011; Mahaney, 2014; Gallotti and Peretto, 2015; Antoine et al., 2016; Nicoud et al., 2016; Santagata et al., 2017). This background has often prevented us from considering this kind of industry from a technological and methodological perspective, eventually leading to another dichotomy between complexity and opportunism. This is particularly relevant for Lower Palaeolithic industries where pattern recognition might be more challenging due to the absence of structure and standardisation (morphologically likewise). However, as previously stated, it is also a rich chronological phase where the development of behavioural complexity is thought to arise in many aspects (Carpentieri and Arzarello, 2022).

Thus, the use of the term opportunism is aimed at re-contextualise the capability of adaptation of prehistoric people in a "positive" way, whereby positive means the plausible presence of a methodological substratum (hinting to the existence of complexity?) within these productions and not merely to point out a technical behaviour enabled in response to specific circumstances without any degree of planning. Moreover, concepts such as expediency, curation, and opportunism often decline according to the description of technical behaviours that already fall into methodological categories. In this sense, they explain tendencies about the information gathered from the technological analysis of a specific assemblage. For instance, Levallois, discoid and laminar reduction sequences can be conceived and conducted in an expedient/opportunistic way when interpreting these industries in light of raw materials exploited, type of site, vegetation, climate, etc. In other words, when an attempt to understand and define human behaviour in terms of a complexity degree is carried out. Being that the case, using these terms does not invalidate the significance of such industries from a methodological perspective. Eventually, by using the term opportunistic debitage, hence defining a flaking method, we want to stress how the incredible versatility and variability implied in these kinds of activities comes from a steady and precise mental scheme (developed at a certain point during times, obviously) in which, for example, the possibility of choosing in which manner a specific volume will be knapped is a part itself of the methodological process.

In any case, the notion of opportunistic debitage defined by Arzarello (2003) has also been applied to other contexts, comprising different chronologies and geographical areas (Moncel and Neruda, 2000; Rufo, 2007; Chabot and Eid, 2007; Casini, 2010; Arzarello et al., 2013; Groucutt and Blinkhorn, 2013; Arzarello et al., 2015; Niang, 2014; Grenet et al., 2016; Moncel et al., 2016a; 2020c; Niang and Ndiaye, 2016; Arnaud et al., 2017; Daffara et al., 2018; 2023; Stojanovski et al., 2018; Levi et al., 2019; Berruti et al., 2020a; 2023; Carpentieri and Arzarello, 2022; Carpentieri et al., 2023a; 2023b).

In particular, in the work of Carpentieri and Arzarello (2022) two sites of the Lower Palaeolithic (Pirro Nord and Cà Belvedere di Montepoggiolo) were analysed to test the methodological feasibility of the opportunistic debitage during such old chronologies. Even though the technological analysis of both lithic assemblages revealed the presence of this debitage process (Arzarello et al., 2016a), an extensive and more methodological study and a dedicated experimental activity were conducted to further validate its methodological usefulness. The proposal was trying to identify how and if the earliest European lithic productions, which developed as quick and efficient responses to a hostile and changing environment, might have gradually changed into systematic and steady productions (even if still firmly subordinated to the surrounding environment) comprising a solid methodological substratum, or in other words, as the concept of flaking method would arise.

Through the technological analysis of the lithic assemblages from both locations and a dedicated experimental activity, it was highlighted that knapping productions developed onto a massive subordination to the raw material's morphology as the main criteria – *i.e.,* the mental scheme at the base of the opportunistic debitage – might lead to a standardisation of the technical gestures. It was noted that similar operative schemes developed both in Pirro Nord and Montepoggiolo when identical morphologies were selected. For instance, a centripetal knapping was more efficient on smaller and rounder morphologies, while on oval and elongated pebbles, unipolar-semitournant debitage was more consistent. On top of this, the experimental activity highlighted that when centripetal reduction sequences were considered, they would progressively allow better control of flakes' morphology. The obtainment, often unintentional, of déjéte points and convergent points found in the archaeological collections of Pirro Nord and Cà Belvedere di Montepoggiolo (Peretto et al., 1998; Potì, 2012; Arzarello et al., 2016a) – or, more generally, of morphologically predetermined flakes, was considerable. Following these results, it was proposed that the systematic and constant application of the same technical behaviours to specific volumes could generate greater awareness in the knappers' minds during the debitage process. Eventually, this process, reiterated over time, might lead to predetermined and hierarchised reduction methods. That being the case, technical expedients can become systemised choices assimilated within a steady mental scheme, thus expanding or creating a methodological substratum (Carpentieri and Arzarello, 2022).

Before concluding this section, we would like to underline once more that we do not want to erase the concept of simplicity from the technological analysis of Lower Palaeolithic contexts. The quest to define level 0 and its existence persists and is of fundamental importance for archaeological research. The analysis process has progressively become more specific and multidisciplinary, allowing a greater resolution in human behaviour understanding. An increasing amount of data contributes to enlarging the umbrella of complexity with new, unexpected evidence. Nonetheless, the accomplishment of reaching a scenario where – almost – everything is labelled as complex should not prevent us from remembering the existence of a complexity-free situation. Chaotic and unstructured technical behaviours might belong to one of the different shades of complexity recently revealed, but they also exist as objectively chaotic and unstructured, equally crucial for our analysis of prehistoric hominins' behaviours.

3.2. The technological and methodological analysis of Notarchirico and Isernia La Pineta

The lithic assemblages from Notarchirico and Isernia La Pineta have been studied using the technological approach and the concept of *chaîne opératoire* (Leroi-Gourhan, 1965; Boëda et al., 1990; Inizan et al., 1995; 1999; Haudricourt, 2018).

For Notarchirico, debitage production (cores, flakes, and retouched flakes) and retouched nodules in chert from archaeological layers F, G, H, I1 and I2, belonging to the 2016-2021 fieldwork, were selected and analysed. Layer F was excavated over 10 m2, layer G over 11 m2, layer H over 8 m2, layer I1 over 14 m2, and layer I2 over 20 m2. The lithic material from layer J, consisting of a few artefacts, is not in situ and has been removed from this analysis, as also from other works (Moncel et al., 2020e; 2023; Rineau et al., 2022; Carpentieri et al., 2023b).

For Isernia La Pineta, chert debitage production (cores, flakes, and retouched flakes) from archaeological layers t.3a and t.3coll of Sector I-1 was considered. Initially, more than 20 squares have been sampled, and then the ones showing the highest density in terms of lithic material, according to the GIS analyses performed by Channarayaptna et al. (2018), have been selected. Eventually, six squares from the level t.3coll (84, 94, 138, 158, 166, 167) and seven squares from the level t.3a (156, 157, 158, 159, 174, 175, 176) were selected and studied. The material from layer t.3coll comes from the 2001–2011 fieldwork, while the one from t.3a comes from the 2016–2017 fieldwork. All the material studied in this work comes from Sector I since it was more extensively excavated and better preserved.

The lithic material from Notarchirico and Isernia La Pineta was selected because of the great diffusion of small-sized flake assemblages within the Italian Peninsula during the Middle Pleistocene, and, unlike bifacial and large cutting tools of Acheulean affiliation, they are an emblematic trait of this chrono-cultural framework that still needs to be properly contextualised. The same approach was applied to analyse both lithic assemblages and facilitate their comparison.

The hierarchy of flaking surfaces, removal organisation, and size were considered on cores to evaluate the knapping strategies employed by the hominins and their degree of complexity. The relationship between the knapping surfaces was thus noted alongside their quantity and the direction of flaking employed. The presence/absence of striking platform preparation and the value angle between the knapping surface and its striking platform were also described. These latter aspects were fundamental to the interpretation of the centripetal reduction sequences for:

1) Identifying a possible hierarchisation of the surfaces;
2) Assessing flaking's direction (parallel or secant) and how much the natural morphology of the blocks influenced it or was instead a researched feature implying the selection of specific morphologies/preparation of the surfaces.

Using terms like unifacial, bifacial, and multifacial applied to cores is meant to describe the number of knapping surfaces. Unifacial describes the presence of one knapping surface; bifacial describes two adjacent or opposite knapping surfaces; multifacial describes the presence of more than two knapping surfaces. The terms unipolar, convergent, crossed, orthogonal, bipolar and centripetal refer to the organisation of the scars on the knapping surfaces and the dorsal face of the flakes. The presence and position of cortex and neo-cortex formation were recorded alongside the typology of the support selected (*e.g.*, pebbles, cobbles, nodules, slabs, flakes). Moreover, the possible reasons regarding the state of abandonment for each core were noted (*e.g.,* insufficient volume available, quality of raw material, absence of exploitable angles, insufficient chert over cortex, retouch/use). Despite this being a delicate and often challenging topic to address, the aim is to identify further patterns in the land-use management of the hominins, the degree of occupation of each site and, obviously, the length of the reduction sequences.

Since bifacial and multifacial cores are often the outcome of multiple separate unipolar knapping events due to core rotation rather than a surface hierarchisation, the description of the removal organisation for these latter categories was removed in favour of terms like S.S.D.A. (Ashton et al., 1992b; Forestier, 1993; Carpentieri and Arzarello, 2022) that better describe these type of knapping strategies. Additionally, the presence of Discoid-like exploitation was also highlighted. In these cases, we adopted the definition found in the work of Peresani (2003), including a wider variability and versatility compared to the original definition of Boëda (1993).

For flakes, the presence and position of the cortex, butt characteristics, removals organisation, the incidence of backed margins, and, when present, the location, delineation, and angle of retouch were recorded. The characteristics of the butt were described according to (Tixier and Inizan, 1983; Inizan et al., 1999; Arzarello et al., 2011), using the terms cortical, natural, flat, dihedral, facetted, punctiform, and linear. It was also noted if the retouch removed the original flakes' platform. The angle of debitage was measured between the butt and the dorsal face. Concerning the incidence of backed margins on flakes, a distinction was made between *débordant* (backed margin on the lateral face of an oriented flake) and plunging (backed margin on the distal end of an oriented flake). The term over-hinged describes a plunging flake whose distal margin completely removed the opposite striking platform. The distinction between plunging and over-hinged aims to facilitate identifying prehensile-backed margins. Additionally, it was recorded whether the backed margin was cortical, natural, obtained by retouching, or bearing the scar of additional knapping surfaces (*e.g.* the term "core's edge" was used to describe this tendency).

The description of retouched flakes was made according to the criteria established by Tixier and Inizan (1983; 1999), including the position (direct, inverse, bifacial, direct and inverse), localisation (the reproduction of a fictional flake was used to find the location), extension (marginal, invasive, abrupt, single), and angle. Furthermore, we applied a typological classification modified from the one created by Bordes (2000). This classification features scrapers, denticulates, notches, beaks, and pointed tools. Despite the evident limitations that such an approach implies through the creation of artificial categories (especially when dealing with such old archaeological palimpsests), we decided to use a basic typological description of these tools to facilitate the comparison from a technological point of view with other lithic assemblages where a similar approach was applied (Moncel et al., 2020a). We want to underline that the adoption of terms like denticulate, scraper, and notch is made only to describe the morphological organisation of the retouch on the lithic pieces without inferring the functional implications of these lithic artefacts. For instance, we consider "scraper" the presence of regular edge modifications (*i.e.* retouch) on a cutting edge regardless of its length, while "denticulate/notch" results in a non-linear configuration of the retouch. "Point" and "beak" describe retouch to configure a pointed shape/termination of the lithic object, while the term "composite tool" was applied to describe a mixture of these characteristics on the same artefact. The terms "double", "convergent", and "simple" describe the global morphology of the retouch on a specific tool. In the case of Notarchirico, where a consistent production of retouched nodules is present, their description was made using the same criteria applied to retouched flakes for a proper comparison (Carpentieri et al., 2023b).

The knapping techniques were identified by analysing the butt and the ventral face (impact point, bulb, ripples, hackles). Since the distinction between freehand percussion by hard hammer and bipolar on anvil technique can be challenging, and both techniques can produce the same marks on the flakes (Jeske and Lurie, 1993; Donnart et al., 2009; Bietti et al., 2010; Moyano et al., 2011; Vergès and Ollé, 2011; Eren et al., 2013; Peña, 2015; Shott and Tostevin, 2015; Pargeter and Eren, 2017; Sánchez-Yustos et al., 2017), a dedicated chapter to the bipolar on anvil technique's identification was created.

The raw material identification for Notarchirico and Isernia La Pineta was made through a macroscopic approach. In the case of Notarchirico, the raw material identification was made according to the petrographic and chemical analyses performed by Eramo et al. (Moncel et al., 2020e), where four main lithotypes of chert were identified: silicified litharenites, nodular chert, vitreous chert, and radiolarite. The presence of limestone is reported as well. Such lithotypes occur in the polygenic pebbles, and cobbles lag formed in the fluvial-lacustrine environment of the area of Notarchirico (Synthem of Palazzo San Gervasio; ISPRA, in press) as products of the erosion of the outer geological units of the southern Apennine formed after the evolution from late Triassic to Miocene of a deep-sea basin on passive margin (Lagronegro basin) to a foredeep basin (Irpinian basin) characterised by flyschoid sequences (Pescatore et al., 1999).

To bring order to the terminology used to classify lithotypes in previous studies and the present work, the term chert is intended here as a generic group used for fine-grained siliceous sedimentary rocks following Tucker (2001). Usually, in the geological record, cherty rocks are subdivided into bedded types resulting from primary accumulation (e.g. radiolarites and diatomites) and the nodular type of diagenetic origin (Trewin and Fayers, 2005; Greensmith, 2012). Excluding radiolarites, although the other identified chert types can be traced to facies and diagenetic conditions of turbiditic systems, the term flysch chert refers to silicified litharenites (Eramo et al., in preparation).

3.3. The bipolar on anvil technique: Definition and experimental activity

This section is dedicated to the definition and history of studies of the bipolar on anvil technique. An experimental activity was performed to quantify the main criteria to distinguish this technique from freehand percussion. For the experiment, the raw material from Isernia La Pineta was selected. A technological and use-wear approach was employed, even though only the results from the technological analysis will be presented in this work.

3.3.1. State of the art of the bipolar on anvil technique

The bipolar on anvil technique – also often referred to as the bipolar on anvil "method" – is a debitage technique in which the core is held with one bare hand, placed on an anvil (consisting of a flat large block of stone), and subsequently hit from above with a hammer held in the other hand. This technique is used for flakes' production and modifications. It is Pleistocene archaeology's most enduring lithic strategy while still being exploited by nineteenth- and twentieth-century knappers (Witthoft, 1966; Weedman, 2006; Pargeter et al., 2019a). The presence of a force applied from two opposite directions (*i.e.,* the hammer's blow and the counterblow from the anvil) originated the introduction of the "bipolar" term in its original definition. The term "anvil" was subsequently introduced to underline the predominant role and necessity of the anvil within the production process and to imply that not all flakes obtained exhibit bipolar features (Crabtree, 1972; Knight, 1991; Mourre, 1996a; Shott, 1999; Mourre and Jarry, 2009; De La Peña Alonso and Vega Toscano, 2013; Shott and Tostevin, 2015; Pargeter and Eren, 2017).

This technique is relatively simple to learn and transmit and is exceptionally efficient at opening large blocks, producing large flakes, blades, and miniaturised tools (Flenniken, 1981; Callahan, 1987; Hiscock, 2015b). More complex variations of bipolar reduction have been described over the years, involving anvil-assisted flaking in which freehand cores are modified after being placed on an anvil (Callahan, 1987; Bradbury, 2010; Pargeter and Tweedie, 2019) and bipolar cobble splitting (Bietti et al., 2010; Duke and Pargeter, 2015; Li et al., 2017). Despite its widespread occurrence in the archaeological record, bipolar reduction is still generally perceived as a second-rate lithic reduction strategy.

In the history of studies, the earliest evidence of this technique in an archaeological context can be found in the work of Evans (1872), who discussed the implications of some bronze age lithic tools labelled as "chisels", which appear to be anvilled pieces from his drawings (Evans, 1872; Knight, 1991). Subsequently, de Mortillet (1883) identified the *taille par contrecoup* (counterstrike knapping) as one of the possible exploitation techniques to produce stone tools during Prehistory. At the beginning of the 20th century, Bardon et al. (1906), in their work *"Outils écaillés par percussion",* described the presence of *"pieces esquillees"* and *"pieces ecailles"* (splintered or scaled pieces) made on chert flakes. Bardon and colleagues defined these splintered pieces as the result of the bipolar knapping of chert through direct percussion. They further elaborate that the "cores" have been rested on a hard surface, causing splintering at both ends of the artefact (Bardon et al., 1906).

The introduction of these terms will be fundamental for developing the bipolar on-anvil technique's definition, as they will represent, from this moment on, one of the most explicit "fossil markers" for its identification. Splintered or scaled pieces were described as small-sized lithic objects, exhibiting a rectangular shape, with a more or less constant thickness and showing traces of knapping – often similar to a retouch – on two opposite extremities. Since their identification, they have been considered, alternatively, flakes, cores, wedges, tools, but always an outcome of the counterstrike knapping. For instance, in 1938, Octobon suggested that splintered or scaled pieces could have been used as wedges to work hard materials or as flake cores (Octobon, 1938).

In 1932, during the excavation of the Chinese site of Chokoutien (Zhoukoudian), the French prehistorian Breuil (1932) described the vein quartz material as *"outil ecailles"* (scaled tools), while Pei (1937), a colleague of Breuil, described the same material as "bipolar". Subsequently, Breuil and Lantier (1951) extended their research to several Middle and Upper Palaeolithic French sites, identifying this technique defined as "*taille bipolaire*" in many lithic assemblages: *« Cette taille est dénommée bipolaire, parce que les éclatements se produisent de haut en bas et de bas en haut et il arrive que, si le deux plans d'éclatement venus de deux pôles coïncident, on obtient des éclats dotés d'un bulbe de percussion à chaque extrémité. Cette technique a été employée, entre autres milieux, à Chou-kou-tien (Chine), par le Sinanthropus pour débiter le quartz »* (Breuil and Lantier, 1951, p. 71). The work of Breuil and Lantier was pioneering, providing accurate descriptions of this technique's technical traits and peculiarities on archaeological and experimental lithic artefacts. Additionally, they highlighted the efficiency of this technique to obtain small-sized flakes from hard-to-knap raw materials, such as quartz: "*Il faut frapper fort et longtemps avant d'obtenir autre chose qu'une poussière de quartz, en même temps qu'un écrasement des deux extrémités du galet percuté. (...) Ce procédé ne permet pas d'obtenir de grands éclats, mais il présente l'avantage, là où les autres méthodes de taille sont inopérantes, de débiter entièrement un bloc de quartz, la taille manuelle ou sur enclume produisant des polyèdres subsphériques sur lesquels la percussion ordinaire n'a plus de prise »* (Breuil and Lantier, 1951, pp. 71–72).

At the same time, Bordes (1947), in his review of the prehistoric debitage technique, included the *percussion écrasée* or *percussion sur enclume* within one of the variants in the group of knapping techniques involving three elements (*taille à trois éléments*). Bordes, similarly to Breuil and Lantier, pointed out the lack of control during the debitage process and underlined the relationship between this technique and qualitatively inferior raw materials – namely quartz: *"Il est difficile par ce procédé de savoir d'avance quel éclat on obtiendra, et il n'est guère intéressant que dans le cas de matières très dures, telles que le quartz"* (Bordes, 1947, p. 16).

The French school initiated a paradigm that would endure through the sixties, seventies, and eighties where, on one side, the bipolar on anvil technique was deemed as a strategy suitable for raw materials of inferior quality, exhibiting a lack of control, not requiring a systematic operative scheme, and primitive. On the other side, the presence of *pièces esquillées*, identified as wedges by many authors, persisted as emblematic lithic objects that would qualify the use of this technique on higher quality raw materials, such as chert. On the other hand, the Anglo-American tradition defended the hypothesis of bipolar knapping from both ethnographic and archaeological perspectives (Binford and Quimby, 1963; White, 1968; Flood, 1980; Hayden, 1980; Flenniken, 1981; Callahan, 1987; Shott, 1989; Knight, 1991; Goodyear, 1993). In these works, the economic value of the bipolar on anvil technique and its expediency as an efficient and rewarding strategy were stressed. Nonetheless, the topic regarding splintered pieces' attribution and function persisted also in the Anglo-American school. As stated by de la Pena: *"The debate remains unresolved [...]. What seems clear from this discussion is that the splintered piece is a common component of archaeological assemblages worldwide and that it is not easy to classify them unequivocally as cores or wedges."* (De La Peña Alonso and Vega Toscano, 2013, p. 35).

Through the nineties and with the beginning of the 21st century, many works addressed the terminological issues affecting the definition and contextualisation of the bipolar on anvil technique (Crabtree, 1972; Tixier and Inizan, 1983; Knight, 1991; Inizan et al., 1995; Mourre, 1996a; Shott, 1999; Mourre and Jarry, 2009).

For instance, in the works mentioned above of Bordes, Breuil and Lantiers, the term *tailler sur enclume* described a technique where the anvil/hammer was static, while in subsequent works of Bordes (1961; 1967; 1969), a terminological confusion regarding techniques using anvils (*enclumes*) or passive hammers (*percuteurs dormants*) was witnessed. He used different synonyms for *"percussion sur enclume"*, such as *"technique sur enclume", "technique clactonienne"*, *"technique bloc contre bloc"*, and *"percussion sur percuteur dormant"* (Bordes, 2000). As a consequence, in English literature, the introduction of the term "anvil" within the "anvil technique" referred to a debitage technique in which the core was the active member striking a stationary block, while the "bipolar technique" or the "block on block technique" described what we define today as "bipolar on anvil technique" (Schick and Toth, 1994; Whittaker, 1994; Odell, 2006; Vergès and Ollé, 2011). For instance, Balout already noted the existing confusion between the use of the *"debitage sur enclume"* in French literature and the "block-on-block technique" in English (Balout, 1967; Balout and Biberson, 1967). Crabtree was one of the first to provide a homogeneous definition stressing the importance of the role of the anvil for flakes' obtainment, together with the presence of a hammer and a core acting as a passive element: *"a technique of resting a core, or lithic implement, on an anvil and striking the core with a percussor."* (Crabtree, 1972, p. 48) although he often used the terms "block-on-block" and "anvil knapping" referring to it. In any case, his definition has often been adopted from then on in English and American archaeological literature, gradually affecting the French school and eventually leading to a reassessment of the lexicon.

In 1996, Mourre, building on Bordes' definition of "*taille à trois éléments"* and Crabtree's work, proposed to homogenise the use of *"tailler sur enclume"* in French literature to include all the techniques involving an anvil (Mourre, 1996a; 1996b). He also made a distinction in counterstrike knapping between the "*taille sur enclume axiale"* (axial knapping on an anvil), where the strike and the counterstrike are situated on the same axis, and the non-axial version, where the two impacts are not on the same axis. The presence of three elements within the knapping process (*i.e.,* the hammer, the core, and the anvil) was deemed fundamental for the definition of the bipolar on-anvil technique.

Crabtree's merit was also addressing the morphological aspect of the products obtained from a bipolar on anvil knapping and the relevance of the bipolar process within lithic productions, inspiring many other experimental and ethnographic works (Barham, 1987; Knight, 1991; Hiscock, 1996; Hayden, 1998; Bradbury, 2010). Following this background, the debate also focused on defining the fracture mechanisms concerning bipolar flaking and the functional distinction of the artefacts (Cotterell and Kamminga, 1987; Bertouille, 1989; Andrefsky Jr, 1994; Hayden et al., 1996; Andrefsky, 1998; Vergès and Ollé, 2011; Viallet, 2016; Arrighi et al., 2020). Eventually, the addressed issue became the investigation of the traces left by the anvil's action on both flakes, cores and debris, and how the position and orientation of the hammer, core and anvil would affect the debitage process, leading to the creation of a detailed and accurate empiric framework for this technique. The relevance of this technique from a methodological perspective was also tackled. For instance, Pelegrin and Inizan stated that the anvil percussion (*percussion sur enclume*) was a technique but also a debitage method (*debitage sur enclume*), qualifying it as a sequence of reasoned gestures aiming at a pre-established goal (Inizan et al., 1995). This work's influence can still be witnessed today as the terms "bipolar on anvil technique" and "bipolar on anvil method" became synonyms of the same debitage technique.

These theoretical and methodological debates matched an increasing interest in archaeological evidence. The chronological framework of the bipolar on-anvil was investigated in different geographical and ecological areas, proving that it was one of the most ancient and most exploited techniques during the Lower Palaeolithic and as valuable as the freehand percussion with the hard hammer (Jeske and Lurie, 1993; Crovetto et al., 1994; Moyano et al., 2011; de Lombera-Hermida et al., 2011; De La Peña Alonso and Vega Toscano, 2013; Cauche et al., 2014; Gurtov and Eren, 2014; de la Peña, 2015; Pargeter and Eren, 2017; Despriée et al., 2018; Horta et al., 2022; 2019; Gallotti et al., 2020; Cauche, 2022; Kot et al., 2022; Lombao et al., 2022a). The original perception of this technique as rudimentary and primitive has been progressively abandoned in favour of a re-evaluation as an efficient, low-cost, planned and versatile knapping strategy.

Within the present state of the art, the scientific community recognised the challenges of adequately recognising bipolar artefacts and reduction sequences within lithic assemblages, mainly when mixed techniques are used. The debate has shifted from theoretical and terminological issues to a more use-wear and functional-oriented approach investigating the traces left by the bipolar on-anvil technique (Alonso, 2011; Eren et al., 2013; Peña, 2015; Duke and Pargeter, 2015; Gurtov et al., 2015; Hiscock, 2015b; Buchanan et al., 2016; Manninen, 2016; Pargeter and Eren, 2017; Pargeter and Tweedie, 2019; Pargeter et al., 2019a). Additionally, the extreme variability of the patterns left on the artefacts is affected by the morphology, type and quality of raw materials exploited, making the need for specific bipolar experiments on a site-to-site raw material basis. As stated by Jeske and Laurie: "*the attributes for the variables tested varied widely in significance due to raw materials. Raw material type, raw material quality, and the presence of heat alteration may significantly affect the appearance of the manufacturing profile. Anyone interested in understanding the different processes that may have been used in the production of lithic debris at any particular site should experiment with the material present at the site.*" (Jeske and Lurie, 1993, p. 45).

3.3.2. The experimental activity

In this work, an experimental activity conducted on the raw material from Isernia La Pineta was realised to distinguish, whether possible, the traces left by freehand percussion with the hard hammer and the bipolar on-anvil technique during a debitage activity. As formerly stated, the enigma of accurately identifying and distinguishing the bipolar on anvil technique in an archaeological context, mainly where mixed techniques have been used, requires a site-to-site experiment and reference (Bietti et al., 2010; Diez-Martín et al., 2011; Peña, 2015; Byrne et al., 2016; Pargeter and Eren, 2017; Pargeter et al., 2019a). This is particularly relevant for the Lower Palaeolithic, where this topic has been addressed only in the last few years – though primarily in quartz-oriented industries (Cauche, 2009; Diez-Martín et al., 2011; Eren et al., 2013; Gurtov and Eren, 2014; Gurtov et al., 2015; de Lombera-Hermida et al., 2016; Sánchez-Yustos et al., 2017). On the other hand, scientific references concerning bipolar on anvil's technological and use-wear identification on Lower Palaeolithic chert assemblages where non-pebbles morphologies were exploited are scarce (Crovetto et al., 1994; Vergès and Ollé, 2011; Li et al., 2017), making it a valuable niche to explore.

The lithic assemblage of Isernia has been analysed in several works (Peretto, 1994; 2006; Gallotti and Peretto, 2015; Carpentieri et al., 2023a) documenting the use of both techniques for debitage production on chert slabs – even with technological (Crovetto et al., 1994) and use-wear (Vergès and Ollé, 2011) experimental activities – although a systematic protocol to quantify their impact on artefacts qualitatively has not been yet attempted.

The experimental activity was exclusively realised on chert slabs collected in the surrounding of Isernia La Pineta and corresponding to the same raw material exploited by the hominins during the Middle Pleistocene (*i.e.*, varicoloured jaspers; Sozzi et al., 1994; Gallotti and Peretto, 2015). The main goal of the experimentation is to provide a qualitative reference collection of macroscopic and microscopic traces/attributes – documented on flakes and cores – to distinguish – if and when possible – the use of one of the two techniques and investigate their range of superimposition. Since both knapping strategies have been intensively documented within the stratigraphic sequence, the question of their productivity will not be addressed.

The definition of direct percussion with a hard hammer was derived from (Tixier and Inizan, 1983; Inizan et al., 1999; Arzarello et al., 2011). Regarding the definition of the bipolar on-anvil technique, we decided to use the "axial bipolar reduction" definition used in scientific literature to describe the classic bipolar on-anvil technique employed for debitage production (Fig. 3.1; Mourre, 1996a; 2004; Diez-Martín et al., 2011; Drift, 2012; Peña, 2015; Byrne et al., 2016; de Lombera-Hermida et al., 2016; Manninen, 2016; Sánchez-Yustos et al., 2017; Pargeter and Eren, 2017; Pargeter and Tweedie, 2019; Pargeter et al., 2019a). In the axial bipolar technique (generally divided into "vertical axial" and "horizontal axial"; Fig. 3.1), the hammer strike and the counterstrike from the anvil are oriented on the same axis, and the two surfaces – the striking platform and the platform resting on the anvil – are parallel. The technical gesture to hit the core is not mandatorily perpendicular to the anvil – as required for the cobble-splitting/split fracture technique (Kuhn, 1995; Duke and Pargeter, 2015), or more in general when the aim is to open a block with no suitable angles – but is also slightly circular. In the scientific literature, "non-axial bipolar reduction" is defined as when the hammer strike and the counterstrike from the anvil are not aligned on the same fracture plane (Mourre, 2004; Diez-Martín et al., 2011; de Lombera-Hermida et al., 2016). This work will use the term "bipolar on-anvil technique", including the axial and non-axial variants (Fig. 3.1).

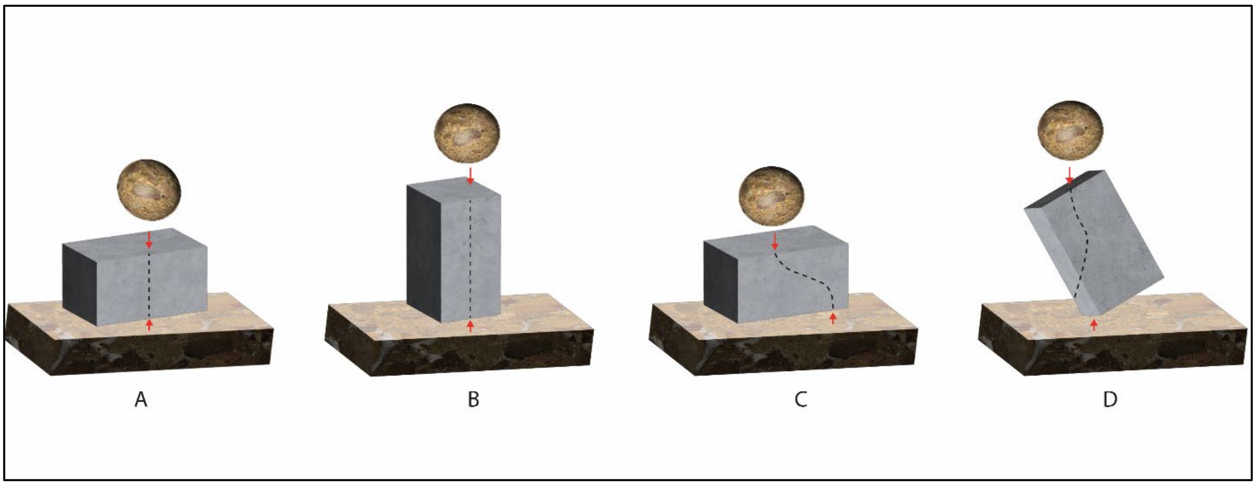

Figure 3.1 Variants of the bipolar on anvil technique (modified from Diez-Martín et al., 2011; de Lombera-Hermida et al., 2016): A) Horizontal axial bipolar reduction; B) Vertical axial bipolar reduction; C-D) Non-axial bipolar reduction.

We also decided to test the relevance of another variant of the bipolar on-anvil reduction, defined as "anvil-assisted freehand percussion" (Fig. 3.2). The existence of this variant has been tested and identified in other works regarding bipolar reduction sequences (Callahan, 1987; e.g., Pargeter and Eren, 2017; Pargeter and Tweedie, 2019; Pargeter et al., 2019a). Callahan (1987) initially described this variant as a "platform on anvil", identifying it on some cores obtained during an experiment on the bipolar on-anvil technique. Pargeter and Tweedie stated, *"Anvil-assisted cores possess freehand flake release surfaces opposed by distal ends showing signs of crushing that indicate their placement on a hard substrate during flaking. This core configuration represents a hybrid of the bipolar and freehand reduction strategies."* (2019, pp. 10–11), separating it from the classic bipolar on-anvil and direct percussion. What discriminates anvil-assisted freehand percussion is that the gesture and the conception of the knapping activity are identical to the direct percussion with a hard hammer, but to stabilise the core, an anvil is required. Consequently, the anvil is not exploited for the counterstrike but as a stabiliser, and the knapping gesture is more tangential to the striking platform. Duke and Pargeter (2015) argue that this variant *"enables toolmakers to overcome difficulties in stabilizing cores"*, thus being extremely efficient on small-sized support – such as the one of Isernia La Pineta. Pargeter and Tweedie (2019) further state that this kind of reduction strategy is a type of bipolar flaking with a different flaking axis from the axial bipolar reduction, which may fit within the "non-axial bipolar reduction" strategy. However, we would like to indicate that the relevance of the anvil-assisted freehand percussion lies within the use of the anvil as a support for a direct percussion technique. The counterstrike is not the researched mechanism in the production process, even if the anvil might still leave some traces on cores and flakes.

To conclude, three techniques were tested within the experiment (Fig. 3.2):

- Direct percussion with a hard hammer
- Bipolar on anvil
- Anvil-assisted freehand percussion

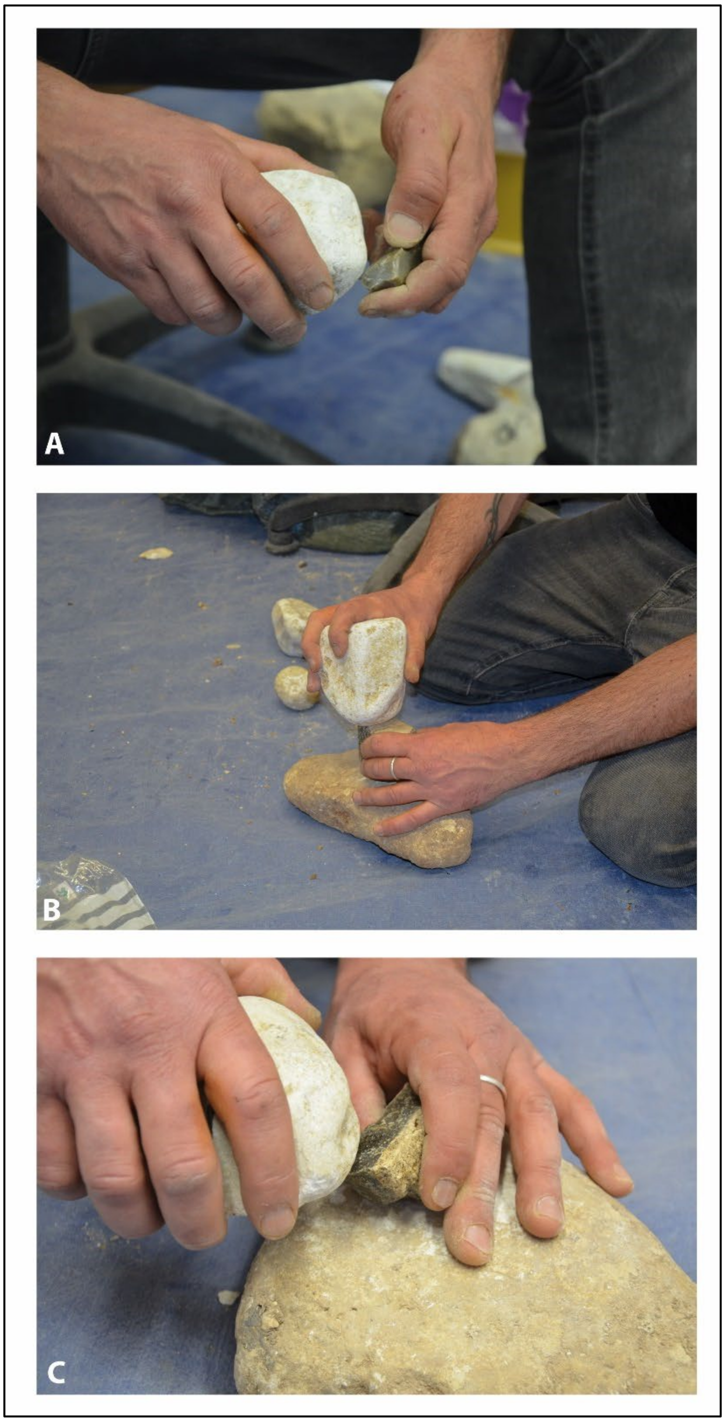

Figure 3.2 Percussion techniques tested during the experiment: A) Direct percussion by hard hammer; B) Bipolar on anvil percussion; C) Anvil-assisted freehand percussion.

The criteria selected to identify these techniques on experimental flakes have been chosen and adjusted from the works of Pargeter et al. (2017; 2019a), Damlien (2015), de la Pena (2013; 2015), Sørensen (2013), Pelegrin (2000; 2006), Diez-Martìn et al. (2011), and Bietti et al. (2010), all focused on experimental activities for techniques' identification through a morpho-technological approach. The selected attributes within the experimental flakes include:

- morphology/shape of the butt and counter-butt: crushed, oval/triangular, quadrangular/trapezoidal, narrow, narrow curved;

- the morphology of the bulb and counter-bulb: none, diffuse, pronounced, crushed, sheared, spike-like, removed;
- lip and counter-lip formation: none, diffuse, pronounced;
- development of the Hertzian cone and counter-Hertzian cone: none, hint, ring crack on the butt, ventral fissures, detached bulb;
- profile of the flake: regular, curved, irregular;
- maximum width of the flake: proximal, mesial, distal, regular, irregular;
- morphology of distal termination of the flakes: rebound force, broken, hinged, regular;
- section of the flake: flat, dihedral, triangular, irregular;
- typology of fracture (Fig. 3.3);
- axis of the distal termination: axial, déjéte.

Furthermore, other attributes regarding a more classic technological approach include dimensional data of the flakes, typology of the butt, debitage angle (measured between the butt and the dorsal face of the flakes), counter-butt angle, presence of the counter-butt, proximal micro-shattering, presence of ripples/undulations on the ventral face, presence of removals on the ventral face, presence of bulbar scars, removals' organisation on the dorsal face, number of removals, and the presence of a backed margin (debordant, plunging, and over hinged).

The analysis of the cores features data on the angle between the striking platform and knapping surface – and, if present, the related counter-angle from the anvil – the presence of counterblows on the opposite side of the hammer striking platform, the number of striking platforms and knapping surfaces the organisation and the number of removals, the presence of micro-shattering on the striking platform and counterstriking platform, the typology of the striking platform, and the morphology of the resulting knapping surfaces after the exploitation: flat, tournant, orthogonal, irregular.

Before moving on to the analysis of the experimental protocol, the chert slabs selected for the experiment have also been classified. Three dimensional categories were realised to compare the obtained data homogeneously. The categories created feature small slabs (including all the slabs with a maximum length of up to 55 mm), medium slabs (all the slabs with a length comprised between 55 and 90 mm), and large slabs (all the slabs with a length more than 90 mm). Additionally, morphological categories were established after examining the sample of selected slabs. These categories feature cubic morphologies, parallelepiped, parallelepiped flat (length and width particularly pronounced but short thickness), parallelepiped tubular (length and thickness pronounced but reduced width), cubic irregular, parallelepiped irregular, and irregular. The orientation of the slabs' surfaces was also classified into parallel, sub-parallel, and rounded. The presence and distribution of cortex were also recorded, alongside visible fracture within the slabs. Furthermore, the anvils and hammers used during the experiment – all collected near the site of Isernia La Pineta –were classified, measured and weighted before the knapping activity.

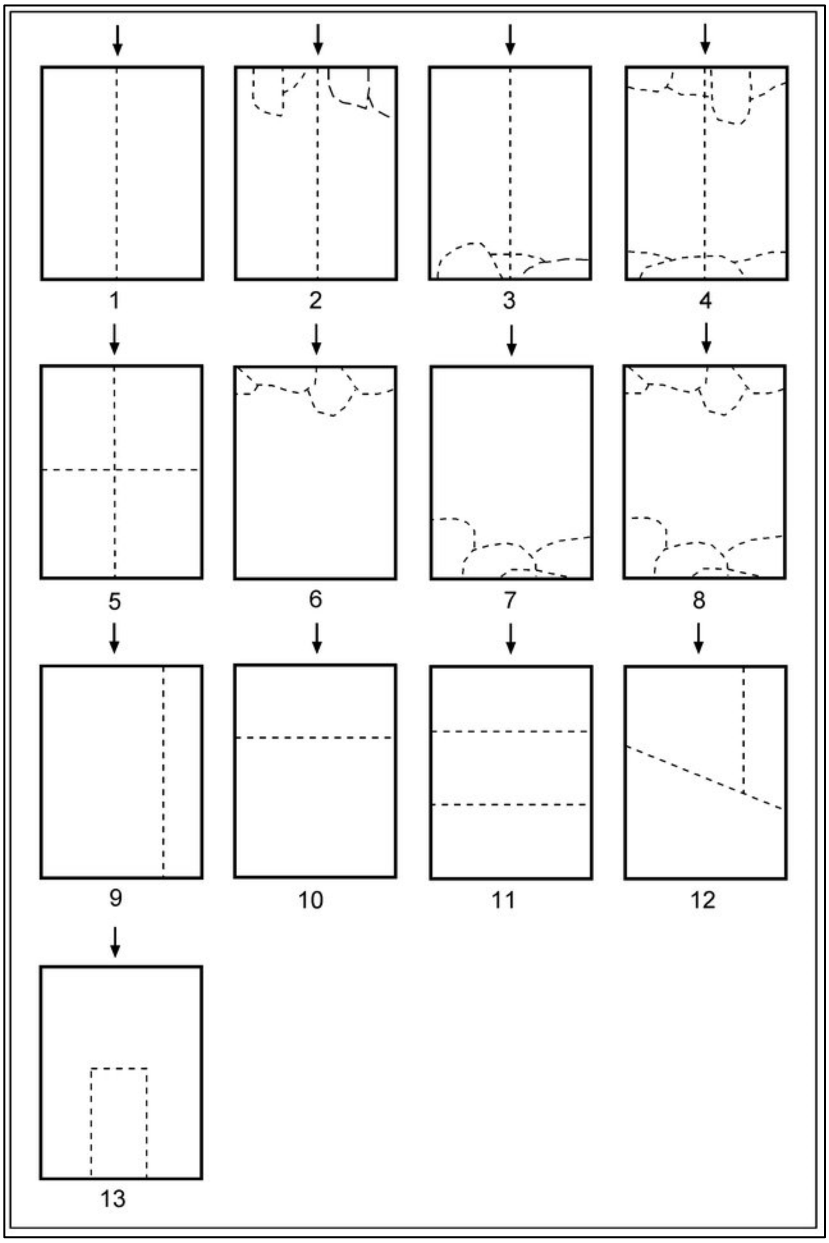

Figure 3.3 Schematic representation of the fracture types recorded on flakes. Arrows show the point of impact. 1. Longitudinal Siret type fracture (flake breaks in two pieces along the axis of impact); 2. Siret type and platform fractures; 3. Siret type and base; 4. Siret, platform and base; 5. Siret and transversal; 6. Platform; 7. Base; 8. Platform and base; 9. Side longitudinal; 10. Transversal; 11. Double transversal.12. Lateral and transversal; 13. Basal flake (from Diez-Martín et al., 2011).

The experimental protocol was realised through the cooperation of G. L. F. Berruti, E. Cancellieri, N. Fasser, and T. G. Palconit. As previously stated, given that the bipolar on anvil technique at Isernia La Pineta has already been attested on the archaeological collection, the experiment aims to search and quantify the most accurate attributes to identify and distinguish this technique from direct percussion through a qualitative and technological approach. The idea is to realise a reference collection to be eventually compared with the archaeological chert lithic corpus of Isernia La Pineta. The experiment was conducted considering several additional discriminating factors that, in our view, could enhance reaching the established goals:

- Only one knapper (E. Cancellieri) experimented as we decided to reduce the possible variants deriving from different knappers employing different gestures and forces as much as possible.
- The choice of the technique (direct percussion, bipolar on anvil, anvil-assisted freehand percussion) for each block was made by the knapper according to the morphology, size and volume of the slabs – to avoid forcing the use of a specific technique on unsuitable supports – even though an attempt to provide a homogeneous quantitative sample of knapped slabs for each technique and size-class was nonetheless performed.
- Since the aim is the qualitative recognition of specific traces left and not the productivity of the debitage techniques, 50 blows were set as a limit for every knapping session to preserve any detectable marks and, at the same time, obtain enough flakes or by-products.
- The initiation of the flaking activity was documented through schematic drawings of the cores. Each slab was ascribed to a hypothetical parallelepiped on which a number from 1 to 6 was assigned to each surface. The knapper's choice of the striking platform and the knapping surface was noted in writing these numbers, where the first number identified the striking platform, and the second number identified the knapping surface (*e.g.* 1-2).
- To further preserve the percussion and anvil marks on the bipolar on anvil and anvil-assisted freehand percussion reduction sequences, the rotation of the cores' surfaces was denied. On the other hand, the rotation of cores knapped through direct percussion by a hard hammer was allowed since considerable literature documenting this technique's identification is already available.
- Each slab was knapped according to length, width, or thickness axis.
- In the case of bipolar on anvil and anvil-assisted freehand percussion reduction sequences, when the knapping surface was not perpendicular to the anvil, it was noted if the flaking was happening through what we defined as "striking platform blow" (*i.e.* the knapping surface creates an acute angle with the anvil) or as "counterblow" (*i.e.* the knapping surface creates an obtuse angle with the anvil). The aim is to verify which of the two variants was more efficient and trace-rewarding.

The end of each knapping session was established by either reaching the maximum number of blows required, inferior quality of the raw material, absence of exploitable volumes, or presence of internal fractures.

Chapter 4 Results

4.1. The opportunistic debitage

Journal of Paleolithic Archaeology (2022) 5:12
https://doi.org/10.1007/s41982-022-00117-9

For Our World Without Sound: the Opportunistic Debitage in the Italian Context—a Methodological Evaluation of the Lithic Assemblages of Pirro Nord, Cà Belvedere di Montepoggiolo, Ciota Ciara Cave and Riparo Tagliente

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Accepted: 20 June 2022

Abstract
The informative potential taken on by lithic artefacts has increased over the years. They gradually grew into proxies to detect the most relevant features of human material culture, including cognitive abilities to realise stone tools or, in other words, to track down the delineation of behavioural complexity. Consequently, notions like predetermination, standardisation (morphologically likewise) and hierarchisation have been intensely used in lithic technology as markers of such complexity, leading to ruling out contexts lacking any trace of these traits. Within the present state of the art, the use of the terms expedient and opportunism has characterised, in a negative way, the dichotomy between complex and simple within prehistoric contexts. Even if a requalification of expedient technologies has been recently observed, opportunistic behaviours still connote the complete absence of planning and complexity (even in terms of the mental scheme) within lithic industries. This background often prevented a consideration as relevant, from a technological and methodological perspective, these assemblages, primarily when Lower Palaeolithic contexts were addressed. With the definition and use of the term opportunistic debitage, this work questions the possible methodological implications of assemblages known as complexity- and planning-free and that can be found throughout different chronological and cultural phases.

Keywords Lithic technology · Palaeolithic · Lower Pleistocene · Middle Pleistocene · Core technology

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Published online: 15 September 2022

Introduction

The topic of complexity in lithic technology, its identification and delineation through the analysis of lithic assemblages goes a long way back in the history of Palaeolithic archaeology, and plays a distinctive role in our understanding of human behavioural evolution (Baena et al., 2010; Binford, 1977; Carbonell et al., 2016; Davis & Ashton, 2019; Gaucherel, 2020; Meignen et al., 2009; Moncel & Ashton, 2018; Ollé et al., 2013; Shea, 2013; Stout, 2011; Vaesen & Houkes, 2017). Because of this, lithic artefacts took on a tremendous informative potential over time, growing into proxies to detect the most prominent aspects concerning the material culture of prehistoric people. This includes the cognitive abilities employed to make stone tools which are important markers of the so-called behavioural complexity (Davis & Ashton, 2019; Garcia et al., 2013; Nelson, 1991; Stout, 2011). Several authors recently argued whether an actual overestimation of the fundamental importance of lithic technology for prehistoric people was taking place in Palaeolithic research (Sillitoe & Hardy, 2003). In this context, ancient knappers were devoting most of their time and energy to the manufacture of stone tools, hence, the involved mental processes were supposedly driven by well-defined concepts reflected into structured, standardised procedures. In this logic, as stated in the work of Vaquero and Romagnoli (2018, p. 337), this tendency "allowed some researchers to maximise the use of the predetermination concept in the interpretation of lithic technologies", resulting in a gradual loss of interest for the contexts lacking any degree of predetermination. In other words, the potential existence of complexity, which in lithic technology often goes hand-in-hand with notions such as standardisation and hierarchisation, was deemed to be rather unlikely or disregarded at all.

It is in this scenario that the concept of expedient technology (Binford, 1973, 1977, 1979), defined in terms of technological investment (i.e. time and energy), has been used from then on to characterize unstructured and chaotic behaviours in contrast with the notion mentioned above of formal complexity (i.e. curated technology). Even though this might be an oversimplification, the dichotomy between high- and low-cost technical behaviours has been steadily present, whether implicit or not, in archaeological research and highly debated ever since its definition to postulate the presence of complex thinking (Romagnoli et al., 2018; Vaquero & Romagnoli, 2018).

As a sign of that, over the years, the notion of expediency has been declining and explored under many aspects concerning lithic technology, expanding its original theoretical boundaries. In one case, Nelson (1991) stated that expedient behaviours presented a degree of planning consisting of scheduled and predictable activities. This allowed him to introduce the distinction between expedient and opportunistic technologies, defining the latter as technical behaviours in response to immediate, unanticipated conditions, hence lacking any degree of planning. Even if a resemblance might be possible at the archaeological level (as pointed out by Nelson, 1991), since both models are inclined to take advantage of time and space, minimising the technical efforts to realise stone tools, the distinction persisted.

Within the present state of the art, the framework of expedient technologies has been significantly reconsidered as an attitude, applied to lithic industries as a whole, in which concepts as complexity might still coexist, albeit with an apparent lack of time, energy and predetermination invested for their realisation (Daffara et al., 2021; de Lombera-Hermida et al., 2016; Mathias et al., 2020; Moncel et al., 2015, 2021; Romagnoli et al., 2018; Vaquero & Romagnoli, 2018). On the other hand, opportunistic behaviours remained as notions designating the complete absence of complexity and planning in lithic assemblages (Antoine et al., 2016, 2019; Bermúdez de Castro et al., 2013; Gallotti & Peretto, 2015; Nicoud et al., 2016; Santagata et al., 2017). Currently, this background is often prevented from considering this kind of industry from a technological and methodological perspective, eventually leading yet to another dichotomy between complexity and opportunism. This is particularly relevant for Lower Palaeolithic industries where pattern recognition might be more challenging due to the absence of structure and standardisation (morphologically likewise). However, it is also a rich chronological phase where the development of behavioural complexity is thought to arise in many aspects.

This paper aims not to entirely erase the concept of simplicity from the analysis of technical behaviours but to question the possible methodological implications of assemblages known as complexity- and planning-free. This purpose will be pursued by defining and using the term opportunistic debitage, building on Arzarello's (2003) work containing an initial reassessment of such behaviours.

The mentioned work aims to address a problematic matter regarding the analysis of lithic productions during the Middle Palaeolithic, which did not fall into the methodological paradigm of Levallois-discoid-laminar. Those kinds of industries, even if attested to by a significant number of artefacts, were often not considered as relevant within archaeological contexts, being either defined as a by-product of more complex reduction sequences or even disregarded at all.

In this case, Arzarello selected the Mousterian sequence of Riparo Tagliente as a testing ground. Starting from the structure of SSDA (Ashton et al., 1992; Forestier, 1993), Arzarello developed the concept of opportunistic debitage which comprise the algorithm and the fundamentals of SSDA (regarding morphology and volume conception) but unlike the latter, it implies the presence of a mental scheme and capacity of abstraction which Forestier did not consider as a requirement for the SSDA: "L'approche du tailleur clactonien n'est pas une approche qui engendre une stratégie issue d'un schéma mental nécessitant, comme dans le Levallois des facultés d'abstraction très développées" (Forestier, 1993, p. 59). Moreover, Arzarello also provided evidence that the SSDA scheme was not the only option in these productions. Still, it would include a much wider variability implying other knapping strategies (for example, centripetal) related to specific morphologies. The opportunistic debitage was then applied to older contexts in more recently published works to describe industries presenting similar patterns (Arnaud et al., 2017; Arzarello et al., 2013, 2016; Daffara et al., 2021; Niang & Ndiaye, 2016).

Concerning its definition, the opportunistic debitage has been initially described as "a flaking method oriented to raw materials' massive exploitation not implying a core, or any surface, preparation. The striking platforms and knapping surfaces are created as far as the flaking activity continues. […] The opportunistic debitage includes an infinite range of variants coming from the same common operative scheme." (Arzarello, 2003, p. 6). The term opportunism was not applied with a negative connotation but referred to its original semantic definition: "a behaviour in which someone adapts his actions to each context to gain from it the most advantage" (The Oxford English Dictionary OED). This method shows strong adaptability to local raw material morphology and its physical characteristics, and it is oriented towards morphologically non-standardised flake production mainly achieved through short reduction sequences. The subordination to morphological criteria comes from a standard predetermined mental scheme producing highly flexible and variable operative knapping schemes (unipolar, orthogonal, bipolar and centripetal). These are constantly influenced by, and adjusted to, raw material volume as far as the flaking activity is carried on. The aim is the production of functional flakes deriving from a mental scheme easily replicable through technical gestures. Therefore, preparation of the surfaces is never required. The operative schemes' variability depends on the available natural morphologies and the cores' volume. In any case, the opportunistic debitage implies a surface's hierarchisation (Boëda, 1994) or subordination of the morphologies to specific technical criteria (Boëda, 1993; Bourguignon, 1997).

In the end, a contextualization had to be made regarding the branched/ramified productions (Bourguignon et al., 2004; Mathias & Bourguignon, 2020; Mathias et al., 2020; Romagnoli et al., 2018) and their role within the opportunistic debitage. Being considered highly dependent on the flaking method used for the primary production (Bourguignon et al., 2004) and standing as a specific behavioural aspect of the human groups related to techno-economic issues (Mathias & Bourguignon, 2020), they may represent one of the several technical responses or adaptation through which a flaking method is achieved (Romagnoli et al., 2018).

The earliest evidence of the opportunistic debitage is related to the first European peopling by *Homo* sp. during the Lower Pleistocene starting from 1.6 Ma and gradually increasing around 1 Ma (Arzarello et al., 2016; Cheheb et al., 2019; Despriée et al., 2010, 2018; Moncel, 2010; Ollé et al., 2013). The lithic industry was obtained in all these sites by exploiting local raw materials of different qualities (such as flint, limestone, sandstone, quartzite and basalt) and morphologies (nodules, cobbles, pebbles, etc.). The reduction sequences attested to are mainly short and finalised to non-standardised flake production presenting at least one cutting edge achieved through multiple types of debitage (unipolar, orthogonal, bipolar, and centripetal), arbitrarily chosen depending on (or according to) the raw material's morphology and quality. Tools (usually denticulate and scrapers) are rarely found (Arzarello et al., 2016; Despriée et al., 2010), and unretouched flakes are predominant. Direct percussion by hard hammer is the most commonly used technique, but bipolar-on-anvil is also recognised (de Lombera-Hermida et al., 2016). Since a significant heterogeneity of the reduction sequences and raw materials employed is highlighted, the scientific community does not always agree on associating the concepts of *opportunism* (Arzarello, 2003) and *method* (Boëda, 1994) to describe the lithic complexes belonging to these sites. This brought to the identification of multiple technical behaviours, still without considering the presence of a possible common methodological *substratum* for these chronological phases, which has only recently started to be considered and regarded as "opportunistic" (Agam et al., 2015; Moncel et al., 2019; Moncel, Ashton, et al., 2020; Moncel, Despriée, et al., 2020; Peretto et al., 2016; Santagata et al., 2017; Vaquero & Romagnoli, 2018).

During the Middle Pleistocene, simultaneously, along with an increase of archaeological evidence, a persistence of the opportunistic debitage can be attested throughout Europe. These assemblages are often associated with the first bifacial complexes (Barsky et al., 2013; Bourguignon et al., 2016; García-Medrano et al., 2015; Martínez & Garcia Garriga, 2016; Moncel et al., 2013, 2014, 2018; Preece & Parfitt, 2012; Santagata, 2016) or to small-medium flake ones (Aureli et al., 2016; Despriée et al., 2010; Gallotti & Peretto, 2015; Grimaldi et al., 2020; Muttillo et al., 2021; Ollé et al., 2013; Parfitt et al., 2008; Preece & Parfitt, 2012; Rocca et al., 2016), although terminological and methodological issues endure. The reduction sequences always comprise strong flexibility and versatility, translating in a constant adaptation to the raw material's morphology and optimisation of flake production. Further implications concerning the increasing complexity highlighted in core technology management for this period (especially regarding the length of the reduction sequences and surface's centripetal conception) are now the centre of an important debate regarding the genesis of more predetermined methods (Moncel Arzarello, & Peretto, 2016; Moncel et al., 2014; Moncel, Ashton, et al., 2020; Ollé et al., 2013; Rossoni-Notter et al., 2016). We suggest that the opportunistic debitage could be the starting point for this process, carrying within itself a tremendous methodological and cultural potential.

Therefore, the first evidence of Levallois production (Moncel, Ashton, et al., 2020) and its earliest diffusion during MIS 12 and MIS 9 (Moncel et al., 2016; Pereira et al., 2016; Rocca, 2016) determined a shift in the flakes complex's methodological analysis at the expense of the opportunistic debitage from this chronological phase onwards. Because of this, the contextualisation of the opportunistic method within the cultural traditions of the Middle and Upper Palaeolithic resulted in being nearly absent, with few cases being excluded (Arzarello, 2003; Daffara, 2017; Santagata et al., 2017).

Materials and Methods

The Italian peninsula provides significant archaeological evidence to contextualise the origin and the evolution of the opportunistic debitage during the Lower, Middle and Upper Pleistocene. For this reason, a selection of four sites (Pirro Nord, Cà Belvedere di Montepoggiolo, Ciota Ciara Cave and Riparo Tagliente; Fig. 1), from different chronological and environmental contexts, was made to better underline this phenomenon through the technological analysis of the lithic assemblages.

Pirro Nord (Foggia, Apulia, Italy) is in an active limestone quarry at the northwestern margin of the Gargano promontory. It is part of a karstic complex developed at the top of the Mesozoic limestone formation, part of the "Apricena horst" (Pavia et al., 2012). In the sedimentary fillings of the Pirro 13 fissure (P13), lithic evidence was found alongside Late Villafranchian vertebrate fossils of the Pirro Nord Faunal Unit (Gliozzi et al., 1997). The origin of the deposit is the result of several massive processes (such as debris flow), which gradually chaotically fill

Fig. 1 Map showing the location and photos of the sites analysed in this work: 1, Pirro Nord; 2, Cà Belvedere di Montepoggiolo; 3, Ciota Ciara cave; 4, Riparo Tagliente

the fissure from the top, determining the transportation of artefacts and faunal remains (Giusti & Arzarello, 2016). The age of the site, estimated using biochronological data, falls between 1.6 and 1.3 Ma (Cheheb et al., 2019; López-García et al., 2015).

Cà Belvedere di Montepoggiolo is in northeast Italy near the town of Forlì. The geological succession of the area originated from the Plio-Pleistocene marine deposits “argille-grigio-blu” (grey-blue clay), later covered by the “sabbie gialle” (yellow sands) and subsequently eroded by marine regression (Ricci Lucchi et al., 1982). The yellow sands are not present in the site, and a pebble beach in a fluvial sand matrix was instead found, containing lithic assemblage in primary position (Peretto et al., 1998). The chronological range of the context has been set to 0.85 Ma (shortly after the cooling of MIS22), correlating the latest paleomagnetic analysis with the biochronological data from the surrounding area since no faunal remains were found (Muttoni et al., 2011).

Ciota Ciara cave is on the west slope of Monte Fenera’s karst (899 m a. s. l.) at the entrance of the Sesia valley (Vercelli, Piedmont, Italy). It is a still active karstic cave whose archaeological interest has been the object of systematic excavations during the ’60s, the ’90s and again from 2009 onwards (Busa et al., 2005; Daffara et al., 2019; Fedele, 1966). During previous investigations, a long sequence at the cave entrance was unearthed, and four main stratigraphical units were found, each one attesting a phase of human occupation (Angelucci et al., 2019). The archaeological record is abundant, comprising faunal remains, lithic industry, and anthropical evidence (hearths and human remains; Arzarello et al., 2014). According to the chronological data gathered, the Ciota Ciara cave's human use may have occurred during the second half of the Middle Pleistocene (Angelucci et al., 2019; Berto et al., 2016; Cavicchi, 2018; Vietti, 2016).

Riparo Tagliente is a rock shelter situated on the west slope of Valpantena, one of the central valley bottoms of Monti Lessini (Verona, Veneto, Italy). Systematically investigated since 1967, a complex stratigraphy was unearthed attesting two distinct phases of human occupation: the lower one referred to MIS 4–3 with Mousterian and Aurignacian assemblages and the upper one dated to the Late Glacial with Late Epigravettian evidence. A rich faunal record alongside human remains was brought to light (Arnaud et al., 2016; Fontana et al., 2002; Thun Hohenstein & Peretto, 2005). The age of the Mousterian sequence (the one studied in this paper) is estimated to be between 60 and 40 ka based on sedimentological analysis associated with the faunal assemblages (Bartolomei et al., 1982).

The technological analysis was performed to reconstruct exclusively opportunistic assemblages' knapping sequences and core reduction strategies. The aim was to identify the objectives of production, the operative schemes applied to obtain such products and, at the same time, to evaluate how morphology affected those aspects. Therefore, technical criteria are required (Boëda, 2013; Inizan et al., 1995).

For the flakes, several attributes were considered. The knapping technique was identified by analysing the butt and the ventral face (impact point, ripples, hackles). The scars and the presence/position of cortex were analysed to define the knapping method and the different reduction sequences employed. The incidence of debordant and plunging flakes and their morphology were used to identify any possible “intended product” together with the presence and position of the cutting edge (Van Gijn, 1989). Moreover, for each core, a diacritical scheme was realised to recognise and interpret the final steps of core reduction. The dimensional analyses were performed on complete pieces. The technical dimensions of the items were measured according to the minimal rectangle or “box method” (Laplace, 1977). No size categories were created, thus a distinction based on flake length was not required.

For all sites, a sample of lithic artefacts was considered with the aim of being, at the same time, the most representative (concerning raw material exploited and products) but also unintentionally selected regarding the opportunistic debitage (Tables 1 and 2). Cores, flakes (length ≥ 10 mm), and tools from the most abundant levels concerning the opportunistic method were analysed and studied. Overall, the technical behaviours identified through the analysis of cores were divided into (I) unifacial and (II) multifacial, depending on the number of knapping surfaces exploited, (III) cores on flake and (IV) split fractures cores. The terms unipolar, centripetal, orthogonal, and bipolar, applied to core descriptions, indicate how each knapping surface was knapped according to scar removal direction (Inizan et al., 1995).

Table 1 Sites, number of pieces and raw materials of the lithic assemblages analysed. In the case of Pirro Nord, the whole stratigraphic sequence has been considered since it is the result of a gravitative accumulation rather than a proper archaeological stratification due to distinct human occupations

Sites and levels	Total pieces	Studied pieces	Cores	Flakes	Raw material
Pirro Nord	340	108	19	89	Flint
Cà Belvedere di Montepoggiolo	1319 (76 refitting)	83 (23 refitting)	14	69	Flint
Level 101			1	7	
Level 102			2	15	
Level 103			6	25	
Level 104			2	10	
Level 105			1	4	
Level 107			1	2	
Level 108			-	2	
Level 109			1	-	
Level 111			-	3	
Level 113			-	1	
Ciota Ciara cave	7046 (5017 quartz)	112	8	104	Quartz
Level 14	3983 (3119 quartz)		8	104	
Riparo Tagliente	36.812	112	11	101	Flint
Level 39	31		-	7	
Level 41	30		-	2	
Level 42	1397		7	36	
Level 42 alfa	380		-	14	
Level 44	672		-	12	
Level 45	160		-	7	
Level 48	87		1	3	
Level 49	187		1	13	
Level 50	861		1	1	
Level 51	356		-	5	
Level 52	409		1	1	

The supplementary data for the archaeological collection are available at this link: https://zenodo.org/record/4228014.

An experimental collection for each site was obtained from the most abundant raw material in every context (Table 3). Pirro Nord and Cà Belvedere di Montepoggiolo were conceived together since the raw material morphology exploited in both is very similar (i.e. small pebbles). Since the experimentation focused exclusively on opportunistic debitage, its purposes revolved around two main aspects to evaluate its stability and versatility as a method: (a) the volumetric evolution of each block from its initial morphology to its gradual modifications as the knapping activity was carried on and (b) the identification of the leading strategies and aspects influencing any operative schemes. To accomplish these tasks, the creation of the *knapping-event* concept, similar to the one of *algorithm* defined by Forestier (1993), was

Table 2 Knapping goals of the experimental protocol

Experimental protocol	
Objectives of production	a) Maximized flake-production
	b) Flake production achieved through a single technical behaviour (i.e. centripetal)
	c) Flake production with predetermined functional and/or dimensional criteria (i.e. flake presenting a cutting edge of at least 40 mm)
Knapping-event change	1) Absence of knapping criteria
	2) Choice of a new striking platform and/or knapping surfaces on arbitrary base (such as "better convexities available")
	3) Raw material quality
	4) Dimensional issues
	5) Impossibility to achieve the objective of production
	6) Core management (such as technical flakes)
	7) Knapping errors and/or accidents

Table 3 Raw materials, the number of blocks collected and flakes obtained during the experimentation

Site	No. of blocks collected	No. of flakes obtained	Raw material	Weight (kg)
Pirro Nord/Cà Belvedere di Montepoggiolo	10	302	Flint	2.960
Ciota Ciara cave	10	204	Quartz	4.220
Riparo Tagliente	10	412	Flint	7.430

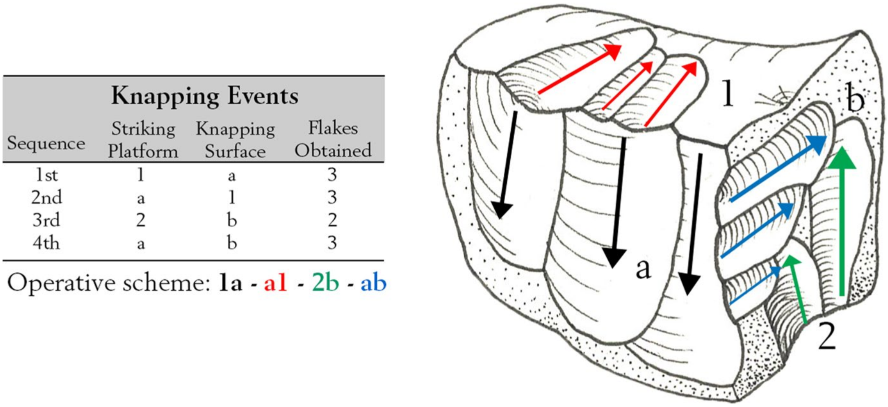


Fig. 2 Experimental protocol: example of an experimental core with its relative operative scheme. The arrows' colours are related to their respective knapping event. Each arrow indicates a removal and its direction. Drawings by M. Cecchetti

necessary (Fig. 2). The *knapping event* can be defined as "the choice of one striking platform and its related knapping surface from which the core will be knapped. The switch or the change of one, or both surfaces previously involved determines the end of that *knapping event* eventually allowing a new one to begin with". Each new striking platform was marked with consecutive numbers while the knapping surface with successive letters. The striking platform was always written before the knapping surface so that in case the chosen striking platform was formerly a knapping surface (or vice versa), the letters and the numbers were switched rather than using new ones. Once the core was discarded, an operative scheme was obtained by indicating the sequence of each *knapping event* in chronological order (Fig. 2).

Moreover, before starting each experimental sequence, specific knapping goals were established to verify if they could have led to different choices regarding core management or if they required specific knapping patterns (Table 3). The selection of goals was set according to the initial morphology and volume of the blocks, always considering the original archaeological context. To keep track of this process, any time a *knapping-event* switch was performed or the core was discarded, the causes were written down based on the knapper's indication (Table 3). The aim was to highlight and quantify the main factors affecting the flaking process by comparing each block's operative scheme with the resulting outcomes. Following the flaking process all along, some questions were addressed. Which are the main aspects influencing the volumetric evolution of the blocks? Are they identifiable? How much does the morphology affect the objectives of production? Is there a concrete subordination to raw material morphology? And, if so, is there any pattern distinguishable in the knapping activity?

The study of the experimental collection took place using the same technical criteria applied for the technological analysis of the archaeological material focusing on the direction of scars, incidence of debordant and plunging flakes and flake functionality (Van Gijn, 1989). The supplementary data for the experimental collection are available at this link: https://zenodo.org/record/4228014.

In the end, it was highlighted once again how the experimental knapping activity was applied as a constant analogy to get as close as possible (aware of being far from the absolute certainty) to the identification of a predominant operative scheme (i.e. method) by its application through several technical behaviours.

The Opportunistic Debitage of Pirro Nord and Cà Belvedere di Montepoggiolo

The raw materials employed in the sites mentioned above were locally selected from secondary deposits. The morphology and volume differed within each context, profoundly affecting the reduction sequences. In Pirro Nord, small and medium-sized pebbles (~30–80 mm), primarily round and oval, were exploited and collected within the range of the site, in riverbeds or slope deposits. The recognised flint types, coming from the Gargano Cretaceous succession, are of good quality. In Montepoggiolo, the procurement strategies recall the Pirro Nord ones qualitatively and morphologically. Pebbles and cobbles are slightly longer and oval (~30–100 mm).

Each opportunistic assemblage was oriented towards non-standardised flake production, presenting at least one cutting edge at times opposite to a backed margin (cortical or flat) (Figs. 6 and 7). The technical behaviours applied in each site are deeply related to the locally available morphologies, resulting in different knapping strategies. The presence of natural convexities on the selected blocks is one of the most relevant and frequently attested features. This allows the production of functional flakes without implying core preparation or a decortication phase.

Production

In Pirro Nord and Cà Belvedere di Montepoggiolo, similar morphologies provided an identical technological response, repetitive and deeply assimilated into the method. In both sites, the production was oriented towards roughly quadrangular flakes, which sometimes could be elongated depending on the initial morphology and volume of the core, especially for Montepoggiolo (Figs. 5, 6, and 7). The flakes were obtained through unipolar, orthogonal, bipolar, and centripetal flaking (Fig. 11; Table 4). The dimensional data available for Pirro Nord, both from the archaeological and the experimental collection highlights how the cobbles were originally mainly spherical, rarely larger than 60 mm (Fig. 5). Concerning Montepoggiolo, mostly large oval pebbles were knapped, resulting in longer flakes (Fig. 5). All in

Table 4 Typology of cores analysed in the archaeological (A.) and experimental (E.) record

Types of core	Pirro Nord		Cà Belvedere di Montepoggiolo	Ciota Ciara cave		Riparo Tagliente	
	A	E	A	A	E	A	E
Unifacial cores							
Unipolar	5	2	5	3	5	1	
Centripetal	1	2	2			1	1
Bipolar		1					
Orthogonal	2	2	1				
Multifacial cores							
Unipolar	3	4	3	3	8	3	7
Unipolar–bipolar					2	1	
Unipolar-orthogonal	1	1	1	2		2	2
Centripetal	1						
Centripetal-unipolar		1	1			2	
Orthogonal			1			1	
Bipolar	2						
Split fracture cores	1						
Cores on flake	3						
Total	19	13	14	8	15	11	10

all, two main reduction strategies were identified: a unidirectional-multifacial flake-production applied on larger volumes and centripetal exploitation of the surfaces on smaller and more rounded cobbles. Given the original dimensions of the raw material and since the adaption to morphology was constant throughout the whole knapping process, the reduction sequences were short and arbitrarily applied on the same core (Table 5).

The unipolar production began with the opening of a flat striking platform decapping one of the extremities of the pebbles or exploiting present suitable convexities (Fig. 4, n°1). Parallel unipolar removals gradually decorticated the knapping surfaces. Therefore, knapping surfaces were orthogonally generated, often by negatives of previous removals. The same scheme is observable on striking platforms. The production was carried on until suitable convexities existed. Usually, 3–4 flakes were extracted from each core, but when bigger pebbles were present, such as in Montepoggiolo, a succession of three or four-generation from the same striking platform is attested (Figs. 3 and 4, n°2). Overall, flake production was achieved while maintaining appropriate convexities. The use of lateral debordant flakes, both for the creation of backed margins and as nervure guides, is the technical expedient more frequently adopted (Fig. 10).

A centripetal conception of the surfaces was applied in the second case mentioned above. A single knapping surface was exploited in different directions (usually orthogonal or bipolar, more rarely centripetal sensu stricto) through a peripheral striking platform (Fig. 3, n°1; Fig. 4, n°1). This strategy was applied on the rounder cobbles, especially the smallest ones, usually opened by the bipolar on anvil technique. In doing so, larger knapping surfaces were made

Table 5 Pirro Nord 13. Analysis of the experimental cores. N° S. P. indicates the final number of striking platforms on the abandoned cores. N° K. S. indicates the final number of knapping surfaces on the abandoned cores

Site	Core ID	Knapping-events sequence	Type of core	N° S. P.	N° K. S.	N° Flakes
Pirro Nord	n1	1a-ab-bc-2c-cd-dc	Multifacial (centripetal–unipolar)	6	5	31
	n2	1a-2a-3a-ab	Multifacial (unipolar)	2	2	34
	n3	1a-ab-bc-cb	Unifacial (unipolar)	1	1	42
	n4a	1a-a1	Unifacial (orthogonal)	2	2	20
	n4b	1a-a1	Unifacial (centripetal)	2	2	36
	n5a	1a	Unifacial (centripetal)	1	1	11
	n5b	1a	Unifacial (unipolar)	1	1	14
	n6	1a-a1-1b-b1	Multifacial (unipolar–orthogonal)	3	3	25
	n8	1a	Unifacial (orthogonal)	2	1	13
	n10	1a-a1	Unifacial (unipolar)	2	2	10
	n7	1a-ab-2(ab)-a1	Multifacial (unipolar)	3	3	21
	n9a	1a-a1	Unifacial (bipolar)	1	1	16
	n9b	1a-ab-bc	Multifacial (unipolar)	3	3	25

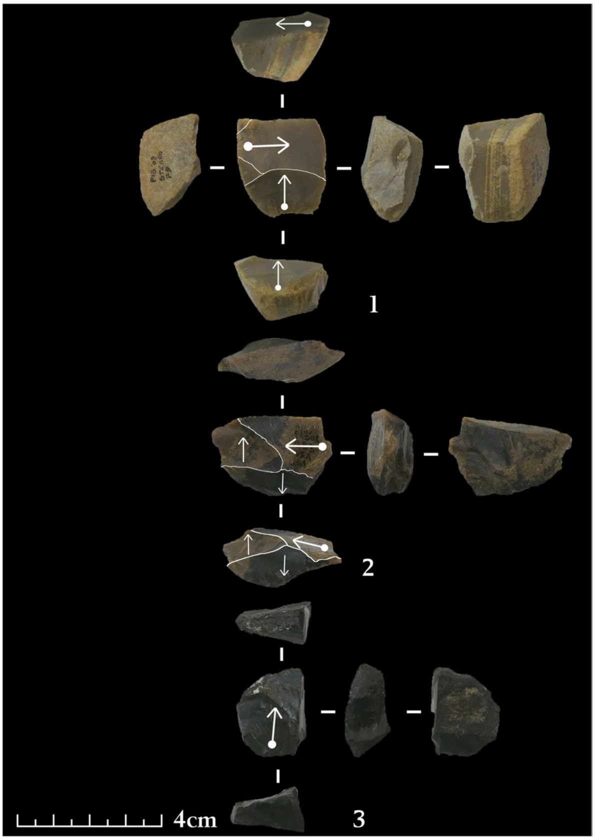


Fig. 3 Pirro Nord, archaeological: 1, orthogonal core; 2, multifacial orthogonal core on flake; 3, unipolar core

available, and it was also the best way to enhance the cobble's volume. Therefore, it is the most efficient behaviour testified in Pirro Nord (Fig. 3; Table 4). The striking platforms were mainly natural, although in Montepoggiolo flat ones are attested by several refits. The latter was realised through one or more orthogonal removals to the knapping surface to prepare a peripheral striking platform (Fig. 4). During the reduction sequence, each removal would often create new convexities (lateral and or distal) and nervures that allowed the debitage to run around the block until suitable technical criteria existed. As aforementioned, also, in this case, the presence of debordant flakes is quite relevant with the aim of maintaining good angles and convexities and to obtain backed flakes (opposite to a cutting edge) (Fig. 6, n° 4, 6, 11, 12; Fig. 7, n° 4, 8, 10; Fig. 10).

The raw material's morphology dictates the best strategy to employ among the two. Nonetheless, both behaviours can be recognised on the same core. The constant adaptation to morphology is the scheme behind the process for accomplishing the production's goals.

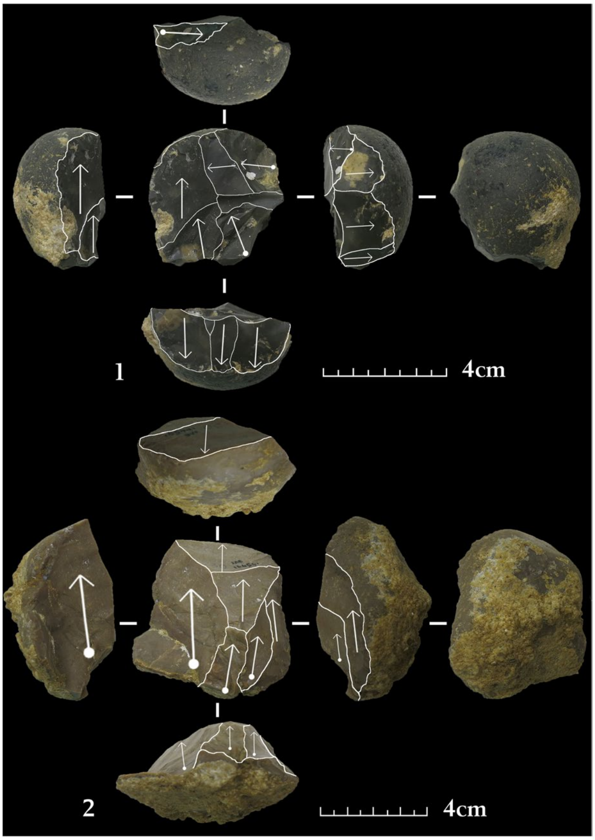


Fig. 4 Cà Belvedere di Montepoggiolo, archaeological: 1, orthogonal multifacial core on small pebble; 2, unipolar core on a large pebble

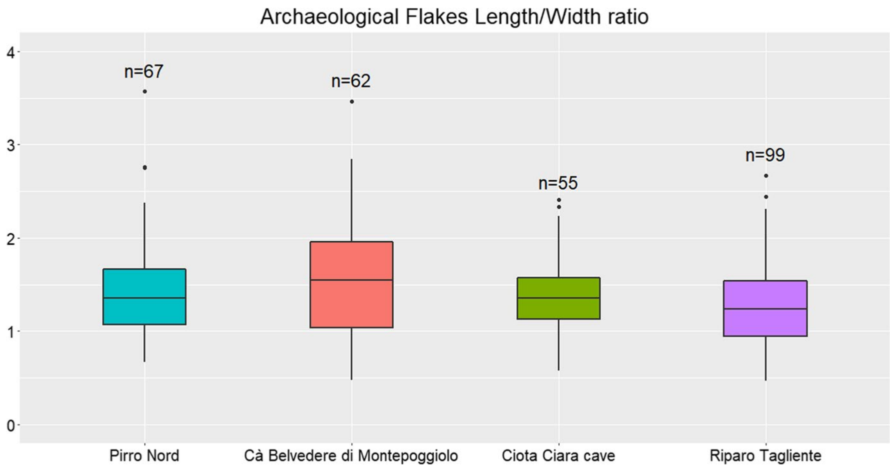
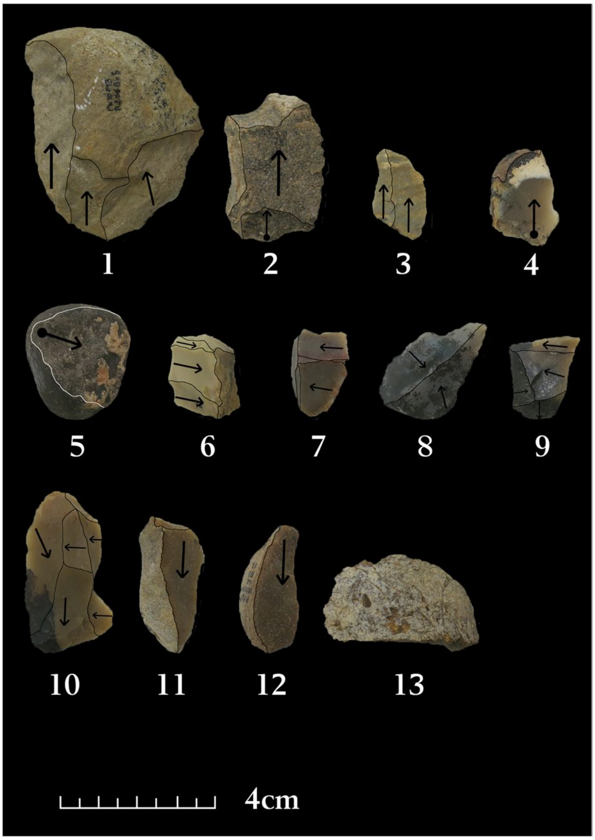


Fig. 5 Dimensional variability of archaeological flakes; yaxis: length/width ratio; xaxis: archaeological site

Fig. 6 Pirro Nord, archaeological: 1–4, flakes with unipolar scars; 5–7, flakes with orthogonal scars; 8–10, flakes with centripetal scars; 11–12, flakes with bipolar scars; 13, cortical flake



Flakes' Analysis

Pirro Nord and Cà Belvedere di Montepoggiolo's flakes share common features. Quadrangular non-standardised shapes are widely attested, slightly longer than larger and with at least one cutting edge, usually on the lateral margin (Figs. 5, 6, and 7). The length of Pirro Nord's flakes ranges between 40 and 15 mm. The average length is 27 mm. Width ranges from 30 to 10 mm, with an average of 20.2 mm. Thickness varies between 16 and 3 mm, and the average value is 8.4 mm. Regarding Cà Belvedere di Montepoggiolo's flakes are longer than Pirro Nord's. Length ranges between 78 and 11 mm; however, for 77% of the pieces, it goes from 19 to 51 mm. The average length is 37.3 mm. Width reaches a maximum value of 51 and a minimum of 12 mm with an average of 26 mm. However, for 87% of flakes, the width spans from 12 to 36 mm. Concerning thickness, it varies from 28 to 2 mm with an average value of 9.3 mm.

The dimensional range of the flakes, with or without cortex, is relatively homogenous, confirming the shortness of the reduction sequences (Fig. 8). The cortical flakes, less attested, are related either to the bipolar technique or to the

Fig. 7 Cà Belvedere di Montepoggiolo, archaeological: 1–7, flakes with unipolar scars; 8–10, flakes with orthogonal scars; 11–12, flakes with centripetal scars; 13–14, cortical flakes

opening of new knapping surfaces. The frequency of functional flakes (with at least one cutting edge) is constant within each employed reduction sequence, indicating that the adaptation to the morphology led to efficient production. Moreover, the presence of backed lateral margins (mainly cortical) opposite to cutting edges can be interpreted as a researched feature for better grasping and, as already mentioned, a technical expedient as well (Figs. 6, 7, and 10). Several refits from Cà Belvedere di Montepoggiolo highlight this strategy as an efficient way to maintain technical criteria alongside flake production. In this case, convergent flakes could be obtained through a removal on the lateral edge of the knapping surface, thus preparing a nervure guide (Fig. 7, n° 4, 5, 6).

The Experimental Collection

The experimental collection of Pirro Nord provided a significant number of debordant flakes, both from unipolar and centripetal cores (Figs. 9 and 10; Table 6). These products were constant in each *knapping event*, showing specific core exploitation behaviours but often being characterised by a lateral cutting edge opposite to a

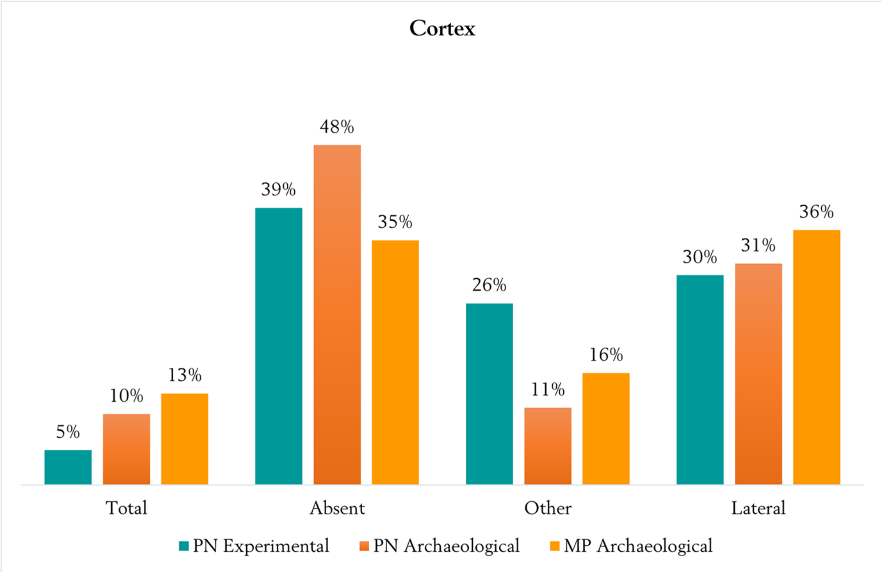


Fig. 8 Pirro Nord and Cà Belvedere di Montepoggiolo. The presence and position of cortex on archaeological and experimental flakes from Pirro Nord (PN) and archaeological flakes from Cà Belvedere di Montepoggiolo (MP)

Fig. 9 Pirro Nord, experimental: 1–7, flakes with unipolar scars; 8–11 flakes with orthogonal scars; 12, flake with centripetal scars; 13, flake with bipolar scars

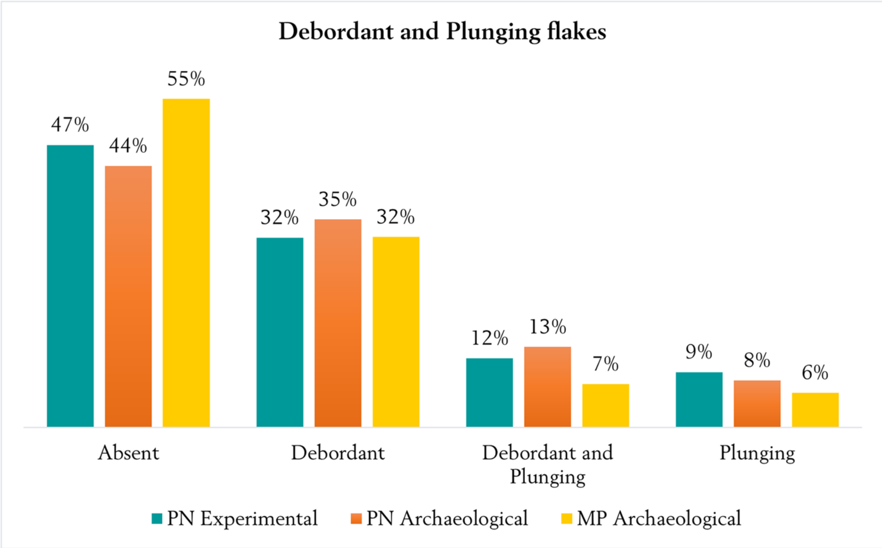


Fig. 10 Pirro Nord and Cà Belvedere di Montepoggiolo. Distribution of debordant and plunging flakes on archaeological and experimental collections from Pirro Nord (PN) and archaeological flakes from Cà Belvedere di Montepoggiolo (MP)

backed margin (Fig. 9, n°1, 3, 4, 9). In unipolar productions, their function was the knapping surface's management, achieved by lowering the core's lateral edges while also creating a nervures guide for the subsequent removals. This way each following flake sets up a lateral convexity and a nervure guide for its consecutive removal, making it possible to quickly obtain sustainable flake-lengths and cutting edges without cortex. In the centripetal sequences, cordal-like removals (Fig. 9, n° 9) were often performed to maintain good convexities, but since the debitage was conducted through a peripheral striking platform, lateral and distal convexities were often, unintentionally, created (Fig. 9, n° 10, 11). This allowed the knapper to effectively run around the block and choose the best surface to control the flake's morphology and functional features. This pattern is evident, especially in the case of smaller cores (Figs. 11 and 12). Therefore, orthogonal removals were performed alternating two distinct directions from the striking platform (Fig. 12, n°3). The experimental collection also yielded many déjeté points, corresponding to 23% of all flakes. The frequency of two orthogonal margins (the lateral and the distal one), forming a tip, often adjacent to a natural backed edge, turned out to be very high in centripetal exploitation (36% of all déjeté points; Fig. 9, n° 8, 10–12). However, these flakes were not morphologically predetermined, as seen in the archaeological record (Arzarello et al., 2016; Potì, 2012). These proved to be rather an unintentional outcome of centripetal reduction sequences, which likely produced quadrangular flakes (i.e. with orthogonal margins) (Fig. 9, n° 8, 10, 11).

The analysis of the experimental production from Pirro Nord displayed a greater affinity between the centripetal reduction sequences and the archaeological collection (Table 5). The ratio between unipolar removals and orthogonal + bipolar ones is

Table 6 Ciota Ciara cave. Analysis of the experimental cores. N° S. P. indicates the final number of striking platforms on the abandoned cores. N° K. S. indicated the final number of knapping surfaces on the abandoned cores

Site	Core ID	Knapping-events sequence	Type of core	N° S. P.	N° K. S.	N° Flakes
Ciota Ciara cave	CC1N	1a-a1-1b-b1	Multifacial (unipolar–bipolar)	3	4	41
	CCN9-1	1a-ab-1c	Multifacial (unipolar)	2	3	3
	CC3N	1a-a1-1b-b1	Multifacial (unipolar–bipolar)	3	3	14
	CCN10	1a-a1	Multifacial (unipolar)	2	2	4
	CCN5	1a-a1-1a1	Multifacial (unipolar)	2	2	23
	CCN9	1a-ab-ba	Multifacial (unipolar)	2	2	23
	CCN7	1a-ab-1a1-a1-1a2	Multifacial (unipolar)	2	2	27
	CCN4b	1a-ab	Multifacial (unipolar)	2	2	10
	CCN4a	1a-a1	Multifacial (unipolar)	2	2	9
	CCN8	1a-21-1aII	Multifacial (unipolar)	1	1	11
	CCN6	1a	Unifacial (unipolar)	1	1	18
	CC2Nb	1a	Unifacial (unipolar)	1	1	3
	CC2Na	1a	Unifacial (unipolar)	1	1	5
	CC2N	1a-21	Unifacial (unipolar)	1	1	2
	CCN4b1	1a	Unifacial (unipolar)	1	1	5

closer when selecting only centripetal reduction sequences. This is also emphasised by a more significant similarity of the flakes thus obtained (Fig. 6, n° 6–9; Fig. 9, n° 7, 8, 10–12). Hence, the centripetal exploitation of the surfaces was more efficient and quantitively import when experimenting on smaller volumes and rounder morphologies.

By observing the refitting of the experimental sequences, it appears that, as already stressed, a centripetal conception of the surfaces quickly leads to better control of the flake's morphology. As a result, this may gradually generate greater *awareness* in the knapper's mind during the flaking activity leading to hierarchised reduction sequences and, eventually, obtaining morphologically predetermined products. The presence of déjeté points in Pirro Nord's archaeological record (Fig. 6, n° 8) and convergent flakes from the Cà Belvedere di Montepoggiolo (Fig. 7, n° 4, 5) may be an example of this. Short reduction sequences intensively and constantly applied on many pebbles could lead to a standardised technical behaviour, modulated on the continually changing morphology, potentially generating predetermined

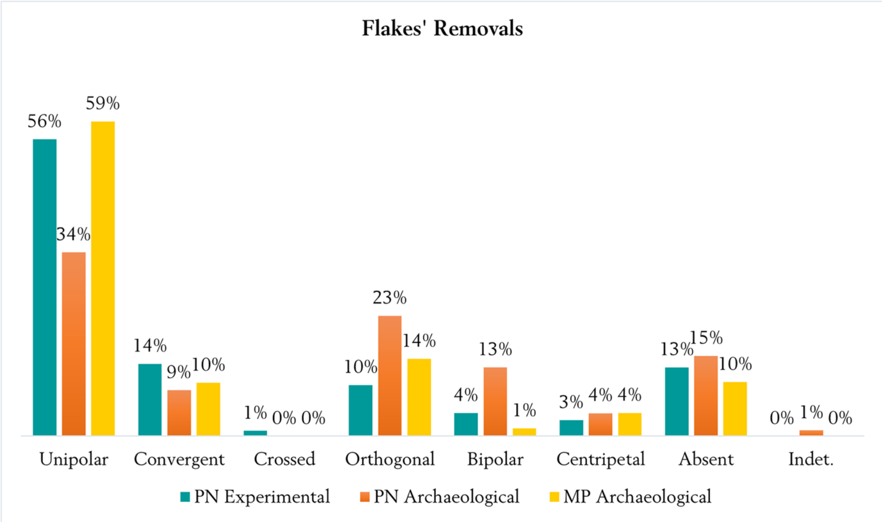


Fig. 11 Pirro Nord and Cà Belvedere di Montepoggiolo. Presence and position of removals on archaeological and experimental flakes from Pirro Nord (PN) and archaeological flakes from Cà Belvedere di Montepoggiolo (MP)

products. In conclusion, similar morphologies can correspond to identical methodological responses (Arzarello et al., 2016).

The Opportunistic Debitage of Ciota Ciara Cave and Riparo Tagliente

In terms of raw material selection, the same pattern can be highlighted for the opportunistic assemblages of Ciota Ciara cave and Riparo Tagliente. In the Ciota Ciara cave, vein quartz is the most exploited raw material for opportunistic reduction sequences and other knapping methods (Daffara, 2017). Blocks and nodules of different morphologies and dimensions (40–100 mm) were locally collected along riverbeds and slope deposits (Daffara et al., 2019). Since vein quartz's texture is mainly coarse, implying shorter reduction sequences, more significant importance was given to the presence of suitable natural convexities rather than to the dimensional issues. The same procurement strategies are seen in Riparo Tagliente, where many large flint blocks and nodules of excellent quality were available. As in the previous context, Levallois and discoid productions were made on the same raw material, alongside the laminar method.

Ciota Ciara Cave—Production

In the Ciota Ciara cave, flake production started straight from the block's natural convexities, or arrows, without foreseeing any core preparation or surface management. The production, then, proceeded mainly through unipolar removals, eventually

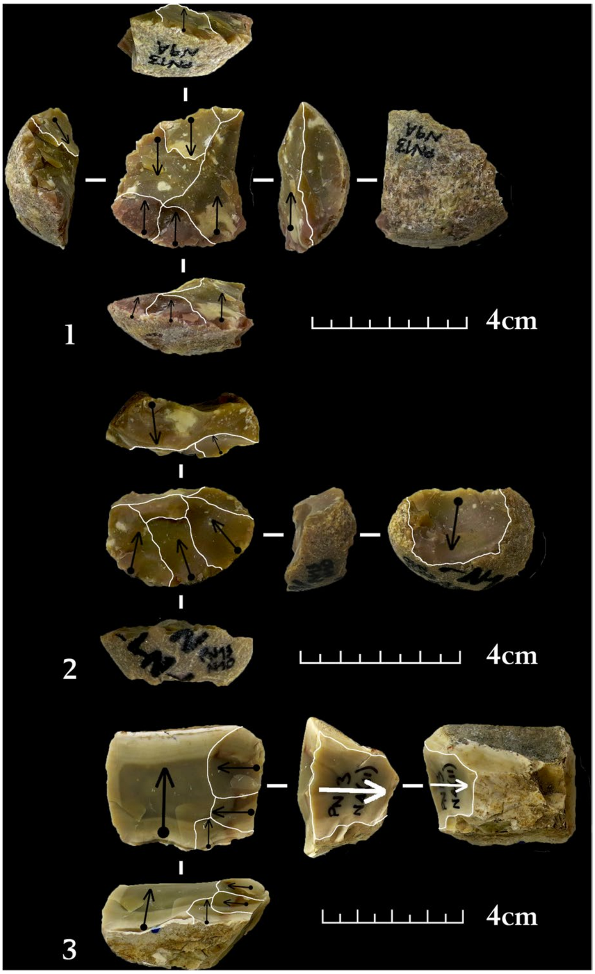


Fig. 12 Pirro Nord, experimental: 1, bipolar core on small pebble open by split fracture; 2, unipolar multifacial core on small pebble open by split fracture; 3, orthogonal multifacial core

including new knapping surfaces or just switching them (Fig. 13; Table 5). Orthogonal and bipolar removals are less attested to (Fig. 13). The use of the same knapping surface and striking platform until the core's exhaustion was relatively common (Table 4). The produced flakes were quadrangular in shape, yet morphologically non-standardised and with at least a cutting edge on the lateral margin (Fig. 16). According to the raw material features, a high rate of flaking accidents and irregular surfaces on the cores are frequent (Daffara, 2017). Therefore, the creation and management of suitable convexities and nervure-guides were related to the initial morphology of the blocks. Reduction sequence length was proportioned to the initial volume of the block but above all to its *morphological flaking-predisposition*. With this expression, we want to indicate the presence of natural suitable angle and convexities as the guiding line for the block's selection and during the knapping activity. The experimental collection confirmed this, which provided a wide

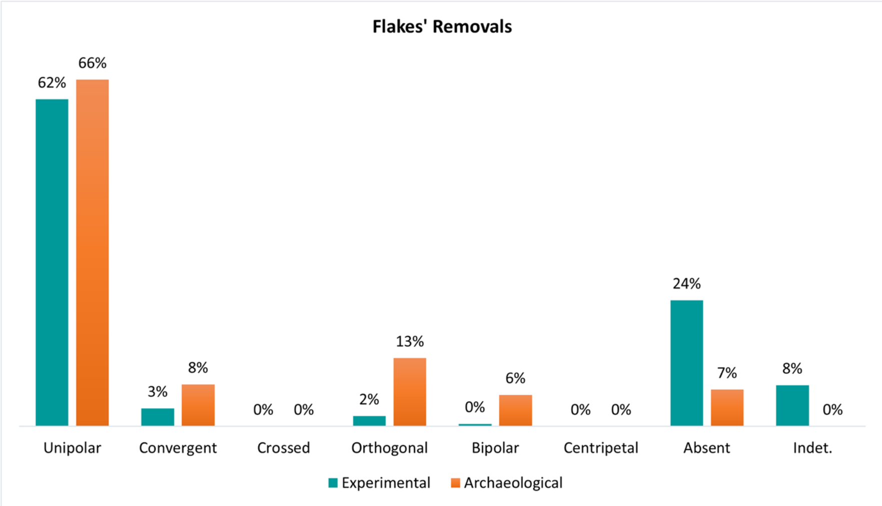


Fig. 13 Ciota Ciara cave. Presence and position of removals on archaeological and experimental flakes

sample of exhausted cores of different morphologies and dimensions. Their analysis emphasises the absence of a specific tendency in choosing one or more striking platforms and knapping surfaces to exploit (Table 6). The objectives of production were instead modulated considering the pre-existing convexities.

No difference was made between natural or flat striking platforms since vein quartz's cortex did not affect the flaking activity. The likelihood of exploiting one knapping surface until the abandonment of the core was relatively high, also considering the high percentage of natural butts. This may also prove that the production phase starts directly on the natural surfaces (Tables 4 and 6).

Ciota Ciara Cave—Flakes

Ciota Ciara's flakes are roughly quadrangular and slightly longer than larger (Fig. 5). Lengths range between 70 and 14 mm with an average of 33.5 mm. Widths span from 12 to 66 mm; however, 82% of flake widths range from 12 to 32 mm. The average width is 25.5. Regarding thickness, it goes from 4 to 24 mm with an average value of 12.5 mm. The flakes show a lateral cutting edge frequently opposite a backed margin (Fig. 16, n° 1, 3, 5, 6; Fig. 18). The presence of guiding arrises is usually related to a single unipolar removal or, more rarely, by a portion of the cortex (Fig. 16, n° 1, 3, 5, 8). Generally, most flakes display only one negative, suggesting that knapping surfaces were not that large, being exploited through few removals until the exhaustion of the natural convexities. In this way, natural edges were used as a technical expedient to achieve functional flake production and create nervure guides. Therefore, the frequency of debordant flakes is quite high (Fig. 18). Orthogonal and bipolar flaking resulted in being sporadically employed (Fig. 13). However, the cores and flakes attesting to these strategies (Fig. 14, n° 2) are not different from the record, fitting well in

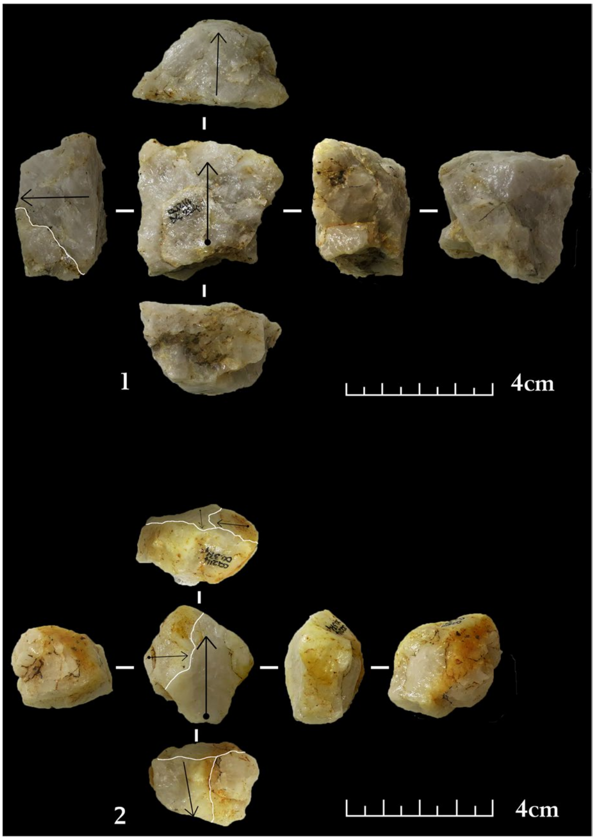


Fig. 14 Ciota Ciara cave, archaeological: 1, unipolar multifacial core; 2, orthogonal multifacial core

the same operative scheme of subordination and adaptation to the morphology that comprises the whole opportunistic production of the Ciota Ciara cave. Supporting this, the experimental reduction sequences occasionally presented knapping surfaces exploited from several directions, but this was not matched by the flake removal analysis, which shows the same trend as the archaeological cases (Tables 5 and 7; Figs. 13, 15, 16, and 17). On an experimental basis, the functionality rate of the flakes proved to be higher on the smallest and thinnest ones. This, however, is not validated by the archaeological sample, attesting, on the other hand, to a homogeneous distribution of functional flakes within the dimensional range. Therefore, in accomplishing the production goals, it was constant along the entire reduction process, without the need for specific morpho-dimensional criteria.

Once again, the high adaptability towards morphologies and volumes of blocks and cores emerges as the central distinguishable aspect of the opportunistic assemblages. The presence of Levallois and discoid productions within the context proves, on one side, that the exploitation of raw materials qualitatively regarded as inferior does not invalidate the possibility of using more complex

Table7 Riparo Tagliente. Analysis of the experimental cores. N° S. P. indicates the final number of striking platforms on the abandoned cores. N° K. S. indicated the final number of knapping surfaces on the abandoned cores

Site	Core ID	Knapping-events sequence	Type of core	N° S. P.	N° K. S.	N° Flakes
Riparo Tagliente	RT1N	1a-a1-1b-a1I-1c	Multifacial (unipolar)	3	3	44
	RT2N	1a-ab-bc-cd	Multifacial (unipolar–orthogonal)	3	3	41
	RT3N	1a-a1-1b-1c	Multifacial (unipolar)	3	3	49
	RT5N	1a-a1-1aI-a1I-1aII	Multifacial (unipolar–orthogonal)	4	5	40
	RT6N	1a-a1	Multifacial (unipolar)	2	2	20
	RT7N	1a-ab-1b-a1-1aI	Multifacial (unipolar)	2	2	43
	RT8N	1a-a1-1b-b1	Multifacial (unipolar)	2	2	18
	RT9N	1a-ab	Multifacial (unipolar)	2	2	25
	RT10N	1a	Unifacial (centripetal)	1	1	54
	RT11N	1a-ab-ac-ba-abI-baI-abII	Multifacial (unipolar)	3	3	78

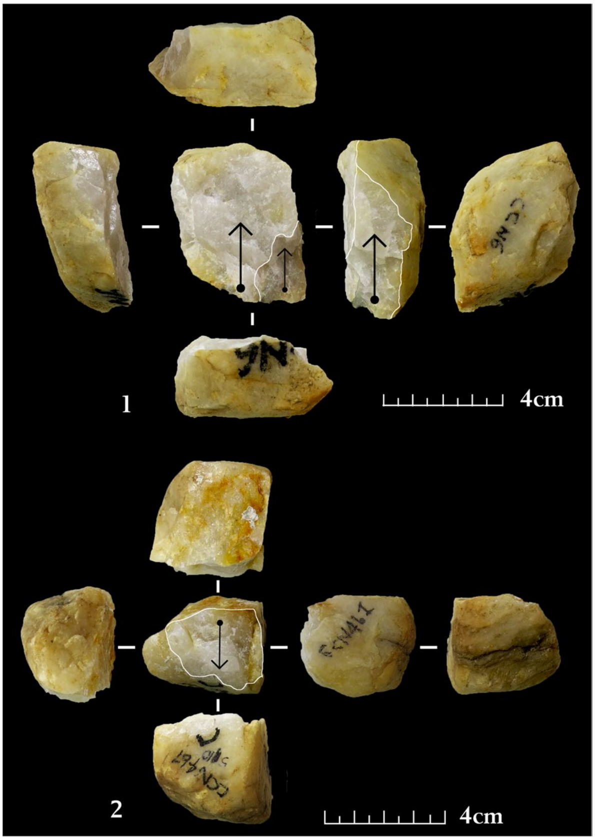


Fig. 15 Ciota Ciara cave, experimental: 1, unipolar multifacial core; 2, unipolar core

flaking methods; On the other hand, it underlines how opportunistic debitage persists during the Middle Palaeolithic as an efficient and independent method (if compared to Levallois and discoid) replicated through several operative knapping schemes (i.e. unipolar, orthogonal, centripetal, bipolar) for the manufacturing of functional products (Figs. 18 and 19).

Riparo Tagliente

Concerning Riparo Tagliente's opportunistic assemblage, the aim was always flake-production achieved through a constant adaptation to the morphological criteria. Since larger, higher-quality blocks were available (nodules and fluvial cobbles), the reduction sequences were longer and more complex (Table 4; Fig. 23). These aspects enhanced the possibility of exploiting more surfaces simultaneously or individually through multifacial removals (unipolar, orthogonal, bipolar, and centripetal s.s.) until the complete depletion of the existent convexities. This determined, eventually, the abandonment of large dimension cores still presenting suitable surfaces for exploitation (Fig. 23). The great abundance of such an excellent raw material

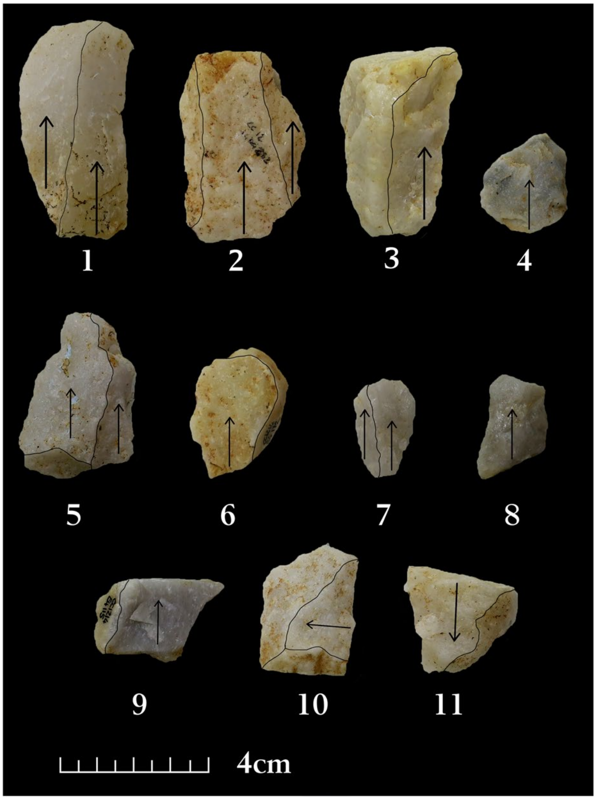


Fig. 16 Ciota Ciara cave, archaeological: 1–9, flakes with unipolar scars; 10, flake with orthogonal scars; 11, flake with bipolar scars

within the site might explain this behaviour (Arzarello, 2003). Of course, the presence of small massively exploited cores also suggests that the production was quantitatively remarking despite anything else.

Again, the initial morphology dictated how the production goals were achieved. This was resolved in a dual case scenario to produce non-standardised quadrangular flakes, slightly elongated with at least one cutting edge (Figs. 5 and 24). In the first case, unipolar-multifacial debitage was set up while a centripetal one occurred in the latter. According to the evolving morphologies, these two strategies were not separately employed but constantly linked and rotated on the same core. The length of these flakes ranges between 20 and 70 mm, with 91% of them ranging from 20 to 50 mm. The average length is 36 mm. Concerning width, it spans from 12 to 65 mm, but 86% is included in a 17–42 mm range. The average width is 30.2 mm. Thickness varies from 4 to 19 mm with an average of 8.6 mm.

Riparo Tagliente—Production

The unipolar production was carried on larger nodules or particularly elongated ones, where the longitudinal axis was often employed as the knapping surface. In

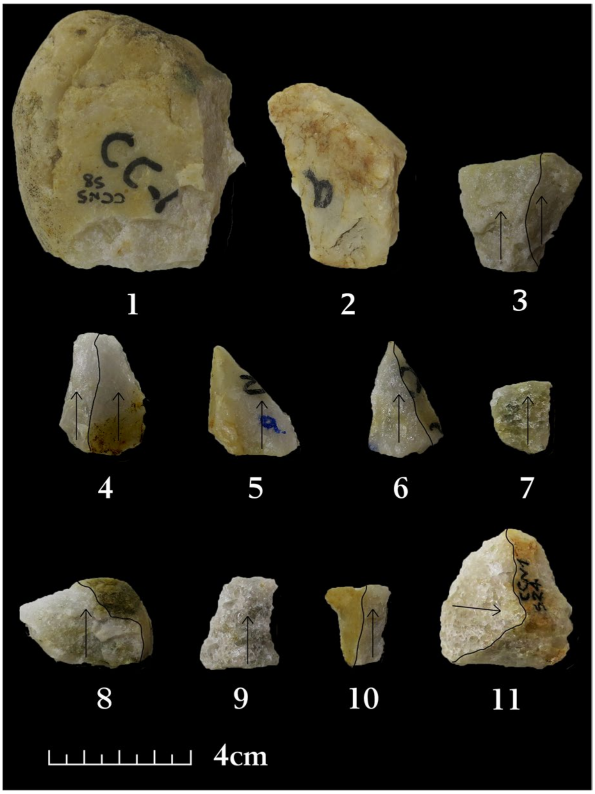


Fig. 17 Ciota Ciara cave, experimental: 1–2, cortical flakes; 3–10, flakes with unipolar scars; 11, flake with orthogonal scars

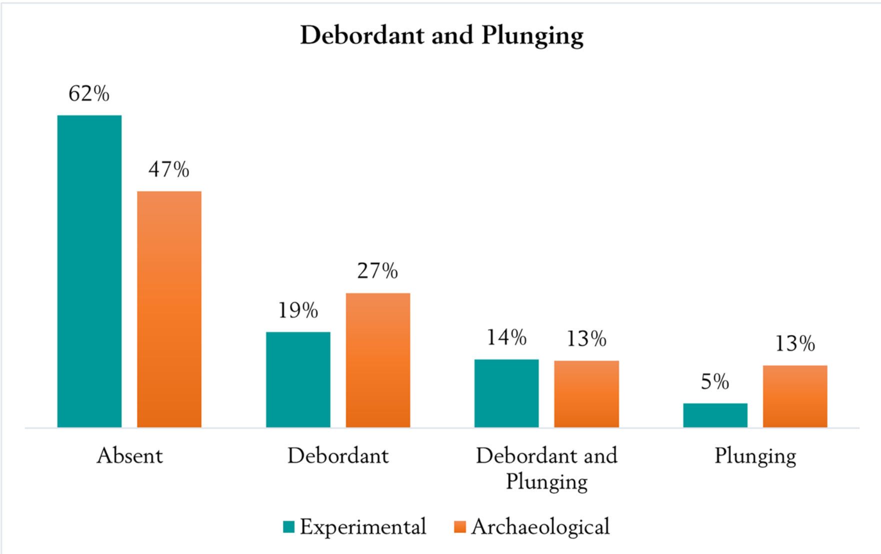


Fig. 18 Ciota Ciara cave. Distribution of debordant and plunging flakes on archaeological and experimental collections

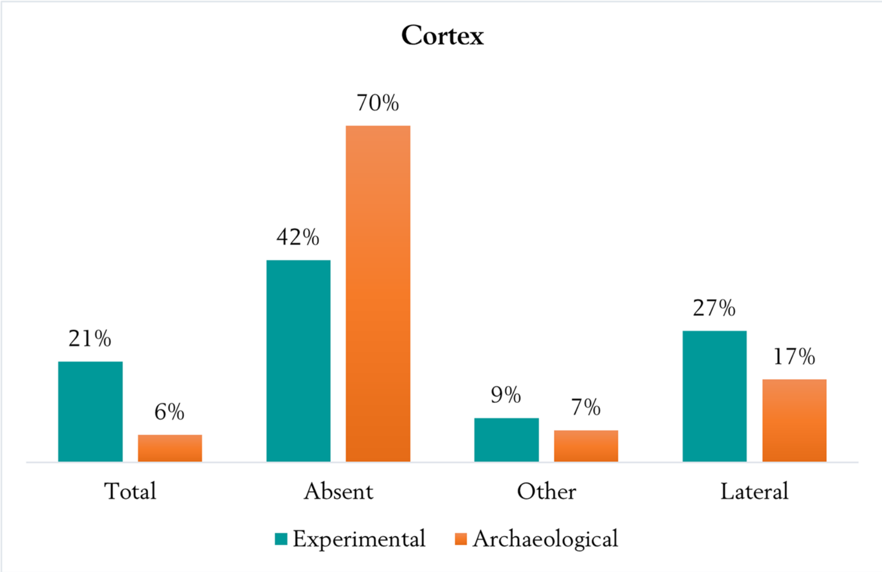


Fig. 19 Ciota Ciara cave. Presence and position of cortex on archaeological and experimental flakes

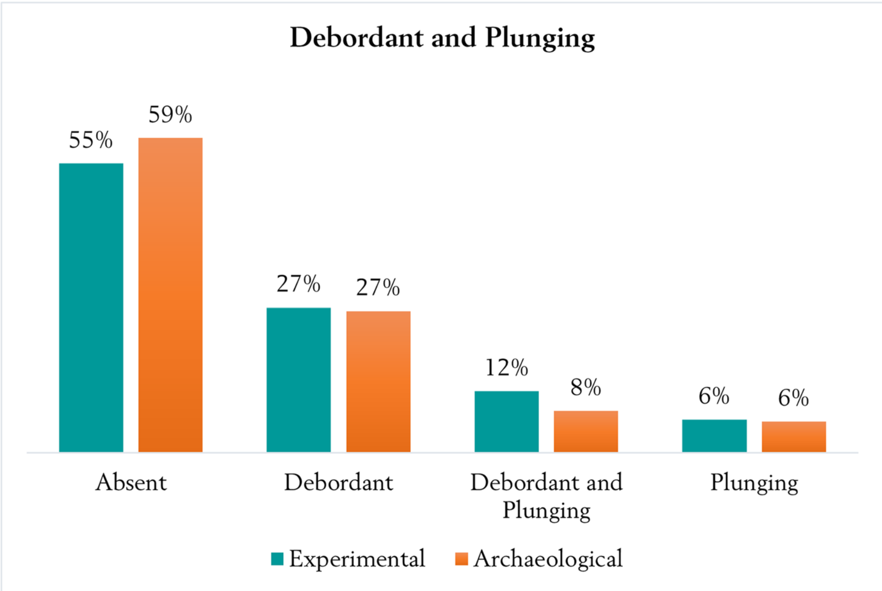


Fig. 20 Riparo Tagliente. Distribution of debordant and plunging flakes on archaeological and experimental collections

this case, the presence of suitable natural convexities was one of the requirements for opening the flaking activity. Most of the nodules presented exposed surfaces due to natural fractures that could speed up the extraction process (Fig. 21). Otherwise, a single cortical flake was needed to prepare the knapping surface. Concerning striking platforms, the same pattern can be attested. The opening of a flat one was necessary when an already existing one was lacking in the initial morphology of the blocks. Elongated laminar-like flakes were thus obtained, more frequently presenting a debordant edge on the lateral margin rather than on the distal one (Fig. 20, 24 n° 1). The cutting edge often corresponded to the scar left by previous removals. The aim was to gradually enlarge the knapping surface, removing the cortex and thus involve the other core's faces. The formation of nervure-guides happened simultaneously to the flake's extraction, being equally exploited as natural edges. These aspects were functional to the flake's length, optimising the knapping surface's productivity in both a quantitative and qualitative way. As stressed above, this strategy resulted, eventually, in semi-tournant behaviours involving, initially, natural edges by progressively exploiting ones created during the production, recalling the laminar conception. As the core's volume decreased, multidirectional flaking could be initiated (Table 5; Figs. 22 and 23). Therefore, switching between the striking platforms and knapping surfaces was rather frequent and functional to preserve the technical criteria. That is why orthogonal and bipolar debitage was likely to happen, both leading to a centripetal conception of knapping surfaces: the same extraction's surface was more frequently knapped as the core's volume decreased. At this stage, the flakes were gradually smaller and quadrangular in shape, bearing no cortex at all. An

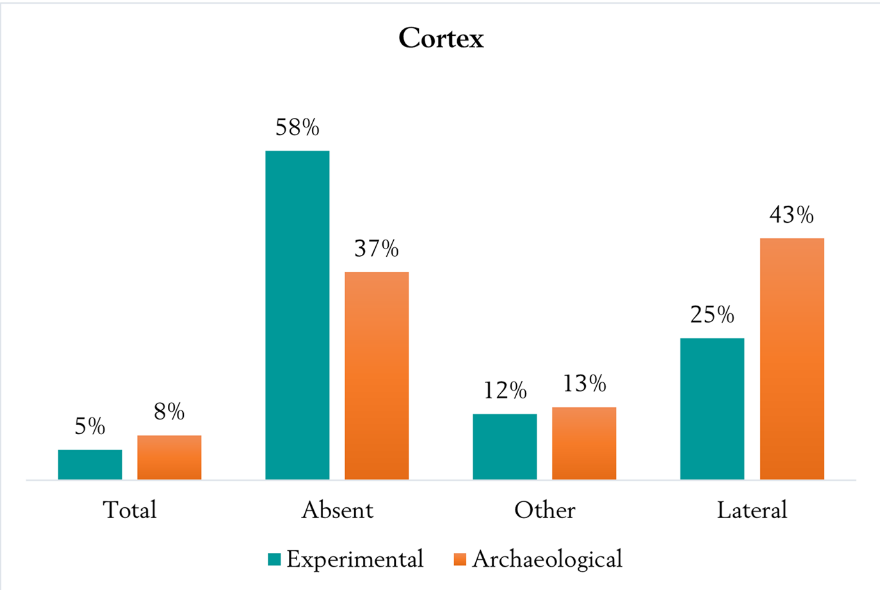


Fig. 21 Riparo Tagliente. Presence and position of cortex on archaeological and experimental flakes

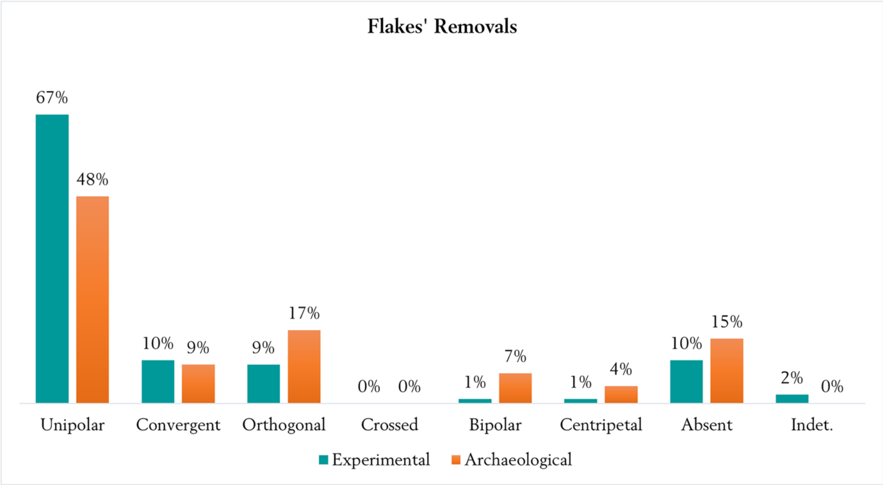
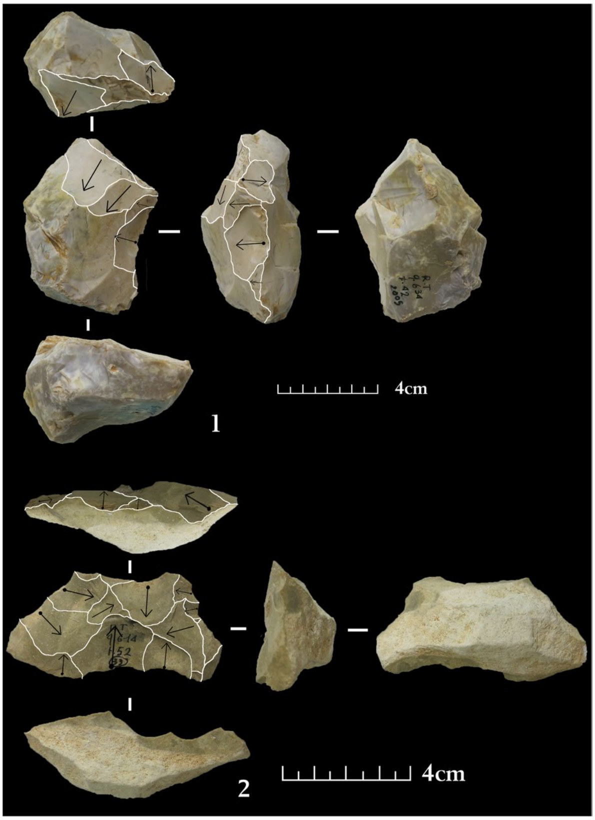


Fig. 22 Riparo Tagliente. Presence and position of removals on archaeological and experimental flakes

Fig. 23 Riparo Tagliente, archaeological: 1, multifacial unipolar core; 2, centripetal core



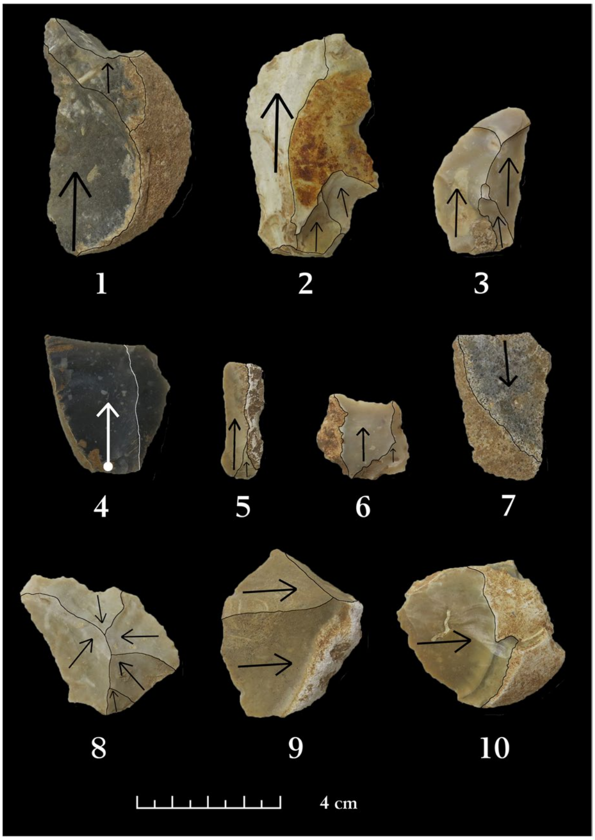


Fig. 24 Riparo Tagliente, archaeological: 1–6, flakes with unipolar scars; 7, flake with bipolar scars; 8, flake with centripetal scars; 9–10, flakes with orthogonal scars

increased number of cutting edges on the distal margins can be observed. This pattern was then repeated until the core was no further exploitable.

When large fluvial pebbles were collected and flattened, and rounder surfaces were available, centripetal flaking was possible to start the production. In this way, a preexisting peripheral striking platform was available (although the extraction of a cortical flake may have been required to initiate the debitage), resulting in optimising the raw material's economy (Fig. 23, n°2). The production focused on parallel removals, which gradually involved the entire surface, allowing better control over the flake's morpho-technical criteria, granted by easier management of the convexities and guiding arrises. In this case, orthogonal debitage could be highlighted in the early stages of the unipolar production as an expedient to create distal and lateral convexities (Fig. 24, n° 8, 9, 10). Together with the unipolar nervure-guides, these guaranteed that each removal would cover the entire knapping surface length, determining an elongated and regular cutting edge on the flakes. As previously stated, centripetal debitage (mainly orthogonal and bipolar) might have occurred during the final phases of the unipolar cores to deal with the unlikelihood of exploiting a surface from one direction. Alternated removals were thus more efficient and productively rewarding.

In conclusion, the strategies employed at Riparo Tagliente proved to be efficient in producing flakes presenting at least one cutting edge. The flakes' functionality rate appeared constant within each core, despite the technical behaviours employed to obtain them. Even with a gradual decrease in flake length, the same pattern can be attested, confirming, overall, a well-organised production. Both on the archaeological record and the experimental one, a global increase of the cutting edges per flake (especially on the distal margins) was observed simultaneously to a lowering of the whole length and a drop of the debordant edge frequency. However, this was seemingly not a relevant production goal but still confirms the reliability of the reduction processes even on the final stages of core exploitation. The experimental collection also provided many déjeté points, primarily through centripetal debitage. Nevertheless, they resulted in being an unintentional outcome of the flaking processes, mainly due to the convexities management and the possibility of obtaining quadrangular flakes rather than a dedicated flaking scheme.

Riparo Tagliente—Experimental Collection

The analysis of the experimental reduction sequences matched the archaeological ones (Table 7; Fig. 26). Both massively exhausted cores, and ones of more oversized dimensions, still presenting a suitable volume to exploit, were present. Multiple *flaking events* involving all block surfaces or single ones carried on until the core's abandonment. Switching between the striking platforms and knapping surfaces was frequent, significantly as the core dimensions decreased (Table 7). As a matter of fact, on the same core, centripetal debitage often developed into a unidirectional one, or vice versa, leading to short reduction sequences. In this case, it was the experimental work's merit to verify and validate how the morphologies could dictate how the objectives of productions were achieved, generating a vast number of diversified operative schemes still originated from the same mental scheme. Along this line, from a methodological perspective and given the definition of method used for this work "Le mot méthode revoit uniquement à l'étape de production: liaison entre la représentation abstraite de l'objectif et sa concrétisation. … il s'agit de l'ensemble des démarches raisonnées –schéma opératoire– suivi pour réaliser les objectifs fixés (The word method refers only to the production stage: the link between the abstract expression of the objective and its concretisation. ... it is the set of reasoned steps-operative scheme-followed to achieve the set objectives)" (Boëda, 1994, p. 35), there is no such difference in the several operative schemes (i.e. unipolar, centripetal or multidirectional debitage) used to achieve flake production since their purpose (i.e. mental scheme, method) remains the same. It is the opportunistic method that differentiates itself in multiple types of debitage according to the raw material morphology and quality.

The presence of more complex flaking methods within the Mousterian sequence of Riparo Tagliente imply either surface' hierarchisation (Levallois) or a strong subordination of the raw material's morphology to specific technical criteria (such as discoid and laminar), certainly played an influencing role in how the opportunistic sequences were achieved resulting in greater flaking-technical awareness. As a sign of this, several experimental cores showed a greater affinity with discoid reduction (Fig. 26, n° 1) sequences and laminar ones. In the first case, the centripetal debitage was addressed regarding the convexity management and the use of cordal-like removals. In the latter, experimental cores presenting an elongated morphology together with a low width were exploited through semi-tournant removals, often implying the presence of a central nervure-guide (like a crest; Fig. 25, n° 3, 5).

For these reasons, one can assume, in a broader chronological perspective, that it was indeed the great versatility of the opportunistic debitage to represent, as seen in its earliest evidence (such as in Pirro Nord and Cà Belvedere di Montepoggiolo), the groundwork for the rise of such highly specialised and predetermined flaking methods. This might suggest that starting from a deep subordination to morphological criteria to achieve an efficient functional flake production (which is the basic aimd of any flaking activity), a greater technical awareness may arise, leading to a possible subordination of the morphology itself to the technical criteria. This aspect may, thus, represent the starting point for Levallois and discoid methods. That being

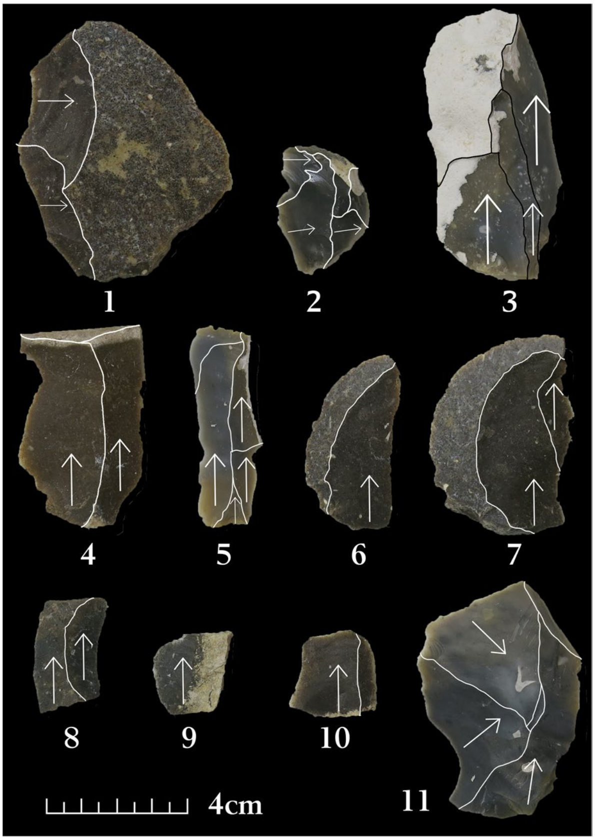


Fig. 25 Riparo Tagliente, experimental: 1–2, flakes with orthogonal scars; 3–10, flakes with unipolar scars; 11, flakes with centripetal scars

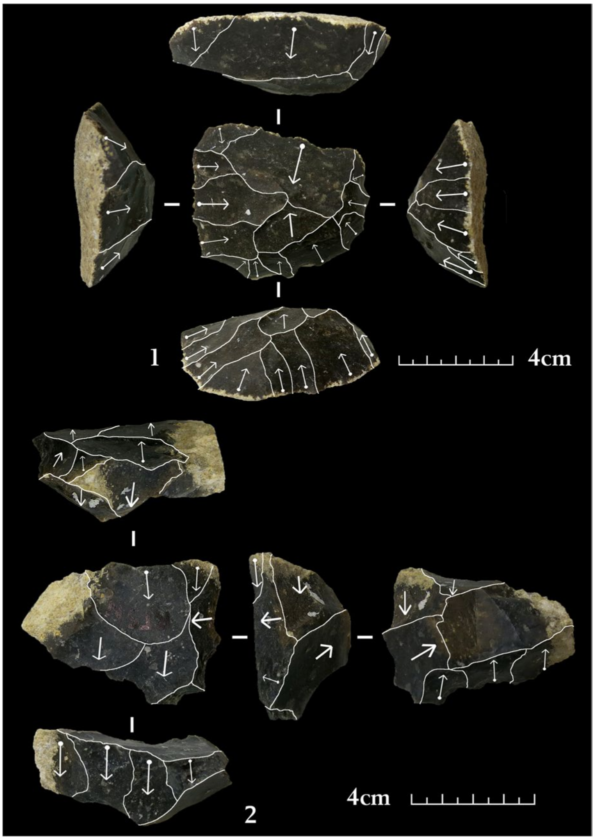


Fig. 26 Riparo Tagliente, experimental: 1, centripetal core; 2, multifacial core

said, their success from the Middle Palaeolithic onward did not prevent opportunistic debitage from persisting during the whole Pleistocene (Fig. 26).

Conclusions

Within the present state of the art, a great debate concerning the methodological attribution of Lower Palaeolithic contexts is taking place. This same debate persists in more recent chronological phases when an attempt to evaluate industries that fall outside the classic Levallois/discoid/laminar paradigm is performed. The quest for complexity within lithic assemblages is strictly related to this matter, being a critical factor and leitmotif of lithic technology. In this perspective, the distinction between complexity and simplicity developed into several dichotomies in archaeological research (i.e. curation/expediency, expediency/opportunism, etc.). Simultaneously, in lithic technology, notions such as predetermination and hierarchisation became the mirror image of these dichotomies, often embodying the boundary among simple and complex in prehistoric contexts. Nonetheless, while this distinction may be more vague for more recent cultural phases, for older ones, where the definition of culture itself seems to be fainter, it is inversely much more pronounced.

Currently, the term opportunism represents the other side of this boundary. It is used to imply a lack of planning in the realisation of stone tools (which, on the other hand, is what define expedient behaviours) and, in a broader sense, also to imply the total absence of complexity/mental scheme. Thus, the use of the term opportunism in this work is aimed to re-contextualise the capability of adaptation of prehistoric people in a "positive" way, where by positive it is meant the plausible presence of a methodological substratum (hinting to the existence of complexity?) within these productions and not merely to point out a technical behaviour enabled in response to specific circumstances without any degree of planning.

Moreover, concepts such as expediency, curation, and opportunism are often declined according to the description of technical behaviours that already fall into methodological categories. In this sense, they explain tendencies about the information gathered from the technological analysis of a specific assemblage. For instance, Levallois, discoid and laminar reduction sequences can be conceived and conducted in an expedient/opportunistic way when interpreting these industries in light of raw materials exploited, type of site, vegetation, climate, etc. Or, in other words, when an attempt to understand and define human behaviour in terms of a complexity degree is carried out. Being that the case, the use of these terms does not invalidate the significance of such industries from a methodological perspective.

When dealing with Lower Palaeolithic contexts, on the other hand, it is much harder to analyse patterns and debate the possible existence of flaking methods. Consequently, technical behaviours are frequently labelled as opportunistic and expedient to point out some potential tendencies but often to exclude the notion of complexity. In this scenario, terms like expedient and opportunism are inclined to assume a much more negative connotation because of the very absence of a methodological substratum beneath those technical behaviours.

On top of this, the definition of expediency refers to a behaviour/attitude characterised by a strong capacity of adaptation in response to external variants (i.e. environment, climate, availability of primary resources such as food, water, the raw material to produce stone tools, etc.) paired with an excellent technical skill (the knapper's expertise) enabling the planning of efficient strategies by prehistoric people. Minimising the technological behaviours of the hominins of the Lower Palaeolithic as practical and mechanical responses (even if planned) to external inputs also means not implying that a methodological background in the lithic productions of these chronological phases could ever exist at any given moment. By doing so, we would assume the absence of "structured expertise" in these lithic assemblages simply because it is not perceivable and it is regarded as a predictable behaviour enabled by adaptability mechanisms under critical conditions (expedient).

By using the terms *opportunistic debitage*, hence defining a flaking method, we want to stress how the incredible versatility and variability implied in these kinds of activities comes from a steady and precise mental scheme (developed at a certain point during times obviously) in which, for example, the possibility of choosing in which manner a specific volume will be knapped is a part itself of the methodological process.

Therefore, the proposal of this work is trying to identify how the earliest European lithic productions, which indeed developed as quick and efficient responses to a hostile and changing environment, gradually changed into systematic and steady productions (even if still strongly subordinated to the surrounding environment) comprising a solid methodological substratum, or in other words, as the concept of flaking method arose. The lack of planning that is assumed under the “opportunistic responses” is what often prevented considering these kinds of productions as methodologically relevant in the past. On the other hand, given that such industries might persist over time through different chrono-cultural phases, it allows a better comparison and contextualisation regarding their methodological relevance. The history of study in lithic technology provides several examples of how the definition of some flaking methods (i.e. Levallois, discoid, among others) underwent several changes and modifications during the years since they included a much wider variability and flexibility than initially expected (Peresani, 2003).

To summarise, the delineation of opportunistic debitage interests a wide chronological frame being characterised all the way through by a strong adaptation and subordination to the morphology and quality of the raw materials locally available, as observed in all the contexts where it was identified. It is defined as “a method oriented to raw materials’ massive exploitation not implying a core, or any surface, preparation. The striking platforms and knapping surfaces are created as far as the flaking activity is carried on. […] The opportunistic debitage includes an infinite range of variants from the same common operative scheme” (Arzarello, 2003, p. 6). Its flexibility allows the modulation into different technical behaviours, constantly aiming to extract functional products in a highly efficient manner. The easy replicability of the operative scheme through the technical gesture, together with an optimisation of the block’s volume, is the methodological *substratum* behind the mental process.

This methodological and cultural substratum can be viewed as the starting point for more complex flaking methods for the oldest contexts. As seen in the Pirro Nord and Cà Belvedere di Montepoggiolo’s contexts, a centripetal approach was intensively applied on the surfaces because of its efficient production of functional flakes on rounder and smaller morphologies (i.e. pebbles and cobbles; Fig. 28). The exploitation of a peripheral striking platform running around a single knapping surface translates into a gradual and better control of the flake’s morphology and the core’s management. Supporting this hypothesis is the occurrence, in both assemblages, of functional flakes often presenting more than one cutting edge, a backed margin, and a tip associated with centripetal flaking (orthogonal, bipolar and centripetal removals).

It can be argued that these features may be the unintentional outcome of a solid adaptation to specific morphologies (as seen in the experimental centripetal cores). Nonetheless, when systematically and constantly applied, they might eventually standardise the technical gestures, which generate greater awareness during the flaking activity. This being the case, technical expedients can become systemised choices assimilated within a steady mental scheme, thus expanding the possible methodological responses of opportunistic debitage.

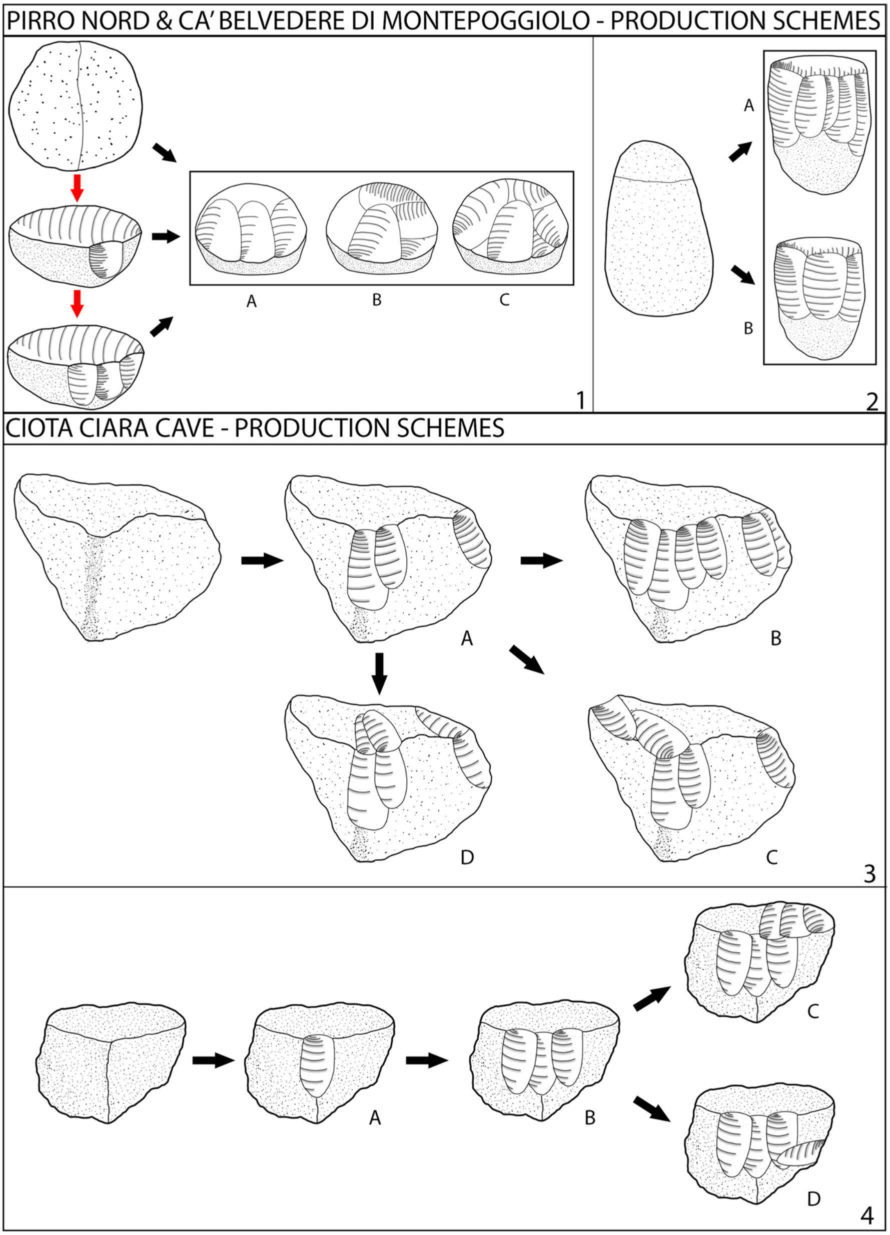


Fig. 27 Pirro Nord and Cà Belvedere di Montepoggiolo production schemes: 1, rounder cobble (A: unipolar production; B orthogonal production; C: centripetal production); 2, oval and elongated pebble (A: unipolar production; B: convergent flake production). Ciota Ciara production schemes: 3, larger blocks and nodules (A: unipolar production on natural arises; B: unipolar production; C: multifacial bipolar/unipolar production; D: multifacial unipolar production); 4, smaller blocks and nodules (A: initialisation on natural arises; B: unipolar production; C: multifacial unipolar production; D: orthogonal production)

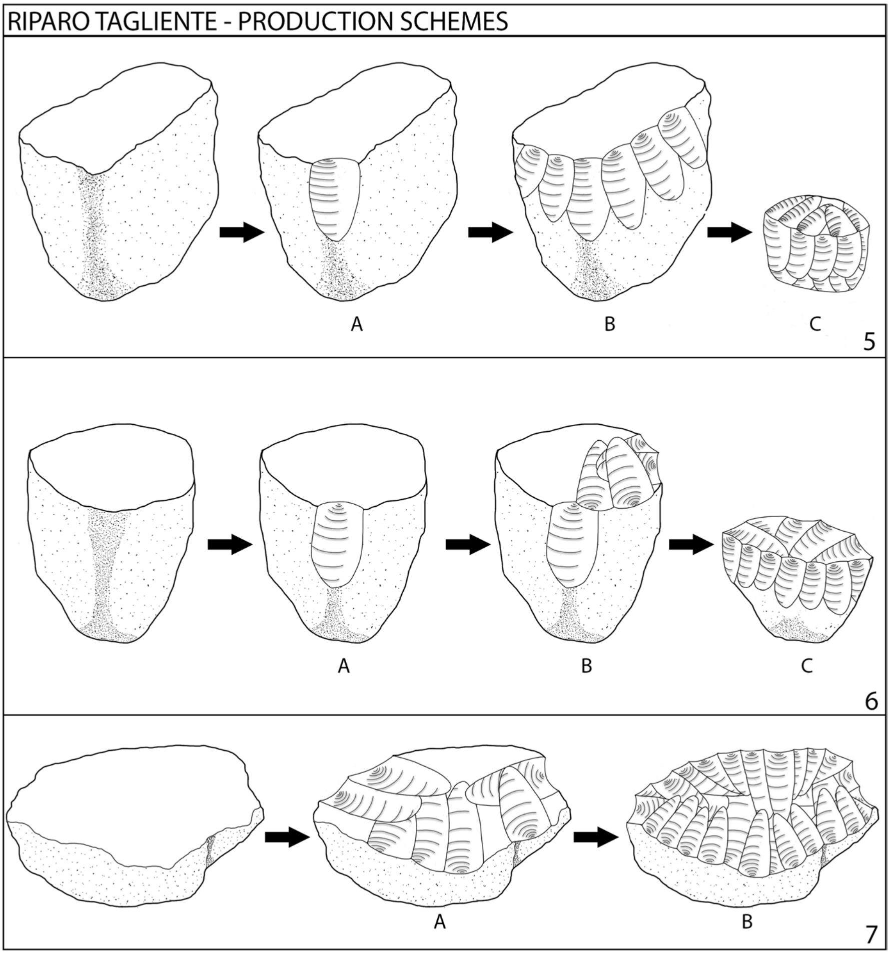


Fig. 28 Riparo Tagliente production schemes: 5, large nodules with longitudinal axis as knapping surface (A: opening of the knapping surface on a natural arris; B: unipolar-semitournant production; C: multifacial production); 6, quadrangular and large nodules (A: opening of the striking platform on natural arris; B: orthogonal production; C: multifacial production); 7, flat and rounder blocks and cobbles (A: initialisation of the centripetal production with orthogonal flaking; B: centripetal production)

Following this argument, when broader chronological and geographical ranges are considered, the process of subordination to morphological criteria can be gradually reversed, and the morphology itself becomes subordinated to the technical criteria for the production of predetermined products. Levallois and discoid methods, both profoundly related to the centripetal concept as well as the bifacial shaping, are based on the idea of altering a pre-existing morphology into a fixed shape. Therefore, technical criteria such as the surface hierarchisation, the need for precise lateral and distal convexities (and their preparation), and the creation of peripherical striking platforms may be viewed as the outcomes of this process, becoming one of the possible, abovementioned, methodological responses.

On the other hand, opportunistic debitage persists as a reliable and independent flaking method for more recent periods such as the Middle Palaeolithic. In these cases, it often coexists with Levallois, discoid and laminar productions, standing as one of the possible behavioural variables of the human groups. It is still identifiable on an archaeological basis through its technical features, even if subjected to different chronological, environmental, and cultural aspects (the latter hardly perceived within the analysis of any lithic industry).

Summing up the results highlighted for Ciota Ciara cave and Riparo Tagliente (Figs. 27 and 28):

1) The former underlines how, despite qualitatively inferior raw materials, several technical strategies were efficiently employed to obtain a steady functional flake production. In this case, the adaptation to the available morphologies becomes obvious: a frequent and almost exclusively use of natural arrises along the entire flaking activity is highly witnessed, not only for opportunistic production but also for Levallois discoid.
2) In the latter, it can be seen how opportunistic debitage, despite Levallois, discoid and laminar productions, is still the most employed method along the Mousterian sequence. Here it is differentiated into multiple technical behaviours according to the morphologies naturally available (or to their gradual change), sometimes showing similarities with the volumetric conception of other methods but still methodologically distinguishable.

In conclusion, the term "opportunism" is not merely applying flaking criteria and technical skills, completely disentangled from any mental scheme. As observed in this work, what defines a flaking method is its flexibility and potential to be efficiently adopted throughout different chronological and cultural phases, constantly referring to a specific mental scheme. Therefore, the opportunistic debitage may be considered the "link between the abstract representation of the object and its realisation" (Boëda, 1994, p. 35) since it connects a series of technical behaviours and gestures for its realisation (Tixier et al., 1980) not only in a synchronic perspective but mainly in a diachronic one. However, it must be underlined that, as a flaking method, it will always just be a partial aspect of a human group's material culture, useful for identifying and interpreting specific behaviours yet far from being its unique component.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s41982-022-00117-9.

Acknowledgements The authors would like to thank Alice Leplongeon, David Hérisson, the anonymous reviewers and the Editor that contributed in the improving of the present work. We would also like to thank Marie-Hélène Moncel for all the advice and constructive criticism during the realisation of this work. Version 9 of this preprint has been peer-reviewed and recommended by Peer Community In Archaeo (https://doi.org/10.24072/pci.archaeo.100007).

Funding Open access funding provided by Università degli Studi di Ferrara within the CRUI-CARE Agreement.

Declarations

Conflict of Interest The authors declare no competing interests.

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4.2. The lithic assemblage of Notarchirico

Journal of Paleolithic Archaeology (2023) 6:27
https://doi.org/10.1007/s41982-023-00154-y

RESEARCH

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With Impressions Chosen from Another Time: Core Technologies and Debitage Production at the Lower Palaeolithic Site of Notarchirico (670–695 ka; layers F to I2)

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Accepted: 2 August 2023

Abstract

The earliest evidence of bifaces in western Europe is dated to the initial phase of the Middle Pleistocene (la Noira, Notarchirico, Moulin Quignon, 700–670 ka), with the findings of Barranc de la Boella (1.0–0.9 Ma) considered to be an earlier local evolution. No transition assemblages are recorded during this time frame, and the “abrupt” appearance of bifaces is associated with significant cognitive shifts in human technological behaviours (Acheulean techno-complex). The new investigations conducted at the site of Notarchirico unearthed 30 ka of repeated human occupation (695–670 ka, layers F-I2) during MIS 17, with evidence of bifacial tools in layer G (680 ka) and F along with other heavy-duty implements (LCTs, pebble tools, etc.). Massive production of *debitage* products realised on local raw materials collected in situ through simple and efficient core technologies characterises a large part of the lithic assemblage with a high ratio of diversified light-duty tools, including modified chert nodules. Despite core and flake assemblages being a recurrent trait of Lower Pleistocene contexts, the increase in retouched implements recorded at the onset of the Middle Pleistocene has been considered a significant technological shift. The technological analysis of the *debitage* products presented in this work highlights recurrent and systematic technological behaviours of the hominins of Notarchirico—who proved to efficiently overcome the raw materials dimensional constraints—even in the layers without bifaces. This may shed light on the meaning of cultural and behavioural innovation that the Acheulean techno-complex is thought to bring over Europe. It is plausible that given the substantial homogeneity of the lithic strategies within the sequence of Notarchirico, which only the “introduction” of the bifaces in the upper layers seems to interrupt, a supposed behavioural or cultural change in the site might have already occurred in the lowermost portion of the sequence. In this work, we evaluate the degree of change—if any—from a technological perspective by analysing the *debitage* reduction sequences.

Keywords Lower Palaeolithic · Core technologies · Acheulean

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Published online: 05 September 2023

Introduction

Within the present state of the art, the earliest appearance of large cutting tools (LCTs) and bifaces on the European continent goes back to the Spanish site of Barranc de la Boella (1.0–0.9 Ma), where some crudely made (i.e. presenting a partial or roughly made shaping without management of the bifacial volume) bifacially worked tools were recovered (Mosquera et al., 2016; Vallverdú et al., 2014). The archaeological evidence that characterises the final stages of the Lower Pleistocene (Fig. 1) features the homogeneous presence of core and flake assemblages such as Atapuerca (levels TE08–TE09, 1.2 Mya; Ollé et al., 2013), Barranco Leòn (1.3–1.1 Mya; Agustí et al., 2015), Pont-de-Lavaud (1.0 Ma; Despriée et al., 2018), Happisburgh 3 (900 ka; Parfitt et al., 2010), Monte Poggiolo (850 ka; Peretto et al., 1998), Pradayrol (900 ka; Guadelli, 2012), and Cueva Negra (900–772 ka; Walker et al., 2020), making the findings of la Boella a unique case and raising questions whether a local development of this technology—versus the hypothesis of an African intrusion—might have taken place (Moncel et al., 2015; Mosquera et al., 2013). With the 800 ka threshold approaching (i.e. transition Lower-Middle Pleistocene), major climatic and environmental changes occur at the onset of the Middle Pleistocene (i.e. Middle Pleistocene Revolution), profoundly affecting the peopling of Europe—corresponding to an archaeological hiatus—and triggering the dispersion of new faunal species alongside vegetal turnovers and the diffusion of human groups (*Homo heidelbergensis* and possibly other hominins) from the African and Asian continents (Abbate & Sagri, 2012; Almogi-Labin, 2011; Belmaker, 2009; Blain et al., 2008; Leroy et al., 2011; Manzi, 2004; Manzi et al., 2011; Moncel et al., 2018a; Muttoni et al., 2018). During this time frame, the Acheulean—and bifacial assemblages—show their first diffusion over western Europe (Fig. 1), which also witnesses a global increase in archaeological evidence (Moncel & Ashton, 2018; Moncel et al., 2018b). As a consequence, after a gap of 200 ka from the findings of La Boella, several bifaces and large cutting tools have been found in three key sites: La Noira (700 ka; Moncel et al., 2020a), Notarchirico (Italy, 680 ka; Moncel et al., 2020b), and Moulin Quignon (France, 670 ka; Moncel et al., 2021b). No transition assemblages are recorded during this chronological gap, even though the persistence of core and flake production is reported in contexts such as Atapuerca TD6 (Spain, 800 ka; Ollé et al., 2013; Mosquera et al., 2018; Lombao et al., 2022), Vallparadìs (Martínez et al., 2010; Spain, 800 ka; Garcia et al., 2013b), Pakefield (England, 700 ka; Parfitt et al., 2010), and Isernia La Pineta (Italy, 590 ka; Gallotti & Peretto, 2015), sometimes also attesting the realisation of large-sized tools. The presence of bifaces and other LCTs is not the only innovation among these lithic assemblages, as evidence of more elaborated core technology, frequency of retouched implements, raw material use, and subsistence strategies are generally documented at Atapuerca TD6, La Noira, and Isernia La Pineta (Hardy et al., 2018; Lombao et al., 2019, 2022; Moncel et al., 2021a; Mosquera et al., 2018).

Climatic and environmental changes are essential in triggering human responses, causing abandonments and re-occupations ("back and forth pattern") of some geographical regions occasionally recorded in the stratigraphic

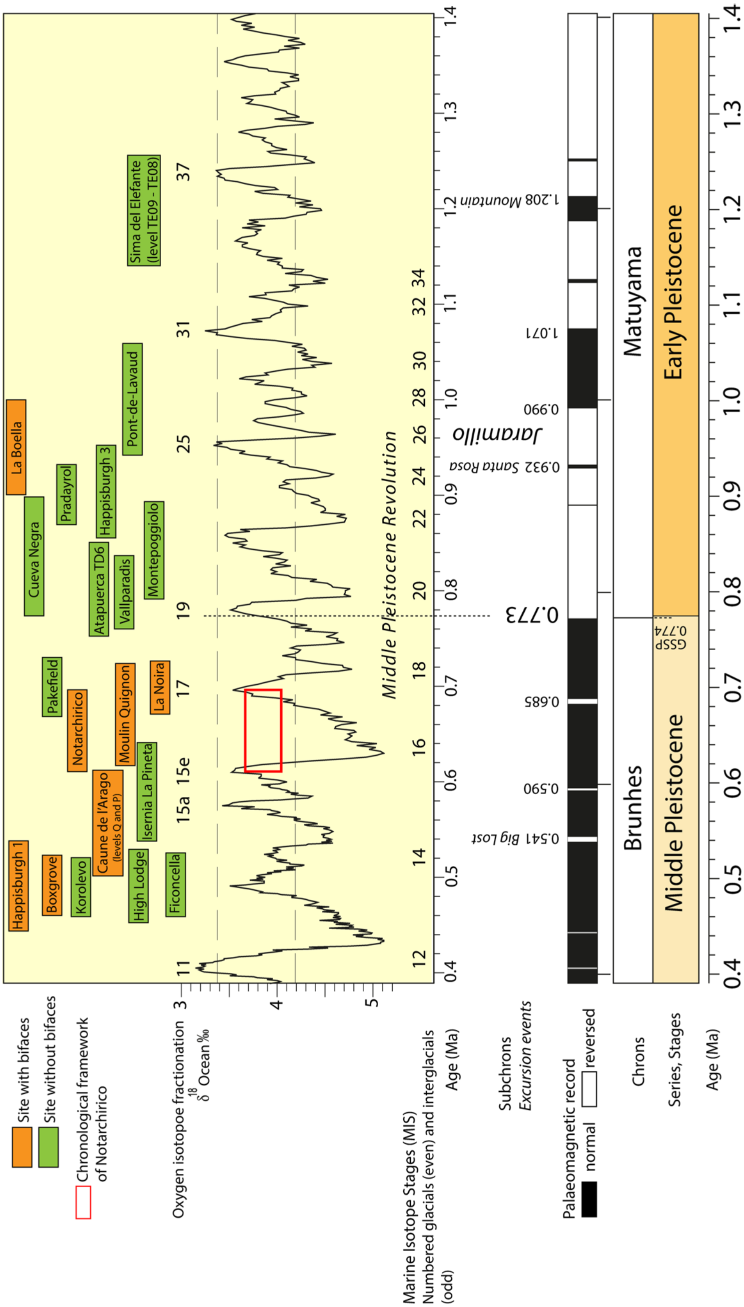

Fig. 1 Lower and Middle Pleistocene sites mentioned in the text in relation to chronology, isotopic stages, and palaeomagnetic record. Chronological chart modified from Cohen and Gibbard (2019)

sequences of different sites (Bermúdez de Castro et al., 2013; Davis et al., 2021; Dennell, 2003; MacDonald et al., 2012). During these events, innovative behaviours might have developed as external pressures often foster reactions that can be archaeologically seen and documented (Davis & Ashton, 2019; Key & Ashton, 2022; Moncel et al., 2021a). Therefore, tracking the evolution of these aspects and comparing them with the material culture—alongside the concepts of innovation, persistence, and whether they are detectable from an archaeological perspective—can enable significant insights into the time, place, and modalities of Europe's colonisation by hominins.

Several works speculated whether these innovations are the outcome of internal behavioural evolution or are due to the arrival of new populations, but undoubtedly, a cognitive shift took place within this chronological framework. According to the available data on the European peopling, the Brunhes-Matuyama shift (780 ka, Lower-Middle Pleistocene boundary) caused a significant break all over the territory, leading to an abandonment of England, France, Spain, and Italy after a moment of continuity between the Jaramillo subchron and MIS 20 (Antoine et al., 2010; Cuenca-Bescós et al., 2015; Davis et al., 2021; Garcia et al., 2013a; Key & Ashton, 2022; Messager et al., 2011; Michel et al., 2017; Muttoni et al., 2010; Preece & Parfitt, 2012). The site of Atapuerca, in level TD6, records an interruption of human occupation right after 800 ka and until 500 ka (Bermúdez de Castro et al., 2013), while other contexts such as Happisburgh 3, Pradayrol, Monte Poggiolo, and Vallparadìs show an absence of human evidence after this threshold. With the onset of interglacial 17 (700 ka) and retreat of the glacial front, a re-occupation, especially at high and middle latitudes (Antoine et al., 2010; Ashton & Lewis, 2012; Preece & Parfitt, 2012), of different areas is witnessed (La Noira stratum a, Moulin Quignon, Pakefield, and Notarchirico)—together with the emergence of bifacial technology—though shortly followed by an abrupt climatic crisis (MIS 16) subsequently causing another abandonment of these regions (Moncel et al., 2021a). The successive interglacials 15 and 13 (the glacial stage 14 is considered to be mild and not so disruptive) are characterised by a prolonged phase of climatic and environmental stasis and, as a consequence, by a reprise in human occupation all over Europe: i.e. Isernia La Pineta, Caune de l'Arago (levels Q and P), Happisburgh 1, Boxgrove, High Lodge, Ficoncella, and Korolevo (Aureli et al., 2016; Barsky, 2013; Falguères et al., 2015; Gallotti & Peretto, 2015; Gibbard et al., 2019; Koulakovska et al., 2010; Roberts & Parfitt, 1999; Zanazzi et al., 2022).

The related lithic assemblages show a mixture of handaxes, diverse LCTs, pebble tools, and core and flake production, attesting to a diversified range of subsistence strategies and functions of the sites (García-Medrano et al., 2019; Moncel et al., 2018c; Muttillo et al., 2021). Nonetheless, the reason for the absence of bifacial tools in some of these contexts is still a debated topic. Aside from more common issues, such as the quality and morphology of the available raw materials that could prevent the realisation of handaxes, recent works highlighted that there is much more than "the traditional concept of the biface" (Moncel et al., 2015, p. 305) to what we define as Acheulean and, more in general, to what is perceived as a sign of complexity (Moncel & Ashton, 2018). The ability to realise dimensionally large implements, the presence of structured centripetal or discoidal cores—implying *debitage* conducted regardless of the original shape with the possibility of subordinating the morphological criteria to the production goals—the degree of retouch on flakes, and the flexibility itself in the concept of *façonnage* and *debitage* are among the addressed matters for the contextualisation of the "European Acheulean" (Martínez & Garcia Garriga, 2016; Moncel, 2017; Rocca et al., 2016).

In this geographical and chrono-cultural framework fits the site of Notarchirico, being the only one recording a continuous human occupation during stages 17 and 16 across the whole sequence (Moncel et al., 2020b; Pereira et al., 2015) and attesting to one of the earliest evidence of bifaces together with core and flake production. The prolonged and repeated frequentation of the site during glacial phases might be due to its southern geographical position, acting as a sheltered area for human groups during the major climatic crisis and as a possible starting point for re-peopling Europe during the earliest phases of the Middle Pleistocene. Thus, the analysis of the lithic production of Notarchirico throughout the entire stratigraphic sequence may offer several hints about the notions of continuity and innovation within European Lower Palaeolithic lithic assemblages, not to mention the opportunity of reconstructing hominin subsistence strategies and their evolution over a significant climatic and chronological range.

In this work, we focused our research on the core, flake, and tool production of the lowermost portion of the sequence of Notarchirico (layers F to I2) chronologically framed between 695 and 670 ka—thus penecontemporaneous to the sites of Moulin Quignon and La Noira—which proved to be a crucial moment for western Europe.

Notarchirico

The site of Notarchirico lies within the fluvial-lacustrine basin of Venosa (Piano Region sedimentary formation), a few kilometres outside of the village of Venosa (PZ, Basilicata) in southeastern Italy (Fig. 2). It is an open-air site originally discovered by M. Piperno in 1979 and extensively excavated for more than 30 years on an area of approximately 133 m^2.

A 7-m-thick sequence of fluvial sediments was unearthed, including 11 archaeological layers, five of which contained bifaces (Fig. 2A) (Piperno, 1999). The sequence is also rich in volcanic material due to the eruptive activity of the Vulture stratovolcano, located 10 km from the site (Lefèvre et al., 2010). The archaeological material consisting of lithic implements associated with large herbivore carcasses lies on beds of pebbles and cobbles corresponding to shallow paleochannels and lakeshore remains. Recent geochronological dating (ESR, 40Ar/39Ar) established the chronological limits of the sequence excavated by Piperno between 675 ka (layer F) and 610 (layer α), corresponding to the glacial stage 16 (Pereira et al., 2015). A fragment of a hominin femur was found in the upper part of the deposit (layer α) and attributed to *Homo heidelbergensis* (Belli et al., 1991), making it the oldest human fossil in the Italian Peninsula.

The faunal assemblage, described by Cassoli et al. (1999), is attributed to the Isernia faunal unit and is mainly composed of the straight-tusked elephant

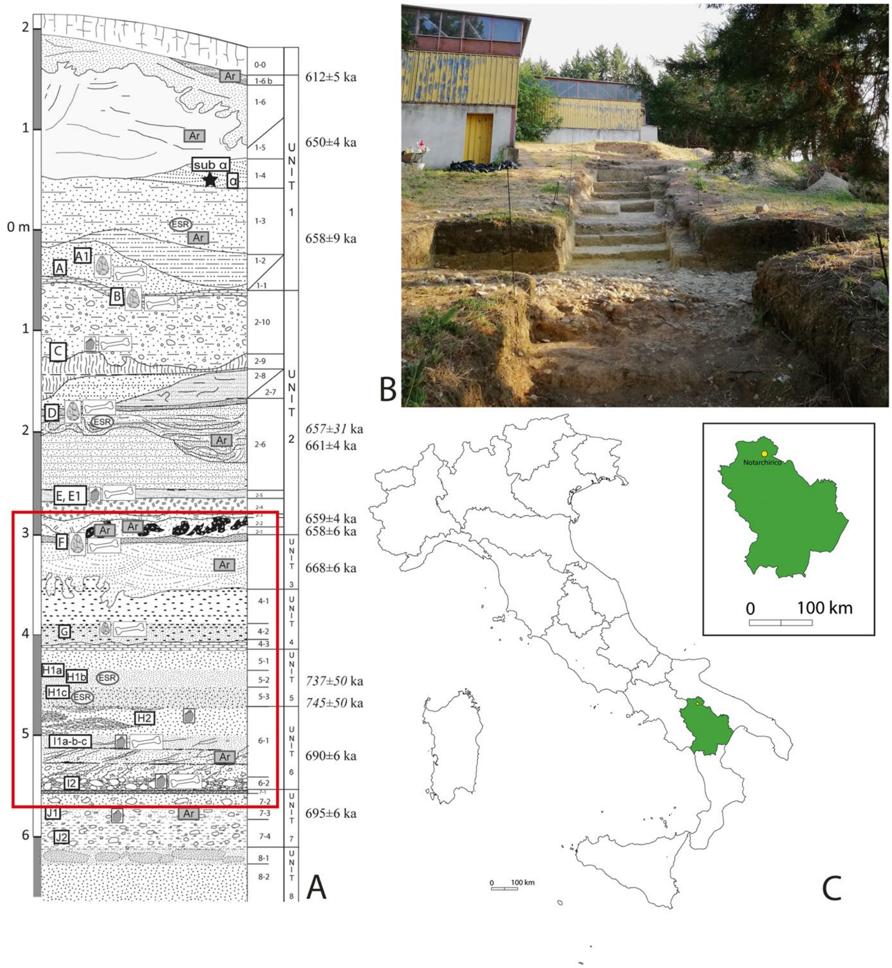

Fig. 2 **A** Complete stratigraphic sequence of Notarchirico. Dates in italics by ESR-U-Th. Other dates by 40Ar/39Ar. Legend is available in Moncel et al. (2020b). The red square indicates the archaeological layers analysed in this work. **B** Photograph of the new excavations on the Notarchirico hill (on the left is the M. Piperno's fieldwork building). **C** Location of the site

(*Palaeoloxodon antiquus*), fallow deer (*Dama clactoniana*), and two species of bovids (*Bos primigenius* and *Bison schoetensacki*). The presence of other herbivores, such as *Megaloceros solilacus* and *Cervus elaphus*, is attested to in the higher levels (α, sub-α, A/A1, B, and D), while the absence of carnivores along the whole sequence was reported. The micromammals, analysed by Sala (1999), consist of *Pliomys episcopalis*, *Chionomys nivalis*, *Microtus* sp., and *Arvicola cantiana*, suggesting a cold climate typical of a cold environment during a glacial stage. The palynological results, conducted by Cattani in 1996 only at the top of the deposit, show an open and cold environment—in agreement with the dates (MIS 16)—consisting of Poaceae meadows with limited presence of trees

(*Pinus sylvestris*, *Quercus pubescens*, *Quercus ilex*, *Corylus*, *Carpinus*, *Fraxinus*, and *Ulmus*).

The lithic industry is realised on local raw materials, including chert and limestone pebbles and nodules, collected in secondary positions along the river banks/lakeshores (Moncel et al., 2019; Piperno, 1999; Santagata et al., 2020). Both heavy-duty tools and core and flake production are attested. The heavy-duty components are on limestone and chert, consisting of various unifacial and bifacial pebble tools, cleavers, pointed elements, and bifaces. Though a low standardisation was observed for this production, the recent revision of the bifaces and LCT demonstrated their affinities with the Acheulean cultural techno-complex s.l. (Moncel et al., 2019; Santagata, 2016; Santagata et al., 2020).

Chert nodules and pebbles of small dimensions are used to produce small flakes (15–20 mm) through unifacial/multifacial *debitage*. Larger flakes (50–100 mm) are rarer and mainly obtained from limestone or chert. Some cores showed alternate *debitage* resembling a discoid conception but no platform preparation. Retouched tools are also attested to, consisting of scrapers, notches, and denticulates. Freehand and bipolar on anvil percussion are both attested for the *debitage*.

Since 2016, new investigations have been taking place at Notarchirico to explore the bottom of the sequence excavated by Piperno below layer F (Moncel et al., 2020b). A 30-m-long trench was thus opened on the side of Notarchirico hill, covering a surface of 8 to 26 m^2. The excavations led to the identification of five lithostratigraphic units (3 to 8), including five new archaeosurfaces (G, H, I1, I2, and J) in addition to the previously known layers G and F (Fig. 2). All of these, except for layer J, bear evidence of human frequentation with layers F, G, I1, and I2 providing evidence of recurrent occupation. On the other hand, layer H is thought to record a sporadic/short-term site frequentation phase.

The basal lithostratigraphic units of the deposit of Notarchirico (units 8 to 6) exhibit low-energy fluvial sedimentation along regular inputs of volcanic materials, while in the upper units (5 to 3), the sedimentation displays higher energy currents and mainly volcano-derived remains. The archaeological horizons of the bottom of the sequence are associated with the lithostratigraphic unit 3 (layer F), the bottom of sub-unit 4.2 (layer G), the bottom of sub-unit 5.3 (layer H), sub-unit 6.1 (layer I1), sub-unit 6.2 (layer I2), and sub-unit 7.4 (layer J) (Fig. 2). According to the available lithostratigraphic analysis (for a more detailed description, see J-P. Raynal, P. Dugas, G. Jouanic and A. Queffelec in Moncel et al., 2020b), the different facies identified corresponds to fills of meandering paleo-channels, crossed in places by the action of low energy currents. The finer component of the deposits derives from the alteration of volcanic fallout, which is particularly common between units three and four. The presence of cobbles and gravels incorporated in the layers corresponds to slope destabilisation processes intervening after the arrival of masses of tephra and the release of lateral contributions from older conglomeratic deposits.

From top to bottom of the stratigraphic sequence, layer F is described as a bed of cobble-pebbles cross-bedded with volcano-derived and non-volcanic sands with a thickness of approximately 20 cm overlying another 20-cm-thick layer of black volcanic sands. Dark-grey volcanic sands characterise layer G (lithostratigraphic unit 4.2, 30 cm thick) dispersed over a coarse sandy sub-unit (lithostratigraphic unit 4.3) with cobbles and sub-angulus gravels (30 cm thick). Layer H (30 cm thick) features a silty-sandy deposit with a few micro-beds of dark minerals. Local lenses of small pebbles characterise layer I1 in the first 15–30 cm, while coarse sands and beds of more or less dense gravels with millimetric anastomosed crusts are distributed in the remaining 45 cm of the layer's thickness. Layer I2 presents a similar characterisation to I1 though displaying a denser accumulation of cobbles and smaller elements with limestone pebbles and a few fine-grained sandstone cobbles and flint nodules over a 10–15 cm thickness. Cobbles in a clayish volcano-derived matrix of 30 cm of thickness underlying a 10-cm-thick tephra-derived coarse with some cobbles characterise layer J.

Datings using 40Ar/39Ar and ESR methodologies placed the chronology of the new sequence between 695 and 670 ka in correspondence with the end of the interglacial 17 and the beginning of glacial 16, providing evidence for continuity in the human occupation of the site (Moncel et al., 2020b). As in the upper part of the sequence, the archaeological material of lithic artefacts associated with faunal remains lies within beds of pebbles and cobbles of approximately 10–30-cm thickness, related to paleo water channels and lakeshores. Layers F and I2 show a dense bed of pebbles in situ, while layers G and I1 are more disturbed.

The new palaeontological analysis available for layers F, G, I1, and I2 (for a more detailed description of the faunal remains recovered from the new excavations, see B. Mecozzi, A. Iannucci and R. Sardella in Moncel et al., 2020b and related supplementary material) (Table 1) highlighted the presence of *Palaeoloxodon antiquus* along the whole sequence, followed by cervids (*Praemegaceros* sp., *Dama* cf. *clactoniana*, and *Cervus elaphus*) and bovids (bison and aurochs) while no carnivores have been found so far. Two new species were reported: *Hippopotamus antiquus* (layers G and I1) and *Macaca sylvanus* spp. (layer G; Mecozzi et al., 2021). Overall, the faunal assemblage of these layers matches the attribution to the Isernia faunal unit made for the upper part of the sequence. Concerning micromammals, few remains were recovered, mainly from layer I1: *Arvicola mosbachensis*, *Microtus* (*Terricola*) cf. *M.* (*T.*) *arvalidens*, and *Microtus* cf. *M. nivaloides* were identified, with the *A. mosbachensis* being one of its earliest occurrences (Moncel et al., 2020b). The attribution to the beginning of

Table 1 Mammal species from layer F-I2 (modified after Moncel et al., 2020b Supplementary Material)

Layer	F	G	I1	I2
Species				
Palaeoloxodon antiquus	X	X	X	X
Hippopotamus antiquus		X	X	
Bison schoetensacki	X	X	X	X
Bovidae indet	X		X	X
Praemegaceros solilhacus			X	X
Cervus elaphus			X	X
Macaca sylvanus spp.		X		

Early Toringian (*Arvicola-Microtus* zone, *Arvicola mosbachensis* subzone 3) is in accordance with the data from previous excavations.

The archaeozoological analysis did not point out cut marks or carnivore tooth marks due to the dire state of preservation of the bone surfaces and the high fragmentation rate. Most of the modifications detected on the bones, such as abrasion, corrosion, and concretions, may be related to the effects of hydraulic transportation and trampling (abrasion) and exposure to water (corrosion and concretions). The abundance of short elements for all species and the amount of post-depositional dry bone fractures confirm the presence of a lacustrine environment and a secondary origin of the deposit (for a more detailed description, see C. Daujeard and A. Curci in Moncel et al., 2020b). Seemingly, the animals died naturally near these lakeshores/water channels and were secondarily transported and accumulated. Therefore, an anthropic origin for the bone accumulation, perhaps with carnivore contribution, cannot be fully supported even though the interaction between hominins and animal carcasses has been assessed based on lithic use-wear (Moncel et al., 2020b).

The lithic industry from these layers consists of more than 900 artefacts realised on chert nodules and various silicified limestone pebbles locally collected in a secondary position. The artefacts can be divided into two main groups: core and flake (analysed in this work) and heavy-duty components (Table 2). The goal of the *debitage* production is mainly small-sized flakes (10–20 mm) and, more rarely, larger flakes (40–120 mm) employing different types of knapping strategies (discoid, unifacial, multifacial, centripetal, etc.). Retouched tools are also present (denticulates, scrapers, and pointed tools). In addition, hominins selected small chert nodules (20–40 mm) to shape through an abrupt or denticulate retouch. Various artefacts characterise the heavy-duty component with a low morphological standardisation (unifacial, bifacial, and trifacial pebble tools; diverse LCTs; rabots; and chopping tools). These are mainly obtained from limestone pebbles, with only one chert implement. The bifaces, on the other hand, show complete control of the bifacial and bilateral symmetry. They are realised mainly on limestone and the few locally available chert pebbles. The shaping process covers a large portion of the periphery and surface of these tools by one or several series of removals with evidence of retouch

Table 2 Heavy-duty component from layers F-I2 (Moncel et al., 2020b)

Layer	F	G	H	I1	I2
Unifacial convergent LCT tools	5	6			2
Bifaces	4	2			
Unifacial pebble tools	34	15	1	9	5
Bifacial pebble tools	6	2		2	1
Pointed unifacial pebble tools	10	6		2	
Pointed bifacial pebble tools/LCTs	4			1	
Trifacial pebble tools		1		1	
Rabots on pebbles	5	2			1
Quadrangular unifacial tools	2				
Broken pebbles with impacts + isolated removals	52	31		1	

to regularise the cutting edges. The cross-sections are symmetrical or plano-convex, often presenting a cortical base. The recent analysis also highlighted evidence of recycling on the cutting edges of one of the handaxes. A total of six bifaces were recovered from layers F and G, further postponing the rise of the Acheulean cultural complex in this region (for a detailed description of the heavy-duty component from layers F-I2 of Notarchirico see Moncel et al., 2020b).

Preliminary use-wear and residue analyses (see C. Lemorini and B. Hardy in Moncel et al., 2020b) have been performed on flakes and tools. The analysis revealed the presence of different post-depositional processes on the artefact surface: patina, gloss (a consequence of the mechanical action of the water flow), striations, and mechanical alterations. Despite these processes, it was possible to observe the presence of use-wear. The results highlighted the interaction with soft to hard materials (fleshy tissue and woods have been identified so far), mainly worked by cutting and scraping and, to a lesser extent, by mixed actions like engraving. Seemingly, the *debitage* implements were employed for different activities and purposes, not only related to food processing (Moncel et al., 2020b).

Materials and Methods

This work focuses on the most significant quantity of the lithic assemblage of Notarchirico: core and flake production and retouched nodules from archaeological layers F, G, H, I1, and I2, belonging to the new fieldwork started in 2016. All the lithic pieces of this classification (i.e. cores, flakes, retouched flakes, and retouched nodules) recovered from these layers were analysed and studied. Layer F was excavated over 10 m^2, layer G over 11 m^2, layer H over 8 m^2, layer I1 over 14 m^2, and layer I2 over 20 m^2. The lithic material from layer J, consisting of a few artefacts, is probably not in situ and has been removed from this analysis (Moncel et al., 2020b). This material was selected because of the great diffusion of small-sized flake assemblages within the Italian Peninsula during the Middle Pleistocene, and, unlike bifacial and large cutting tools of Acheulean affiliation, they are an emblematic trait of this chrono-cultural framework that still needs to be properly contextualised.

The technological analysis (Inizan et al., 1999) and the concept of *chaîne opératoire* (Boëda et al., 1990; Geneste, 1991; Leroi-Gourhan, 1965; Roche, 2005) have been applied to study the lithic material to conceive all the phases of the flaking activity as a single process from the raw material selection through the obtainment of flakes until their abandonment. The hierarchy of flaking surfaces, removals organisation, and size were considered on cores to evaluate the knapping strategies employed by the hominins and their degree of complexity (Moncel et al., 2020a). The use of terms like unifacial, bifacial, and multifacial applied to cores is meant to describe the number of the knapping surfaces, while “unipolar”, “convergent”, “crossed”, “orthogonal”, “centripetal”, and “bipolar” were applied to describe the distribution and the organisation of the removals over the knapping surfaces. Since bifacial and multifacial cores of Notarchirico are the outcome of multiple separate unipolar knapping events due to core rotation rather than a surface hierarchisation, the description of the removal organisation for these latter categories was removed in favour of terms like SSDA (*systeme par surface* *de débitage* alterné) (Ashton et al., 1992; Forestier, 1993) that better describe these type of knapping strategies.

For flakes, the presence and position of the cortex, butt characteristics, removals organisation, the incidence of backed margins, and, when present, the location, delineation, and angle of retouch were recorded. The description of retouched nodules was made using the same criteria applied to retouched flakes for a proper comparison.

Concerning the typological classification employed to classify the retouched component (flakes and nodules), despite the evident limitations that such an approach implies through the creation of artificial categories (especially when dealing with such old archaeological palimpsests), we decided to use a basic typological description of these tools to facilitate the comparison from a technological point of view with other lithic assemblages where a similar approach was applied. We want to underline that the adoption of terms like denticulate, scraper, and notch is made only to describe the morphological organisation of the retouch on the lithic pieces without inferring the functional implications of these lithic artefacts. For instance, we consider "scraper" the presence of regular edge modifications (i.e. retouch) on a cutting edge regardless of its length, while "denticulate/notch" results in a non-linear configuration of the retouch. "Point" and "beak" describe retouch to configure a pointed shape/termination of the lithic object, while the term "composite tool" was applied to describe a mixture of these characteristics on the same artefact.

The raw material identification was made according to the petrographic and chemical analyses performed by Eramo et al. (in Moncel et al., 2020b), where four main lithotypes of chert were identified: silicified litharenites, nodular chert, vitreous chert, and radiolarite. The presence of limestone is reported as well. Such lithotypes occur in the polygenic pebbles, and cobbles lags formed in the fluvial-lacustrine environment of the area of Notarchirico (Synthem of Palazzo San Gervasio; ISPRA, in press) as products of the erosion of the outer geological units of the southern Apennine formed after the evolution from late Triassic to Miocene of a deep-sea basin on passive margin (Lagronegro basin) to a foredeep basin (Irpinian basin) characterised by flyschoid sequences (Pescatore et al., 1999).

To bring order to the terminology used to classify lithotypes in previous studies and the present work, the term *chert* is intended here as a generic group used for fine-grained siliceous sedimentary rocks following Tucker (2001). Usually, in the geological record, cherty rocks are subdivided into bedded types resulting from primary accumulation (e.g. radiolarites and diatomites) and the nodular type of diagenetic origin (Greensmith, 2012; Trewin & Fayers, 2005). Excluding radiolarites, although the other identified chert types can be traced to facies and diagenetic conditions of turbiditic systems, the term *flysch chert* refers to silicified litharenites (Eramo et al., in preparation).

Results

A total of 591 pieces from layers F, G, H, I1, and I2, which will be discussed separately, were analysed and studied (Table 1). The lithic assemblage is mainly composed of flakes and flake tools, followed by retouched nodules and cores in a minor

Table 3 List of analysed lithic material

Layers	F		G		H		I1		I2		Total	
Categories	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Cores	8	5.4	24	11.8	0	-	22	12.8	9	23.1	63	10.6
Flakes (unretouched)	104	70.3	58	28.4	15	53.6	77	44.8	20	51.3	274	46.4
Flakes (retouched)	30	20.3	52	25.5	4	14.3	34	19.7	4	10.2	124	21.0
Retouched nodules	6	4.0	70	34.3	9	32.1	39	22.6	6	15.4	130	22.0
Total	148	-	204	-	28	-	172	-	39	-	591	-

percentage (Table 3). Small retouched nodules constitute a peculiar aspect for this site, representing 20% of all the analysed pieces and being more or less constant along the entire stratigraphic sequence (Table 3). The *debitage* production was achieved through a direct percussion by hard hammer technique. Nonetheless, the use of anvil percussion (both for *debitage* and retouch actions) cannot be entirely ruled out, given the importance of this technique in similar contexts exploiting small-sized raw materials (Isernia La Pineta) and its well-known difficulties in being adequately distinguished from direct percussion (Pargeter & Eren, 2017; Peña, 2015; Peretto, 1994; Sánchez-Yustos et al., 2017; Vergès & Ollé, 2011).

The global distribution of the raw materials in the analysed sample highlights the predominance of chert lithotypes (Table 4), with flysch chert being the most represented in all the technological categories (87%), followed by nodular chert (10%) and radiolarite (3%). As previously mentioned, hominins collected chert nodules in a secondary position. For this reason, the percentage of cortical patches on the support is relatively low (rolling, breakages, fragmentation, etc.). The development of the neocortex on the nodules is recorded alongside the massive presence of natural surfaces (i.e. surfaces naturally deprived of the cortex and without a neocortex formation).

The state of preservation of the lithic material can be globally considered as ranging between good and medium, with evidence of poorly preserved and "fresh" artefacts. Most of the sample shows different degrees of patination and superficial alteration that prevented the correct assessment of each lithotype's colour but did not influence the technological analysis. Evidence for roundings of the edges or natural removals on the pieces is relatively common though the presence of fresh cutting edges on the artefacts is also frequent. Thus, the lithic pieces were accurately selected, discarding from the analysis all the artefacts not presenting clear knapping marks or clear removal organisation.

Layer F

There are 148 lithic implements from layer F (Table 3; Figs. 3 and 4). Flakes and tools represent 90% of the whole layer, with rare cores and retouched nodules, and flysch being the most exploited raw material (Table 4). The privileged support for cores is small, cubic, or roundly shaped nodules (20–80 mm; see Table 5) bearing

Table 4 Distribution of the lithotypes

Layers	F	G	H	I1	I2	Total	
Lithotypes and technological categories						*n*	%
Flysch chert							
Cores	7	17	-	18	8	50	8.9%
Flakes	89	48	11	67	19	234	41.9%
Retouched flakes	25	40	3	28	4	100	17.9%
Retouched nodules	5	61	8	26	3	103	18.4%
Total						487	87.1%
Nodular chert							
Cores	1	1	-	2	-	4	0.7%
F lakes	7	8	4	8	-	27	4.8%
Retouched flakes	3	7	-	1	-	11	2.0%
Retouched nodules	1	6	1	5	2	15	2.7%
Total						57	10.2%
Radiolarite							
Cores	-	1	-	-	-	1	0.2%
Flakes	1	1	-	-	-	2	0.4%
Retouched flakes	-	1	-	2	-	3	0.5%
Retouched nodules	-	3	-	5	1	9	1.6%
Total						15	2.7%
Total						559	-

cortex on one or two faces (Fig. 3). Cores are equally knapped on one or more knapping surfaces according to the available natural convexities, showing mainly unipolar removals followed by centripetal and bipolar ones (Fig. 3; Table 6), with a mean of three removals per core. The *debitage* often uses cores edges as a technical expedient to speed up production, explaining the high ratio of backed flakes. Multifacial cores present alternate flaking recalling an SSDA type (*systeme par surface de débitage*; Ashton et al., 1992; Forestier, 1993), but there is also evidence of a small core selected for just two removals (Fig. 3, n 4). Striking platforms are natural in most cases (7 out of 11), but a preparation of the surfaces is attested nonetheless.

Flakes ($N=104$) and tools ($N=30$) exhibit a small quadrangular shape slightly longer than wide, with the latter being bigger and longer than the former (Table 5). The presence of residual cortex is low (19%) and usually located on the lateral margins of the supports (Fig. 4). The removal analysis highlights a mixture of knapping strategies: unipolar and convergent scars are the most common (41%), followed by orthogonal (17%), centripetal (10%), crossed (4.5%), and bipolar (4.5%) with 8% of undetermined. The incidence of natural-backed margins is high for flakes and tools (49%), and they are frequently opposed to cutting edges or retouched ones (see Fig. 4, n 1, 2, 5, and 6). The striking platforms are predominantly flat (49%), while the surface preparation is rare and attested by a few dihedral (9%) and facetted (2%) butts, primarily associated with orthogonal and centripetal removals. On the other hand, the exploitation of natural (13%) and cortical (7%) platforms is more frequent.

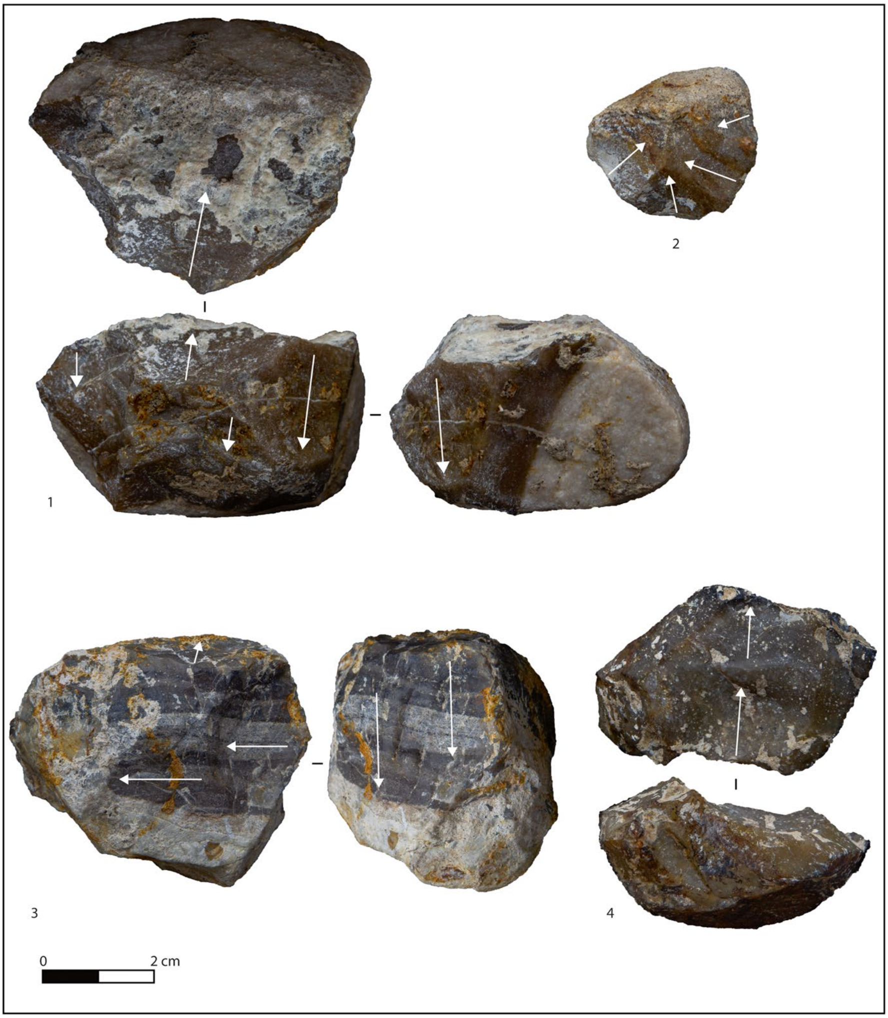

Fig. 3 Cores from layer F. 1 Multifacial core on round nodule of flysch chert. 2 Unifacial centripetal core on small nodule of flysch chert. 3 Multifacial core on flysch chert. 4 Unifacial unipolar core on flysch chert

The presence of punctiform and linear butts is due to the high number of small-sized flakes. The angle flaking has a mean value of 105°, regardless of the platform type, showing a homogeneous use of surfaces.

Retouch is located on the dorsal face for most cases (27 out of 30 pieces), and it seems to affect, to the same degree, single sections of the flakes' margin, various portions or the entire perimeter (Table 7). The extension of the retouch is equally marginal, abrupt, or invasive, sometimes even combined, regardless of the flake type and, more rarely, characterised by a single removal (Table 5). The identified tools (Table 8) are mainly denticulates, scrapers retouched on

Fig. 4 Layer F: debitage products and nodules. **1** Débordant flake on flysch. **2** Scraper on flake of nodular chert. **3** Convergent scraper/pointed tool on flake of nodular chert. **4** Denticulate on flysch flake. **5** Scraper on flysch flake. **6** Denticulate on débordant flysch flake. **7** Convergent scraper/pointed tool on débordant flake of nodular chert. **8** Centripetal flake on flysch. **9** Notch on nodule of flysch. **10–11** Flake with orthogonal removals on flysch. **12** Flake on nodular chert

Table 5 Dimensional values

Layers	F			G			H			I1			I2		
	l	w	t	l	w	t	l	w	t	l	w	t	l	w	t
Flakes	$n=75$			$n=40$			$n=9$			$n=57$			$n=19$		
Min	12.5	9.1	3.2	6.4	9.2	2.1	8.9	9.3	3.5	5.3	7.4	1.9	14.1	12.4	5.5
Max	59.9	56.5	22.3	62.3	49.5	18.2	23.2	16.9	6.9	45.6	33.7	21.7	37.2	32.4	18.0
Mean	26.2	22.4	9.4	21.4	20.2	8.21	14.0	13.4	5.2	19.9	18.5	8.4	23.9	21.0	10.3
Tools	$n=17$			$n=41$			$n=2$			$n=22$			$n=4$		
Min	22.5	14.7	6.6	13.7	12	4.6	11.4	13.7	4.6	9.3	10.9	4.2	18.4	16.9	7.3
Max	61.6	41.2	22.4	68.1	47.5	25.5	15.3	15.7	4.9	48.8	37.5	19.2	60.1	31.4	17.6
Mean	34.7	25	12.4	26.8	22.3	11.8	13.3	14.7	4.7	26.7	23.2	10.3	38.2	24.5	12.6
Nodules	$n=6$			$n=67$			$n=9$			$n=38$			$n=5$		
Min	18.2	17.3	6.65	11.5	12.1	5	12.8	11.5	5.1	9.8	11.1	4	15.2	12.1	3.9
Max	73.2	53.7	30.1	53.1	38.7	24.0	34.4	29.5	13.5	42.5	36.3	21.2	31.9	25.1	13.2
Mean	32.0	25.8	13.0	26.0	20.7	12.7	21.9	19.6	9.3	24.9	20.0	11.9	21.0	18.7	8.9
Cores	$n=6$			$n=19$			$n=0$			$n=16$			$n=9$		
Min	26.1	30.7	17.1	18.9	20.2	15.4	-	-	-	19.7	18.1	11.7	18.7	19.5	15.5
Max	77.4	59.4	51.3	98.9	87.7	67.3	-	-	-	72.7	47.3	29.9	82.9	70.2	55.2
Mean	45.4	43.1	34.2	41.8	36.3	28.2	-	-	-	35.0	28.9	20.1	46.2	37.7	27.6

Table 6 Core classification

Layers	F	G	H	I1	I2	Total
Core classification						
Unifacial						
Unipolar	2	11	-	9	4	26
Convergent	-	-	-	-	1	1
Bipolar	-	1	-	-	-	1
Centripetal	1	-	-	3	1	5
Total						33
Bifacial	2	9	-	8	1	20
Multifacial	2	3	-	-	2	7
Total	7	24	-	20	9	60

Table 7 Characterisation of the retouch (position and extension) of retouched flakes (F.) and nodules (N.)

Layers	F		G		H		I1		I2		Total	
Retouched tools	F	N	F	N	F	N	F	N	F	N	F	N
Position												
Direct	27	4	38	51	4	6	25	32	4	6	98	99
Inverse	1		6	10	1	1	4	2			12	13
Direct and inverse	2	2	8	6		1	5	5			15	14
Extension												
Abrupt	7	4	23	40	1	4	12	22	1	4	44	74
Abrupt and invasive	2	1	4				3	1			9	2
Covering	2		1	1							3	1
Invasive	7		6	2				2			13	4
Marginal	6	1	10	7	3		12	3	2	1	33	12
Marginal and abrupt	1		3	2			2	1			6	3
Marginal and invasive	2		2				1				5	
Single	3		3	15	1	4	4	10	1		12	29

one edge, followed by some notches, points (beaks and more or less convergent pointed retouched edges), and composite tools (Fig. 4, n 2–7).

Significantly, few retouched nodules were recovered from this layer ($N = 6$; see Fig. 4, n 9). They are morphologically and dimensionally similar to retouched flakes (Table 5). The retouch is unifacial in four cases, bifacial in two, usually abrupt and located on two adjacent margins of the support (Table 7). Typologically, there are scrapers and denticulates (Table 8).

Table 8 Typology of retouched flakes (F.) and nodules (N.)

Layers	F		G		H		I1		I2		Total	
Type	F	N	F	N	F	N	F	N	F	N	F	N
Beak			1	7	1			2		1	2	10
Beak and denticulate							1				1	
Denticulate simple	9	2	5	13			5	9	1		20	24
Denticulate double		1	2					1			2	2
Denticulate convergent			4	1		1	3		1		8	2
Notch (single)	2		5	15		4	6	9	1	1	14	29
Notch and scraper			2	1			1	1			3	2
Point	2		3	2			2	1			7	3
Point and scraper	1		1								2	
Scraper simple	10	3	19	19	3	3	9		1	3	42	28
Scraper double	1		5	4			1	2			7	6
Scraper convergent	3			5			1	11		1	4	17
Total	28	6	47	67	4	8	29	36	4	6	112	123

Layer G

Layer G is the richest level of Notarchirico. The distribution of lithotypes always reveals a predominance of flysch chert, but there is a slight increase in nodular chert and radiolarite (Table 4). Retouched nodules ($N=70$) are the most common artefacts, followed by flakes ($N=58$), retouched flakes ($N=52$; showing a higher ration compared to the other layers), and, lastly, cores ($N=24$).

Cores, realised on cubic or rounder nodules, show a complete absence of cortex ($N=16$) or a portion on one face ($N=8$) due to the secondary origin of the nodules' deposit and are characterised by a lower quality of the raw material (Fig. 5). They are mainly exploited on one or two knapping surfaces with unipolar removals (a mean value of 3 per core), occasionally producing semitournant supports (Table 6; Fig. 5, n 3). Among bifacial cores, there is a fragmented one with alternate flaking exploited through a peripherical striking platform (resembling a discoid conception). Multifacial cores display an SSDA (*systeme par surface de débitage* alterné) conception being the outcome of single unifacial-unipolar events (Fig. 5, n 5). Natural striking platforms ($N=26$) are preferred over flat ones ($N=5$), showing limited surface preparation on the cores.

Flakes ($N=58$) and retouched flakes ($N=52$) are quadrangular shaped, more developed in length than in width (Table 5; Fig. 6), with a low presence of cortical patches (19%). The presence of a back, often natural, is predominant (64%), especially on bigger flakes and tools (Fig. 6, n 5, 9). As for layer F, tools are larger than unretouched implements (Table 5). The platform analysis reveals a prevalence of flat (32%) and natural (21%) butts, then dihedral (12%), cortical (7%), facetted (5%), punctiform (4%), and linear (2%). Products without removals constitute the largest group of this layer (32%), followed by unipolar (22%), orthogonal (17%), centripetal

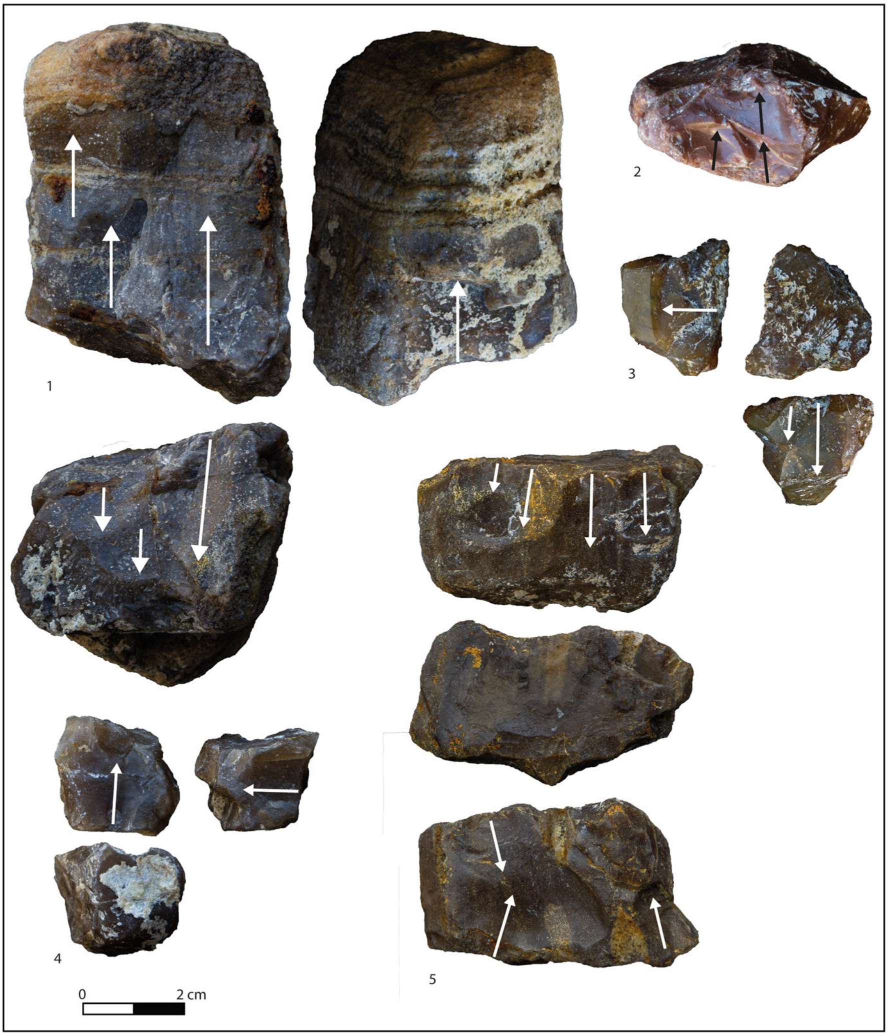

Fig. 5 Layer G: cores. 1 Multifacial core on flysch. 2 Unifacial core on radiolarite. 3 Semitournant core on flysch chert. 4 Multifacial core on flysch. 5 Multifacial core on flysch

(6%), crossed (6%), convergent (5%), and bipolar (4%). The angle of flaking has a mean value of 100°, with dihedrals butts showing a wider angle (106°). No specific relation has been detected between the removal organisation and the platform type.

A wide variety of tools can be recorded (Table 8). Scrapers are the most common, then denticulates, notches, pointed and various composite tools (Fig. 6, n 1, 3, 4, 7). The retouch is often present on more than one margin of the flakes, frequently altering their original shapes but being abrupt most of the time (Table 7). It is usually applied on the dorsal face, sometimes on the ventral or both sides (Table 7). Retouched nodules (*N* = 70) are dimensionally similar to retouched flakes

Fig. 6 Layer G: debitage products and nodules. 1 Denticulate and point on flake of nodular chert. 2 Denticulate on nodule of flysch. 3 Double scraper on flysch flake. 4 Scraper with peripherical retouch on flysch flake. 5 Scraper on débordant flysch flake. 6 Notch with inverse retouch on nodule of flysch. 7 Point on flake with covering retouch on nodular chert. 8 Centripetal flake on flysch. 9 Scraper on débordant flysch flake. 10 Centripetal flake on flysch. 11 Retouched nodule of nodular chert: tool or core? 12 Flake on nodular chert. 13 Denticulate and point on nodule of flysch. 14 Flake on flysch. 15 Notch on nodule of flysch. 16 Flake on flysch. 17 Beak on nodule of flysch

(Table 5). Scrapers are the most relevant category as well, followed by denticulates and notches, which show a significant increase compared to flakes and some pointed implements (Table 8; Fig. 6, n 2, 6, 13, 15, 17). The retouch is mostly abrupt and unifacially applied on one margin (Table 7).

Layer H

Layer H is the poorest level of Notarchirico, counting 28 lithic artefacts (Table 3) with flakes, retouched flakes, nodules, and no cores. These all exhibit smaller dimensional values than the other layers (Table 5), with retouched nodules slightly bigger than the rest. Flysch chert is the most represented raw material, followed by a small percentage of nodular chert. Flakes ($N=15$) and tools ($N=4$) are without cortex and show a variety of removals organisation even though opening flakes seem to prevail. The incidence of backed margin is very low (3 out of 15). Platforms are primarily flat ($N=7$), then natural ($N=4$), punctiform ($N=2$), facetted ($N=1$), and linear ($N=1$) with a mean angle of flaking of 105°. One beak and three scrapers were recorded among the retouched flakes (Table 8), showing direct edge modifications with a marginal extension (Table 7). On the other hand, retouched nodules exclusively present an abrupt retouch to create four notches, three scrapers, and one denticulate (Table 8).

Layer I1

Layer I1 contains 172 lithic artefacts (Table 3) mainly realised on flysch chert, even though nodular chert and radiolarite are also present in minor percentages (Table 4). Cores ($N=18$), ranging between 20 and 80 mm (Table 5), are realised using small nodules except for one case obtained from a small fluvial pebble ($30\times35\times0.30$ mm). Cortex is present on 12 supports, equally on one or two portions.

Unifacial cores prevail ($N=12$) and are exploited through unipolar or centripetal removals (Table 6). Centripetal ones take advantage of the natural convexities existing on some rounded nodules; they all record natural peripherical striking platforms with a flaking angle of 70° and present a maximum of three removals. Unipolar cores exhibit shorter reduction sequences, being selected for one or two removals only and exploiting almost exclusively natural platforms without cortex (Fig. 7, n 1, 4). Several cores present natural fractures and hinged removals, hinting at repetitive impacts. Bifacial cores ($N=8$) show a mixture of removal organisation (unipolar, convergent, orthogonal, and crossed), witnessing an SSDA conception of the surfaces with a frequent inversion between the knapping surfaces and the striking platforms (Fig. 7, n 2, 3). As a result, the latter are equally natural or flat, being the outcome of the core rotation, and the angle of flaking is approximately 90°. Usually, three of four flakes were extracted from these types of supports.

Flakes ($N=77$) and tools ($N=34$) are always of small dimensions, ranging between 20 and 26 mm in length and 18.5 and 23 mm in width (Table 5) and quadrangular shaped. The percentage of *debitage* products bearing cortex is higher than the other layers, being present on 30% of the sample, and the cortical flakes (9%)

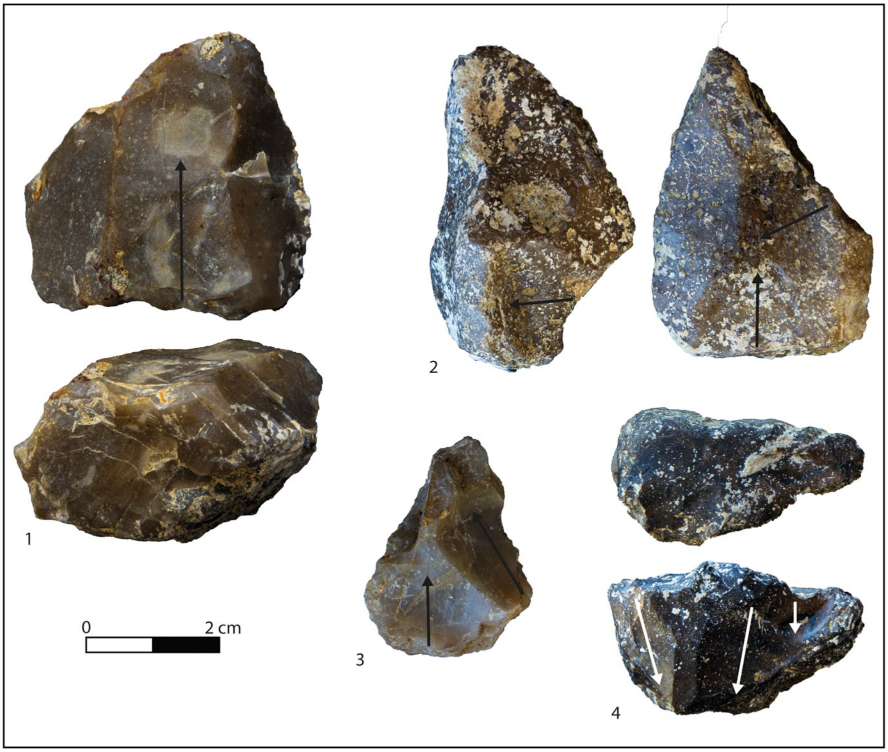

Fig. 7 Layer I1: cores. 1 Unifacial core on nodule of flysch. 2 Bifacial core on nodule of flysch. 3 Bifacial core on nodule of flysch. 4 Semitournant core on nodule of flysch

also show an increase. The incidence of naturally backed margins is close to 50% confirming to be a recurrent technical expedient. As seen in layer G, *debitage* products without removals constitute the largest group (30%) together with unipolar (30%) and followed by orthogonal (10%), crossed (9%), and centripetal (6%). The platform analysis reveals the prevalence of flat butts (35%), natural (16%), and cortical (15%).

Larger flakes were selected for edge modification (Table 3). They consist of various types of scrapers, denticulates, notches, beaks, and pointed implements (Table 8; Fig. 8, n 1, 3, 6, 7, 9, 10, 13). The retouch is primarily direct and either abrupt or marginal applied on one single margin of the flakes (Table 7). Retouched nodules are slightly smaller than tools (Table 5) and are characterised by an abrupt retouch unifacially applied to produce convergent scrapers, denticulates, and notches (Tables 7 and 6; Fig. 8, n 4, 8, 16).

Layer I2

Layer I2 is the oldest level of Notarchirico and represents the beginning of the site occupation. Thirty-nine lithic artefacts were collected, including cores, flakes, tools,

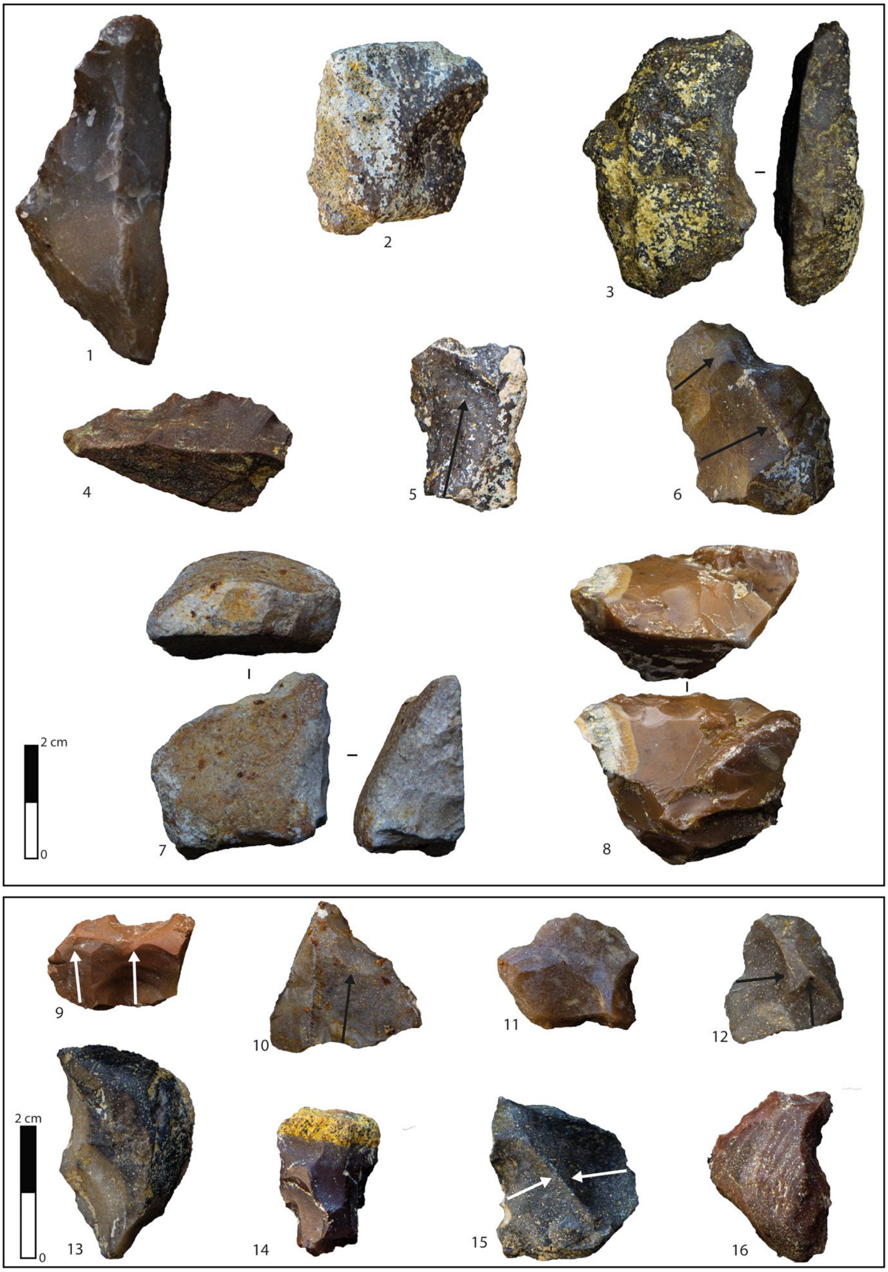

Fig. 8 Layer I1: debitage products and nodules. 1 Composite tool with convergent retouch on flysch flake. 2 -; 3 Denticulate on flysch flake. 4 Scraper on nodule of radiolarite. 5 Débordant flake on flysch. 6 Denticulate on flake with orthogonal removals on flysch chert. 7 Convergent scraper on flysch flake. 8 Scraper on nodule of nodular chert. 9 Notch on flake of radiolarite. 10 Pointed tool on flysch flake. 11 Double ventral flake on nodular chert. 12 Flake on nodular chert. 13 Denticulate on débordant flysch flake. 14 Flake on radiolarite. 15 Flake on flysch. 16 Scraper on nodule of radiolarite

and retouched nodules (Table 3), mostly realised on flysch chert (Table 4). The nine cores are exploited through unipolar removals, with a mean of three per support, generally on one knapping surface in a semitournant way (Table 6; Fig. 9, n 1–3). The centripetal core takes advantage of the existing convexity of the block. Bifacial and multifacial cores witness longer reduction sequences by progressively rotating

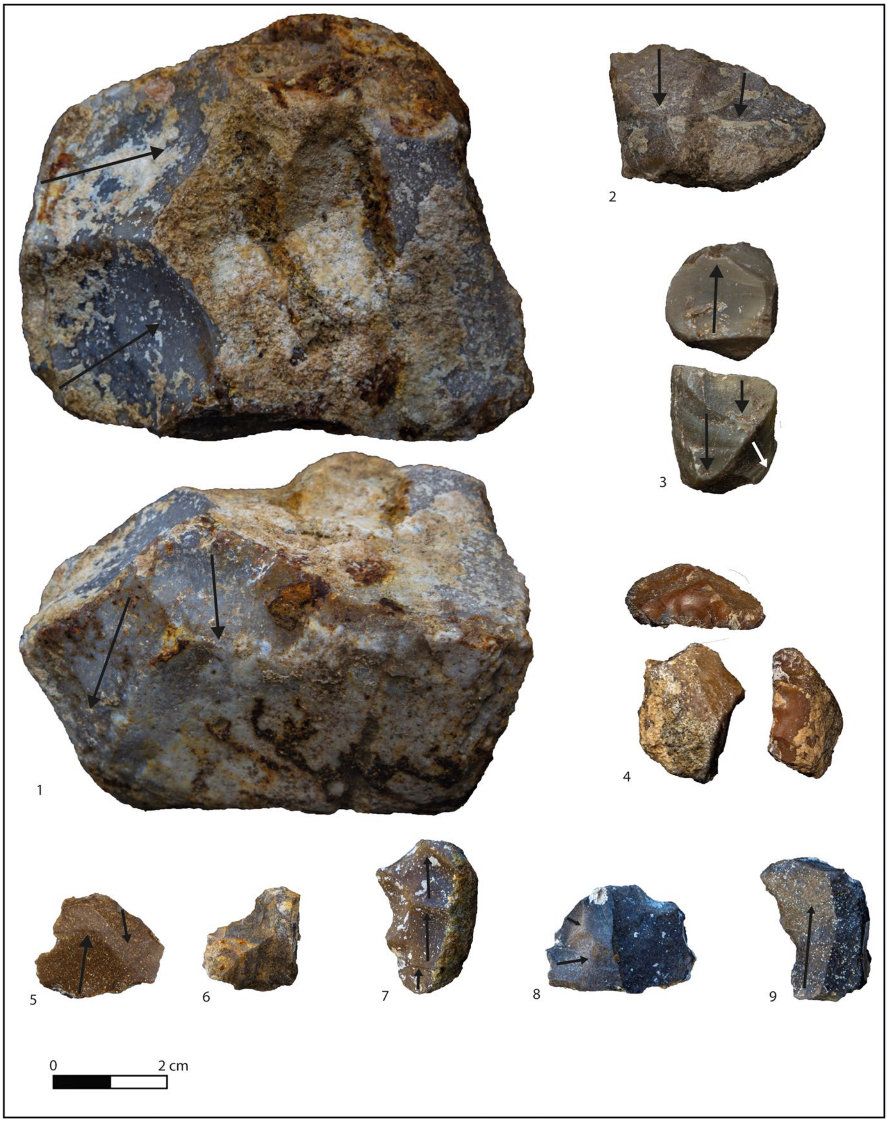

Fig. 9 Layer I2: cores, flakes, retouched flakes, and nodules. 1 Bifacial core on large nodule of flysch. 2 Unifacial core on flysch. 3 Multifacial core on small nodule of nodular chert. 4 Scraper on nodule of nodular chert. 5 Flake on flysch. 6 Notch on flysch flake. 7 Débordant flake on flysch. 8 Flake on flysch. 9 Denticulate on débordant flysch flake

the nodule surfaces once the natural convexities are depleted. The striking platforms are natural in most cases, with the flat ones attested on bifacial and multifacial exploitations being former knapping surfaces.

Flakes and tools fit within the dimensional values of the other layers (Table 5) and are characterised by a high incidence of backed margins (65%). Despite a small sample of flakes, the removal organisation displays a mixture of unipolar (29%), centripetal (16%), crossed (13%), and orthogonal (8%) scars, while flakes without removals (20%) show a significant percentage also for this layer. Platforms are flat in half of the sample with limited presence of natural, cortical, dihedral, and punctiform butts. The absence of cortex is prevalent (63%), even if a moderate increase between the *debitage* products can be recorded. The four tools comprise two denticulates, a notch and a scraper (Table 8; Fig. 8, n 6, 9), all retouched on the dorsal face (Table 7). The retouched nodules ($N=6$) display similar characteristics and are obtained through an abrupt modification of the margins applied on one face (Table 7; Fig. 8, n 4).

Discussion

The new investigations conducted at the site of Notarchirico record almost 30 ka of human occupation during the initial phases of the Middle Pleistocene (695–670 ka). The technological analysis of the *debitage* products from layers F, G, H, I1, and I2 offers critical insights into hominin technological behaviour, highlighting possible similarities and discrepancies within the chrono-cultural framework of the European continent (Moncel et al., 2020b; Rineau et al., 2022).

At Notarchirico, hominins knapped different lithologies of small-sized fragmented chert nodules (30–100 mm) locally available in secondary deposits. These nodules exhibit a cubic or rounded shape with limited presence of cortex, usually located on one or two opposite edges or naturally rolled surfaces. Flysch chert is the most exploited lithotype in the stratigraphic sequence, showing a variable knapping quality according to its texture, silicification, and fracturation. The dimensional analysis of the technological categories subdivided according to the raw materials shows that flysch chert was also available in slightly larger supports than radiolarite and nodular chert (Table 9). The percentages of radiolarite and nodular chert, exhibiting a finer texture, are scarce: this is seemingly due to the actual availability in situ of these two lithotypes, but it might also reflect a systematic choice of the hominins because of dimensional values (Table 9).

The morphology and size of the supports strongly influenced the technical features of the lithic assemblage of Notarchirico, which, as a result, is characterised by a homogeneous *debitage* production of small flakes and tools. The result of core technology highlights several recurrent behaviours in all layers (Fig. 10). Above all, the shape of the available nodules explains most of the hominin technical choices. However, we should also consider that technical traditions might have been developed during this process.

Cores are usually unifacially knapped through unipolar removals, sometimes producing semitournant exploitation (Fig. 10) or selected to extract one or two flakes in what might be defined as expedient behaviour. The presence of natural convexities

Table 9 Size of raw material (l. = length; w. = width; t. = thickness) according to technological categories

Raw material	Flysch chert			Nodular chert			Radiolarite		
	l	w	t	l	w	t	l	w	t
Flakes	*n* = 241			*n* = 28			*n* = 4		
Min	7.7	8	2.3	5.3	7.4	1.9	14.7	12.8	6.1
Max	68.1	56.5	25.5	46.4	32.9	15.4	25.2	22.9	10.7
Mean	25.0	21.5	9.8	18.8	18.0	7.5	18.4	19.0	7.9
Ret. flakes	*n* = 73			*n* = 7			*n* = 3		
Min	9.3	10.9	4.2	15.8	12.8	5.4	14.7	12.8	6.1
Max	68.1	48	25.5	46.4	32.9	15.4	25.2	22.9	11
Mean	28.9	23.4	11.5	26.8	21.1	11.2	18.7	19.3	8.3
Ret. nodules	*n* = 100			*n* = 15			*n* = 9		
Min	12.1	12	3.9	9.8	11.1	4	11.5	14.3	5.4
Max	73.2	54	30	39.1	36.3	21.2	41.8	23.6	13
Mean	26.7	21.3	12.6	22.3	18.8	10.7	20.6	18.4	9.7

and arrises was crucial for the nodules selection, as they were often abandoned once the morphologies were not suitable anymore, hence the high distribution of flakes without removals along the stratigraphic sequence. The *debitage* was generally conducted on the peripherical margins of the blocks, hardly altering their original volume (Fig. 10). Thus, the systematic production of *débordant* flakes could have been an efficient technical expedient to overcome the raw material constraints and speed up production. When nodules were roundly shaped, and a larger surface was available, centripetal *debitage* was also applied, exhibiting similar characteristics to unipolar cores (Fig. 10). Platforms were mostly natural without evidence of any preparation though single removals might have occurred to facilitate the obtainment of flat surfaces. This confirms a global attitude to subordinate the *debitage* to the morphological aspects of the supports. Unipolar removals characterise bifacial and multifacial cores with a frequent inversion of striking platforms and knapping surfaces pointing to an SSDA conception (Ashton et al., 1992; Forestier, 1993). The reduction sequences were more prolonged in this situation, involving a significant percentage of the core volumes but always with a maximum of two or three removals per face and limited to the exploitation of natural convexities. As previously mentioned, the incidence of flat platforms is due to the core rotation rather than the platform preparation.

Evidence of cores showing a discoid conception or structured *debitage* is scarce: only one bifacial core from layer G exhibits alternate flaking through two peripherical striking platforms. However, the *debitage* is still strongly influenced by the nodule's morphology, and there seems to be no explicit attempt to shape the surfaces regardless of their original morphologies (Santagata et al., 2020). For the time being, there is no evidence that cores were retouched or used after being discarded, though, given the sample size so far analysed and the extension of the excavation, it cannot be entirely excluded. As witnessed by several other contexts, even in the

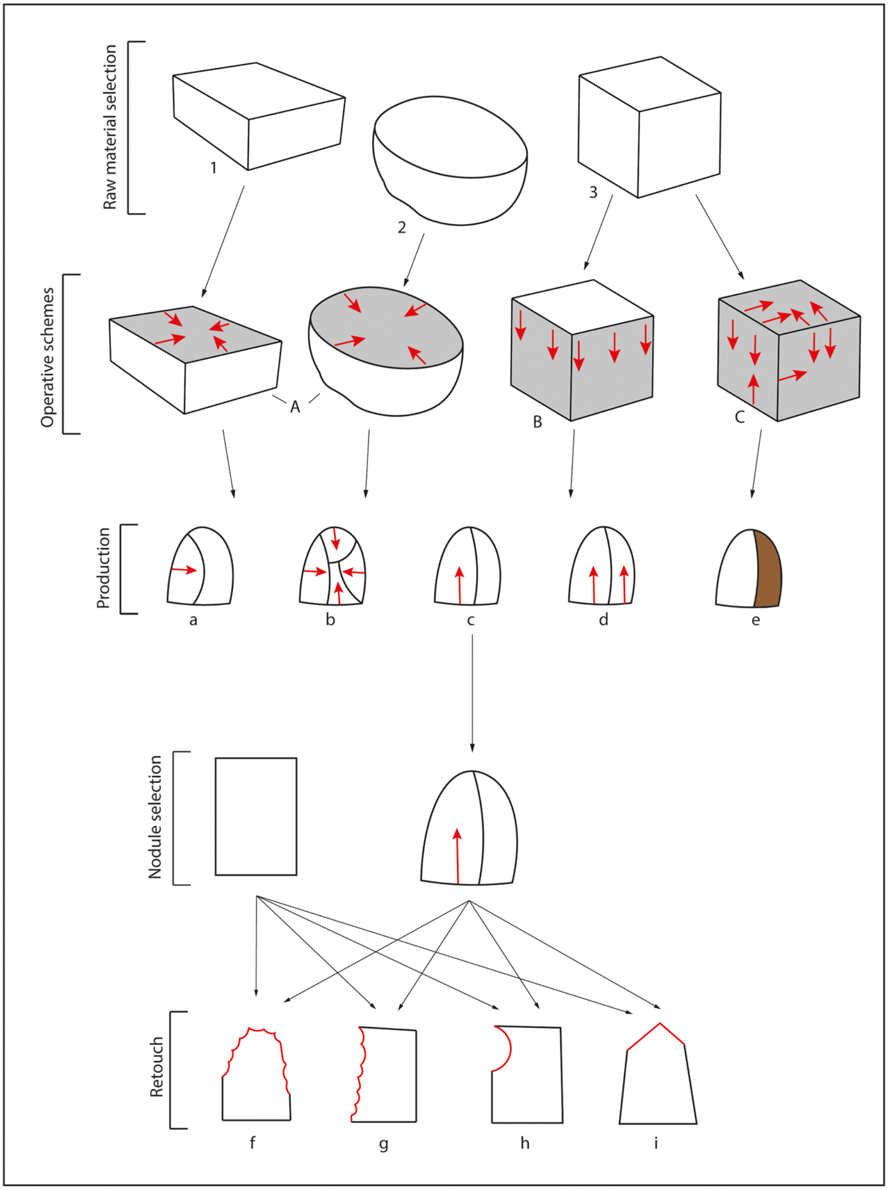

Fig. 10 Production schemes of Notarchirico. Raw material selection: selection of nodules with rectangular (1), round (2), or cubic (3) morphologies. Operative schemes: A exploitation of one large knapping surface through a peripherical striking platform producing either orthogonal or centripetal negatives; B unipolar exploitation, eventually leading to semitournant behaviour using the natural convexities (edges and arises) of the nodules; C SSDA (systeme par surface de débitage alterné) exploitation of the cores, frequent rotation and inversion of the striking platforms and knapping surfaces. Production: typical obtained products: orthogonal flake (a), centripetal flake (b), unipolar débordant flake (c), unipolar flake (d), débordant flake without removals (e). Retouch of flakes and nodules: researched morphologies: peripheral convex retouch (f), lateral rectilinear retouch (g), notch (h), convergent/pointed retouch (i)

Italian Peninsula (Isernia La Pineta and Fontana Ranuccio, Ficoncella), it can be an efficient strategy—usually referred to as circularity of the reduction sequences—especially when dealing with small-sized raw materials (Aureli et al., 2016; Grimaldi et al., 2020).

The analysis of knapping strategies reveals a global mixture of unipolar, orthogonal, centripetal, bipolar, and crossed *debitage* with more or less the same distribution across the layers and a prevalence of the former. The ratio of scars per flake matches the shortness of the reduction sequences, with a mean value of 1. Only orthogonal and centripetal products present a higher proportion, given the exploitation of larger knapping surfaces. Evidence for a greater degree of complexity represented by these latter reduction sequences is, for the time, not supported by the data, indicating homogeneous yet equally complex technical behaviours modulated according to the morphological criteria. The platform distribution is dominated mainly by flat and natural butts. Still, the sporadic presence of dihedral and facetted ones indicates that preparation of the surfaces might have occurred when needed. No particular correlations were found between the platform type and the removal organisation.

If we exclude layer H, which seemingly represents a short-time occupation of the site during a mild climatic crisis (Moncel et al., 2020b; Rineau et al., 2022), the same dimensional values characterise the *debitage* products in all the layers. Flakes and tools without a cortex are predominant. An increase in cortical and partially corticated chips can be recorded in the lowest levels (I1 and I2), but it does not seem to correspond to a different economy of the raw material or technological differences. This data and the frequency of products showing no removals confirm the scarcity of cortical remains on nodules, including their intentional selection and the massive exploitation of natural surfaces. Backed flakes are also abundant, attested on at least 50% of the lithic assemblage for each layer and often opposed to a cutting margin. Retouched tools are always realised on bigger implements and are characterised by scrapers, denticulates, notches, beaks, and pointed flakes, revealing various types and, seemingly, functions. Their distribution is uniform across the stratigraphy, with layers G and I1, the richest of the site, exhibiting a greater diversity. The retouch can vary, applied on a single margin or peripherally and frequently altering the original shape of the support to obtain specific morphologies. The angle of retouch is mainly included between 60° when it is marginal and located on thin edges and 80° when it is abrupt. Regardless of the selected layer, this pattern is constant along the stratigraphic sequence. No relations were detected between the flakes chosen for the retouch and the knapping strategies.

Hominins also selected many small nodules of the same size as tools to be retouched. These nodules show a cubic/rectangular shape, hardly exhibiting natural cutting edges and with scarce attestation of the cortex. Naturally backed margins on the nodules could have played an essential role in their selection, representing a possible prehensile part, opposed to the modified edge. Consequently, the retouch was almost exclusively abrupt on one face to obtain scrapers, denticulates, beaks, and notches. It may be safe to argue that the role of tools and retouched nodules was the same since the latter represents a valid substitute for retouched flakes, even from a typological point of view. The dimensional values confirm this aspect showing an intentional selection of supports with a specific length. The analysis of the raw material economy provided the same result as the *debitage* production. It is essential to point out that retouched nodules and flakes do not show a second phase of reshaping or recycling, which could indicate a single-time use and short lifespan of these products. Several retouch flakes have been found in different layers, which, together with all the gathered data, indicate that the lithic objects were knapped, used, and abandoned in the same area.

The possibility of nodules being used as passive supports/cores to extract small-sized flakes is still open for the time being. On larger nodules, there is evidence of removals dimensionally comparable to the end products with a suitable flaking angle (close to 90°). Further investigations are required to clarify the possible existence of this behaviour; however, the ambivalence of the concepts of *debitage* and *façonnage*, which seems to affect these chronological phases—particularly in contexts characterised by raw materials of small dimensions like Isernia La Pineta, Ficoncella, Fontana Ranuccio, and Soucy—might be a crucial technological trait to track down and a possible marker of innovation (Aureli et al., 2016; Grimaldi et al., 2020; Lhomme, 2007).

Ultimately, the analysis of the core does not reveal remarkably structured reduction sequences from a morphological and conceptual point of view. Nevertheless, this does not mean that the lithic assemblage of Notarchirico lacks complexity from a methodological perspective. The systematic use of retouch to shape the original morphologies of the small available supports according to the production goals and the exploitation of nodules demonstrate a skilful adaptation to the raw material by these hominins, balancing out the qualitative and dimensional constraints and allowing them to obtain a great variety of products. Besides, core management homogeneity along the stratigraphic sequence highlights a behavioural response of these hominins to approach this type of raw material that gradually becomes systematic and is assimilated within the methodological process.

Following this idea, it is remarkable noticing that the Italian Peninsula is noted for numerous sites (Notarchirico, Isernia La Pineta, Loreto, Ficoncella, Cimitero di Atella, Fontana Ranuccio, among others; Abruzzese et al., 2016; Aureli et al., 2016; Gallotti & Peretto, 2015; Grimaldi et al., 2020; Lefèvre et al., 2010; Muttillo et al., 2021) spanning from the beginning of the Middle Pleistocene (MIS 19) to approximately 400 ka (MIS 11) exhibiting a massive production of small-sized flakes and retouched tools—sometimes associated with the production of handaxes as in the case of Cimitero di Atella and Notarchirico itself. This aspect has often led the scientific community to identify a potential pattern in the Italian Peninsula originating from the raw material's availability and seemingly becoming cultural and behavioural (Gallotti & Peretto, 2015; Muttillo et al., 2021).

Various pebbles and large cutting tools also characterise the site of Notarchirico (Moncel et al., 2020b), showing a sharp increase in the uppermost portion of the sequence simultaneously with the appearance of the earliest bifaces of the site so far (layers G and F; Table 2). Pebble and large cutting tools are described as poorly standardised from a morphological point of view (Moncel et al., 2020b); they exhibit a broad diversification with unifacial, bifacial, and trifacial retouch, partially altering the original shape of the supports when possible and consistently taking advantage of the available natural convexities recalling the pattern seen for the *debitage* products and retouched nodules. On the other hand, the six bifaces are reported to show skilful management of the bifacial and bilateral symmetry—with peripherical removals and a final retouch phase to regularise the cutting edges—fitting into the Acheulean paradigm that begins to emerge at the onset of the Middle Pleistocene within the European continent and of which Notarchirico represent one of the earliest evidence (Moncel et al., 2019).

The presence of bifaces is commonly associated with technological—and cognitive—shifts in the lithic assemblages where they have been found, which, in this case, the *debitage* production does not seem to reflect. The analysis of all the layers witnesses an—alleged—abrupt appearance of these items starting from layer G but does not reveal a change in the degree of complexity of core technologies and flake production—together with nodule fabrication—whose characteristics and conception are somewhat similar to the heavy-duty components remaining homogeneous along the considered layers (Rineau et al., 2022). It is plausible that the absence of bifaces in layers H, I1, and I2 could be due to the excavation's size—as already proposed in other works (Moncel et al., 2020b; Rineau et al., 2022)—despite being investigated on the same area of layers F and G but might also reflect a change in the site's role and function over time. On the other hand, layers F and G are indeed the richest and most diversified quantitatively and typologically speaking, which could suggest an actual shift in the modalities of the occupation or the conducted activities.

Could we truly assign to the bifaces this role of cultural marker/complexity changer in the site of Notarchirico, which might already be present in the lowest levels? If we assume that (1) the hominins' adaptive response to the exploitation of identical raw materials of small morphologies becomes systematical from the bottom of the stratigraphic sequence to which handaxes are later integrated, (2) aspects such as the spatial mobility within the site and its function may vary over time, and (3) the absence/presence of the bifaces is seemingly not due to an actual shift from a complexity-free context to a more complex one—as the technological analysis seems to suggest—then other behavioural variables should also be considered as additional proxies of possible "cultural" and evolutionary changes (Binford & Binford, 1966; Henrich, 2015; Davis & Ashton, 2019; Pargeter et al., 2019). For instance, the possible exploitation of organic material (i.e. bones) to compensate the lack of raw materials of large dimensions.

The archeozoological and functional data available do not record discrepancies along the stratigraphic sequence in the exploitation of faunal remains and worked materials, though the data are partial and still being processed (Moncel et al., 2020b). The use-wear analysis proved that the site was not exclusively cutting-oriented, especially from the basal portion of the sequence—which might have explained a delayed introduction of bifaces—with evidence of wood and plant processing preserved on the margins of the *debitage* products. This aspect might contribute to the potential continuity of the site concerning the practised activities and following the substantial homogeneity depicted by the lithic assemblage, portraying Notarchirico as a multi-functional context with recurrent continuous occupations during both glacial and interglacial phases (Moncel et al., 2020b; Rineau et al., 2022).

Moving onto the European chrono-cultural framework, Notarchirico provides one of the earliest examples of the Acheulean techno-complex together with the French sites of La Noira (700 ka) and Moulin Quignon (Moncel et al., 2020a; 2021c). In these contexts, some similarities exist within the degree of complexity of bifacial assemblages, exhibiting the complete ability to manage bifacial and bilateral symmetry, other than the presence of heavy-duty implements and large cutting tools; however, both French contexts show the use of soft hammer percussion for the final shaping of the bifaces which Notarchirico does not. The use-wear analysis of La Noira also indicates the presence of diversified activities and exploited materials such as cutting meat, wood and plant processing, bone-working, and engraving, similar to Notarchirico (Hardy et al., 2018). Unlike the latter, however, La Noira shows traits of knapping innovations, primarily when centripetal cores are addressed, highlighting more structured and organised reduction sequences capable of subordinating the raw material morphologies, hierarchising the surfaces, and closer to the bifacial conception of *shaping* (Moncel et al., 2021a). It is essential to underline that the raw material employed at La Noira is composed of large slabs of fine texture that could have granted dimensional and technical advantages to the hominins.

Aside from this, the core and flake production of Notarchirico fits within the "small-sized" flakes contexts of the Middle Pleistocene, such as Isernia La Pineta (590 ka), Ficoncella (500 ka), and Atapuerca TD6 (800 ka), whose lithic assemblages resemble the Mode 1 *debitage* (Aureli et al., 2016; Gallotti & Peretto, 2015; Mosquera et al., 2018). In these contexts, characterised by the massive production of small flakes and tools on local raw materials, the absence of bifacial implements is reported. It is unclear whether this is due to block's dimension, cultural substratum—which has often led the scientific community to exclude them from the Acheulean techno-complex—functional reasons or size of the excavations area. Recent works from Atapuerca TD6 pointed out that the absence of handaxes at the site is due to an actual absence of the bifacial concept implying a systematic technological choice of the hominins rather than issued from the raw materials availability (Lombao et al., 2022; Mosquera et al., 2018).

Nonetheless, Notarchirico stands in a crucial spot because of its geographic location, close to the other Italian Lower Palaeolithic sites, and as an alternative entry route to Europe for the African migratory fluxes together with Gibraltar and Levantine corridor (Abbate & Sagri, 2012). Besides, the climatic background of the Italian peninsula at the beginning of the Middle Pleistocene makes it a sort of shelter area, occupied during both interglacial and glacial stages—due to the moderate climatic variations—as confirmed by the radiometric datings, and thus offered continuous frequentation (Bertini, 2003; Pereira et al., 2018). In the end, the mixed features of Notarchirico's lithic assemblage, halfway in between "persistency" (cores and flake production) and innovation (bifacial tools), make it a cornerstone in understanding the different behavioural responses of the hominins. The data so far gathered raised questions about whether the emergence of handaxes is due to an in situ evolution or an allochthonous introduction, with a constant reminder that the function and occupation of a site strongly influence the material culture and the human response.

Conclusion

The new investigations conducted at the site of Notarchirico pushed back the emergence of the bifaces within the Italian Peninsula to 680 ka (layer G), aligning with the recent discoveries of the French sites of La Noira and Moulin Quignon and attesting to a homogeneous arrival of the Acheulean techno-complex in Europe during the interglacial 17. The site features a prolonged human occupation during stages 17 and 16 of the Middle Pleistocene, being a unicum in the European Lower Palaeolithic and acting as an ecological niche for faunal and human groups. Hominins of Notarchirico took advantage for a long time of the paleo-channels to exploit the presence of water, animal carcasses, woods, plants, and lithic raw materials (limestone and various type of chert). The archaeological data suggest recurrent and stable occupation of the hominins across all the layers of the site, whose activities are diversified, including cutting meat, wood and plant processing, and bone-working, hinting at a “domestic” configuration of Notarchirico—as also proposed for La Noira—with seemingly high mobility over large areas (sitewide). The analysis of the lithic assemblage shows the exploitation of locally collected chert and limestone to realise various large-sized tools (bifaces, cutting tools, pebble tools, etc.) and small flakes and tools (scrapers, denticulates, notches, and pointed implements). Hominins also selected small-sized chert nodules directly to be retouched, functioning as an alternative to retouched flakes. The technological behaviour proved to be homogeneous from the bottom to the top of the newly investigated sequence (layers I2, I1, H, G, and F), focusing on *debitage* production and pebble tools. At the same time, the presence of bifaces is attested only from layers G and F.

This raises questions about whether the introduction of this particular technology is due to an abrupt arrival of new populations—and behaviours—or to a local evolution as an adaptive response to environmental pressures. It should also be considered that a change in the site function might have occurred, leading to the integration of bifaces within the toolkit of the hominins of Notarchirico, adding to an already diversified lithic corpus comprising *debitage* production and heavy-duty components. To conclude, Notarchirico is characterised by a substantial homogeneity of techno-economic behaviours, covering both an interglacial and glacial phase in southern Europe where the climatic variations were low, which, allegedly, only the presence of bifaces seems to break, acting as an element of innovation and connoting the site as in between cultural innovation and continuity.

Acknowledgements The authors would like to dedicate the present work to the loving memory of Marcello Piperno. We thank R. Gallotti and J-P. Raynal for their advice in the field. Thanks to Pasquale Acquafredda and Nicola Mongelli for technical support with the SEM analysis. This study benefited from instrumental upgrades of “Potenziamento Strutturale PONa3_00369—Università degli Studi di Bari Aldo Moro, entitled Laboratorio per lo Sviluppo Integrato delle Scienze e delle Tecnologie dei Materiali Avanzati e per dispositivi innovativi (SISTEMA)”. The paper was edited by Louise Byrne, an official translator and native English speaker. We thank the Soprintendenza of Basilicata (Italy) for their scientific support, especially Dr T.E. Cinquantaquattro, Dr F. Canestrini, Dr R. Pirraglia, and Dr S. Mutino. We also thank the Venosa Museum, the city of Venosa and the mayor, Dr A. Mantrisi and Dr R. Calabrese, for their assistance.

Author Contribution M. C.: writing—original draft, visualisation, conceptualisation, methodology, and investigation; M-H. M.: conceptualisation, methodology, investigation, and writing—review and editing, project administration, funding acquisition, and supervision; G. E.: writing—review and editing, investigation, and methodology. M. A.: conceptualisation, methodology, and writing—review and editing.

Funding Open access funding provided by Università degli Studi di Ferrara within the CRUI-CARE Agreement. Fieldwork was carried out with the financial and scientific support of the Leakey Foundation ("Early Evidence of Acheulean bifacial technology in Europe" grant, 2015–2016 and 2019–2021), the National Museum of Natural History, Paris, France (ATM Action Transversale du Muséum, 2016–2018) and the ERC-Adv. LATEUROPE n 101052653.

Data Availability Not applicable.

Declarations

Ethical Approval Not applicable.

Competing Interests The authors declare no competing interests.

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4.3. The lithic assemblage of Isernia La Pineta

Archaeological and Anthropological Sciences (2023) 15:93
https://doi.org/10.1007/s12520-023-01791-8

ORIGINAL PAPER

Brief interviews with hideous stone: a glimpse into the butchery site of Isernia La Pineta — a combined technological and use-wear approach on the lithic tools to evaluate the function of a Lower Palaeolithic context

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Received: 16 May 2022 / Accepted: 12 May 2023 / Published online: 7 June 2023

Abstract

The onset of the Middle Pleistocene (780 ka) in the European continent is associated with significant environmental variations (Middle Pleistocene Revolution), innovative behavioural strategies (bifacial productions, land-use patterns, raw material management) and a global increase in the archaeological evidence from 600 ka onward. Whether these changes are related to the rise of the Acheulean, the informative potential carried by these contexts is currently being explored through multidisciplinary approaches, allowing us to infer the role of these sites and the type of activities conducted. From this perspective, the Italian peninsula is a hot spot to compare the different technical behaviours and strategies human groups employ, given its crucial geographic location and solid archaeological record, both culturally and functionally speaking (the presence of sites with and without bifaces and core-and-flake assemblages). The site of Isernia La Pineta (590 ka), offering a rich lithic and faunal record, is an excellent case to join together the lithic technological study (i.e. “cultural” and technical tradition) with the functional analysis (i.e. activities conducted and exploited materials). Here, we present the result of the combined approach of these two disciplines on flint assemblages from layers t.3a and t.3coll. The new data will be discussed within the chrono-cultural framework of the Middle Pleistocene Revolution, linking the degree of complexity of the lithic production of Isernia with its function as a butchery site.

Keywords Isernia La Pineta · Lower Palaeolithic · Middle Pleistocene Revolution · Use-wear analysis · Lithic technology

Introduction

Comprehending the degree of connection between human occupation and environmental conditions at the boundary between the Lower and the Middle Pleistocene has become a crucial and highly addressed topic to understand the European peopling — its modalities and the development of behavioural innovations that might have facilitated the facing of harsh climatic conditions by the hominids — during the Lower Palaeolithic (Hosfield and Cole 2018; Moncel et al. 2018b; Key and Ashton 2022; Zanazzi et al. 2022). Several recent works highlighted that during this chronological framework, major climatic variations occurred and played a fundamental role in the pattern of human colonisation — even though, in some cases, the “lack of hominin occupation without any climatic-based reasons” (Moncel et al. 2018b, p. 78) has been observed — while the archaeological data itself provided evidence for significant anatomical, behavioural and possibly cultural changes confirming the relevance from different aspects of this chronological phase (Moncel et al. 2018c; 2021; García-Medrano et al. 2019; Rineau et al. 2022). Additionally, the final stages of the Lower Pleistocene and the first half of the Middle Pleistocene represent a prolonged phase of environmental, cultural and evolutionary “turmoil” characterised by considerable diversity, ultimately culminating in the transition to Middle Palaeolithic (400–350 ka/MIS 11) during which a solid demographic expansion and regionalisation of the

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cultural aspects will be gradually taking place all over Europe (Moncel et al. 2016; 2020c; Davis and Ashton 2019).

The transition between the Lower and Middle Pleistocene on the European continent is often referred to as Middle Pleistocene Revolution. Its beginning has been universally set to 780 ka with the beginning of the Middle Pleistocene, but it is considered to cover a significantly larger period based on climatic and environmental data (1.2 – 0.45 Ma; Manzi et al. 2011; Moncel et al. 2018b; Muttoni et al. 2018). The Middle Pleistocene Revolution is associated with an abrupt change in the climatic and environmental conditions affecting the faunal assemblages and most likely triggering fluxes of human groups and significant behavioural changes (Manzi 2004; Muttoni et al. 2010; 2018; Manzi et al. 2011; Abbate and Sagri 2012; Moncel et al. 2018b). The change of periodicity in the alternation of glacial/interglacial phases from 41 to 100 ka marked important geomorphic changes and vegetational turnovers all over Europe (Paillard 1998). A global extension of grassland habitats was documented. The increased periodicity resulted in a sharper alternation of close and more open environments corresponding, on a larger scale, to a clearer gap between glacial and interglacial events (Moncel et al. 2018b). According to the available data, this has seemingly enhanced corridors' opening/closing, favouring the diffusion of new faunal species and human groups from Africa and Asia with evidence of anthropic occupation even at higher latitudes (Northern France, England; Parfitt et al. 2010; Preece and Parfitt 2012; Antoine et al. 2019; Moncel et al. 2020a). At the same time, these climatic changes equally affected the continuity of human frequentation, creating a distinct scenario between Northern and Southern Europe. The former was intermittently occupied primarily during favourable climatic phases — as witnessed by the sites of Happisburgh 3, Pakefield, La Noira and Moulin Quignon, which show an abrupt abandonment at the onset of glacial stage 16 — while the latter was more continuously occupied over time due to less-impacting climatic variations (for example, at the site of Notarchirico during MIS 16), depicting an "ebb and flow" model for European peopling (Parfitt et al. 2010; Dennell et al. 2011).

The emergence of bifacial and LCTs industries, new land-use patterns and raw material management and a global increase in the degree of complexity of the lithic productions, even in contexts without bifacial tools (i.e., core and flakes assemblages, such as Pakefield, Atapuerca Gran Dolina TD6, and Isernia La Pineta; Parfitt et al. 2010; Ollé et al. 2013; Gallotti and Peretto 2015; Davis et al. 2021), are among the innovations documented during this important chronological transition (Moncel et al. 2015; Schreve et al. 2015; Moncel and Ashton 2018). The appearance of handaxes in Europe is commonly associated with the Acheulean cultural complex, which should mark a moment of significant cultural and technical renovation related to the arrival of new human species (*Homo heidelbergensis*, *Homo antecessor*) from the African and Asian continents (Manzi 2004; Moncel et al. 2018a). The recent findings of La Noira, Moulin Quignon and Notarchirico show an abrupt and homogeneous emergence of bifacial tools during the interglacial 17 (700 ka), supporting the hypothesis of the arrival of new human groups over the European continent during this time frame. On the other hand, the bifaces recently discovered at La Boella (1.0–0.9 Ma) may question the chronological validity of this model. The most recent works considered them a local evolution rather than an external introduction (Vallverdú et al. 2014; Mosquera et al. 2016), even though, given the proximity of La Boella to the Gibraltar corridor, an earlier arrival of human groups could not be entirely ruled out.

Following this line of thought, this recent increase of data observed all over Europe (Fig. 1) allowed scholars to keep fuelling the debate regarding the timing of the appearance of biface production, its spreading and diversity across Southern, Western and Northern Europe, not to mention its possible connections with pre-existing European human groups (Vallverdú et al. 2014; Schreve et al. 2015; Moncel and Ashton 2018; Moncel et al. 2021). The same concept of what the Acheulean world should include and mean is now being questioned, as pointed out in a recent work: "The term "Acheulean", rather than one uniform cultural tradition, is more appropriate for describing the puzzle of assemblages and strategies recorded in western Europe" (Moncel and Ashton 2018). This is leading to a global shift from the classic paradigm *Bifacial = Acheulean*, also witnessed in the African and Asian continents (Sharon et al. 2011), where the contextualisation of the Acheulean is not strictly based on the presence/absence of bifacial artefacts. Though this recent growth of discoveries, the sporadicity of the archaeological evidence (both chronologically and geographically) still prevents the scientific community from getting a homogeneous framework, and several hypotheses have been suggested to explain the arrival of the Acheulean in the European region (Martínez and Garcia Garriga 2016; Moncel 2017; Moncel et al. 2018c). Within the present state of the art, a dual case scenario is usually assumed concerning either a local origin suggesting evolution from previous occupations (Mode 1, core-and-flake traditions) or an allochthonous introduction (whether episodical or continuous) of new populations alongside the diffusion of new technical traditions (Manzi 2004; Moncel et al. 2015; Voinchet et al. 2015).

With these hypotheses being equally valid and currently debated, it is generally accepted that a cognitive shift occurred during this period, but what are the most valuable and available tools for us to recognise it? The chance of identifying, in terms of material culture, the presence of behavioural changes or being able to discern between

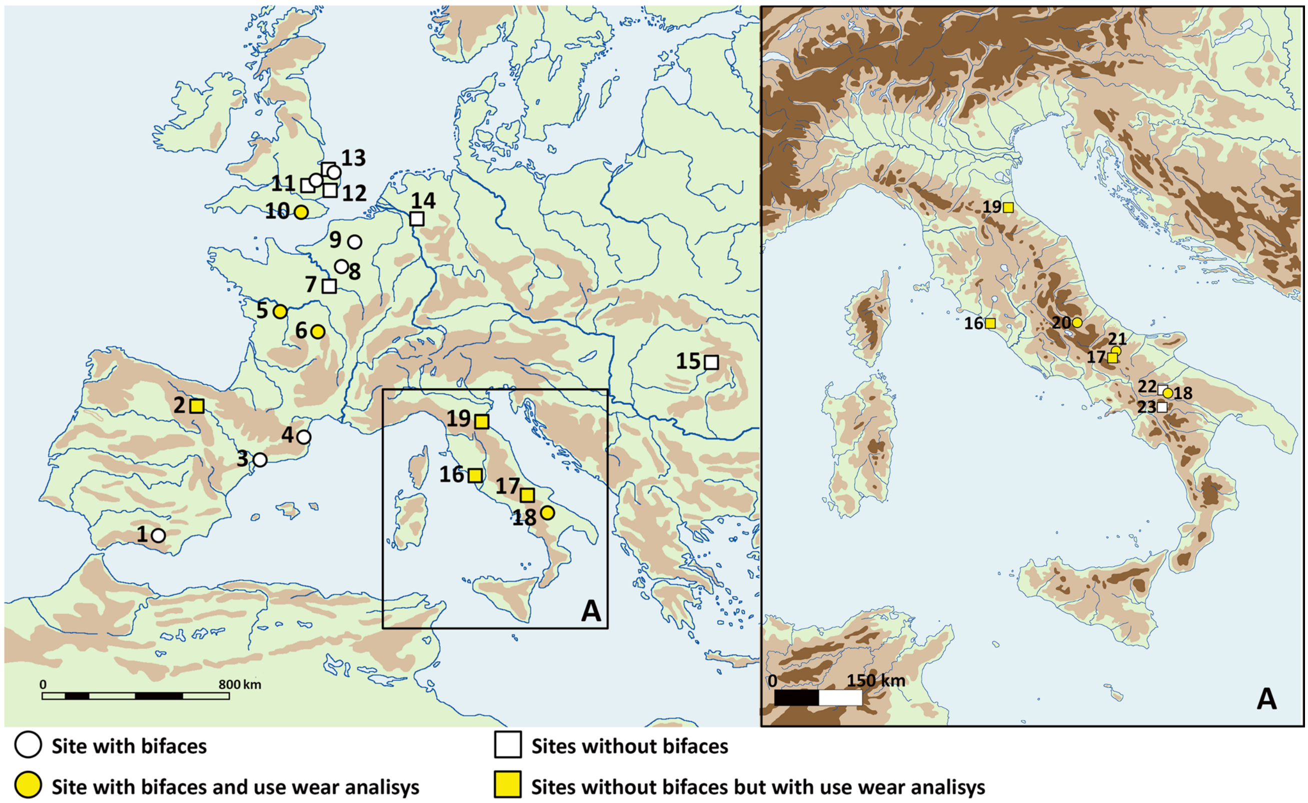


Fig. 1 Map showing Lower Palaeolithic sites mentioned in the text: 1, Cueva Negra; 2, Atapuerca TD6, TD10/Galerìa; 3, Barranc de la Boella; 4, Caune de l'Arago; 5, La Grande Vallée; 6, La Noira; 7, Pradayrol; 8, Moulin Quignon; 9, Cagny la Garenne; 10, Boxgrove; 11, High Lodge, Maidscross Hill; 12, Pakefield; 13, Happisburgh 1, Happisburgh 3; 14, Rhine Basin; 15, Korolevo; 16, Ficoncella; 17, Isernia La Pineta; 18, Notarchirico; 19, Cà Belvedere di Montepoggiolo; 20, Valle Giumentina; 21, Guado San Nicola; 22, Loreto; 23, Atella. A Map of Italy showing major Lower Palaeolithic sites during the first half of the Middle Pleistocene

what is a sign of complexity and what is not are all challenging topics that need to be scientifically addressed and investigated.

From this perspective, the European archaeological background during the Middle Pleistocene Revolution proved to be highly diversified yet quantitatively and geographically fragmented. If we consider the lithic assemblages of this period, for instance, they are characterised by multiple types of debitage (SSDA/opportunistic, centripetal, discoid), which are often not associated with bifacial industries and therefore excluded from the Acheulean revolution (Barsky et al. 2013; Gallotti and Peretto 2015; Aureli et al. 2016; Moncel et al. 2018c). Nonetheless, the documented increase in the centripetal and discoid reduction sequences — even from a complexity point of view — the frequency of retouched flakes and the ability to realise large-sized tools are now considered possible material evidence for the alleged arrival of new populations or the development of new traditions in Western Europe (Roberts 1993; Parfitt et al. 2005; 2010; Carbonell et al. 2010; Guadelli 2012; Ollé et al. 2013; Rossoni-Notter et al. 2016; Moncel and Ashton 2018; Mosquera et al. 2018; Fiedler et al. 2019).

On top of that, recent works highlighted how the concepts of behavioural innovation and cultural change could and should be explored in other areas, such as the analysis of the activities conducted on the different sites, the subsistence strategies pattern or the land-use management (Hardy et al. 2018; Zanazzi et al. 2022; Zohar et al. 2022). These proved to be all valuable proxies to the archaeological investigation, and their integrated approach enabled a higher resolution and a more accurate reconstruction of the Lower Palaeolithic contexts in many cases.

During the Lower/Middle Pleistocene transition, the Italian is a crucial spot for tracking down human dispersal across the European continent, witnessing a solid increase in the archaeological evidence from this chronological phase (Muttillo et al. 2021). It shows a consistent range of contexts spanning from the end of marine isotope stage 17 onwards (Fig. 1A; Pereira et al. 2018), offering one of the earliest traces of the Acheulean cultural complex (approximately 680 ka, in the level G of Notarchirico; Moncel et al. 2020d), providing at the same time contexts without bifaces (Isernia La Pineta, Ficoncella, Loreto and Atella; Gallotti and Peretto 2015; Abruzzese et al. 2016; Aureli et al. 2016) and eventually including the transition to the Middle Palaeolithic with one of the earliest evidence of Levallois technology (Pereira et al. 2016; Guado San Nicola; Arnaud et al. 2017; Moncel et al. 2020b). Additionally, the site of Montepoggiolo also attests to an earlier frequentation of the Italian peninsula during the final stages of the Lower Pleistocene (MIS 21; Falguères 2003).

As previously mentioned, the climatic and environmental data available for the Italian peninsula during this chronological time frame (Bertini 2003; Moncel et al. 2018b; Zanazzi et al. 2022) depicts it as a "shelter" zone during severe climatic crises making it an ideal territory for human occupation during glacial phases and for prolonged periods (as witnessed by the stratigraphic sequence of Notarchirico). Moreover, its role as the possible starting area for the recolonisation of the northern portions of Europe, together with its proximity to Sub-Saharan Africa, makes up for the Italian peninsula's crucial role within the European peopling during the Middle Pleistocene Revolution (Moncel et al. 2020d).

So far, the archaeological record features various technical responses in the lithic assemblages analysed. This includes the realisation of large-sized implements (LCTs, different types of handaxes, pebble tools etc.), a miniaturisation of the debitage products with a high rate of retouched flakes and elaborated and flexible core technologies realised through multiple types of debitage exploiting different qualities (different types of chert, limestone) and morphologies of raw materials (slabs, pebbles, nodules). The additional presence of human remains from the sites of Notarchirico (Belli et al. 1991; Pereira et al. 2015) and Isernia La Pineta (Peretto et al. 2015), attributed to *Homo heidelbergensis* contributed to enriching our vision of this region as a hot spot to explore the diffusion's pattern of new human groups over Europe, not to mention the implications concerning the modalities of the arrival/development of the Acheulean cultural complex in this continent. Thus, tracking innovations and persistent strategies among these contexts through analysing their lithic assemblages could be a valuable way to comprehend the hominin behaviour better and gain more insights into the Lower Palaeolithic.

The site of Isernia La Pineta perfectly fits into this chronological and cultural framework, recording a prolonged phase of human occupation, approximately 600 ka, during the MIS 15 interglacial and witnessing a long tradition of multidisciplinary studies (Longo 1994; Sozzi et al. 1994; Peretto 1996; Coltorti et al. 2005; Rufo et al. 2009; Vergès and Ollé, 2011; Pereira et al. 2015; Peretto et al. 2015; Lugli et al. 2017; Zanazzi et al. 2022). Its lithic assemblage belongs to the small debitage complexes (cores and flakes technology), showing the absence of LCT and bifacial tools and therefore being excluded from the classical Acheulean archetype (Gallotti and Peretto 2015; Muttillo et al. 2021). Nevertheless, complex mental templates can be highlighted in the centripetal and discoid reduction sequences alongside a massive presence of retouched flakes (Gallotti and Peretto 2015). Isernia La Pineta is also close to the site of Notarchirico (695–610 ka; Fig. 1), which was occupied during both warm and cold phases (MIS 17–16) and showed the earliest arrival of bifacial industries into this region (Moncel et al. 2020d). The lithic collection of Notarchirico has yielded handaxes, LCT, pebble tools, cores, flakes and retouched tools (Moncel et al. 2019; Santagata et al. 2020). They are all produced on local raw material, using different kinds of flint and limestone and employing different knapping strategies (i.e. centripetal, SSDA/opportunistic debitage etc.).

Furthermore, the number of open-air sites in Western Europe increased during Middle Pleistocene (Fig. 1), becoming the primary source of information for studying human behaviour through a multidisciplinary approach (Hardy et al. 2018; Pineda et al. 2020; Marinelli et al. 2021). This can raise important questions regarding the complexity and affinity of these two sites and the timing and spreading of possible behavioural innovations regardless of the presence of bifacial/LCT industries. Assessing the strategies adopted by the hominins to access carcasses and meats (scavenging/hunting; primary access or not), types of occupation (prolonged or short-term), spatial use of the area and frequentation over time represent some crucial questions that might help improve the knowledge over the role of this sites and the associated lithic industry. In light of these questions, interpreting the lithic assemblage of Isernia will take on a more specific meaning, not only concerning the chrono-cultural context (Acheulean or not, the complexity of reduction sequences etc.) but also the functional aspect of the sites attesting butchering activities.

The combined approach of lithic technology and use-wear analysis proved to be rewarding for several Lower Palaeolithic contexts (Mitchell J. C., 1998; Peretto et al. 1998; Ollé et al. 2013; Aureli et al. 2016; Hardy et al. 2018; Venditti et al. 2019). This will allow us to address the issues mentioned above and, at the same time, pursue the recent works' tradition of contextualisation of the site of Isernia La Pineta within the "Middle Pleistocene Revolution", the Acheulean paradigm and the peopling of the Italian continent during the final stages of Lower Palaeolithic (Gallotti and Peretto 2015; Moncel et al. 2018c; 2020d). Therefore, this work aims to provide new data on the unpublished materials from layers t.3a and t.3coll of Sector I combining the technological study and the use-wear analysis of the lithic industry realised on flint. The limestone industry is also the object of ongoing research by the same team, whose preliminary results will be presented.

Isernia La Pineta

The site of Isernia La Pineta is within the fluvial basin of the Upper Volturno Valley, a few kilometres outside the town of Isernia (Molise, Italy; Fig. 2). It is an extensive open-air site located at an elevation of 457 m a.s.l. and systematically excavated since 1979 by one of the authors (C. P.; Coltorti 1983; Peretto 1996; 1999). The present area of excavation comprehends Sector I (250 square meters; Fig. 2) and Sector II (90 square meters).

The site lies inside the main fluvial-lacustrine filling of the "Le Piane basin", representing the highest and, at the same time, the oldest Pleistocene sedimentological unit described in this area. The deposits, composed of a series of fluvial terraces, comprehend a sequence of fluvial, lacustrine and volcanic sediments in which lies the archaeological deposit (Coltorti et al. 2005; Peretto et al. 2015).

The stratigraphy of Isernia La Pineta from the base to the top consists of five sedimentary units (Fig. 2; Coltorti 1983; Peretto et al. 2015): Unit 5 with clayey lacustrine sediments alternated to thin levels of gravels and debris; Unit 4 is characterised by travertines deposited by the freshwater river and, on its top, by a primary pyroclastic flow, named Unit 4 T; Unit 3 is a palustrine deposit with sand and thin layers of gravels and is subdivided into three sedimentary sub-Units (U3A, U3E, U3F); Unit 2 is composed of sands and gravels as well; Unit 1 is a colluvium sequence with sand gravels attesting a pyroclastic fall and weathered by a paleosol at the top. The archaeological layers were identified in the sub-Units 3F (t.3c, t.3b, t.3a) and 3E (3coll, 3 s 1–5, 3 s 6–9) with the layers t.3c, t.3a, and 3coll being the richest in lithic and faunal remains (Fig. 2).

Single sanidine crystals were dated through the 40Ar/39Ar laser fusion method. The crystals were selected from the tephra layer U4T (585 ± 1 ka), and the fluvial units 3coll (586 ± 2 ka), 3s10 (583 ± 3 ka) and 3s6-9 (587 ± 2 ka), right above the archaeosurface t.3a (Fig. 2). The site's age has been recently set to approximately 583 ka, i.e. to the end

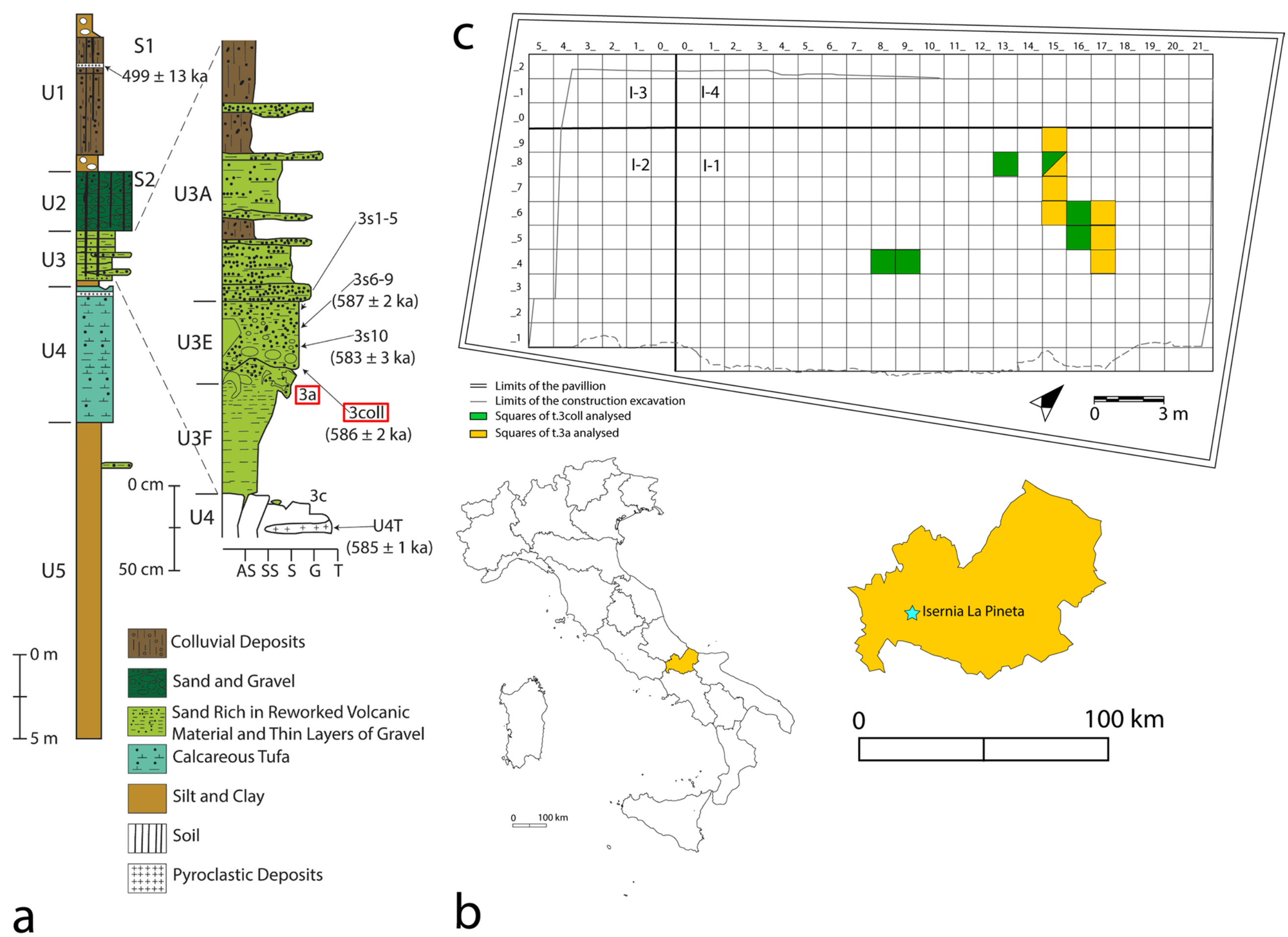


Fig. 2 **a** Stratigraphic sequence of Isernia La Pineta with the indication of the analysed layers (modified from Zanazzi et al. 2022). **b** Location of the site. **c** Excavation area of Sector I with the indication of the analysed squares (modified from Gallotti and Peretto 2015).

of interglacial 15 (MIS 15), according to new 40Ar/39Ar measurements (Peretto et al. 2015).

The faunal assemblage of Isernia La Pineta (Middle Galerian), dominated by large herbivores, suggests an open arboreal steppe environment with the fluctuating presence of ephemeral watercourse and pond (Coltorti et al. 2005). According to the available data, the climate was arider and colder than the present. The abundant faunal remains are associated with numerous lithic tools knapped in situ, exploiting local raw materials to obtain small-sized flakes (flint and limestone) and hammers (Rufo et al. 2009; limestone; Gallotti and Peretto 2015). The hominins' intensive exploitation of the herbivores' carcasses is confirmed by cut marks and intentional fresh bone fractures, pointing to systematic butchering activities over a wide area (Peretto 1996; Pineda et al. 2020). Moreover, in 2014 a human deciduous tooth (*Homo cf. heidelbergensis*) was found within layer 3coll (U3E) (Peretto et al. 2015).

The lithic industry is realised on flint and limestone, with the latter (varicoloured jaspers; Sozzi et al. 1994) being the most exploited raw material (Rufo et al. 2009; Gallotti and Peretto 2015; Rivera Peréz, 2016). The primary deposit is about 5 km from the site where the flint occurs in slabs and lenses inside the Cretaceous limestones. It was locally collected alongside the Carpino river, within the excavation area, under sub-cubic/rectangular slabs (60–100 mm) and exhibited a fine-grained texture and quality. Fracture planes are relatively common within these layers due to the intense tectonic activity recorded in this region. Moreover, given its collection alongside secondary deposits, flint underwent further tectonic breakages (along with the existing fractures) and chemical alterations during the alluvial transport.

Overall, the use of different knapping strategies for flint's reduction sequences (unipolar, centripetal, discoid etc.), some of them applied regardless of the slab shape and volume, alongside the systematic use of retouch, allowed the scientific community to reconsider Isernia La Pineta in the network of those sites witnessing a rise in complexity following the "Middle Pleistocene Revolution" (Gallotti and Peretto 2015; Moncel et al. 2018c).

The lithic industry on flint is oriented to producing morphologically non-standardised flakes of small and medium dimensions (Peretto 1999; Gallotti and Peretto 2015). Even though initially described as unstructured and opportunistic, with a negative connotation (Peretto 1994), a recent review of the lithic assemblage revealed the presence of more complex reduction sequences, suggesting the presence of a high degree of expertise and planning by the hominids (Gallotti and Peretto 2015). Extensive use of freehand percussion and bipolar on anvil technique is reported alongside a massive presence of retouched tools (Peretto 1994; Gallotti and Peretto 2015).

The limestone implements are realised on fluvial pebbles and cobbles available in situ of different morphologies and qualities. The reduction sequences, mainly conducted through unipolar-unifacial debitage, are short and aim to obtain medium-sized flakes sporadically retouched (Rufo et al. 2009; Gallotti and Peretto 2015). The bipolar on anvil technique and freehand percussion are equally attested for this raw material. The collection also identified a few chopper cores, large denticulates (Anconetani et al. 1992) and heavy-duty tool morphotypes (Barsky et al. 2018).

Material and method

The archaeological layers 3a and 3coll

This work focuses on the flint lithic material recovered from the archaeological layers t.3a and 3coll. All the coordinated flint lithic industry (> 1 cm) from layers t.3a and t.3coll of Sector I-1 was initially examined. Then six squares from the level t.3coll (84, 94, 138, 158, 166, 167) and seven squares from the level t.3a (156, 157, 158, 159, 174, 175, 176) were randomly selected and studied (Fig. 2; Table 1). The number of squares was decided to reach a reasonable number of lithic pieces statistically significant. The material from layer t.3coll comes from the 2001–2011 fieldwork, while the one from t.3a comes from the 2016–2017 fieldwork.

Both layers were extensively excavated in Sector I with t.3a in Sector II. All the material studied in this work comes from Sector I since it was more extensively excavated and better preserved. Layer t.3a is at the bottom of sub-unit 3F. It is composed of a high concentration of flint and limestone artefacts and faunal remains lying on the sand and gravel of Unit 3 and the travertines of Unit 4 (Fig. 2; Coltorti et al. 2005). The layer t.3coll (sub-unit 3E) directly lies above t.3a. It is a pyroclastic layer (debris-flow) of reworked and well-sorted elements with a thickness between 30 and 100 cm (Fig. 2). Large sanidine and pyroxene crystals occurred within this layer and were used for the new datations. Numerous lithic and faunal remains were also recovered from this unit (Peretto 1994).

Table 1 The total number of flint pieces from squares 84, 94, 138, 158, 166, and 167 for layer t.3coll and from squares 156, 157, 158, 159, 174, 175, and 176 for layer t.3a (first column) and the ones selected for use-wear analysis

Layer	Flint lithic pieces from selected squares	Selected for use-wear	Flake	Retouched flakes
t.3a	142	25	14	11
t.3coll	817	141	90	51
Total	959	166	104	62

In parallel with the detailed analysis of the siliceous material, the limestone implements from layer t.3coll are being studied and will be the object of a dedicated publication. This ongoing work will focus on unpublished material (up to 2016 fieldwork), integrating the previous work on 304 limestone pieces (Rufo et al. 2009).

Technological analysis

The t.3a and t.3coll lithic assemblages were analysed following the technological approach proposed by Inizan (1999) and Boëda (2013). The concept of *chaîne opératoire* (Leroi-Gourhan 1965; Haudricourt 2018) was applied to conceive all the phases of the flaking activity as a single process, from the raw material selection through the flake's obtainment to their abandonment. Cores were analysed to identify the technical behaviours, the volume management, the techniques used and their ascription to specific flaking methods. The relationship between the knapping surfaces was thus noted alongside their quantity and the direction of flaking employed. The presence/absence of striking platform preparation and the value angle between the knapping surface and its striking platform were also described. These latter aspects were fundamental to the interpretation of the centripetal reduction sequences for:

1) Identifying a possible hierarchisation of the surfaces
2) Assessing flaking's direction (parallel or secant) and how much it was influenced by the natural morphology of the blocks or was instead a researched feature implying the selection of specific morphologies/preparation of the surfaces

For the numbering of knapping surfaces, the terms unifacial (one single flaking surface), bifacial (two adjacent or opposite flaking surfaces) and multifacial (more than two flaking surfaces) were used (Gallotti and Peretto 2015). The terms unipolar, convergent, crossed, orthogonal, bipolar and centripetal refer to the organisation of the scars on the knapping surfaces and the dorsal face of the flakes.

For the flakes' analysis, several other attributes were considered besides the presence and position of the cortex and the butt's shape. For example, data regarding the incidence of *débordant* and plunging margin and whether this could reveal the existence of other knapping surfaces (core's edge), the position, delineation and location of retouch were recorded (Bordes 2000). The angle between the ventral face and the butt was also measured. By using the term *débordant*, we indicate the presence of a back (whether it could be natural or characterised by removals, i.e. core's edge) on the lateral face of an oriented flake. In contrast, the term plunging describes the presence of a back on the distal portion of the flake.

A total of 959 flint lithic artefacts were analysed in this work, 817 from layer t.3coll and 142 from layer t.3a, including cores, flakes, retouched tools and undetermined fragments (Table 2). The high number of undetermined pieces is due to numerous crossed and parallel fractures within the raw material (Gallotti and Peretto 2015) and the use of bipolar on-an-anvil techniques (Vergès and Ollé, 2011). These factors seemingly caused flaking incidence/unintentional breakages to be relatively common during the knapping activity.

Use-wear analysis

The flint lithic industry for the use-wear analysis was selected following two criteria: the presence of at least one useful edge (i.e. edge with an angle between 80° and 60° regardless of its length; chosen according to the criteria developed by Terradillos-Bernal and Rodríguez-Álvarez 2017) and surface preservation (the absence of marked PDSMs, i.e. post-depositional surface modifications; Levi Sala 1986). The sample comprises 166 debitage products (flakes and tools) from stratigraphic units (SU from now on) 3a (25) and 3coll (141); cores and debris were excluded.

The study began with the preliminary evaluation of the state of preservation on the selected samples to identify the different PDMS (post-depositional alterations) that affected the flint lithic industry. After this stage, each artefact was carefully washed with warm water and soap (pH 6) and then furtherly washed for 3 min in demineralised water (75%) and alcohol (25%) using an ultrasonic tank and then left to dry.

The present use-wear study combined the low-power approach (Odell and Cowan 1986) with the high-power

Table 2 Composition of the analysed lithic assemblage from the selected squares from layers t.3a and t.3coll

Categories	Layer t.3a		Layer t.3coll		Total	
	Number	%	Number	%	Number	%
Cores	7	4.9	62	7.5	69	7.2
Unretouched flakes	33	23.2	330	40.5	363	37.9
Retouched flakes	18	12.7	111	13.6	129	13.4
Undetermined fragments	84	59.2	314	38.4	398	41.5
Total	142	-	817	-	959	-

approach (Keeley 1980). The low-power approach provides information about the potential activities (e.g. cutting, scraping, piercing etc.) and identifies the hardness of the worked materials. The worked materials are then grouped into categories: soft (e.g. animal soft tissue, herbaceous plants and some tubers), medium (e.g. fresh wood and hide) and hard (e.g. bone, horn, antler, dry wood and stone). There are some materials with intermediate hardness or resistance, such as soft/medium materials (e.g. fresh hide, wet softwood) or medium/hard materials (e.g. softwood, wet antler; Semenov 1964; Tringham et al. 1974; Odell 1981; Lemorini et al. 2006; 2014). Some works (Moss 1983; Beyries 1987; Ziggiotti 2011; Berruti and Daffara 2014; Burbidge et al. 2014; Lemorini et al. 2014; Van Gijn 2014; Wilkins et al. 2015; Cruz et al. 2015; Berruti and Arzarello 2020; Berruti et al. 2020b; Daffara et al. 2021) show that the combined use of these two approaches is more effective and productive. The high-power approach studies micro-edge rounding, polishes, abrasions and striations. This study provides a more detailed understanding of the activities carried out with the lithic artefacts and supports the diagnosis of the processed materials (Keeley 1980; Ziggioti 2005; Lemorini et al. 2006; 2014; Rots 2010; Van Gijn 2014). The use-wear analysis was conducted using different microscopes: a stereoscopic microscope Seben Incognita III with magnification from 20× to 80×, a Leica EZ4 HD stereoscopic microscope with magnification from × 8 to × 40, a Microscope Camera Dinolight Am413T (for the low power approach analysis) and a metallographic microscope Optika B 600 Met supplied with oculars 10× and five objectives PLAN IOS MET (5–10-20–50-100×) (for the high-power approach analysis).

A detailed study of lithic taphonomy was completed (Burroni et al. 2002; Mazzucco et al. 2013). Based on their origin, post-depositional alterations can be divided into mechanical and chemical alterations. Several of the mechanical post-depositional alterations (PDMS) (cracks, edge crumbling, fractures and rounding of edges and ridges) are visible to the naked eye and can be analysed in detail with the help of the stereomicroscope (Levi Sala 1986; Burroni et al. 2002; Eren et al. 2011a; Mazzucco et al. 2013; Asryan et al. 2014; Lemorini et al. 2014; Asryan 2015). The bright spots (Moss 1983; Levi Sala 1986; Mazzucco et al. 2015) and the polished surfaces' study (Moss 1983; Burroni et al. 2002; Mazzucco et al. 2013) were carried out through the metallographic microscope. The chemical modifications include various degrees of patination (Van Gijn 1990b; Burroni et al. 2002; Glauberman and Thorson, 2012; Mazzucco et al. 2013; Asryan et al. 2014; Asryan 2015), primarily visible in the naked eye, but also some polished areas on the lithic surfaces better discernible at greater magnification with the stereomicroscope (Burroni et al. 2002).

Each artefact was analysed first through the low-magnification methodology and subsequently with the high-magnification methodology. First, recorded in an Access database, the post-depositional alterations, the position and the type of traces of use identified were recorded. The position of the traces identified on the surface of the findings was documented using the diagram created by Van Gijn (1989) and modified by the authors (Fig. S8).

The use-wear analysis and the taphonomic analysis were conducted using different microscopes: a stereoscopic microscope Seben Incognita III with magnification from 20× to 80×, a Leica EZ4 HD stereoscopic microscope with magnification from × 8 to × 40, a Microscope Camera Dinolight Am413T (for the low power approach analysis) and a metallographic microscope Optika B 600 Met supplied with oculars 10× and five objectives PLAN IOS MET (5–10-20–50-100×) (for the high-power approach analysis).

A reference collection with flint flakes was created to better identify the traces of use on the artefacts. The collection was created by one of the authors during the use-wear study of the archaeological site of Guado San Nicola (located a few km from the site of Isernia; Berruti et al. 2020b) in which the raw materials used for stone tools are the same attested at Isernia la Pineta (Peretto et al. 2014). Several specific activities were then completed on different materials (skinning, filleting, woodworking etc.) with the experimental lithic tools to link the use-wear features to tool motions and the processed materials (Table S1). Unretouched flakes issued from the S.S.D.A. method through the hard hammer percussion technique were also used during the experimental work. For each of them, the time of use, the direction of the gesture and the material worked were recorded. Adobe Photoshop CS6 Portable (© Adobe) software was used for image processing since it allows a single image to be built up from several photos taken, focussing on different sample heights.

Result

The technological analysis

Layer t3.coll — cores

At Isernia La Pineta, flint slabs exhibit a sub-cubic/rectangular morphology ranging between 80 and 30 mm. They show tiny portions, or complete absence, of cortex due to their massive natural breakages. Larger blocks often present a thick cortex layer alongside raw material scarcity, making them quantitatively inefficient for flaking. Fractures (visible or not) strongly affected the reduction sequences starting from the slabs' collection.

Cores were classified according to the number of knapping surfaces and their removals (Table 3). The main category is the one with a single extraction surface exploited,

Table 3 Categories of analysed cores coming from the sampled squares from layers t.3a and t.3coll

Categories	t.3a				t.3coll			
	Support				Support			
	Slab	Flake	Pebble	Total	Slab	Flake	Pebble	Total
Unifacial								
Unipolar	2	2	-	4	19	6	1	26
Orthogonal	-	-	-	-	2	1	-	3
Convergent	-	-	-	-	1	-	-	1
Bipolar	-	-	-	-	-	1	-	1
Bifacial								
Unipolar	-	2	-	2	10	2	-	11
Orthogonal	1	-	-	1	2	-	-	2
Centripetal	-	-	-	-	2	-	-	2
Bipolar	-	-	-	-	1	-	-	1
Multifacial								
Unipolar	-	-	-	-	10	-	-	10
Orthogonal	-	-	-	-	2	-	-	2
Bipolar	-	-	-	-	1	-	-	1
Total	3	4	-	7	51	10	1	62

followed by bifacial and multifacial ones (Table 3). The debitage was mainly unipolar, sometimes orthogonal, more rarely, centripetal and bipolar for all categories. The preferred support is slabs, but a conspicuous production using flakes as cores is also attested (Table 3). Slabs measure between 20 and 75 mm, while cores-on-flake are smaller and included within 15 and 50 mm (Table 4). Only one core on a pebble was recorded.

Table 4 Size (mm) of cores' support from the sampled squares from layers t.3a and t.3coll

Layer	t.3coll		t.3a	
Cores' support	Slab ($n = 51$)	Flake ($n = 10$)	Slab ($n = 3$)	Flake ($n = 4$)
Length (mm)				
Min	17	21.45	35.9	30.2
Max	74.5	52.75	44.65	50.35
Mean	37.06	31.39	41.42	37.82
St. dev	11.1	8.61	3.92	7.63
Width (mm)				
Min	15.75	17.3	22.4	33.45
Max	58.7	37.05	46.6	41
Mean	29.6	24.91	33.63	37.93
St. dev	10.04	5.81	9.95	3.15
Thickness (mm)				
Min	9.3	12.2	14	19.8
Max	50.1	22.6	30.6	26
Mean	22.95	16.33	22.83	22.9
St. dev	8.33	3.3	6.81	2.53

Cores on slabs show three main categories: (1) large cores with few removals abandoned for their scarcity of raw material or quality ($n = 16$; Fig. 3, n°1); (2) small cores, often on slabs' fragments, unifacially exploited for very short reduction sequences (even for a single removal), and still preserving natural surfaces ($n = 20$; Fig. 3, n°3; Fig. S1, n°3); (3) cores attesting prolonged flaking, occasionally involving other faces and partially altering the original volume/morphology of the slab ($n = 16$; Fig. 3, n. 2; Fig. S1, n°1, 2). Overall, the raw material quality of these cores ranges from poor, for the first category, to average/good for the rest, while the fine-grained flint, attested by several flakes, seems to be nearly absent on the sample selected. The recorded striking platforms on the cores on slabs are mainly natural (33) and flat (17), showing little evidence of preparation. Unifacial cores are primarily associated with natural striking platforms, while bifacial and multifacial cores exhibit a balance between natural and flat. Flat striking platforms are due to cores rotation but might also indicate the research for more suitable knapping angles. Overall, the angle of flaking is attested by a mean value of 78°. The vast majority of the cores still preserve several natural surfaces associated with various portions of the cortex (Fig. 3, n°1, 3).

Cores on flakes are obtained on small flakes (Table 4; Fig. S1, n°4, 5). Just one core on a bigger flake was recorded from this layer. It exhibits a lower quality of the raw material and presents a single removal overlapped by several smaller hinged ones. The reduction sequences show a mean of three removals (Fig. S1, n 4, 5). The cores are knapped unifacially and mainly through unipolar debitage. The ventral face is often the striking platform, while the dorsal face is

Fig. 3 Flint cores from analysed squares from layer t.3coll. 1, bifacial core with unipolar removals; 2, discoidal core; 3, unifacial core with a single removal

the knapping surface. The mean value of the flaking angle is 60°.

Layer t.3a — cores

Seven cores were recorded from layer t.3a, three realised on slabs and four on flake (Table 3; Fig. S2). The debitage is mainly unipolar (Fig. S2, *n*°3), with only one core orthogonally exploited, and is usually conducted on one or two surfaces of the cores. Their size is between 50 and 15 mm for both slabs and cores-on-flakes (Table 4).

Flat striking platforms, attested on two cores on slabs, result from the slabs' opening or the cores' rotation. Larger dimension cores are abandoned at an early stage of flaking due to the quality of the raw material (Fig. 2, *n*. 3), while others of smaller sizes are selected for 1–2 removals (Fig. 3, *n*. 1, 6, 7). The angle of flaking is orthogonal in the core, attesting unipolar debitage, while it measures 70° in the one with orthogonal removals. The absence of cortex is reported for all samples except for one testifying a thin layer in the upper and lower face of the slab.

The four cores-on-flake, all recording unipolar debitage, use the ventral face as the striking platform (with a mean angle of 70°), taking advantage of the convexity on the dorsal face for the production of flakes (Fig. S2, *n*°1, 2). On one of the bifacial cores, the inversion between the knapping surface and the striking platform was performed, while semi-tournant exploitation was recorded on one of the unifacial cores (Fig. S2, *n*°3). Four removals per core were observed except the largest one, an opening flake of a large nodule of poor quality presenting one single removal.

Layer t.3coll — flakes

Unretouched flakes from layer t.3coll are 330, accounting for 40% of the entire layer (Table 2). Their morphology is roughly quadrangular, slightly longer than large (Table 5; Fig. 4). The presence of a backed margin, whether it is *débordant* (31%), plunging (11%), *débordant* and plunging (10%), or on all sides (2%), is quite frequent. An additional knapping surface was recorded on 25% of these backed margins. The incidence of a backed margin opposite to a cutting edge, lateral or distal, was also quite common (Fig. 4, *n*. 2, 3, 7, 11).

The absence of cortex was recorded on 82% of the flakes. Striking platforms mainly exhibit exploitation of natural (40.6%) and flat (37%) surfaces followed by cortical (6%), dihedral (3%), linear (3%), facetted (1%; *n* = 4) and punctiform (1%; *n* = 4). The butts fractured during knapping are relatively low (5%). All striking platforms present a mean angle of 100°, including within a range of 70° and 130°.

Table 5 Size (mm) of unretouched and retouched flakes from selected squares from layers t.3a and t.3coll

Layer	t.3coll		t.3a	
Flakes	Unretouched	Retouched	Unretouched	Retouched
Length (mm)				
Min	10.7	11.55	14.55	14.7
Max	49.35	67.25	46.1	60.8
Mean	23.8	28.79	25.85	31.07
St. dev	7.64	9.21	7.46	13.92
Width (mm)				
Min	5.75	11.2	13.35	20.2
Max	41.95	62.95	40.5	52.45
Mean	20.98	25.34	20.51	28.99
St. dev	6.59	8.84	6.25	9.75
Thickness (mm)				
Min	2.6	4.6	4.85	5
Max	25.2	33.2	17.1	27.8
Mean	9.54	11.66	9.94	13.31
St. dev	3.86	4.83	3.24	6.4

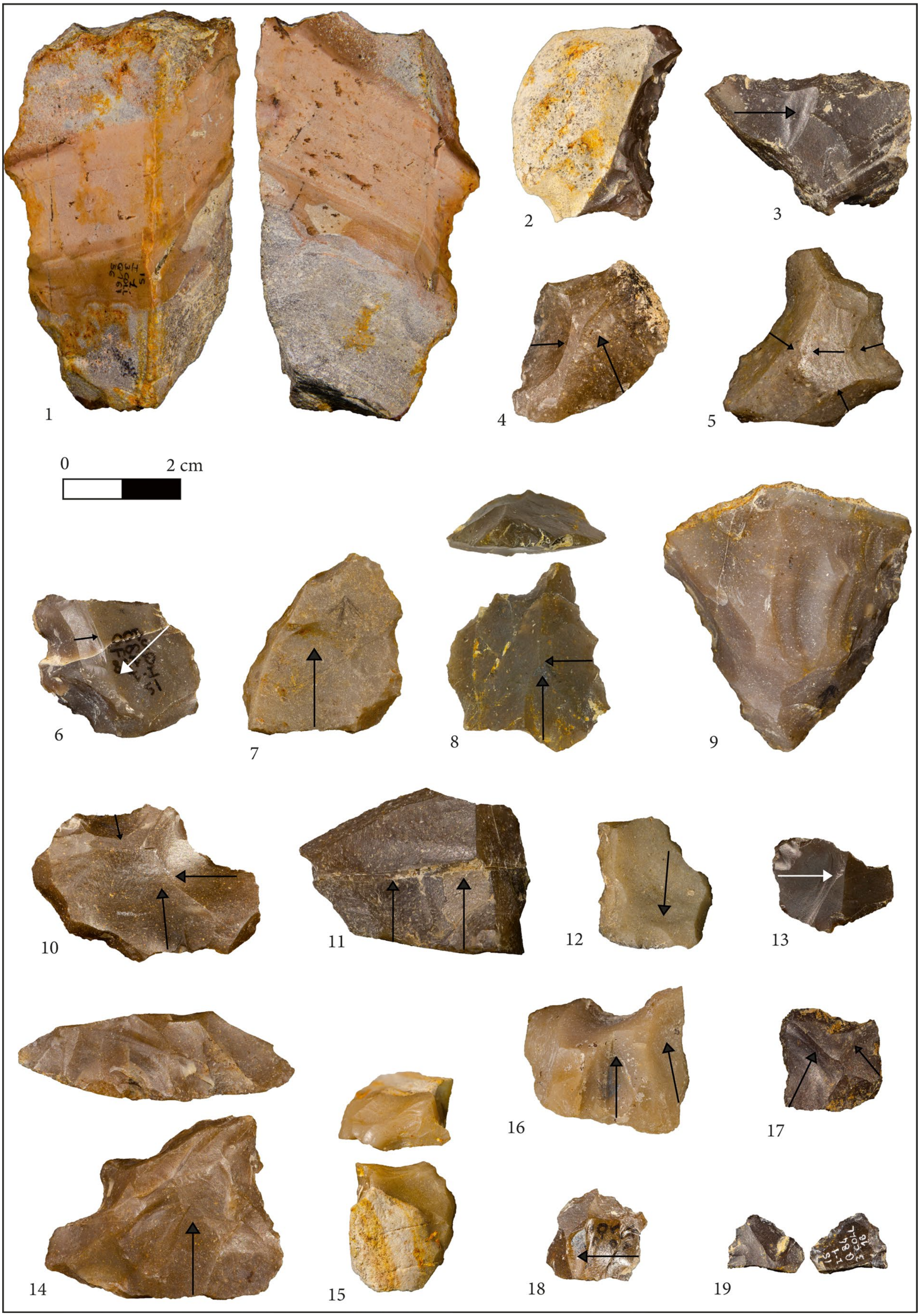
The organisation of the removals display a preferential use of unipolar debitage alternated with an orthogonal one (Fig. 4; *n*° 3, 7, 8, 11, 13, 14, 16, 18). Flakes without negatives on the dorsal face represent the largest group (27%), highlighting the massive usage of natural surfaces throughout the flaking process. They are followed by unipolar (23.3%), orthogonal (18%), convergent (14.6%), bipolar (8%), centripetal (4%) and crossed (4%). The evidence for a Kombewa debitage was found only on 4% (*n* = 13) of all flakes.

Layer t.3coll — retouched flakes

Retouched flakes represent 13.6% of the sample from this layer (Table 2; Fig. 4, *n*°1–3, 6, 8, 9, 12, 14–16, 19). Their dimensional values are more significant than the unretouched pieces (Table 5; Fig. 4, *n*°1). The extension of the retouch is mainly marginal, followed by abrupt and invasive and is usually located on the longest margin of the flakes (the lateral one). However, edge modification of the distal and proximal side is also witnessed within the assemblage (Table 6). The angle of retouch has a mean value of 62° when it is marginal or invasive and 74° when it is abrupt. Tools are retouched on the dorsal face for most cases, even if alternated, and inverse retouches are also attested (Table 6). Concerning tools-typology (Bordes 2000), scrapers are the most common ones (Fig. 4, *n*°1, 3, 9, 12, 19) followed by denticulates (Fig. 4, *n*°2, 6 14) and notches (Table 6; Fig. 4, *n*°8, 16). Then, some composite tools are witnessed, including beaks and points, sometimes combined with scrapers, notches and denticulates (Fig. 4, *n*°8, 15, 16). Scrapers are usually marginally retouched on one side (simple scrapers; Fig. 4, *n*°1, 3) or, more rarely, on two (double and convergent scrapers; Fig. 4, *n*°9, 12). The double-scrapers present a convex delineation of the retouch, usually applied on the lateral and distal margins. The same pattern is witnessed for denticulates, simple and double (Table 6).

Layer t.3a — flakes

From layer t.3a, 33 unretouched flakes were analysed (Table 2; Fig. S3). The dimensional values show quadrangular flakes, slightly longer than larger, comprised between 25 mm in their length and 20 mm in their width (Table 5). The presence of backed margins was recorded on 21 artefacts: 13 *débordant* flakes (Fig. S3, *n*°3, 8) four plungings (Fig. S3, *n*°9), three *débordant* and plunging and one *débordant* on all sides. Only two flakes attested an additional knapping surface on their backed margin (i.e. core's edge). Portions of the cortex were recorded only on seven flakes, usually located on the lateral and distal margins. The analysis of striking platforms shows a preferential use of natural (10) and flat (9) butts, followed by cortical (2) and dihedral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◂**Fig. 4** Flakes and retouched flakes from selected squares from layer t.3coll. 1, Scraper on large flake; 2, denticulate on cortical backed flake; 3, scraper on debordant flake; 4, 5, 10, flakes with centripetal removals; 6, denticulate on flake; 7, debordant flake with unipolar removal; 8, point and notch on a flake with orthogonal removals; 9, convergent scraper with abrupt retouch; 11, debordant flake with unipolar removals; 12, double scraper on flake with bipolar removal; 13, small-sized flake with orthogonal removal; 14, denticulate on flake with unipolar removal; 15, retouched pointed flake; 16, notch and point on flake with unipolar removals; 17, small flake with convergent removals; 18, small flake with orthogonal removal; 19, scraper on small flake

(2). The absence of dihedral, facetted, linear and punctiform ones is reported. Only two fractured butts were found. All striking platforms display a mean angle of 98.5°, including within a range of 86° and 113°. The majority of flakes show either the absence of removals (11; Fig. S3, *n*°1, 6, 8) or unipolar removals (8; Fig. S3, *n*°5), and then orthogonal (4; Fig. S3, *n*°2, 3, 7, 10), convergent (3; Fig. S3, *n*°9), bipolar (2) and crossed (1) removals are almost equally attested within the record, though an absence of centripetal ones was noted. Evidence for Kombewa debitage was reported only on one fragmented piece.

Layer t.3a — retouched flakes

Eighteen retouched flakes were analysed from this layer (Table 2; Fig. S3, *n*°1–4, 6–8). Larger supports have been selected for the retouch, as shown in the dimensional value (Table 5). The retouch is almost exclusively marginal, followed by invasive and abrupt; it is mainly located on the dorsal face and, more rarely, on the ventral (Fig. S3, *n*°1, 6) or both sides (Table 6). Slight preferential use of lateral margin for edge modification was also observed, though the distal part, or even both, are equally retouched. The angle of retouch associated with marginal retouch has a mean value of 61°, while the single abrupt retouch exhibits an edge inclination of 71°. Scrapers (Fig. S3, *n*°1–3, 6) are this layer's most common tool typology, followed by denticulates (Fig. S3, *n*°4, 7, 8) and notches. Scrapers are primarily retouched on one margin, but double and convergent scrapers exist, while notches and denticulates are realised on one side only. Only one composite tool (notch + scraper) is present (Table 5).

Layer t.3coll — limestone

The limestone material from layer t.3coll comprised 748 (Table 7; Fig. S4) pieces and was classified into structural categories (Leakey 1971; Clark and Kleindienst 1974; Chavaillon and Chavaillon 1976; Isaac 1977; Chavaillon 1979; Bordes 2000; Barsky et al. 2015). Most of the collection includes whole non-flaked pebbles and cobbles of different volumes and morphologies, among which 11 percussors were identified (Table 7; Fig. S4, *n*°a). The knapped pieces comprise several morphotypes such as denticulates, heavy-duty scrapers and chopper-like (13%). The ratio between flakes and cores suggests less intensive raw material exploitation than flint. Retouched flakes are rare, consisting of only 6% of all flakes.

Use-wear analysis

Taphonomic analysis result

Most of the selected lithic pieces did not show evident post-depositional alterations, even with the naked eye. Thanks to the microscopic analysis, it was possible to highlight how in some cases, the post-positional tares affected even 90% of the analysed finds (Table 8; Fig. S5). In any case, the selection made in the study's first phase made it possible not to exclude any element from the study.

The taphonomic analysis confirms that the two SU (stratigraphic units) display few differences in the state of preservation (Arzarello and Peretto 2006; Pineda et al. 2020). As noted in the past technological analysis of the lithic industry, the geomorphological analysis and the spatial analysis, the two SU have suffered various post-depositional alteration processes (Arzarello and Peretto 2006; Channarayapatna et al. 2018; Pineda et al. 2020). All 166 flint lithic remains analysed show at least one post-depositional alteration (with various degrees of development; Table 8). The microscopic analysis identifies these alterations: polishing, edge crumbling, deposition of concretion and different patinas (white and Fe–Mn; Fig. S5). Rounding of the surfaces can be attributed to the transport of the lithic industry in the sediment (like a debris flow); edge crumbling can be due to the same phenomenon or to a trampling activity. Although not significantly developed, white patina testifies to alkaline and wet deposition conditions (Dove and Nix 1997; Dove et al. 2008; Glauberman and Thorson 2012). The presence of rare spots of Fe–Mn patina is ascribable to the decomposition of organic materials due to bacteria (Marín-Arroyo et al. 2014). Concretion deposition refers to a deposit of a solid mass, usually composed of inorganic material (also mineral matter). It is typical of sedimentary rocks, especially siliceous ones (Mangado 2004).

Use-wear analysis result

The use-wear analysis of the flint lithic assemblage identified 68 artefacts with traces of use: 8 belonged to SU 3a and 60 to SU 3coll (Fig. 6, 7 S6 and S7). The use-wear analysis of the artefacts belonging to SU 3a allowed identifying eight flakes with wear traces (Table 9). Among them, three artefacts show two zones of use (ZU). In

Table 6 Categories of tools with the position (D = direct, I = inverse) and extension (M = marginal, A = abrupt, I = invasive) of retouch from selected squares from layers t.3a and t.3coll. Values in bold indicate the total number of pieces from layers t.3coll and t.3a

Layer	t.3coll							t.3a							
		Position			Extension				Position			Extension			
Type	n	D	I	D+I	M	A	I	N°	D	I	D+I	M	A	I	Total
Beak	**2**	1	-	1	1	-	1	**-**	-	-	-	-	-	-	**2**
Denticulate simple	**21**	17	4	-	11	5	5	**5**	3	2	-	5	-	-	**26**
Denticulate double	**4**	3	-	1	2	1	1	**-**	-	-	-	-	-	-	**4**
Denticulate and beak	**1**	1	-	-	1	-	-	**-**	-	-	-	-	-	-	**1**
Notch (single)	**14**	12	1	1	-	-	-	**2**	2	-	-	-	-	-	**15**
Notch and point	**1**	-	1	-	1	-	-		-	-	-	-	-	-	**1**
Notch and scraper	**4**	3	-	1	2	2	-	**1**	-	-	1	1	-	-	**5**
Point	**1**	1	-	-	1	-	-	**-**	-	-	-	-	-	-	**1**
Point and scraper	**1**	1	-	-	-	1	-	**-**	-	-	-	-	-	-	**1**
Scraper simple	**48**	31	10	7	34	12	2	**6**	6	-	-	5	1	-	**54**
Scraper double	**10**	5	-	5	4	5	1	**2**	1	-	1	1	-	1	**12**
Scraper convergent	**4**	3	-	1	1	1	2	**2**	2	-	-	1	-	1	**6**
Total	**111**	**78**	**16**	**17**	**58**	**27**	**12**	**18**	**14**	**2**	**2**	**13**	**1**	**2**	**128**

SU 3coll, 63 use-wear traces referable to 60 flakes were found (Table 10). Three of them have two different ZU: two flakes show the same type of traces on both the ZU and one has two different ZU, referable to different types of traces. Of the 68 artefacts with wear traces identified, 31 are retouched (Tables 11 and 12); 4 are from SU 3a (two denticulates and two sidescrapers), and 27 are from SU 3coll (8 denticulates; 16 sidescrapers, two beaks and one notch).

The identification of use-wear traces and their interpretation is based on the experimental activity conducted by Berruti et al., (2020b) and on the description presented by Anderson (1990) (1990), Lemorini et al., (1997, 2006), Hardy (2004), Palmqvist et al., (2005), Claud et al., (2012), Zupancich (2016), Berruti et al., (2020b) and Beyries (2020).

The traces recorded on the Isernia la Pienta flint lithic assemblage can primarily refer to the processing of animal resources. The low-power approach identified a clear predominance of edge removals for processing soft and medium-soft materials. Many traces have been identified linked to a longitudinal action on soft or medium-soft material: small, diagonally oriented edge-removals. During this stage of the analysis have also been recognized traces linked to the longitudinal or transversal action on medium-soft or medium-hard material: big overlapping edge removals with a mixed orientation, diagonal and perpendicular (in many cases associated with edge rounding). During the analysis with the high-power approach, typical polishes of the processes of these materials were identified: hide (edge rounding associated pitted polish), fresh bone (smooth and flat spots of polish), soft animal tissue (lines and band of rough

Table 7 Structural categories of the limestone material from layer t.3coll. *Whole non-flaked pieces are included in the limestone study to determine any (qualitative and morphological) anthropic selective processes (Titton et al. 2018; 2021)

	Categories	Layer t.3coll			
		N	%	*N*	%
Non-modified	*Whole, non-flaked pebbles and cobbles	363	48.5	374	50
	Percussion instrument	11	1.5		
Knapped pieces	Cores	113	15.1	130	17.4
	Retouched cores (denticulate morphology)	7	0.9		
	Loosely configured tools (heavy-duty scraper morphotype)	8	1.1		
	Chopper-like cores	2	0.3		
Flakes	Flakes (unretouched)	115	15.4	122	16.3
	Flake-tools	7	0.9		
Fragments	Broken pebbles and cobbles	3	0.4	122	16.3
	Pebbles and cobble fragments	119	15.9		
Total		748	100	748	100

Table 8 PDMS identified in the lithic industry studied from selected squares from layers t.3coll and t.3a

PDMS	t.3coll (*n* = 141)		t.3a (*n* = 25)		Total (*n* = 166)	
	n	%	*n*	%	*n*	%
Rounding	126	89	24	96	150	90
Edge crumbling	102	72	23	92	125	75
Fe-Ma patina	68	48	14	56	82	49
White patina	19	13	8	32	27	16
Concretion	92	65	15	60	107	64

polish), butchering (usually are a mix of all the other traces individuated) and also indeterminate traces of polish (Fig. 6, 7 S6 and S7).

Tables 9 and 10 show that the identified traces correspond to activities linked to animal carcass processing: butchering, hide, fresh bone and soft animal tissue working. The hardness of the worked materials deduced by the analysis with the low power approach shows a clear predominance of soft and medium-soft materials (Tables 9 and 10).

Discussion

Lithic technology

The site of Isernia is characterised by the exploitation of locally collected rectangular flint slabs ranging between 30 and 80 mm for length/width and 10–35 mm for thickness. These slabs were available within the site as their abundance is reported within the entire archaeological sequence (Peretto 1994; Gallotti and Peretto 2015; Channarayapatna et al. 2018). The massive fractures and the raw material scarcity on larger blocks determined a systematic optimisation of surfaces and volumes during knapping. The rare evidence for fractures and impurities on flakes confirms an efficient raw material selection and reduction processes, while the non-predominant presence of cortex on flakes and cores suggests that hominids selected already broken slabs of small dimensions.

The raw material constraints determined several approaches for flakes' production and cores' management. Direct percussions by hard hammer and bipolar on anvil technique were equally employed (Peretto 1994; Gallotti and Peretto 2015). Even if the latter's identification could be difficult and sometimes produce the same outcome as the former (Jeske and Lurie 1993; Donnart et al. 2009; Bietti et al. 2010; Moyano et al. 2011; Vergès and Ollé, 2011; Eren et al. 2013; Peña, 2015; Shott and Tostevin 2015; Pargeter and Eren 2017; Sánchez-Yustos et al. 2017), these techniques were applied according to raw material morphology and quality. For instance, more cubic slabs without proper convexities could require the bipolar on anvil technique to initialise the flaking activity (Moyano et al. 2011; de Lombera-Hermida et al. 2016). This allowed the check for internal impurities other than producing smaller blocks, eventually knapped through freehand percussion and larger flakes to be retouched later. The bipolar on anvil technique proved to be vastly employed in older sites to overcome the raw materials' quality and volumes and obtain specific products in a controlled way (Barsky 2013; de Lombera-Hermida et al. 2016; Gallotti et al. 2020).

When better convexities existed, direct percussion by a hard hammer was applied right from the start. Given the small dimension of end-products and some cores, both techniques could have been applied on the same core at different stages. In this case, using an anvil might have eased the core handling (Hiscock 2015). The particular hardness (in terms of resistance to fracture) of the raw material of Isernia La Pineta (Crovetto et al. 1994; Peretto 1994; 1999) must also be considered since the requirement for significant strength in the technical gesture could be a requirement have been facilitated by the presence of an anvil. Fractured butts are

Table 9 Use-wear traces on selected squares from layer t.3a lithic industry, grouped by action, method of débitage and worked material. Values in bold indicate the total number of pieces with traces detected for each technique

Material	Bipolar on anvil			Freehand percussion			Tot
	Tran. Act	*Long. Act*	*Mix*	*Tran. Act*	*Long. Act*	*Mix*	
Soft animal tissue					1		1
Butchering				1			1
Soft		2			2		4
Medium soft				1			2
Medium hard				2	1		3
Tot	**0**	**2**	**0**			**0**	10
Tot. for technique	**2**			**8**			

Table 10 Use-wear traces on selected squares from layer t.3coll lithic industry, grouped by action, method of débitage and worked material. Values in bold indicate the total number of pieces with traces for each technique

Material	Bipolar on anvil			Freehand percussion				Tot
	Tran. Act	*Long. Act*	*Mix*	*Tran. Act*	*Long. Act*	*Drill*	*Indet*	
Soft animal tissue		1		1	1			3
Butchering	1			2	4			7
Fresh skin				1		1		2
Fresh Bone				1				1
Soft				2	19			21
Medium soft		1		7	11		1	20
Medium hard				8			1	9
Tot	**1**	**2**	**0**	**23**	**35**	**1**	**2**	63
Tot. for technique	**3**			**60**				

relatively low, though crushing marks on the edge of the platforms, sometimes associated with internal fractures, can be globally observed, pointing to the evidence of repeated impacts. Moreover, the knapping angle (100°) suggests the exploitation of wide and open surfaces. This aspect and the flakes' thickness, often coinciding with the butt's thickness, may confirm the need for inner, possibly stronger, blows to obtain flakes.

Two main strategies were identified (Fig. 5) to manipulate slabs' volumes: (a) the most prominent and flattest surface was knapped through a peripherical striking platform; (b) volumetric exploitation, i.e. semitournant, of the most convex faces from a single striking platform was performed.

In the first case, orthogonal debitage was preferred, possibly leading to a centripetal one (Fig. S1, *n*° 3; Fig. 5). The striking platforms were mainly natural, taking advantage of the natural angles of the slabs without cortex. Opening one or more striking platforms was occasionally required through single removals when the angle between the surfaces was too orthogonal. The direction of flaking was often parallel to the knapping surface, exploiting wide angles (> 100°) and thus obtaining flakes with a constant thickness along their length. The lateral and distal convexities management happened simultaneously with the flaking activity and was usually achieved with orthogonal/bipolar debitage alongside plunging and *débordant* flakes. Reduction sequences were not particularly long, even though the organisation and the number of the removals on flakes suggest the presence of debitage carried on regardless of the slabs' natural shape (Fig. 4, n°5, 10; Fig. S3, n°2).

In the second case, more prominent convexities were favoured on cubic-shaped slabs over flatter surfaces as knapping surfaces (Fig. 5). The debitage was mainly unipolar or convergent, exploiting one slab's face and potentially becoming semitournant (Fig. S1, *n*°2; Fig. S2, *n*°3). The direction of flaking was secant to the knapping surface, given its more pronounced convexity. Consequently, flakes are thicker in the proximal part and thinner in the distal one. The preparation of striking platforms is primarily achieved through single removals, even though natural ones are also frequently used. Usually, only one generation of removals is attested, confirming the deliberate exploitation of natural convexities.

This latter strategy might generate a discoid conception of the volumes (Fig. 3, *n*°2; Fig. S1, *n*°1), already attested in layer t.3c (Gallotti and Peretto 2015) and considered an innovative feature for the Middle Pleistocene transition, as also witnessed in the sites of Notarchirico (Moncel et al. 2020d), Atapuerca (Ollé et al. 2013), Caune de l'Arago (Barsky 2013) and La Noira (Stratum a; Moncel et al. 2020a), simultaneously to the general increase of centripetal productions observed in the sites of Moulin Quignon (Antoine et al. 2019), Atapuerca (Ollé et al. 2013) and Boxgrove (Roberts and Parfitt 1999). The site of Isernia exhibits several technological affinities with the mentioned sites, providing evidence for centripetal and discoid productions, fitting at the same time the "innovations package" supposedly introduced with the Acheulean after MIS 19 but lacking bifacial tools and LCT (Gallotti and Peretto 2015; Moncel and Ashton 2018; Moncel et al. 2018c).

In both layers analysed, unifacial debitage is the most attested strategy. The limited presence of bifacial and multifacial cores is due to the raw material constraints rather than a lack of complexity of the entire assemblage. They either result from single unifacial events occurring at the end of reduction sequences or testify to the opening of striking

Table 11 Zones of use with use-wear traces from selected squares from layer t.3a lithic tools, grouped by action, typology and worked material (four lithic remains four zones of use). Values in bold indicate the total number of retouched pieces with traces

Material	Denticulates		Sidescrapers		Tot
	Tran. act	*Long. act*	*Tran. act*	*Long. act*	
Soft		1			1
Medium soft				1	1
Medium hard	1		1		2
Hard					0
Tot	**1**	**1**	**1**	**1**	4

Table 12 Zones of use with Use-wear traces from selected squares from layer t.3coll lithic tools, grouped by action, typology and worked material (27 lithic artefacts, 30 zones of use). Values in bold indicate the total number of retouched pieces with traces

Material	Denticulates			Sidescrapers		Notches		Beaks		Tot
	Tran. act	*Long. act*	*Mix*	*Tran. act*	*Long. act*	*Long. act*	*Tran. act*	*Long. act*	*Drilling*	
Butchering	1				2	1				4
Hide	1								1	2
Soft animal tissue					1					1
Fresh bone	1									1
Indet pol			1							1
Soft	1	1			1					3
Medium soft	1	3		5	4			1		14
Medium hard				4						4
Tot	**5**	**4**	**1**	**9**	**7**	**1**	**0**	**1**	**1**	30
Tot. for typology	**10**			**17**		**1**		**2**		**30**

platforms to optimise unifacial debitage. The incidence of plunging and *débordant* flakes reveals that knapping surfaces and cores were not remarkably large but still efficiently exploited according to the existing natural arrises to manage the cores' convexities. This might suggest that the need for specific convexities/angles, regardless of the slabs' shape, was seemingly a researched feature within the reduction sequences. These technical expedients proved to be also employed in the coeval Acheulean sites of Moulin Quignon (Antoine et al. 2019) and La Noira (Moncel et al. 2021), especially on centripetal cores.

Besides this, a tendency to exploit cores *expediently* was also identified. Small and, in a minor portion, big cores selected for just one or two removals, even of lower-quality raw material, highlights that the need to produce small functional flakes was the cornerstone of the entire production, as witnessed in other sites associated with animal carcasses exploitation (Mosquera et al. 2015; Aureli et al. 2016; Moncel et al. 2021).

The significant number of recorded core-on-flakes might be a technical expedient to enhance the blocks' volume to obtain small flakes and overcome the presence of cortex and fractures. The removals' dimensions fit the size of the small flakes attested in the rest of the site. However, six cores share some similarities with retouched tools if their size and the presence of functional cutting edges (<75°) are considered (Fig. S1, *n*°4, 5; Fig. S2, *n*°2). Since we are dealing with a lithic assemblage that produces mainly small flakes, can we correctly distinguish between passive supports (i.e. core) and active ones (i.e. flake/tool)? It is plausible that, given the great flexibility that characterises this lithic industry and its production goals, the boundary between the concept of *debitage* and *façonnage* was subtle and functional to the hominins' necessities. From this point of view, similar behaviours were found at the sites of Ficoncella (Aureli et al. 2016) and Soucy 3 (Lhomme 2007), where a "circularity" of the reduction sequences was reported.

Larger supports were selected for the retouch. The original morphology of flakes was not profoundly altered, even though a substantial modification of the margins was performed to obtain specific shapes (points and scrapers), showing great flexibility and a high level of expertise. Edge modification was applied on all flakes regardless of their characteristics and shapes to get a wide variety of tools, suggesting various functions and usage. Scrapers, denticulates and notches are the most attested tools recalling a pattern seen in other butchery sites of the Middle Pleistocene (Ollé et al. 2013; Aureli et al. 2016; Hérisson et al. 2016; Moncel et al. 2020a; 2020d). However, in Isernia's case, the retouched implementation rate seems much more relevant and comparable with the Acheulean sites of La Noira and Notarchirico, where the presence of points and convergent tools was also reported (Moncel et al. 2020a; 2020d).

Overall, the flint industry of Isernia is characterised by a miniaturisation of the end products and the supports, showing small dimensional values (Fig. 4, *n*°13, 15, 17–19; Fig. S1, *n*°1–5; Fig. S2, *n*°1–3; Fig. S3, *n*°5–10). This is undoubtedly due to the raw material constraints, which the hominins efficiently overcame, highlighting a high level of expertise and producing a sophisticated range of flakes and tools through numerous technical expedients. The Italian peninsula shows an interesting pattern of "miniaturised" lithic production throughout the Middle Pleistocene (Abruzzese et al. 2016; Aureli et al. 2016; Arnaud et al. 2017; Grimaldi et al. 2020; Moncel et al. 2020d). The sites of Notarchirico, Ficoncella, Atella, Guado San Nicola and Fontana Ranuccio all share this feature, especially when flint-realised implements are considered. This pattern may undeniably originate from the available raw materials exploited but also resulted in similar methodological and

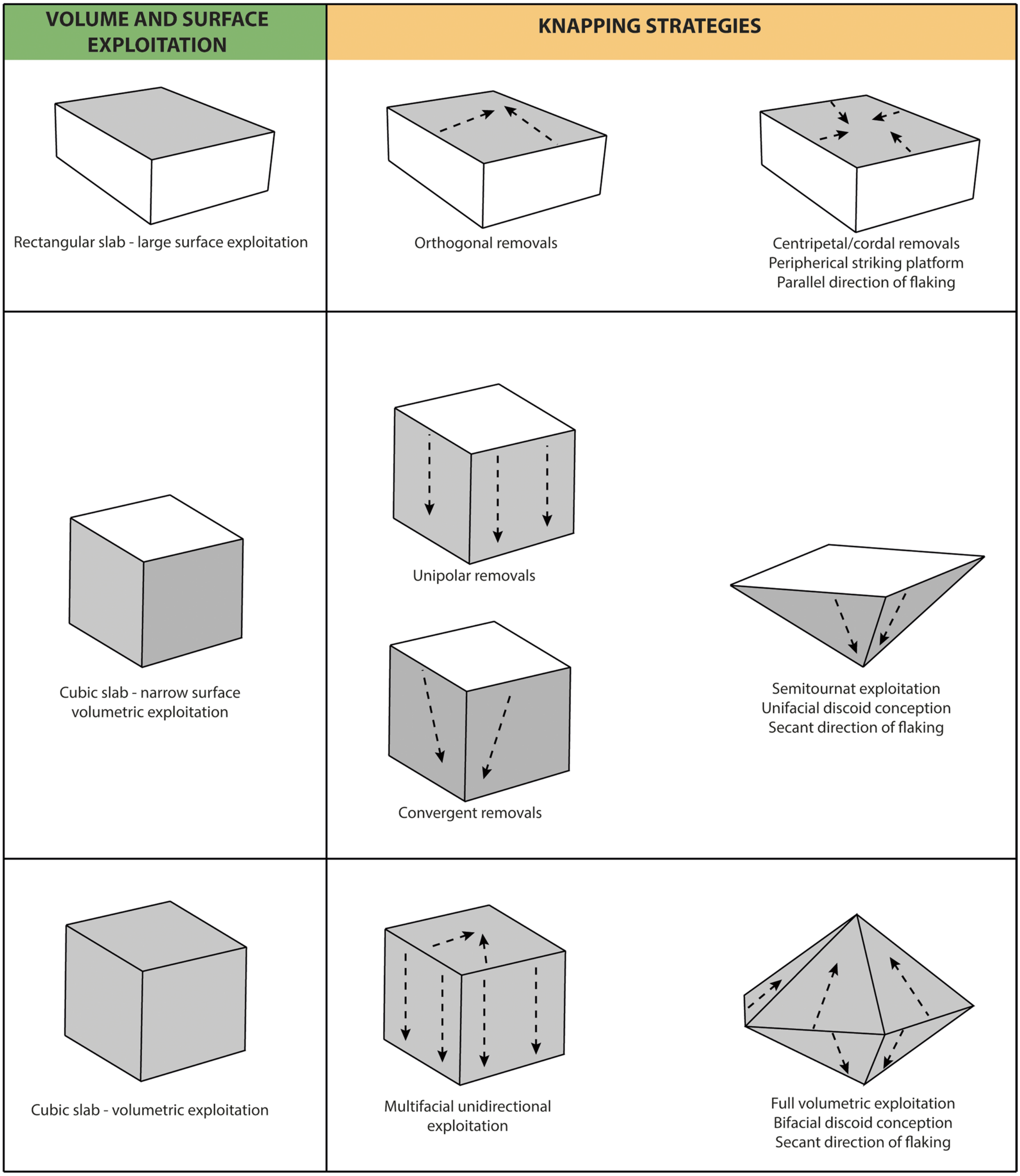


Fig. 5 Diacritic schemes of the knapping strategies documented for layers t.3coll and t.3a at the site of Isernia La Pineta. Drawings and graphic elaboration by M. Carpentieri

technical responses (i.e. the previously mentioned ambivalence between debitage and faconnage, cores-on-flakes, tool-core etc.) that could indicate the possible emergence of a common — possibly cultural? — substratum, as will happen with the Middle Palaeolithic transition (Moncel et al. 2016; 2020c; 2021; Davis and Ashton 2019).

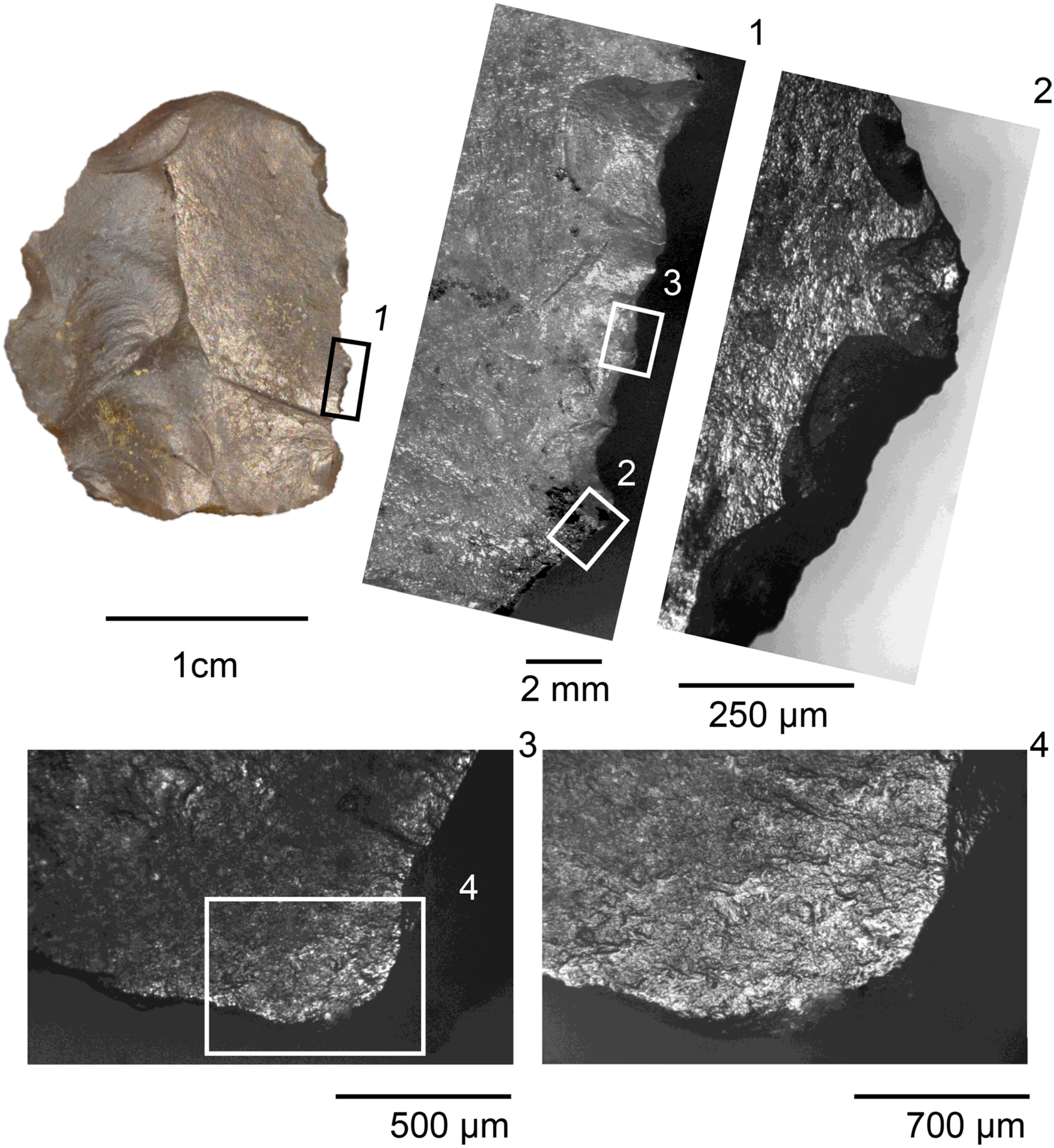
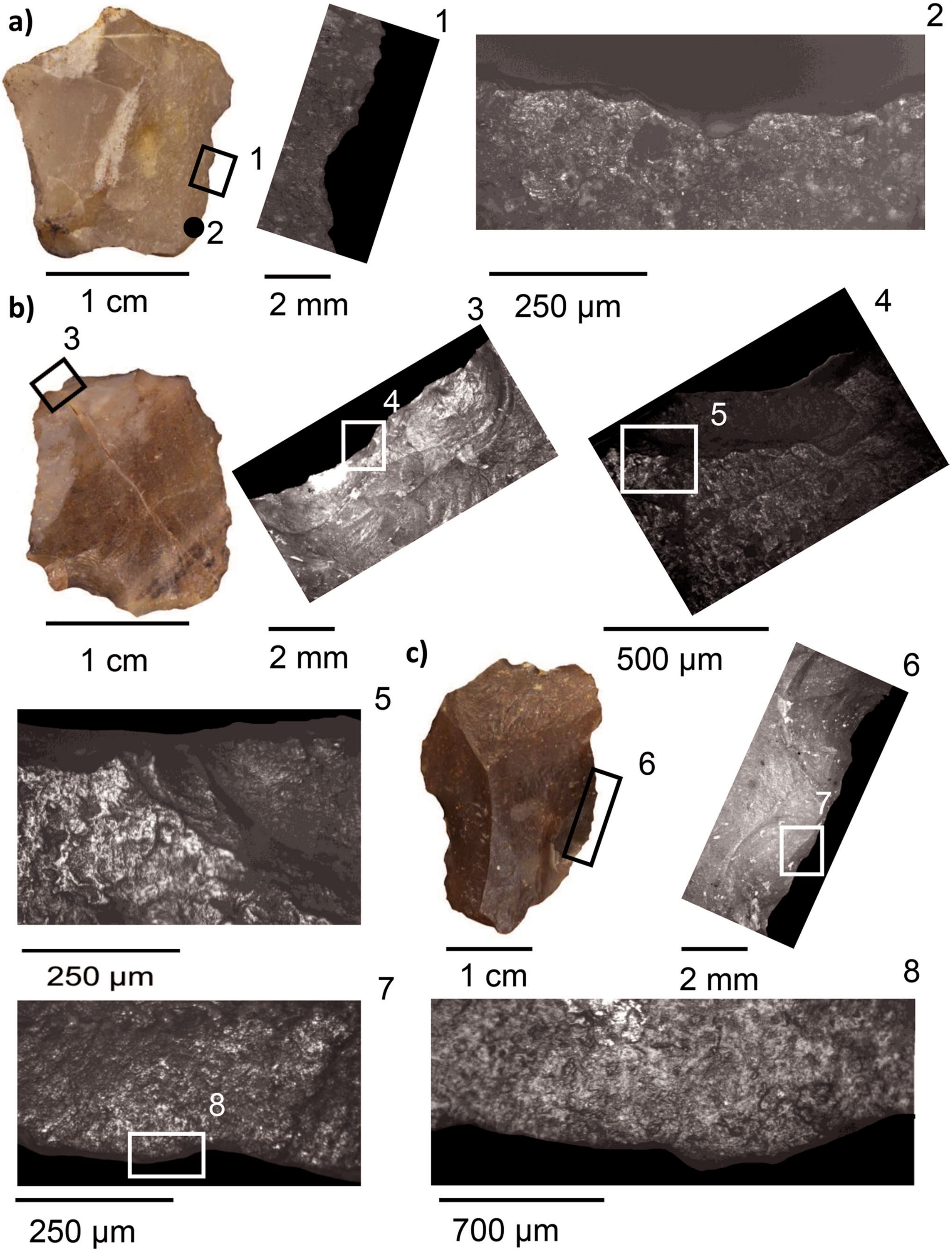


Fig. 6 Use-wear traces on Isernia la Pineta flint flake 157 18 3a with traces interpreted as the result of longitudinal activity on medium soft animal tissue: crescent shape, diagonally oriented edge-removals (1) with a band of rough polish (fleshy tissues) (2, 3 and 4); the identification of use-wear traces and their interpretation is based on the experimental activity conducted by G. L. F. Berruti (2020b) and on the description of use-wear traces presented for example by Anderson (1990), Lemorini et al. (1997; 2006; 2016), Hardy (2004), Palmqvist et al. (2005), Claud et al. (2012), Berruti et al. (2020ab) and Beyries, (2020)

Use-wear analysis and taphonomy

Use-wear studies have already been successful for Lower Pleistocene contexts in Africa: Koobi Fora (1.5 Ma; Keeley and Toth 1981), Kanjera South (2.0 Ma; Lemorini et al. 2014), El-Kherba (1.8 Ma; Sahnouni et al. 2013), Peninj (1.5 Ma; Domínguez-Rodrigo et al. 2001); Asia: Xiaochangliang (1.36 Ma; Chen and Chun 2000) and


a)
1
2
1 cm
2 mm
250 µm
b)
3
4
5
1 cm
2 mm
500 µm
5
250 µm
c)
6
7
1 cm
2 mm
7
8
8
250 µm
700 µm

◂**Fig. 7** Use-wear traces on Isernia la Pineta artefacts from selected squares from layers t.3a and t.3 coll. a Simple scraper 138–198 3coll: (1) use-wear traces interpreted as longitudinal action on fleshy tissues: small, diagonally oriented edge-removals; (2) polish issued from the work of fleshy tissues: part of the polish is characterized by a band of rough polish linked to the edge morphology. b Simple scraper 138–207 3coll: use-wear traces interpreted as transversal action on bone: cracks and latent fractures typical of hard material working (3) with localized areas of smooth and flat polish (4 and 5). c Simple scraper 166–116 use-wear traces interpreted as the result of longitudinal butchering activity: (6) diagonally oriented edge-removals with a (7) band of rough polish (fleshy tissues) and (8) edge rims heavily worn (fresh hide); the identification of use-wear traces and their interpretation is based on the experimental activity conducted by G. L. F. Berruti (2020b) and on the description of use-wear traces presented, for example, by Beyries (2020), Anderson-Gerfaud (1990), Palmqvist (2005), Lemorini (1997; 2006; 2016), Hardy (2004), Claud (2012), Berruti (2020ab) and Zupancich (2016)

Europe: Pirro Nord (1.5–1.3 Ma; Cheheb et al. 2019), El Pino (1.0–0.9 Ma; Domínguez-Solera et al. 2022), Atapuerca Gran Dolina (TD 6, 0.8 Ma; Sala 1998; TD 10, 1.2 Ma; Pedergnana and Ollé, 2020) and Montepoggiolo (0.85 Ma; Peretto et al. 1998). The Middle Pleistocene records increase with use-wear data, such as in the sites of La Noira (700 ka; Hardy et al. 2018), Boxgrove (500 ka; Mitchell 1998), Terra Amata (400 ka; Viallet 2016), Schöningen (300 ka; Rots et al. 2013), Revadim (Agam et al. 2015; Solodenko et al. 2015; Venditti et al. 2019; Marinelli et al. 2021; Zupancich et al. 2021) and Qesem Cave (Lemorini et al. 2006; 2016; 2020). In Italy, use-wear studies comparable with the site of Isernia from a chronological and cultural perspective (Rocca et al. 2016; Muttillo et al. 2021) were realised at Notarchirico (Moncel et al. 2020d; Santagata et al. 2020) and Ficoncella (Aureli et al. 2016), while the works on Guado San Nicola (370–400 ka; Berruti 2017; Berruti et al. 2020b) and Fontana Ranuccio (Marinelli et al. 2019; 2021) belong to MIS 11.

At Isernia La Pineta, post-depositional alterations affected the flint lithic industry to different degrees along the stratigraphic sequence, but they did not prevent the use-wear analysis. The analysis of the post-depositional alterations recorded on lithic artefacts (Eren et al. 2011b; 2011a) can be an essential indicator for the reconstruction of past environmental conditions and site formation processes (Van Gijn 1990a; Mazzucco et al. 2013; Asryan et al. 2014; Chakraborty et al. 2014; Berruti and Arzarello 2020).

The taphonomic analysis shows that the same post-depositional alterations affected the two considered SU with approximately the same intensity (Table 8 and Fig. S5). The degrees of development of the same alterations in the different SU testify that they underwent similar processes. The high percentage (more than 70% of the analysed sample) of lithic artefacts showing smoothing on the surfaces and rounding of edges and ridges can be related to a transport phenomenon, like a debris flow, as also assumed by the previous studies concerning geoarchaeology, taphonomy of the faunal remains and GIS (Peretto 1999; Thun Hohenstein et al. 2009; Gallotti and Peretto 2015; Channarayapatna et al. 2018; Pineda et al. 2020). The taphonomical analysis of the flint lithic industries of the Isernia La Pineta site is the subject of an ongoing study that uses the overlapping method for the taphonomy of the lithic artefacts (Berruti and Arzarello 2020), which aims to relate the different sequences of alterations post depositions found on elements from the various stratigraphic units.

The results of the use-wear analysis on flint flakes through the Low Power approach show that in both the SU (Tables 8 and 9), the flakes were used mainly for cutting (38 on 68) and, to a slightly lesser extent, scraping (28 on 68) soft and medium-soft materials (52 on 68). The high-power approach allowed us to locate diagnostic polish on 14 flint lithic remains correlated to animal carcass processing (Tables 9 and 10) (Fig. 6, 7, S6 and S7). In particular, all the activities associated with carcass processing are attested: cutting of soft animal tissue on four artefacts; cutting, drilling and scraping of fresh hide on two artefacts; and traces of butchering on eight artefacts (mixed traces of working of skin, bone and soft animal tissues) (Fig. 6, 7, S6 and S7). Bone working traces are present on one artefact, exhibiting a scraping action, and are probably linked to the periosteum removal required during marrow extraction (Grayson 1984; Crovetto et al. 1994; Longo 1994). Combining the results of the use-wear analysis (predominant use of the lithic artefacts for the processing of lightly resistant materials) with the palaeontological data is evident that the faunal remains of Isernia la Pineta include animals of various sizes, it is then reasonable to suggest that these tools may have been part of the toolkit used for butchering activities. Furthermore, the presence of cut marks and intentional fractures was highlighted in previous works (Peretto et al. 2004; 2016; Thun Hohenstein et al. 2009; Thun-Hohenstein et al. 2015; Pineda et al. 2020; Zanazzi et al. 2022) and is consistent with the results obtained by the use-wear analysis.

Traces hinting at butchering activities (soft and medium-soft material) are present on 39 lithic artefacts from SU 3coll (Fig. 6, 7, S6 and S7). The exploitation of medium-hard materials is only attested in four pieces (Table 10). From SU 3a, only four elements with these characteristics were found, exhibiting traces linked to the work of soft and medium-soft materials (Table 11). These data are also confirmed by the experimental work made under the supervision of Longo (1994). The results of this work, proving the preferential use and efficiency of small-sized unretouched flakes in butchering activities, fit with the data obtained for other sites of the Middle Pleistocene such as Ficoncella (Aureli et al. 2016), Fontana Ranuccio (Marinelli et al. 2021) and Revadim (Venditti et al. 2019).

Regarding the study of retouched flakes in SU 3a, only four exhibit use-wear traces. Due to this reduced sample, it is impossible to make general considerations (Table 11). On the other hand, in SU 3coll, there are 29 formal tools with wear traces (Table 12). There is a greater incidence of traces linked to transversal work on medium hard and medium soft materials. However, it is impossible to associate a tool with a particular action or a worked material. This data can be related to the results of the experimental work completed in 1993 and with the data obtained by the different studies that assert that in sites of this chronology and with these characteristics, retouching can be associated with the necessity to consolidate the cutting edges or to improve tools' grip (Longo 1994; Aureli et al. 2016; Marinelli et al. 2019; 2021). Both cases can be easily adapted to the need for working with more resistant materials, consequently fitting with the results of our study.

Overall, the use-wear analysis results are consistent with the previous studies conducted by Longo on 1367 lithic artefacts from SU 3a, even if from another sector of the site (Crovetto et al. 1994; Longo 1994) and by Verges on 105 artefacts coming from SU 3a (Sector I) and on 87 elements coming from SU 3a (Vergés, 2002; Vergès and Ollé, 2011). The study conducted by Longo (Crovetto et al. 1994; Longo 1994) highlighted the presence of traces exclusively related to animal carcass processing; on the contrary, the study conducted by Verges (2002, 2011), although identifying more of the 90% of traces as due to butchering activities also found traces linked to the working of vegetal materials. This result might be due to the different areas analysed in these works. In any case, all the studies on the use-wear traces provided similar results proving how the lithic industry of Isernia La Pineta was deeply linked with the exploitation of animal carcasses through the massive production of small-sized flakes and tools, recalling a pattern highlighted by other sites of the first half of the Middle Pleistocene in Europe and the Levant (Longo 1994; Vergés, 2002; Aureli et al. 2016; Hardy et al. 2018; Marinelli et al. 2019; 2021; Venditti et al. 2019).

Recent studies on the identification of use-wear traces on limestone industries granted a better understanding of the function and use of this raw material during the Lower Palaeolithic (Titton 2021; Titton et al. 2021). From this perspective, the ongoing study on the limestone implements of layer t.3coll, presented at a preliminary stage, will allow us to obtain a much higher resolution on the type of activities performed at Isernia La Pineta and the role of this site. The new methodological approach finalised to the analysis of macro-tools with an experimental activity aimed to comprehend the mechanical response of limestone within the reduction sequences (cores exploitation, tool production etc.) and use will be the groundwork to gather possible new behavioural information.

Conclusion

The technological and functional analysis performed on the flint assemblages of layers t.3a and t.3coll provided important information on the function and role of Isernia La Pineta during the first half of the Middle Pleistocene.

Many authors have been questioning the dichotomy between Acheulean and non-Acheulean on the presence of handaxes in the last years based on the recent evidence from Western and Eastern Europe, which shows a wide range of complex technical behaviours (Rocca et al. 2016; Moncel et al. 2018c; Davis and Ashton 2019; Davis et al. 2021). From a technological perspective, the industry of Isernia La Pineta exhibits complex mental templates that allowed some authors to infer its possible relation with the Acheulean complex (Gallotti and Peretto 2015; Muttillo et al. 2021) following the general increase in complexity witnessed during the Middle Pleistocene. The combined approach of lithic technology and use-wear analysis, here as in other sites, proved to be rewarding from a behavioural perspective because it enables the comparison between the degree of complexity of any lithic assemblage (raw material, cores' management, flakes, retouch etc.) with its functional aspects (Mitchell 1998; Aureli et al. 2016; Hardy et al. 2018; Venditti et al. 2019; Moncel et al. 2020d; Marinelli et al. 2021). This would give a more detailed picture of the hominins' subsistence strategies and relative changes/innovations from a "cultural" perspective.

The lithic industry of Isernia La Pineta aimed to produce small-sized flakes and tools realised on local raw material through different debitage attesting to more complex reduction sequences (centripetal and discoid) achieved through various technical expedients. Direct percussion and bipolar on-anvil techniques were employed, accounting for a codified choice from the hominids to overcome the slabs' morphology and quality, reflecting a well-known behaviour observed in other Lower Palaeolithic contexts (de Lombera-Hermida et al. 2016). All the knapping phases were recorded in these layers, confirming that the hominids seemingly selected, used and abandoned the lithic artefacts in the same area.

The use-wear analysis showed that flint artefacts were exclusively used for carcass processing on soft and soft-medium material (meat, fresh hide and animal tissues). Flakes' function was primarily cutting and, to a slightly lesser extent, scraping activities, although all the phases of carcass processing were identified. Minor traces of bone working were also observed and might be related to periosteum removal required during marrow extraction, confirming a butchery-related role of the site (or at least of the flint materials). Different tools were identified from a typological point of view, but no associations were found between specific shapes and worked materials. The efficiency of small unretouched flakes for butchery activities on large herbivores carcasses has been proved in many experimental activities and witnessed in several other Lower Palaeolithic contexts within the Italian peninsula (Boschian and Saccà, 2015; Marinelli et al. 2019; 2021; Rocca et al. 2021).

In conclusion, the analysis of the flint industry of Isernia La Pineta configures the site as specialised in butchering activities on large herbivores' carcasses. Whether these were hunted or scavenged is still a debated topic. The flint lithic assemblage reflects these specific activities by providing many small-sized flakes and tools. This would allow us to compare Isernia with other specialised butchery sites of the first half of the Middle Pleistocene, such as Notarchirico, Ficoncella and Boxgrove, all of them characterised by a massive presence of small-sized artefacts (Roberts and Parfitt 1999; Aureli et al. 2016; Moncel et al. 2020d). The absence, so far, of other kinds of activities conducted at the site, such as the woods and plant processing witnessed at La Noira, Atapuerca, and in some levels of l'Arago, might suggest a different type of occupation and role of these contexts over time (Hardy et al. 2018). Furthermore, the lack of largely shaped tools (i.e. bifaces, LCT) at Isernia seems unrelated to the activities conducted here since, in other sites, such as La Noira, the bifaces were also employed for butchery activities.

The systematic exploitation of local raw materials in all the mentioned sites, often placed in the proximity of watercourses, indicates that the subsistence strategies of the hominins involved a relatively small area of action, whether short- or long-term occupations were performed. The analysis of the isotopes of strontium performed on the human tooth of Isernia seems to confirm this trend (Lugli et al. 2017).

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12520-023-01791-8.

Acknowledgements The authors would like to thank the anonymous reviewers and the editor who contributed to improving the present work with their constructive criticism and suggestions.

Funding Open access funding provided by Università degli Studi di Ferrara within the CRUI-CARE Agreement.

Declarations

Competing interests The authors declare no competing interests.

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Supplementary Information

Brief Interviews with Hideous Stone. A glimpse into the butchery site of Isernia La Pineta: a combined technological and use-wear approach on the lithic tools to evaluate the function of a Lower Palaeolithic context.

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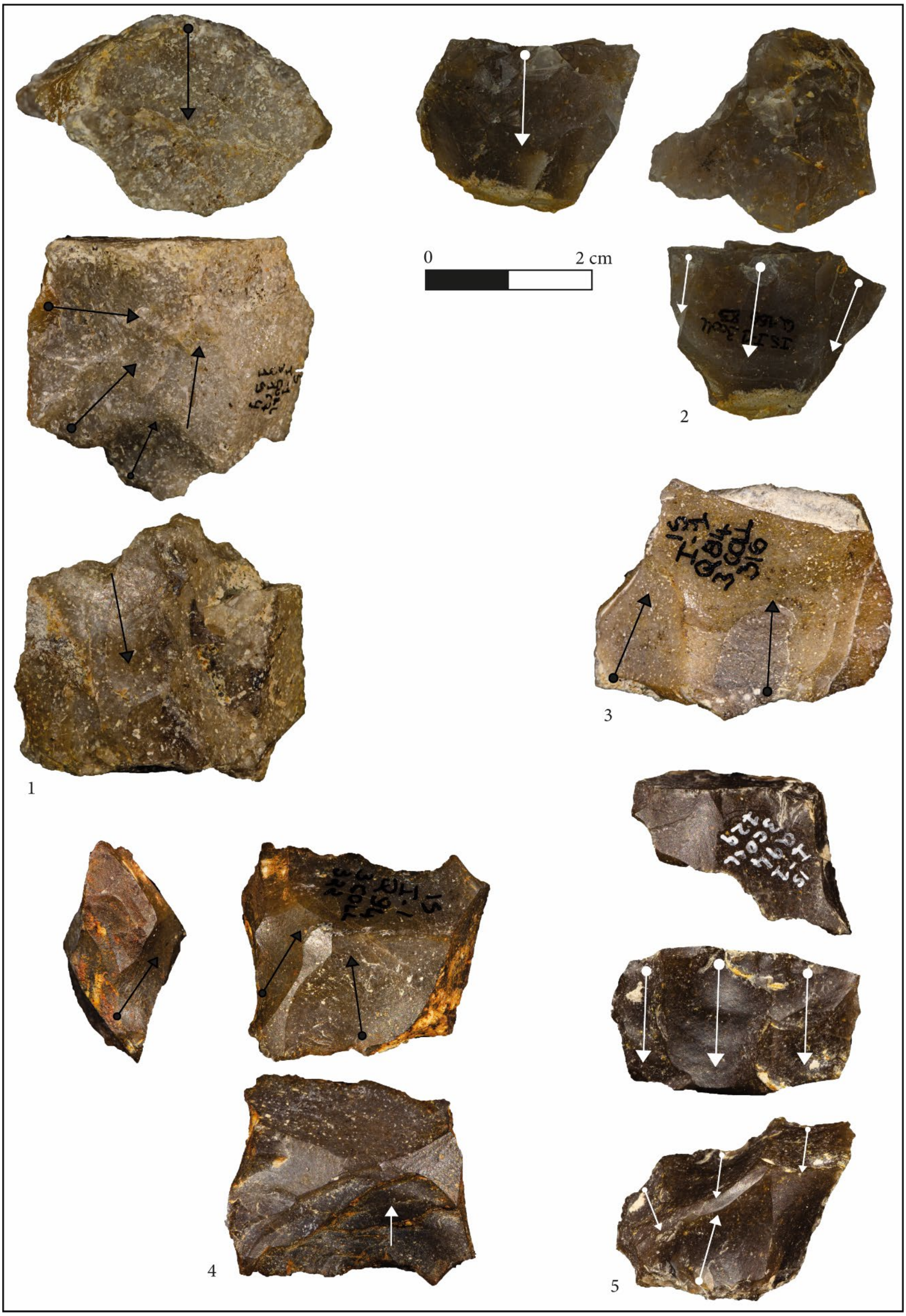


Figure S1. Small-sized cores from selected squares from layer t.3coll. 1: discoidal core; 2: unifacial core with semi-tournant exploitation; 3: unifacial core with orthogonal removals; 4: retouched core on a small slab; 5: core on flake

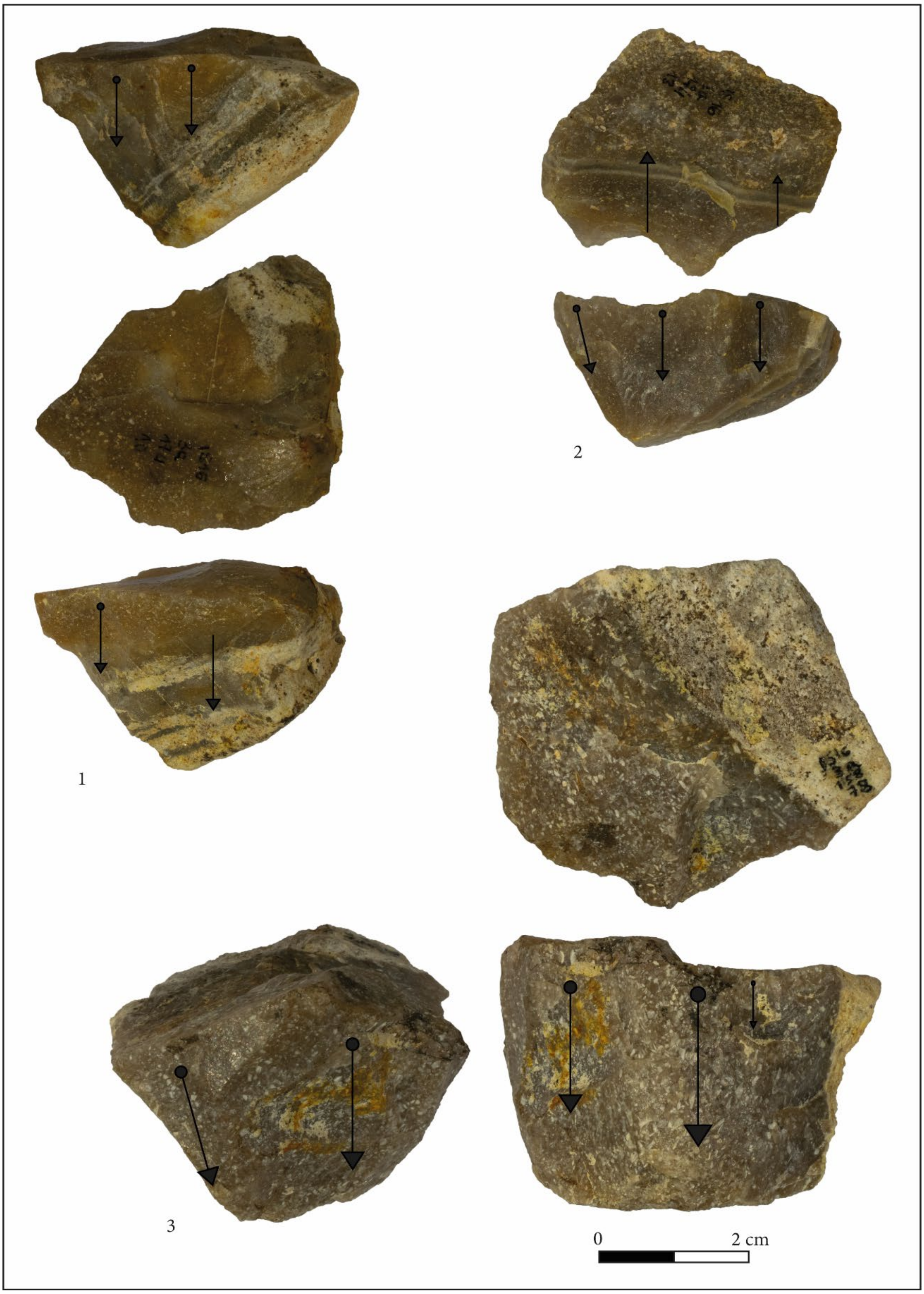


Figure S2. Cores from selected squares from layer t.3a. 1, 2: cores on flake; 3: unifacial core with unipolar removals and semitournant exploitation.

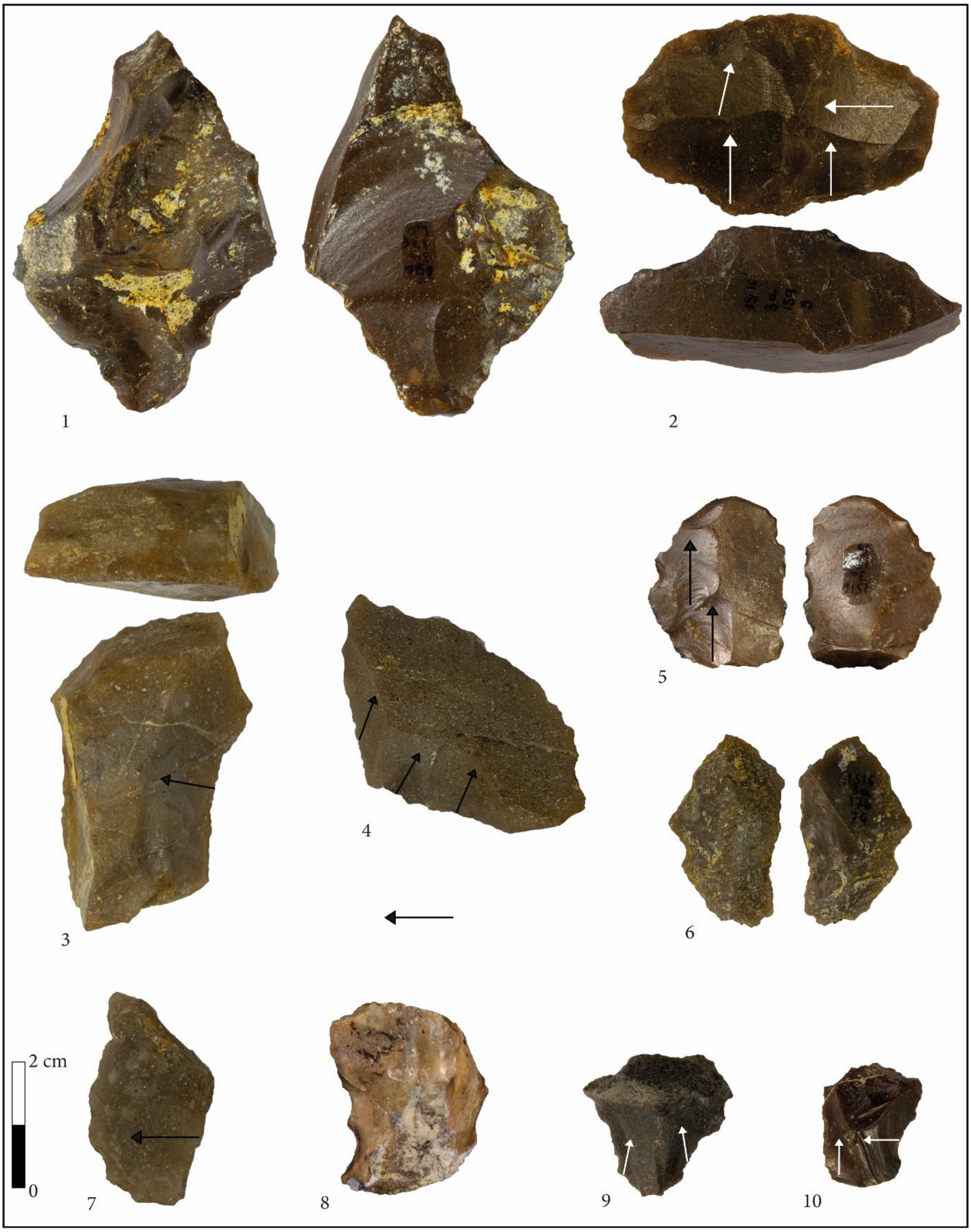


Figure S3. Flakes and retouched flakes from selected squares from layer t.3a. 1: convergent scraper with inverse retouch; 2: scraper with peripherical retouch on a flake with orthogonal removals; 3: scraper on debordant flake with orthogonal removal; 4: denticulate with convergent removals; 5: flakes with unipolar removals; 6: scraper with inverse retouch; 7: denticulate on a flake with orthogonal removal; 8: denticulate on backed flake; 9: small plunging flake with unipolar removals; small flake with orthogonal removals.

Figure S4. Limestone artefacts from layer t.3coll: a.) Hammer (IS.I-4.3COLL.Q111.183) with percussion marks including an accidental removal, surface scarring and impact point on the active surface localised at the top of the pebble; b.) Unifacial core (IS.03.I-1.3COLL.Q115.144) on a pebble with bipolar removals obtained through bipolar on anvil technique; c.) Flake (IS.04.I-4.3COLL.Q107.62) with a portion of cortex *Type II* (based on Toth's classification).

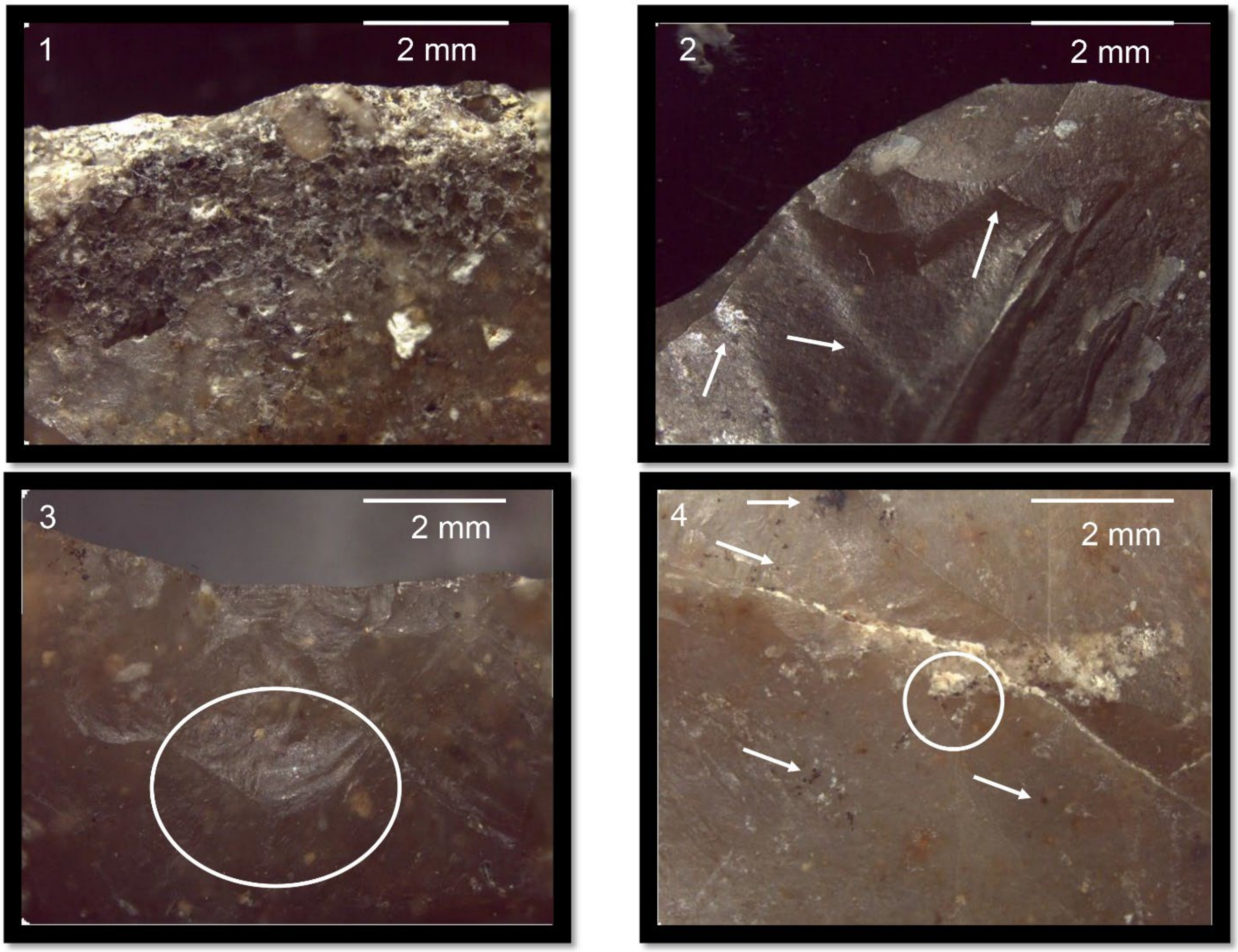


Figure S5. Post depositional traces on Isernia la Pineta flint flake: 1 part of the edge of the 94-164 3coll artefact covered by concretion and a Fe-Ma patina, rounding of the ridge (indicated by the arrows) on the artefact 176-42 3a; area of rounding on the retouched edge of the 166-67 3coll (in the circle); spots of Fe-Ma patina and construction (in the circle there is indicated an overlap of the two post-depositional alterations) of on the artefact 94-164 3coll.

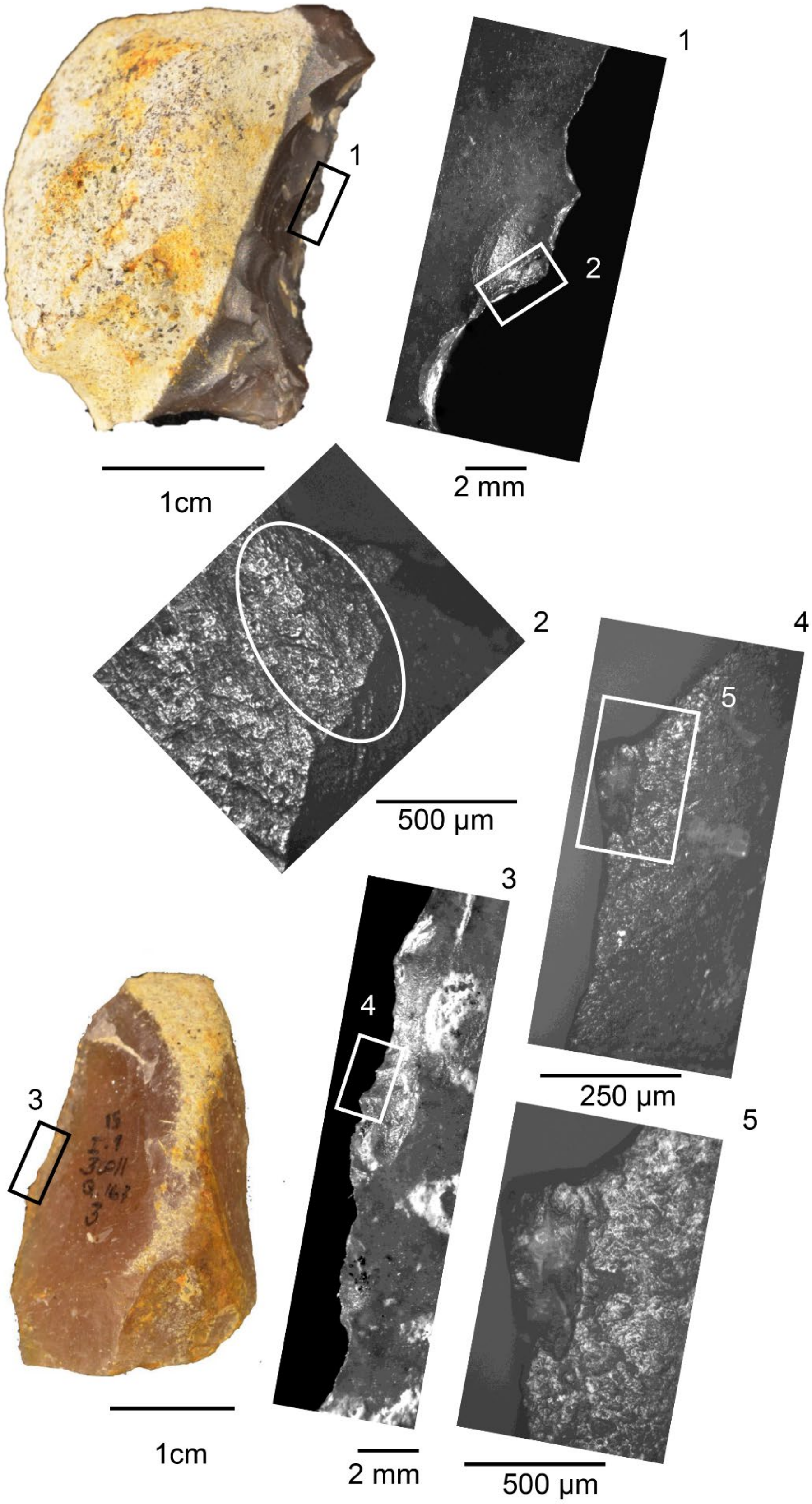


Figure S6. Use-wear traces on Isernia la Pineta flint artefacts. (a) denticulate 167-70 3coll: 1) use-wear traces interpreted as transversal action of skin work/butchering: big, superimposed, and scalar edge-removals with the rounded edges (fresh skin); 2) line of rough polish transversal to the edge (soft animal tissue); (b) flake 167-3 3coll use-wear traces interpreted as the result of longitudinal activity on soft animal tissue: crescent shape, diagonally oriented edge-removals (3 and 4) with a band of rough polish linked with the edge morphology (fleshy tissues) (5); The identification of use-wear traces and their interpretation is based on the experimental activity conducted by G. L. F. Berruti (2020b) and on the description of use-wear traces presented for example by (Anderson, 1990; Lemorini et al., 1997; 2006; 2016; Hardy, 2004; Palmqvist et al., 2005; Claud et al., 2012; Berruti et al., 2020a; 2020b; Beyries, 2020).

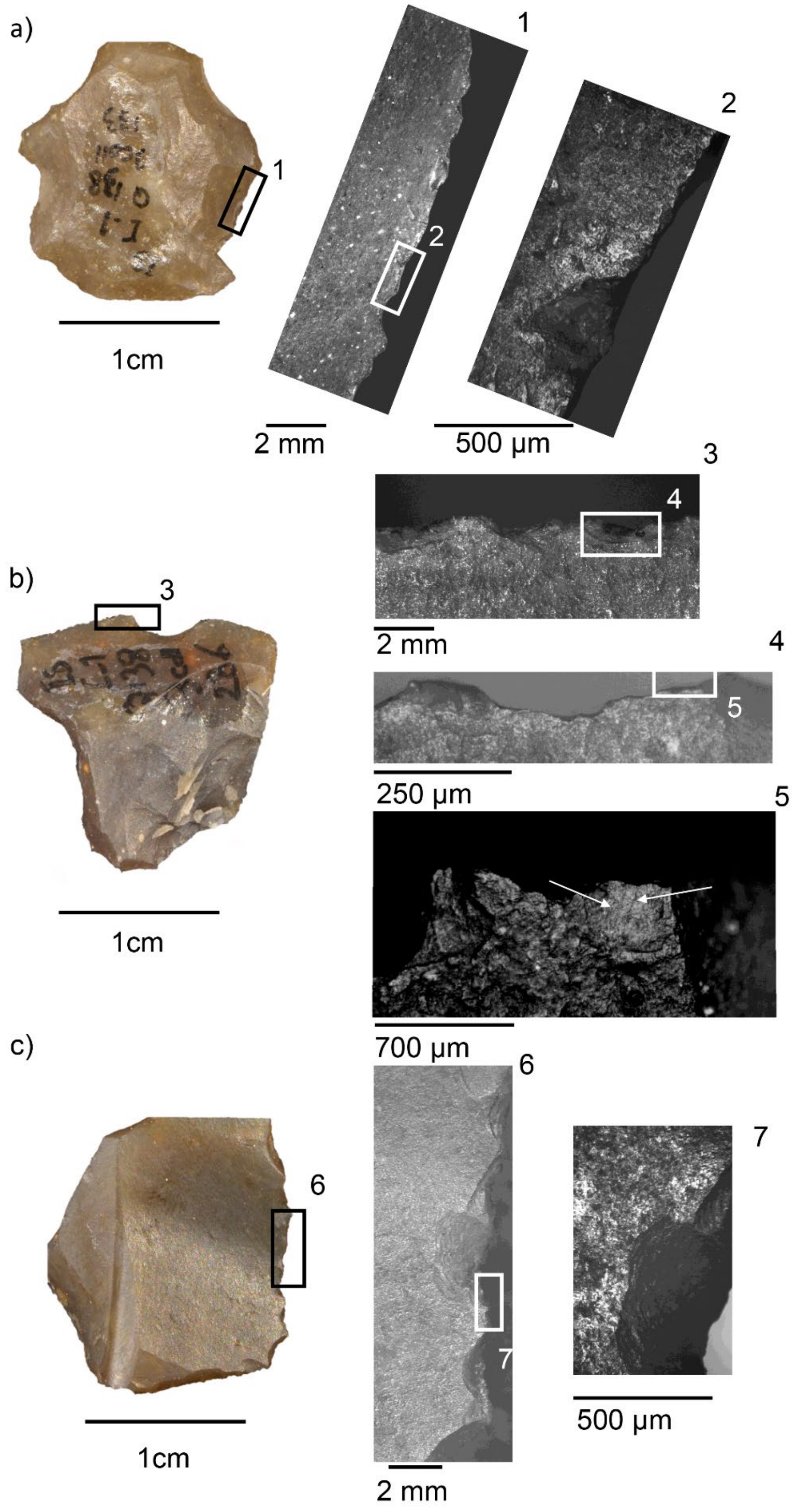


Figure S7. Use-wear traces on Isernia la Pineta flint artefacts. (a) Denticulate 138-133 3coll: 1) use-wear traces interpreted as transversal action of butchering: big, superimposed, and scalar edge-removals; 2) polish issued from the work of medium soft animal tissues: part of the polish is characterised by a band of rough polish linked to the edge morphology; b) flake 138-268 3coll: use-wear traces interpreted as longitudinal action of butchering: diagonally oriented edge-removals with a band of rough polish, soft animal tissue (3 and 4), localised areas of smooth and flat polish with two striae (indicated by the arrows) typical of bone working (5); c) flake 158-2 3coll use-wear traces interpreted as the result of longitudinal activity on soft animal tissue: diagonally oriented edge-removals (6) with a band of rough polish (fleshy tissues) (7); The identification of use-wear traces and their interpretation is based on the experimental activity conducted by G. L. F. Berruti (2020b) and on the description of use-wear traces presented for example by (Anderson, 1990; Lemorini et al., 1997; 2006; 2016; Hardy, 2004; Palmqvist et al., 2005; Claud et al., 2012; Berruti et al., 2020a; 2020b; Beyries, 2020).

Table S1 Experimental data

Action	Materials worked							
	Skinning	Filleting	Hide	Butchering	Bone	Fresh Wood	Dry Wood	Antler
Transversal	-	-	1	2	1	2	1	2
Longitudinal	2	2	1	2	1	1	1	2
Mixed	2	-	1	2	1	2	-	1
							Total	30

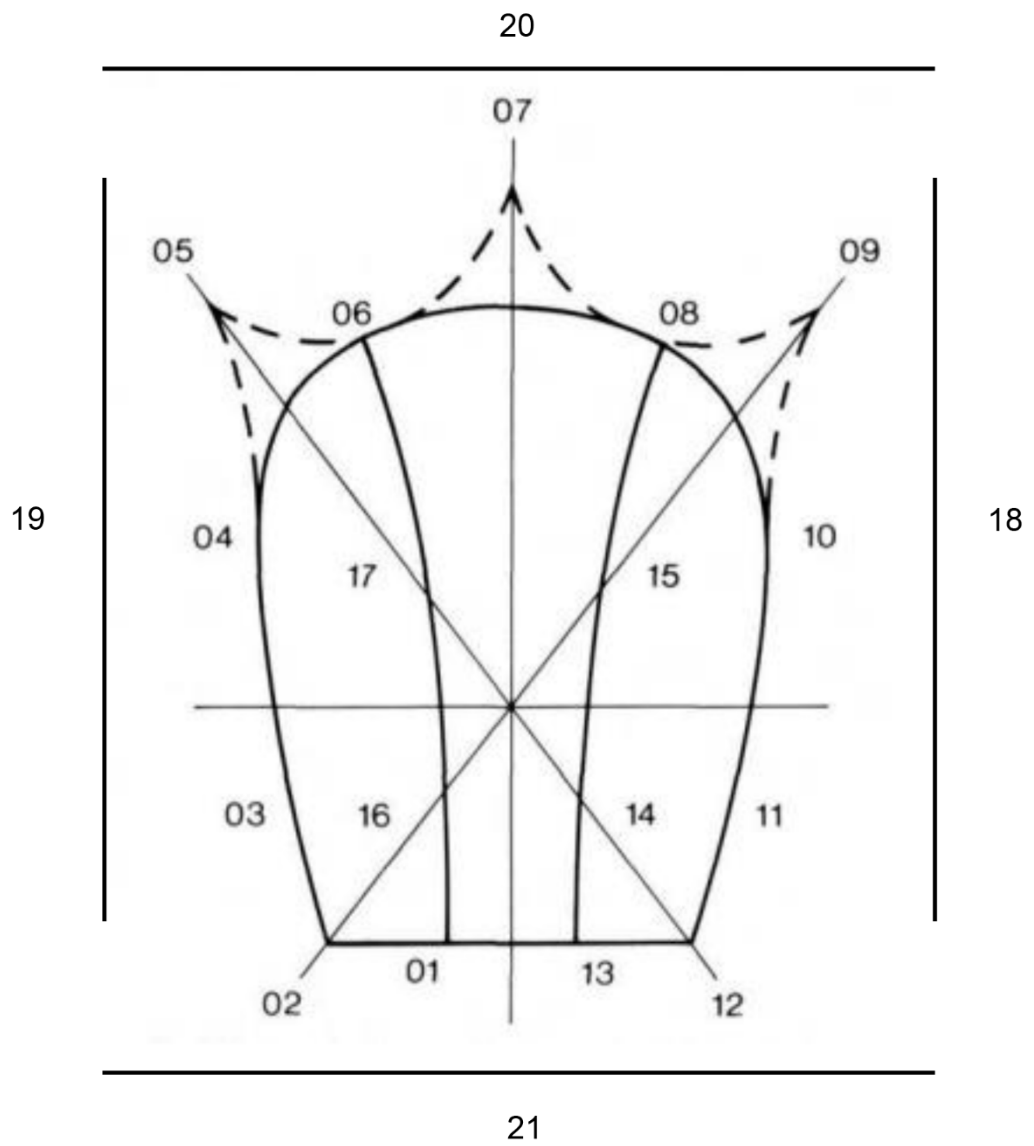


Figure S8. Coordinate system used for the positioning of the functional areas proposed by Van Gijn (1989) and then modified by the addition of the fields 18, 19, 20, 21 in order to always indicate the functional area with a single number.

4.4. The bipolar on anvil experimentation

In this section, the result of the experimentation performed on three debitage techniques (direct hand percussion with the hard hammer, bipolar on anvil percussion, and anvil-assisted freehand percussion) will be presented. Each technique will be discussed separately according to the morphological class of the slabs, the cores obtained, and the flakes produced. The cores and flakes were analysed only when presenting clear traces of debitage activities.

A total of 59 chert slabs, collected in the proximity of the archaeological site of Isernia La Pineta, were knapped during the experimentation (Tab. 4.57). The slabs exhibit a parallelepiped morphology in most of the cases (41 out of 59), followed by cubic-type (n=16). Irregular morphologies are somewhat rare (n=2; Tab. 4.58). The margins of the slabs are equally parallel, parallel and sub-parallel or rounded (Tab. 4.59). The presence of cortical or neocortical patches is documented on 51 of the 59 slabs, being relatively frequent and usually located on two opposite sides (n=22), on one side (n=12), on more than two faces (n=5), or in small inhomogeneous portions (n=12). The visible fractures on the slabs are recurrent, being attested on 40 blocks.

The quality of the chert slabs is generally low, and the same considerations made for the paragraph dedicated to Isernia La Pineta's raw material are valid also for this case. Some slabs display a finer quality and texture, particularly on smaller dimensions, while a lower and coarser texture mainly characterises larger slabs. A particular qualitatively inferior raw material variety was documented on several medium and larger slabs; it exhibits coarse grains macroscopically visible and somewhat similar to a coarser quartz-related raw material.

Table 4.1 List of slabs knapped during the experimentation

Technique	Freehand	Bipolar on anvil	Assisted	Total
Slabs' dimensional class	n	n	n	n
Small	4	9	3	16
Medium	10	11	10	31
Large	3	4	5	12
Total	17	24	18	59

Table 4.2 Morphology of the slabs

Slabs' dimensional class	**Small**	**Medium**	**Large**	**Total**
Morphology	n	n	n	n
Cubic	2	7	3	12
Cubic Irregular	3	-	1	4
Total Cubic	5	7	4	16
Parallelepipedon	1	7	4	12
P. Irregular	3	5	1	9
P. Tubular	2	8	1	11
P. Flat	5	2	2	9
Total Parallelepipedon	11	22	8	41
Irregular	-	2	-	2
Total	16	31	12	59

Table 4.3 Edges configuration of slabs

Slabs' dimensional class	Small	Medium	Large	Total
Edges' organisation				
Parallel	3	12	5	20
Sub-Parallel	1	3	-	4
Rounded	2	5	-	7
Parallel and Sub-Parallel	8	7	2	17
Rounded and Parallel	2	4	5	11
Total	16	31	12	59

4.4.1. Direct percussion with the hard hammer

A total of 17 slabs were knapped using direct percussion with the hard hammer: four belonging to the small-sized dimensional class, ten to medium one, and three to the large one (Tab. 4.57). Initially, 19 slabs were selected, but two were discarded due to the quality of the raw material, which caused the fragmentation of the slab in one case and, in the other, prevented the obtaining of flakes. The 17 slabs selected produced 17 cores.

Small slabs

The four cores obtained from the small-sized slabs were knapped on the thickness axis using the 50 blows available and producing 18 flakes (Tab. 4.60; Fig. 4.13, 4.14). All the cores were knapped without any inversion of the initial striking platform and knapping surface – producing unipolar removals (Fig. 4.13). The debitage angle shows a mean value of 70°. All the striking platforms were natural and without cortical patches. The morphology of the knapping surfaces is flat, except for one core where a semi-tournant exploitation of the volume was performed (Fig. 4.13, n° 5). The presence of micro-shattering (*i.e.,* abrasions, micro-removals) on the edges of the striking platforms was documented on two cores, exhibiting the finest texture (Fig. 4.13, n° 4, 5).

Table 4.4 Small-sized slabs dimensions and number of obtained flakes

Slab/Core ID	Length		Width		Thickness		Flakes obtained
	Initial	Final	Initial	Final	Initial	Final	n
1	46,3	43,7	38,2	34,6	26,2	25,9	7
7	46,6	41,6	30,1	28,1	22,6	21,8	8
17	55	50	48,7	45,4	40,1	26,4	1
20	55	41,5	33,3	25,8	16,5	16,3	2
Total							18

Figure 4.1 Small-sized cores knapped by direct percussion with hard hammer. 1. Core of bad quality with hard-to-read removals and unifacial exploitation; 2. Core of medium quality showing unifacial exploitation;

3. Focus on small removals from cores n° 2; 4. Core of good quality showing slight presence of proximal micro-shattering; 5. Core of good quality with pronounced proximal micro-shattering and semi-tournant exploitation of the surfaces.

A total of 18 flakes were produced, bearing evident marks of debitage activities (Fig. 4.14). They exhibit a quadrangular shape, with 19,7 mm in length, 19,2 mm in width, and 5,9 mm in thickness (Tab. 4.61). The section of the flakes is flat on 14 artefacts and triangular on four (Tab. 4.62). The maximum width of the products is mainly on the distal portion (n=11), followed by proximal (n=2) and mesial (n=1). On four artefacts, the width was regular along the profile. The maximum thickness coincided with the proximal portion of the flakes (n=7), followed by the distal portion (n=4) and the mesial one (n=2; Tab. 4.63). On four artefacts, the thickness was regular, but it did not match those flakes with regular width (Tab. 4.64). The typology of the platforms revealed a predominance of natural butts (n=12), followed by dihedral (n=3) and punctiform (n=1; Tab. 4.65). The predominant morphology of the platforms is either oval/triangular (n=7) or quadrangular/trapezoidal (n=5), followed by narrow curved platforms (n=3). Two crushed butts were observed (Tab. 4.66).

The development of the bulb on the ventral face of the flakes was diffused on eight artefacts, pronounced on three, sheared on one artefact, and removed on another. On three flakes, there was no formation of the bulb (Tab. 4.67). The cone formation was attested by ventral fissures (n=6) and ring cracks on the platform (n=4), while it was very subtle on one artefact, and on another, it was detached. No cone was developed on five products (Tab. 4.68). Regarding the lip, it was mostly diffused (n=9) and pronounced (n=3), while it was absent on four flakes (Tab. 4.69). The presence of ripples/undulations was documented on 3 out of 17 flakes, while bulbar scars were present on five artefacts (Tab. 4.70).

The distal termination of the flakes was regular in most cases (n=15). It was hinged in two cases, and in another, it was broken (Tab. 4.71). The flaking axis was regular (*i.e.,* axial) on seven artefacts and *dejete* on ten (Tab. 4.72). Unipolar scars are predominant in the removals' organisation (n=11), followed in equal quantities by convergent (n=2) and orthogonal (n=2) scars. Flakes without removals are two (Tab. 4.73). The incidence of backed margins was very low (4 out of 14 flakes; Tab. 4.74). To conclude, the presence of fractures within debitage products was low (14 complete pieces), and they were placed on the proximal part (n=1), transversally (n=2), and longitudinally on the lateral margins (n=1; Tab. 4.75).

Table 4.5 Dimensional values of flakes obtained through direct percussion.

Slabs dimensional class	**Small**			**Medium**			**Large**		
Direct percussion	length	width	thickness	length	width	thickness	length	width	thickness
Flakes	n=17			n=69			n=29		
min	13,6	8,1	2	11,1	6,9	2	16,3	12	3,1
max	44,7	39,2	19,1	69,4	73,5	34,7	46,5	45,4	19,8
mean	**19,7**	**19,2**	**5,9**	**28,8**	**26,7**	**10,2**	**32,3**	**25,7**	**10,3**

Table 4.6 Section of flakes obtained through direct percussion.

Direct Percussion	Small	Medium	Large	Total	
Flakes' section	n	n	n	n	%
Flat	14	43	18	75	62,5
Dihedral		8	3	11	9,2
Triangular	4	17	6	27	22,5
Irregular		4	3	7	5,8
Total	18	72	30	120	-

Table 4.7 Maximum width of direct percussion flakes

Direct Percussion	Small	Medium	Large	Total	
Maximum Width	n	n	n	n	%
Proximal	2	17	12	31	26,5
Mesial	1	11	7	19	16,2
Distal	11	23	7	41	35
Regular	4	18	3	25	21,4
Irregular		1	-	1	0,9
Total	18	70	29	117	-

Table 4.8 Maximum thickness of direct percussion flakes

Direct Percussion	Small	Medium	Large	Total	
Maximum Thickness	n	n	n	n	%
Proximal	7	26	12	45	38,5
Mesial	2	13	7	22	18,8
Distal	4	16	5	25	21,4
Regular	4	14	5	23	19,7
Irregular	-	2	-	2	1,7
Total	17	71	29	117	-

Table 4.9 Platform type of direct percussion flakes.

Direct percussion					
Size	Small	Medium	Large	**Total**	
Platform Type				**n**	**%**
Cortical		2	1	**3**	**2,7**
Natural	12	31	15	**58**	**51,3**
Flat		21	10	**31**	**27,4**
Dihedral	3	3		**6**	**5,3**
Punctiform	1	1	1	**3**	**2,7**
Linear		7	2	**9**	**8**
Fractured		3		**3**	**2,7**
Total	16	68	29	**113**	**-**

Table 4.10 Platform morphology of direct percussion flakes.

	Direct percussion				
Size	Small	Medium	Large	**Total**	
Platform Morphology				**n**	**%**
Oval/Triangular	7	17	4	**28**	**24,8**
Quadr./Trapez.	5	27	15	**47**	**41,6**
Narrow curved	3	6	4	**13**	**11,5**
Narrow		8	4	**12**	**10,6**
Crushed	2	10	1	**13**	**11,5**
Total	17	68	28	**113**	**-**

Table 4.11 Bulb morphology of direct percussion flakes.

	Direct percussion				
Size	Small	Medium	Large	**Total**	
Bulb morphology				**n**	**%**
None	3	16	3	**22**	**19**
Diffuse	8	30	10	**48**	**41**
Pronounced	4	9	8	**21**	**18,1**
Crushed		4	5	**9**	**7,8**
Sheared	1	1		**2**	**1,7**
Spike-like		1	1	**2**	**1,7**
Removed	1	9	2	**12**	**10,3**
Total	17	70	29	**116**	**-**

Table 4.12 Cone formation on direct percussion flakes.

	Direct percussion				
Size	Small	Medium	Large	**Total**	
Cone formation				**n**	**%**
None	5	32	15	**52**	**45,6**
Ring crack on butt	4	12	4	**20**	**17,5**
Ventral fissures	6	15	6	**27**	**23,7**
Detached bulb	1	7	2	**10**	**8,8**
Hint	1	2	2	**5**	**4,4**
Total	17	68	29	**114**	**-**

Table 4.13 Lip formation of direct percussion flakes.

Direct Percussion	Small	Medium	Large	**Total**	
Lip formation	n	n	n	n	%
None	4	42	15	61	60,4
Diffuse	9	14	6	29	28,7
Pronounced	3	2	6	11	10,9
Total	16	58	27	101	-

Table 4.14 Traces on direct percussion flakes.

Direct Percussion	Small	Medium	Large	**Total**	
Traces	n	n	n	n	%
Ripples/Ondulation	3/18	6/72	0/30	9/120	7,5
Bulbar scar	5/18	28/72	0/30	33/120	27,5
Proximal micro-shattering	6/18	7/72	0/30	13/120	10,8

Table 4.15 Distal termination of direct percussion flakes.

Direct Percussion	Small	Medium	Large	**Total**	
Distal termination	n	n	n	n	%
Rebound force		7		7	5,8
Broken	1	5	3	9	7,5
Hinged	2	9	2	13	10,8
Regular	15	51	25	91	75,8
Total	18	72	30	120	-

Table 4.16 Flaking axis of direct percussion flakes.

Direct Percussion	**Small**	**Medium**	**Large**	Total	
Flaking axis	n	n	n	n	%
Axial	7	35	17	59	53,2
Dejete	10	33	9	52	46,8
Total	17	68	26	111	-

Table 4.17 Removals organisation of direct percussion flakes

	Direct percussion				
Size	Small	Medium	Large	**Total**	
Removals				**n**	**%**
Absent	2	18	7	**27**	**23,1**
Unipolar	11	41	17	**69**	**59**
Convergent	3	1	1	**5**	**4,3**
Crossed					
Orthogonal	2	2	1	**5**	**4,3**
Centripetal		3		**3**	**2,6**
Bipolar		5	3	**8**	**6,8**
Indetermined		2	1	**3**	**2,6**
Total	18	72	30	**120**	

Table 4.18 Backed margins on direct percussion flakes.

Direct Percussion	**Small**	**Medium**	**Large**	Total	
Backed margin	n	n	n	n	%
Present	4	35	17	56	47,9
Debordant	2	16	5	23	19,7
Plunging	2	13	9	24	20,5
Debordant and Plunging		5	3	8	6,8
All sides		1		1	0,9
Absent	14	35	12	61	52,1
Total	18	70	29	117	-

Table 4.19 Type of fracture on direct percussion flakes.

Direct Percussion	Small	Medium	Large	**Total**	
Type of fracture				n	%
Longitudinal Siret type fracture		4	2	6	5
Siret type and platform fractures		1		1	0,8
Siret type and base					
Siret, platform and base					
Siret and transversal					
Platform	1	2	2	5	4,2
Base		1		1	0,8
Base and basal flake					
Platform and base					
Platform and basal flake					
Side longitudinal	1	6	3	10	8,3
Side longitudinal and base		1		1	0,8
Side longitudinal and platform					
Side longitudinal, platform and base					
Side longitudinal and basal flake					
Transversal	2	14	2	18	15
Transversal and platform					
Transversal and base		1	1	2	1,7
Transversal, base and platform					
Double transversal		1	1	2	1,7
Lateral and transversal		1	1	2	1,7
Lateral, transversal and base					
Lateral, transversal and platform					
Basal flake					
None	14	40	18	72	60
Total	18	72	30	120	-


1
2
3
4
5
6
7
0
1 cm

Figure 4.2 Selection of small-sized direct percussion flakes. 1. Flake of bad quality with internal fractures, oval/triangular platform, undeveloped bulb; 2. Medium quality flake with oval/triangular platform, ring crack on the butt attesting the Hertzian cone development, pronounced bulb and slight evidence of proximal micro-shattering; 3. Flake of good quality with narrow curved platform and diffused bulb; 4. Flake of good quality with punctiform butt and traces of shattering on the dorsal face; 5. Flake of good quality with linear platform and evidence of proximal micro-shattering; 6. Flake of good quality with oval/triangular platform, diffused bulb and dèjète flaking axis; 7. Flake of medium quality with quadrangular/trapezoidal platform, pronounced proximal micro-shattering on the dorsal face, and absence of bulb or Hertzian cone on the ventral face.

Medium slabs

A total of 10 cores from medium slabs was obtained (Tab. 4.76). Most cores (n=7) were knapped on the thickness axis, while two were cubic, and the last was exploited using the width (Fig. 4.15). Two cores were discarded before the analysis: slab 35 was abandoned after ten blows as the particular hardness of the raw material made the obtainment of any flake impossible. In contrast, s31 was discarded due to the massive internal fractures. 72 flakes out of 8 cores were obtained at the end of the experimentation (Tab. 4.76; Fig. 4.16). In this case, a rotation of the surfaces was performed on five cores, mainly leading to multifacial exploitation of the surfaces in four cases and to centripetal debitage in the last (Fig. 4.15, n° 3). The three remaining cores exhibit unipolar removals. The debitage angle shows a mean value of 75°. Striking platforms were flat on four cores, natural on two, cortical on one and crushed on the last one. The morphology of the final knapping surfaces was mainly orthogonal (n=4), flat (n=2), and tournant (n=2).

On four cores (s33, s43, s46, s47), the quality of the raw material was poor, with a coarser texture, making the reading of the surfaces challenging (Fig. 4.15, n° 1, 2). On these four cores, possible counterblows were documented on three slabs associated with bipolar removals (Fig. 4.15, n° 1). Micro-shattering marks between the striking platform and the knapping surfaces were also documented on the three cores associated with counterblows (Fig. 4.15, n° 1).

Table 4.20 Medium-sized slabs dimensions and number of obtained flakes.

Slab/Core ID		Length		Width		Thickness		Flakes obtained
Medium	Blows	Initial	Final	Initial	Final	Initial	Final	n
30	50	65,7	32,9	44,8	32,6	37,4	27,7	12
31	-	84,5	-	50,35	-	43,6	-	-
33	50	72,7	50,7	51,2	43,3	41,5	40,2	7
35	10	57,9	-	54,2	-	53,6	-	-
43	50	87,5	43,2	63,3	42,8	42	38,9	12
46	9	73,3	51,6	55,4	32,7	46,1	23,8	2
47	30	72	51,3	59,3	37,9	29,1	27,7	2
59	43	68,6	43,7	49,2	38,8	42,2	20,9	16
61	50	66,5	36,9	53,8	25,5	34,6	23	12
65	50	79,8	61,5	76,3	49,7	63,6	41,5	9
Total								72


1
2
3
4
0 1 cm

Figure 4.3 Medium sized cores knapped by direct percussion with the hard hammer. 1. Core exhibiting low quality of raw material, similar to quartzite, generating hard-to-read surfaces. There is evidence of bipolar removals characterised by counter-bulbs. 2. Core of good quality exhibiting several internal fractures. The proximal micro-shattering produced by the contact with the hammer is pronounced. 3. Core of medium quality with centripetal removals. 4. Core of good quality with semi-tournant exploitation of the surfaces and slight evidence of proximal micro-shattering at the contact between the striking platform and the knapping surface.

A total of 72 flakes were produced, bearing evident marks of debitage activities (Fig. 4.16). Their shape is quadrangular, showing mean values of 28,8 mm in length, 26,7 mm in width, and 10,2 mm in thickness (Tab. 4.61). The section of the flakes is primarily flat (n=43), followed by triangular (n=17), dihedral (n=8), and irregular (n=4; Tab. 4.62). The maximum width is equally distributed on the distal (n=23) and proximal (n=17) portions of the products, and sometimes it coincides with the mesial part (n=11). Flakes with a regular width are 18 (Tab. 4.63). The maximum thickness is often placed on the proximal part (n=26), followed by distal (n=16) and mesial (n=13). It is regular on 14 flakes and irregular on two (Tab. 4.64). Platforms are either natural (n=31) or flat (n=21), with sporadic evidence of linear (n=7), dihedral (n=3), cortical (n=2), and punctiform (n=1; Tab. 4.65). Fractured butts are three. The predominant morphology of the platforms is quadrangular/trapezoidal (n=27), followed by oval/triangular (n=17). Narrow platforms are 14 and divided into narrow curved (n=6) and narrow rectilinear (n=8). Crushed morphologies are documented on ten artefacts (Tab. 4.66).

The documented bulbs on the ventral faces of the flakes are often diffused (n=30) or, in minor quantities, pronounced (n=9), crushed (n=4), sheared (n=1), or spike-like (n=1). The bulb was removed on nine artefacts and did not develop on 16 flakes (Tab. 4.67). The cone formation was attested by ventral fissures (n=15) and ring cracks on the platform (n=12), while it was very subtle on two artefacts, and on seven, it was detached. On 32 flakes, the Hertzian did not develop (Tab. 4.68). Regarding the lip, in most cases, it was not formed (n=42). When present, it was usually diffused (n=14) and rarely pronounced (n=2; Tab. 4.69). The presence of ripples/undulations was very low, documented on 6 out of 72 flakes, while bulbar scars were present on 28 out of 72 artefacts (Tab. 4.70).

Moving onto the distal termination, it was regular in most cases (n=51), with sporadic evidence of hinged (n=9) and broken (n=5) terminations. A “rebound force” distal termination type was documented on seven flakes (Tab. 4.71). Regarding the flaking axis, it was equally axial (n=35) and *dejete* (n=33; Tab. 4.72). Unipolar scars are predominant in the removals’ organisation (n=41), followed in more or less equal quantities by centripetal (n=3), orthogonal (n=2), and convergent (n=1) scars. Bipolar removals were documented on five artefacts, while flakes without removals are 18 (Tab. 4.73). The incidence of backed margins is attested on 50% of the flakes, equally debordant or plunging. Fractures within debitage products were low (40 complete pieces; Tab. 4.74). The most recurrent fracture types were transversal (n=14), longitudinal (n=13), platform (n=2), and base (n=1; Tab. 4.75).

To conclude, percussion traces on the ventral face but located on the distal portion were documented on four flakes deriving from three different cores. Counter-bulbs were found on four artefacts exhibiting a crushed morphology associated with cortical crushed platforms. No counter-lip was found. The formation of a counter-cone was detected on three flakes, detached in two cases and with ventral fissures on the last one. Bulbar scars were found on three flakes as well. The mean debitage angle associated with the counter-butts is 94°.


1
2
3
4
5
6
7
8
0 1cm

Figure 4.4 Selection of direct percussion obtained from medium-sized slabs. 1. Flake of low quality exhibiting crushed platform morphology and transversal fracture. There is evidence of removed bulb on the ventral face; 2. Flake of good quality with oval/triangular platform and diffused bulb; 3. Flake of low quality exhibiting distal fracture and dèjète flaking axis. The platform morphology is quadrangular/trapezoidal. On the ventral face there is evidence of bulbar scar and crushed bulb (where the lip is supposed to be). 4. Laminar flake of good quality with crushed platform; 5. Flake of medium quality with centripetal removals and oval/trinagular platform; 6. Flake of medium quality with several internal fractures, crushed platform, and undeveloped bulb/Hertzian cone; 7. Flake of good quality with internal fractures and quadrangular/trapezoidal platform. There is evidence of undeveloped bulb and Hertzian cone. 8. Flake of good quality with siret-type fracture, proximal micro-shattering and quadrangular/trapezoidal platform with traces of impact from the hammer.

Large slabs

A total of three large slabs were knapped, producing three cores and a total of 30 flakes (Tab. 4.77; Fig. 4.17, 4.18). Two cores were obtained from one slab (63) since the original slab was fractured into two large blocks after the first blow. One slab (84) was abandoned after 17 blows due to its hardness, making the production of flakes impossible. Two slabs were knapped on the width axis, and one using the thickness. The quality of these slabs is poor, with coarser textures, leading to an inefficient optimisation of the volumes. Only one core was rotated, though the removals' organisation showed unipolar scars on all three cores. The debitage angle shows a mean value of 77°. Striking platforms were natural on two cores and flat on the rotated core. All the knapping surfaces exhibit a tournant morphology (Fig. 4.17). No traces of micro-shattering were found, except in one case (Fig. 4.17), where slight evidence of shattering were documented.

Table 4.21 Large-sized slabs dimensions and number of obtained flakes.

Slab/Core ID	Technique	Blows	Length		Width		Thickness		Flakes obtained
Large			Initial	Final	Initial	Final	Initial	Final	n
63_1	Direct p.	11	91,8	52,7	75,2	39,2	61,2	33,9	10
63_2	Direct p.	20	91,8	39,3	75,2	36	61,2	29,3	6
79	Direct p.	45	107,6	45	58	36,1	37,8	29,3	14
84	Direct p.	17	115	-	95,7	-	89	-	-
Total									30

Figure 4.5 Large sized core knapped through direct percussion with the hard hammer showing unipolar removals and tournant morphology of the knapping surface. The micro-shattering is partially attested.

A total of 30 flakes were produced, bearing evident marks of debitage activities (Fig. 4.18). Their rectangular shape is 32,3 mm long, 25,7 mm large, and 10,3 mm thick (Tab. 4.61). The section of the flakes is generally flat (n=18), then triangular (n=6), dihedral (n=3), and irregular (n=3; Tab. 4.62). The maximum width coincided with the proximal portion of the products (n=12), followed by mesial (n=7) and distal (n=7), being regular on three artefacts (Tab. 4.63). The maximum thickness is often placed on the proximal part (n=12), followed by the mesial portion (n=7), and then distal (n=5). Five flakes exhibit a regular thickness along their profiles (Tab. 4.64). Platforms are either natural (n=15) or flat (n=10), with sporadic evidence of cortical (n=1), punctiform (n=1), and linear (n=2). No fractured butts were found (Tab. 4.65). Their morphology is primarily quadrangular/trapezoidal (n=15), then equally oval/triangular (n=4), narrow, curved (n=4), and narrow (n=4). Only one flake shows a crushed morphology on the butt (Tab. 4.66).

The documented bulbs are diffused (n=10), pronounced (n=8), crushed (n=5), and spike-like (n=1). The bulb was removed on two flakes but did not develop on three (Tab. 4.67). The Hertzian cone developed on 12 flakes, attested by ventral fissures (n=6), ring cracks (n=4), or being very subtle (n=2). It was detached on two flakes and did not develop on 15 artefacts (Tab. 4.68). The lip was documented on 12 flakes, being either diffused (n=6) or pronounced (n=6), while it was absent on 15 (Tab. 4.69). Bulbar scars and ripples/undulations were absent on the entire analysed sample. No micro-shattering was detected (Tab. 4.70).

The distal termination of the flakes was mainly regular (n=25), with few cases of hinged terminations (n=2) or broken ones (n=3; Tab. 4.71). Regarding the flaking axis, it was primarily axial (n=17) than *dejete* (n=9; Tab. 4.72). The removals' organisations exhibit a predominance of unipolar scars (n=17), followed by bipolar (n=3), orthogonal (n=1), and convergent ones (n=1; Tab. 4.73). Seven flakes were without removals. Backed margins were attested on the majority of the sample (n=17), being more often plunging (n=9) than debordant (n=5), with a compresence of both on three artefacts (Tab. 4.74). Complete pieces comprise more than half of the sample (18 out of 30). Fractures usually occurred longitudinally, on the platform margin, or transversally (Tab. 4.75).

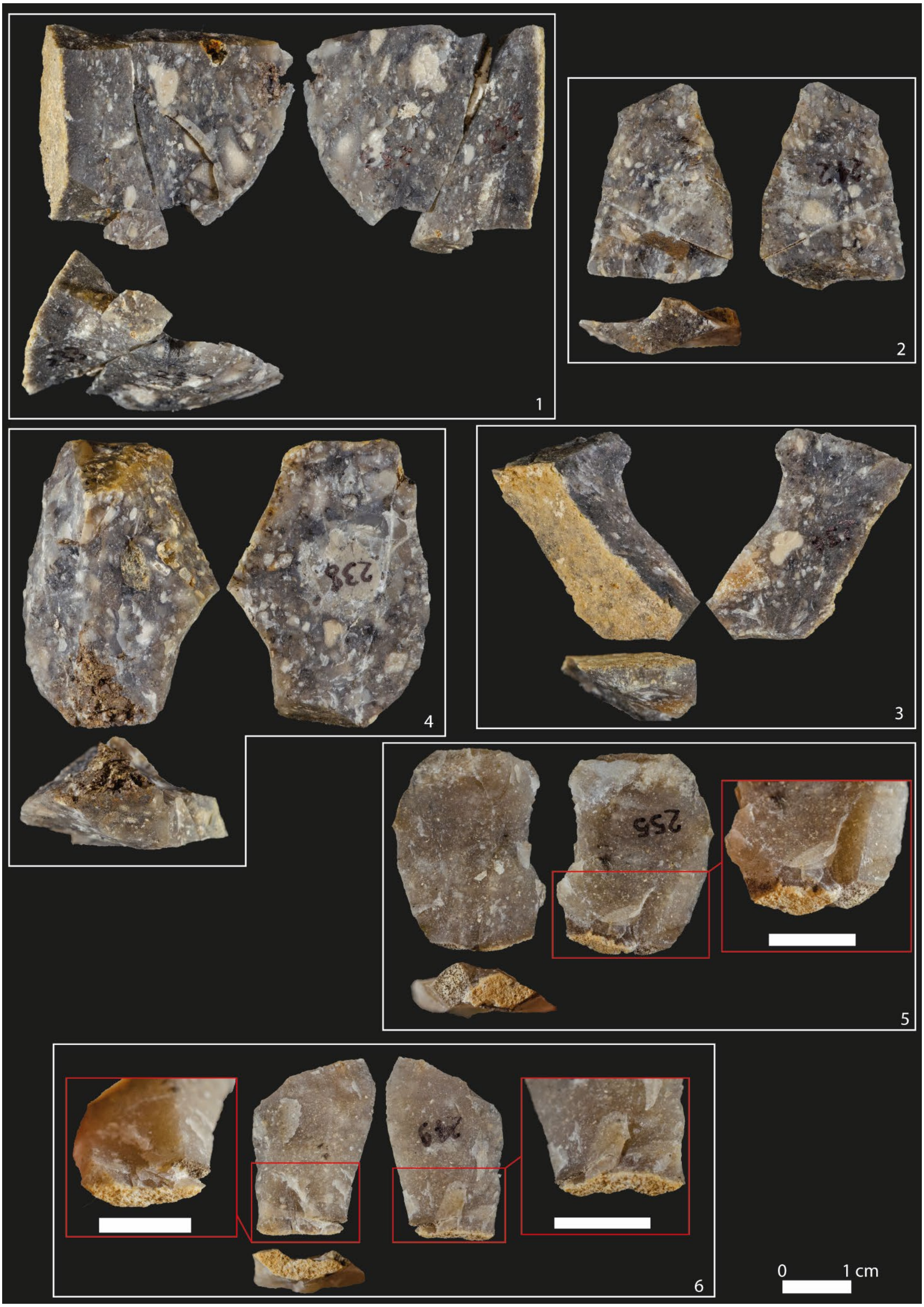

238
255
249
1
2
3
4
5
6
0
1 cm

Figure 4.6 Selection of flakes obtained from large-sized slabs knapped through direct percussion with the hard hammer. 1. Flake of medium quality with siret-type fracture and oval/triangular platform; 2. Flake of medium quality with narrow curved platform; 3. Flake of medium quality narrow platform and dèjète flaking axis; 4. Flake of medium quality with quadrangular/trapezoidal platform; 5. Flake of good quality with quadrangular/trapezoidal platform and presence of bulbar scar on the ventral face; 6. Flake of good quality with proximal micro-shattering, narrow curved platform, and dèjète flaking axis.

4.4.2. Bipolar on anvil percusssion

A total of 24 slabs were knapped using the bipolar on anvil percussion: nine small-sized slabs, eleven medium-sized, and four large-sized. The 24 slabs selected produced 25 cores.

Small slabs

A total of nine slabs were knapped, producing eight cores (Fig. 4.19) and a total of 34 flakes (Fig. 4.20) and four chunks (*i.e.*, fragments with traces of percussion activities but lacking the classic characteristics of a flake; Tab. 4.78). The core was missing on one slab (3) as it was destroyed during the knapping activity, and another (21) fractured into two smaller fragments during the debitage. Seven cores were exploited on the thickness axis, one on the length and one on the width. Four slabs (5, 6, 15, and 24) presented sub-parallel margins on the initial knapping surfaces and were knapped using the counterblow technique (*i.e.* the knapping surface created an obtuse angle with the anvil; Fig. 4.19, n° 2, 4). Striking platforms are natural on all cores except for one where a cortical surface was exploited. The debitage angle (striking platform and knapping surface) shows a mean value of 78°, while the counter-debitage angle (between the anvil and the knapping surface) has a mean value of 88°. The morphology of the knapping surfaces was equally flat (n=3), orthogonal (n=3), or tournant (n=2), regardless of the counterblow technique. The removals' organisations show bipolar scars on six cores (including three of the four cores knapped through the counterblow technique; Fig. 4.19, n° 1 - 4) and unipolar scars on one (knapped with the counterblow technique). It was impossible to read the scars' organisation on one core (21, the fractured one) due to the raw material texture. Evidence of proximal micro-shattering (where the hammer hit the striking platforms) was detected on six out of eight cores. The striking platforms in contact with the anvil did not yield traces of micro-shattering, except in one case (Fig. 4.19, n° 4). On one core, the debitage angle at the contact with the anvil was compatible with a direct percussion angle. Another core is similar to a scaled piece (Fig. 4.19, n° 3).

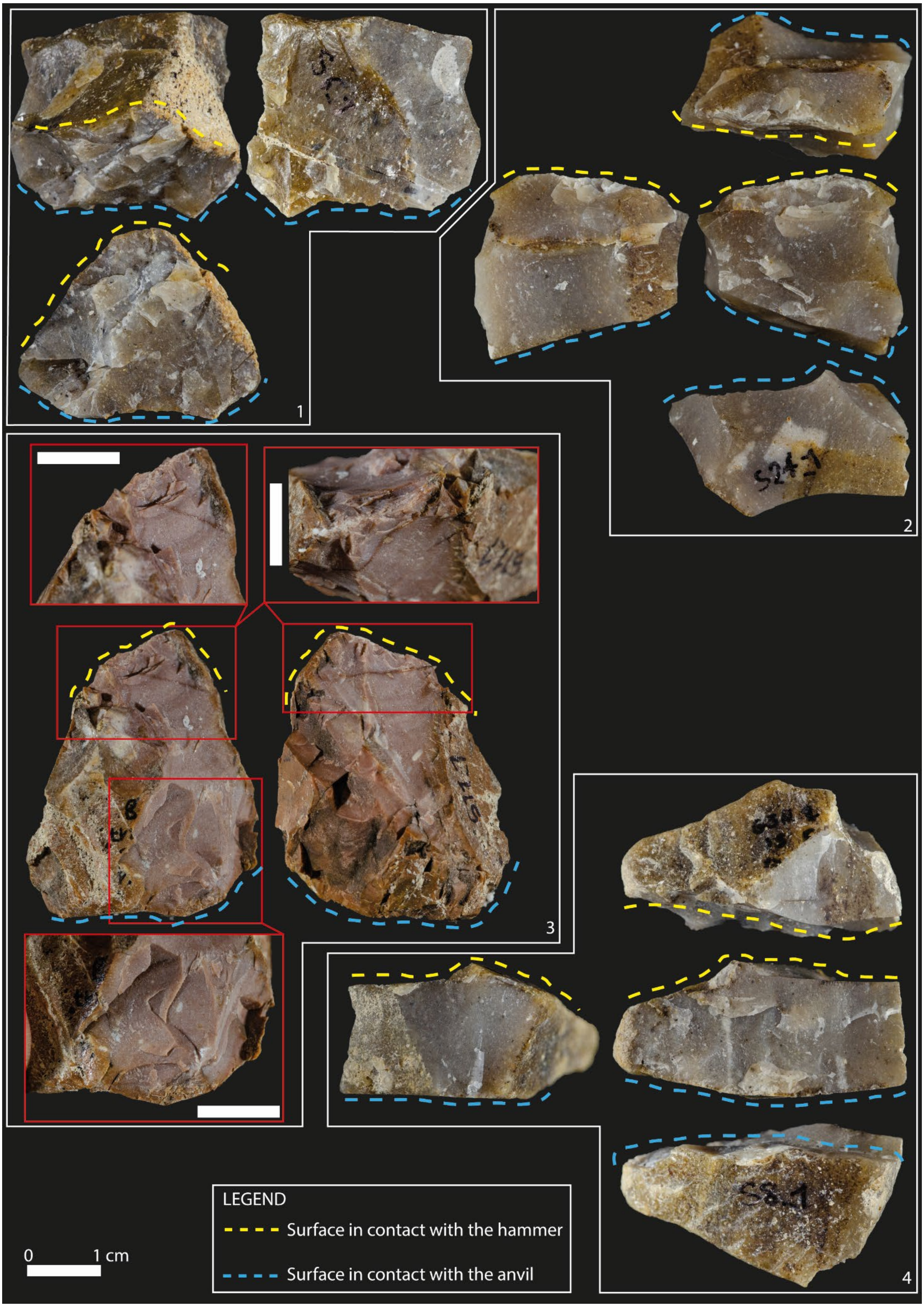

1
2
3
4
LEGEND
Surface in contact with the hammer
Surface in contact with the anvil
0
1 cm

Figure 4.7 Selection of cores knapped through the bipolar on anvil technique using small-sized slabs. 1. Core of good quality with bipolar removals; 2. Core of good quality with bipolar removals and evidence of micro-shattering where the hammer came in contact with the striking platform; 3. Core of medium quality with bipolar removals and crushed striking platform. There is evidence of micro-shattering where the hammer came in contact with the striking platform; 4. Core of medium quality with a clear removal detached from the anvil and evidence of micro-shattering where the core cae in contact with the anvil.

Table 4.22 Small-sized slabs dimensions and number of obtained flakes.

Slab/Core ID	**Technique**	**Blows**	**Length**		**Width**		**Thickness**		**Flakes obtained**
Small			Initial	Final	Initial	Final	Initial	Final	n
3	Bipolar	10	51,2	-	36,9	-	30,7	-	3 (3 chunks)
5	Bipolar	50	56,7	41,2	36,7	30	37,5	21,7	4
6	Bipolar	50	40,3	34	36,1	31,5	32,1	26,8	5 (1 chunk)
8	Bipolar	50	38,5	37,1	33,3	18,8	26,5	17,9	5
11	Bipolar	50	46,6	39,3	32,7	31,6	30,4	20,7	3
13	Bipolar	16	50,9	39,5	41,5	34,5	15,3	15,1	9
15	Bipolar	50	47,4	32,5	36,4	26,4	25,7	21,7	2
21	Bipolar	11	39,9	28,5	29,8	21,8	33,3	17	2
24	Bipolar	12	45,7	30,7	42	20,8	22,6	16,3	5
Total	9								38

A total of 34 flakes were produced, bearing evident marks of debitage activities (Tab. 4.78; Fig. 4.20). The number of fragments and indeterminable pieces was relevant. When the flakes were detached from the anvil (*i.e.* established during the refitting of the cores) but were not exhibiting counter-bulbs/butts/etc. they were classified as "regular" flakes, though it was noted that they were produced from the impact with the anvil. The shape of the produced flakes is quadrangular, dimensionally included within mean values of 19,9 mm in length, 19,3 in width, and 8,4 mm in thickness (Tab. 4.79). The section of the flakes is mostly flat (n=18), then dihedral (n=9), and more rarely triangular (n=5) or irregular (n=2; Tab. 4.80). The maximum width is equally distributed along the distal (n=8), mesial (n=7), and proximal (n=6) portions, being regular on eleven flakes and irregular on one (Tab. 4.81). The maximum thickness often corresponds to the proximal part of the flakes (n=13), followed by the distal (n=8) and mesial (n=4) parts. The thickness was constant on six flakes and irregular on one (Tab. 4.82). The general profile of the flakes is primarily regular (n=21), then curve (n=9), and more rarely irregular (n=3; Tab. 4.83). Platforms are natural on most of the flakes (n=14), but punctiform (n=4), flat (n=3), linear (n=3), and cortical (n=2) butts were also recorded. Five fractured butts were documented (Tab. 4.84). The platform's morphology is generally quadrangular/trapezoidal (n=11) or oval/triangular (n=9), more rarely crushed (n=4), narrow (n=3), and narrow curved (n=1; Tab. 4.85).

Table 4.23 Dimensional values of bipolar on anvil flakes.

Slabs dimensional class	**Small**			**Medium**			**Large**		
Bipolar on anvil	length	width	thickness	length	width	thickness	length	width	thickness
Flakes	n=28			n=53			n=13		
min	8,3	7,3	1,5	10,3	6,4	1,4	22,9	14,6	3,4
max	32,4	50,4	24,9	55,9	52,6	39,8	71,4	59,9	53,6
mean	**19,9**	**19,3**	**8,4**	**25,8**	**19**	**8,5**	**45,7**	**31,7**	**20,6**

The documented bulbs are diffused in most cases (n=14), then pronounced (n=4), sheared (n=4), crushed (n=1), and spike-like (=1). The bulb was removed on two flakes and did not develop on seven artefacts (Tab. 4.86). The Hertzian cone was developed on 13 flakes, usually attested by ventral fissures (n=9), rings crack (n=4), or subtle (n=3). It was detached on two flakes but did not form on fourteen (Tab. 4.87). Regarding the lip, it was absent on a large portion of the sample (22 out of 25 flakes) or sporadically diffused (n=2) and pronounced (n=1; Tab. 4.88). The presence of ripples/undulations was somewhat low (3/34), while a higher frequency of bulbar scars (9/34) and proximal micro-shattering (7/34) was reported (Tab. 4.89).

The distal termination of the flakes detected traces of rebound impacts on 13 artefacts, while it was broken down on seven and hinged on one. On the remaining 13 flakes, the distal termination was regular (Tab. 4.90). The flaking axis was axial on 19 flakes and *dejete* on 5 (Tab. 4.91). The removal organisations exhibit a predominance of unipolar (n=12) and bipolar (n=8) scars, followed by 12 flakes without removals (Tab. 4.92). Backed flakes are also very common (n=20), being equally debordant (n=8) and plunging (n=8). Evidence of flakes with backed margins on all sides (n=3) was also reported. Ten flakes showing no backed margins were documented (Tab. 4.93). Concerning fractures, seven flakes were complete, while on the remaining, the most frequently attested fractures were located transversally, longitudinally, on the platform or at the base of the flakes. Siret accidents were also present (n=3; Tab. 4.94).

Table 4.24 Bipolar on anvil flakes' section.

Bipolar on Anvil	Small	Medium	Large	Total	
Flakes' section	n	n	n	n	%
Flat	18	29	2	49	47,6
Dihedral	9	17	6	32	31,1
Triangular	5	9	4	18	17,5
Irregular	2	1	1	4	3,9
Total	34	56	13	103	-

Ten of all the flakes – belonging to the different cores – obtained were detached from the anvil during the debitage (Fig. 4.20, n° 1, 2, 4-6), but only two of these ten flakes exhibited evident traces on the distal portion (Fig. 4.20, n° 2, 6). On the other hand, counterblows or anvil marks at the distal end of the flakes were detected on 6 out of 22 flakes. Four of these six flakes come from the same core (core 8), while two are from different cores (cores n° 5 and 6). The six documented counter-butts are natural (n=4), then cortical (n=1), and punctiform (n=1). Their morphology is quadrangular/trapezoidal (n=3), oval/triangular (n=2), and narrow (n=1). The mean counter-angle recorded is 88°. The morphology of the counter-bulb is diffused (n=3) and sheared (n=1), while it was removed on one flake and did not develop on the last. The lip was diffused on one flake and absent on three other flakes. The counter-cone was present on two flakes, attested by ventral fissures, while on the other three flakes did not develop.

Table 4.25 Maximum width of bipolar on anvil flakes.

Bipolar on Anvil	Small	Medium	Large	Total	
Maximum Width	n	n	n	n	%
Proximal	6	13	1	20	19,8
Mesial	7	7	-	14	13,9
Distal	8	17	4	29	28,7
Regular	11	15	7	33	32,7
Irregular	1	3	1	5	5
Total	33	55	13	101	-

Table 4.26 Maximum thickness of bipolar on anvil flakes.

Bipolar on anvil	Small	Medium	Large	Total	
Maximum Thickness	n	n	n	n	%
Proximal	13	19	4	36	36
Mesial	4	3	2	9	9
Distal	8	19	3	30	30
Regular	6	11	4	21	21
Irregular	1	3	-	4	4
Total	32	55	13	100	100

Table 4.27 Profile of bipolar on anvil flakes.

Bipolar on Anvil	Small	Medium	Large	**Total**	
Flakes' profile	n	n	n	n	%
Regular	21	28	6	55	53,9
Irregular	3	5	-	8	7,8
Curve	9	23	7	39	38,2
Total	33	56	13	102	-

Table 4.28 Platform type of bipolar on anvil flakes.

	Bipolar on anvil				
Size	Small	Medium	Large	**Total**	
Platform Type				**n**	**%**
Cortical	2			**2**	**2**
Natural	14	30	9	**53**	**53**
Flat	3	5	2	**10**	**10**
Dihedral					**-**
Punctiform	4	4		**8**	**8**
Linear	3	12		**15**	**15**
Fractured	5	5	2	**12**	**12**
Total	31	56	13	**100**	**-**

Table 4.29 Platform morphology of bipolar on anvil flakes.

Bipolar on anvil					
Size	Small	Medium	Large	**Total**	
Platform Morphology				**n**	**%**
Oval/Triangular	9	16	2	**27**	**28,4**
Quadr./Trapez.	11	14	6	**31**	**32,6**
Narrow curved	1	2	1	**4**	**4,2**
Narrow	3	14		**17**	**17,9**
Crushed	4	8	4	**16**	**16,8**
Total	28	54	13	**95**	**-**

Table 4.30 Bulb morphology of bipolar on anvil flakes.

Bipolar on anvil					
Size	Small	Medium	Large	**Total**	
Bulb morphology				**n**	**%**
None	7	7	6	**20**	**19,8**
Diffuse	14	16	2	**32**	**31,7**
Pronounced	4	8	2	**14**	**13,9**
Crushed	1	12	2	**15**	**14,9**
Sheared	4	5		**9**	**8,9**
Spike-like	1				**-**
Removed	2	8	1	**11**	**10,9**
Total	33	56	13	**101**	**-**

Table 4.31 Cone formation of bipolar on anvil flakes.

Bipolar on anvil					
Size	Small	Medium	Large	**Total**	
Conus formation				**n**	**%**
None	14	19	5	**38**	**37,6**
Ring crack on butt	4	12	3	**19**	**18,8**
Ventral fissures	9	15	4	**28**	**27,7**
Detached bulb	2	8	1	**11**	**10,9**
Hint	3	2		**5**	**5**
Total	32	56	13	**101**	**-**

Table 4.32 Lip formation of bipolar on anvil flakes.

Bipolar on Anvil	**Small**	**Medium**	**Large**	Total	
Lip formation	n	n	n	n	%
None	22	39	10	71	94,7
Diffuse	2		1	3	4
Pronounced	1			1	1,3
Total	25	39	11	75	-

Table 4.33 Traces of bipolar on anvil flakes.

Bipolar on Anvil	**Small**	**Medium**	**Large**	Total	
Traces	n	n	n	n	%
Ripples/Ondulation	3/34	8/56	0/13	11/103	10,7
Bulbar scar	9/34	24/56	6/13	39/103	37,9
Proximal micro-shattering	7/34	19/56	0/13	26/103	25,2

Table 4.34 Distal termination of bipolar on anvil flakes.

Bipolar on anvil	Small	Medium	Large	**Total**	
Distal termination	n	n	n	n	%
Rebound force	13	19	4	36	35
Broken	7	5	1	13	12,6
Hinged	1	4		5	4,9
Regular	13	28	8	49	47,6
Total	34	56	13	103	-

Table 4.35 Flaking axis of bipolar on anvil flakes.

Bipolar on Anvil	Small	Medium	Large	**Total**	
Flaking axis	n	n	n	n	%
Axial	19	36	13	68	81,9
Dejete	5	10		15	18,1
Total	24	46	13	83	-

Table 4.36 Removals organisation of bipolar on anvil flakes.

Bipolar on anvil					
Size	Small	Medium	Large	**Total**	
Removals				**n**	**%**
Absent	12	16	6	**34**	
Unipolar	12	19	2	**33**	
Bipolar	8	17	5	**40**	
Indetermined	2	4		**6**	
Total	34	56	13	**113**	

Table 4.37 Backed margins of bipolar on anvil flakes.

Bipolar on Anvil	**Small**	**Medium**	**Large**	Total	
Backed margin	n	n	n	n	%
Present	20	33	6	59	60,2
Debordant	8	7		15	15,3
Plunging	8	16	2	26	26,5
Debordant and Plunging	1	8	1	10	10,2
All sides	3	2	3	8	8,2
Absent	10	22	7	39	39,8
Total	30	55	13	98	-

Table 4.38 Type of fracture of bipolar on anvil flakes.

Bipolar on anvil	Small	Medium	Large	**Total**	
Type of fracture	n	n	n	n	%
Longitudinal Siret type fracture	1		1	2	2,2
Siret type and platform fractures		1		1	1,1
Siret type and base	1			1	1,1
Siret, platform and base					
Siret and transversal	1			1	1,1
Platform	3	2	2	7	7,8
Base	1	5	2	8	8,9
Base and basal flake	1			1	1,1
Platform and base	1	1		2	2,2
Platform and basal flake					
Side longitudinal	6	12	2	20	22,2
Side longitudinal and base	1	1		2	2,2
Side longitudinal and platform	1			1	1,1
Side longitudinal, platform and base		2		2	2,2
Side longitudinal and basal flake					
Transversal	9	8		17	18,9
Transversal and platform					
Transversal and base	1			1	1,1
Transversal, base and platform					
Double transversal					
Lateral and transversal					
Lateral, transversal and base		3		3	3,3
Lateral, transversal and platform					
Basal flake		2		2	2,2
None	7	19	6	32	35,6
Total	34	56		90	-


1
2
3
4
5
6
7
0
1 cm

Figure 4.8 Selection of bipolar on anvil flakes obtained from small-sized slabs. 1. Flake of good quality detached from the anvil with oval/triangular platform, pronounced bulb and diffused lip. The Hertzian cone is characterised by ring crack on the butt. The distal termination is characterised by traces of rebound force, with evidence of distal fracture and distal shattering. In this case the distal termination correspond to the portion of the core in contact with the hammer; 2. Flake of good quality detached from the anvil with oval/triangular platform, ventral fissures characterising the Hertzian cone, and partial evidence of proximal micro-shaterring. The distal end is characterised by a punctiform counter-butt with a micro-negative on the ventral face; 3. Flake of good quality with crushed platform and spike-like bulb. The distal end is characterised by the presence of a quadrangular/trapezoidal counter-butt with a sheared bulb; 4. Flake of medium quality detached from the anvil with fractured platform; 5. Flake of good quality detached from the anvil with oval/triangular platform and diffused bulb. There is evidence of rebound force traces on the distal end; 6. Flake of good quality detached from the anvil with counter-bulbar scar at the distal end of the ventral face; 7. Flake of good quality with punctiform platform, distal micro-shattering and traces of rebound force at the distal end.

Medium slabs

A total of twelve slabs were knapped, producing twelve cores and a total of 56 flakes (Tab. 4.95; Fig. 4.21, 4.22). Two cores did not yield any flakes because of the internal fractures of the slabs, which caused several breakages and indeterminable fragments (Fig. 4.21, n° 5). Six cores fragmented during the debitage, and from slab 67, two cores were obtained. Cores were exploited along the width axis in five cases, on the thickness axis in three cases, on the length axis in three cases, and one was cubic-shaped. Three cores presented sub-parallel margins and were knapped using the counterblow technique. The quality of the raw material prevented an accurate reading of the surfaces in most cases (Fig. 4.21, n° 1, 5). All the exploited striking platforms were natural. The presence of proximal micro-shattering was documented on six cores (Fig. 4.21, n° 1, 2, 4), while traces of shattering produced by the anvil were detected on one single core. On the other hand, the presence of counterblows (*i.e.,* negatives on opposite striking platforms) was recorded on seven cores (Fig. 4.21, n° 3, 4). The debitage angle between the striking platform and the knapping surface shows a mean value of 78°, while the counter-debitage angle has a mean value of 90°. The morphology of the knapping surfaces were flat (n=4), orthogonal (n=4), and tournant (n=2). The removal organisation showed unipolar scars on five slabs and bipolar ones on four cores. One of the cores (n°34) was opened through the split fracture technique to overcome the lower quality of the raw material, while another core (n°62) was realised from a large flake deriving from one of the fragments during the opening of the initial slab. Also, in this case, a core exhibiting some similarities with scaled pieces – associated with a fine texture of the chert - was recorded.

Table 4.39 Medium-sized slabs dimensions and number of obtained flakes

Slab/Core ID	Technique	Blows	Length		Width		Thickness		Flakes obtained
Medium			Initial	Final	Initial	Final	Initial	Final	n
34	Bipolar	50	70,4	55	61,8	44,3	36,3	36,3	2
40	Bipolar	20	81,7	53	59,4	47,6	43,4	43,1	-
48	Bipolar	9	60,2	55,5	33,4	20,6	31,8	12	6
53	Bipolar	40	73,7	67,6	34,5	25,5	29,2	13,1	5
54	Bipolar	10	59,5	59,1	57,7	44,4	45,8	40,2	2
56	Bipolar	32	67,7	63,3	41,7	36,9	34,1	30,7	2
58	Bipolar	40	74,4	25,5	34,6	25,3	20,7	19,6	15
62	Bipolar	20	66,7	32,5	34,6	29,8	31,5	15,4	11
64	Bipolar	7	87,4	-	71,3	-	38,1	-	1
66	Bipolar	15	89,3	-	59,4	-	50	-	-
67_1	Bipolar	50	63,3	39,8	39,2	26,4	27,5	26,1	2
67_2	Bipolar	35	63,3	22,1	39,2	20	27,5	15	10
Total	12								56

A total of 56 flakes bearing evident marks of debitage activities were obtained during the experimentation (Fig. 4.22). The number of debris and fragments was significant. The shape of the flakes is rectangular, more developed in length than width. The mean dimensions of the pieces are 25,8 mm in length, 19 mm in width, and 8,5 mm in thickness (Tab. 4.79). The section of the flakes is usually flat (n=29), followed by dihedral (n=17). Triangular sections were documented on nine flakes, with only one irregular section on the sample (Tab. 4.80). The maximum width is equally distributed along the distal (n=17) and proximal (n=13) portion of the dorsal face, less frequently located on the mesial part (n=7). Width is regular on 15 artefacts and irregular on three (Tab. 4.81). In most cases, the maximum thickness coincided with the proximal (n=19) or distal (n=19) portion. It was sporadically attested on the mesial part (n=3). Thickness was regular along the entire profile on 11 flakes and irregular on three (Tab. 4.82). Overall, the profile of the products is either regular (n=28) or curve 8n=23), rarely irregular (n=5; Tab. 4.83).

Platforms are primarily natural (n=30), then linear (n=12), flat (n=5), fractured (n=5), or punctiform (n=4; Tab. 4.84). The predominant morphology is either oval/triangular (n=16) or quadrangular/trapezoidal (n=14). Narrow and narrow curved platforms are also common (n=16), though almost exclusively associated with linear butts. Crushed morphologies were recorded on eight platforms (Tab. 4.85). Regarding bulbs' morphology, it is recurrently diffused (n=16) or crushed (n=12), followed by pronounced (n=8) and sheared (n=5). Bulbs were removed on eight flakes and did not develop on seven (Tab. 4.86). The Hertzian cone was documented on 29 flakes, mostly attested by ventral fissures (n=15), rings crack (n=12), and more rarely subtle (n=2). It coincided with a detached bulb on eight flakes but did not develop on 19 artefacts (Tab. 4.87). The lip was completely absent on all the flakes analysed (n=39; Tab. 4.88). The presence of ripples/undulations was documented on 8 out of 56 flakes, being somewhat scarce, while bulbar scars (24/56) and proximal micro-shattering (19/56) were more frequently attested (Tab. 4.89). The mean value of the debitage angle is 90°.

The distal termination of the flakes is characterised by traces of rebound impacts on 19 artefacts, broken down on five flakes and hinged on four others. On 28 flakes, the distal termination was regular (Tab. 4.90). The flaking axis is axial on 36 flakes and *dejete* on 10 (Tab. 4.91). The removal organisations exhibit a predominance of unipolar (n=19) and bipolar (n=17) scars, though flakes without removals are also quite frequent (n=16; Tab. 4.92). The incidence of backed margins was documented on 33 out of 22 flakes, being recurrently located on the distal margins (plunging; n=16), less frequently on the lateral (debordant; n=7), or both (n=8). Two flakes with backed margins on all sides were also recorded (Tab. 4.93). The incidence of fractures was relatively common (19 complete pieces on a sample of 56 flakes). Fractures occurred predominantly longitudinally, transversally, or, more sporadically, at the base of the flakes (Tab. 4.94).

Ten flakes were detached from the anvil, though only two present characteristics of counterblows/bulbs/butts/etc. on their distal end. These flakes derive from three cores (one from core n°34, four from core n°58, and five from core n°62). Flakes presenting counterblows or anvil marks at their distal margin were detected on 14 of 54 artefacts deriving from five cores. The counter-platforms, which show a mean debitage angle of 94°, are mostly natural (n=8), punctiform (n=1), and linear (n=1). In three cases, they were fractured. The morphology of the butts is crushed (n=6), quadrangular/trapezoidal (n=4), oval/triangular (n=2), and narrow curved (n=1). The morphology of the counter-bulb, which did not form on three flakes and was removed on two others, is diffused (n=5), pronounced (n=2), and crushed (n=1). The lip was absent on five artefacts, diffused on one, and pronounced on another. The cone developed on ten flakes, being attested by ventral fissures (n=5), rings crack (n=4), or associated with a detached bulb (n=1). In four, flakes did not develop.

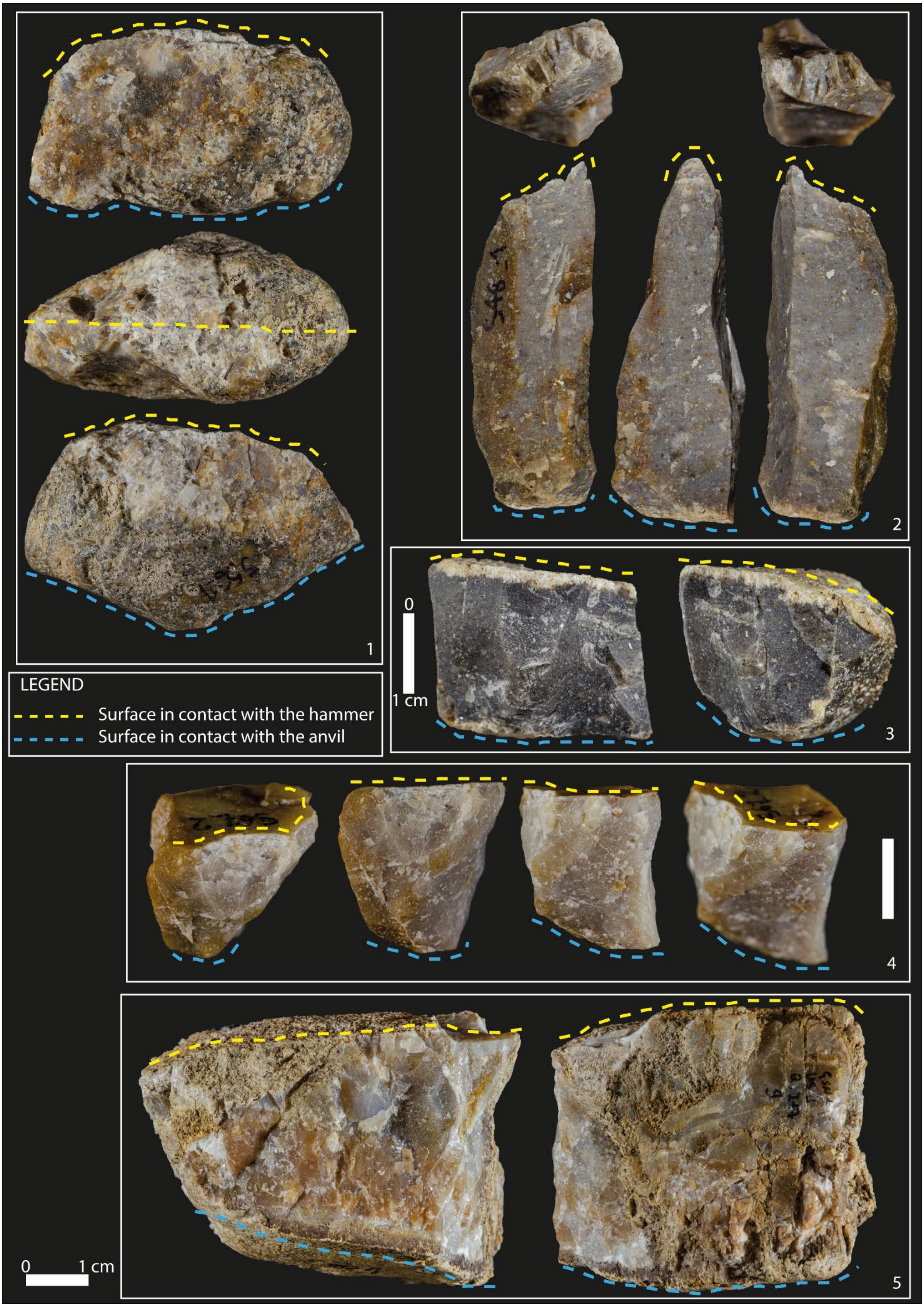
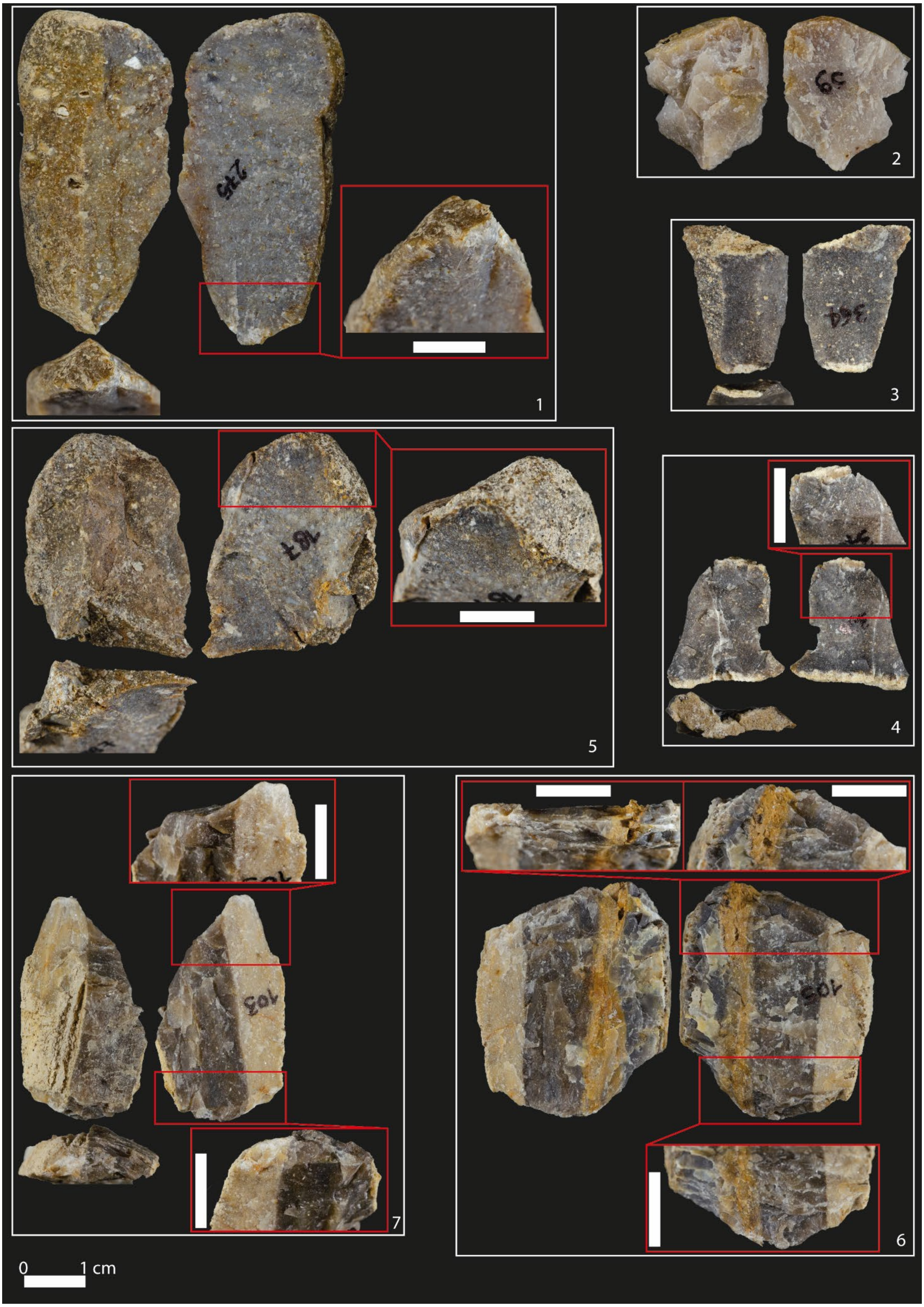

1
2
0
1 cm
3
4
5
0
1 cm
LEGEND
Surface in contact with the hammer
Surface in contact with the anvil

Figure 4.9 Selection of cores knapped through the bipolar on anvil technique from medium-sized slabs. 1. Core of low quality with evidence of removals only deriving from the contact with the hammer. The micro-shattering is pronounced. 2. Dihedral core of medium quality with pronounced micro-shattering on the striking platform in contact with the hammer. The contact with the anvil did not produce any traces. 3. Core of medium quality with bipolar removals and partial evidence of micro-shattering derived from the contact with the anvil. 4. Core of medium quality with pronounced micro-shattering but only in corrispondence with the portion of the striking platform in contact with the hammer. There is evidence of bipolar removals; 5. Core of low quality with several internal fractures making it impossible to analyse.

Figure 4.10 Selection of bipolar on anvil flakes obtained from medium-sized slabs. 1. Flake of medium quality with quadrangular/trapezoidal platform, diffused bulb, and ventral fissures attesting to the Hertzian cone development; 2. Flake of low/medium quality with crushed platform, evidence of distal micro-shatterin on the dorsal face, counter-bulb with diffused morphology and counter-platform of narrow morphology; 3. Flake of medium quality with narrow platform and dèjète flaking axis. There is evidence of a small fracture on the distal end of the ventral face which could be indicate a contact with the anvil. 4. Flake of medium quality with narrow curved platform, diffused counter-bulb, narrow counter-butt, with ventral fissures attesting to the development of the counter-Hertzian cone; 5. Flake of medium/low quality detached from the anvil. On the ventral face, at the distal end, there is evidence of a counter-bulb produced by the contact with the hammer. 6. Flake of medium/low quality with several internal fractures and crushed platform. There is evidence of pronounced proximal and distal micro-shattering. This flake is similar to a scaled piece; 7. Flake of good quality with narrow curved platform, evidence of proximal micro-shattering, and sheared bulb. On the distal end there is evidence of a crushed counter-butt associated with ventral fissures and diffused bulb. The lateral margin of the flake is characterised by several factures produced during the knapping activity.



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3
4
5
6
7
0 1 cm

Large slabs

A total of four slabs were knapped, producing four cores and a total of 13 flakes (Tab. 4.96; Fig. 4.23, 4.24). One core (n°73) did not yield any identifiable flakes and was abandoned after 20 blows due to the internal fractures producing many fragments. All the cores, except one cubic-shaped, were knapped on the thickness axis. Natural striking platforms were exploited on three cores and a cortical one. Proximal micro-shattering was documented on two cores (Fig. 4.23, n° 1), with no evidence of anvil micro-shattering. On the other hand, counterblows produced from the anvil were attested on two cores (Fig. 4.23, n° 1). The debitage angle between the striking platform and the knapping surface shows a mean value of 95°, while the counter-debitage angle has a mean value of 87°. The morphology of knapping surfaces was diversified, including tournant, irregular, flat and orthogonal morphologies. The removal organisations exhibit unipolar scars on two cores and bipolar scars on the remaining two.

Table 4.40 Large-sized slabs and number of obtained flakes.

Slab/Core ID	Technique	Blows	Length		Width		Thickness		Flakes obtained
Large			Initial	Final	Initial	Final	Initial	Final	n
69_2	Bipolar	50	130,8	59	63	56,9	58,7	53,2	5
73	Bipolar	20	93	68,7	60,8	43,9	44,9	37,2	-
75	Bipolar	20	98,7	59	62,6	39,6	44,8	37,2	3
76	Bipolar	10	119,5	81	101,3	66,6	65,9	50,4	5
Total	4								13

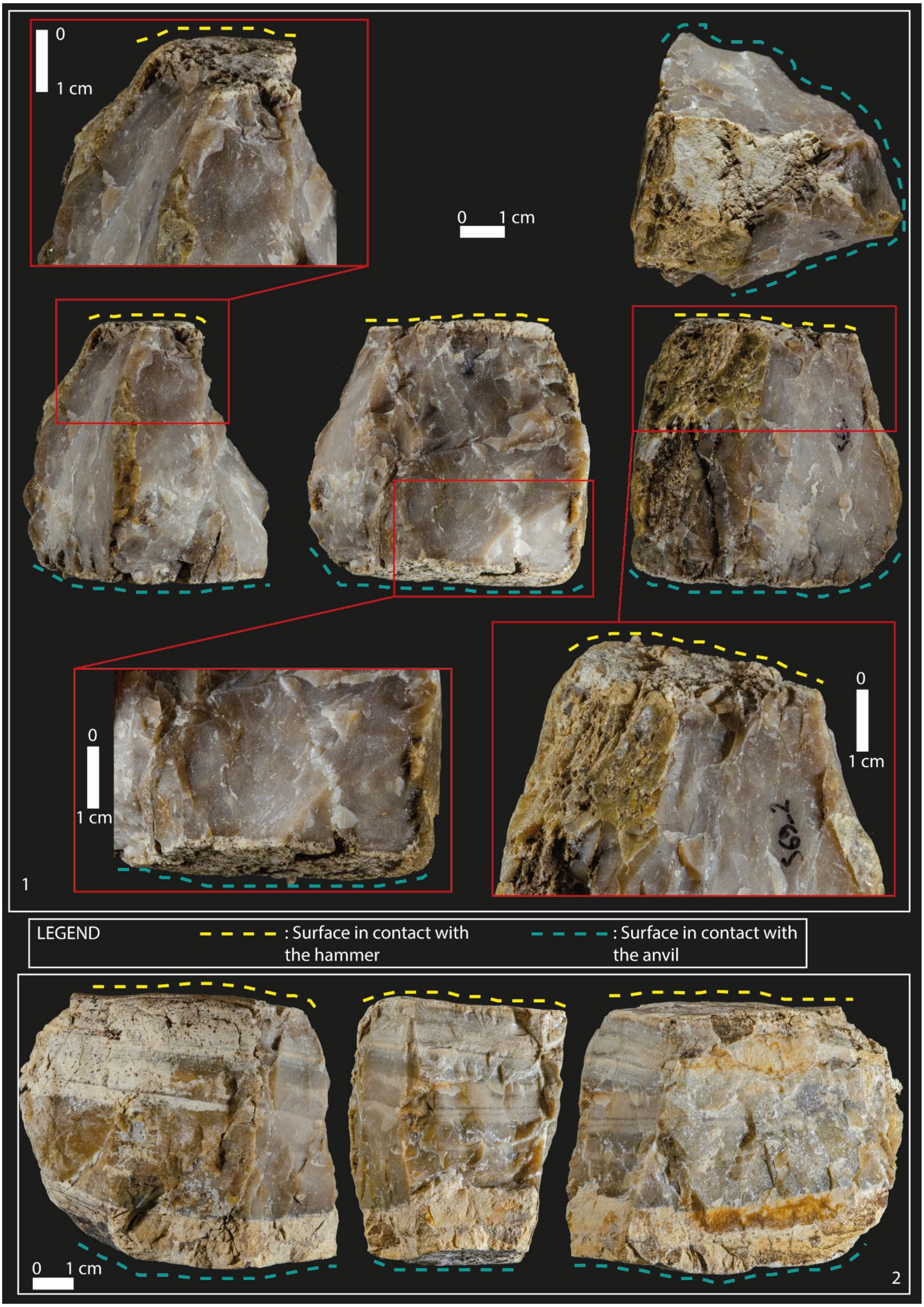
Thirteen flakes were obtained during the experimentation (Tab. 4.96; Fig. 4.24). The large size of the slabs was matched by a high number of internal fractures, the absence of suitable angles, and the hardness of the raw material. The shape of the flakes is rectangular, mainly developed in length. The mean dimensions of the products are 45,7 mm in length, 31,7 mm in width, and 20,6 mm in thickness (Tab. 4.79). The section of the flakes was dihedral on six flakes, triangular on four, flat on two and irregular on one (Tab. 4.80). The general profile was either curve (n=7) or regular (n=6; Tab. 4.83). The maximum thickness was equally distributed on the proximal (n=4) distal (n=3) and mesial (n=2) portion of the flakes, being regular on four products (Tab. 4.82). Concerning maximum width, it was more often regular (n=7) or located on the distal part (n=4) and occasionally placed on the proximal part (n=1) or irregular (n=1; Tab. 4.81).

Platforms are usually natural (n=9) or flat (n=2) and fractured (n=2; Tab. 4.84). The most recurrent morphology is quadrangular/trapezoidal (n=6), followed by crushed (n=4), oval/triangular (n=2), and narrow curved (n=1; Tab. 4.85). Bulbs were documented on six flakes, showing diffused (n=2), pronounced (n=2), and crushed (n=2) morphologies. The bulb did not develop on six artefacts; it was removed on another (Tab. 4.86). The cone was present on seven flakes, attested by ventral fissures (n=4) and ring crack (n=3). On the remaining six flakes, it was either absent (n=5) or removed (n=1; Tab. 4.87). The lip was almost absent on all the flakes except for one where it was diffused (Tab. 4.88). The incidence of ripples/undulations and proximal micro-shattering was also absent, while bulbar scars were attested on 6 of 13 flakes (Tab. 4.89). The mean value of the angle of debitage was 92°.

The distal portion of the flakes is characterised by traces of rebound forces on four cases, with one broken fragment, while it was regular on eight products (Tab. 4.90). The flaking axis was exclusively axial (Tab. 4.91). The incidence of bipolar scars documented on the dorsal faces was higher (n=5) than flakes with unipolar scars (n=2), though the absence of removals was also recurrent (n=6; Tab. 4.92). Backed margins are present on six out of 13 flakes, being plunging (n=2), plunging and debordant (n=1), or located on all sides (n=3; Tab. 4.93). Fractured flakes are also relatively common (six complete pieces), documented on the longitudinal margin or at the platform or the base of the products (Tab. 4.94).

Three flakes were detached from the anvil, deriving from the same core (n°69) and not exhibiting any traces of counterblows/bulbs/butts on the distal margin. On one flake a counter-butt was documented, exploiting a natural surface and exhibiting a quadrangular morphology. The associated bulb was diffused without developing the Hertzian cone or the lip but with evidence of bulbar scars. The relative angle of detachment is 101°. On another flake a huge counter-bulbar scar was recorded (Fig. 4.24, n° 3).

Figure 4.11 Selection of bipolar on anvil cores obtained from large-sized slabs. 1. Core of medium quality with internal fractures and bipolar removals. Evidence of micro-shattering is scarce and slightly documented only on the portion of the core in contact with the hammer; 2. Core of low quality with several internal factures which prevented from accurately reading the knapping surfaces. There is evidence of some negatives.


0
1 cm
0 1 cm
0
1 cm
0
1 cm
7695
1
LEGEND
: Surface in contact with the hammer
: Surface in contact with the anvil
0 1 cm
2

311
311
311
0 1 cm
408
2
1
310
310
310
310
0 1 cm
3
307
0
1 cm
0
1 cm
4

Figure 4.12 Selection of bipolar on anvil flakes obtained from large-sized slabs. 1. Flake of medium quality with oval/triangular platform; 2. Flake of medium quality with quadrangular/trapezoidal platform and diffused bulb. 3. Flake of good quality detached from the anvil with crushed platform, detached bulb, and traces of rebound force on the distal end where is the huge negative of a removal produced by the contact with the hammer; 4. Flake of medium quality with several internal fractures, quadrangular/trapezoidal platform, and possible evidence of fractures and micro-negatives on the distal end of the ventral face.

4.4.3. Anvil-assisted freehand percussion

Nineteen slabs were knapped using the anvil-assisted freehand: three small-sized slabs, ten medium-sized, and six large-sized. The selected slab produced 19 cores and a total of 140 flakes.

Small slabs

Three small-sized slabs have been knapped, producing three cores and eleven flakes (Tab. 4.97; Fig. 4. 25, 4.26). One core (n°14) was knapped using the striking-platform variant. The other two yielded few flakes as the number of fragments and debris obtained during the debitage was rather significant. Additionally, one core (n°2) fragmented after the first blow, generating a smaller volume to exploit. All the cores were knappped on the thickness axis, using natural striking platforms. Proximal micro-shattering was documented on one core (n° 14; Fig. 4.25, n° 1), while counterblows from the anvil were detected on two cores (n° 2, 14; Fig. 4.25, n° 1). The debitage angle between the striking platform and the knappping surface has a mean value of 82°, while the counter-debitage angle is 72° - though documented on one core. The morphology of the knapping surface is tournant on two cores. The third was heavily fragmented and fractured, so reading the surfaces was challenging. The organisation of the removals was bipolar on the core knapped with the counterblow variant (n° 14; Fig. 4.25, n° 1) – associated with counterblows from the anvil – and unipolar on the other one (Fig. 4.25, n° 2). Notably, most of the flakes produced from core 14 were detached from the anvil. The core knapped through the counterblow technique yielded a denticulate shape of the striking platform (Fig. 4.25, n° 1).

Table 4.41 Small-sized slabs dimensions and number of obtained flakes.

Slab/Core ID	Technique	Blows	Length		Width		Thickness		Flakes obtained
Small			Initial	Final	Initial	Final	Initial	Final	n
2	Assisted	10	43,5	34,6	37,7	34,5	27,6	14,1	1
14	Assisted	50	47,6	39,3	40,8	37,8	17,6	17,3	8
23	Assisted	50	48,4	30,6	39,6	30,3	21,8	21,2	2
Total	3								11

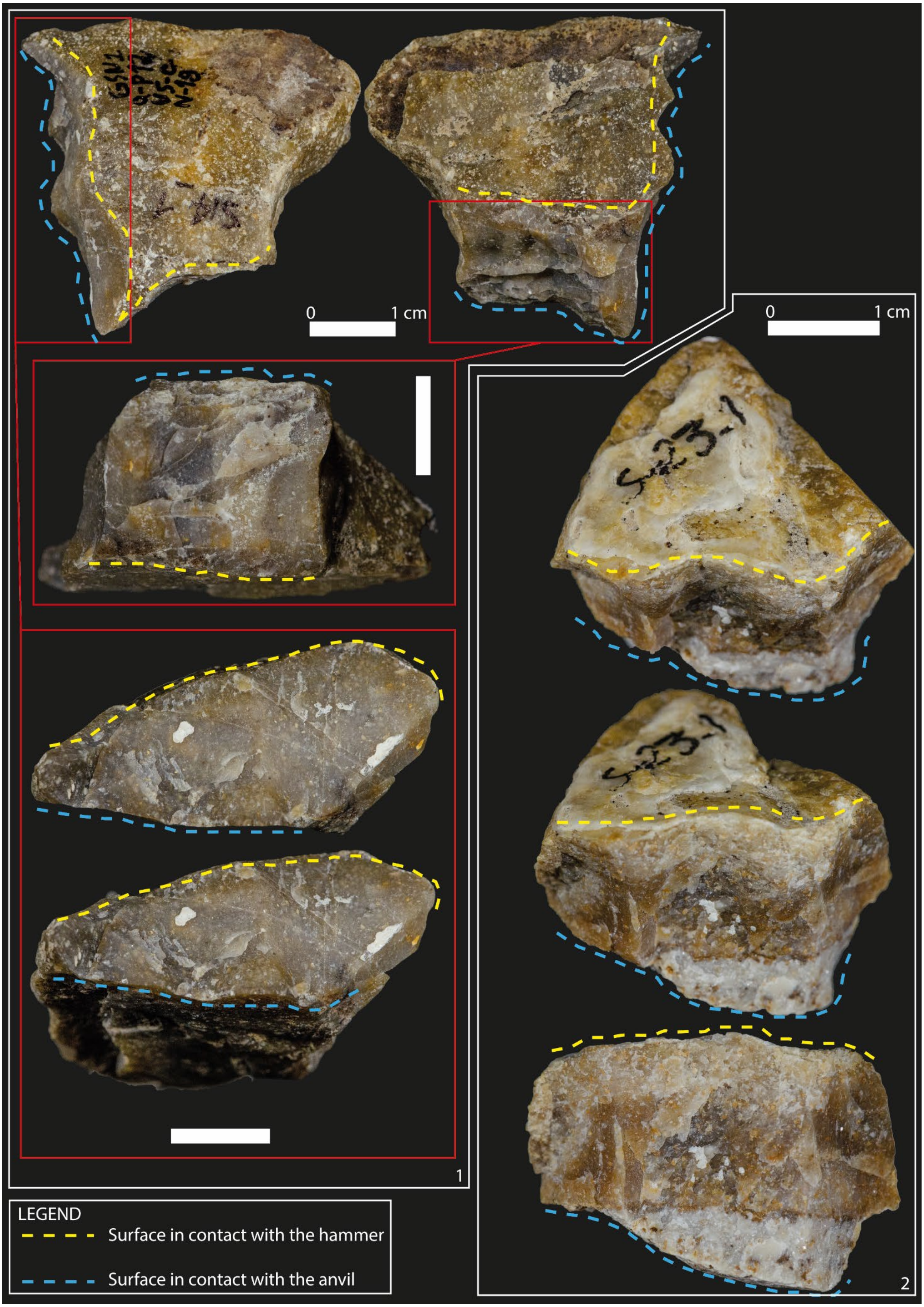

0
1 cm
0
1 cm
1
2
LEGEND
Surface in contact with the hammer
Surface in contact with the anvil

Figure 4.13 Selection of anvil assisted cores obtained from small-sized slabs. 1. Core of medium quality with several internal fractures, knapped with the counterblow technique. The core exhibit bipolar removals and pronounced micro-shattering, mainly in the portion of the striking platform in contact with the hammer. Most of the flakes were detached from the anvil since a better convexity and knapping angle was available. The negatives left by the removals created a denticulate-like shape of the margin; 2. Core of low quality with unipolar removals, only produced from the contact of the striking platform with the hammer. No traces left by the anvil were recorded.

A few flakes were obtained (n=11; Fig. 4.26), while many indeterminable pieces were produced. Their shape is quadrangular, more developed in width than in length. The mean dimensions of the pieces are 17,4 mm in length, 21,4 mm in width, and 7,8 mm in thickness (Tab. 4.98). The section of the products is equally flat (n=4), dihedral (n=3), and triangular (n=3). Only one flake exhibits an irregular section (Tab. 4.99). The maximum width is often placed on the distal end (n=6), followed by proximal (n=3) and mesial (n=2) portions (Tab. 4.100). The maximum thickness coincides with the proximal (n=4) and distal (n=4) parts. In one case, the thickness was more accentuated on the mesial portion and regular on two (Tab. 4.101). The general profile of the flakes is regular (n=6), curve (n=3), and irregular (n=2; Tab. 4.102).

Platforms are natural (n=6) in most of the flakes, followed by flat (n=2) and linear (n=2) ones, with one case of punctiform platform (Tab. 4.103). The associated morphologies are oval/triangular (n=5) or quadrangular/trapezoidal (n=3), with single evidence of narrow, narrow curved, and crushed butts (Tab. 4.104). The documented mean debitage angle is 82°. Bulbs were recorded on nine flakes, usually attested by diffused morphologies (n=6), then pronounced (n=2) or crushed (n=1). On two flakes, there was no development of the bulb (Tab. 4.105). When present, Hertzian cones are associated with ventral fissures (n=6) or ring cracks (n=2). They are absent on three flakes (Tab. 4.106). The lip was present on three flakes, usually diffused, but it did not form on the other six (Tab. 4.107). The incidence of ripples/undulations on the ventral faces of the flakes was low (1/11), while bulbar scars (4/11) and proximal micro-shattering (5/11) were more frequent (Tab. 4.108).

The distal portion of the flakes was either regular (n=5) or characterised by rebound impacts (n=5). Only one broken-down termination was found (Tab. 4.109). The flaking axis was equally *dejete* (n=6) and axial (n=5; Tab. 4.110). Unipolar scars are present on five artefacts, followed by three flakes with bipolar removals. The absence of scars was reported on three other flakes (Tab. 4.111). The ratio of fractured pieces is more or less equal to complete pieces, which is 5 out of 11. Fractures were documented on the artefacts' longitudinal, transversal, and base margins. Debordant and plunging flakes are five (Tab. 4.113).

Six flakes were detached from the anvil: five from core n°14 and one from core n°23 (Fig. 4.26, n° 3-5). Globally, three flakes present traces of counterblows (Fig. 4.26, n° 5). The counter-platforms (2/11) are natural and fractured, respectively, associated with quadrangular/trapezoidal and crushed morphologies. Only one counter-debitage angle was recorded, measuring 99°. The counter-cone was documented on three flakes by ventral fissures (n=2) and ring cracks (n=1). Only one diffused counter-lip was present.

Table 4.42

Slabs dimensional class	**Small**			**Medium**			**Large**		
Anvil-assisted	length	width	thickness	length	width	thickness	length	width	thickness
Flakes	n=11			n=74			n=49		
min	7,2	11	2	7,5	7,1	1,5	10,2	9,6	1,8
max	24,7	36,9	15,4	45,8	40,1	22,2	139,6	107,1	56,4
mean	**17,4**	**21,4**	**7,8**	**23,2**	**20,7**	**7,7**	**32**	**33**	**10,9**

Table 4.43 Section of anvil assisted flakes

Anvil Assisted	Small	Medium	Large	**Total**	
Flakes' section	n	n	n	n	%
Flat	4	46	31	81	57,9
Dihedral	3	17	7	27	19,3
Triangular	3	8	7	18	12,9
Irregular	1	8	5	14	10
Total	11	79	50	140	-

Table 4.44 Maximum width of anvil assisted flakes

Anvil Assisted	Small	Medium	Large	**Total**	
Maximum Width	n	n	n	n	%
Proximal	3	16	14	33	24,1
Mesial	2	23	8	33	24,1
Distal	6	21	17	44	32,1
Regular		15	9	24	17,5
Irregular		1	2	3	2,2
Total	11	76	50	137	-

Table 4.45 Maximum thickness of anvil assisted flakes

Anvil assisted	Small	Medium	Large	**Total**	
Maximum Thickness	n	n	n	n	%
Proximal	4	37	24	65	47,1
Mesial	1	7	6	14	10,1
Distal	4	17	10	31	22,5
Regular	2	15	7	24	17,4
Irregular		1	3	4	2,9
Total	11	77	50	138	-

Table 4.46 Profile of anvil assisted flakes

Anvil Assisted	Small	Medium	Large	**Total**	
Flakes' profile	n	n	n	n	%
Regular	6	31	24	61	43,9
Irregular	2	8	5	15	10,8
Curve	3	39	21	63	45,3
Total	11	78	50	139	-

Table 4.47 Platform type of anvil assisted flakes

Anvil-assisted					
Size	Small	Medium	Large	**Total**	
Platform Type				**n**	**%**
Cortical		2		**2**	**1,4**
Natural	6	47	28	**81**	**58,3**
Flat	2	6	4	**12**	**8,6**
Dihedral			1	**1**	**0,7**
Punctiform	1	5	5	**11**	**7,9**
Linear	2	16	6	**26**	**18,7**
Fractured		2	4	**6**	**4,3**
Total	11	78	48	**139**	**-**

Table 4.48 Platform morphology of anvil assisted flakes

Anvil-assisted					
Size	Small	Medium	Large	**Total**	
Platform Morphology				**n**	**%**
Oval/Triangular	5	19	13	**37**	**30,6**
Quadr./Trapez.	3	27	6	**36**	**29,8**
Narrow curved	1	9	4	**14**	**11,6**
Narrow	1	14	5	**20**	**16,5**
Crushed	1	6	7	**14**	**11,6**
Total	11	75	35	**121**	**-**

Table 4.49 Bulb morphology of anvil assisted flakes.

Anvil-assisted					
Size	Small	Medium	Large	**Total**	
Bulb morphology				**n**	**%**
None	2	8	5	**15**	**10,7**
Diffuse	6	30	17	**53**	**37,9**
Pronounced	2	22	11	**35**	**25**
Crushed	1	13	5	**19**	**13,6**
Sheared		2	3	**5**	**3,6**
Spike-like		1	5	**6**	**4,3**
Removed		3	4	**7**	**5**
Total	11	79	50	**140**	

Table 4.50 Cone formation of anvil assisted flakes.

Anvil-assisted					
Size	Small	Medium	Large	**Total**	
Cone formation				**n**	**%**
None	3	25	18	**46**	**33,6**
Ring crack on butt	2	21	7	**30**	**21,9**
Ventral fissures	6	29	16	**51**	**37,2**
Detached bulb		3	3	**6**	**4,4**
Hint			4	**4**	**2,9**
Total	11	78	48	**137**	**-**

Table 4.51 Lip formation of anvil assisted flakes.

Anvil assisted	Small	Medium	Large	**Total**	
Lip formation	n	n	n	n	%
None	6	42	22	70	64,2
Diffuse	3	19	13	35	32,1
Pronounced		2	2	4	3,7
Total	9	63	37	109	-

Table 4.52 Traces on anvil assisted flakes.

Anvil Assisted	Small	Medium	Large	**Total**	
Traces	n	n	n	n	%
Ripples/Ondulation	1/11	7/79	11/50	19/140	13,6
Bulbar scar	4/11	25/79	17/50	46/140	32,9
Proximal micro-shattering	5/11	28/79	17/50	50/140	35,7

Table 4.53 Distal termination on anvil assisted flakes.

Anvil Assisted	Small	Medium	Large	**Total**	
Distal termination	n	n	n	n	%
Rebound force	5	22	10	37	26,4
Broken	1	13	10	24	17,1
Hinged		7	5	12	8,6
Regular	5	37	25	67	47,9
Total	11	79	50	140	-

Table 4.54 Flaking axis on anvil assisted flakes.

Anvil Assisted	Small	Medium	Large	**Total**	
Flaking axis	n	n	n	n	%
Axial	5	34	16	55	48,2
Dejete	6	31	22	59	51,8
Total	11	65	38	114	-

Table 4.55 Removals of anvil assisted flakes

Anvil-assisted					
Size	Small	Medium	Large	**Total**	
Removals				**n**	**%**
Absent	3	17	11	**31**	**22,1**
Unipolar	5	50	24	**79**	**56,4**
Convergent		1	1	**2**	**1,4**
Crossed					
Orthogonal		1	2	**3**	**2,1**
Centripetal			1	**1**	**0,7**
Bipolar	3	10	9	**22**	**15,7**
Indetermined			2	**2**	**1,4**
Total	11	79	50	**140**	**-**

Table 4.56 Backed margin on anvil assisted flakes.

Anvil Assisted	Small	Medium	Large	**Total**	
Backed margin	n	n	n	n	%
Present	5	36	26	67	49,6
Debordant	2	14	14	30	22,2
Plunging	3	10	8	21	15,6
Debordant and Plunging		11	2	13	9,6
All sides		2	2	4	3
Absent	6	38	24	68	50,4
Total	11	74	50	135	-

Table 4.57 Type of fracture on anvil assisted flakes

Anvil assisted	Small	Medium	Large	**Total**	
Type of fracture	n	n	n	n	%
Longitudinal Siret type fracture	1	2	2	5	3,6
Siret type and platform fractures			1	1	0,7
Siret type and base		1	1	2	1,4
Siret, platform and base			2	2	1,4
Siret and transversal			1	1	0,7
Platform		5	3	8	5,8
Base	2	6	1	9	6,5
Platform and base		2		2	1,4
Platform and basal flake		2		2	1,4
Side longitudinal	2	8	2	12	8,6
Side longitudinal and base		3		3	2,2
Side longitudinal and basal flake		1		1	0,7
Transversal	1	17	9	27	19,4
Transversal and platform		1	1	2	1,4
Transversal and base		2	1	3	2,2
Transversal, base and platform			1	1	0,7
Lateral and transversal			1	1	0,7
Lateral, transversal and base		1	1	2	1,4
Lateral, transversal and platform			1	1	0,7
Basal flake		3	1	4	2,9
None	5	24	21	50	36
Total	11	78	50	139	-

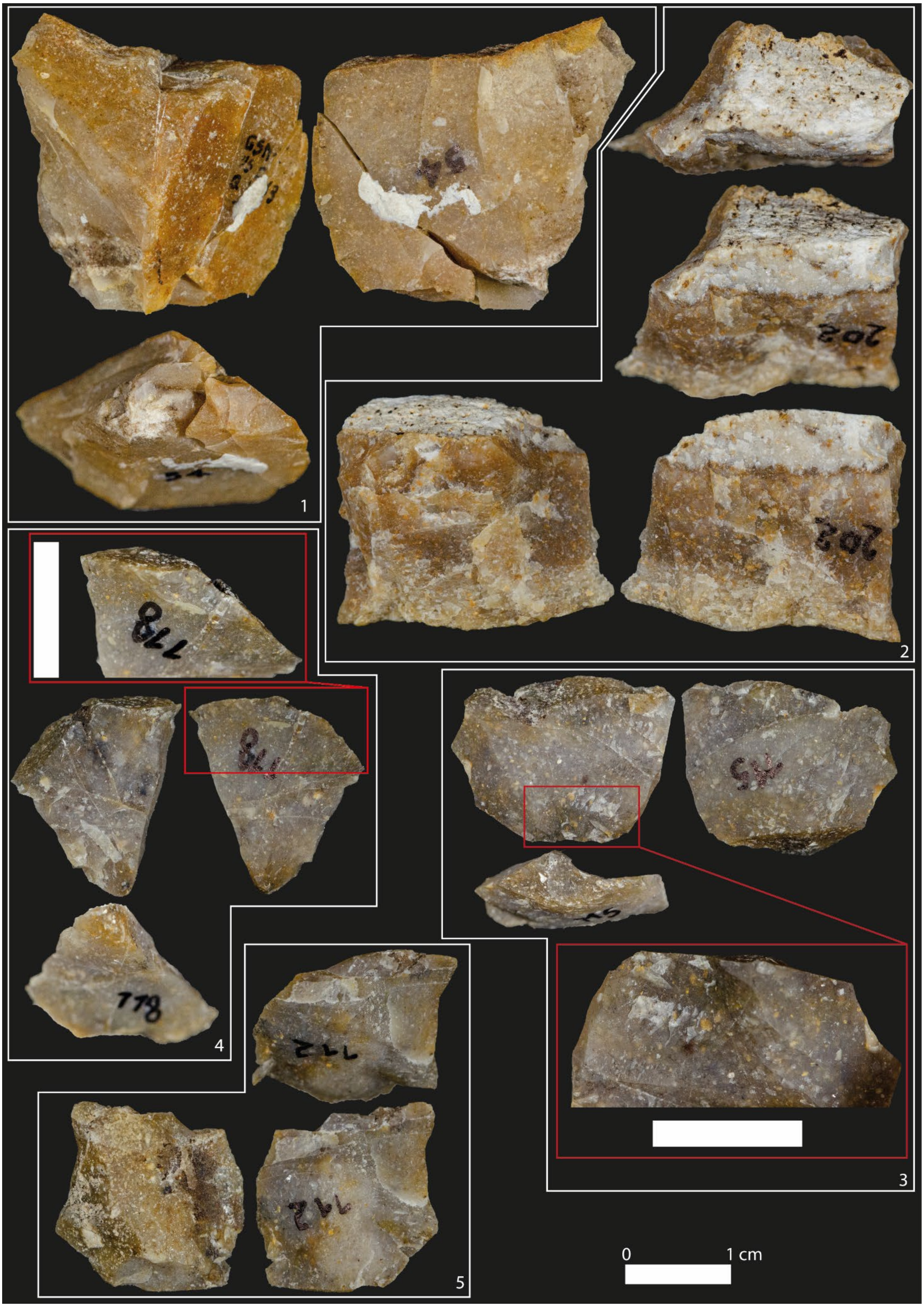

1
2
4
3
5
0
1 cm

Figure 4.14 Selection of anvil assisted flakes obtained from small-sized slabs. 1. Flake of medium quality with crushed platform, undeveloped bulb and Hertzian cone. The flake exhibits a side longitudinal fracture; 2. Flake of low quality with quadrangular/trapezoidal platform, with possible presence of counter-bulb/cone on the left margin of the distal end on the ventral face. The texture of the raw material prevented an accurate reading of the surfaces; 3. Flake of good quality detached from the anvil with oval/triangular platform, diffused bulb, and partial proximal micro-shattering on the dorsal face; 4. Flake of good quality with internal fractures detached from the anvil. The platform is oval/triangular, the bulb is diffused and the Hertzian cone is attested by ring cracks on the platform. The flake exhibits a longitudinal fracture similar to a Siret-type. On the distal margin of the ventral face a micro-negative is recorded, produced by the contact of the hammer with the striking platform; 5. Flake of medium/good quality detached from the anvil exhibiting narrow curved platform, and on the distal margin, a crushed counter-platform, sheared counter-bulb and ventral fissures documenting the formation of the counter-Hertzian cone.

Medium slabs

Nine medium-sized slabs were knapped, producing ten cores and 79 flakes (Tab. 4.114; Fig. 4.27, 4.28). The raw material was extremely fractured in two cases (cores n° 22 and 39). One core did not yield any identifiable flakes because of the internal fractures, making it impossible to control the fracture dynamic. Three cores fractured after the initial blows. The thickness was the privileged axis for the production on eight cores, followed by width (n=2). Only one core (n° 22) was knapped with the striking platform variant, though the raw material texture was coarse and similar to quartzite (Fig. 4.27, n° 3). All the striking platforms are natural and associated with proximal micro-shattering on seven cores (Fig. 4.27, n° 1 – 4). Traces of counterblows were detected on seven cores (Fig. 4.27, n° 2 – 4). The associated debitage angle with the “hammer” striking platforms is 84°, while anvil-associated counterblows show a mean angle value of 92°. The morphology of the knapping surfaces is generally flat (n=5) or tournant (n=4), with one core exhibiting an orthogonal morphology (Fig. 4.27, n° 4). The organisation of the removals highlights a slight predominance of bipolar scars (n=6; Fig. 4.27, n° 2 - 4) compared to unipolar ones (n=4; Fig. 4.27, n° 1). Bipolar scars are associated with counterblow traces on all six cores where they were documented. Core n°60 was a core-on-flake since it split at the beginning of the experiment.

Table 4.58 Medium-sized slabs dimensions and number of obtained flakes.

Slab/Core ID	Technique	Blows	Length		Width		Thickness		Flakes obtained
Medium			Initial	Final	Initial	Final	Initial	Final	n
22	Assisted	50	56,4	48	40,8	39	29,8	28,8	4
26	Assisted	24	71,9	32,7	46,7	31,8	30,2	28,9	7
32	Assisted	20	59,4	41,7	40,6	27,8	31,6	27	6
39	Assisted	13	75,5	42,1	55,6	39,4	45,4	38,3	7
44	Assisted	25	75,4	61,8	35,7	33,7	31,7	30	15
49_2	Assisted	50	63,1	48,6	45	23,3	36,4	19,5	16
50_1	Assisted	44	77,2	57,5	41,3	44,7	36,4	35	6
50_2	Assisted	40	77,2	18,5	41,3	16,4	36,4	10,5	-
52	Assisted	40	77,8	29,3	39,7	22,3	17,6	17,4	10
60	Assisted	36	60	29,3	32,4	27,3	26,8	19,4	8
Total	10								79

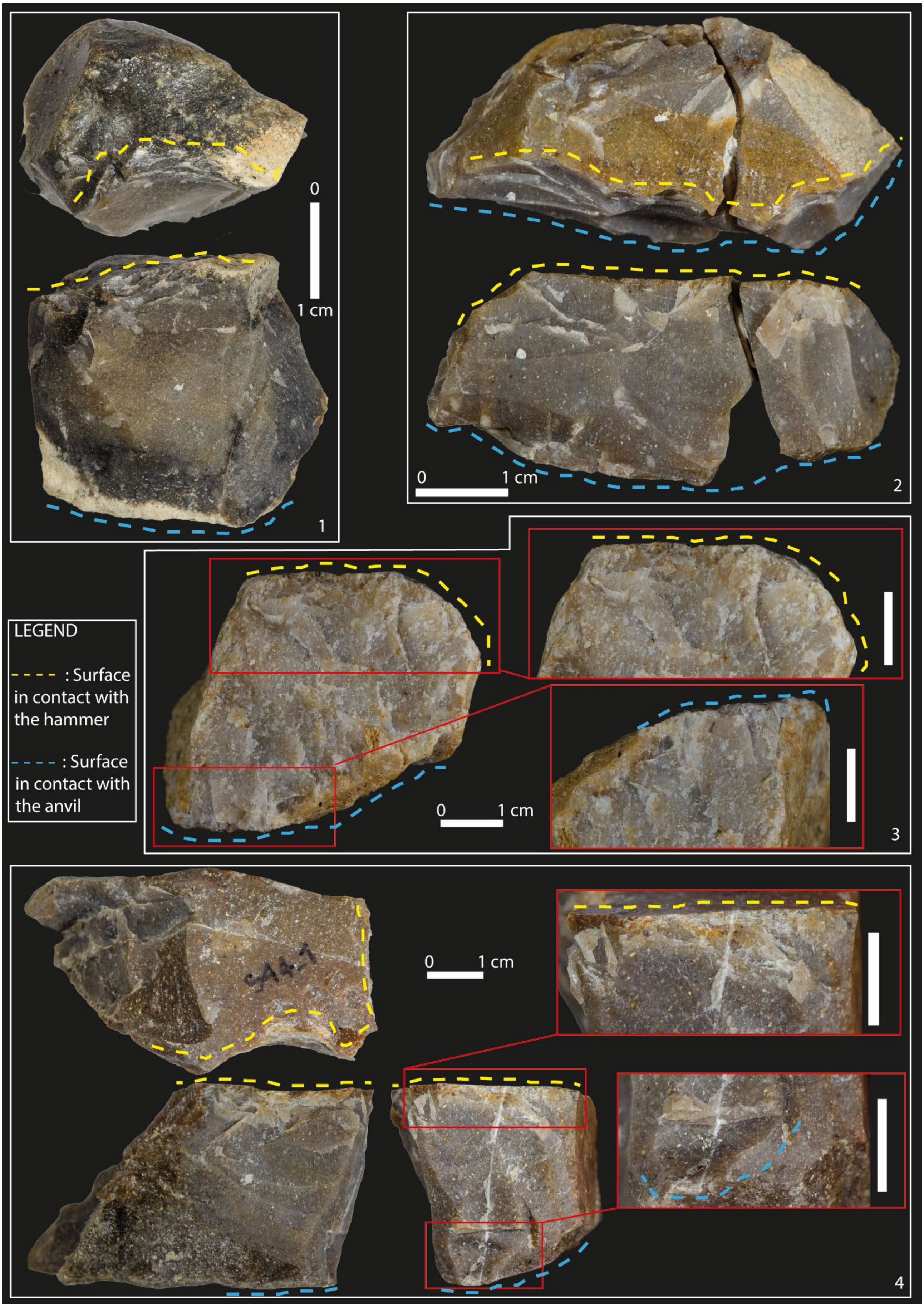
The flakes obtained from the ten cores are 79 (Fig. 4.28), showing a quadrangular shape, slightly longer than large. The mean values show 23,2 mm in length, 20,7 mm in width, and 7,7 mm in thickness (Tab. 4.98). The quadrangular shape is associated with a flat section on most of the sample (n=46), followed by dihedral (n=17), triangular (n=8), and irregular sections (n=8; Tab. 4.99). The general profile of the products is equally curved (n=39) or regular (n=31) but rarely irregular (n=8; Tab. 4.102). The maximum width is recorded, more or less in equal proportion, on the mesial (n=23), distal (n=21), and proximal (n=16) portions. Fifteen flakes exhibit a regular width (Tab. 4.100). Thickness is generally more pronounced at the proximal portion of the flakes (n=37), less frequently at the distal (n=17) or mesial (n=7), and is regular on fifteen artefacts (Tab. 4.101). Platforms' analysis highlights a predominance of natural butts (n=47), then linear (n=16), punctiform (n=5), cortical (n=2), and fractured (n=2; Tab. 4.103). The associated morphologies of the platforms are more often quadrangular/trapezoidal (n=27) or oval/triangular (n=19). Narrow and narrow curved morphologies are often related to linear platforms, while crushed ones are more distributed within flat, fractured, punctiform and linear butts (Tab. 4.104). The mean debitage angle recorded between the butts and the dorsal faces has a mean value of 81°.

The development of the bulb was documented on 68 flakes since it did not form on eight artefacts, and it was removed during the impact on the remaining three. When attested, it was mainly diffused (n=30), then pronounced (n=22), and crushed (n=13). It was rarely sheared (n=2) or spike-like (n=1; Tab. 4.105). The frequency of the Hertzian cone is lower than the bulbs', present on 53 flakes and absent on 25. The cone is either associated with ventral fissures (n=29) or ring crack (n=21) but rarely detached (n=3; Tab. 4.106). The incidence of lip formation is low, documented on 21 flakes (19 diffused and 2 pronounced) and absent on 42 (Tab. 4.107). As for small-sized slabs, the frequency of ripples/undulations on the ventral faces is rather low (7/79), while bulbar scars (25/79) and proximal micro-shattering (28/79) are considerably more common (Tab. 4.108).

Traces of rebound impacts on the distal termination of the products were recorded on 22 artefacts. Broken-down (n=13) and hinged (n=7) terminations are relatively frequent. A regular distal end was attested on 37 flakes (Tab. 4.109). The flaking axis was equally straight (n=31) or *dejete* (n=34; Tab. 4.110). Moving onto the dorsal faces, unipolar removals are predominant (n=50). The incidence of bipolar scars is poor (n=10), with flakes without removals being always common (n=17; Tab. 4.111). Flakes present a backed margin on 36 out of 74 cases, usually located on the lateral (n=14), distal (n=11), or both (n=11) portions. Flakes with backed margins on the whole volume are two (Tab. 4.112). Fractured pieces (n=54) are more frequently attested than complete pieces (n=24). The typology of the fractures is diversified but recurrently located transversally, longitudinally or at the platform or base of the supports (Tab. 4.113).

The presence of flakes detached from the anvil was documented on ten products, deriving from six cores (Fig. 4.28, n° 4). The presence of counterblows on the distal end of these flakes was attested only on two. On the other hand, flakes with counterblow traces on the distal margins are eleven, including the two detached from the anvil. Ten counter-platforms were present in this category: six natural, one cortical, one linear and two fractured. The morphology of the butt is quadrangular/trapezoidal (n=5), crushed (n=3), and oval/triangular (n=1). When present, the counter-debitage angle has a mean value of 102°. Counter-bulbs are diffused (n=3), pronounced (n=3), crushed (n=1), or removed (n=1), while lips are always absent. Counter-Hertzian cones, when present, are associated with ring cracks (n=4) or ventral fissures (n=4). The counter-debitage angle has a mean value of 102°. The presence of counter-bulbar scars was documented on seven flakes.

Figure 4.15 Selection of anvil assisted cores obtained from medium-sized slabs. 1. Core of medium quality with unipolar removals and micro-shattering produced by the contact of the hammer with the striking platform. No traces left by the anvil were recorded; 2. Fractured core of good quality with bipolar removals and micro-shattering attested both on the hammer and anvil surface, though the micro-shattering produced by the hammer is more pronounced. In this case the portion of the striking platform in contact with the hammer assumed a denticulate-like shape, though the debitage angle is close to 90°; 3. Core of low quality with bipolar removals and traces of counter-bulbs on both sides of the striking platform (i.e., hammer-side and anvil-side); 4. Core of medium/good quality with bipolar removals. The micro-shattering is only documented on the portion of the striking platform in contact with the hammer and is extremely pronounced.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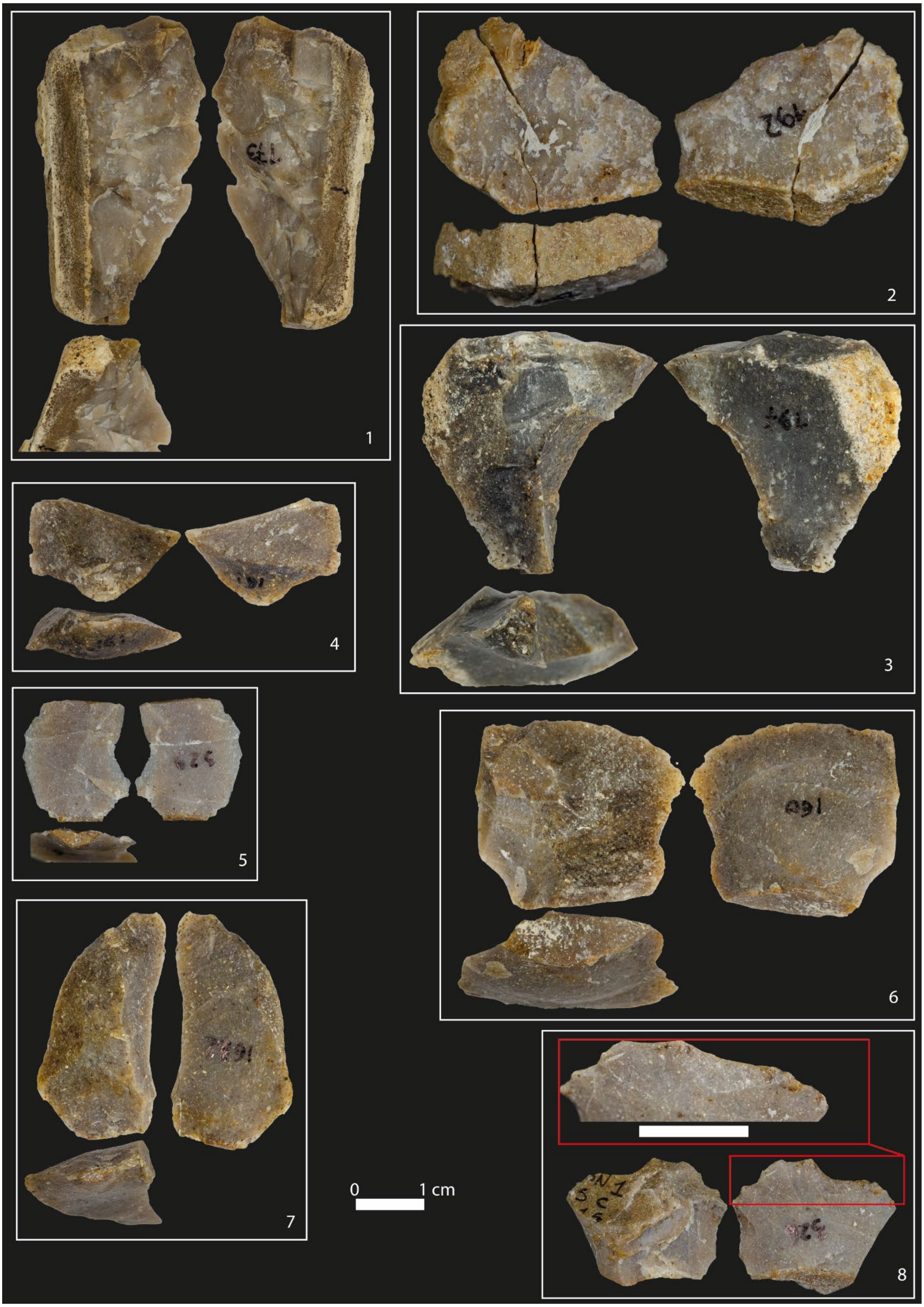
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Figure 4.16 Selection of anvil assisted flakes obtained from medium-sized slabs. 1. Flake of medium quality with several internal fractures, quadrangular/trapezoidal platform, crushed bulb and ventral fissures. The flake exhibit bipolar removals and, on distal end of the ventral face is a counter-bulb and a counter-Hertzian cone; 2. Low quality flake, similar to quartzite-like raw materials. The flake exhibits quadrangular/trapezoidal platform and a siret-type fracture. The impact point on the platform is documented by a micro-negative associated with a crushed area of whiter colour; 3. Flake of good quality with oval/triangular platform, bipolar removals, and pronounced distal micro-shattering produced by the contact with the anvil located on the dorsal face; 4. Flake of medium quality detached from the anvil exhibiting narrow platform and proximal micro shattering on the dorsal face; 5. Flake of good quality with oval/triangular platform, diffused bulb, and unipolar removals; 6. Flake of good quality with oval/triangular platform, pronounced bulb, and diffused lip; 7. Flake of good quality with narrow platform and proximal micro-shattering; 8. Flake of good quality with quadrangular/trapezoidal platform and proximal micro-shattering. On the distal end of the ventral face is a small negative – similar to a small retouch – produced by the contact with the anvil.

Large slabs

Five large-sized slabs were knappped, producing six cores and 50 flakes (Tab. 4.115; Fig. 4.29, 4.30). As stated for the other large-sized slabs knapped using the other techniques, the quality of the raw material decreased as the size increased, except for one slab (Fig. 4.29, n° 3). A quartzite-type raw material was documented in several of these cores, leading to inefficient volume management and invalidating the knapping activity. The thickness was the privileged axis on all six slabs. Striking platforms are always natural, except for one core where the exploited striking platform was flat due to the accidental opening of a flat surface during the blows. The core is missing in one case (core n°82_2), as it shattered during the debitage. Micro-shattering traces were documented on two cores (Fig. 4.29, n° 1, 3), while anvil counterblows on three (Fig. 4.29, n° 1, 3). The mean debitage angle is 85°, while the mean counter-debitage angle is 94°. The morphology of the knapping surfaces is tournant (n=2), flat (n=2), and orthogonal (n=1). Removals are bipolar on three cores (Fig. 4.29, n° 1), associated with counterblows, and unipolar on the two remaining (Fig. 4.29, n° 2, 3).

Table 4.59 Large-sized slabs dimensions and number of obtained flakes.

Slab/Core ID	Technique	Blows	Length		Width		Thickness		Flakes obtained
Large			Initial	Final	Initial	Final	Initial	Final	n
57	Assisted	21	98	57,7	48,4	43,9	21,3	20,3	6
71	Assisted	50	102	60,8	44,1	43,8	38,9	37,2	24
74	Assisted	17	103,2	80,4	64,6	63,4	62	61,3	6
82_1	Assisted	9	122,6	93,8	109	74,5	103,9	55	4
82_2	Assisted	15	122,6	-	109	-	103,9	-	4
83	Assisted	43	151,7	108	104,4	103,2	61,1	60,6	6
Total	6								50

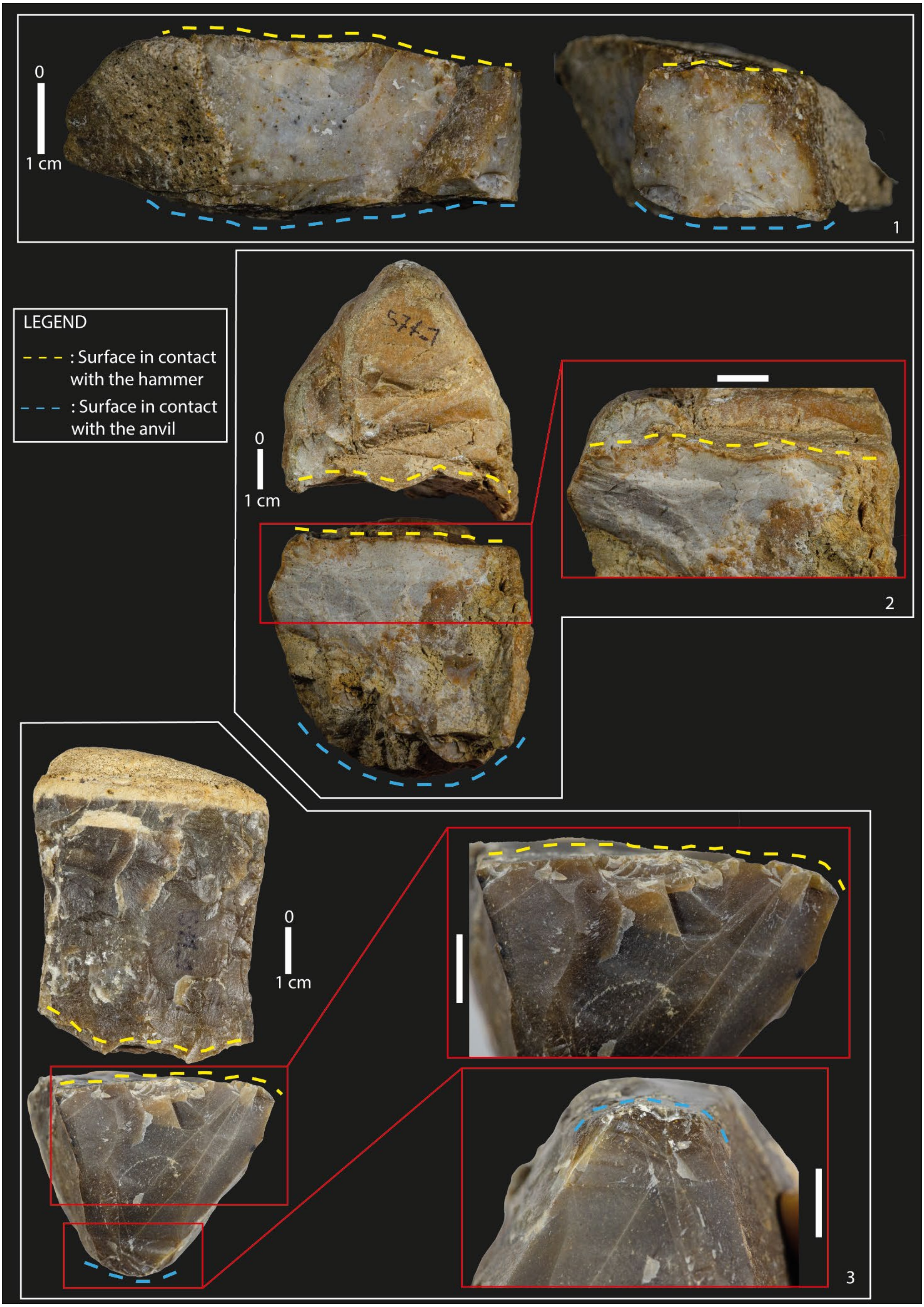
Fifty flakes presenting clear percussion marks, ventral faces, platforms, etc., were produced and analysed (Fig. 4.30). Their shape is quadrangular, more pronounced on the width axis than the length. The dimensional values show a mean length of 32 mm, a mean width of 33 mm, and a mean thickness of 10,9 mm (Tab. 4.98). Flakes' section is mainly flat (n=31) and more rarely dihedral (n=7), triangular (n=7), and irregular (n=5; Tab. 4.99). The general profile is equally distributed between regular (n=24) and curved (n=21), being irregular on five flakes (Tab. 4.102). The maximum width is attested in the majority of the cases on the distal (n=17) or proximal (n=14) portions, followed by mesial (n=8). Flakes with a regular width are nine, while two are irregular (Tab. 4.100). Regarding maximum thickness, it was frequently attested on the proximal part (n=24), followed by the distal (n=10) and mesial (n=6). The regular thickness along the entire profile of the flakes was recorded on seven flakes (Tab. 4.101).

Platforms are predominantly natural (n=28), with sporadic evidence of flat (n=4), linear (n=6), punctiform (n=5), fractured (n=4), and dihedral (n=1; Tab. 4.103) butts. The related morphologies are quadrangular/trapezoidal (n=16) or oval/triangular (n=13), narrow and narrow, curved (n=9), and crushed (n=7; Tab. 4.104). Linear butts are associated with narrow and narrow curved morphologies in most flakes. The mean value of the debitage angle is 80°. The bulb was documented on 46 flakes, being absent on four. When present, it was associated with diffused (n=17), pronounced (n=11), crushed (n=5), spike-like (n=5), and sheared (n=3) morphologies while being removed on three flakes (Tab. 4.105). Hertzian cones are attested on 30 of 48 flakes: 16 ventral fissures, 7 ring cracks, 4 subtle, and 3 detached (Tab. 4.106). On a sample of 37 flakes, the lip developed on 15 artefacts (13 diffused and 2 pronounced; Tab. 4.107). The incidence of ripples/undulations was higher than the other dimensional classes (11/50). Bulbar scars (17/50) and proximal micro-shattering (17/50) are also quite common (Tab. 4.108).

The distal termination of the flakes is regular on half of the sample (n=25), followed, in equal number, by traces of rebound impacts (n=10) and broken-down terminations (n=10). Hinged distal termination is present on five flakes (Tab. 4.109). The flaking axis is slightly more *dejete* (n=22) than axial (n=16; Tab. 4.110). The removals' organisation show a mixture of scars, with unipolar ones being predominant (n=24), followed by bipolar (n=9), orthogonal (n=2), centripetal (n=1) and convergent (n=1). Flakes without removals are 11 (Tab. 4.111). The proportion between flakes exhibiting backed margins and not is equal. Debordant (n=14), plunging (n=8), both (n=2), and backed margins on all sides (n=2) feature 26 of the 50 flakes analysed (Tab. 4.112). The incidence of fracture (29/50) shows a diversified combination of siret, transversal, base and platform types, often mixed on the same artefact (Tab. 4.113).

No flakes detached from the anvil were documented, and only four products – obtained from two cores – show traces of counterblows on the distal margins. The associated counter-platforms are natural, punctiform and fractured, exhibiting crushed, quadrangular/trapezoidal and narrow curved morphologies. The debitage angle, documented on two artefacts, has a mean value of 98°. Counter-bulbs are crushed (n=1) and sheared (n=1). On one flake, it did not develop. Counter-cones are associated with crushed and sheared bulbs, exhibiting either ventral fissures or ring cracks. Also, in this case, the cone did not develop on flake. Lips were not detected, as well as counter-bulbar scars.

Figure 4.17 Selection of anvil assisted cores obtained from large-sized slabs. 1. Core of medium quality with bipolar removals and orthogonal morphology of the knapping surface. Evidence of micro-shattering are documented on both portions of the striking platform in contact with the hammer and the anvil; 2. Core of low quality with unipolar removals. No traces were produced from the contact with the anvil. The presence of micro-shattering is sporadic and only attested on the hammer side; 3. Core of good quality with unipolar removals. The presence of micro-shattering is particularly pronounced on the portion of the striking platform in contact with the anvil. The portion of the striking platform in contact with the anvil did not produce remarkable traces, though some small impacts and crushed areas are present.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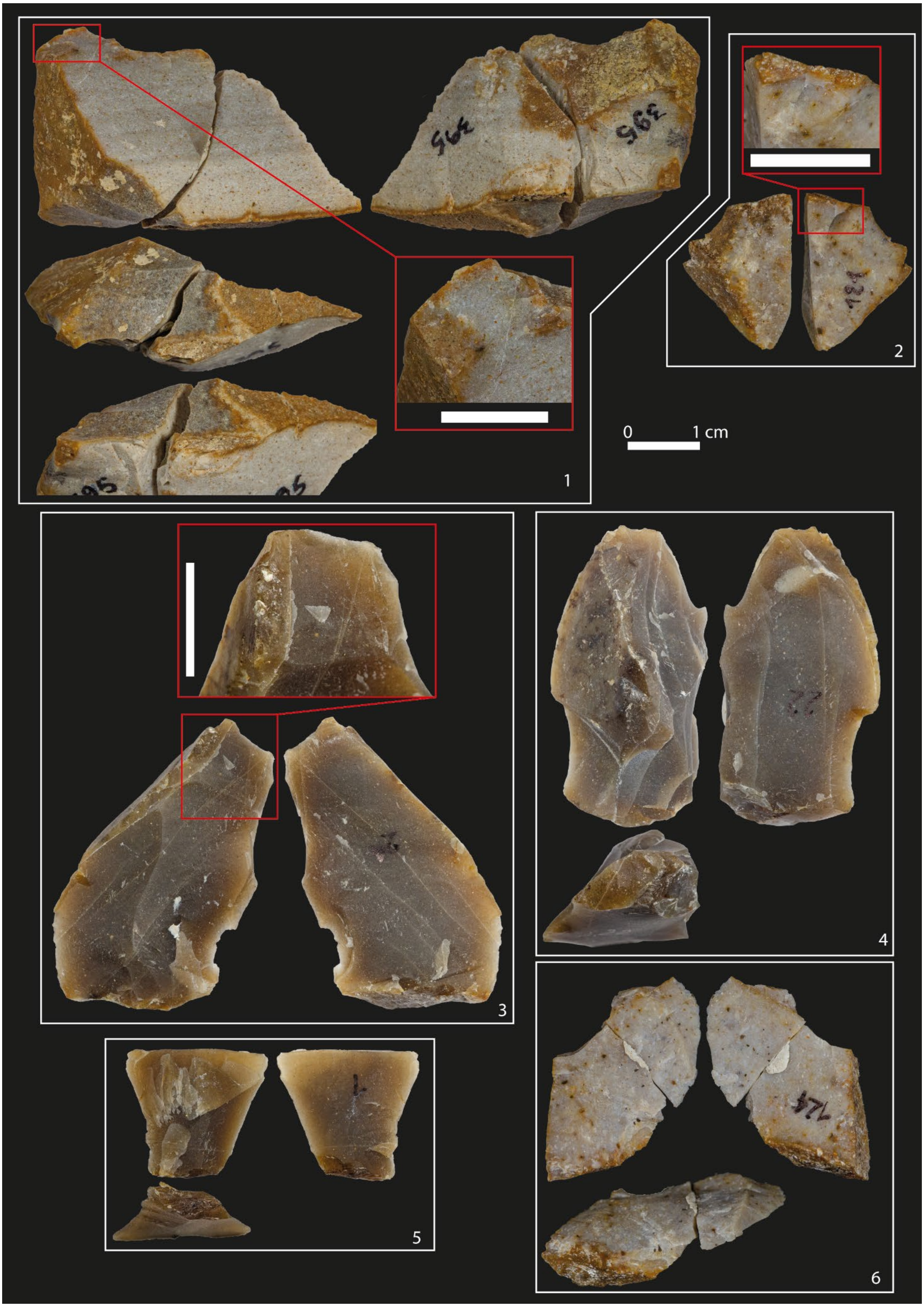
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Figure 4.18 Selection of anvil assisted flakes obtained from large-sized slabs. 1. Flake of medium quality with oval/triangular platform, crushed bulb, and siret-type fracture. On the distal end of the dorsal face (left side), is a small removal; 2. Flake of medium quality with punctiform platform. On the distal end of the ventral face is a narrow counter-butt, associated with ventral fissures of the Hertzian cone; 3. Flake of good quality with bipolar removals, and partial proximal micro-shattering on the dorsal face; 4. Flake of good quality with quadrangular/trapezoidal platform and pronounced bulb. There is evidence of proximal micro-shattering on the ventral face, in correspondence with the lip area; 5. Flake of good quality with oval/triangular platform, removed bulb and traces of shattering on the dorsal face and the platform; 6. Flake of medium quality with quadrangular/trapezoidal platform and transversal fracture. The bulb is absent and the lip is pronounced.

Table 4.60 Flakes dimensions according to slabs size and employed debitage technique.

Slabs dimensional class	**Small**			**Medium**			**Large**		
Direct percussion	length	width	thickness	length	width	thickness	length	width	thickness
Flakes	n=17			n=69			n=29		
min	13,6	8,1	2	11,1	6,9	2	16,3	12	3,1
max	44,7	39,2	19,1	69,4	73,5	34,7	46,5	45,4	19,8
mean	**19,7**	**19,2**	**5,9**	**28,8**	**26,7**	**10,2**	**32,3**	**25,7**	**10,3**
Slabs dimensional class	**Small**			**Medium**			**Large**		
Bipolar on anvil	length	width	thickness	length	width	thickness	length	width	thickness
Flakes	n=28			n=53			n=13		
min	8,3	7,3	1,5	10,3	6,4	1,4	22,9	14,6	3,4
max	32,4	50,4	24,9	55,9	52,6	39,8	71,4	59,9	53,6
mean	**19,9**	**19,3**	**8,4**	**25,8**	**19**	**8,5**	**45,7**	**31,7**	**20,6**
Slabs dimensional class	**Small**			**Medium**			**Large**		
Anvil-assisted	length	width	thickness	length	width	thickness	length	width	thickness
Flakes	n=11			n=74			n=49		
min	7,2	11	2	7,5	7,1	1,5	10,2	9,6	1,8
max	24,7	36,9	15,4	45,8	40,1	22,2	139,6	107,1	56,4
mean	**17,4**	**21,4**	**7,8**	**23,2**	**20,7**	**7,7**	**32**	**33**	**10,9**
Technique	**Direct percussion**			**Bipolar on anvil**			**Anvil assisted**		
	length	width	thickness	length	width	thickness	length	width	thickness
Flakes	n=115			n=94			n=134		
min	11,1	6,9	2	8,3	6,4	1,4	7,2	7,1	1,5
max	69,4	73,5	34,7	71,4	59,9	53,6	139,6	107,1	56,4
mean	**28,3**	**25,3**	**9,6**	**26,8**	**20,8**	**10,2**	**25,9**	**25,3**	**8,9**

Chapter 5 Discussion

5.1. The Lower Palaeolithic site of Notarchirico

The new investigations conducted at the site of Notarchirico record almost 30 ka of human occupation during the initial phases of the Middle Pleistocene (695–670 ka). The technological analysis of the debitage products (cores, flakes, retouched flakes, and retouched nodules) from layers F, G, H, I1, and I2 offers critical insights into hominin technological behaviour, highlighting possible similarities and discrepancies within the chrono-cultural framework of the European continent. This section will compare the results obtained from the core and flake production analysis with the other lithic components (pebble tools, LCTs, handaxes) coming from the same stratigraphic sequence.

At Notarchirico, hominins knapped different lithologies of small-sized fragmented chert nodules (30–100 mm) locally available in the site's secondary deposits (fluvial-lacustrine deposits). The presence of fluvial chert pebbles, documented on the natural surfaces of a small percentage of flakes, is attested, though seemingly representing a sporadic morphology within secondary deposits. The lithologies of chert nodules identified correspond to flysch chert, nodular chert, and radiolarite. These nodules exhibit a cubic or rounded shape with limited presence of cortex, usually located on one or two opposite edges or naturally rolled surfaces. The presence of neocortical patches is recurrent, confirming the secondary origin of the deposits. The occurrence of external and internal fractures is sporadic but relevant.

Flysch chert is the most exploited lithotype in the stratigraphic sequence – attesting to at least 80% of the debitage lithic productions of Notarchirico – showing a variable knapping quality according to its texture, silicification, and fracturation ranging from good to average. The dimensional analysis of the technological categories subdivided according to the raw materials shows that flysch chert was seemingly available in slightly larger supports than radiolarite and nodular chert for producing flakes, retouched flakes, and retouched nodules. The radiolarite and nodular chert percentages, exhibiting the finest texture and quality within lithotypes, are significantly scarce across all the analysed layers. Furthermore, given its lithogenesis, radiolarite is naturally deprived of cortical surfaces, which could have represented an additional incentive for hominins' raw material collection. It is plausible that the low incidence of radiolarite and nodular chert within lithic production might be due to their actual low *in situ* availability. On the other hand, as the dimensional values seem to suggest, it is also possible that raw materials' incidence could reflect a systematic choice of the hominins, valuing size and quantity "more" than quality.

The morphology and size of the supports strongly influenced the technical features of the lithic assemblage of Notarchirico, which, as a result, is characterised by a homogeneous debitage production of small-sized flakes and tools (retouched flakes and retouched nodules). The result of core technology highlights several recurrent behaviours in all layers, which will be adequately discussed. Above all, the shape of the available nodules explains most of the hominin technical choices. However, we should also consider that technical traditions might have been developed during this process. Considering that the site of Notarchirico witnesses repeated human occupation over a prolonged chronological phase, this could offer us a valuable opportunity to observe the evolution of a lithic assemblage in a “closed system”.

As previously stated, hominins collected small-sized chert nodules near the site. Most supports show the limited presence of cortical patches, facilitating the production initiation straight from the available natural convexities. Nodules of flysch chert were the most available variety, though hominins may have researched for specific characteristics when collecting the supports, such as size, absence of cortex, and suitable debitage angles.

Cores are mainly unifacially knapped through unipolar removals, sometimes producing semitournant exploitation (Fig. 10), attesting to longer reduction sequences or selected to extract one or two flakes in what might be defined as expedient behaviour. Unifacial-unipolar cores are recurrent within all analysed layers except for layer H and represent the most attested category at Notarchirico (n=33). The presence of natural convexities and arrises was crucial for the nodules selection, as they were often abandoned once the morphologies were not suitable anymore, hence the high distribution and incidence of flakes without removals along the stratigraphic sequence.

The debitage was generally conducted on the peripherical margins of the blocks, hardly altering their original volume (Fig. 10). Thus, the systematic production of debordant flakes could have been an efficient technical expedient to overcome the raw material constraints and speed up production. On the other hand, it is also true that the exploitation of small-sized knapping surfaces, given the original dimensions of the supports, leads to a mathematical, unintentional increase in backed products, especially laterally backed ones. The mean number of removals attested on unipolar flakes (*i.e.* flakes exhibiting unipolar and convergent scars) is 1,6, possibly indicating the exploitation of small-sized knapping surfaces through few parallel removals.

Additionally, the recurrent presence of plunging flakes might confirm that the original knapping surfaces were not notably bigger than the obtained flakes, being extensively exploited on their whole small dimensions. From this perspective, the predominance of debordant over plunging flakes, besides being a more practical and efficient technical expedient – as mentioned above – points to knapping surfaces exploited more frequently along their width than length. Considering the apparent shortness of the reduction sequences, primarily focused on the exploitation of natural surfaces and convexities before the cores’ abandonment, this should not surprise since producing elongated flakes – hence exploiting knapping surfaces along their length – requires a significant commitment to the convexities’ management.

The unifacial debitage could occur by taking a volumetric advantage of the nodules on their longer or shorter axis, mainly when rectangular-shaped nodules were selected. In the first case of the length as the central axis, semitournant exploitations were the primary outcome of this strategy. The shortest-sized surface was employed as a striking platform, and the most extended surface functioned as a knapping surface. Using the natural arrises would grant an optimisation of the volumes on the entire perimeter, leading to tournant or semitournant technical behaviours and longer reduction sequences. A first generation of removals seems to characterise these sequences, given the absence of superimposed scars on cores and the frequency of debordant natural flakes. In the second case scenario, the shortest surface was used as a knapping surface and the longest as a striking platform. Subsequently, parallel removals were performed to lower the core’s volume progressively. In this way, the volume of the nodule was still optimised, yet producing shorter-sized flakes. The incidence of debordant flakes was seemingly high given the exploitation of the lateral natural convexities, but plunging flakes could have been frequently obtained, given the shortness of the knapping surface. Considering the relevant number of cores selected for one or two removals, more expedient behaviours could have also been employed on both strategies. Striking platforms were predominantly natural, often exploiting neocortical surfaces.

When nodules were roundly shaped, and a larger surface was available, centripetal debitage was also applied, exhibiting similar characteristics to unipolar cores but being far less attested (Fig. 10). Platforms were mostly natural without evidence of any preparation. However, single removals might have occurred to facilitate the obtainment of flat surfaces. This confirms a global attitude to subordinate the debitage to the morphological aspects of the supports. Unipolar removals characterise bifacial and multifacial cores with a frequent inversion of striking platforms and knapping surfaces pointing to an SSDA conception rather than surfaces' hierarchisation. The reduction sequences were more prolonged in this situation, involving a significant percentage of the core volumes but always with a maximum of two or three removals per face and limited to the exploitation of natural convexities. As previously mentioned, the incidence of flat platforms is seemingly due to the core rotation rather than the platform preparation.

Evidence of cores showing a discoid conception or structured debitage is scarce: only one bifacial core from layer G exhibits alternate flaking through two peripherical striking platforms. However, the debitage is still strongly influenced by the nodule's morphology, and there seems to be no explicit attempt to shape the surfaces regardless of their original morphologies. For the time being, there is no evidence that cores were retouched or used after being discarded, though, given the sample size so far analysed and the extension of the excavation, it cannot be entirely excluded. As witnessed by several other contexts, even in the Italian Peninsula (Isernia La Pineta and Fontana Ranuccio, Ficoncella), it can be an efficient strategy – usually referred to as circularity of the reduction sequences – especially when dealing with small-sized raw materials. The absence of cores on flakes was also reported. It is plausible that the small available volumes, the medium quality of the texture within flysch chert nodules and the partial presence of cortical and neo-cortical patches would decrease the chances of obtaining large enough flakes to be transformed into cores. Furthermore, the production goals of the chert-related industries – small flakes – were seemingly achieved through the reduction strategies mentioned above, further facilitated by the availability of local raw materials.

The analysis of knapping strategies from the dorsal faces of the flakes reveals a global mixture of unipolar, orthogonal, centripetal, bipolar, and crossed debitage with more or less the same distribution across the layers and a prevalence of unipolar scars. The ratio of scars per flake matches the shortness of the reduction sequences, with a mean value of 1 when flakes without removals are included and a mean value of 2 when excluded. Only orthogonal and centripetal products present a higher proportion, given the exploitation of larger knapping surfaces from different directions. Evidence for a greater degree of complexity represented by these latter reduction sequences is, for the time, not supported by the data, indicating homogeneous yet equally complex technical behaviours modulated according to the morphological criteria.

However, when larger supports and better qualities were available, the removal organisation indicated skilful management of the surfaces. The platform distribution is dominated mainly by flat and natural butts. Still, the sporadic presence of dihedral and facetted ones indicates that preparation of the surfaces might have occurred when needed. No particular correlations were found between the platform type and the removal organisation. The predominance of natural platforms confirms the data gathered from the cores, highlighting the recurrent use of natural surfaces to produce flakes. At the same time, flat butts could be associated with many bifacial and multifacial cores exploited through multiple rotations and inversions of the knapping surfaces and striking platforms.

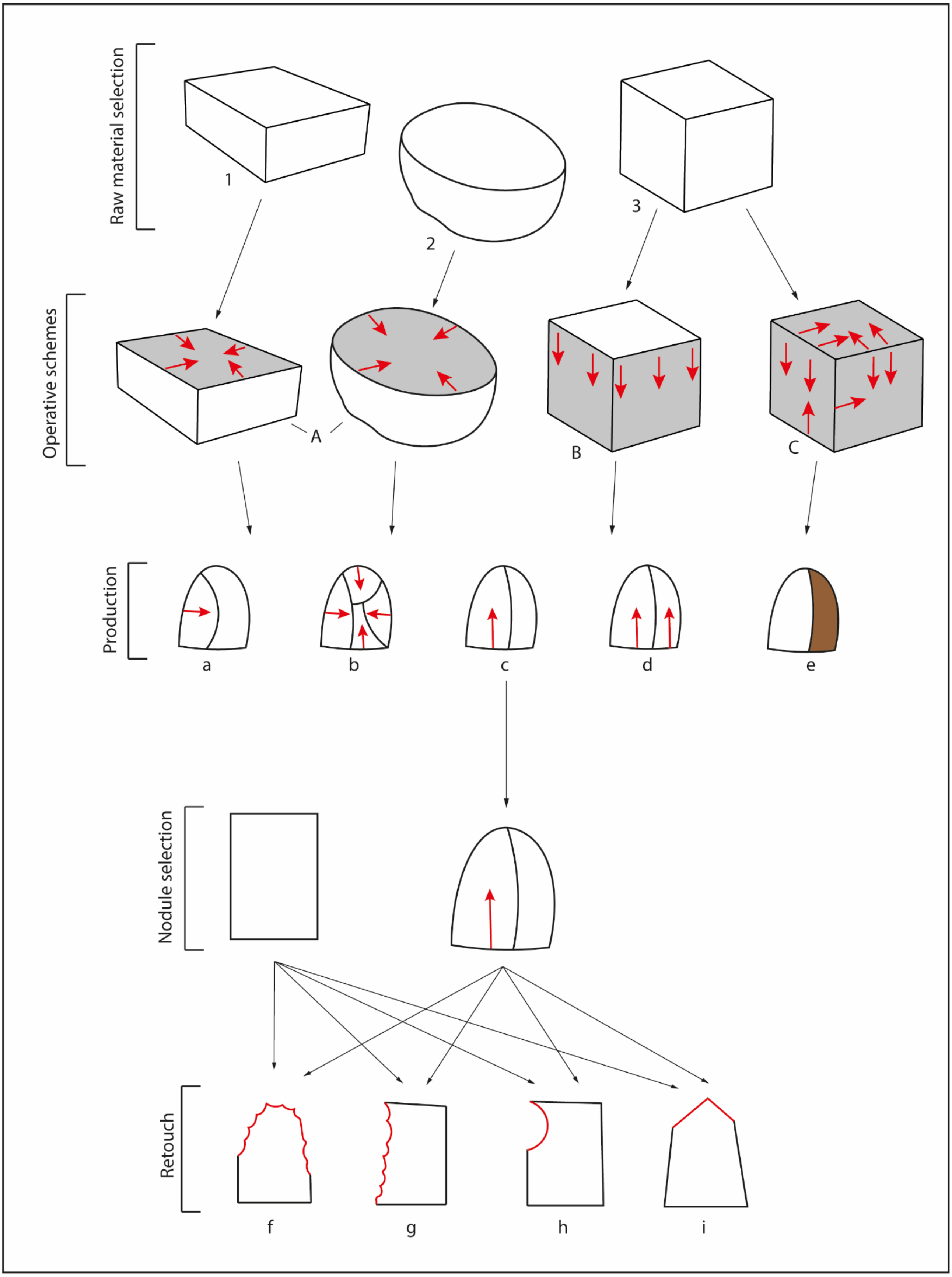

Figure 5.1 Production schemes of Notarchirico. Raw material selection: selection of nodules with rectangular (1), round (2), or cubic (3) morphologies. Operative schemes: A exploitation of one large knapping surface through a peripherical striking platform producing either orthogonal or centripetal

negatives; B unipolar exploitation, eventually leading to semitournant behaviour using the natural convexities (edges and arises) of the nodules; C SSDA (systeme par surface de débitage alterné) exploitation of the cores, frequent rotation and inversion of the striking platforms and knapping surfaces. Production: typical obtained products: orthogonal flake (a), centripetal flake (b), unipolar débordant flake (c), unipolar flake (d), débordant flake without removals (e). Retouch of flakes and nodules: researched morphologies: peripheral convex retouch (f), lateral rectilinear retouch (g), notch (h), convergent/pointed retouch (i).

Another critical aspect that might be interesting to point out is that the cores' analysis does not match the variety and relevance of flakes' knapping strategies, mainly when addressing orthogonal and centripetal debitage. On the one hand, most cores are indeed abandoned when angles, surfaces or volumes are exhausted and depleted or when raw materials' quality determines the impossibility of going further, even causing an abandonment of "large" sized supports. Because of this, specific reduction sequences might be underestimated or obliterated. On the other hand, since Notarchirico is an open-air palimpsest, it is plausible that hominins moved over large areas, carrying within themselves cores with a better texture/volume ratio, mostly abandoning exhausted or low-quality cores.

The technological analysis revealed that cores are characterised by efficient, simple, and often short reduction sequences mostly achieved through unipolar removals and often realised on medium/low-quality nodules, while flakes, for instance, point to more diversified technical behaviours, mainly when higher quality supports are available. It is also true that the ratio between cores and flakes within lithic assemblages always favours the latter, making cores partially revealing the actual debitage schemes employed, thus turning flakes into essential tools for understanding reduction strategies and granting possible insights regarding the spatial mobility and land use of human groups.

If we exclude layer H, which seemingly represents a short-time occupation of the site during a mild climatic crisis, the same dimensional values characterise the debitage products in all the layers. Flakes and retouched flakes without a cortex are predominant. An increase in cortical and partially corticated chips can be recorded in the lowest levels (I1 and I2), but it does not seem to correspond to a different economy of the raw material or technological differences. This data and the frequency of products showing no removals confirm the scarcity of cortical remains on nodules, including their intentional selection and the massive exploitation of natural surfaces. Backed flakes are also abundant, attested on at least 50% of the lithic assemblage for each layer and often opposed to a cutting margin. A central arris on the dorsal face of the flakes, either natural or formed by parallel removals, is also recurrent.

Many retouched flakes characterise the entire sequence of Notarchirico, being a recurrent aspect in all layers. Retouched flakes are always realised on more extensive supports and are characterised by scrapers, denticulates, notches, beaks, and pointed flakes, revealing various types and, seemingly, functions. Their distribution is uniform across the stratigraphy, with layers G and I1, the richest of the site, exhibiting a greater diversity in tool types. The retouch can vary, applied on a single margin or peripherally and frequently altering the original shape of the support to obtain specific morphologies. Often, edge modification is applied through a few removals, simultaneously creating denticulate-like margins through an "active" retouch and unretouched points/beaks on the same flakes. It is challenging to assess whether the researched parts of these objects were the retouched margin, the point/rostrum/beak subsequently left on the unretouched portion or both.

Despite the absence of recurrent tool types across the stratigraphy, a significant technological investment is seemingly put into the confection of these diversified objects. It can be suggested that if, on one side, flakes production was relatively expedient and unstructured, strongly codified on the existing morphologies generating short reduction sequences, on the other side, retouched flakes could be massively modified through the retouch, regardless of the initial support's morphology, assuming diversified shapes and, possibly, functions. In other words, we might assume that hominins might have shifted their focus on the edge modification rather than flakes' obtainment since retouch would grant more outcomes efficiently, in terms of time and energy invested, than cores' management.

The angle of retouch is mainly included between 60° when it is marginal and located on thin edges and 80° when it is abrupt. Regardless of the selected layer, this pattern is constant along the stratigraphic sequence. Traces of rejuvenation of the margins were not detected, and the retouch is generally applied through a single generation of removals, covering in different degrees the dorsal face of the supports. No relations were detected between the flakes chosen for the retouch and the knapping strategies.

Nonetheless, within the reconstruction of the reduction sequences, it is plausible that hominins selected bigger implements for edge modification deriving from the initial phase of the debitage activity. From this perspective, more than half of the retouched flakes are characterised by naturally backed margins (lateral or distal). Backed flakes show higher dimensional values in length, width, and thickness than flakes without a backed margin, regardless of whether they are retouched. This might confirm that a backed margin coincided with bigger flakes, representing an additional selection criterion for edge modifications.

While dimensional values confirm that supports selected for edge modification are more developed in length and width, it is also true that among unretouched flakes is a significant cluster of micro-flakes (*i.e.,* flakes exhibiting a length within a maximum of 15 mm; Fig. 5.2). A cutting edge on one or two margins, usually the lateral and distal, characterises this category of flakes. This cluster could reveal the importance of small-sized unretouched flakes at Notarchirico since many experimental and archaeological works highlighted the importance of unretouched flakes for cutting-oriented purposes, especially in sites where butchering activities were performed (Boschian and Saccà, 2015; Mosquera et al., 2015; 2016; Aureli et al., 2016; Cheheb et al., 2019; Venditti et al., 2019; Berruti et al., 2023; Carpentieri et al., 2023a). Before moving into the discussion over the function and role of the site of Notarchirico, it is essential to underline that such flakes could have represented a researched and intentional aspect within the production goals of the human groups as relevant as retouched flakes.

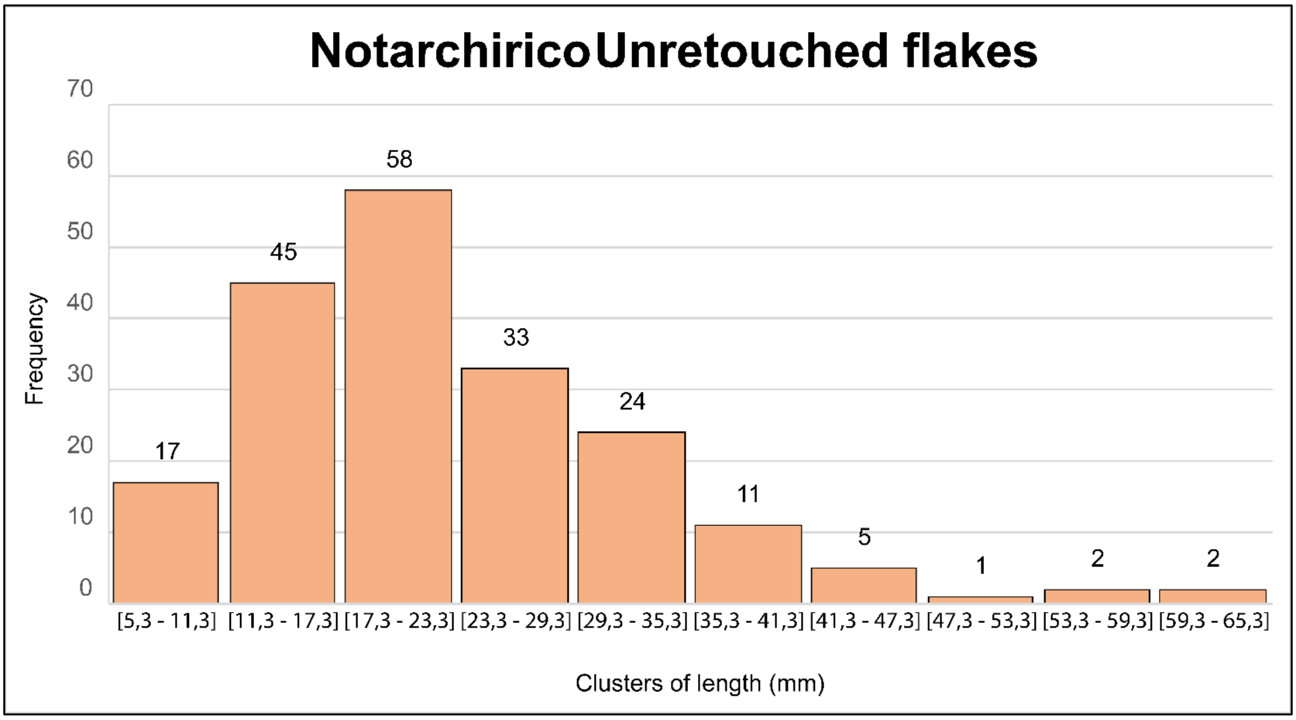

Figure 5.2 Histogram plotting unretouched flakes length (mm). The values in brackets express the beginning and ending of each cluster in terms of length.

Hominins also selected many small nodules of the same size as supports to be retouched. These nodules show a cubic/rectangular shape, hardly exhibiting natural cutting edges and with scarce attestation of the cortex. Naturally backed margins on the nodules could have played an essential role in their selection, representing a possible prehensile part opposite to the modified edge, as also witnessed for retouched flakes. Consequently, the retouch was almost exclusively abrupt on one face to obtain scrapers, denticulates, beaks, and notches. It may be safe to argue that the role of retouched flakes and retouched nodules was the same since the latter represents a valid substitute for retouched flakes, even from a typological point of view. The dimensional values confirm this aspect, showing an intentional selection of supports with a specific length. The analysis of the raw material economy provided the same result as the debitage production, with flysch chert being the most exploited lithology and also available in more significant dimensions. It is essential to point out that retouched nodules and flakes do not show a second phase of reshaping or recycling, which could indicate a single-time use and short lifespan of these products. Several retouch flakes have been found in different layers, which, together with all the gathered data, indicate that most lithic objects were knapped, used, and abandoned in the same area.

The likelihood of nodules being used as passive supports/cores to extract small flakes remains open. On larger nodules, there is evidence of removals dimensionally comparable to the end products with a suitable flaking angle (close to 90°). Further investigations are required to clarify the possible existence of this behaviour; however, the ambivalence of the concepts of debitage and shaping, which seems to affect these chronological phases – particularly in contexts characterised by raw materials of small dimensions like Isernia La Pineta, Ficoncella, Fontana Ranuccio, and Soucy – might be a crucial technological trait to track down and a possible marker of innovation (Peretto, 1994; Lhomme, 2007; Gallotti and Peretto, 2015; Aureli et al., 2016; Grimaldi et al., 2020; Carpentieri et al., 2023a). From this perspective, we should remember that concepts of debitage and shaping are artificial categories created by the scientific community to classify and analyse lithic objects. The flexibility lithic artefacts assume during their creation, use, and abandonment – how they are conceived and their spatial and functional dimensions within archaeological contexts – is significant and strongly influenced by the environmental context and cultural background.

Ultimately, the analysis of the core does not reveal remarkably structured reduction sequences from a morphological and conceptual point of view. Nevertheless, this does not mean that the lithic assemblage of Notarchirico lacks complexity from a methodological perspective. The systematic use of retouching to shape the original morphologies of the small available supports according to the production goals and the exploitation of nodules demonstrate a skilful adaptation to the raw material by these hominins, balancing out the qualitative and dimensional constraints and allowing them to obtain a great variety of products. Besides, core management homogeneity along the stratigraphic sequence highlights a behavioural response of these hominins to approach this type of raw material that gradually becomes systematic and is assimilated within the methodological process. Furthermore, the quantity and variety of retouched objects (*i.e.,* flakes and nodules) point to a significant relevance of this category. Seemingly, hominins researched lithic implements to modify not only through the debitage activities but also through the collection of small-sized nodules, confirming the importance of these tools within the *chaine operatoire*.

As previously stated, while core reduction might look unstructured, it is plausible that hominins were aware that these reduction strategies were seemingly the most efficient and rewarding according to the available raw materials, especially considering that through the subsequent retouching of the products, they could further reach their goals. The recurrent homogeneity of the debitage productions might be the additional proof for this statement. It is also true that retouched tools were not the only goal within reduction sequences, as unretouched flakes, especially the smallest ones, were also an essential component of the chert-oriented industries.

Following this idea, it is remarkable to notice that the Italian Peninsula is noted for numerous sites (Notarchirico, Isernia La Pineta, Ficoncella, Cimitero di Atella, Fontana Ranuccio, among others) spanning from the beginning of the Middle Pleistocene (MIS 19) to approximately 400 ka (MIS 11) exhibiting a massive production of small-sized flakes and retouched tools – sometimes associated with the production of handaxes as in the case of Cimitero di Atella and Notarchirico itself. This aspect has often led the scientific community to identify a potential pattern in the Italian Peninsula originating from the raw material's availability and possibly becoming cultural and behavioural (Gallotti and Peretto, 2015; Abruzzese et al., 2016; Aureli et al., 2016; Grimaldi et al., 2020; Moncel et al., 2020e; Muttillo et al., 2021a; Rineau et al., 2022; Carpentieri et al., 2023a; 2023b).

Various pebbles and large cutting tools also characterise the site of Notarchirico (Moncel et al., 2020e; Santagata et al., 2020; Rineau et al., 2022), showing a sharp increase in the uppermost portion of the sequence simultaneously with the appearance of the earliest bifaces of the site so far (layers G and F). Pebble and large cutting tools are described as poorly standardised from a morphological point of view (Santagata et al., 2020); they exhibit a broad diversification with unifacial, bifacial, and trifacial retouch, partially altering the original shape of the supports when possible and consistently taking advantage of the available natural convexities recalling the pattern seen for the debitage products and retouched nodules. Some of these tools can be described as "rabots" with a limited and regular invasive retouch. Some broken pebbles with impact points and others with isolated removals – possibly remains of hammerstones – should also be mentioned within the corpus of lithic tools. Their size varies between 40 and 200 mm, though most are included between 60 and 80 mm and exhibiting cutting edge angles between 30 and 90°. This category of tools is mostly realised from limestone pebbles locally collected.

On the other hand, the six bifaces are reported to show skilful management of the bifacial and bilateral equilibrium – with peripherical removals and a final retouch phase to regularise the cutting edges always realised with the use of a hard hammer– fitting into the Acheulean paradigm that begins to emerge at the onset of the Middle Pleistocene within the European continent and of which Notarchirico represent one of the earliest evidence. The bifaces from Notarchirico are realised on nodules of local chert, which could indicate a different raw material economy for their realisation compared to the limestone pebble tools. The presence of bifaces is commonly associated with technological – and cognitive – shifts in the lithic assemblages where they have been found, which, in this case, the debitage production does not seem to reflect (Rineau et al., 2022).

The technological analysis of all the layers presented in this work witnesses an – alleged – abrupt appearance of these items starting from layer G but does not reveal a change in the degree of complexity of core technologies and flake production – together with nodule fabrication – whose characteristics and conception are somewhat similar to the heavy-duty components remaining homogeneous along the considered layers (Moncel et al., 2020e; Rineau et al., 2022; Carpentieri et al., 2023b). It is plausible that the absence of bifaces in layers H, I1, and I2 could be due to the excavation's size – as already proposed in other works (Moncel et al., 2020e; 2023; Rineau et al., 2022) – despite being investigated on the same area of layers F and G but might also reflect a change in the site's role and function over time. On the other hand, layers F and G are indeed the richest and most diversified quantitatively and typologically speaking, which could suggest an actual shift in the modalities of the occupation or the conducted activities. Could we genuinely assign to the bifaces this role of cultural marker/complexity changer in the site of Notarchirico, which might already be present in the lowest levels?

If we assume that (1) the hominins' adaptive response to the exploitation of identical raw materials of small morphologies becomes systematic from the bottom of the stratigraphic sequence to which handaxes are later integrated, (2) aspects such as the spatial mobility within site and its function may vary over time, massively affecting the lithic assemblage composition, and (3) the absence/presence of the bifaces is seemingly not due to an actual shift from a complexity-free context to a more complex one – as the technological analysis seems to suggest – then other behavioural variables should also be considered as additional proxies of possible "cultural" and evolutionary changes (Moncel et al., 2015; 2021a; Moncel and Ashton, 2018; Pope et al., 2018; Vaquero and Romagnoli, 2018).

For instance, the possible exploitation of organic material (i.e. bones) to compensate for the lack of raw materials of large dimensions. The archeozoological and functional data available do not record discrepancies along the stratigraphic sequence in the exploitation of faunal remains and worked materials, though the data are partial and still being processed (Moncel et al., 2023). The use-wear and residue analyses (Moncel et al., 2020e; 2023) proved that the site was not exclusively cutting-oriented, especially from the basal portion of the sequence – which might have explained a delayed introduction of bifaces – with evidence of wood and plant processing preserved on the margins of the debitage products. This aspect might contribute to the potential continuity of the site concerning the practised activities and following the substantial homogeneity depicted by the lithic assemblage, portraying Notarchirico as a multi-functional context with recurrent continuous occupations during both glacial and interglacial phases.

Before moving onto the contextualisation of the site of Notarchirico within the European archaeological evidence during the Middle Pleistocene, the discussion of the results obtained from the technological analysis of Isernia La Pineta will be presented. By doing this, a comparison between the two sites will be performed, and then within the European Lower Palaeolithic.

5.2. The Lower Palaeolithic site of Isernia La Pineta

The site of Isernia is characterised by the exploitation of locally collected rectangular chert slabs ranging between 30 and 80 mm for length/width and 10–35 mm for thickness. These slabs were available within the site as their abundance is reported within the entire archaeological sequence (Peretto, 1994; Gallotti and Peretto, 2015; Channarayapatna et al., 2018; Carpentieri et al., 2023a). The massive fractures and the raw material scarcity on larger blocks determined a systematic optimisation of surfaces and volumes during knapping, favouring smaller dimensions. The rare evidence for fractures and impurities on flakes confirms an efficient raw material selection and reduction processes, while the non-predominant presence of cortex on flakes and cores suggests that hominids selected already broken slabs of small dimensions. When present, cortical patches were located on two opposite surfaces of the slabs or, more rarely, on three faces. The thickness of the cortex was diversified, ranging from a millimetric thickness to thicker layers (1-2 cm). The presence of fluvial pebbles was also documented among the exploited supports, though they represent a minority compared to slabs.

The quality of the chert is relatively high despite showing a significant variability within the available lithotypes. Aside from fractures due to tectonic activity and fluvial transport, the texture of the slabs ranges from coarse to vitreous, granting, on the higher-quality blocks, excellent control and management of the debitage. On the other hand, the coarser varieties of chert are significantly harder to knap, making the use of large-sized slabs almost impossible and, at the same time, partially invalidating the exploitation of smaller blocks.

The raw material constraints determined several approaches for flakes' production and cores' management. Direct percussions by hard hammer and bipolar on anvil technique were equally employed (Crovetto et al., 1994; Peretto, 1994; Gallotti and Peretto, 2015; Carpentieri et al., 2023a). Traces of clear counterblows (counter-butts, counter-bulbs, bipolar removals, etc.) on the analysed flakes and cores from Isernia La Pineta were not detected. Even if the bipolar on-anvil technique's identification could be challenging and sometimes produce the same outcome – in terms of productivity and traces – as the direct percussion with the hard hammer (Jeske and Lurie, 1993; Donnart et al., 2009; Bietti et al., 2010; Moyano et al., 2011; Vergès and Ollé, 2011; Eren et al., 2013; Peña, 2015; Shott and Tostevin, 2015; Pargeter and Eren, 2017; Pargeter et al., 2019a), these techniques were applied according to raw material morphology and quality. For instance, more cubic slabs without proper convexities could require the bipolar on-anvil technique to initialise the flaking activity (de Lombera-Hermida et al., 2016). This allowed the check for internal impurities other than producing smaller blocks, eventually knapped through freehand percussion and larger flakes to be retouched later. The bipolar on anvil technique proved to be vastly employed in older sites to overcome the raw materials' quality and volumes and obtain specific products in a controlled way (Barsky, 2013; Barsky et al., 2013; Gallotti et al., 2020; Horta et al., 2022).

When better convexities existed, direct percussion by a hard hammer was applied right from the start of the reduction sequence. Given the small dimension of end-products and some cores, both techniques could have been applied on the same core at different stages. In this case, using an anvil might have eased the core handling (Hiscock, 2015b). The particular hardness (in terms of resistance to fracture) of the raw material of Isernia La Pineta must also be considered since the requirement for significant strength in the technical gesture could have been facilitated by using an anvil. From this perspective, fractured butts are relatively low, though crushing marks on the edge of the platforms, sometimes associated with internal fractures, can be globally observed, pointing to the evidence of repeated impacts. Moreover, the mean knapping angle (70°) suggests exploiting wide and open surfaces. This aspect and the flakes' maximum thickness, often coinciding with the butt/proximal portion, may confirm the need for inner, possibly more potent, blows to obtain flakes.

Three main strategies were identified to manipulate slabs' volumes: (a) the most prominent and flattest surface was knapped through a peripherical striking platform; (b) volumetric exploitation, *i.e.* semitournant/tournant, of the most convex faces from a single striking platform was performed; (c) SSDA/opportunistic conception of the volumes through single unifacial-unipolar knapping events.

In the first case, orthogonal debitage was preferred – along with being the most attested strategy on cores using a peripherical striking platform – possibly leading to a centripetal one. The striking platforms were mainly natural, taking advantage of the natural angles of the slabs without cortex. Opening one or more striking platforms was occasionally required through single removals when the angle between the surfaces was too orthogonal. The direction of flaking was often parallel to the knapping surface, exploiting wide angles (> 100°) and thus obtaining flakes with a constant thickness along their length – hypothetically similar to Levallois flaking. The lateral and distal convexities management happened simultaneously with the flaking activity and was usually achieved with orthogonal/bipolar debitage alongside plunging and debordant flakes – representing a recurrent trait within debitage products. Reduction sequences were not particularly long, even though the organisation and the number of the removals on flakes (counting a mean of 2,3 removals) suggest the presence of debitage carried on regardless of the slabs' natural shape, highlighting skilful management of the convexities. The incidence of plunging flakes exhibiting orthogonal, bipolar, crossed and centripetal scars is lower than debordant ones. This data should confirm that lateral convexities were often more used as technical expedient than distal margins – while also suggesting a more frequent use of cores' edges regardless of whether it was a technical expedient or not –indicating that rarely flakes covered the entire length of knapping surfaces. As a side note, it should also be mentioned that the incidence of orthogonal, bipolar and centripetal scars on flakes during centripetal debitage might be underestimated in favour of unipolar/convergent removals, further underrepresenting this type of production.

In the second case, more prominent convexities were favoured on cubic-shaped slabs over flatter surfaces as knapping surfaces. In other words, several faces of the slab were exploited for flakes' production from a single striking platform instead of the opposite, as mentioned in the former debitage strategy. In this case, the debitage was mainly unipolar or convergent through parallel removals, exploiting one slab's face and potentially becoming semitournant when involving the rest of the slab's volume. The direction of flaking was secant to the knapping surface, given its more pronounced convexity. Consequently, flakes are supposedly thicker in the proximal part and thinner in the distal one. The preparation of striking platforms is primarily achieved through single removals, even though natural ones are also frequently and predominantly used. Usually, only one generation of removals is attested, confirming the deliberate exploitation of natural convexities, particularly natural arrises on cubic-shaped slabs.

This strategy might generate a discoid conception of the volumes, already attested on 76% of the chert cores from layer t.3c of Isernia (Gallotti and Peretto, 2015). In layers t.3coll and t.3a (analysed in this work), discoid productions are seemingly less relevant than in layer t.3c. Nonetheless, they are still attested and share some similarities with layer t.3c such as the preferential use of unifacial debitage – though bifacial discoid-like cores are present – and scars left by removals which do not overshoot the most prominent point of the central part of the knapping surface. On the other hand, the preparation of the knapping surfaces by peripherical removals and flakes exploited as discoid cores, despite being rather recurrent in layer t.3c, are not documented within layers t.3coll and t.3a. Additionally, the incidence of discoid flakes within layer t.3c makes up for almost one-third of the entire debitage production (Gallotti and Peretto, 2015), while very few, if none, discoid flakes were documented from layers t.3coll and t.3a. It should also be mentioned that, while for layer t.3c the lithic corpus from the entire excavation area was examined – despite being quantitatively identical to the sample analysed in this work – the lithic pieces from layers t.3a and t.3coll derives from a selection of the richest squares. Aside from this, it is interesting to notice that both the orthogonal/centripetal and discoid conception of the surfaces were recurrent traits of the Isernia chert productions. As we will see in the following paragraphs, when the archaeological evidence during the European Middle Pleistocene is addressed, these conceptions share an identical methodological substratum: the use of a peripherical platform to shape and control the volume of the cores, which is considered one of the innovative features documented during the Middle Pleistocene Revolution.

The third strategy is applied on rectangular and cubic-shaped slabs without a preferential use for one or the other morphology. In this case, the debitage was mainly unifacial with unipolar parallel removals. Once the available natural convexities of the knapping surfaces were exhausted or the quality of the raw material prevented from proceeding, the cores were often rotated, or the striking platforms and the knapping surfaces were inverted analogously to an SSDA conception. Striking platforms were natural, though flat ones could have been exploited during one of the inversion or rotation events. As in the other strategies, extensive use of the natural convexities was performed, often leading to the obtainment of backed flakes. Reduction sequences were mainly short, limited to 2-3 removals per surface, or longer when additional surfaces of the slabs were involved. These last two aspects are rather transversal to the entire debitage production of Isernia La Pineta in both layers analysed. The incidence of flakes without removals, representing the largest group within the removals' organisation, additionally highlights the massive exploitation of natural surfaces regardless of the knapping strategy.

In both layers analysed, unifacial debitage associated with unipolar removals is the most attested strategy. The limited presence of bifacial and multifacial cores is due to the raw material constraints rather than a lack of complexity of the entire assemblage. In most cases, bifacial and multifacial cores are characterised by unipolar scars on two or more knapping surfaces, resulting from single unifacial events that are eventually repeated on new surfaces once cores are rotated. On the other hand, mostly on bifacial cores, the additional knapping surfaces testify to the opening of flat striking platforms to optimise the unifacial-orthogonal/centripetal debitage – in this category also fits cores showing a discoid-like conception of the surfaces. Another peculiar trait that emerged in the Result section is that among unifacial, bifacial, and multifacial cores, bifacial ones exhibit higher dimensional values (43 x 35,6 x 28 mm), while unifacial (34,4 x 26,5 x 21,1 mm) and multifacial ones (33,8 x 27,3 x 19,3 mm) are dimensionally similar. Since we are dealing with miniaturised productions and the size differences between these categories are negligible, plus there seems to be no correlation between the size values and the reduction strategies, this data is seemingly irrelevant.

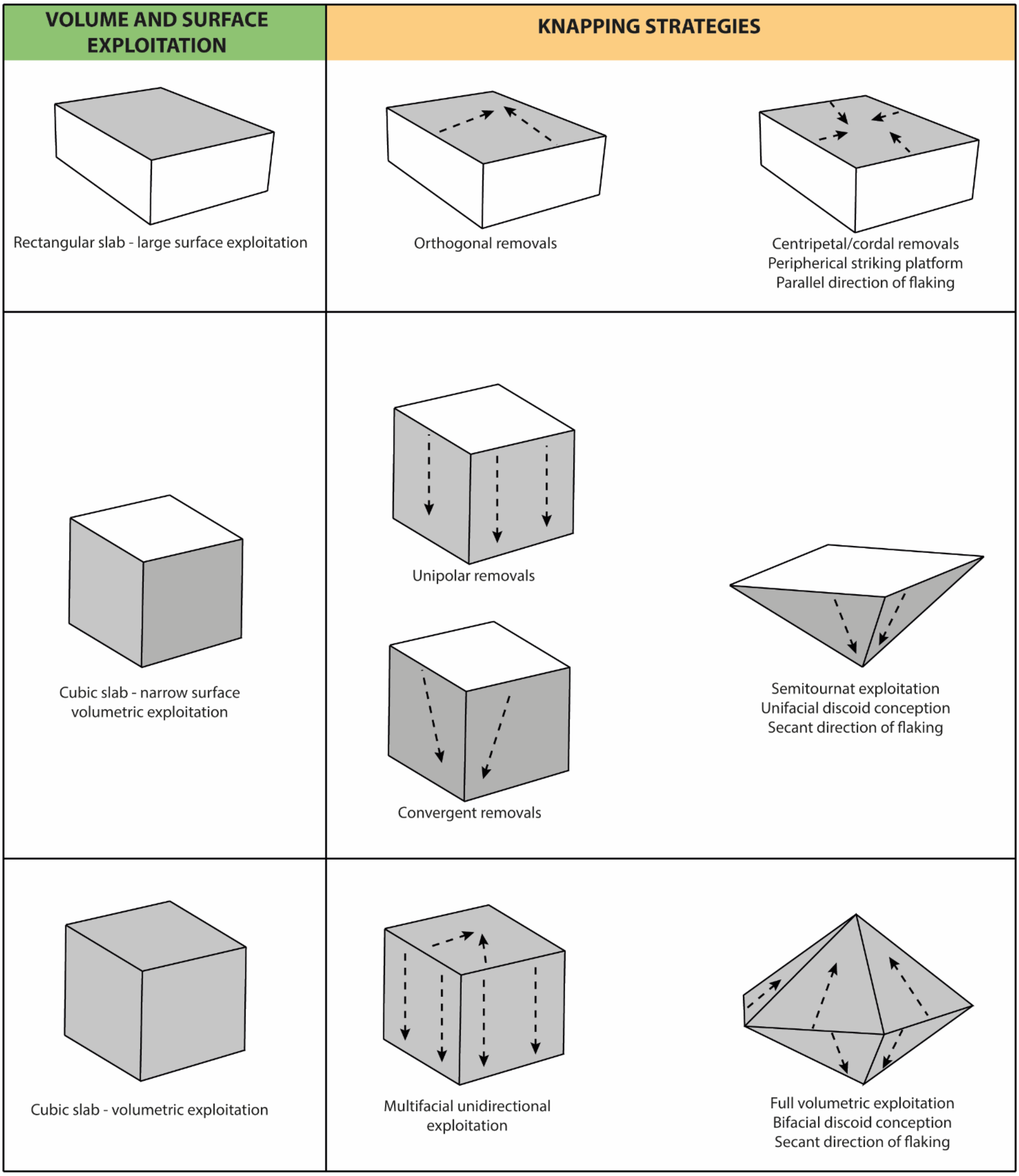

Figure 5.3 Diacritic schemes of the knapping strategies documented for layers t.3coll and t.3a at the site of Isernia La Pineta.

Aside from this, striking platforms are predominantly natural. Plunging and debordant flakes incidence reveals that knapping surfaces and cores were not remarkably large but still efficiently exploited according to the existing natural arrises to manage the cores' convexities. This might suggest that the need for specific convexities/angles, regardless of the slabs' shape, was seemingly a researched feature within the reduction sequences. Besides this, a tendency to exploit cores expediently was also identified. Small and, in a minor portion, larger cores selected for just one or two removals, even of lower-quality raw material, highlight that the need to produce small functional flakes was the cornerstone of the entire production, as witnessed in other sites associated with animal carcasses exploitation (Mosquera et al., 2015; Aureli et al., 2016; Moncel et al., 2021a).

Generally speaking, cores are abandoned at different stages of exhaustion – small-sized supports without suitable knapping angles, broken cores, larger slabs still exploitable, etc. – which, together with flakes, retouched flakes, and debris should confirm the completeness of all the phases of the reduction sequences. Nonetheless, cores obtained from the highest quality of chert – documented on several flakes and retouched flakes – seem underrepresented, if not completely absent. It should be mentioned that this fine quality chert recorded on the debitage products is not associated with specific knapping strategies or tools' production. On one side, this indicates that production goals were achieved regardless of the supports' quality – though the hominins seemingly executed an accurate selection of the slabs – and that reduction sequences were massively modulated on the available morphologies and qualities, being able, when possible, also to alter the original slabs' volume. Conversely, it is plausible that the highest-quality supports were transported and knapped over larger areas by the hominins who could take advantage of better support to exploit prolongedly. It is also possible that this lithological variety of chert was less available in secondary deposits – hence being less attested within lithic artefacts – and, at the same time, available in smaller volumes which were massively exploited, producing an underrepresentation within cores.

Another peculiar trait of the debitage strategies documented at the site of Isernia is the presence of cores-on-flake productions. The significant number of recorded core-on-flakes might be a technical expedient to enhance the slabs' volume to obtain small flakes and overcome the presence of cortex and internal fractures. The removals' dimensions fit the size of the small flakes attested in the rest of the site. It is also possible that during the slabs' opening – either through direct percussion or bipolar on-anvil technique – larger flakes were unintentionally obtained. The reduction sequences obtained from flakes as cores are relatively short and attest to one generation of removals without altering the original support's morphology. The cores-on-flakes exhibit small dimensions, suggesting their obtainment from the slabs' opening is unlikely. Additionally, it could be argued that given their small dimensions, they were exploited mainly to obtain small-sized flakes not to be retouched (*i.e.*, smaller than the mean dimensional values of flakes and retouched flakes). Cores on flakes are quantitatively inferior to "regular" cores but represent a recurrent and efficient strategy employed by the hominins of Isernia, also fitting the production goals and the flexibility of the mental schemes adopted.

Another aspect worth mentioning is the presence of six cores, which share similarities with retouched tools if their size and functional cutting edges (< 75°) are considered. These lithic objects can be considered ambiguous as their technological characteristics are halfway between cores – the presence of removals dimensionally similar to the end-products – and retouched flakes – the presence of cutting edges and regular distribution of the removals. Since we are dealing with a lithic assemblage that produces mainly small flakes, can we correctly distinguish between passive supports (*i.e.* cores) and active ones (*i.e.* flakes/tools)? It is plausible that, given the great flexibility that characterises this lithic industry and its production goals, the boundary between the concept of debitage and façonnage was subtle and functional to the hominins' necessities. From this point of view, similar behaviours were found at the sites of Ficoncella and Soucy 3, where a "circularity" of the reduction sequences was reported, and supports were simultaneously active and passive within the same reduction process.

Moving onto the end-products, flakes and retouched show similar characteristics in both layers analysed. The analysis of knapping strategies from the dorsal flakes highlighted the relevance of unipolar and orthogonal debitage, confirming the data obtained from the cores' analysis. Flakes without removals are nonetheless predominant, stressing the massive exploitation of natural surfaces and the completeness of the reduction sequences. From this perspective, cortical patches are absent on more than 80% of flakes and retouched flakes, which indicates the natural absence of cortex on the selected supports. The ratio of scars per flake confirms the shortness of the reduction sequences with a mean value of 1 when flakes without removals are counted and a mean value of almost 2 (1,8) when excluded. Understandably, orthogonal, centripetal and crossed removals are associated with more scars (2,5). Specific differences between the products obtained through different removal organisations were not documented. Orthogonal and centripetal scars, when present, are associated with skilful management of the lateral and distal convexities, confirming that knapping surfaces were extensively exploited regardless of their small size. Backed margins are equally present, regardless of the debitage strategies, and are recurrent traits of the flakes' production. It is interesting to notice that backed flakes are longer than flakes without backed margins, though width values are the same. Platform distribution is dominated by flat and natural butts, with traces of platforms' preparation documented on a very reduced percentage (around 5% of facetted and dihedral butts). No particular correlations were observed between the platform type and the removal organisation. The predominance of natural platforms confirms the data gathered from the cores, highlighting the recurrent use of natural surfaces to produce flakes. At the same time, flat butts could confirm the opening of striking platforms on bifacial cores to set up better angles for orthogonal and centripetal debitage and indicate the recurrent rotation of the surfaces on multifacial cores. Given the predominance of unipolar scars on cores and flakes, we would say that the latter hypothesis was the most frequently adopted by the hominins.

Larger supports were selected for the retouch. The original morphology of flakes was not profoundly altered in most cases since the modification was generally applied on the marginal side of the flakes – usually the lateral or distal margins. Nonetheless, on several occasions, the flakes' margins and original volume were substantially modified to obtain specific shapes (points and scrapers with invasive or covering retouching), showing great flexibility and high expertise. Edge modification was applied on all flakes regardless of their characteristics and shapes to get various tools, suggesting various functions and usage. Scrapers, denticulates, and notches are the most attested typologies. Backed margins were frequently attested and generally opposite to the retouched margins, seemingly representing possible prehensive parts of the artefacts. Though one generation of removals characterises most of the retouched flakes, several artefacts attest to a possible, prolonged use documented through a rejuvenation of the margins. It is plausible that while some of these tools characterised by a single generation of removal were employed for immediate use or short-time events, others displayed prolonged life and functions. If we link this data to the hypothesis that the highest-quality chert is underrepresented in cores' analysis, we might suppose that while, on the one hand, hominins knapped cores, produced flakes, retouched, used, and abandoned them "at the same time", on the other hand, some artefacts were transported over larger areas, experiencing a prolonged use, and possibly retaining a higher connotation and function, fitting within a sort of prehistoric tool-kit.

Also, for the site of Isernia, a cluster of smaller flakes exists within unretouched flakes, though it is less pronounced than Notarchirico (Fig. 5.3). In other words, while the production of miniaturised products is present, they are not as miniaturised when compared to retouched flakes (always realised on longer and larger supports), and especially when compared to unretouched flakes. However, it is clear that the goal of the chert debitage production at Isernia was, at the same time, unretouched and retouched flakes, equally relevant to the activities conducted on the site.

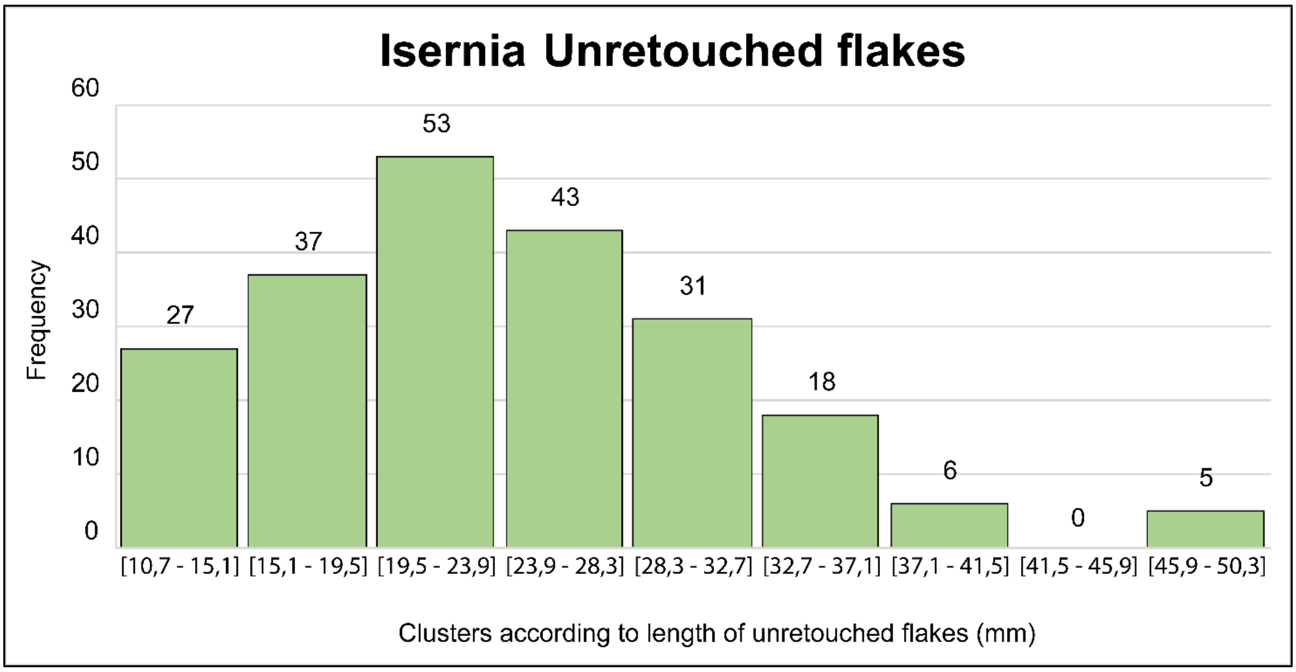

Figure 5.4 Histogram plotting unretouched flakes length (mm). The values in brackets express the beginning and ending of each cluster in terms of length.

From this perspective, recent use-wear analyses performed on the same sample analysed for layers t.3coll and t.3a (Carpentieri et al., 2023a) revealed that flakes and retouched flakes were exclusively used for carcass processing on soft and soft-medium materials (meat, fresh hide, and animal tissues). Flakes' function was primarily cutting and, to a slightly lesser extent, scraping activities, although all the phases of carcass processing were identified. Minor traces of bone working were also observed and might be related to periosteum removal required during marrow extraction, confirming a butchery-related role of the site (or at least of the chert materials), also proposed in other previous works (Longo, 1994; Peretto, 1994; Gallotti and Peretto, 2015; Peretto et al., 2015; Lugli et al., 2017; Channarayapatna et al., 2018; Pineda et al., 2020). On a side note, no associations were found between specific shapes and worked materials among the different retouched flakes identified from a typological point of view. Following these lines of thought, the importance of small-sized unretouched flakes for butchering activities, especially on large herbivore carcasses, has been validated and proven in many experimental activities (Longo, 1994; Boschian and Saccà, 2015; Venditti et al., 2019; Rocca et al., 2021), further enhancing the value of the small-sized implements produced at the site of Isernia.

Overall, the chert industry of Isernia is characterised by miniaturisation of the end products and the supports. This is undoubtedly due to the raw material constraints the hominins efficiently overcame, highlighting a high level of expertise and producing a sophisticated range of flakes and tools through numerous technical expedients. Core technologies display, on one side, short reduction sequences on different qualities of chert – ranging from poor to vitreous – often conducted on single knapping surfaces and massively subordinated to the available morphologies. On the other hand, a consistent production of flakes obtained through centripetal and, in minor portions, discoid-like debitage can be witnessed on several cores and flakes, attesting to the capacity of the hominins to alter the original shape of the supports, subordinating the morphological criteria to the production goals. Direct percussion and bipolar on-anvil techniques were employed, accounting for a codified choice from the hominins to overcome the slabs' morphology and quality, reflecting a well-known technical behaviour.

Hominins also locally collected several limestone pebbles to produce and perform several activities. The limestone industry from layers t.3coll and t.3a has been analysed by Rufo and colleagues (2009) and partially by Carpentieri and colleagues (2023a) for a total of 401 limestone implements from layer t.3a and 748 limestone objects from layer t.3coll. The limestone assemblage from both layers features pebbles' predominant presence, followed by flakes, retouched flakes, cores, and, in minor percentages, hammers, choppers, and anvils. Limestone cores were exploited through several unprepared and non-hierarchised striking platforms and knapping surfaces (Rufo et al., 2009) and knapped using direct percussion with the hard hammer. The removal organisation show mostly unipolar and orthogonal scars, with a mean of two removals per surface. Flakes and retouched flakes are medium and large-sized, often associated with cortical patches or entirely corticated, and are characterised by cortical and natural butts. Edge modification was sporadically applied on small portions of the flakes, always marginally and on the dorsal face. Pebbles with single removals or traces of impacts/percussions are the most attested category within the limestone industry. Despite the lack of use-wear data for these pieces and an experiment to accurately distinguish between intentional and post-depositional fractures, a battering or percussive use was hypothesised for these artefacts. Since chert industries were seemingly oriented to butchering-related activities, it is plausible that limestone choppers and pebbles might have been used for similar purposes, such as marrow extraction or bone fracturation. On a more superficial level, they were used as hammers for the *in situ* debitage production, both for the direct percussion technique and the bipolar on-anvil one – as the presence of a couple of anvils seems to confirm.

The presence of more "complex" tools, such as rabots, heavy-duty scrapers, and choppers (Anconetani et al., 1992; Rufo et al., 2009; Carpentieri et al., 2023a), was also reported, though their analysis is still at a preliminary stage. Nonetheless, their presence could be significant in terms of the capabilities of the hominins to produce large-sized objects through an elaborate shaping.

Overall, limestone industries represent a quantitative minor portion – but not less significant – of the lithic assemblage from Isernia, whose primary goal was to obtain small-sized flakes with sharp cutting edges and retouched tools from chert slabs. The economy of the raw material performed on limestone revealed that two typologies of this raw material were locally available, one coarser and more friable (marl-type, white calcarenite), the other softer and exhibiting a finer texture (microcrystalline laminated limestone) (Rufo et al., 2009; Gallotti and Peretto, 2015). Hominins selected, knapped, and used (as hammers and anvils) only the microcrystalline limestone, indicating a skilful knowledge of the lithotypes available in the site's proximity, as also underlined for chert slabs.

5.3. Notarchirico and Isernia La Pineta: two Lower Palaeolithic sites of the Italian peninsula within the Middle Pleistocene Revolution – affinities and discrepancies

Now that the two lithic assemblages have been extensively analysed and discussed, it is time to evaluate and compare their eventual similarities as two Lower Palaeolithic contexts of the first half of the Middle Pleistocene and their role within the European archaeological background.

The lithic assemblages of Notarchirico and Isernia La Pineta are realised on local raw materials, featuring the presence of chert and limestone in both contexts. Chert was available under small-sized nodules at Notarchirico and slabs at Isernia La Pineta. The presence of chert fluvial pebbles was documented in both contexts, though being sporadically attested as support. The small volumes determined several technological strategies for the chert production at the two sites, always aimed at obtaining flakes with sharp cutting edges and several tools. On the other hand, limestone pebbles were collected at both locations under medium and large-sized fluvial pebbles to realise flakes, retouched flakes, large-sized tools (chopper, heavy-duty scrapers, pebble tools, etc.), and, possibly, employed as hammers for percussive purposes.

The composition of the chert industries (Tab. 5.1) is characterised by a predominance of unretouched flakes (65% at Isernia and 46% at Notarchirico), followed by retouched flakes (23% at Isernia and 21% at Notarchirico) and retouched nodules (22% at Notarchirico). Cores are the least attested category in both contexts, in similar quantities. Retouched nodules are one of the first peculiarities that distinguish these sites, as at Notarchirico, hominins selected small chert nodules dimensionally analogous to flake to be subsequently retouched. Since these nodules fulfil the same goal as retouched flakes, being collected as an additional solution to compensate for the chert's quality and volume, they will be considered the same as retouched flakes to facilitate the comparison between Notarchirico and Isernia's technical behaviours. Considering this, the amount of retouched tools documented at Notarchirico (43%) is considerably higher than in Isernia (23%), while for unretouched flakes is the opposite, representing 65% of the entire assemblage at Isernia, and the 46% at Notarchirico.

Table 5.1 List of chert lithic artefacts analysed from Notarchirico and Isernia La Pineta

Site	**Notarchirico**		**Isernia La Pineta**	
Categories	n	%	n	%
Cores	63	10,6	69	12,3
Flakes	274	46,4	363	64,7
Retouched flakes	124	21	129	23
Retouched nodules	130	22	-	-
Total	591	-	561	-

The direct percussion with the hard hammer is employed for debitage production at both locations. The use of the bipolar on-anvil technique has been attested and confirmed at the site of Isernia La Pineta through indirect evidence (anvils) and experimental sessions (Crovetto et al., 1994; Peretto, 1994; Vergès and Ollé, 2011). Direct evidence on flakes and cores is challenging to assess and obtain as the bipolar on-anvil technique can often produce identical traces to direct percussion (e.g., Jeske and Lurie, 1993; Bietti et al., 2010; Hiscock, 2015b; 2015a; Peña, 2015; Pargeter et al., 2019a) on the artefacts, while the incidence of its "fossil markers" (*i.e.,* counter-bulbs, counterblows, counter-platforms, etc.) are somewhat sporadical, leading to an overall underestimation of the use this technique within archaeological contexts. Additionally, the raw material plays a predominant role in its identification since the texture quality might enable the development of specific traces or grant a better reading of the surfaces. From this perspective, the raw material of Isernia La Pineta can be challenging to analyse, macroscopically and microscopically, given its coarser texture on some slabs and the recurrent presence of internal fractures. However, since its particular resistance to mechanical fracturation, the requirement for a major strength in the blows could have been enhanced and facilitated by using an anvil. For instance, in the work of Gallotti (2015), focused on layer t.3c from Isernia, no traces of the anvil technique were documented within the debitage production, while in this work, its presence was hypothesised for some pieces, though no clear traces allowing a sharp distinction between direct percussion and bipolar technique were recorded (Carpentieri et al., 2023a). Nonetheless, many recent works – experimental and not – highlighted how, within a core-and-flake assemblage, the same goals could be achieved using both techniques, boosting the significance of the bipolar technique, primarily within Lower Palaeolithic sites.

At the site of Notarchirico, cores, flakes, and retouched flakes bear evident marks of direct percussion with the hard hammer, while the presence of counterblows or counterbulbs was not detected in any artefact from the different layers (Moncel et al., 2020e; Rineau et al., 2022; Carpentieri et al., 2023b). Whether the hominins could have used the bipolar technique is an idea that, for now, seems far from the available data. Realising a dedicated experimental activity could be significant to recording the response of the Notarchirico's raw material to different debitage techniques, granting greater insights into the possible technical responses enabled by the hominins. The efficiency of the bipolar technique in miniaturised productions – such as the ones of Isernia and Notarchirico – has been demonstrated in different works, making using this technique in such contexts still viable. It is also plausible that given the texture and quality of the raw materials of Notarchirico, there was no need for the use of this expedient. About this, the average quality of the raw material of Notarchirico is lower than the one from Isernia La Pineta – both feature a broad spectrum of varieties, ranging from coarse to vitreous textures, but at Isernia, finer qualities seem more common within secondary deposits – though the former is not as fractured as the latter.

Furthermore, "cultural" reasons or functional choices might also dictate the techniques' choice. The presence of several limestone pebbles, chert pebbles, and many chert slabs and nodules available at both locations should indicate that the lack of raw material was seemingly not a discriminating factor. Additionally, all the phases of the reduction sequences were documented in both sites, so a different pattern in the spatial use of the site might also be excluded.

Another aspect that might be interesting to explore is the retouching technique. Direct percussion is usually the classic technique to retouch any support, and the scientific literature, primarily when

Lower Palaeolithic contexts are addressed, did not provide any evidence of the contrary. Flakes and nodules from Notarchirico and Isernia are characterised by an edge modification seemingly performed through direct percussion. However, using an anvil to facilitate the supports' positioning and retouching might also be efficient, as proved for debitage activities. Evidence of retouching through an anvil percussion is mostly documented in Late-Middle Palaeolithic, Upper Palaeolithic and Mesolithic contexts associated with flakes, laminar and bladelets productions to obtain morphologically standardised backed supports (for instance, see Delpiano et al., 2019; Fasser et al., 2019 and reference therein). A soft hammer is generally employed in these contexts, as the supports can be extremely thin, narrow, and delicate, though in older contexts where the retouching supports are small and medium-sized flakes, a hard hammer is also used (Delpiano et al., 2019). In these more recent contexts, the anvil percussion was aimed at the confection of abrupt backed margins, which is not the case for Notarchirico and Isernia La Pineta, where backed margins were sporadically retouched and almost exclusively obtained from natural surfaces. Nonetheless, since we are dealing with small-sized assemblages where the mean dimensions of the implements are roughly equal to 20-25 mm for length and width, it could be an additional efficient expedient to modify their edges. The versatility and flexibility of the bipolar on the anvil are being explored in different aspects (Gallotti et al., 2020; Horta et al., 2022), as are the retouching techniques (see, for instance, the recent evidence of bulb retouchers from Levant and European Lower and Middle Palaeolithic contexts in Centi et al., 2019; Mathias et al., 2021; 2023).

Core technologies from Notarchirico and Isernia La Pineta share several similarities. Unifacial cores are the most frequently attested (55% at Notarchirico, 51,5% at Isernia), followed by bifacial cores, slightly more frequent at Isernia than Notarchirico, and multifacial cores, more recurrent at Isernia than Notarchirico (Tab. 5.2). Unipolar debitage characterises most cores, which are usually reduced through short reduction sequences exploiting the natural convexities and arrises of the blocks. Striking platforms are generally natural, exploiting surfaces naturally deprived of cortical patches. Orthogonal and, more rarely, centripetal debitage are documented on a minor portion of cores when larger surfaces were available, though they are more recurrent at Isernia than Notarchirico. On these cores, the opening of a flat striking platform through single removals was sporadically attested to facilitate the debitage. Bifacial and multifacial cores often document an SSDA conception of the surfaces at both locations, with multiple events of surfaces' rotation according to the available volumes. In these cases, a maximum of two or three removals was obtained from each knapping surface. The rotation or inversion of the surfaces regularly generated flat striking platforms. The mean number of removals for all the cores' categories is 2,9 for Notarchirico and 3,5 for Isernia La Pineta, perhaps indicating longer reduction sequences performed at Isernia.

Cores were abandoned at different stages of exploitation. For instance, there is evidence of large and medium-sized cores abandoned after a few removals – even on several surfaces – due to a poorer quality of the raw material (internal fractures, predominant presence of cortical patches); small-sized blocks selected for just one or two removals, regardless of the quality of the raw material; small-sized cores of good quality abandoned at an advanced stage of knapping, attesting to prolonged sequences and often obliterating natural surfaces and the original morphology of the support, due to the exhaustion of the volumes; medium and small-sized cores still preserving natural surfaces and suitable angles with a couple of removals per surface. These patterns, besides confirming that seemingly all the knapping phases were performed in situ, suggest that flakes' obtainment was the cornerstone of the production goals, being carried out on all the accessible supports, taking advantage of the natural convexities of the blocks and codifying the length of the reduction sequences according to the texture and volumes available.

Table 5.2 Typologies of cores on chert from Notarchirico and Isernia La Pineta

Site	**Notarchirico**		**Isernia La Pineta**	
Cores	n	%	n	%
Unifacial	33	55	35	51,5
Bifacial	20	33,3	20	29,4
Multifacial	7	11,7	13	19,1
Total	60	-	68	-

This behaviour was deeply assimilated within the methodological responses of the hominins of Notarchirico and Isernia La Pineta. Furthermore, even if the hominins undoubtedly performed a selection of specific nodules and slabs to optimise the raw material's exploitation, when needed, they also selected supports of inferior quality expediently knapped to obtain some flakes. It could be argued that, on certain occasions, the pros of knapping these supports were higher or matched the time and energy invested in knapping higher-quality blocks for a prolonged time since the outcomes (flakes' obtainment) were identical.

On the other hand, evidence of a more structured debitage, conducted regardless of the original shape of the blocks, is documented at Isernia La Pineta through several centripetal and discoid-like cores when a peripherical striking platform was employed. The presence of discoid reduction sequences was highlighted in layer t.3c at Isernia (Gallotti and Peretto, 2015). These strategies are seemingly absent from the lithic assemblage of Notarchirico. Indeed, the analysis of the removal organisation from the dorsal face of the flakes (Tab. 5.3) revealed that orthogonal and centripetal debitage represented a consistent portion of the knapping strategies of the hominins. Skilful management of the lateral and distal convexities was recorded on several flakes. However, they do not seem to derive from a structured conception of the surfaces as documented at Isernia. Furthermore, the absence of such behaviours from Notarchirico's core assemblage might indicate that these strategies were not employed at the site or, to the utmost, extremely sporadically.

Table 5.3 Removals' organisation on flakes and retouched flakes from Notarchirico and Isernia La Pineta.

	Notarchirico						**Isernia La Pineta**					
	Flakes		Retouched flakes		Total		Flakes		Retouched flakes		Total	
Removals	n	%	n	%	n	%	n	%	n	%	n	%
Absent	53	20,9	44	41,9	**97**	**27**	92	28	34	28,3	**126**	**28,1**
Unipolar	82	32,3	26	24,8	**108**	**30,1**	78	23,8	29	24,2	**107**	**23,9**
Convergent	15	5,9	9	8,6	**24**	**6,7**	47	14,3	9	7,5	**56**	**12,5**
Crossed	20	7,9	7	6,7	**27**	**7,5**	14	4,3	2	1,7	**16**	**3,6**
Orthogonal	43	16,9	13	12,4	**56**	**15,6**	58	17,7	25	20,8	**83**	**18,5**
Bipolar	14	5,5	1	1	**15**	**4,2**	26	7,9	8	6,7	**34**	**7,6**
Centripetal	27	10,6	5	4,8	**32**	**8,9**	13	4	13	10,8	**26**	**5,8**
Total	254	-	105	-	**359**	**-**	328	-	120	-	**448**	**-**

Lastly, evidence of cores on flakes is documented at Isernia La Pineta but absent from Notarchirico. These cores are realised on small-sized flakes, dimensionally similar to cores on slabs, and exploited on one knapping surface, usually corresponding to the dorsal face of the flake-core, taking advantage of its convexity. The associated striking platforms were primarily flat, deriving from the ventral face. Reduction sequences based on the exploitation of flakes as cores are relatively rare during the Lower Palaeolithic (Ashton, 2007) and are often described as "ramification" or "branched productive sequences" (Bourguignon et al., 2004; Romagnoli et al., 2018; Mathias and Bourguignon, 2020; Mathias et al., 2020). The concept of "ramification" can be summarised as *"[…] the technical role of a flake changes from that of an object ready to be used (with or without retouch) and which possesses a functional edge and a prehensile portion to that of an object which serves as raw material stock for production and which possesses a specific volumetric construction suitable to be divided into tools."* (Romagnoli et al., 2018, p. 168).

Several works highlighted the dual role of flakes used as cores (Delagnes, 1993; Geneste and Plisson, 1996; Ashton, 2007; Lhomme, 2007; Meignen et al., 2009; Agam et al., 2015; Assaf et al., 2015; Romagnoli, 2015; Aureli et al., 2016), and, particularly from the late 1990s, the classical technological categories of "tool" and "core" have been explored and considered more ambiguous and mutually exchangeable than previously thought (Tixier and Turq, 1999; Bernard-Guelle and Porraz, 2001; Bourguignon and Turq, 2003; McPherron, 2009). Ramified productions, mainly in Middle and Late-Middle Palaeolithic contexts where they have been intensively investigated, are considered a sign of planned behaviours, assimilated within provisioning strategies since the beginning of the reduction sequences (Bourguignon et al., 2004). Their flexibility might also reflect a multi-functionality of cores and flakes at different times and places, hinting at complex dynamics within production, use, discard, and even recycle events. According to Romagnoli and colleagues (2018) and Bourguignon and colleagues (2004), ramified or branched productions are strictly related to cores' mobility – often being underrepresented within lithic assemblages. They state that, from a behavioural and complexity perspective, the mobility of cores-on-flakes has significant implications in three fields (Romagnoli et al., 2018):

1) *Planning and task organisation*: a distinction has to be made between knapping activities carried out in the same place (*i.e.*, tools are used and subsequently transformed into cores on flakes) and a fragmentation of the ramified sequences into different places and at different times. According to the authors, in the first case, *"[…] ramification sequences could have simply been the response to knapping constraints or a quick way to obtain sharpened edges as a response to immediate needs. In this case, a low level of standardisation of procedures and products as well as of morpho-technical characteristics of cores-on-flakes could be expected given that the activity was quite extemporaneous."* (Romagnoli et al., 2018, p. 169). This is considered the "opportunistic" variant, often implying a negative connotation and therefore excluded from the classic definition of the ramified strategies defined by Bourguignon (Bourguignon et al., 2004). However, as explained in the Materials and Methods section, we stressed how opportunistic behaviours can be as complex and planned as others. In the second case, the location and timing of ramified products are foreseen, and, theoretically, all or some of the flakes were transported as a stock of raw material, being subsequently reduced.

2) *Human mobility strategies*. Ramified productions allow a maximisation of the raw material productivity and, simultaneously, a minimisation of the costs of raw material provisioning. There are several situations in which these features were seemingly advantageous: lack of available raw materials near the site, presence of time stress during tasks, high mobility of the human groups, specific use-life of tools, absence of heavy-weighted objects to transport, possibility of focusing on the search for edible resources rather than knapping-related resources.
3) *Informal versus formal knapping*. It has often been argued that, particularly from Middle Palaeolithic contexts onward, ramified productions were as predetermined and complex as other more "classic" reduction sequences (*i.e.,* Levallois, Discoid, Quina), pointing out their importance within human behaviours, ending being associated with micro-productions as part of the human tool-kit (Mathias and Bourguignon, 2020; Mathias et al., 2020). However, cores and flakes productions might not necessarily have such socio-economic implications. Their expediency might hint at different social dimensions in debitage activities and task organisation.

Although all these considerations were made considering more recent contexts than the one analysed in this work – thus offering more accurate resolutions within human group dynamics, not to mention the state of preservation and the number of sites available – it is worth noting that, at least for Isernia La Pineta, the cores-on-flakes reduction sequences might be a significant factor in evaluating the degree of complexity of Lower Palaeolithic's lithic assemblages. In this sense, the first (*Planning and task organisation*) and the second (*Human mobility strategies*) fields might apply to this site, hinting at one of the hominins' possible, equally complex, strategic choices to obtain specific lithic products, manage the raw material's economy, and the exploitation of other resources within the same "area". Even though cores on flakes have not been documented at Notarchirico for now, the possibility that some of the retouched nodules were used as cores and tools, given the similarities that these instruments both share with tools (presence of edge modification, cutting edges, small-sized) and cores (removals dimensionally analogous to the end-products documented in the sequence, suitable debitage angles) might be a significant marker. This tendency has also been documented on some tools/cores from Isernia La Pineta, further enhancing the presence of these types of strategies.

Additionally, retouched nodules represent an essential component of the chert industry of Notarchirico, even if we consider them exclusively as tools. Besides being as numerous as retouched flakes and morphologically similar, they indeed are a dedicated and separated reduction sequence that shares several theoretical connections with branched/ramified productions. For instance, they allow for an immediate response to tools' confection necessities (*Planning and task organisation*). They also allow for a maximisation of raw material productivity – suitable for being transformed into tools in a much more efficient way than flakes – and, at the same time, allow for a minimisation of the costs of raw material provisioning (*Human mobility strategies*).

Within this scenario, if we consider that Notarchirico and Isernia La Pineta are two open-air palimpsests representing ideal spots for human groups to gather food, water, organic resources, and lithic raw materials – hence, contexts subjected to higher internal mobility – but seemingly not being places for permanent staying – such as rock shelters or caves –, the relevance of *"planning and task organisation"* and *"human mobility strategies"* associated to ramified productions, and, more in general, to the composition of the two lithic assemblages assume even more importance and meaning. From this perspective, the idea that the highest quality raw materials were underrepresented within cores' assemblage due to the higher mobility of these objects within the territory might also be more plausible.

Moving onto the end products, flakes, retouched flakes, and retouched nodules from Notarchirico and Isernia La Pineta are very much alike (Tab. 5.4; Fig. 5.5, 5.6). Their dimensions are analogous, though Notarchirico's retouched flakes exhibit a slightly greater length/width ratio than Isernia La Pineta's. This pattern is also present for unretouched flakes, though less prominently, and is the opposite, with Isernia's flakes showing a higher length/width ratio than Notarchirico's. Additionally, while at Notarchirico, a higher length/width ratio was favoured for edge modification, it was the opposite at Isernia. It is plausible that elongated products were more valuable at Notarchirico than at Isernia. However, since the documented discrepancies between these values are relatively negligible, we might confirm that the objects' dimensions rather than their elongation were the most crucial elements for edge modification at both localities.

Table 5.4 Mean dimensional values of cores, flakes, retouched flakes, and retouched nodules from Notarchirico and Isernia La pineta. All values are expressed in millimetres.

Site	**Notarchirico**			**Isernia La Pineta**		
Categories	length	width	thickness	length	width	thickness
Cores	**n=50**			**n=61**		
mean	40,8	35	26,2	36,9	30,1	22,4
Flakes	**n=198**			**n=220**		
mean	22,7	20,3	8,8	24	20,9	9,6
Retouched flakes	**n=88**			**n=95**		
mean	28,3	22,9	11,4	29,1	25,9	11,9
Retouched nodules	**n=115**			**-**		
mean	26,1	20,8	12,1	-	-	-

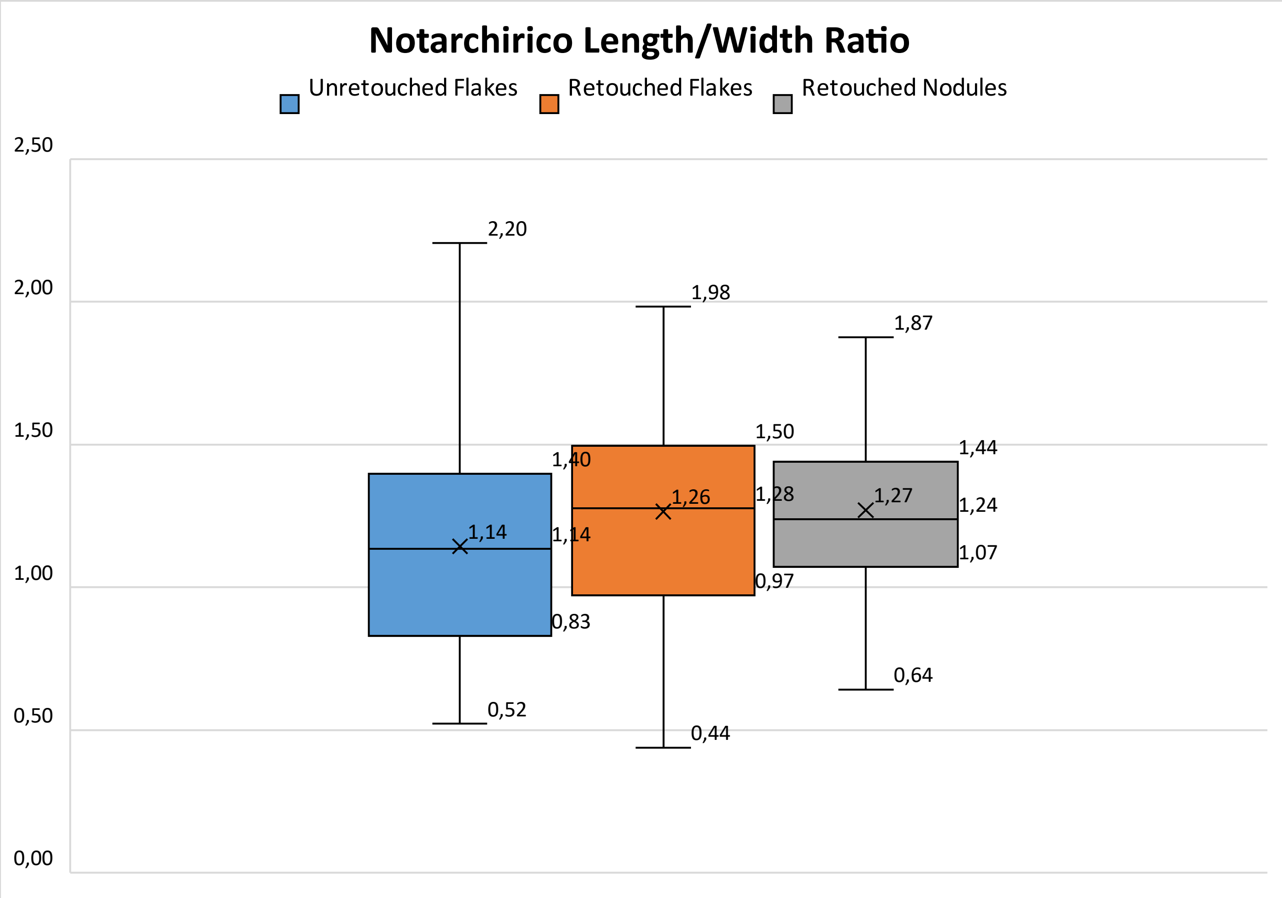

Figure 5.5 Length-width ratio of flakes, retouched flakes, and retouched nodules from Notarchirico.

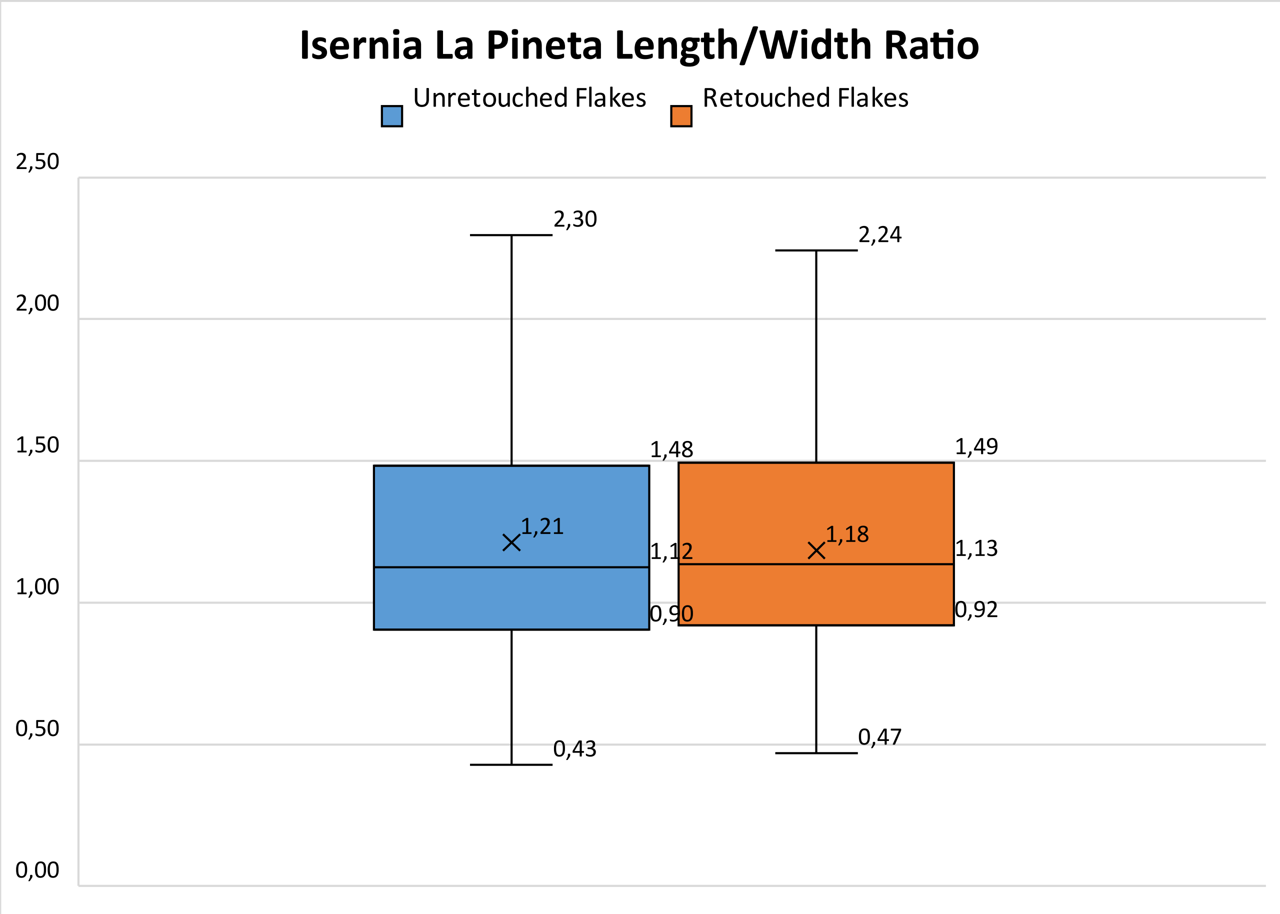

Figure 5.6 Length-width ratio of flakes and retouched flakes from Isernia La Pineta.

The reduction strategies (Tab. 5.3) reveal that unipolar scars are predominant in both sites, though at Notarchirico, they are more recurrent (30,1% vs 23,9%). Convergent scars are more attested at Isernia than at Notarchirico (12,5 % vs 6,7%), while orthogonal – being the second most common debitage strategy in both assemblages – convergent, crossed, bipolar, and centripetal removals are recorded on more or less the same proportions in the two contexts. Furthermore, if we consider the removals attesting to unequivocal peripherical flaking (*i.e.,* orthogonal, crossed, bipolar, and centripetal scars), we can see that the proportion between Notarchirico and Isernia is perfectly balanced (36,2% vs 35,2%; Tab. 5.3). This indicates that orthogonal and centripetal flaking were equally employed, though surfaces and volume conception were seemingly different, as documented by cores' analysis. Flakes without removals are the largest group in both sites, highlighting the recurrence of natural surfaces' exploitation. The platforms associated with this category of flakes are mostly natural (64,8 % at Isernia and 38,1% at Isernia), flat (25,4% at Notarchirico and 17% at Isernia), then cortical (19% at Notarchirico and 14,8% at Isernia), followed, in minor quantities, by linear and punctiform butts (Tab. 5.5). Five dihedral platforms were associated with flakes without removals but only at Notarchirico. There seems not to be specific patterns between platforms' distribution and removals' organisation when the two sites are compared. Traces of platform preparation are documented on both assemblages in negligible quantities. However, dihedral and facetted platforms are more attested at Notarchirico than Isernia.

As previously mentioned, retouched implements are more frequently recorded at Notarchirico than at Isernia (Tab. 5.6). The retouch was located in most cases on the dorsal face of the flakes – or on one face for retouched nodules – creating thin or abrupt margins. Typologically, edge modification was applied to create scrapers – the most recurrent type at both sites - followed by denticulates and notches. Composite tools, beaks, and pointed tools are sporadically attested with slight differences according to each context. For instance, beaks and pointed tools are more common at Notarchirico than at Isernia despite being represented by a small sample. Marginal retouching characterises scrapers, often placed on the lateral margin, but double and convergent scrapers are also documented in the same proportions at Notarchirico and Isernia. The same pattern happens for denticulates, though abrupt retouching is more frequent and convergent denticulates are only found at Notarchirico (Tab. 5.6).

Table 5.5 Platforms' distribution according to removals' organisation on debitage products (flakes and retouched flakes) from Notarchirico and Isernia La Pineta.

	Notarchirico													
Removals/Platform	Cortical		Natural		Flat		Dihedral		Linear		Punctiform		Facetted	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Absent	12	*44,4*	24	*41*	16	*12,3*	5	*16,1*	2	*14,3*	4	*22,2*	-	-
Unipolar	6	*22,2*	13	*22*	45	*34,6*	12	*38,7*	6	*42,9*	7	*38,9*	2	*22,2*
Convergent	-	-	6	*10*	9	*6,9*	2	*6,5*	2	*14,3*	-	-	1	*11,1*
Crossed	1	*3,7*	2	*3,4*	13	*10*	2	*6,5*	-	-	2	*11,1*	2	*22,2*
Orthogonal	6	*22,2*	10	*17*	24	*18,5*	5	*16,1*	2	*14,3*	2	*11,1*	2	*22,2*
Centripetal	1	*3,7*	1	*1,7*	15	*11,5*	4	*12,9*	2	*14,3*	3	*16,7*	1	*11,1*
Bipolar	1	*3,7*	2	*3,4*	8	*6,2*	1	*3,2*	-	-	-	-	1	*11,1*
Total	27	-	58	-	130	-	31	-	14	-	18	-	9	-
	Isernia La Pineta													
Removals/Platform	Cortical		Natural		Flat		Dihedral		Linear		Punctiform		Facetted	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Absent	13	*59,1*	57	*38*	15	*11,1*	-	-	1	*11,1*	2	*50*	-	-
Unipolar	4	*18,2*	30	*20*	36	*26,7*	4	*30,8*	4	*44,4*	-	-	1	*16,7*
Convergent	3	*13,6*	14	*9,3*	23	*17*	3	*23,1*	1	*11,1*	1	*25*	1	*16,7*
Crossed	-	-	3	*2*	7	*5,2*	1	*7,7*	2	*22,2*	-	-	-	-
Orthogonal	2	*9,1*	31	*21*	27	*20*	3	*23,1*	-	-	-	-	1	*16,7*
Centripetal	-	-	7	*4,6*	12	*8,9*	1	*7,7*	-	-	-	-	2	*33,3*
Bipolar	-	-	9	*6*	15	*11,1*	1	*7,7*	1	*11,1*	1	*25*	1	*16,7*
Total	22	-	151	-	135	-	13	-	9	-	4	-	6	-

One thing that might be interesting to point out is that if we observe the removals' distribution between unretouched flakes and retouched flakes, the same proportion is observed at Isernia, while at Notarchirico, there are some differences. Flakes without removals are always the predominant category, though they are far more recurrent within retouched flakes than unretouched ones. As a consequence, while the mean of removals per unretouched flake documented at Notarchirico is 1,6 when retouched flakes are considered, this value drops to 1,1, while at Isernia La Pineta, a mean number of 1,3 removals per flake is equally shared between unretouched and retouched flakes.

We demonstrated that bigger implements were selected for edge modification at both localities, and we proposed that flakes deriving from the initial part of the reduction sequences were favoured. If we add the mean removal data to this scenario, we might suggest that at Notarchirico, greater commitment to selecting bigger supports to be retouched deriving from the knapping initiation phase was seemingly devoted. It is also possible that larger cores were collected to produce mostly supports for edge modification, while small-sized nodules were exploited for unretouched flake obtainment. This behaviour might have also been documented at Isernia, though the removals distribution highlights that larger flakes deriving from several reduction sequences were seemingly selected. It is also plausible that larger volumes were more common at Isernia than Notarchirico, granting a more homogeneous production of more extensive flakes through different debitage strategies.

Table 5.6 Typological list of retouched tools (flakes and nodules) from Notarchirico and Isernia La Pineta.

	Notarchirico				**Isernia La Pineta**	
Retouched tools	Flakes	Nodule	Total		Flakes	
Type	n	n	n	%	n	%
Beaks	2	10	12	**5**	2	**1,6**
Denticulates	33	28	61	**25,5**	30	**23,3**
simple	21	24	45	-	26	-
double	2	2	4	-	4	-
convergent	10	2	12	-	-	-
Notches	14	29	43	**18**	16	**12,4**
Pointed tools	7	3	10	**4,2**	2	**1,6**
Scrapers	54	51	105	**43,9**	72	**55,8**
simple	42	39	81	-	54	-
double	8	7	15	-	12	-
convergent	4	5	9	-	6	-
Composite tools	6	2	8	**3,3**	7	**5,4**
Total	116	123	239	-	129	-

If, on one side, cores' analysis from Isernia yielded more structured reduction strategies than Notarchirico, whose cores' assemblage somehow indicates shorter and more simple reduction strategies, heavily codified on the available morphologies, without evidence of hierarchised sequences or debitage independent from natural volumes, on the other side, flakes' analysis and the presence of retouched nodules indicate that equally complex, but diversified, technical and behavioural choices were adopted by the hominins of Notarchirico. As previously hypothesised, it might seem that greater attention – in terms of time and energy invested – to tools' confection was conferred than to cores' reduction. In other words, while the production goals of both sites might have been similar, at Notarchirico, a shift between debitage activities and retouching activities (*i.e.,* faconnage activities?) was performed in favour of the latter.

Considering the activities performed at each locality, we might also state that the significant quantity of tools realised at Notarchirico rather than at Isernia might be due to the fact that butchering activities require more consistent and recurrent use of unretouched implements. The use-wear, taphonomical and archaeozoological analyses conducted at the site of Isernia La Pineta suggest that carcass processing and cutting-oriented gestures were among the primary – if not the only ones – activities performed (Longo, 1994; Thun Hohenstein et al., 2009; Pineda et al., 2020; Carpentieri et al., 2023a). On the other hand, the analyses conducted at Notarchirico, despite being still preliminary, revealed that hominins realised several activities ranging from butchering-related, organic material interactions (plants and woods), engravings, etc (Moncel et al., 2020e; 2023). This might explain the relatively minor importance of unretouched flakes – given that cutting activities were not primary – while, on the other side, it could confirm that these different activities required different tools – from this perspective, the relative increase of beaks and pointed tools among retouched implements might also be an indicator. As a sign of this, the limestone production of Notarchirico, featuring a broader and diversified range of tools compared to Isernia La Pineta, could represent an additional aspect to the different roles of the two sites (Piperno, 1999; Santagata, 2016; Moncel et al., 2019; 2020e; 2023; Santagata et al., 2020). Bifacial tools could also play a distinct role in this discussion. We should remember that the density of the two lithic assemblages is quite different, as Isernia features a massive quantity of lithic objects associated with many faunal remains. On the other hand, Notarchirico, despite exhibiting a consistent number of faunal remains – though not as many as Isernia – is characterised by a low density of lithic artefacts. Considering these data, the unretouched flakes/tools ratio could assume even more significance. We could suggest that, while being both open-air palimpsests characterised by several human occupations events, on one side, Isernia is a context featuring repeated butchery events from the hominins that seemingly occupied the area exclusively for that purpose along the presence of watercourses and lithic raw materials, generating an accumulation – certainly over an indefinite amount of time – of bones, lithic tools, and anthropic marks. Conversely, Notarchirico could represent a broader "passage" area, seemingly attracting hominins' attention due to the presence of water, plants, lithic raw materials, and sporadic herbivore carcasses, not to mention the absence of carnivores. As a result, hominins performed several activities without favouring specific tasks over others and possibly not as intensively as Isernia, hence the lower material density.

Moving onto the European framework, Notarchirico and Isernia La Pineta are two sites of the first half of the Middle Pleistocene witnessing several innovative and archaic features that allow for their contextualisation within the appearances of several behavioural changes occurring during this period, such as the Acheulean cultural complex.

Starting with Isernia, the efficient use of the bipolar on-anvil technique is an aspect that characterises several European sites of the Lower Pleistocene, such as Barranco Leon, Fuente Nueva 3, Pirro Nord and Cà Belvedere di Montepoggiolo, but also, with innovative features, Pont de Lavaud where this technique was vastly employed through dedicated reduction sequences (Peretto et al., 1998; Moyano et al., 2011; Arzarello et al., 2016a; de Lombera-Hermida et al., 2016; Despriée et al., 2018; Titton et al., 2018; 2020).

On the other hand, the increase in the use of centripetal debitage and the appearance of discoid-like reduction strategies witnessed at Isernia has often been considered one of the innovative features brought during the Middle Pleistocene Revolution and, sometimes, associated with bifacial industries (Gallotti and Peretto, 2015; Ravon et al., 2016b; Rossoni-Notter et al., 2016; Barsky et al., 2019). Analogous technical behaviours were recorded at other "contemporaneous" sites such as Moulin Quignon, La Noira, Gran Dolina TD6, Caune de l'Arago, and Boxgrove (Barsky and de Lumley, 2010; Barsky, 2013; Stout et al., 2014; Moncel et al., 2016a; 2018d; 2021a; 2022; Mosquera et al., 2018; García-Medrano et al., 2019; 2020; Lombao et al., 2022a). In the cases of Moulin Quignon, La Noira, and Caune de l'Arago, several bifacial industries were recovered, and centripetal reduction sequences highlighted structured debitage, with recurrent use of platform preparation, rectification of the knapping surfaces, and hierarchisation of the surfaces – traits often not as common, if not absent at all, at Isernia, and somehow closer to the bifacial conception of *shaping*.

It should be mentioned that for La Noira and Moulin Quignon, the exploited raw materials were chert of high quality available in large-sized supports, seemingly granting longer reduction sequences and greater possibilities to subordinate the morphological criteria of the blocks to the technical and methodological goals of the hominins (Moncel et al., 2020b; 2022). On the other hand, the site of l'Arago is characterised by the massive exploitation of quart-like raw materials, highlighting skilful techniques by the hominins. Gran Dolina TD6 features discoid and centripetal debitage, representing a significant component of the lithic assemblage, but no bifacial industries were recorded. Through the technological analysis of the reduction sequences, which also documented the increased frequency of retouched flakes, the authors stated that Gran Dolina TD6 exhibits significant behavioural innovations, possibly allowing for a comparison with other bifacial-bearing contexts and fitting within the Acheulean paradigm (Mosquera et al., 2018). From this perspective, Isernia features many retouched implements, and several recent studies have pointed out that the characteristics of the lithic assemblage of Isernia La Pineta are equally complex and innovative as other classic Acheulean sites (such as Moulin Quignon and La Noira), allowing for a recontextualisation of this site within the Middle Pleistocene Revolution (Gallotti and Peretto, 2015; Grimaldi et al., 2020; Carpentieri et al., 2023a).

Centripetal and orthogonal reduction sequences have also been documented at Notarchirico, though, as previously stated, they do not exhibit specific traits of knapping innovations that, on the other hand, were documented at Isernia, La Noira, Moulin Quignon, Gran Dolina TD6 and l'Arago. Despite this, a certain degree of complexity was recorded within the economy of the raw materials, embodied by the confection of retouched nodules to compensate for the consistent need for retouched tools. Also, in this case, a significant increase in the number of tools was encountered, being even more frequently attested than at Isernia. Within the present state of the art, only the site of La Noira seems characterised by this high number of retouched implements, including, other than scrapers, denticulates and notches – somehow recurrent in all the European sites previously mentioned – points, beaks and convergent tools, similarly to Notarchirico (Moncel et al., 2020b; 2020e).

Undoubtedly, the presence of bifacial industries is among the most striking evidence from Notarchirico, as it provides one of the earliest examples in Europe of the Acheulean techno-complex, together with the French sites of La Noira (700 ka) and Moulin Quignon (670 ka). In these contexts, some similarities exist within the degree of complexity of bifacial assemblages, exhibiting the complete ability to manage bifacial and bilateral symmetry, other than the presence of heavy-duty implements and large cutting tools; however, both French contexts show the use of soft hammer percussion for the final shaping of the bifaces which Notarchirico does not (Moncel et al., 2019; 2020b; 2020e; 2021a; 2022; Santagata et al., 2020). The use-wear analysis of La Noira also indicates the presence of diversified activities and exploited materials such as cutting meat, wood and plant processing, bone-working, and engraving, similar to Notarchirico (Hardy et al., 2018). The data gathered from Notarchirico until today still cast doubts about whether the emergence of handaxes is due to an in situ evolution or an allochthonous introduction. From this perspective, the homogeneity of the debitage production recorded along the entire stratigraphic sequence is emblematic and should incentivise us to explore accurately how the occupation patterns of a site and the activities conducted can massively influence the material culture and human response.

Aside from this, a tendency to exploit cores expediently was also identified, both at Notarchirico and Isernia. Small and, in a minor portion, large-sized cores selected for just one or two removals, even of lower-quality raw material, highlight that the need to produce small functional flakes was the cornerstone of the entire production at both localities. From this perspective, some similarities might exist with sites attesting to butchering activities, such as Barranc de la Boella, Ficoncella, and Gran Dolina TD6, where this type of artefact was relevant (Mosquera et al., 2015; 2018; Aureli et al., 2016; Ollé et al., 2023). Additionally, the presence of cores-on-flakes and the documented ambivalence of some tools/cores highlighted additional complexity within the lithic assemblages of the two Italian sites (Carpentieri et al., 2023a; 2023b). The implications represented by the ramified/branched productions (Romagnoli et al., 2018; Mathias and Bourguignon, 2020; Mathias et al., 2020) shed light on the multiple behavioural strategies that the hominins of Notarchirico and Isernia might have enabled as a response to the surrounding environmental conditions. Though these types of productions are typical of Middle and Late-Middle Palaeolithic contexts, the connection might not be chronologically related but could enhance the relevance of Isernia La Pineta and Notarchirico from a behavioural complexity perspective. Similar behaviours have been recorded at the site Italian site of Ficoncella (MIS 13), the British site of Boxgrove (MIS 15-13), and the French site of Soucy 3 (MIS 9), where a “circularity” of the reduction sequences – a term that the authors analysing Ficoncella and Soucy 3 used to describe the duality of some lithic objects as cores and tools – was reported (Lhomme, 2007; Smith, 2013; Stout et al., 2014; Aureli et al., 2016).

As previously mentioned, the core and flake production of Notarchirico and Isernia La Pineta fits within the “small-sized” flakes contexts of the Middle Pleistocene, such as Ficoncella (500 ka) and Atapuerca TD6 (800 ka), whose lithic assemblages resemble the Mode 1 debitage. In these contexts, characterised by the massive production of small flakes and tools on local raw materials, the absence of bifacial implements is reported – except for Notarchirico. It is unclear whether this is due to the blocks’ dimensions, cultural substratum – which has often led the scientific community to exclude them from the Acheulean techno-complex – functional reasons or size of the excavations area. Recent works from Gran Dolina TD6 pointed out that the absence of handaxes at the site is due to an actual absence of the bifacial concept, implying a systematic technological choice of the hominins rather than issued from the raw materials availability (Mosquera et al., 2018; Lombao et al., 2022a). On the other hand, at Isernia La Pineta, the butchery-oriented function that seems to characterise the site might have played a significant role in the absence of bifacial tools. It is also possible that the volume of the available raw materials prevented the hominins from shaping such tools, though, for instance, the site of Guado San Nicola (480 ka), located in the proximity of Isernia, yielded several bifacial tools realised on the same raw materials (Peretto et al., 2016; Arnaud et al., 2017). It is also true that the site of Guado San Nicola exhibits one of the earliest Levallois production in Europe, so the comparison between the two sites might not be as solid as it seems. The ability to produce bifacial industries has often been connected with the capability of realising centripetal and discoid reduction sequences – and, for more recent chronologies, also with Levallois – which, according to some authors, share the same methodological background (Ollé et al., 2013a; Moncel et al., 2014; 2020c; 2021a; Rossoni-Notter et al., 2016). From this perspective, the hominins of Isernia were capable of realising equally complex reduction sequences through the exploitation of peripherical striking platforms, therefore, the hypothesis that a certain degree of complexity was missing might not be valid (Gallotti and Peretto, 2015; Carpentieri et al., 2023a).

Another interesting topic is the miniaturisation of the end products that characterise Notarchirico and Isernia La Pineta. This is undoubtedly due to the raw material constraints, which the hominins efficiently overcame, highlighting a high level of expertise and producing a sophisticated range of flakes and tools through numerous, yet different, technical expedients. The Italian peninsula shows an interesting pattern of “miniaturised” lithic production throughout the Middle Pleistocene, ranging from the Lower Palaeolithic's end to the Middle Palaeolithic's beginning. To cite the most relevant sites, Ficoncella, Cimitero di Atella, Fontana Ranuccio, and Guado San Nicola, all share this feature, mainly when chert-realised implements are considered (Abruzzese et al., 2016; Aureli et al., 2016; Rocca et al., 2016; Arnaud et al., 2017; Grimaldi et al., 2020; Muttillo et al., 2021a). This pattern may undeniably originate from the available raw materials exploited but also resulted in similar methodological and technical responses (*i.e.* the previously mentioned ambivalence between debitage and shaping, cores-on-flakes, tool-core, etc.) that could indicate the emergence of a common — possibly cultural? — substratum, as will happen with the Middle Palaeolithic transition all over Europe, where a regionalisation of several technological aspects develops (Rocca, 2013; Moncel et al., 2016b; 2020c; 2020d; Ravon et al., 2016b; Stojanovski et al., 2018; Davis and Ashton, 2019; Ashton and Davis, 2021; Carpentieri and Arzarello, 2022).

5.4. The bipolar on anvil dilemma – Discussion and contextualisation of the experimental activity

In this section, we will discuss the results obtained from the experimentation. We will begin by comparing the raw data we gathered from each technique (tipology and morphology of butts and platforms, development of bulbs and Hertzian cone, presence/absence of proximal and distal micro-shattering, counter-butts, counter-bulbs, dimensional values, length/width ratios, removals organisation, etc.), subsequently crossing what we considered the most significant morphological features to highlight the possible differences or similarities.

The dimensional data show that, more or less, the flakes produced share the same size (Tab. 4. 116; Tab. 5.7; Fig. 5.7). The flakes obtained through the direct percussion technique show slightly higher dimensions than the other techniques, followed by the bipolar on-anvil and the anvil-assisted. Flakes are rectangular-shaped, longer than larger, except for the ones produced through the anvil-assisted, which are perfectly quadrangular (Tab. 5.7; Fig. 5.7). Bipolar on-anvil flakes exhibit a higher elongation ratio (1,42), while direct percussion (1,23) and anvil-assisted flakes (1,15) are more similar (Fig. 5.8). It is plausible that bipolar flakes are more elongated since they reach the end of the knapping surface more often than the other techniques. On the other hand, the width-thickness ratio revealed that anvil-assisted flakes are thinner while being larger than the others (3,59; Fig. 5.8). Direct percussion flakes present a width-thickness ratio of 3,12, closer to the anvil-assisted ones, though slightly thicker. Bipolar flakes show the lowest width-thickness ratio (2,54), exhibiting a closer relationship between width and thickness. The length-thickness ratio provides similar data patterns to the width-thickness. Anvil-assisted and direct percussion flakes exhibit the highest values, respectively, 3,77 and 3,66, though bipolar flakes are not significantly different (3,40). Generally speaking, the dimensional ratios are homogeneous, with the direct percussion and anvil-assisted techniques providing slightly more analogous data than the bipolar on-anvil (Fig. 5.7, 5.8).

Table 5.7 Dimensional values of flakes obtained through the different techniques employed. All values are expressed in millimetres.

Technique	**Direct percussion**			**Bipolar on anvil**			**Anvil assisted**		
	length	width	thickness	length	width	thickness	length	width	thickness
Flakes	n=115			n=94			n=134		
min	11,1	6,9	2	8,3	6,4	1,4	7,2	7,1	1,5
max	69,4	73,5	34,7	71,4	59,9	53,6	139,6	107,1	56,4
mean	**28,3**	**25,3**	**9,6**	**26,8**	**20,8**	**10,2**	**25,9**	**25,3**	**8,9**

Concerning the flakes' section (Tab. 5.8), the direct percussion technique produced flat sections in most cases (62,5%), followed by triangular (22,5%), dihedral (9,2%), and irregular (5,8%). The bipolar on-anvil technique also yielded a predominance of flat sections, though they are attested on minor percentages (47,5%). Dihedral sections are relatively frequent within this technique (31,1%), followed by triangular ones (17,5%, slightly less common than in the direct percussion), while irregular sections are sporadic (3,9%). The anvil-assisted technique provided hybrid patterns halfway between direct percussion and bipolar-on anvil productions. Flat sections are the most recurrent in more than half of the sample (57,9 %), followed by dihedral ones (19,3%), triangular (12,9%), and irregular (10%). Overall, flat sections are the largest group in all techniques, with dihedral sections that exhibit a significant increase, particularly in the bipolar on-anvil and, in the minor portion, in the anvil-assisted. Triangular sections are more frequently attested on direct percussion flakes, followed by bipolar-on anvil and anvil-assisted. Irregular sections are somewhat sporadic, though a slight increase in their obtainment is witnessed on the anvil-assisted technique.

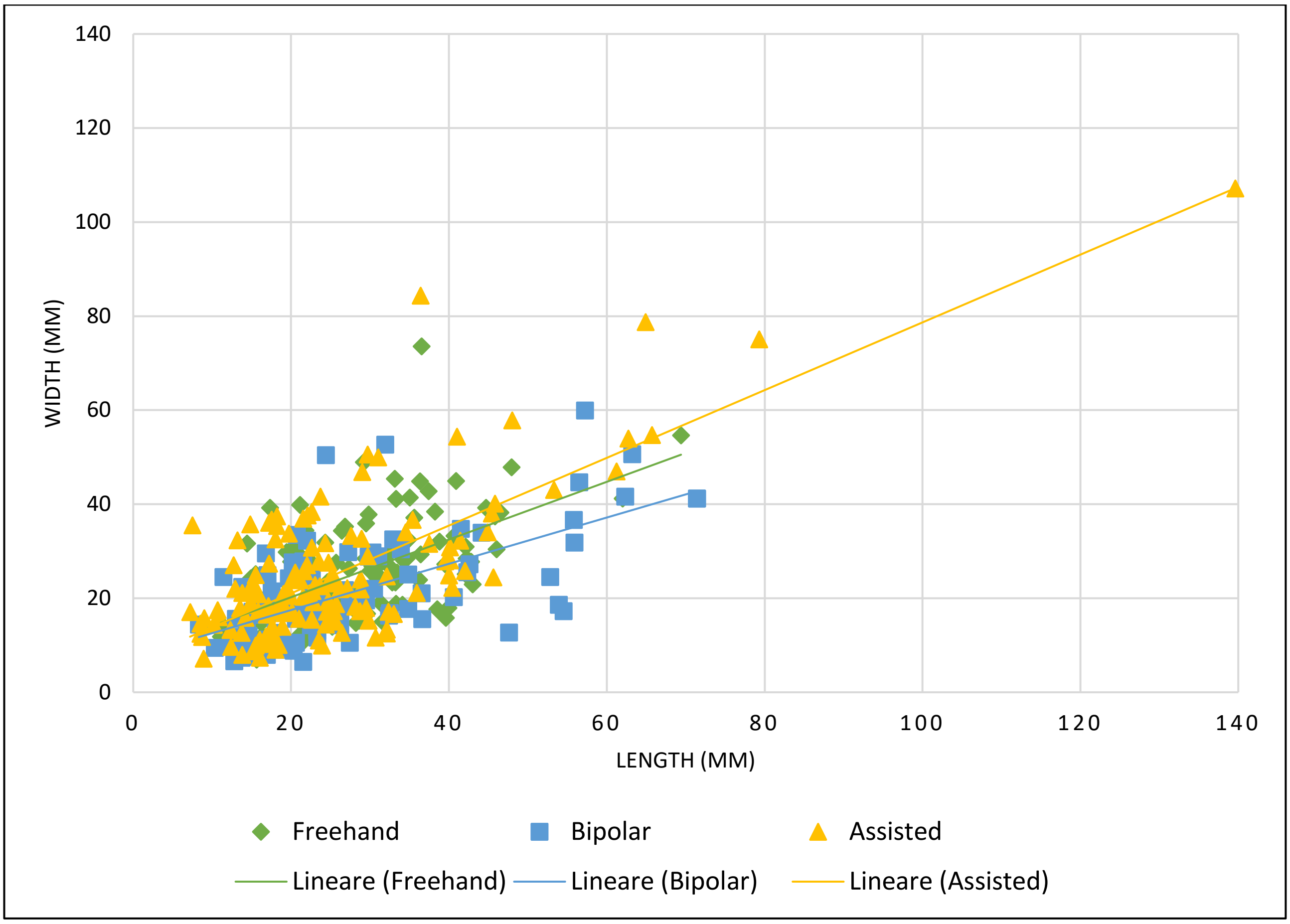

Figure 5.7 Scatter plot of length and width of flakes obtained during the experimentation according to the techniques employed.

If we check the dimensional data according to the sections' distribution (Tab. 5.10), we notice that among direct percussion products, irregular and dihedral sections are associated with the biggest flakes in length, width, and thickness, followed by triangular and flat ones. Flat sections correspond to small-sized flakes, while triangular sections coincide with the highest elongation ratio. The same pattern can be witnessed on bipolar on-anvil and anvil-assisted products, where flat sections correspond to the tiniest flakes. Dihedral and irregular sections are also associated with the biggest products, though in the bipolar on-anvil flakes, dihedral flakes are more elongated. Flakes presenting a triangular section obtained through anvil-assisted and bipolar on-anvil techniques exhibit the highest length/width ratio, similar to direct percussion flakes. The analysis of the width/thickness and length/thickness ratio yielded more or less the same trends witnessed through the dimensional analysis. The highlighted patterns are relatively common in all three techniques (Tab. 5.10).

Moving on the flakes' profiles (Tab. 5.9), curved and regular flakes are almost equivalent among direct percussion products, with the former (51,3%) slightly more frequent than the latter (44,5%). Irregular profiles are sporadic. Bipolar on-anvil flakes show a predominance of regular profiles (53,9%) compared to curved ones (38,2%), while anvil-assisted flakes present an equal proportion of curved (45,3%) and regular (43,9%) profiles, attesting to a slight increase of irregular ones (10,8%). Generally speaking, regular and curved profiles are ubiquitous, regardless of the technique employed, though bipolar on anvil products are slightly more regular than curved, while for direct percussion products, it is the opposite (Tab. 5.9).

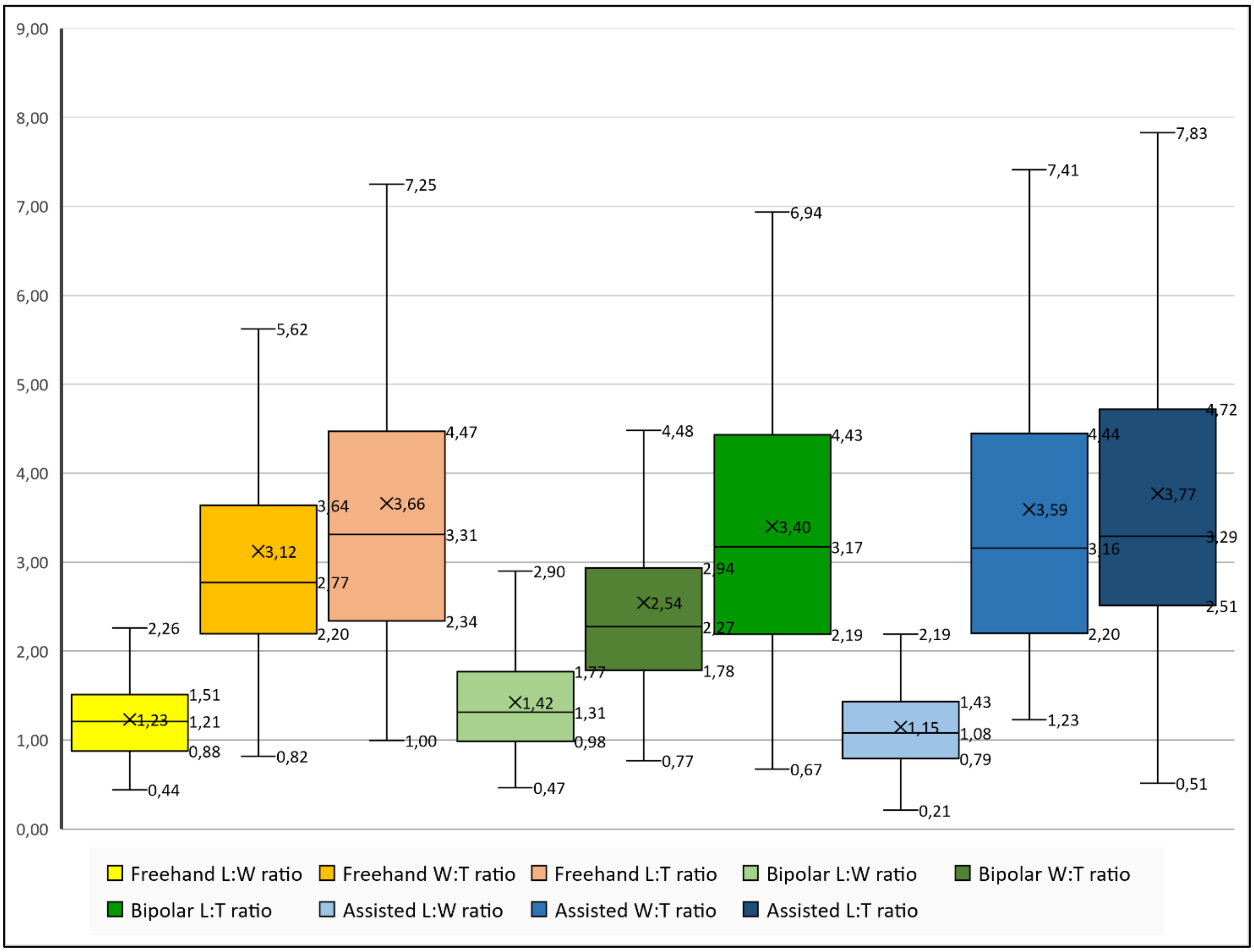

Figure 5.8 Boxplots containing length/width (L:W), width/thickness (W:T), and length/thickness (L:T) ratios of flakes according to the employed techniques.

Table 5.8 Section of the flakes.

Technique	**Direct Percussion**		**Bipolar on Anvil**		**Anvil Assisted**	
Section	n	%	n	%	n	%
Flat	75	62,5	49	47,6	81	57,9
Dihedral	11	9,2	32	31,1	27	19,3
Triangular	27	22,5	18	17,5	18	12,9
Irregular	7	5,8	4	3,9	14	10
Total	120	-	103	-	140	-

Table 5.9 Profile of the flakes

Technique	Direct Percussion		Bipolar on Anvil		Anvil Assisted	
Flakes' profile	n	%	n	%	n	%
Regular	53	44,5	55	53,9	61	43,9
Irregular	5	4,2	8	7,8	15	10,8
Curve	61	51,3	39	38,2	63	45,3
Total	119	-	102	-	139	-

Table 5.10 Dimensional values of flakes according to section's morphology. L:W = length/width; W

Technique	**Direct percussion**			**Bipolar on Anvil**			**Anvil Assisted**		
	length	width	thickness	length	width	thickness	length	width	thickness
Section									
flat	26,2	23,4	7,3	21,5	17,1	5,8	23,6	23,3	6
dihedral	33,8	33,6	17	30,1	24,7	15,3	30,9	29,6	14,7
triangular	30,4	24,8	11,9	31,3	22,5	11,1	25,3	20,2	9,5
irregular	35	35,7	14,5	35,6	21	9,9	30,9	35	12,9
Technique	**Direct percussion**			**Bipolar on Anvil**			**Anvil Assisted**		
Section	L:W	W:T	L:T	L:W	W:T	L:T	L:W	W:T	L:T
flat	1,21	3,65	4,22	1,34	3,29	4,15	1,11	4,57	4,68
dihedral	1,23	2,21	2,36	1,41	1,82	2,48	1,13	2,08	2,21
triangular	1,38	2,18	2,89	1,56	2,24	3,39	1,49	2,16	3,12
irregular	0,98	2,54	2,53	2,03	2,12	3,6	0,9	2,81	2,42

Table 5.11 Flakes' profile dimensional values

Technique	**Direct percussion**			**Bipolar on Anvil**			**Anvil Assisted**		
	length	width	thickness	length	width	thickness	length	width	thickness
Profiles									
Curve	29	25,9	9,5	28,3	19,3	8,4	30	28,5	10,3
Regular	27,4	24,8	9,1	26,7	22,1	11,3	22,4	22,1	7
Profiles	L:W	L:T	W:T	L:W	L:T	W:T	L:W	L:T	W:T
Curve	1,22	3,68	3,17	1,6	3,84	2,66	1,15	3,4	3,28
Regular	1,24	3,77	3,18	1,33	3,25	2,55	1,17	4,46	4,18

Crossing the flakes' profile with the dimensions, it turns out that curved products are slightly longer and larger than regular products in every technique (Tab. 5.11). The distinction is insignificant as a few millimetres of mean separates the trends. On the other hand, looking at anvil-assisted products, there is a sharp distinction between curved and regular profiles, with the former being substantially bigger than the latter. However, besides the dimensions, anvil-assisted regular flakes do not exhibit other specific features except a higher length-thickness and width-thickness ratio. The elongation ratio is relatively similar in each technique analysed, with regular flakes slightly more elongated than curved flakes (Tab. 5.11). Among bipolar on-anvil flakes, the elongation ratio is more pronounced than the others, while the length-thickness and width-thickness ratios are lower.

Again, these data seem to confirm what emerges from the general dimensional analysis, with anvil-assisted and direct percussion products showing analogous elongation ratios, bipolar on-anvil flakes more pronounced in length than width, and anvil-assisted flakes significantly thinner in relation to their length and width (Fig. 5.7, 5.8; Tab. 5.7).

The analysis of the thickness distribution on the flakes (Tab. 5.12) revealed that the proximal portion coinciding with the maximum thickness of the products was the most frequent in all techniques: 38,5 % for direct percussion, 36% for bipolar on-anvil, and 47,1% for anvil-assisted. The distal portion was the second most frequent pattern in different proportions within the techniques. For instance, on direct percussion flakes, it was documented on 21,4% of the sample, immediately followed by a maximum thickness located on the mesial portion (18,8%) and a regular thickness (19,7%). On the bipolar on-anvil flakes, a maximum thickness coinciding with the distal end of the flakes was more common than on direct percussion products (30%), followed by regular (21%) and mesial (9%). Anvil-assisted flakes revealed similar patterns to the direct percussion and the bipolar on anvil techniques. The frequency of the maximum thickness on the distal end was attested on 22,5% of the sample (similar to the direct percussion), followed by 17,4% of flakes with a regular thickness (more or less analogous to the other two techniques), and a 10,1% of products exhibiting it on the mesial portion. Irregular thickness was sporadically documented in all techniques, never exceeding 5%.

The width distribution was mostly documented on the distal end of the products (35% for direct percussion, 28,7% for bipolar on-anvil, and 32,1% for anvil-assisted; Tab. 5.12). Interestingly, regular width was more frequent on bipolar on-anvil products (32,7%) than direct percussion (21,4%) or anvil-assisted ones (17,5%). Maximum width coinciding with the proximal portion was also documented on several flakes (26,5% on direct percussion, 19,8% on bipolar on-anvil, and 24,1% on anvil-assisted), followed by mesial (16,2% for direct percussion products, 13,9% for bipolar on-anvil ones, and 24,1% for the anvil-assisted). Irregular distribution of the width was sporadic.

There is no specific correlation between the width or thickness distribution and the technique employed. The maximum thickness often coinciding with the proximal portion of the flakes is relatively common within debitage unstandardised productions due to the presence of the bulb (Tab. 5.12). Additionally, without preparation of the lateral and distal convexities, the flakes' morphology will be massively influenced by the strength of the gesture –concentrated in the proximity of the striking platforms. The same can be said for the maximum width often located on the distal end. A lack of proper preparation of the transversal convexity of the knapping surfaces, which, on the other hand, can be recurrently flat, will lead to a dispersion of the impact wave, generating a width distribution more concentrated on the distal margins.

Table 5.12 Distribution of maximum width and thickness on flakes.

	Direct Percussion		Bipolar on Anvil		Anvil Assisted	
Maximum Width	n	%	n	%	n	%
Proximal	31	26,5	20	19,8	33	24,1
Mesial	19	16,2	14	13,9	33	24,1
Distal	41	35	29	28,7	44	32,1
Regular	25	21,4	33	32,7	24	17,5
Irregular	1	0,9	5	5	3	2,2
Total	117	-	101	-	137	-
Maximum Thickness	n	%	n	%	n	%
Proximal	45	38,5	36	36	65	47,1
Mesial	22	18,8	9	9	14	10,1
Distal	25	21,4	30	30	31	22,5
Regular	23	19,7	21	21	24	17,4
Irregular	2	1,7	4	4	4	2,9
Total	117	-	100	-	138	-

It is interesting to notice that regular products, not only concerning the profile but also the thickness and width, are rather common regardless of the technique employed. On the contrary, the bipolar on-anvil yielded the highest ratio of regular profiles, width and thickness between all the techniques (Tab. 5.8, 5.9, 512). Given the small dimensions of the slabs exploited, it is possible that stronger blows performed through an orthogonal gesture can favour the production of parallel margin and dihedral sections along the entire length of the knapping surfaces – we mentioned that elongation ratio is higher for bipolar on-anvil products. On the other hand, as previously mentioned, this will also generate products with a higher width-thickness ratio.

The platforms' analysis will focus on their morphology rather than their type since the rotation of the surfaces was prevented during the experimentation – except for the direct percussion reduction sequences – generating almost exclusively natural platforms, followed by linear and punctiform butts (Fig. 5.9). The presence of flat platforms on bipolar on-anvil and anvil-assisted reduction sequences was due to the accidental fracturation of the striking platforms. Fractured butts are more frequent within bipolar on-anvil products than the anvil-assisted, though the difference is not so pronounced. This pattern could be explained by the major strength employed during the bipolar on-anvil gesture (Fig. 5.9).

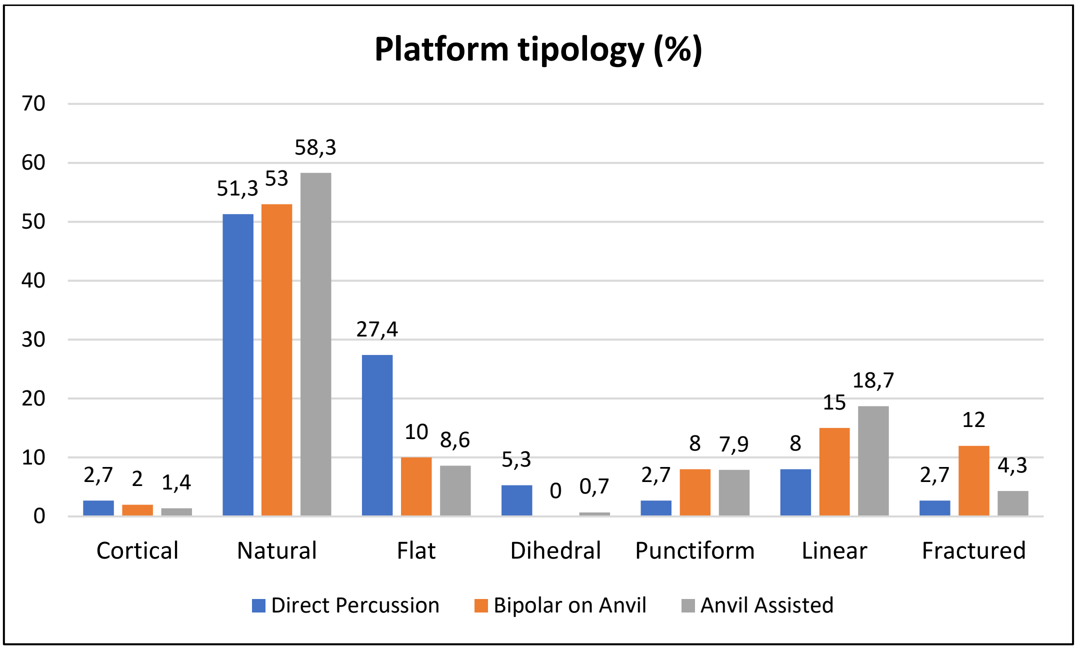

Figure 5.9 Distribution of platforms' tipology.

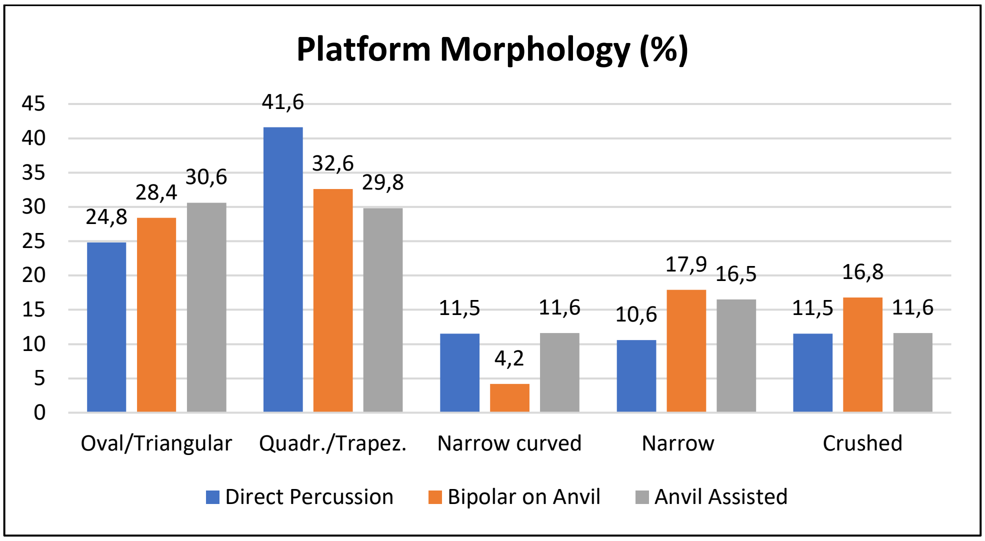

Figure 5.10 Distribution of platforms' morphology

Quadrangular/trapezoidal platforms are the most recurrent morphology across all techniques, followed by oval/triangular shapes (Fig. 5.10). Narrow and narrow curved morphologies are also documented with different patterns, while crushed platforms are more or less homogeneous. Direct percussion products are characterised by a more evident distribution of the platforms, with a predominance of quadrangular/trapezoidal morphologies (41,6%), followed by oval/triangular ones (24,8%). Narrow, narrow curved and crushed platforms are all attested by the exact percentages (11-10% ca). Bipolar on-anvil flakes exhibit a predominance of quadrangular/trapezoidal and oval/triangular shapes, attested by more or less identical quantities, followed by narrow and crushed platforms. Narrow curved morphologies are documented exclusively on three artefacts. Anvil-assisted sequences present the same pattern witnessed on the bipolar on-anvil ones, with a predominance of quadrangular/trapezoidal and oval/triangular morphologies followed, in the same proportion, by narrow, crushed, and narrow curved platforms.

Even if quantitative differences exist between the platforms' distribution associated with the debitage techniques, these do not seem significantly pronounced or associated with a specific technique (Fig. 5.10). On the contrary, all morphologies are documented more or less in the same quantities and proportion within the three techniques (Fig. 5.10). It is worth noticing that crushed morphologies are not more frequent within anvil sequences (bipolar and assisted) than direct percussion ones. Quadrangular/trapezoidal and oval/triangular are seemingly predominant because they are associated with larger dimensions of the butts, suggesting global homogeneous strength in the technical gestures.

Regardless of the butts morphology, the mean debitage angle documented on flakes is 78° for direct percussion sequences, 87,5° for bipolar on-anvil ones, and 81° for the anvil-assisted ones (Tab. 5.13). From this perspective, a clear distinction emerges between the direct percussion and the bipolar on-anvil products, with almost orthogonal angles in the latter and more acute in the former. Anvil-assisted exhibits a hybrid mean angle but is seemingly closer to the direct percussion technique. Among direct percussion reductions, the lowest debitage angles are associated with narrow curved and quadrangular/trapezoidal morphology, while oval/triangular and crushed butts exhibit values closer to 80° (Tab. 5.13). Narrow platforms document the highest debitage angles, closer to 90°. For bipolar on-anvil products, oval/triangular platforms present the lowest angles (84°), while quadrangular/trapezoidal shapes are associated with debitage angles identical to the mean value of the technique. Crushed platforms show orthogonal debitage angles, while narrow ones, as for the direct percussion, exhibit the highest value, in this case even greater than 90°. Anvil-assisted flakes feature a more homogeneous pattern with smaller gaps (Tab. 5.13). From this perspective, it is interesting that the debitage angles superimpose across all techniques, particularly within the 80-85° range. Direct percussion seems the only technique capable of generating debitage angles of 75°, while the bipolar on the anvil is the only one featuring orthogonal and even obtuse angles – though only documented on one type of platform (Tab. 5.13).

Table 5.13 Dimensional values and flaking angle of flakes according to platform morphology.

Direct percussion	length	width	thickness	Flaking Angle
Platform Morphology	mean value (mm)			mean (°)
Oval/Triangular	24	21,7	7,6	80,4°
Quadr./Trapez.	31,9	28,8	12,6	76,9°
Narrow curved	31,1	24,9	7,8	75,7°
Narrow	21,9	17,2	5,3	85°
Crushed	28,2	28,1	9,6	79,8°
Bipolar on anvil	length	width	thickness	Flaking Angle
Platform Morphology	mean value (mm)			mean (°)
Oval/Triangular	25,5	20,3	9,1	84,4
Quadr./Trapez.	30,6	27,9	15,8	88,2
Narrow curved	24,6	17,4	3,4	76 (1 flake)
Narrow	22,2	14,5	5,9	94
Crushed	31	18,2	8,4	91
Anvil Assisted	length	width	thickness	Flaking Angle
Platform Morphology	mean value (mm)			mean (°)
Oval/Triangular	21,5	24,4	7,7	80,4
Quadr./Trapez.	33,4	30,5	13	81,6
Narrow curved	17,2	17,3	4,7	81,3
Narrow	19,9	18,6	5,7	82,2
Crushed	33,5	32,7	9,7	84

The dimensional values according to the platform morphology show more or less the same distribution across all techniques, though some patterns seem to emerge (Tab. 5.13; Fig. 5.11, 5.12, 5.13). Narrow-shaped butts are associated with the tiniest flakes in all techniques, except for the anvil-assisted, where narrow curved ones exhibit even smaller values. The biggest flakes are documented on quadrangular/trapezoidal and crushed platforms for direct percussion, bipolar on-anvil, and anvil-assisted sequences, though among the bipolar on-anvil, crushed butts are associated with particularly elongated flakes. Oval/triangular-shaped platforms are associated with medium-sized flakes.

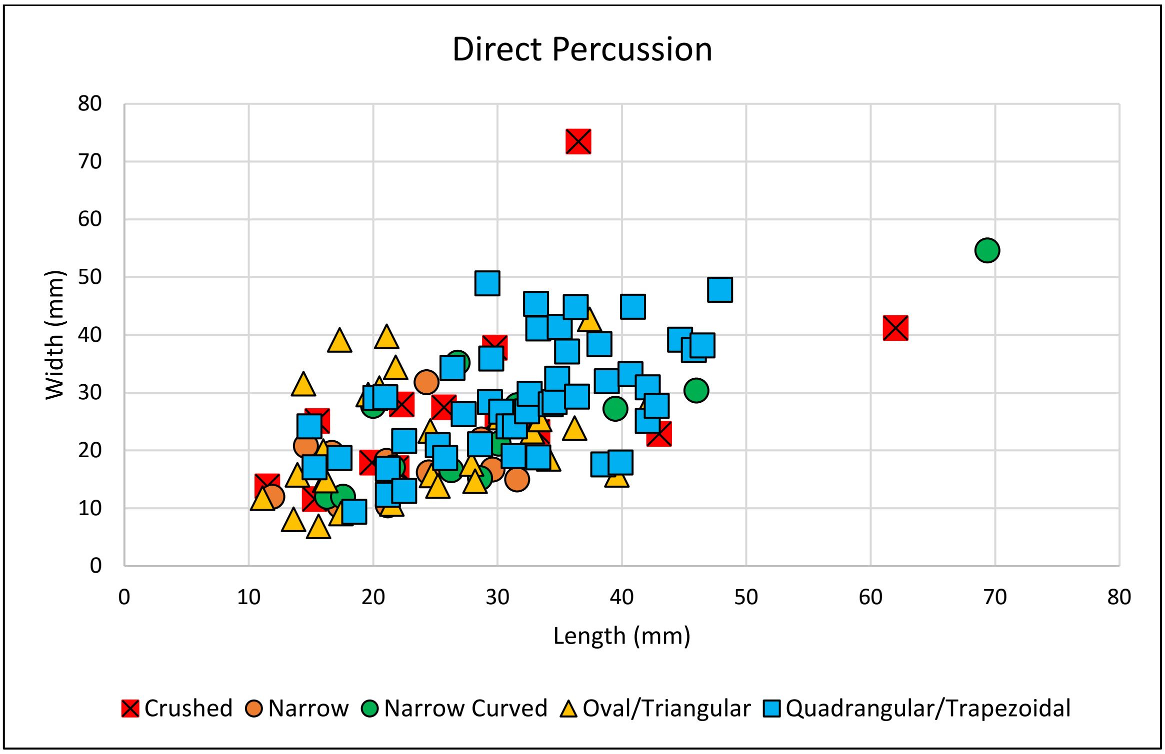

Figure 5.11 Scatter plot of direct percussion flakes according to platform morphology.

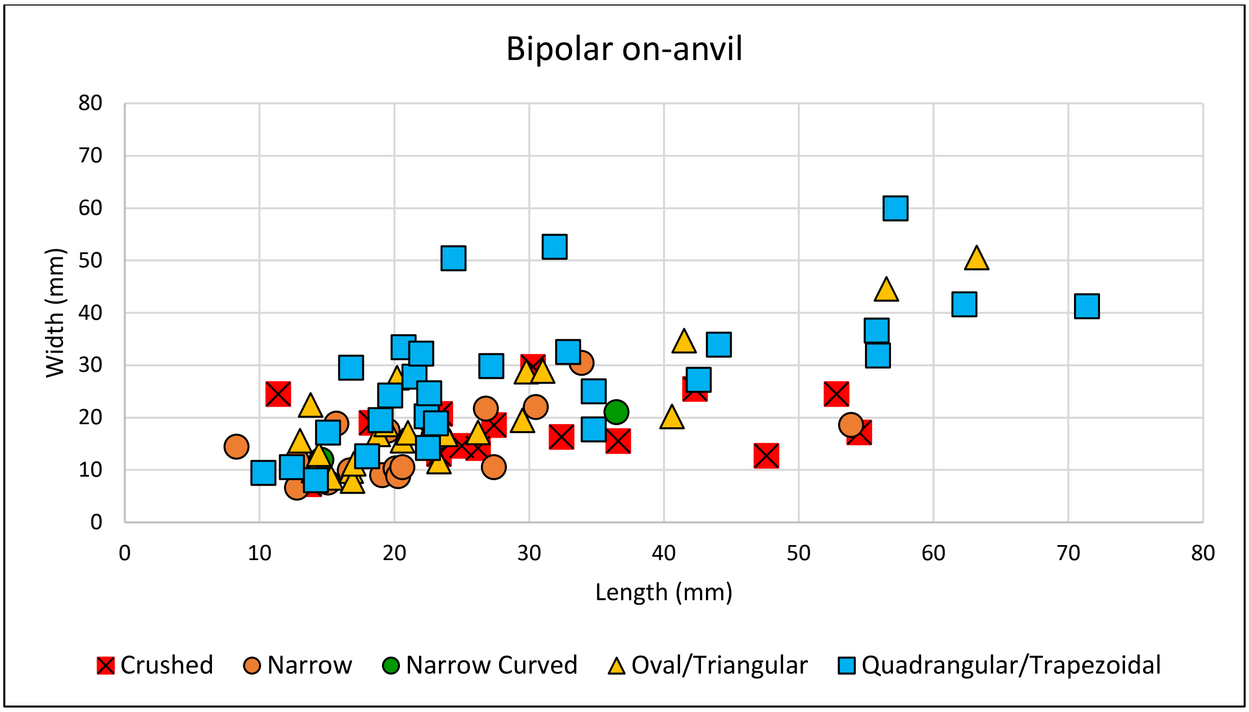

Figure 5.12 Scatter plot of bipolar on-anvil flakes according to platform morphology.

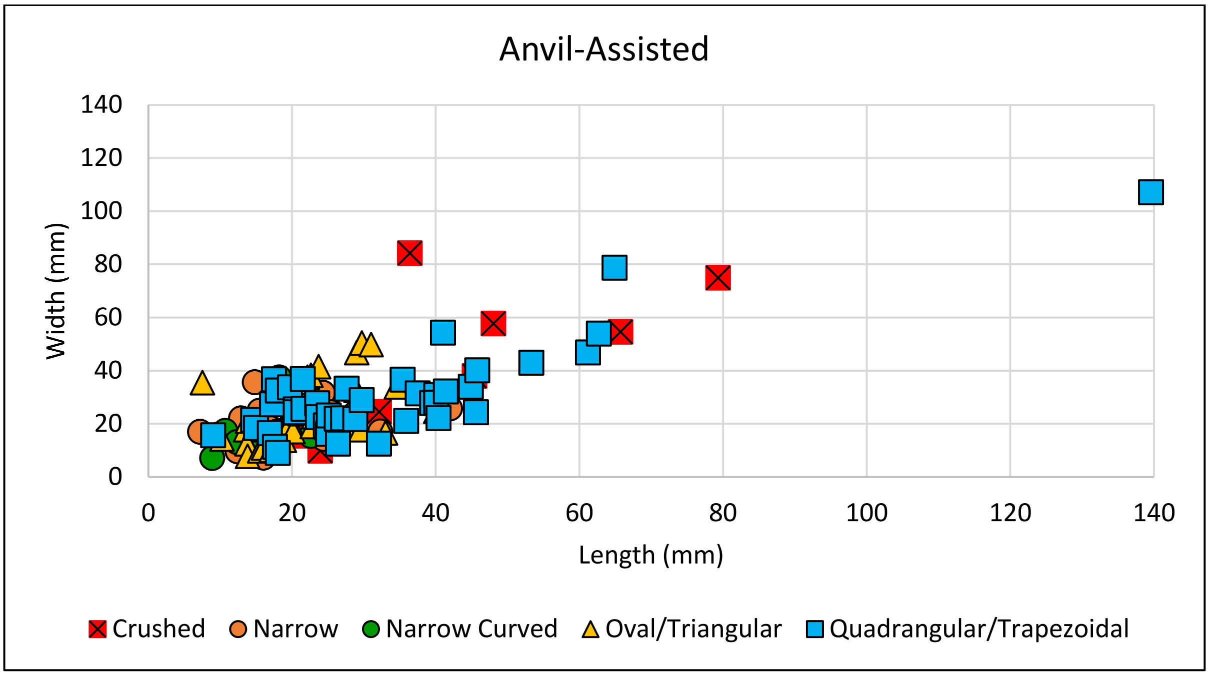

Figure 5.13 Scatter plot of anvil-assisted flakes according to platform morphology.

Moving on the dimensional ratios (Fig. 5.14 – 5.18), crushed platforms exhibit higher elongation ratios on bipolar on-anvil reduction sequences, while anvil-assisted and direct percussion products are less elongated and, particularly for direct percussion flakes, quadrangular-shaped. The length-thickness ratio of crushed-shaped platforms is more or less equivalent across all techniques. In this case, anvil-assisted flakes present the highest ratio, followed by bipolar and direct percussion (Fig. 5.14).

Narrow platforms are characterised by the same ratios, regardless of the technique, though some minor differences can be witnessed (Fig. 5.15). Again, bipolar flakes exhibit higher elongation values, followed by direct percussion flakes and anvil-assisted ones. Length-thickness analysis revealed that direct percussion flakes present higher pronounced length and reduced thickness ratios than the other two techniques, though all three reduction sequences are more or less overlapped. The width-thickness ratio is higher on anvil-assisted flakes, followed by direct percussion ones, while bipolar reduction sequences show lower values, indicating that width and thickness were more or less similar. Globally, narrow platforms show more similarities between direct percussion and anvil-assisted than bipolar on-anvil (Fig. 5.15).

Narrow curved platforms (Fig. 5.16) are documented on the direct percussion and anvil-assisted reduction sequences, being present on only three artefacts obtained through the bipolar on-anvil and, therefore, not statistically significant. These shapes, similar to those previously mentioned, exhibit low length-width ratios, while length-thickness ratios are more pronounced, showing higher variability on anvil-assisted productions. The relationship between width and thickness confirms that anvil-assisted products are way larger than thicker than the other techniques.

Oval/triangular morphologies share similar ratios across all techniques (Fig. 5.17), with bipolar flakes slightly more elongated than the others and anvil-assisted products yielding higher length-thickness and width-thickness ratios. Quadrangular/trapezoidal platforms are also homogeneous across the different techniques (Fig. 5.18). The length/width ratio is even more similar, while the length-thickness and width-thickness ratios are slightly more pronounced within direct percussion and anvil-assisted sequences. Globally, the dimensional ratios did not provide significant differences across the platforms' morphology. On the contrary, the most recurrent shapes across all techniques, oval/triangular and quadrangular/trapezoidal shapes, exhibit even closer and more homogeneous ratios.

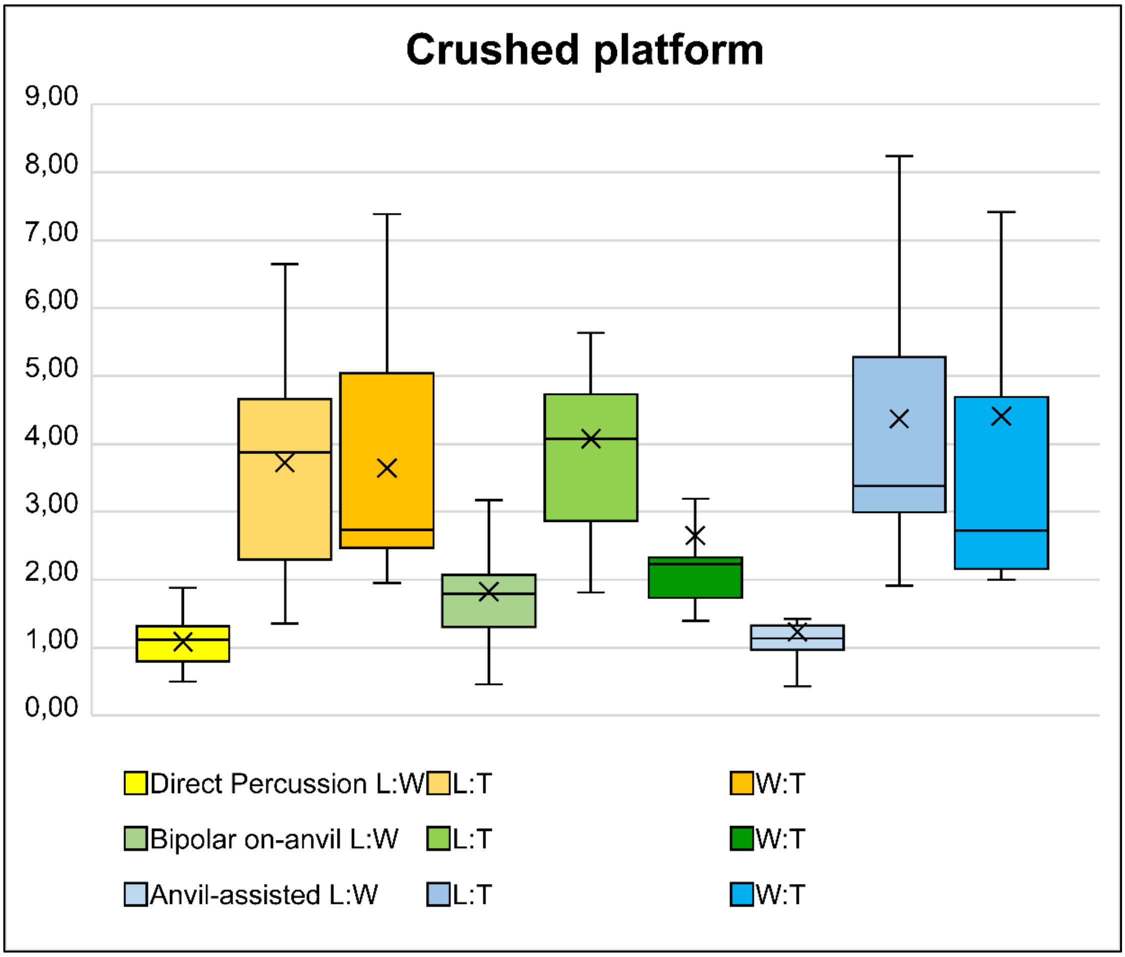

Figure 5.14 Boxplot with length/width (L:W), length/thickness (L:T), and width/thickness (W:T) ratios of flakes exhibiting crushed platforms.

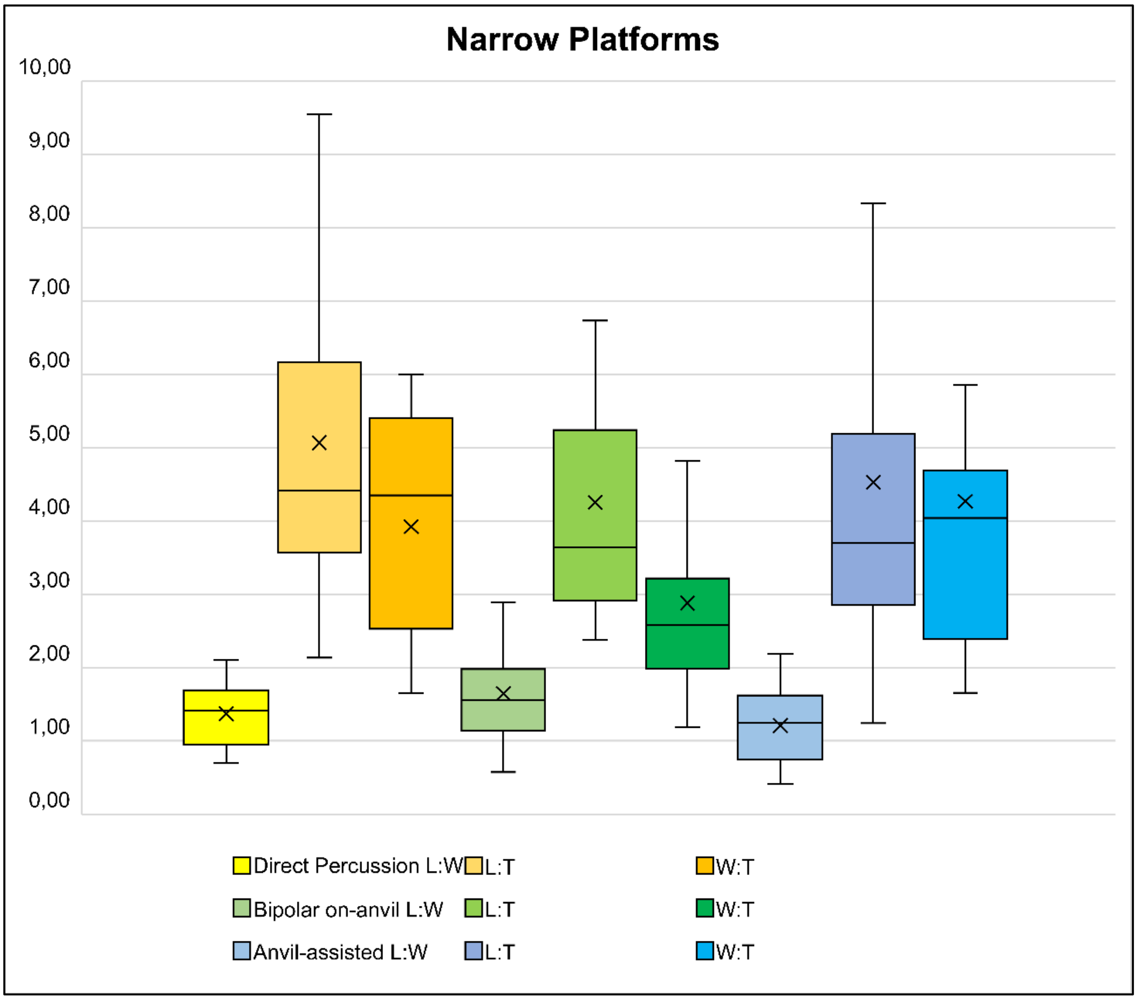

Figure 5.15 Boxplot with length/width (L:W), length/thickness (L:T), and width/thickness (W:T) ratios of flakes exhibiting narrow platforms.

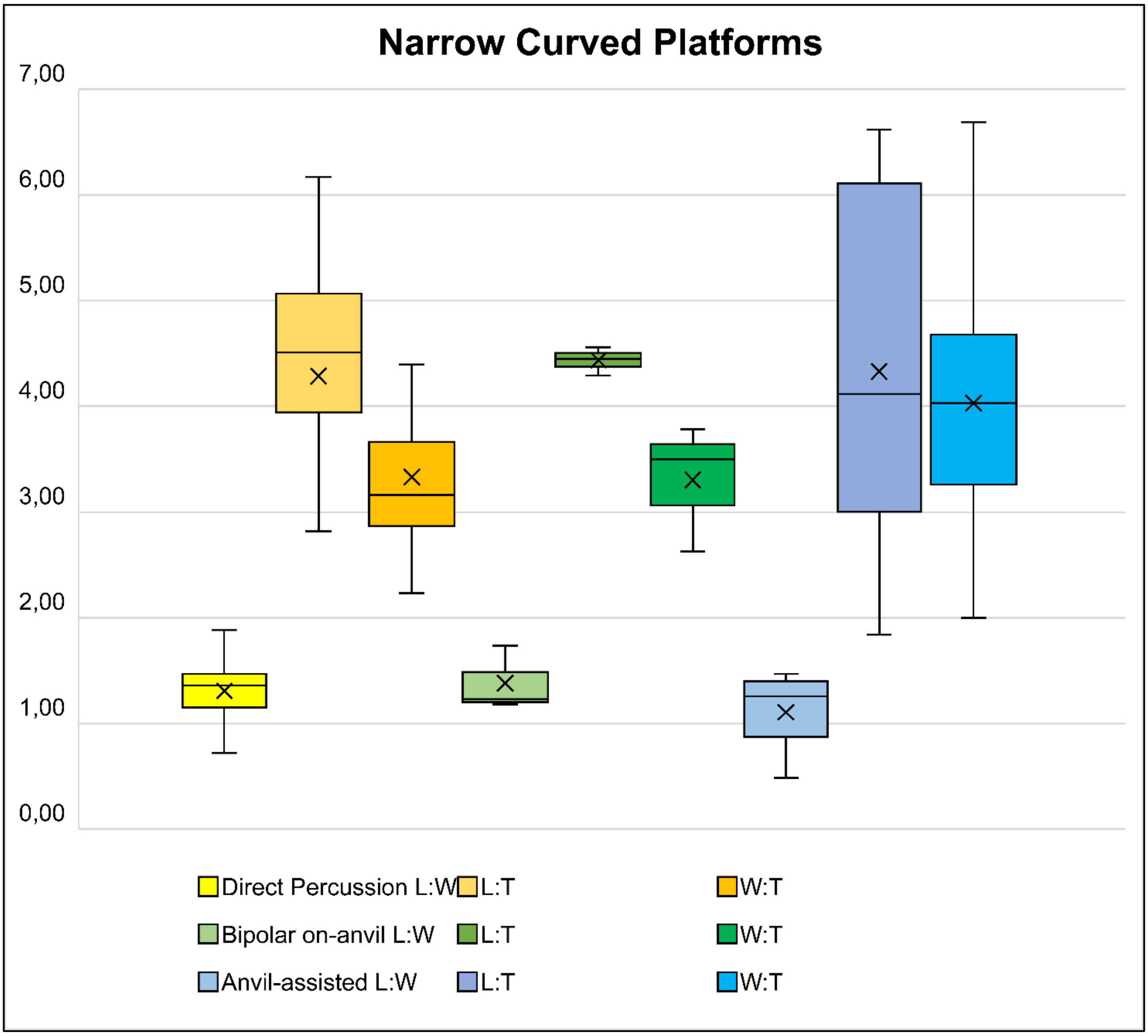

Figure 5.16 Boxplot with length/width (L:W), length/thickness (L:T), and width/thickness (W:T) ratios of flakes exhibiting narrow curved platforms.

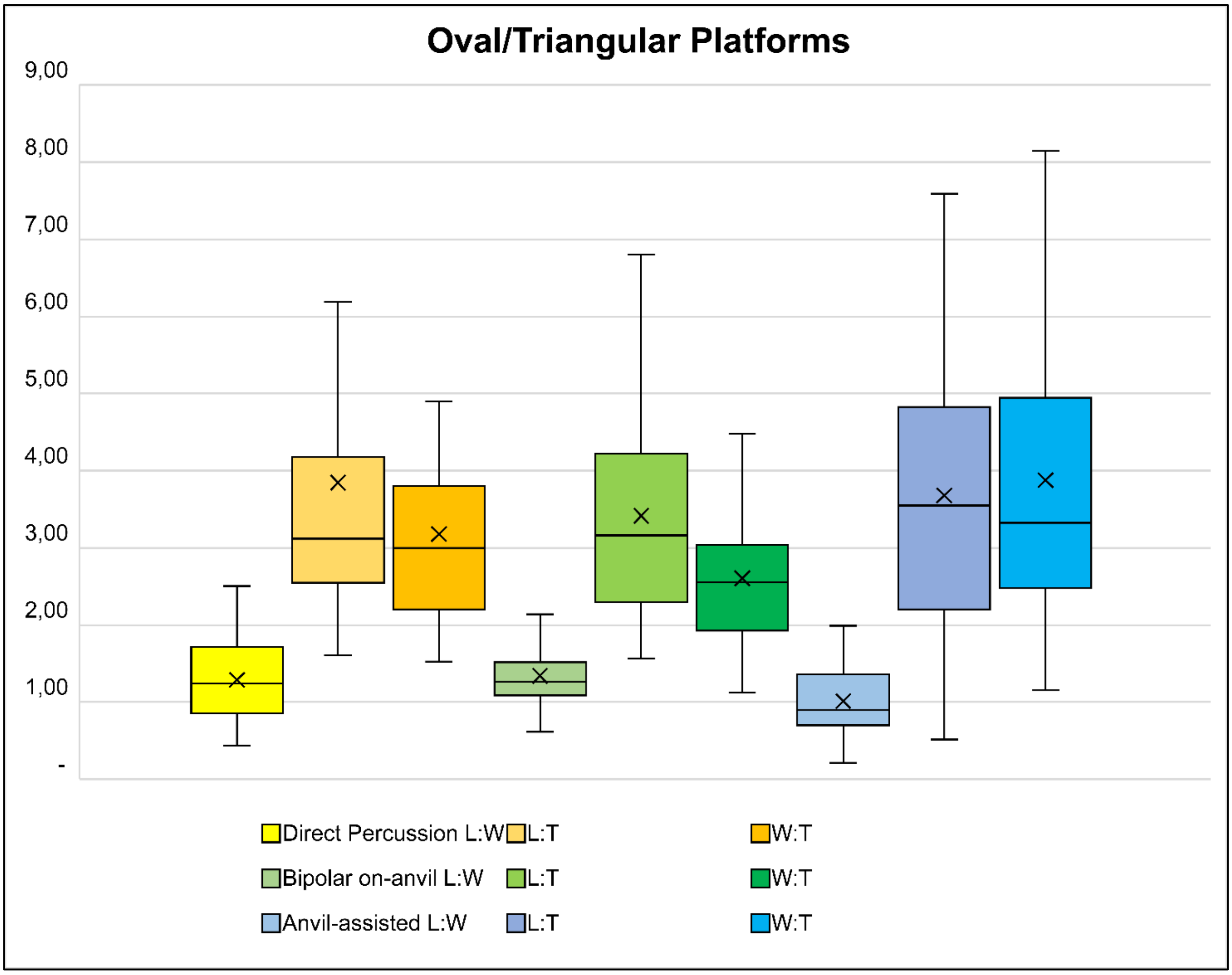

Figure 5.17 Boxplot with length/width (L:W), length/thickness (L:T), and width/thickness (W:T) ratios of flakes exhibiting oval/triangular platforms.

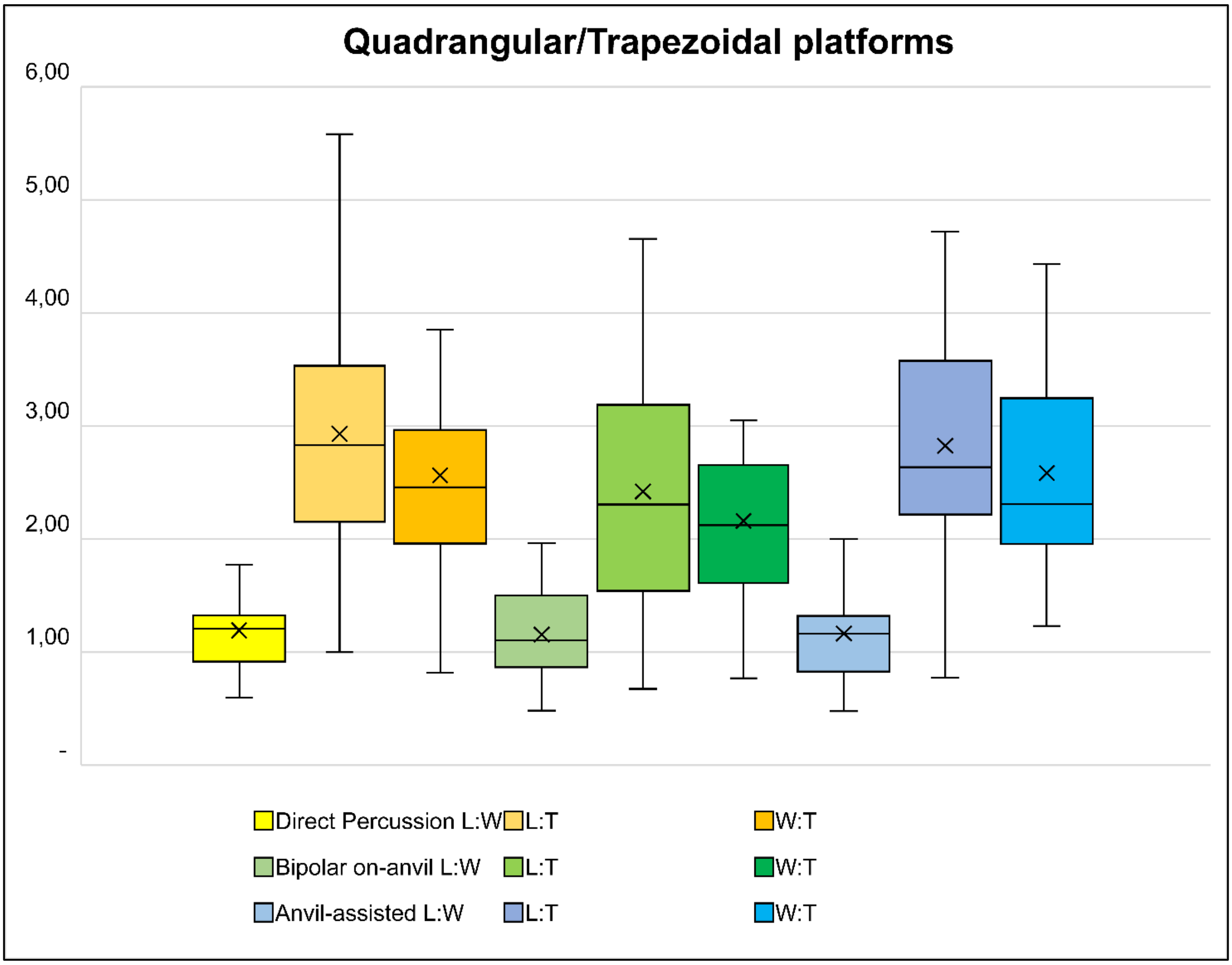

Figure 5.18 Boxplot with length/width (L:W), length/thickness (L:T), and width/thickness (W:T) ratios of flakes exhibiting quadrangular/trapezoidal platforms.

Diffused bulbs are the most common type within all techniques, though they are more frequent on direct percussion and anvil-assisted flakes (41% and 37,9%) than bipolar on-anvil ones (31,7%; Fig. 5.19). Interestingly, pronounced bulbs – the second most recurrent typology – are more frequent within anvil-assisted reductions (25%) than bipolar on-anvil ones (13,9%), with direct percussion showing in-between values (18,1%). Crushed bulbs are documented in the same percentages on bipolar on-anvil and anvil-assisted productions (14,9% and 13,6%) and less attested on direct percussion ones (7,8%). Removed bulbs are present on more or less 10% of bipolar on-anvil and direct percussion flakes while being more sporadic (5%) on the anvil-assisted. Few artefacts generally attest sheared and spike-like bulbs, though the former is documented within bipolar on-anvil products. Undeveloped bulbs are relatively frequent (around 20%) in direct percussion and bipolar on-anvil debitage and less attested in anvil-assisted (10%).

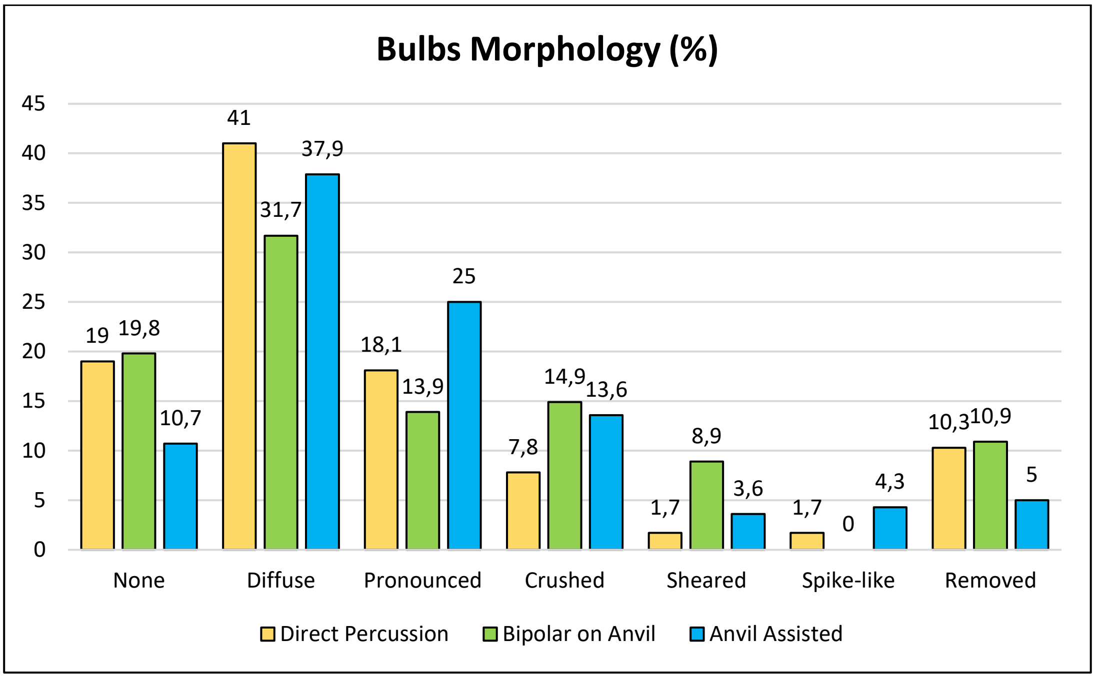

Figure 5.19 Histograms showing bulbs morphology.

According to the bulb typology, the length-width ratio (Fig. 5.20) shows that direct percussion products exhibit extremely homogeneous ratios across the bulbs, ranging from a mean value of 1,16 (undeveloped bulbs) to 1,29 (crushed bulbs). The length-thickness ratio (Fig. 5.26) is also somewhat regular, between a mean of 3,21 (removed bulbs) and 3,96 (diffused bulbs). Though the gap of the length-thickness is higher (0,75), the range of distribution of the boxplots shows a global homogeneity. The width-thickness ratio (Fig. 5.23) witnesses the same pattern, with a 0,7 gap between the minimum (2,64 removed bulbs) and the maximum (3,34 diffused bulbs). For bipolar on-anvil flakes, the length-width ratio (Fig. 5.21) is slightly more diversified than direct percussion, included between a mean value of 1,15 (pronounced bulbs) and 1,98 (crushed bulbs), with a gap of 0,83. The length-thickness ratio (Fig. 5.27) presents a more diversified distribution (1,7 of gap), ranging from a minimum mean value of 2,88 (pronounced bulbs) to a maximum mean value of 4,58 (sheared bulbs). The width-thickness ratio (Fig. 5.24) is homogeneous across the different bulbs (0,6 of gap), spanning from 2,24 (crushed bulbs) to 2,85 (diffused bulbs). For anvil-assisted flakes, the length-width ratio (Fig. 5.22) is extremely homogeneous (0,2 of gap) within diffused, pronounced, crushed, removed, and absent bulbs, being included in a range of 1,01 (pronounced bulbs) and 1,22 (diffused bulbs). However, sheared and spike-like bulbs – documented on a small percentage of artefacts – show values out of range, with the former being particularly elongated (1,82) and the latter being larger than longer (0,88). The pattern of the length-thickness (Fig. 5.28) ratio is similar to the length-width ratio, though the difference between the bulbs is even more pronounced. The mean values range from a minimum of 2,50 (crushed bulbs) to a maximum of 4,94 (sheared bulbs), with a gap value of 2,44. On the other hand, the width-thickness ratio (Fig. 5.25) presents a more homogeneous distribution in the boxplots, as also documented in the other techniques, though the mean values are significantly different, spanning from a minimum of 2,43 (crushed bulbs) to a maximum of 5,02 (removed bulbs).

No particular patterns were documented comparing the length-width ratios across all techniques (Fig. 5.20 – 5.28). Bipolar on-anvil flakes exhibit higher elongation ratios, mainly when crushed bulbs are considered. Interestingly, sheared bulbs – absent from direct percussion productions because they were documented exclusively on two artefacts – revealed higher elongation ratios in bipolar and anvil-assisted sequences. However, as previously mentioned, since their presence is relatively low among both reduction sequences, it could not be significant data when a greater sample of artefacts is analysed. Regarding the length-thickness ratio, all techniques exhibit similar elongation ratios regardless of the bulbs. However, among bipolar and anvil-assisted reductions, the bulb morphology affected this ratio much more, with crushed and sheared bulbs in bipolar sequences and sheared bulbs in the anvil-assisted ones showing higher values. Undeveloped, diffused, pronounced, and removed bulbs show similar distribution across the different techniques, with some negligible differences. The bulbs did not particularly affect the width-thickness of the products, though anvil-assisted flakes present higher mean values than the other techniques.

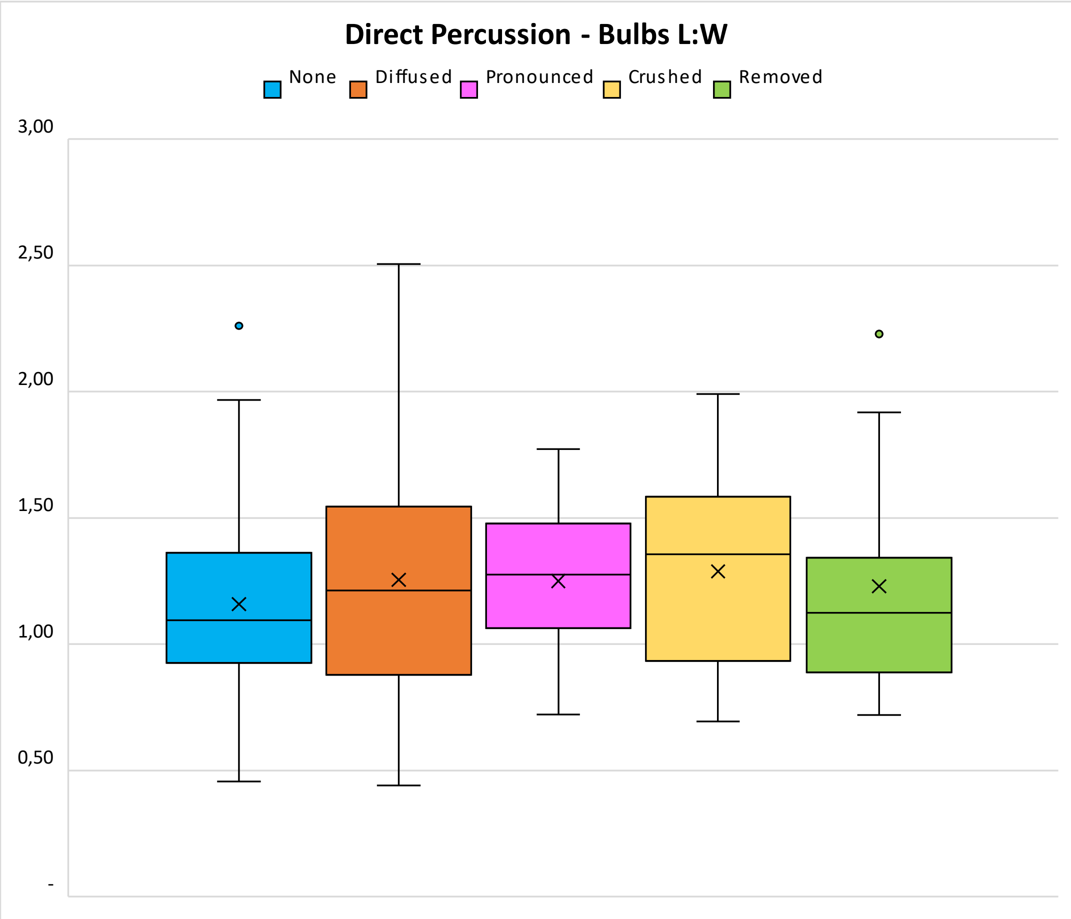

Figure 5.20 Boxplot showing length/width ratio of direct percussion flakes according to bulbs morphology.

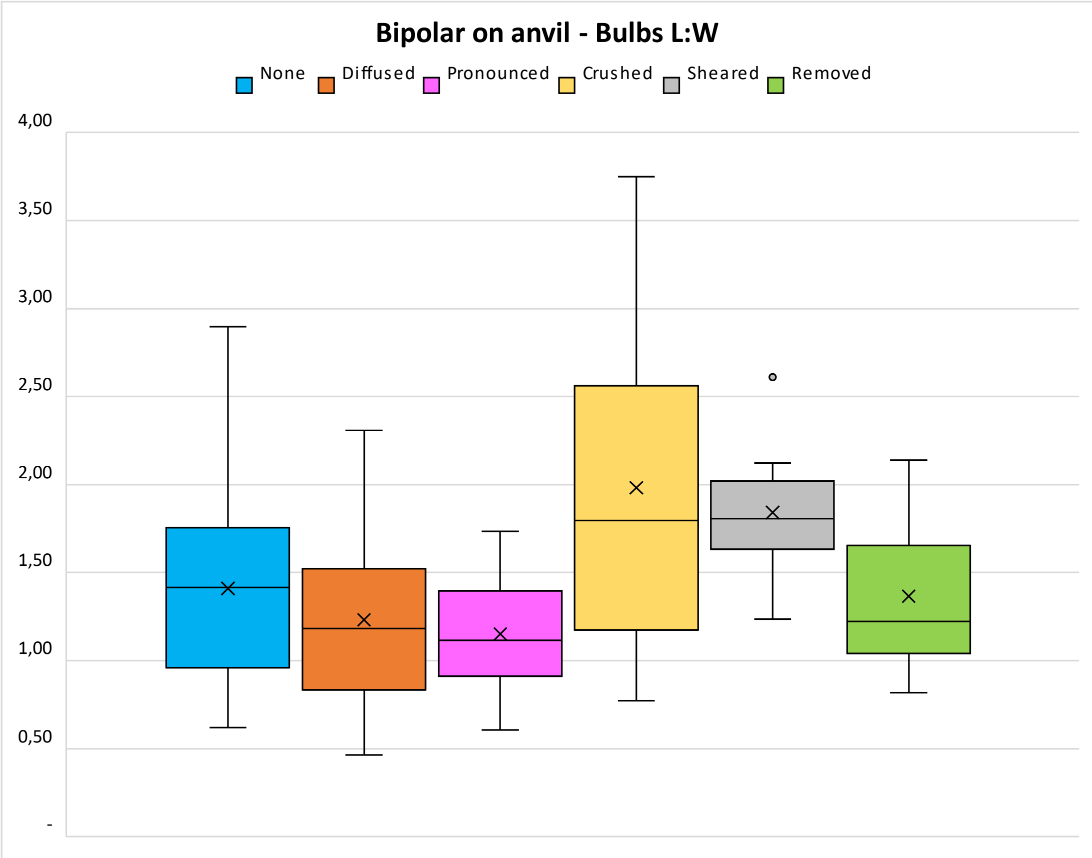

Figure 5.21 Boxplot showing length/width ratio of bipolar on anvil flakes according to bulbs morphology.

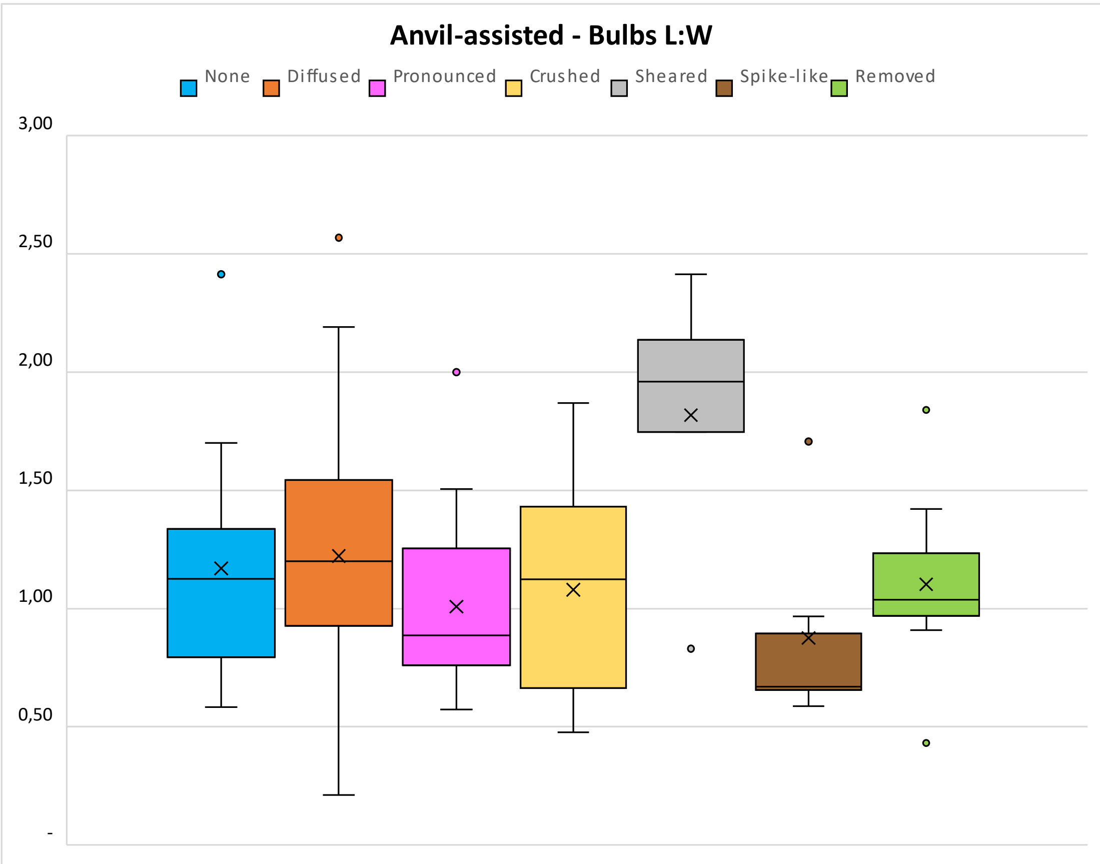

Figure 5.22 Boxplot showing length/width ratio of anvil-assisted flakes according to bulbs morphology.

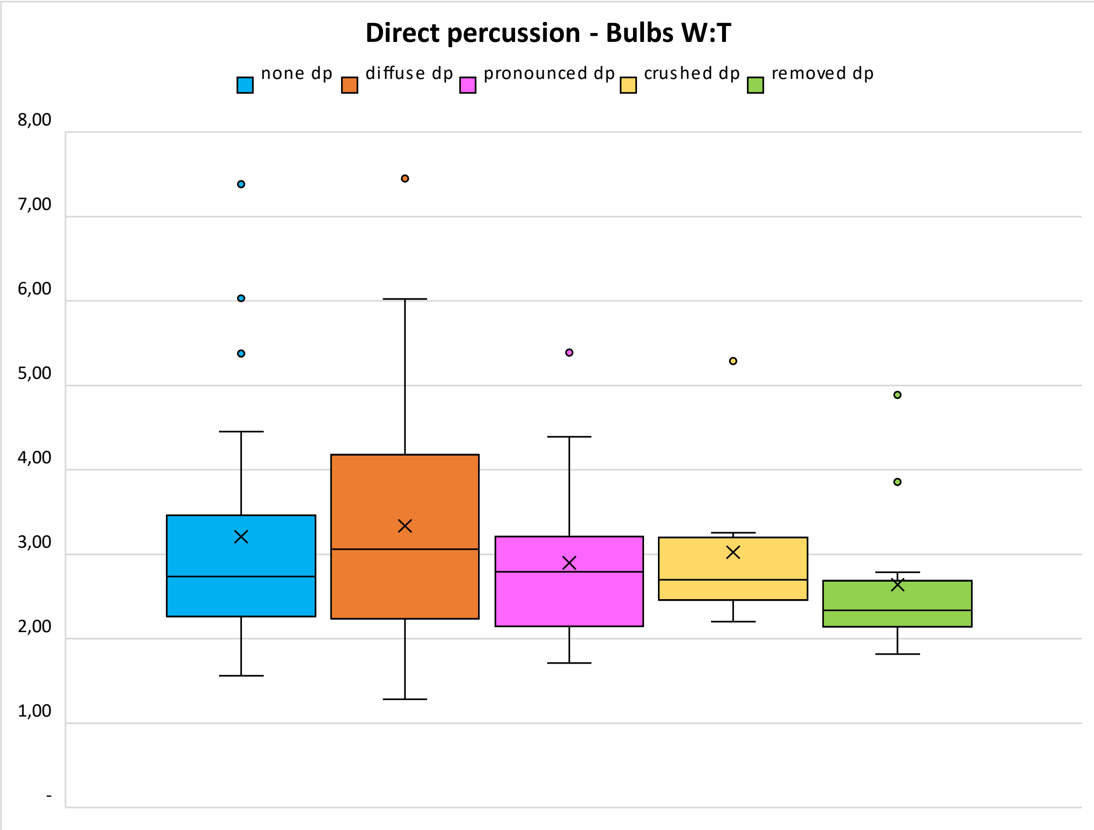

Figure 5.23 Boxplot showing width/thickness ratio of direct percussion flakes according to bulbs morphology.

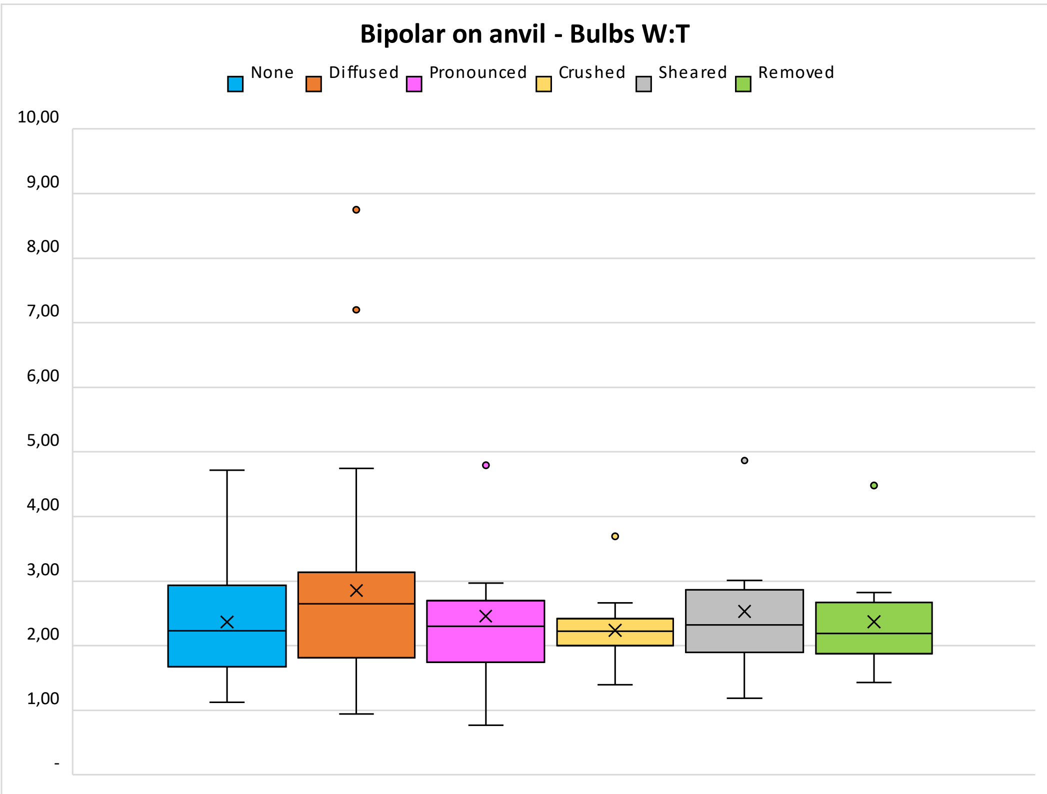

Figure 5.24 Boxplot showing width/thickness ratio of bipolar on anvil flakes according to bulbs morphology.

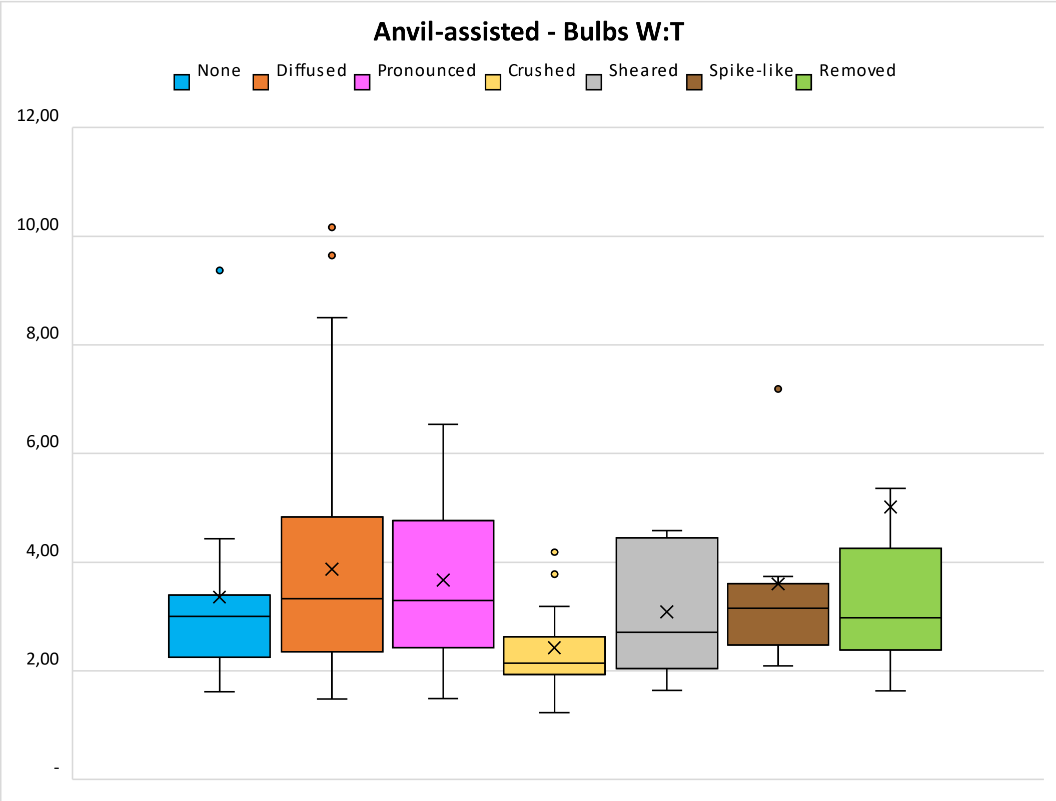

Figure 5.25 Boxplot showing width/thickness ratio of anvil-assisted flakes according to bulbs morphology.

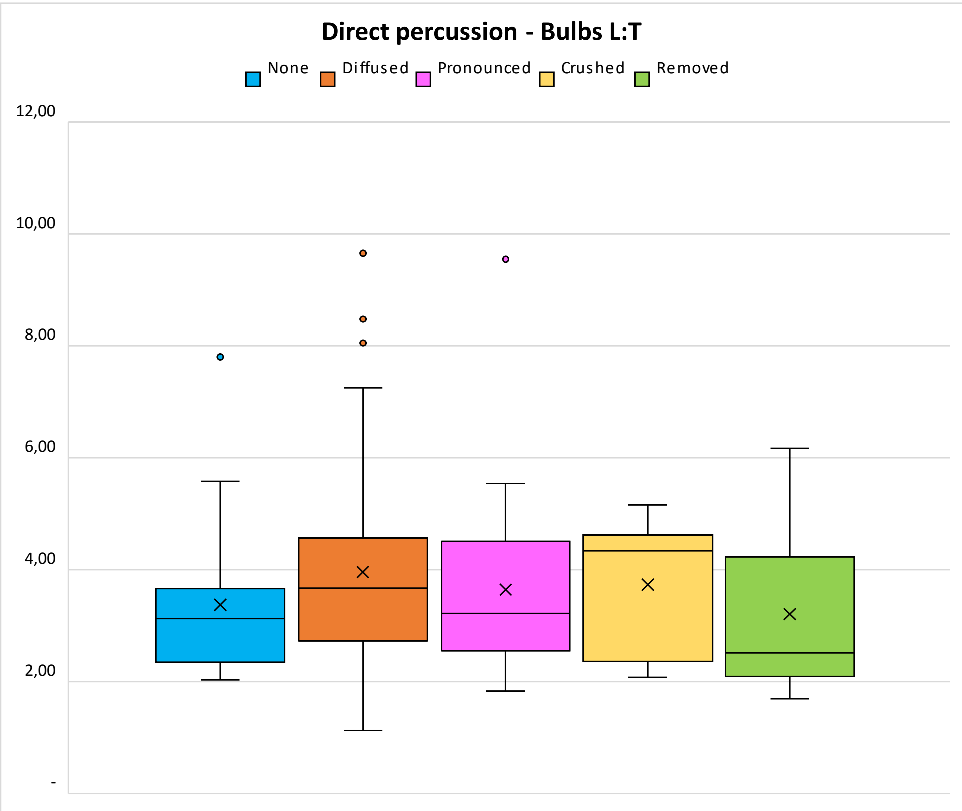

Figure 5.26 Boxplot showing length/thickness ratio of direct percussion flakes according to bulbs morphology.

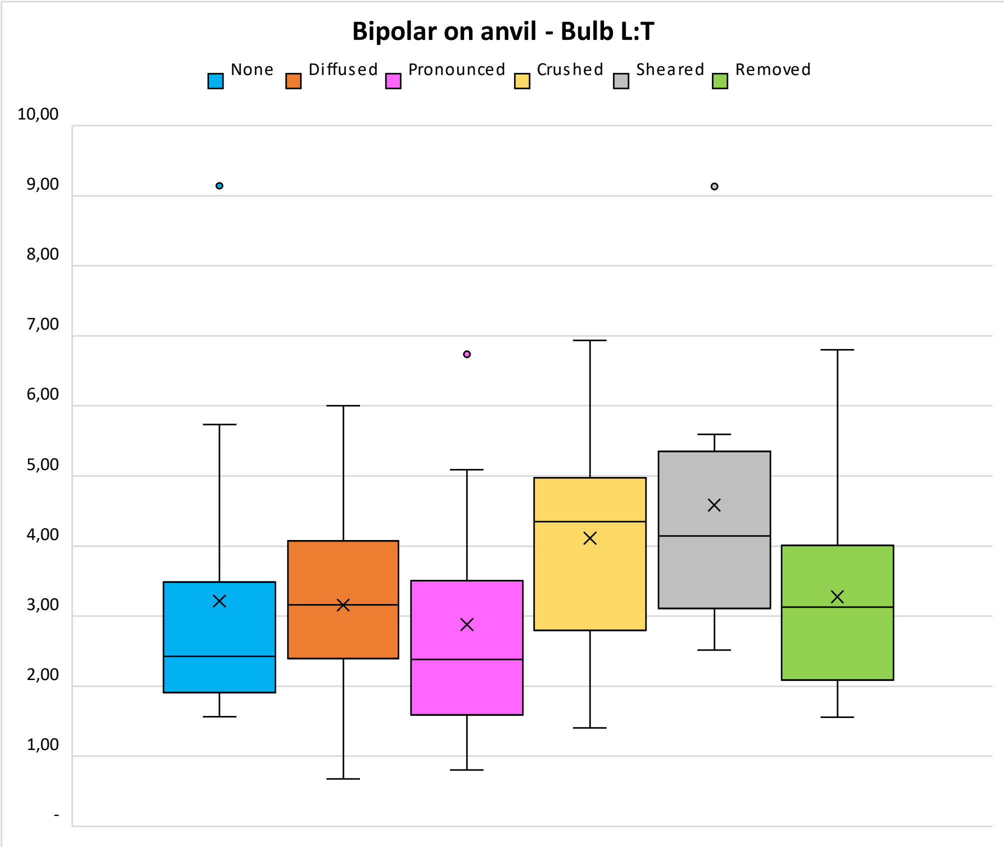

Figure 5.27 Boxplot showing length/thickness ratio of bipolar on anvil flakes according to bulbs morphology.

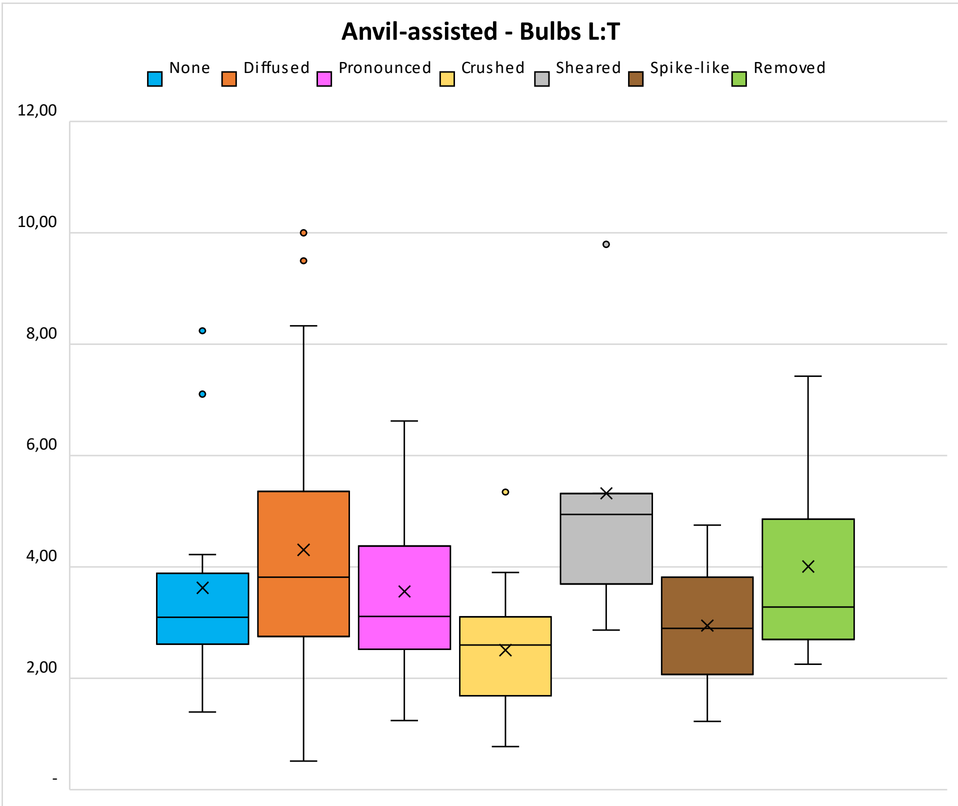

Figure 5.28 Boxplot showing length/thickness ratio of anvil-assisted flakes according to bulbs morphology.

Looking at the mean dimensions of the products according to the bulbs (Tab. 5.14), direct percussion flakes show similar values in length, width, and thickness. Among bipolar on anvil products, the biggest flakes are associated with crushed bulbs – exhibiting the highest elongation ratio – while the tiniest ones are documented on removed and sheared bulbs. Crushed bulbs associated with the biggest flakes were also recorded on anvil-assisted productions, though if we compare the dimensions between the techniques, the differences are not so pronounced. Generally, direct percussion products seem to present more homogeneous flakes – dimensions-wise – while bipolar on anvil and anvil-assisted flakes exhibit higher gaps in length, width, and thickness, perhaps indicating less consistent productions.

Table 5.14 Dimensional values of flakes according to bulb morphology. The green cells indicate the lowest dimensional value in each technique while the orange cells indicate the highest value.

	Direct percussion		
	length	width	thickness
Bulbs morphology	mean value (mm)		
None	28,4	26,3	9,8
Diffused	27,8	24,9	9,1
Pronounced	29,4	25,1	9,5
Crushed	28,9	24,7	8,6
Sheared (n=2)	16,3	11	3,6
Spike-like (n=2)	35,5	36,6	27,3
Removed	29,4	26,3	10,9
	Bipolar on-anvil		
Bulbs morphology	length	width	thickness
None	32,3	25,3	13,3
Diffused	22,14	19,8	8,5
Pronounced	27,5	25	14,9
Crushed	37,5	22,3	10,1
Sheared	22,8	13,2	6
Spike-like (n=1)	-	-	-
Removed	20,8	16	7,3
	Anvil-assisted		
Bulbs morphology	length	width	thickness
None	28,5	26,8	9,5
Diffused	23,8	21,6	7,2
Pronounced	25,4	26,1	9,2
Crushed	31	31,6	13,7
Sheared (n=2)	29,7	21,2	6,6
Spike-like (n=2)	21,1	25,8	8,5
Removed	27,4	31,2	8,2

Lastly, we compared the distribution of the bulbs according to the platforms' morphology to check whether specific associations might emerge (Fig. 5.29 – 5.31).

On undeveloped bulbs, quadrangular/trapezoidal platforms are predominant among direct percussion and bipolar on anvil sequences, though they are far more present on the former. Undeveloped bulbs are characterised by a more or less homogeneous presence of quadrangular/trapezoidal, oval/triangular, and crushed platforms on anvil-assisted productions. Oval/triangular platforms present the same distribution as anvil-assisted ones when undeveloped bulbs from bipolar on anvil sequences are addressed, while they are more sporadic on direct percussion technique. A 20% of bipolar flakes attests to the incidence of crushed platforms associated with undeveloped bulbs, while they decrease on direct percussion undeveloped bulbs.

Diffused bulbs are primarily associated with oval/triangular platforms among direct percussion sequences and quadrangular/trapezoidal platforms among bipolar on anvil and anvil-assisted ones. Nonetheless, oval/triangular platforms are relatively recurrent in bipolar and anvil-assisted productions. Narrow platforms associated with diffused bulbs present more or less the same percentages across all techniques. Pronounced bulbs are characterised by a predominance of quadrangular/trapezoidal platforms within direct percussion sequences, while for bipolar on anvil and anvil-assisted ones, oval/triangular platforms prevail. On the other hand, oval/triangular platforms are sporadically associated with pronounced bulbs for direct percussion flakes. From this perspective, narrow curved platforms emerge among pronounced bulbs of direct percussion products (28,6%) and anvil-assisted ones (14,7%) while being absent from bipolar on-anvil pronounced bulbs.

Crushed bulbs feature a majority of quadrangular/trapezoidal platforms in direct percussion and anvil-assisted. For bipolar on-anvil, while they are relatively frequent on this typology of bulbs, crushed platforms prevail. Interestingly, crushed platforms are extremely rare on anvil-assisted crushed bulbs while being rather frequent on direct percussion ones. As previously mentioned, sheared and spike-like bulbs are a minority across all techniques. The two direct percussion flakes exhibiting sheared bulbs are associated with crushed and narrow platforms. The same pattern can be documented for anvil-assisted sheared bulbs, while on bipolar on anvil sequences, narrow curved platforms are associated with sheared bulbs and crushed and narrow platforms. Removed bulbs show a predominance of quadrangular/trapezoidal platforms across all techniques, followed by oval/triangular ones, crushed ones – only for bipolar on anvil and anvil-assisted flakes – narrow and narrow curved platforms – only on direct percussion products.

In the end, quadrangular/trapezoidal and oval/triangular platforms together, which are the most common morphology across all techniques, represent at least 50%, if not more, of each bulb. Narrow curved platforms are more frequently attested on direct percussion and anvil-assisted sequences, while they are almost absent (three artefacts in total) from bipolar on anvil flakes. The distribution of the bulbs according to the platforms did not reveal significant patterns that would allow a proper distinction between these techniques.

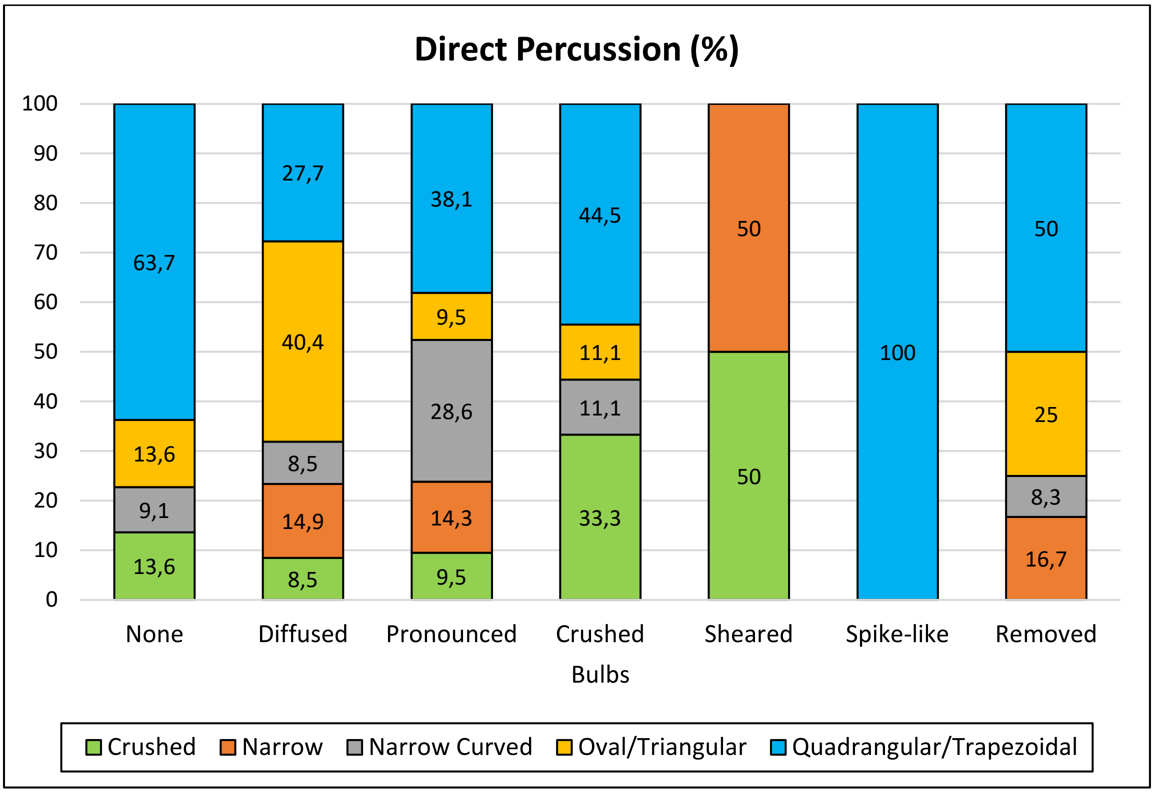

Figure 5.29 Frequency of platform morphology according to bulb morphology on direct percussion flakes

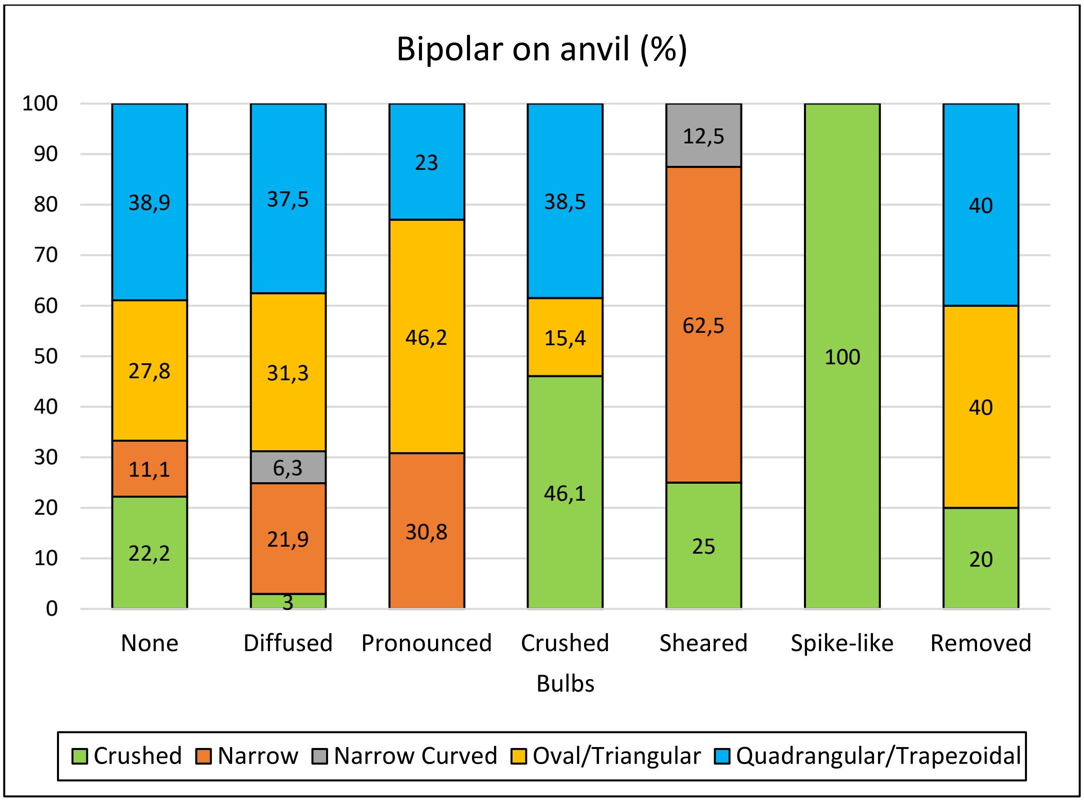

Figure 5.30 Frequency of platform morphology according to bulb morphology on bipolar on anvil flakes

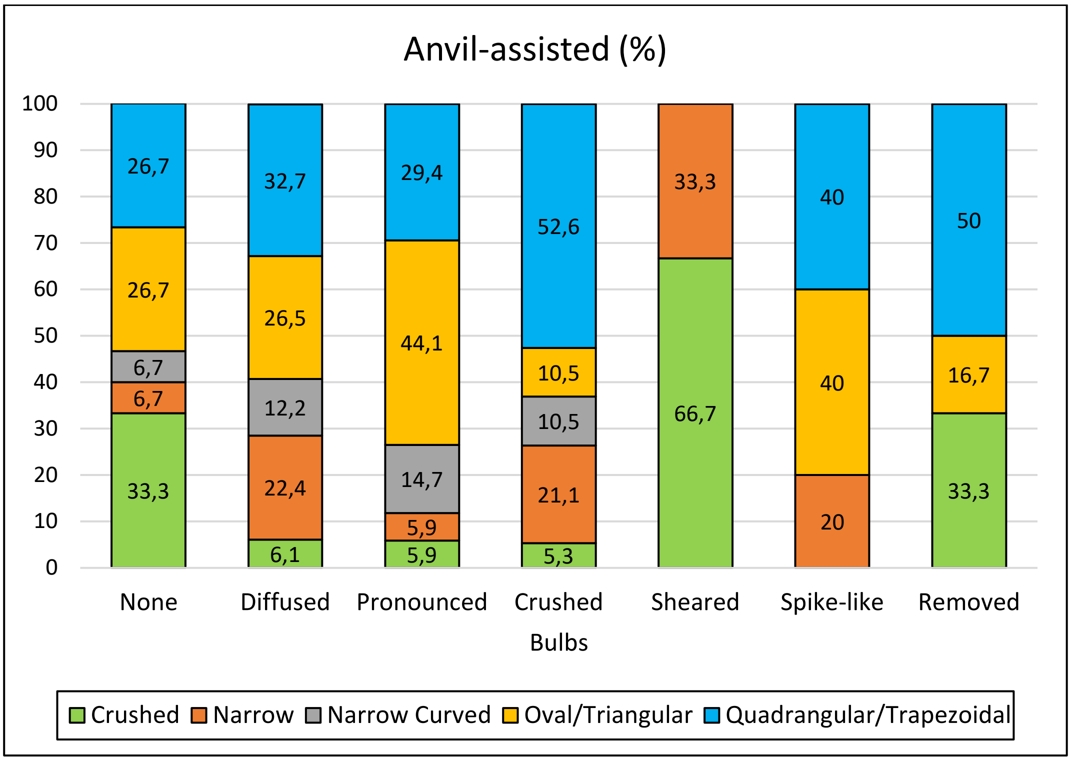

Figure 5.31 Frequency of platform morphology according to bulb morphology on anvil-assisted flakes

The Hertzian cone distribution shows extremely homogeneous values (Fig. 5.32). The development of the fracture's cone was absent in most flakes, respectively documented on 45,6%, 37,6% and 33,6% of direct percussion, bipolar on anvil, and anvil-assisted products. This means that slightly more than half of the direct percussion flakes present a Hertzian cone (55%), while for bipolar and anvil-assisted flakes, the percentage increases (63% and 67%). Ventral fissures are the most characteristic evidence of the presence of the cone. They are more frequent among anvil-assisted flakes, followed by roughly the same percentages on bipolar on anvil and direct percussion. Ring cracks are equally attested across all techniques and are the second-most recurrent type of Hertzian cone. A detachment of the bulb was relatively sporadic, more frequent within bipolar and direct percussion flakes than anvil-assisted ones. Small cones (*i.e.,* hint) are sporadic. From this perspective, the cone's distribution revealed a global homogeneity between the techniques. However, it seems that anvil-assisted and bipolar-on anvil sequences are slightly more likely to develop Hertzian cones on their flakes than direct percussion – even though 55% of the direct percussion products presented traces of its development in the latter.

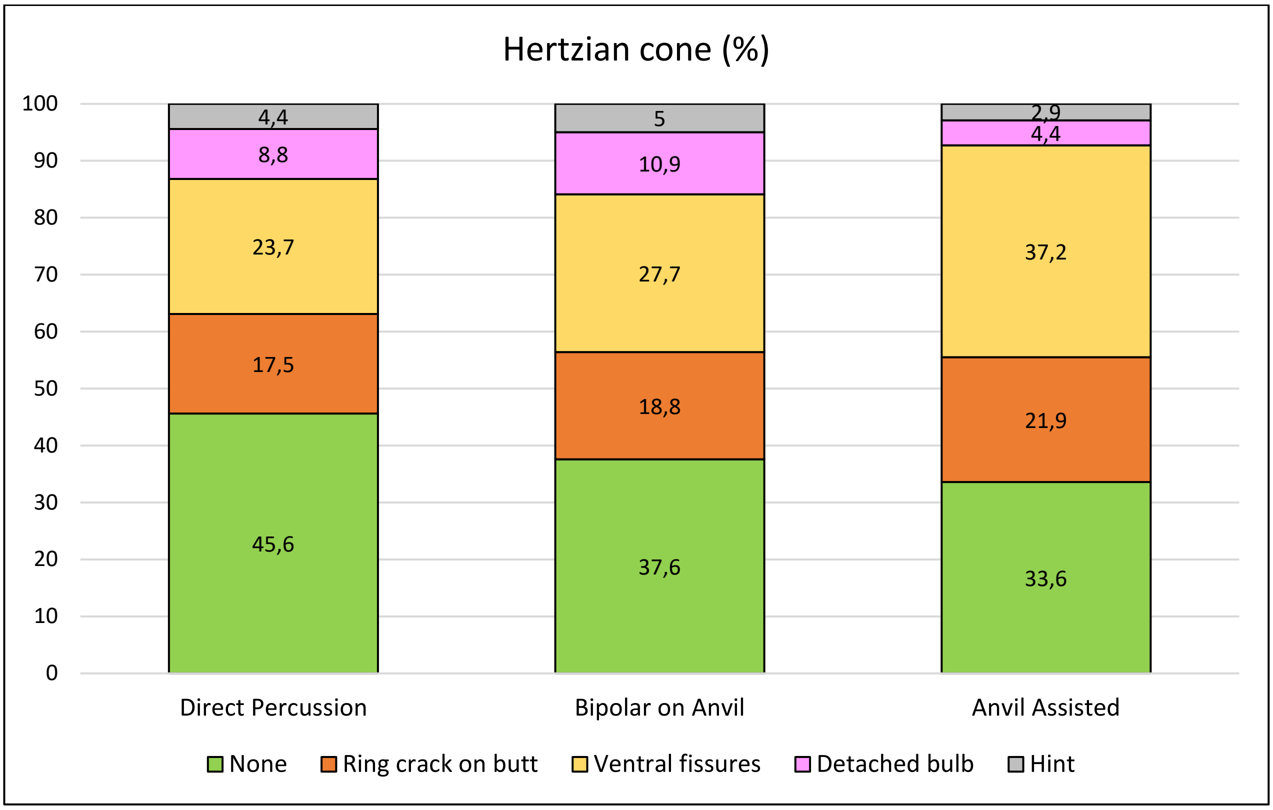

Figure 5.32 Hertzian cone distribution

The dimensions of the products, according to the Hertzian cone, revealed that the flakes' size is homogeneous among direct percussion sequences without remarkable differences in length, width, or thickness (Tab. 5.15). On the other hand, bipolar on anvil flakes exhibit a sharper distinction between detached and hint cones, associated with small-sized flakes and products bearing ventral fissures documented on the biggest flakes. The same pattern is present on anvil-assisted artefacts, with ventral fissures associated with the biggest implements. The remaining categories within anvil-assisted artefacts show homogeneous dimensions.

Plotting the Hertzian cone development with the platforms' morphologies provided no specific pattern to distinguish between the debitage techniques clearly (Fig. 5.33, 5.34, 5.35). Oval/triangular and quadrangular/trapezoidal platforms are more or less predominant across the different Hertzian cones and techniques, comprising at least 50% of every category. The only minor difference that might be relevant, despite a low number of artefacts, is the presence of crushed platforms associated with detached Hertzian cone, which is documented exclusively on bipolar on anvil and anvil-assisted productions.

Table 5.15 Dimensional values of flakes according to cone formation. The green cells indicate the lowest dimensional value in each technique while the orange cells indicate the highest one.

Direct percussion	length	width	thickness
Cone formation	mean value (mm)		
Detached bulb	29,4	25,5	10,6
Hint	31	22,4	10,7
None	27,9	25,2	9,1
Ring cracks	30,8	28,3	11,6
Ventral fissures	27,2	24	8,8
Bipolar on anvil	length	width	thickness
Cone formation	mean value (mm)		
Detached bulb	20,8	16	7,3
Hint	20,1	18,6	7,4
None	24,8	20,3	10,6
Ring cracks	28,1	19,6	7,8
Ventral fissures	33,2	25,2	13,2
Anvil-assisted	length	width	thickness
Cone formation	mean value (mm)		
Detached bulb	25,9	22,4	8,8
Hint	24,2	20	5
None	24,6	23,2	7,6
Ring cracks	24,4	22,3	7,6
Ventral fissures	28	29,3	11,1

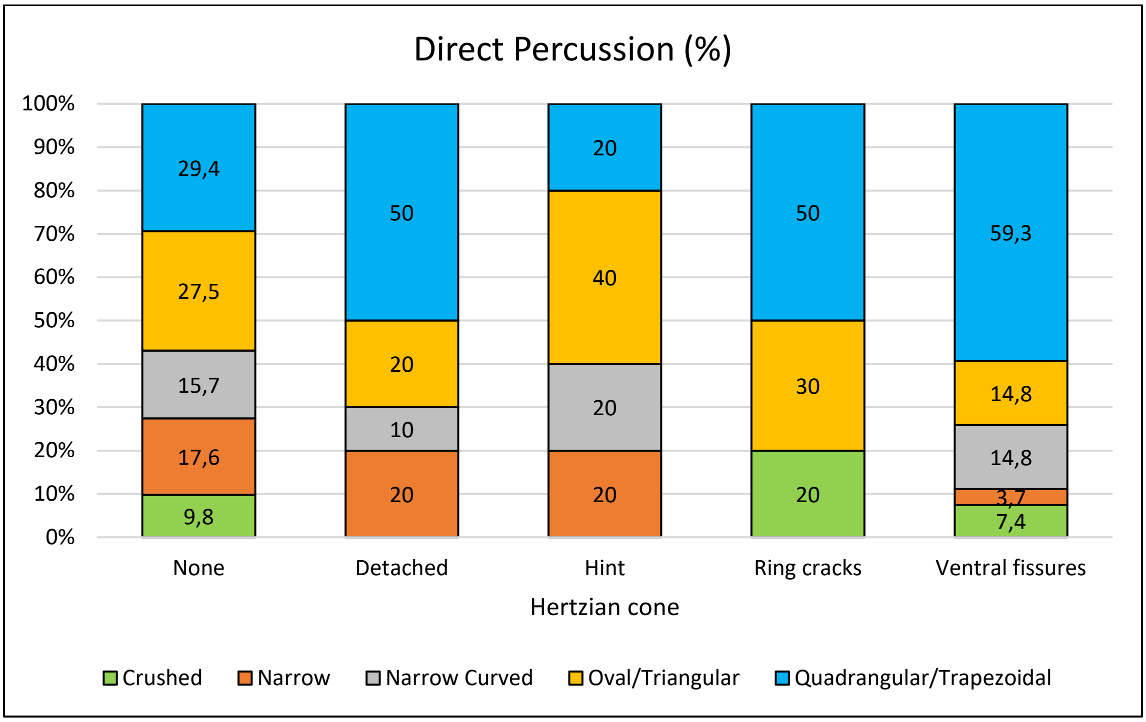

Figure 5.33 Distribution of platform morphology according to the Hertzian cone on direct percussion flakes.

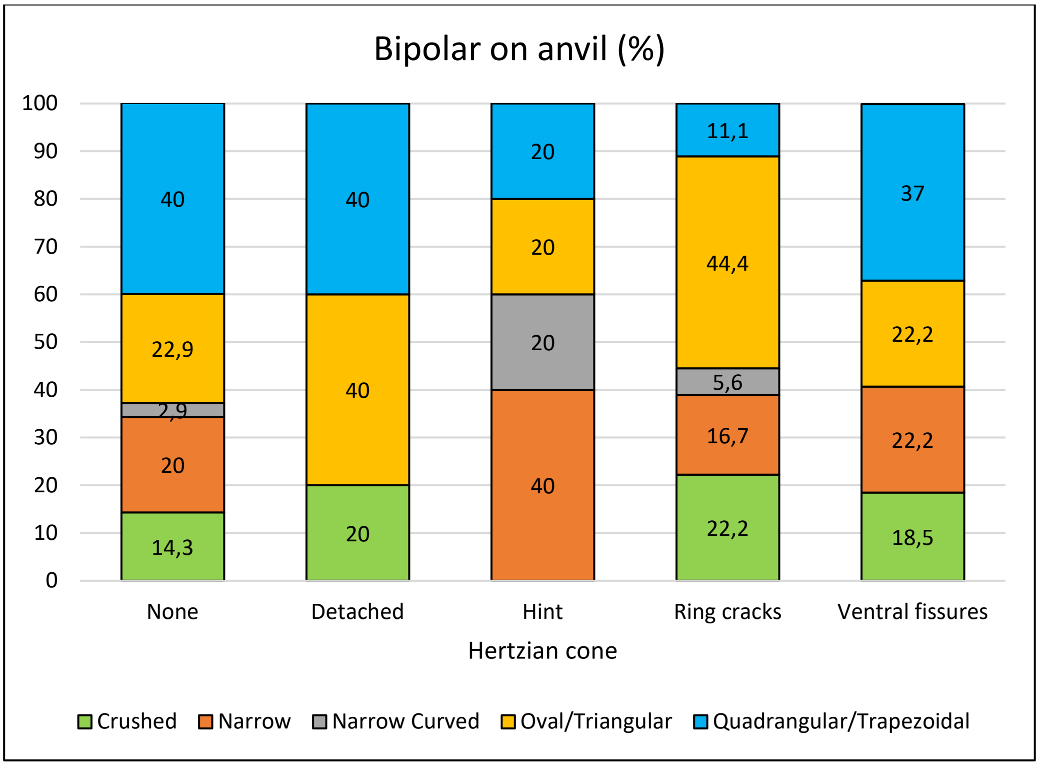

Figure 5.34 Distribution of platform morphology according to the Hertzian cone on bipolar on anvil flakes.

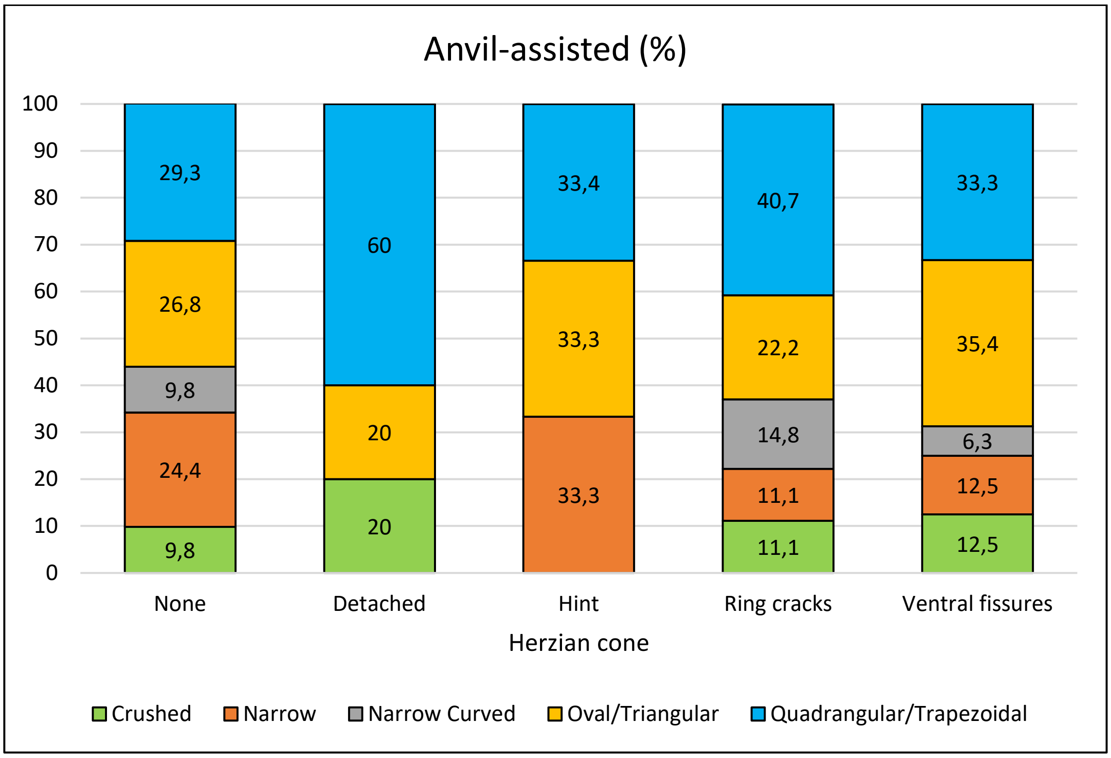

Figure 5.35 Distribution of platform morphology according to the Hertzian cone on anvil-assisted flakes.

The data concerning lip formation between the butt and the ventral face of the flakes revealed that on bipolar on anvil sequences, it is improbable to develop since it was absent in 95% of the products (Fig. 5.36). On the other hand, no distinction was detected between direct percussion and anvil-assisted flakes. The absence of the lip was predominant in both techniques, roughly attested by the same percentages. When present, lips are diffused and sporadically pronounced. As a side note, pronounced lips are more common within direct percussion sequences (10,9 % vs 1,3% and 3,7% respectively). Generally speaking, lips are not a typical morphological feature of debitage techniques employing significant strength in the gestures and using hard hammers. Therefore, this data distribution should not surprise. However, in this case, a clear distinction between the direct percussion and the bipolar on the anvil was possible. At the same time, on the other side, it strengthened the similarities between anvil-assisted and direct percussion, which, from the lip formation perspective, are substantially identical.

The presence of ripples/undulations on the ventral face of the flakes did not turn out to be a significant marker for techniques' identification (Fig. 5.37). The incidence of ripples or percussion waves was relatively low (from 7,5% to 13,6% across all techniques), though an increase was witnessed in the bipolar on anvil and anvil-assisted reductions. Far more frequent are bulbar scars, though no significant discrepancies were recorded between the different techniques. Direct percussion flakes attest to the lowest frequency of bulbar scars (27,5%), increasing among anvil-assisted ones and reaching its maximum (37,9%) on bipolar-on anvil products. On the other hand, the presence of proximal micro shattering between the butts and the dorsal face of the flakes was documented on 35,7% of anvil-assisted flakes, followed by 25,2% of bipolar on-anvil flakes. The incidence of proximal micro-shattering on direct percussion reductions was relatively low (10,8%). It is possible that since the anvil-assisted gesture is more tangential than orthogonal to the striking platforms, the hammer produced more traces.

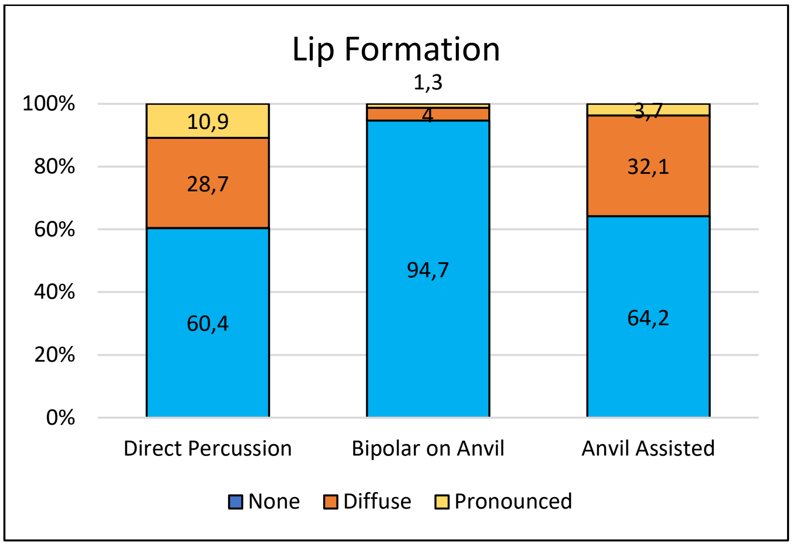

Figure 5.36 Lip formation according to the employed techniques

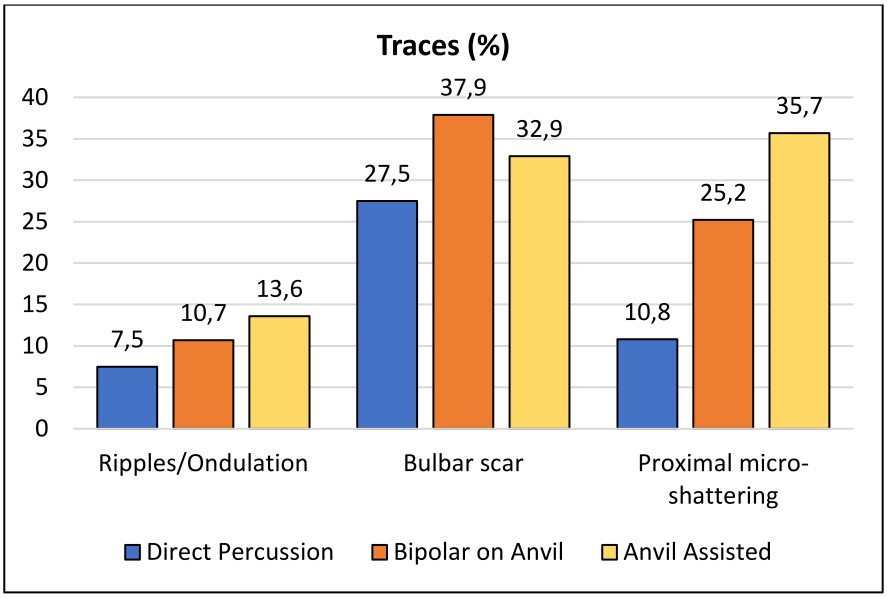

Figure 5.37 Frequency of ripples/ondulations, bulbar scar and proximal micro-shattering according to the employed techniques.

The analysis of the distal terminations (Fig. 5.38) revealed that for direct percussion, regular terminations are predominant, followed by sporadic presence of hinged, broken, and even rebound force. As expected, rebound force terminations within anvil-related techniques are more pronounced but not predominant. Traces of rebound force are more common within bipolar on anvil than anvil-assisted productions. This pattern might not be as relevant as we think since traces of rebound forces indicate the presence of counterblows, seemingly due to an anvil in most cases. Nonetheless, it is interesting that rebound forces were still documented among direct percussion flakes, even though only on 5% of the sample. Regular terminations are also predominant on bipolar on anvil and anvil-assisted, characterising 50% of the artefacts, thus making this data not discriminant for distinguishing techniques. Hinged terminations are less attested than on direct percussion flakes, while fractures on the distal end were more frequent, seemingly due to the impact of the anvil.

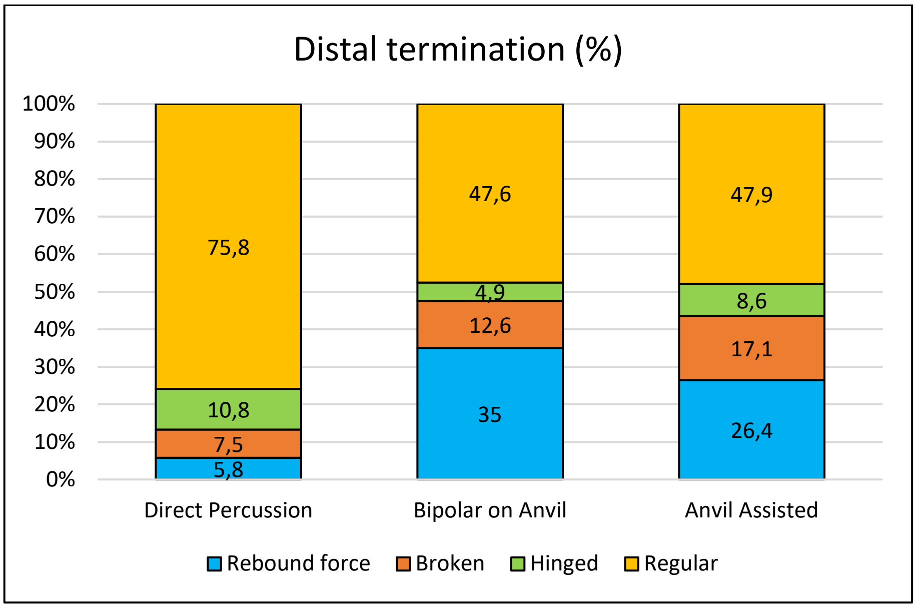

Figure 5.38 Tipology of distal termination according to the employed technique.

The flaking axis revealed a substantial homogeneity between direct percussion and anvil-assisted reduction sequences, while for the bipolar on-anvil, it turned out that 82% of the artefacts presented a rectilinear flaking axis (Fig. 5.39). This pattern can be associated with the higher elongation ratio that bipolar flakes exhibit compared to the others, with the predominance of dihedral sections within this technique and the incidence of a regular width along the flakes profile. Eventually, it would seem that bipolar flaking allows for more regular products. These products are often dihedral, mainly developed in length and exhibiting a lower width-thickness ratio.

The incidence of backed margins was more or less homogeneous (Fig. 5.40). Direct percussion and anvil-assisted flakes exhibit backed margins in 50% of the cases, while for bipolar on anvil flakes, backed margins increase to 60%. Debordant flakes (*i.e.,* flakes presenting a backed margin on the lateral side) are included roughly within 15-20% of the flakes across all techniques, showing a slight predominance on anvil-assisted products. Plunging flakes (*i.e.*, flakes presenting a backed margin on the distal side) are more common within bipolar on anvil artefacts, followed by direct percussion and anvil-assisted ones. The higher incidence of plunging flakes among bipolar reduction might be another aspect confirming the higher elongation ratio of these products. The strength in the blow and the orthogonal gesture could facilitate obtaining flakes exploiting the entire length of the knapping surface. However, this pattern is not particularly significant compared to the other techniques. On the contrary, anvil-assisted flakes present the lowest incidence of plunging flakes, seemingly demonstrating that the presence of the anvil, from this perspective, does not grant reaching the end of the extraction surface. Again, it is plausible that the technical gesture's orientation might affect these variables more consistently. Lastly, flakes with backed margins on all sides – except for the proximal one – are almost absent on direct percussion and anvil-assisted products, while it is slightly more recurrent among bipolar productions, further confirming what was previously stated.

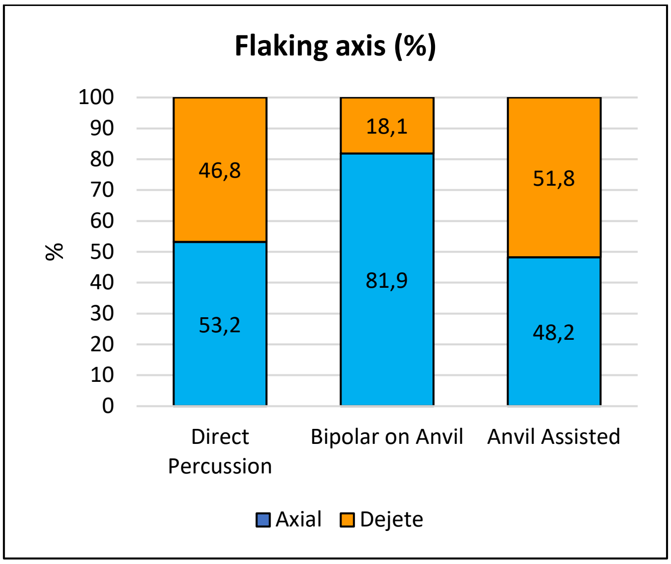

Figure 5.39 Distribution of flaking axis according to the employed debitage technique

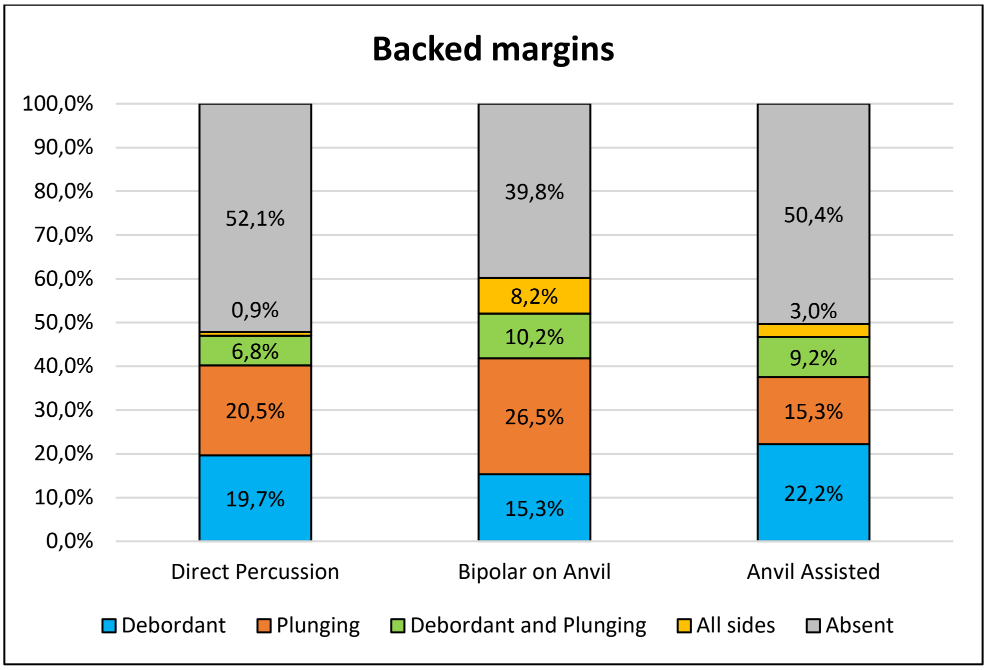

Figure 5.40 Distribution of backed margins tipology according to the employed debitage technique

The removals' organisation does not represent an efficient proxy for this work since, as stated in the Materials and Methods sections, the rotation of the cores was prohibited on bipolar and anvil-assisted reductions to preserve eventual traces. This means that while the scars' organisation on direct percussion flakes might reflect an actual direct percussion reduction sequence, for bipolar on anvil and anvil-assisted ones, this pattern will be altered. Nonetheless, it could be interesting to notice the incidence of bipolar scars on bipolar on anvil and anvil-assisted flakes.

Observing the data distribution (Fig. 5.41), direct percussion and anvil-assisted show homogeneous patterns: unipolar scars are predominant and attested by identical percentages, respectively 59% and 57,2 %, followed by flakes without scars (23,1% and 22,5%). Orthogonal, centripetal, and convergent scars are more frequent on direct percussion flakes, as expected, though they are sporadically documented on anvil-assisted products as well. Bipolar scars are slightly more frequent among anvil-assisted flakes than direct percussion ones, seemingly demonstrating a low incidence of these removals for the anvil-assisted debitage. Moving on bipolar on anvil artefacts, bipolar scars are the most recurrent category (37,4%), followed by flakes without removals (31,8%) and unipolar scars (30,8%). In this case, the higher incidence of bipolar scars is evident, while it is, once again, interesting to notice that anvil-assisted productions are more similar to direct percussion ones. Even if the anvil was employed for both techniques, it is also evident that for bipolar on anvil reduction sequences, it played a much more "active" role, seemingly due to the inclination of the technical gesture that determined a more frequent contact between the core and the anvil.

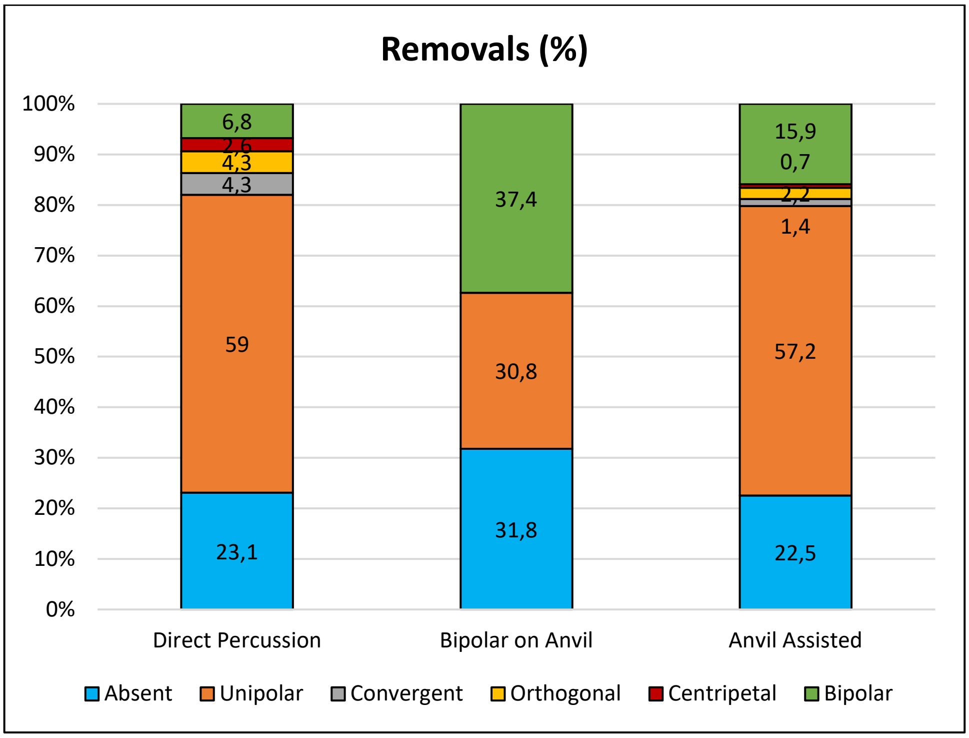

Figure 5.41 Frequency of removals' organisation according to the employed debitage technique

About the role of the anvil (Fig. 5.42, 5.43, 5.44, 5.45, 5.46, 5.47), 39 flakes were obtained through the impact of the lower portion of the core with the anvil, 23 (22,3%) from bipolar on anvil reduction sequences and 16 (11,4%) from anvil-assisted ones. These flakes represent 16% of the bipolar on-anvil and anvil-assisted productions and 10,5% when direct percussion flakes are included. Size-wise, they present smaller dimensions than other flakes: 22,6 x 21,6 x 9,1 mm vs 26,9 x 24,1 x 9,5 mm and are more quadrangular-shaped. The platforms' type revealed almost identical patterns between "regular" and detached from the anvil flakes, with a predominance of natural butts (Fig. 5.42). The only slight difference is the higher frequency of linear butts among flakes detached from the anvils. The mean debitage angle is the same for both categories, attested on 81-82° and closer to the anvil-assisted productions. The morphology of the platforms is also relatively similar (Fig. 5.43), though quadrangular/trapezoidal shapes are more common on regular flakes, while narrow shapes are more frequent on detached from anvil ones. Bulbs morphology analysis indicates that diffused bulbs are more frequent on flakes detached from the anvil, and, generally, these flakes are more likely to develop bulbs than regular flakes (Fig. 5.44). No patterns emerged from the Herzian cone formation since both categories show a predominance of undeveloped cones, followed by ventral fissures – slightly more frequent among detached from the anvil flakes – ring cracks, and detached bulbs (Fig. 5.44).

The maximum width distribution revealed a predominance of distal portions for both groups of flakes, though detached from the anvil ones are more frequent than the others (Fig. 5.44). Proximal portions are more recurrent on regular flakes, while mesial portions are the opposite. Flakes exhibiting regular width along their profile are more documented on regular flakes. Despite these differences, the gaps are rather tight. Concerning maximum thickness, slightly more accentuated trends emerge. Maximum thickness coincides with the distal end of the flakes more often when detached from the anvil flakes (41% vs 22,6%), while coincides with the proximal portion more often on regular flakes (42,4% vs 25,6 %; Fig. 5.44). The same distribution attests to mesial and regular thickness. From this perspective, flakes produced from the anvil seem more developed on the distal portion of the supports (Fig. 5.44). The higher recurrence of narrow and narrow curved shapes on the platforms, associated with the predominant presence of diffused bulbs, might suggest that the counterblow from the anvil does not affect the proximal portion of the flakes as much as it affects the distal one, and, more in general, that the counterblow from the anvil is not as strength as the one received from the hammer. The smaller mean dimensions of the flakes produced from the anvil might also confirm this pattern.

The analysis of the flakes' sections, profiles, and flaking axis did not provide any difference between the two categories (Fig. 5.45). As expected, the distal termination revealed a predominance of rebound force traces on the flakes detached from the anvil, attested on 43% of the artefacts. The lip was absent on 86,2 % of the products detached from the anvil versus the 69,8% of regular flakes, indicating a closer similarity with bipolar on anvil products from this point of view. The presence of ripples or percussion waves on the ventral face of the products did not provide remarkable differences, even attested on low percentages. Bulbar scars and proximal micro-shattering are slightly more recurrent on flakes detached from the anvil, recalling the patterns witnessed on bipolar on anvil flakes – for bulbar scars – and anvil-assisted – for the frequency of proximal micro-shattering. The proportion between backed flakes is more or less identical, with debordant flakes being slightly more frequent on flakes detached from the anvil and plunging flakes being more recurrent on regular ones.

To conclude, no differences were detected between flakes obtained through the impact with the hammer and flakes produced from the impact with the anvil. There are some morphological patterns that, on the one hand, make these flakes more similar to direct percussion flakes and, on the other hand, make them more similar to bipolar on-anvil and anvil-assisted ones. However, such differences are not so pronounced to grant a sharp distinction between regular and detached from the anvil flakes.

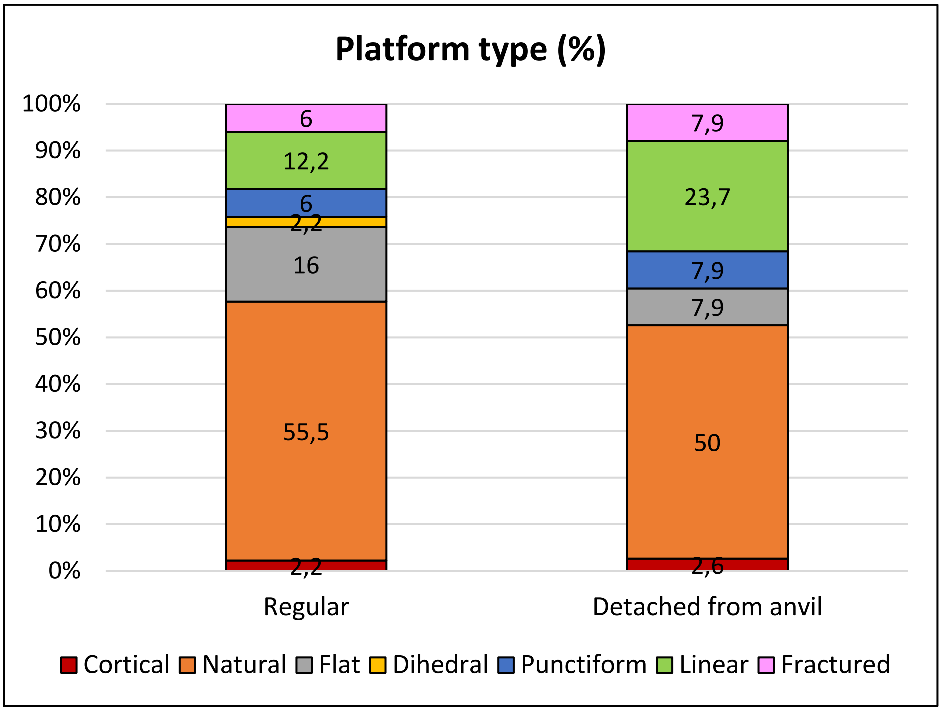

Figure 5.42 Frequency of platform type on regular flakes and detached from the anvil flakes.

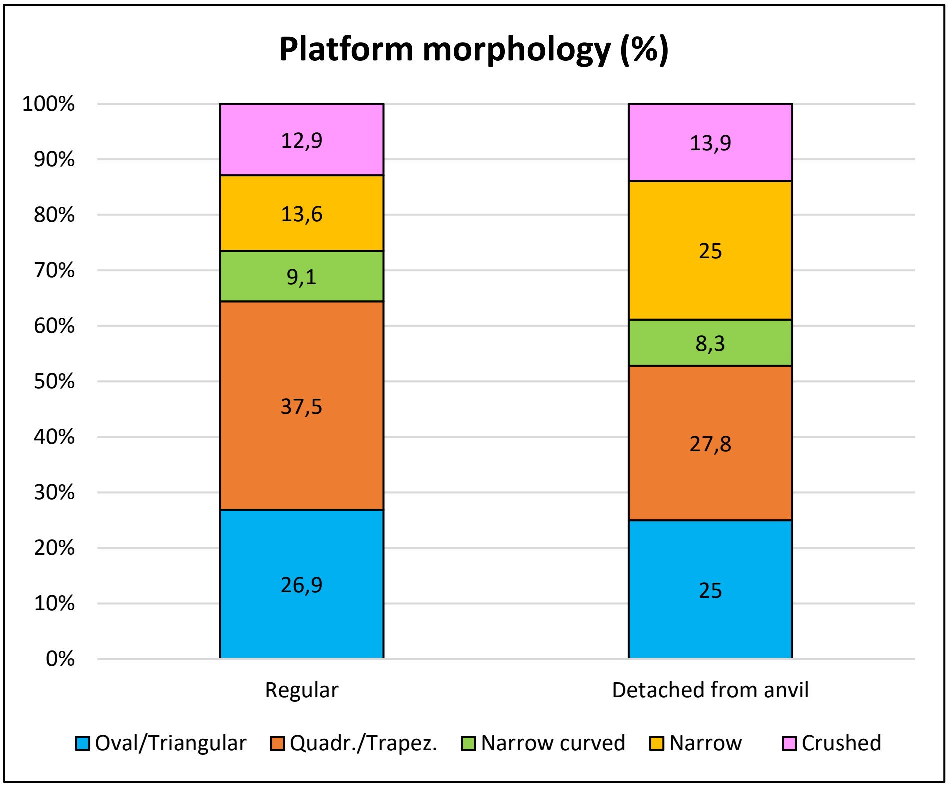

Figure 5.43 Frequency of platform morphology on regular flakes and detached from the anvil flakes.

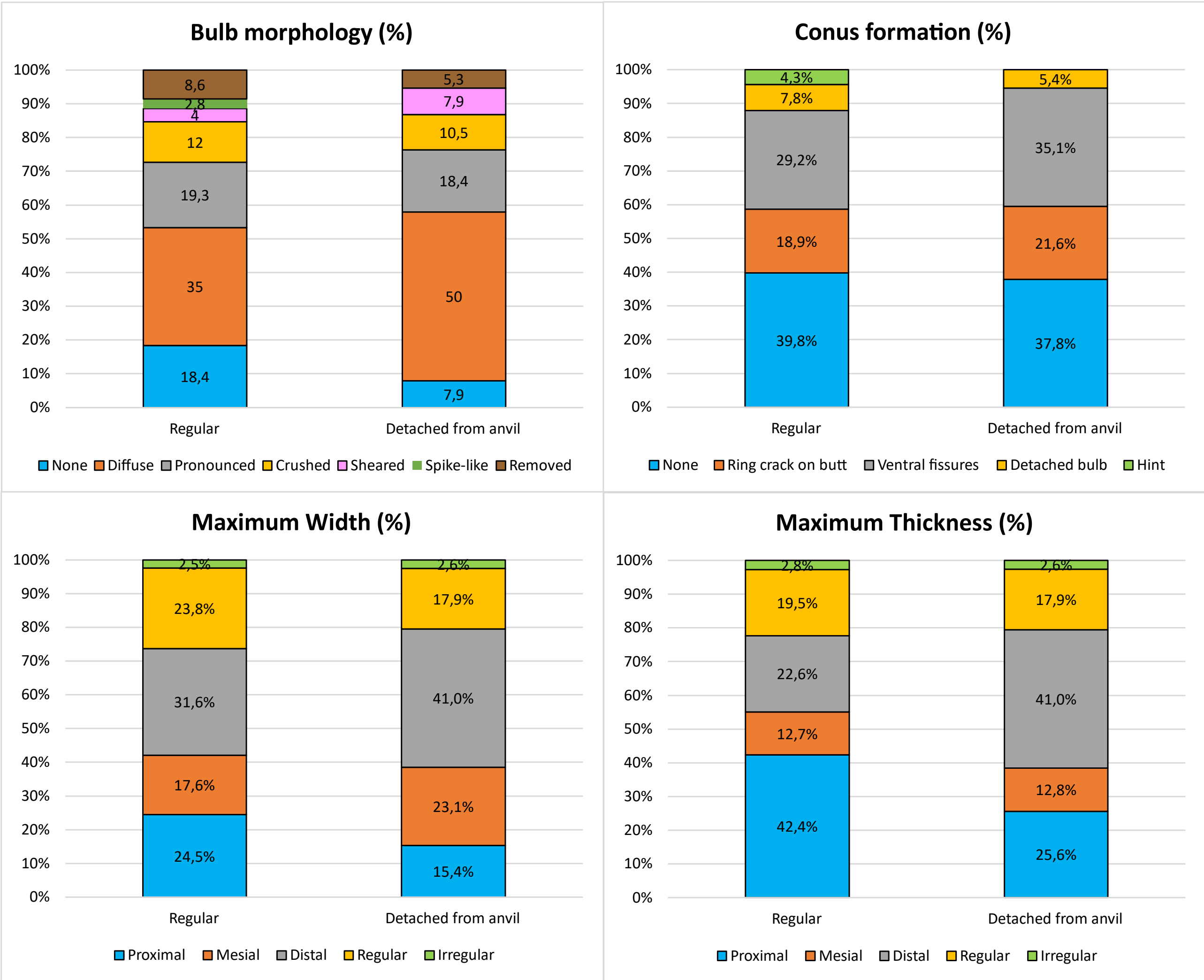

Figure 5.44 Frequency of Bulb morphology (top left), conus formation (top right), maximum width (bottom left), and maximum thickness (bottom right) of regular flakes and detached from the anvil flakes.

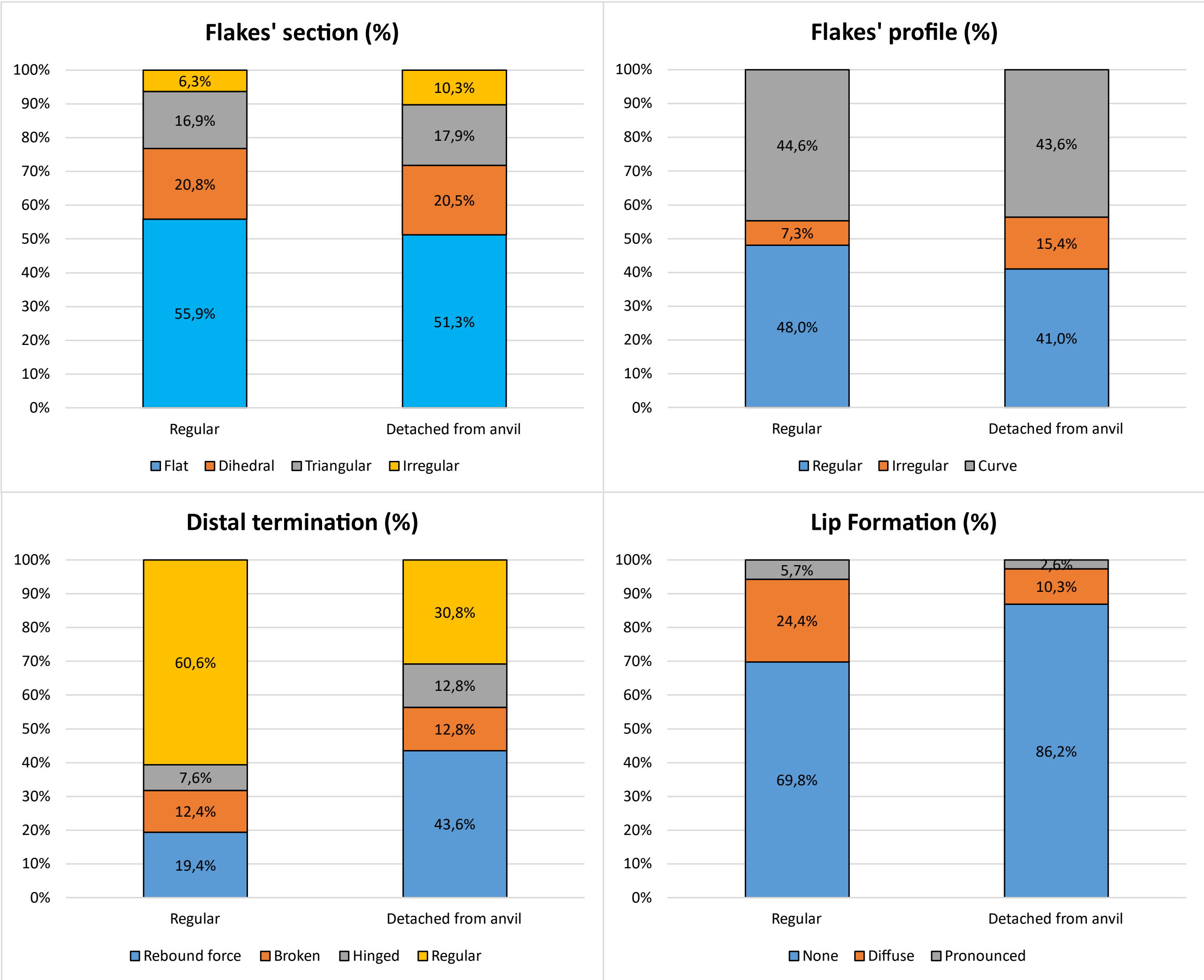

Figure 5.45 Frequency of flakes' section (top left), flakes' profile (top right), distal termination (bottom left), and lip formation (bottom right) on regular flakes and detached from the anvil flakes.

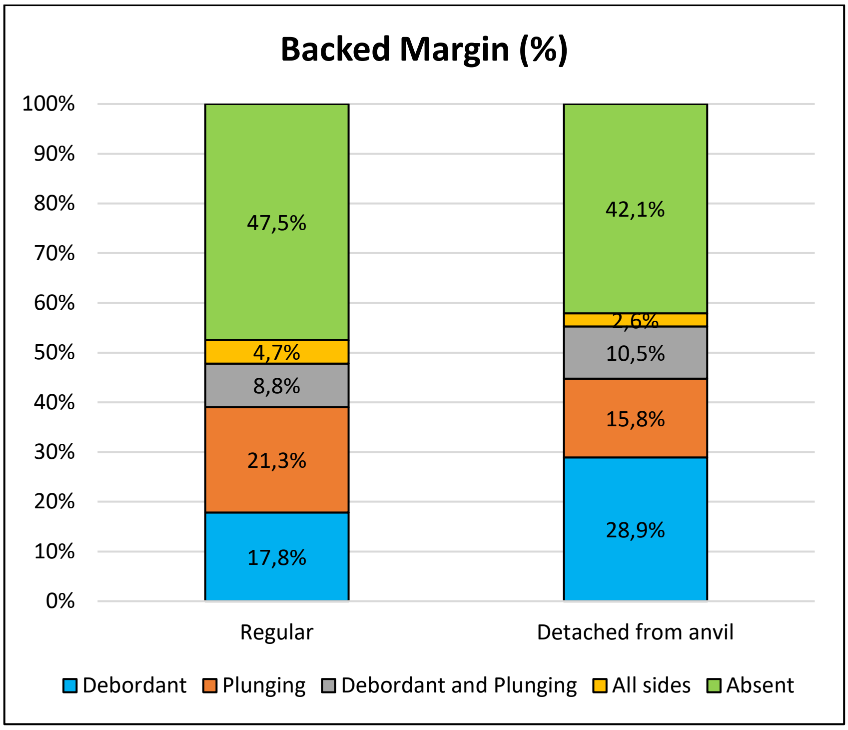

Figure 5.46 Frequency and tipology of backed margins on regular flakes and detached from the anvil flakes.

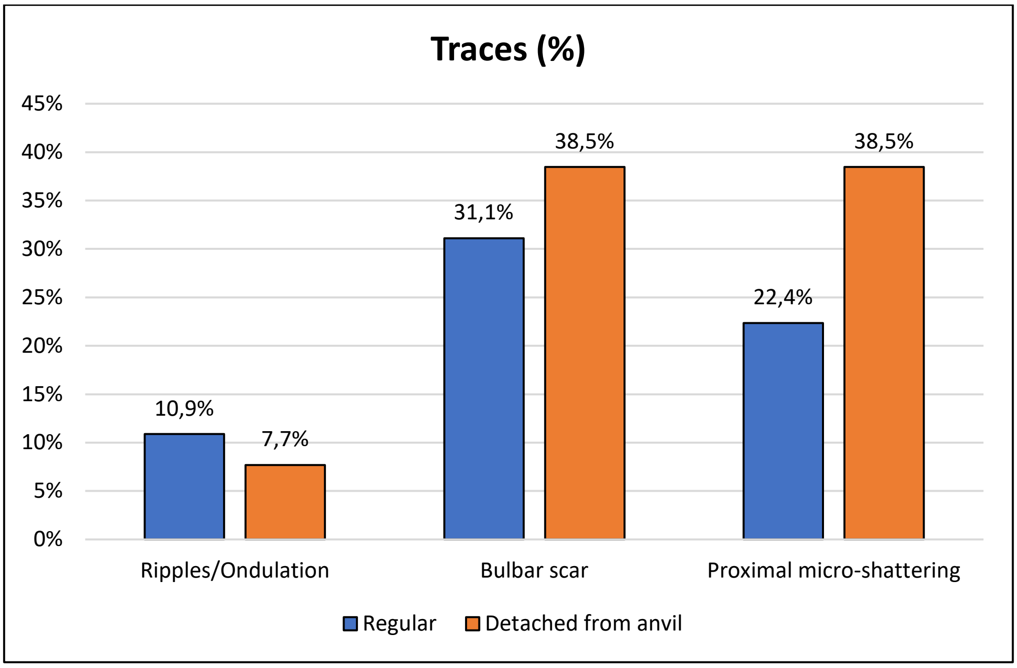

Figure 5.47 Frequency of ripples/ondulations, bulbar scar and proximal micro-shattering on regular flakes and detached from the anvil flakes.

Flakes with clear traces of counterblows are 43, corresponding to 11,8% of all the artefacts analysed. Four of these flakes derive from direct percussion sequences, 18 from anvil-assisted, and 21 from bipolar on-anvil ones. This means counterblows are more recurrent on bipolar on anvil (20,4%) than anvil-assisted (12,9%) productions. Overall, flakes bearing clear traces of using the anvil are not so frequent. For the purpose of this work – identification of qualitative attributes to distinguish direct percussion from anvil debitage – their characterisation might not be as relevant since the presence of counterblows on the distal portions of the flakes unequivocally confirms the presence of an anvil. However, recording their incidence is another valuable piece of information indicating the actual frequency of these pieces within lithic assemblages.

These flakes are characterised by higher mean length than regular and detached from the anvil flakes, seemingly because their length is equivalent to the original length of the knapping surfaces (Tab. 5.16). Their mean width is identical to regular flakes, while their thickness is a couple of millimetres higher. Comparing the morphological traits of flakes with traces of counterblows with flakes detached from the anvils revealed a global homogeneity of the two categories, although some differences are present. The analysis of the platforms' morphology (Fig. 5.48) – for counterblow flakes, we mean the analysis of the counter-platform morphology, equivalent to the platforms produced through the anvil's impact – revealed that crushed morphologies are more frequent on counterblow flakes (34% vs 14%), while narrow shapes are far more sporadic (5% vs 25%). Additionally, an increase in quadrangular/trapezoidal platforms was detected (36,8% vs 27,8%), along with a decrease in oval/triangular ones (15,8% vs 25%). This trend seems to indicate that counterblow flakes are associated with stronger blows – the higher frequency of crushed morphologies – and bigger flakes – we witnessed that quadrangular/trapezoidal shapes of the platforms are often associated with longer and larger flakes – than flakes detached from the anvil.

On the other hand, the development of the bulbs was slightly more frequent on flakes detached from the anvil (Fig. 5.49). Diffused bulbs are less frequent on counterblow flakes (33% vs 50%), while pronounced, crushed, sheared, and removed bulbs are more or less equivalent between the two categories. The comparison of the Hertzian cone led to homogeneous trends, with an equivalence of ventral fissures, ring cracks, detached bulbs, and undeveloped bulbs (Fig. 5.50). The same applies to lip formation, which is highly sporadic on both flakes (Fig. 5.51). The only remarkable difference lies within the counter-debitage angle, which, on counterblow flakes, has a mean value of 95,5° compared to 81-82° of detached from the anvil and regular flakes.

Table 5.16 Dimensional values of regular flakes, detached from the anvil flakes, and counterblow flakes. All values are expressed in millimetres.

	length	width	thickness
Flakes			
Regular	27,4	24,4	9,3
Detached from anvil	22,6	21,6	9,1
Counterblow	28,3	24,1	11,2

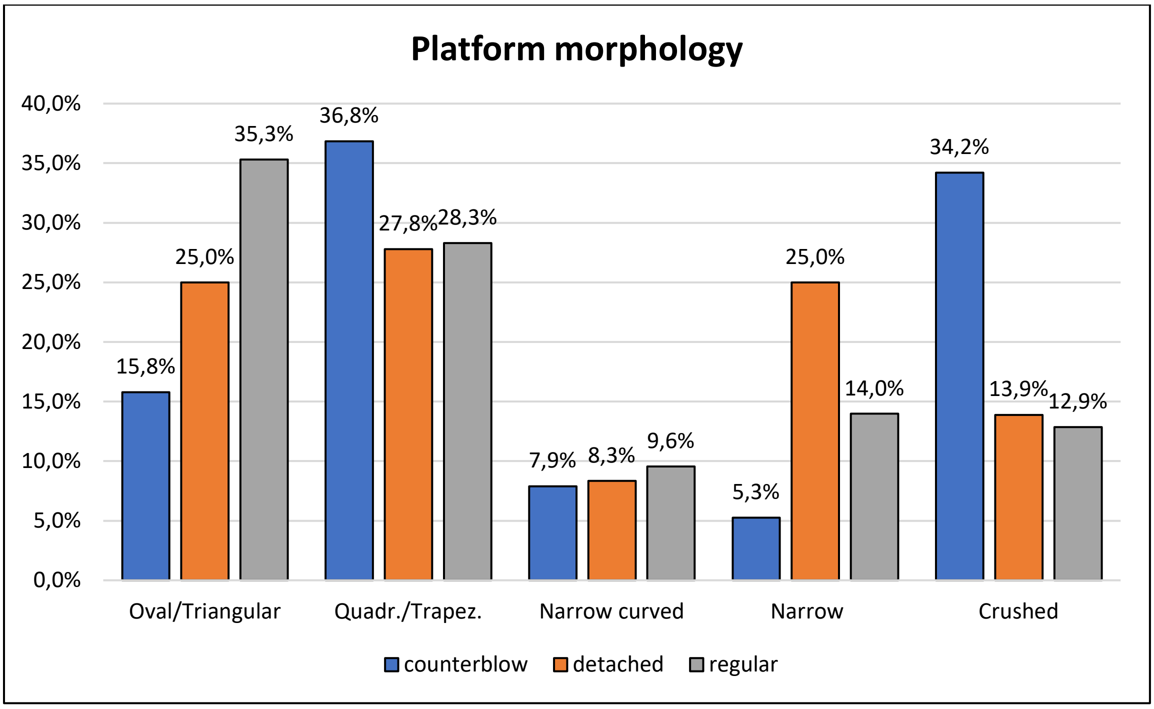

Figure 5.48 Platform morphology of counterblow, detached from the anvil, and regular flakes.

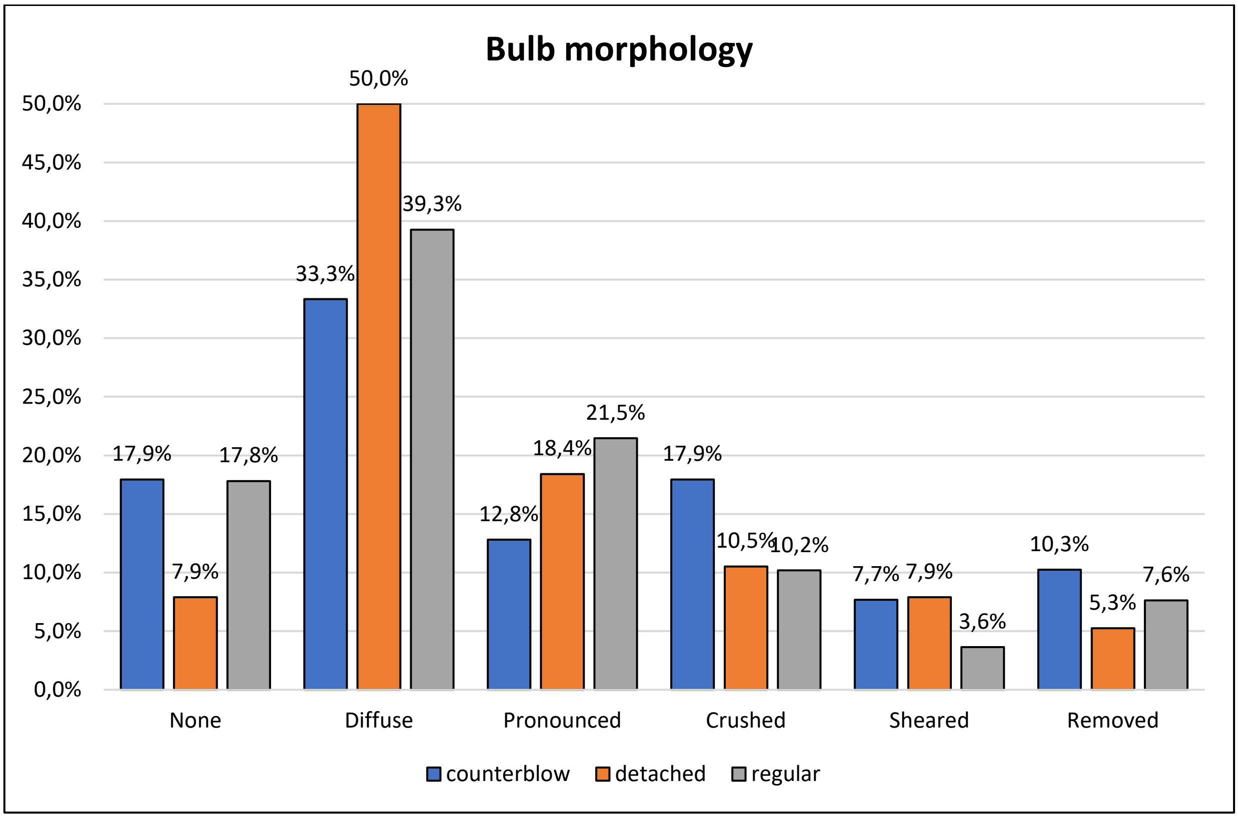

Figure 5.49 Bulb morphology of counterblow, detached from the anvil, and regular flakes.

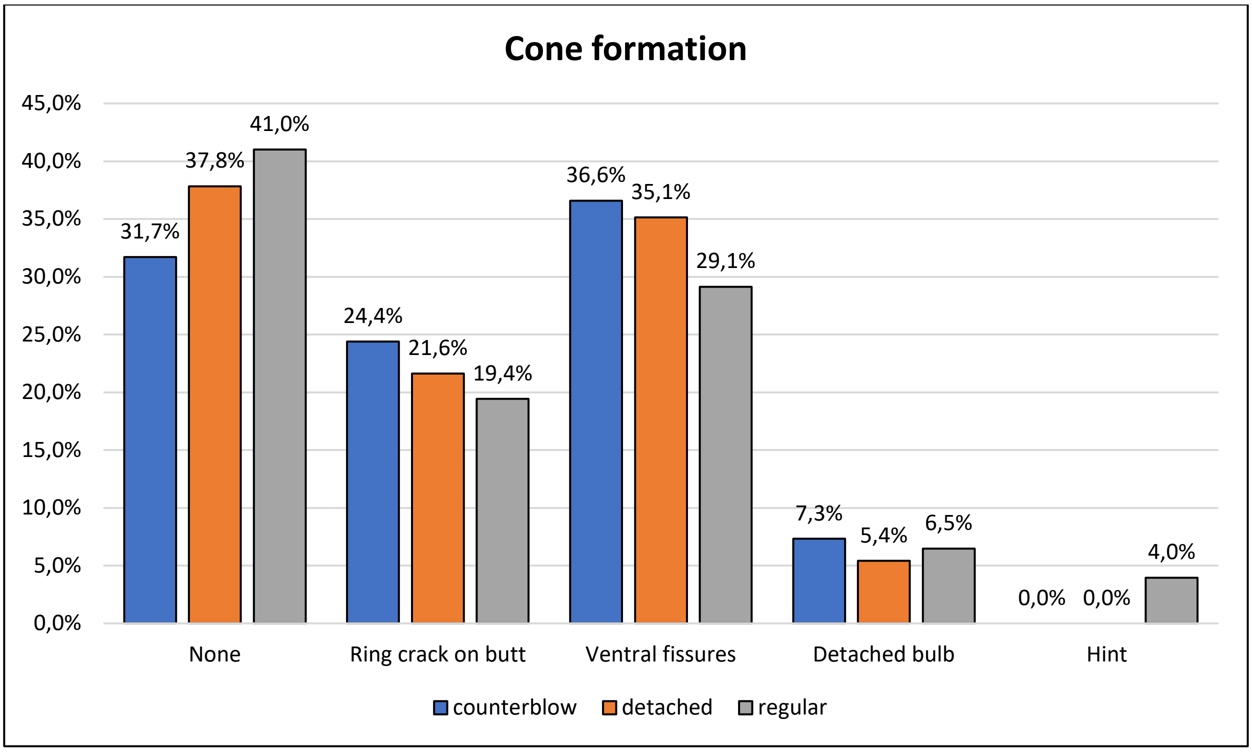

Figure 5.50 Cone formation on counterblow, detached from the anvil and regular flakes.

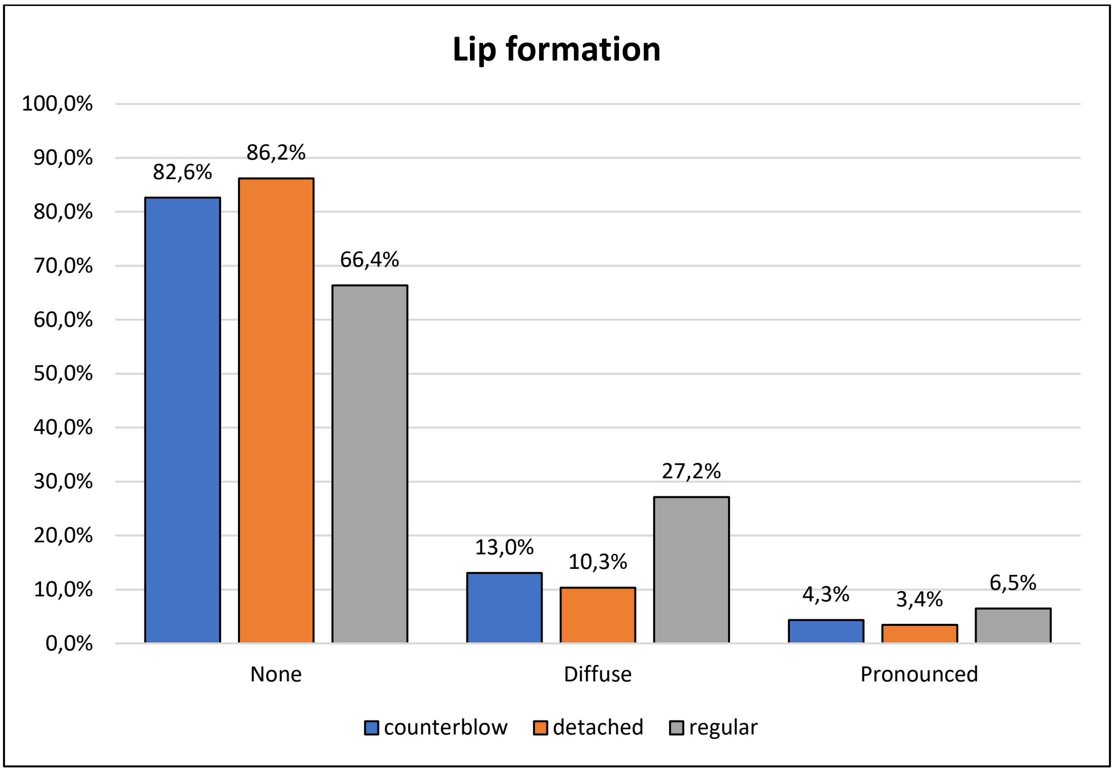

Figure 5.51 Lip formation on counterblow, detached from the anvil, and regular flakes.

Moving on to the cores' analysis, their size revealed a global homogeneity across the employed techniques (Tab. 5.17). Anvil-assisted cores exhibit higher mean values of length, width, and thickness, while direct percussion and bipolar on anvil cores are more or less identical. The distribution of the length-width, length-thickness, and width-thickness ratios is also relatively homogeneous. Bipolar cores exhibit higher elongation ratios for width and thickness, while anvil-assisted cores present slightly higher width-thickness ratios. In any case, the boxplots show a general overlapping of the dimensions without outstanding trends (Fig. 5.52). The morphology of the knapping surfaces (Fig. 5.53) indicates that tournant surfaces are predominant within direct percussion and anvil-assisted cores, respectively 43,1% and 47,1% while being more sporadic on bipolar on-anvil cores (22,7%). Flat surfaces are more or less recurrent in the same percentages across all techniques, though they are more common on anvil-assisted (41,2%) and bipolar (36,4%) cores than direct percussion ones (31,3%). Orthogonal surfaces present a more diversified distribution, being more recurrent on bipolar cores (36,4%), followed by direct percussion (25%), and being sporadic on anvil-assisted cores (11,8%). The mean number of removals indicates the highest value for anvil-assisted cores (5,4), followed by direct percussion (4,8) and bipolar ones (3,9). The associated mean debitage angles show identical values for bipolar and anvil-assisted (84° and 84,8°), while direct percussion cores exhibit more acute angles with a mean value of 75,8°. This seems to be the most discriminating factor, seemingly separating direct percussion from anvil-assisted and bipolar cores. The presence of micro shattering on edge between the striking platforms and knapping surfaces was rather frequent on bipolar cores (68%), decreasing on anvil-assisted cores (55,6%), and being minoritarian on direct percussion ones (37,5%). As expected, counterblows were more common on bipolar and anvil-assisted cores, respectively, with 68,2% and 66,7%. Nonetheless, a small number of direct percussion cores (18,8%, n=3) also provided evidence of counterblows. The discussion of the removals' organisation, as stated during the flakes' analysis, is biased since bipolar cores were not rotated. In any case, the incidence of bipolar removals was extremely low on direct percussion cores (12,5%), while on bipolar and anvil-assisted cores, they were recurrent on more than half of the supports (around 60%; Fig. 5.54).

To conclude this section on cores, the debitage angle was the most crucial proxy to attempt differentiating the debitage techniques, although no distinction between bipolar and anvil-assisted debitage was possible. Micro-shattering frequency was also significant to distinguish the techniques, although it should be verified if the same ratio would persist once bipolar and anvil-assisted cores were rotated. The same rule applies to the removals' organisation. Concerning counterblows, they also seem a solid proxy, being attested on at least 65% of the bipolar and anvil-assisted cores. We could suppose that introducing cores' rotation would not significantly invalidate the presence of these traces since a portion of the cores will always be in contact with the anvil.

Table 5.17 Dimensional values of cores according to the employed debitage technique. All values are expressed in millimetres.

Technique	Direct percussion			Bipolar on anvil			Anvil assisted		
Size	length	width	thickness	length	width	thickness	length	width	thickness
Cores	n=16			n=22			n=18		
min	28,3	25,5	16,3	20	18,8	12	18,5	16,4	10,5
max	61,5	49,7	41,5	81	66,6	53,2	108	103,2	62
mean	**44,6**	**36,1**	**28**	**46,5**	**34**	**26,8**	**50,6**	**41,1**	**30,5**

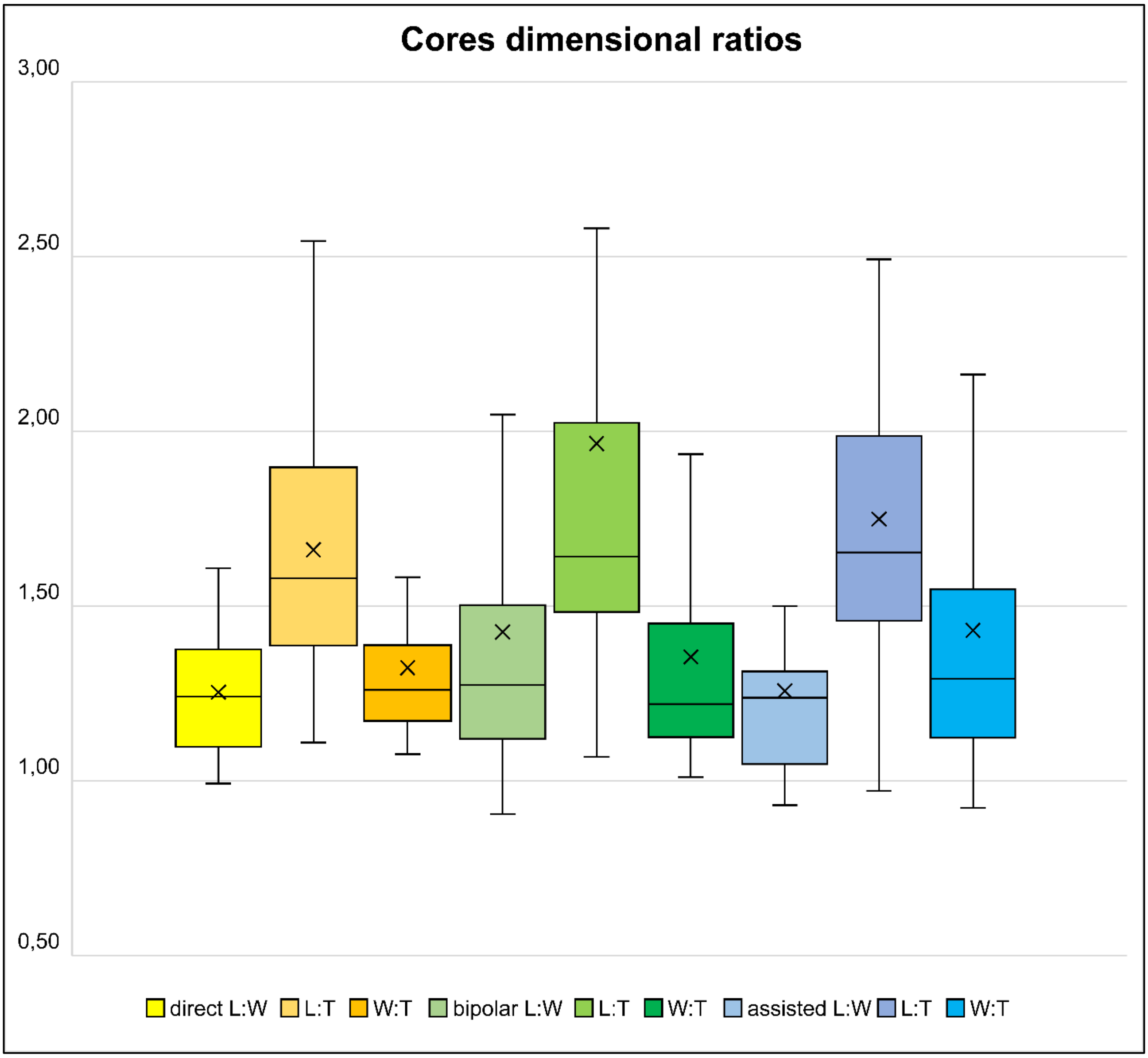

Figure 5.52 Length/width (L:W), Length/Thickness (L:T), and Width/Thickness (W:T) ratios of cores knapped through direct percussion ,bipolar on anvil, and anvil-assisted.

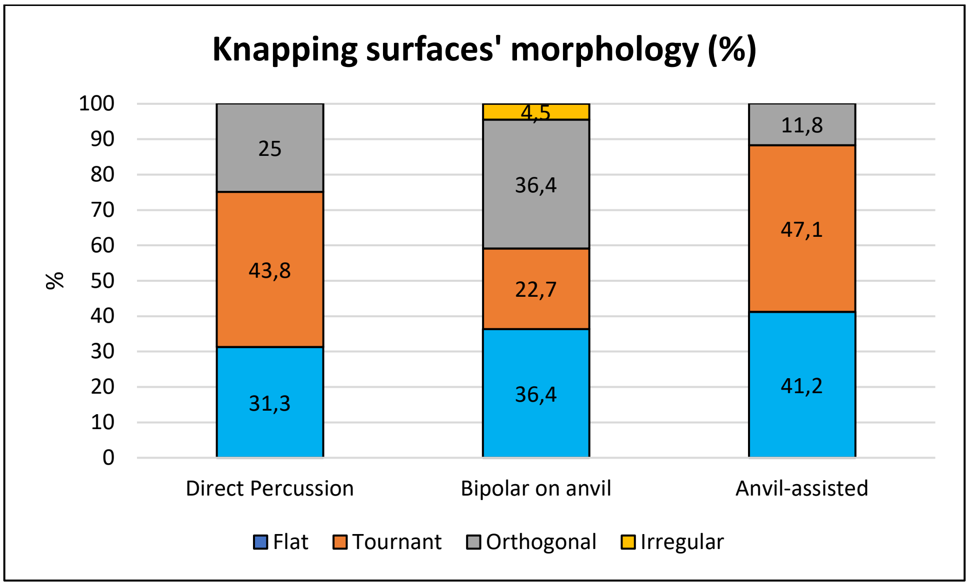

Figure 5.53 Distribution of knapping surfaces' morphology according to the employed debitage technique.

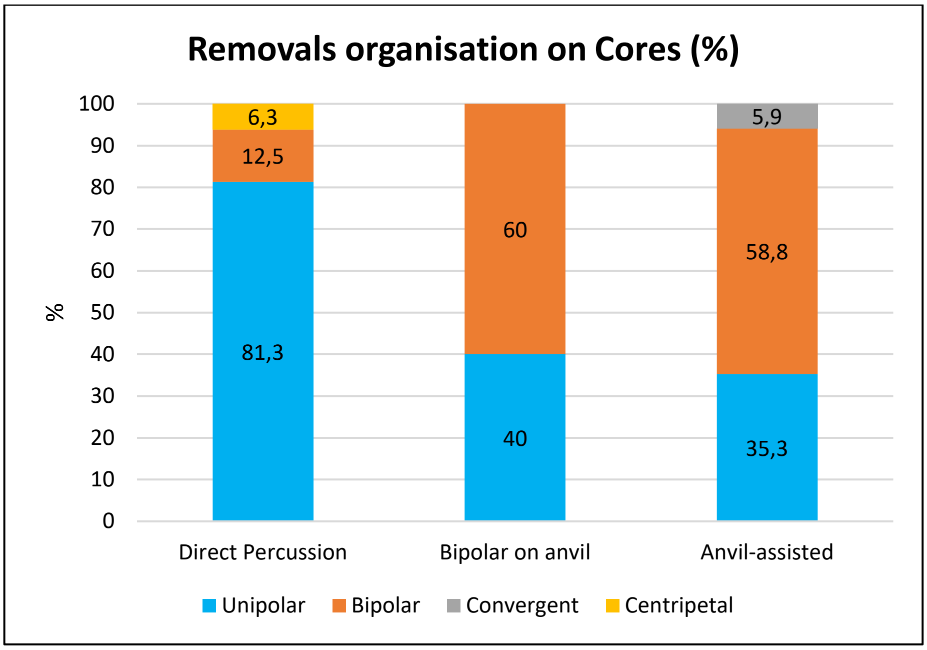

Figure 5.54 Removals organisation on cores according to the employed debitage technique.

The results of this experimentation highlighted that direct percussion, bipolar on anvil, and anvil-assisted techniques exhibit a significant range of overlap through the several morpho-technological criteria adopted. The emerging patterns provided interesting similarities between direct percussion and anvil-assisted debitage, but also between bipolar on anvil and anvil-assisted reductions, making anvil-assisted a hybrid yet efficient strategy halfway in between direct and bipolar productions. It is fundamental to underline that the results of this work are strictly related to the typology of raw material exploited, which in this case is chert, under the form of slabs, deriving from the Varicoloured Jasper Formation of Central-Southern Italy. As pointed out by other studies focusing on the identification of bipolar on anvil reduction sequences, the raw material's response is almost unique, making a comparison between morphologically and qualitatively identical raw materials unavoidable.

In the case of Isernia's raw material, the collected slabs exhibit many fracture planes together with a diversified texture that often prevents trace development. Nonetheless, a substantial homogeneity emerged across the debitage techniques, raising significant questions about the possibilities of accurately distinguishing an anvil from a direct percussion within a lithic assemblage employing the same lithotypes and morphologies. Clear traces that have been demonstrated to characterise the bipolar on anvil productions in the archaeological and experimental literature were relatively low during this work (Crovetto et al., 1994; Bietti et al., 2010; Eren et al., 2011a; 2013; De La Peña Alonso and Vega Toscano, 2013; Peña, 2015; Shott and Tostevin, 2015; Buchanan et al., 2016; Manninen, 2016; Pargeter and Eren, 2017; Pargeter and Tweedie, 2019; Pargeter et al., 2019a). From this perspective, cores are more indicative than flakes, though they are often underrepresented within lithic assemblages. The overlapping range witnessed across more or less all the morpho-technical criteria adopted was significant, though some trends, also documented during other experiments, emerged.

For instance, Pargeter and colleagues (2017) highlighted that bipolar cores were marginally, though not significantly, more elongated than freehand cores, a pattern also witnessed during our experiment. They further state that the width-thickness ratio was irrelevant, as it was identical across all cores. Direct percussion cores also presented a higher average number of scars per core. In their case, the gap between direct percussion production and bipolar ones was more significant (10 vs 4,27), while in our study, it was far less pronounced (4,8 vs 3,9). Pargeter and colleagues recorded that bipolar scars on cores were more frequent on bipolar reduction while being absent from freehand ones. In contrast, freehand cores exhibited a much higher frequency of unipolar scars. Additionally, the incidence of micro-shattering traces between the striking platforms and knapping surfaces was more pronounced on bipolar than freehand cores (65% vs 13%) – a pattern documented in our experiment, with roughly identical percentages.

The analysis of the products from Pargeter and colleagues' experiments revealed some similar patterns (Pargeter and Eren, 2017). Direct percussion flakes presented a higher width-thickness ratio than bipolar ones. On the other hand, they reported a significant distinction in the elongation ratio between freehand and bipolar products, which was documented but not so pronounced in our case. However, they also stated that a significant overlap between dimensions and ratios was generally documented. A substantial homogeneity in the production of morphologically non-standardised flakes was also reported. Interestingly, in our case, bipolar reductions provided evidence of more flakes exhibiting parallel margins and rectilinear profiles. It is also true that bipolar products exhibited a slightly more irregular distribution of the values when different categories (*i.e.*, platform shapes, bulbs, Hertzian cones, dimensional ratios, etc.) were selected, suggesting that bipolar products were more diversified without following specific patterns. For instance, direct percussion and anvil-assisted flakes presented less diversified trends, hinting at more homogeneous products.

Pargeter and colleagues also recorded other differences when sections, profiles, maximum width and thickness, platform shape, bulb morphology, etc., were addressed. However, the differences in their patterns, similar to our experiments, do not seem particularly pronounced to be effective once a mixed lithic assemblage is analysed. It is plausible that no single factor would allow us to distinguish between direct and bipolar debitage accurately, and it is more the contribution of different attributes and patterns crossed together that could grant us a higher identification rate. Nonetheless, we should consider that distinguishing these techniques could be highly challenging and almost impossible. Different blind tests performed in other works to check whether direct percussion assemblages were distinguishable from bipolar ones revealed that such a task is often tricky since the range of overlap between the two techniques has been pointed out by many authors (Jeske and Lurie, 1993; Fasser et al., 2019). Once we move out of a controlled situation where we cannot quantify and determine the impact of each technique of the lithic pieces, the boundaries become more subtle. For instance, introducing the anvil-assisted variant in our experiment demonstrated that, in many cases, there were more similarities between the direct percussion and the anvil-assisted than between the anvil-assisted and the bipolar on anvil.

Chapter 6 Conclusions

The transition between the Lower and Middle Pleistocene on the European continent is often called the Middle Pleistocene Revolution. Its beginning has been universally set to 780 ka with the beginning of the Middle Pleistocene, but it is considered to cover a significantly larger period based on climatic and environmental data (1.2 – 0.45 Ma). The Middle Pleistocene Revolution is associated with an abrupt change in the climatic and environmental conditions affecting the faunal assemblages and most likely triggering fluxes of human groups and significant behavioural changes. The change of periodicity in the alternation of glacial/interglacial phases from 41 to 100 ka marked significant geomorphic changes and vegetational turnovers all over Europe. The increased duration of glacial periods led to the aridification of many areas, expanding open landscapes, such as savannahs and grasslands, and reducing more wooded environments. The subsequent expansion of continental ice caps, accumulating large amounts of water, lowered the sea level, thus generating prolonged periods of droughts and opening land areas previously covered by water. This dual process – aridification and ice caps expansion – led to a depopulation of high-latitude territories in Central and Northern Europe and tropical and dry areas such as Sub-Saharan Africa, Northern Africa, the Arabian peninsula and Eurasia. All these climatic perturbations also led to an environmental fragmentation (*i.e.,* regional diversification) with the development of several ecological niches, further pushing specialisation processes within faunal and human communities (Manzi, 2004; Stewart and Stringer, 2012; Maslin et al., 2014; Potts and Faith, 2015; Ashton, 2017; Moncel et al., 2018c; 2022; Hu et al., 2023; Margari et al., 2023).

Besides causing several mass extinction events in the faunal and anthropic communities, these processes have also enhanced corridors' opening/closing, favouring the diffusion over Europe of new faunal species and human groups from Africa and Asia with evidence of anthropic occupation even at higher latitudes. At the same time, these climatic changes equally affected the continuity of human frequentation, creating a distinct scenario between Northern and Southern Europe. The former was intermittently occupied primarily during favourable climatic phases — as witnessed by the sites of Happisburgh 3, Pakefield, La Noira and Moulin Quignon, which show an abrupt abandonment at the onset of glacial stage 16 — while the latter was more continuously occupied over time due to less-impacting climatic variations (for example, at the site of Notarchirico during MIS 16), depicting an "ebb and flow" model for European peopling (Parfitt et al., 2010; Dennell et al., 2011; Manzi et al., 2011; Moncel et al., 2022).

According to many authors, these abrupt modifications forced species to move and adapt rapidly to changing environments, thus enhancing the evolution, selection and speciation processes (Muttoni et al., 2010; 2018; Timmermann and Friedrich, 2016; Timmermann et al., 2022). These processes, considered to be fundamental for the earliest human migrations outside of Africa with *Homo erectus* that shifted from *"regional dweller to early global wanderer"* (Timmermann et al., 2022, p. 6), have also been proposed for *Homo heidelbergensis,* which, in order to face harsher climatic conditions, should have acquired new adaptation skills, *"strengthening their ability to further expand their geographical range"* (Timmermann et al., 2022, p. 6). On top of that, the structural changes that large mammal communities underwent during the Middle Pleistocene Revolution resulted in an enlarged prey spectrum for the hominins, further facilitating their dispersal in a pattern of predators' dependency on the migration of their prey. The development of ecological niches and the increased habitat heterogeneity allowed predators to diversify in specific niches, reducing the inter-specific competition and thus offering hominins several opportunities to fill in the gaps left in a more flexible environment with a broader spectrum of accessible resources and reduced species competition (Dennell et al., 2011; Manzi et al., 2011; Rodríguez et al., 2012; Palombo, 2014; Saladié et al., 2014; Rodríguez-Gómez et al., 2016; 2017; Palmqvist et al., 2023).

As mentioned, climatic and environmental changes are essential in triggering human responses, and during these disruptive climatic events, innovative behaviours that can be archaeologically seen and documented might have developed. The emergence of bifacial and LCTs industries, increased frequency of retouched implements, new land-use patterns, improved raw material management, and a global increase in the degree of complexity of the lithic productions, even in contexts without bifacial tools (i.e., core and flakes assemblages), are among the innovations documented during this important chronological transition in the related archaeological sites. The appearance of handaxes in Europe is commonly associated with the Acheulean cultural complex, which marks a moment of significant cultural and technical renovation related to the arrival of new human species (*Homo heidelbergensis*) from the African and Asian continents. The Acheulean is considered the first cultural complex of prehistory – though some scholars proposed the Olduvaian/Mode 1 complex, and also the Mode 0 industry of Lomekwi as "cultural complexes" (de la Torre and Mora, 2014; Harmand et al., 2015; Duke et al., 2021) – and is associated with hominins' acquisition of new impactful cognitive abilities, establishing a crucial evolutionary shift before and after its diffusion.

The recent findings of La Noira, Moulin Quignon and Notarchirico show an abrupt and homogeneous emergence of bifacial tools during the interglacial 17 (700 ka) – following a gap of approximately 200 ka from the last evidence of human occupation in Europe – and supporting the hypothesis of the arrival of new human groups over the European continent during this time frame (Moncel et al., 2020a; 2020e; 2021b). The reasons behind this gap, aside from the loss of evidence due to possible erosive and taphonomic processes, seemingly lie within the glacial intervals 22, 20 and 18, which were particularly harsh and could have acted as an environmental barrier for human groups (Head and Gibbard, 2005; Muttoni et al., 2010; Blain et al., 2021; Margari et al., 2023). On the other hand, the bifaces recently discovered at La Boella (1.0–0.9 Ma) and the French site of Bois de Riquet (US4, 0.8 Ma) may question the chronological validity of this model – though many doubts were cast on the chronological and archaeological validity of US4 of Bois de Riquet (Bourguignon et al., 2016b; 2021; Lozano-Fernández et al., 2019). The most recent works considered them a local evolution rather than an external introduction, even though, given the proximity of La Boella to the Gibraltar corridor, an earlier arrival of human groups could not be entirely ruled out (Ashton and Davis, 2021; Moncel et al., 2022; Ollé et al., 2023).

The massive climatic instability characterising the transition between the Lower and the Middle Pleistocene is at the centre of this delicate matter. The dispersal events caused by the environmental crisis might have introduced new species and technologies over the European regions through multiple waves of migrations, producing an evolutionary turnover that was initially sporadic (La Boella, Bois de Riquet) and then gradually more frequent (abrupt spread of bifacial tools in France and Italy around 650-700 ka). On the other hand, the prolonged glacial periods established by the change of periodicity might have caused isolation and local evolution (both genetic and technological) of human groups retreated to warmer spots (*i.e., the* Mediterranean basin), thus inducing the development of behavioural adaptation (cultural and evolutional convergence). In any case, from this chronological phase onward, a progressive increase of Acheulean industries over Europe can be witnessed (600 – 400 ka) along with sites bearing the absence of such tools (core-and-flake assemblages), portraying a significantly diversified archaeological scenario.

Following this line of thought, this recent increase of data observed all over Europe allowed scholars to keep fuelling the debate regarding the timing of the appearance of biface production and the Acheulean (Moncel et al., 2018d). The classic Acheulean paradigm features bifacial tools as discriminating proxies of its presence (or absence). The European archaeological context of the Early Middle Pleistocene comprises sites with bifaces and sites without bifaces, producing a dichotomy between Acheulean sites and non-Acheulean sites (often described as Mode 1 industries; Aureli et al., 2016; Ashton and Davis, 2021; Burdukiewicz, 2021; Moncel et al., 2021a; Muttillo et al., 2021b; Ollé et al., 2023). Aside from more common issues, such as the quality and morphology of the available raw materials that could prevent the realisation of handaxes, recent works highlighted that there is much more than *"the traditional concept of the biface"* to what we define as Acheulean and, more in general, to what is perceived as a sign of complexity and culture (Carbonell et al., 2010a; Stout, 2011; Vaesen and Houkes, 2017; Davis and Ashton, 2019; Key, 2023). Questions regarding what the Acheulean world should include and mean have also been raised, as pointed out in a recent work: *"The term "Acheulean", rather than one uniform cultural tradition, is more appropriate for describing the puzzle of assemblages and strategies recorded in western Europe"* (Moncel and Ashton, 2018). The ability to realise dimensionally large implements, the presence of structured centripetal or discoidal cores — implying debitage conducted regardless of the original shape with the possibility of subordinating the morphological criteria to the production goals — the degree of retouch on flakes, and the flexibility itself in the concept of façonnage and debitage are among the addressed matters for the contextualisation of the "European Acheulean" (Rocca et al., 2016; Gallotti and Mussi, 2018; Mussi et al., 2021; Moncel et al., 2022; Rineau et al., 2022; Carpentieri et al., 2023b). This process is generating a gradual shift from "the presence of bifaces as exclusive markers of the Acheulean" paradigm to a package of diversified behavioural innovations falling under the umbrella of the Acheulean culture, further supported by the recent re-contextualisation of important Lower Palaeolithic sites showing the absence of bifaces, such as Isernia La Pineta, Pakefield, Gran Dolina TD6, Ficoncella, and Korolevo (Koulakovska et al., 2010; Parfitt et al., 2010; Gallotti and Peretto, 2015; Aureli et al., 2016; Lombao et al., 2022a; Carpentieri et al., 2023a).

Despite this recent growth of discoveries, the sporadicity of the archaeological evidence (both chronologically and geographically) still prevents the scientific community from getting a homogeneous framework, and several hypotheses have been suggested to explain the arrival of the Acheulean in the European region. Within the present state of the art, a dual case scenario is usually assumed concerning either a local origin suggesting evolution from previous occupations (Mode 1, core-and-flake traditions) or an allochthonous introduction (whether episodical or continuous) of new populations alongside the diffusion of new technical traditions (Leroyer and Cliquet, 2010; Haidle and Braeuer, 2011; Mosquera et al., 2016; Moncel and Ashton, 2018; Moncel et al., 2018d; 2020a; Ashton and Davis, 2021; Ollé et al., 2023). With these hypotheses being equally valid and currently debated, it is generally accepted that a cognitive shift occurred during this period, but what are the most valuable and available tools for us to recognise it? The chance of identifying, in terms of material culture, the presence of behavioural changes or being able to discern between what is a sign of complexity and what is not are all challenging topics that need to be scientifically addressed and investigated. On top of that, recent works highlighted how the concepts of behavioural innovation and cultural change could and should be explored in other areas, such as the analysis of the activities conducted on the different sites, the subsistence strategies pattern or the land-use management (Huguet et al., 2013; Orain et al., 2013; Smith, 2013; Lemorini et al., 2015; 2020; Mosquera et al., 2015; Schreve et al., 2015; Lugli et al., 2017; Lupien et al., 2020; Zohar et al., 2022). These proved to be all valuable proxies to the archaeological investigation, and their integrated approach enabled a higher resolution and a more accurate reconstruction of the Lower Palaeolithic contexts in many cases.

From this perspective, the Italian peninsula is a crucial spot for tracking down human dispersal across the European continent, and the behavioural responses eventually adopted, witnessing a solid increase in the archaeological evidence from the Early Middle Pleistocene (Peretto et al., 1998; 2016; Lefèvre et al., 2010; Abruzzese et al., 2016; Arzarello et al., 2016a; Aureli et al., 2016; Moncel et al., 2020e; 2020c; Muttillo et al., 2021a). It shows a consistent range of contexts spanning from the end of marine isotope stage 17 onwards, offering one of the earliest traces of the Acheulean cultural complex (approximately 680 ka, in the level G of Notarchirico) providing at the same time, contexts without bifaces (Isernia La Pineta, Ficoncella, Loreto and Atella) and eventually including the transition to the Middle Palaeolithic with one of the earliest evidence of Levallois technology at the site of Guado San Nicola (380 ka).

As previously mentioned, the climatic and environmental data available for the Italian peninsula during this chronological time frame depicts it as a “shelter” zone during the severe climatic crises of the Middle Pleistocene, making it an ideal territory for human occupation during glacial phases and for prolonged periods (as witnessed by the stratigraphic sequence of Notarchirico; Messager et al., 2011; Combourieu-Nebout et al., 2015; Moncel et al., 2018c; 2020e; Zanazzi et al., 2022). Moreover, its role as the possible starting area for the recolonisation of the northern portions of Europe, together with its proximity to Sub-Saharan Africa, makes up for the Italian peninsula’s crucial role within the European peopling during the Middle Pleistocene Revolution (Moncel et al. 2020d). So far, the archaeological record features various technical responses in the lithic assemblages analysed. This includes the realisation of large-sized implements (LCTs, different types of handaxes, pebble tools etc.), a miniaturisation of the debitage products with a high rate of retouched flakes and elaborated and flexible core technologies realised through multiple types of debitage exploiting different qualities (different types of chert, limestone) and morphologies of raw materials (slabs, pebbles, nodules). The additional presence of human remains from the sites of Notarchirico (Belli et al. 1991; Pereira et al. 2015) and Isernia La Pineta (Peretto et al. 2015), respectively attributed to *Homo heidelbergensis* and *Homo cf. heidelbergensis* contributed to enriching our vision of this region as a hot spot to explore the diffusion’s pattern of new human groups over Europe, not to mention the implications concerning the modalities of the arrival/ development of the Acheulean cultural complex in this continent. Thus, tracking innovations and persistent strategies among these contexts through analysing their lithic assemblages is a valuable way to comprehend the hominin behaviour better and gain more insights into the Lower Palaeolithic. So, what can we infer from the sites of Notarchirico and Isernia La Pineta through the technological analysis of their lithic assemblages performed in this work?

The new investigations conducted at the site of Notarchirico pushed back the emergence of the bifaces within the Italian Peninsula to 680 ka (layer G), aligning with the recent discoveries of the French sites of La Noira and Moulin Quignon and attesting to a homogeneous arrival of the Acheulean techno-complex in Europe during the interglacial 17 (Moncel et al., 2016a; 2020e; Pereira et al., 2018; Antoine et al., 2019). The site features a prolonged human occupation during stages 17 and 16 of the Middle Pleistocene, being a unicum in the European Lower Palaeolithic and acting as an ecological niche for faunal and human groups. Hominins of Notarchirico – who seemingly lived nearby – took advantage for a long time of the paleo-channels to exploit the presence of water, animal carcasses – although no clear evidence of butchering activities emerged from the archaeozoological analyses – woods, plants, and lithic raw materials (limestone and various types of chert). The archaeological data suggest recurrent and stable occupation of the hominins across all the layers of the site, whose activities are diversified, including cutting meat, wood and plant processing, and bone-working, hinting at a "domestic" configuration of Notarchirico – as also proposed for La Noira – with seemingly high mobility over large areas (Hardy et al., 2018; Moncel et al., 2023). Evidence of recycling lithic materials is observed, further hinting at recurrent hominin presence on the site. The recent multidisciplinary approach to the material (Moncel et al., 2023) did not reveal any spatial organisation of the occupations or differentiate occupation events. It is also true that due to the limited excavated area and the distribution of the material, the *in situ* mobility of the pieces, or the presence of workshops/areas dedicated to specific activities – as documented at La Noira, excavated over 100 m² - cannot be still adequately addressed and considered. The taphonomic analyses revealed that Notarchirico is a palimpsest characterised by several post-depositional processes erasing the feature of each hominin occupation, resulting in a stratified accumulation of anthropic and faunal material. The authors state, *"Each archaeological layer might be one phase of multiple hominin halts at the site, which thwarts our understanding of habitat organisation"* (Moncel et al., 2023, p. 33). From this perspective, the density of the material is more similar to other palimpsests, such as Isernia La Pineta (Peretto, 1994; 1999; Channarayapatna et al., 2018; Pineda et al., 2020), than to sites with snapshots or single occupational events (e.g., La Boella; Ficoncella; Mosquera et al., 2015; Aureli et al., 2016). However, as proposed in the Discussion section, Isernia La Pineta exhibit a significantly higher quantity of lithic and faunal material, perhaps indicating that the intensity within the frequentation and function of the two sites differed. The technological, archeozoological, taphonomical, and use-wear analyses from Isernia depict it as a butchery-oriented site (Longo, 1994; Thun Hohenstein et al., 2009; Pineda et al., 2020; Carpentieri et al., 2023a), while Notarchirico seemingly served as a multi-functional area less heavily occupied (Moncel et al., 2020e; 2023).

The analysis of the lithic assemblage shows the exploitation of locally collected chert and limestone to realise various large-sized tools (bifaces, cutting tools, pebble tools, etc.) and small flakes and tools (scrapers, denticulates, notches, and pointed implements). Hominins also selected small-sized chert nodules directly to be retouched, functioning as an alternative to retouched flakes. The technological behaviour proved to be homogeneous from the bottom to the top of the newly investigated sequence (layers I2, I1, H, G, and F), focusing on debitage production and pebble tools. Despite the lack of structured reduction sequences, which, on the other hand, were an emblematic and innovative trait of other penecontemporaneous sites such as La Noira, Moulin Quignon, Atapuerca TD6 and Isernia La Pineta (Gallotti and Peretto, 2015; Mosquera et al., 2018; Moncel et al., 2021a; 2022), the technical behaviours adopted by the hominins of Notarchirico for the debitage productions revealed equally complex and peculiar characteristics, including massive attention to the confection of retouched tools (flakes and nodules) and the possible presence of core/tool objects, confirming an exceptional economy of the local raw materials. At the same time, bifaces are attested only from layers G and F, representing the most innovative technological elements from the bottom to the top of the sequence (Piperno, 1999; Moncel et al., 2020e; Rineau et al., 2022). This raises questions about whether the introduction of this particular technology is due to an abrupt arrival of new populations – and behaviours – or to a local evolution as an adaptive response to environmental pressures. We could exclude the lack of adequate raw material since large nodules and pebbles are recurrent within the entire sequence of Notarchirico. It should also be considered that a change in the site function might have occurred, leading to the integration of bifaces within the toolkit of the hominins of Notarchirico, adding to an already diversified lithic corpus comprising debitage production and heavy-duty components. In this case, we can propose a dual-case scenario. If we support the hypothesis of the allochthonous introduction of innovative behaviours, then either the supposed arrival of new human groups already occurred at the bottom of the sequence (layer I2), leading to the realisation of bifaces only at a later time due to functional/logistic reasons, or, an actual abrupt arrival of human groups happened during the formation of layer G. Nonetheless, if we accept an abrupt introduction from layer G, why would the bifaces be the only "innovative" aspects while all the rest of the lithic productions, on chert and limestone, remain identical? Additionally, the core and flake technology from the sequence excavated by M. Piperno (layers F to α) is the same as the one examined in this work, meaning that it remained unchanged for at least 80 ka (Moncel et al., 2019; 2020e; Santagata et al., 2020). To conclude, Notarchirico is characterised by a substantial homogeneity of the techno-economic behaviours, which, allegedly, only the presence of bifaces seems to break, acting as an element of innovation and connoting the site between cultural innovation and continuity.

The site of Isernia La Pineta is an open-air palimpsest witnessing repeated human occupation over a "restricted" period (approximately 580 ka) compared to Notarchirico. An open arboreal steppe with scattered woody areas alongside ephemeral watercourses and ponds characterise the site, seemingly attracting large herbivore herds and, subsequently, human groups, further attracted by the additional presence of lithic resources (Peretto et al., 2015; Zanazzi et al., 2022). The archaeological data indicates that the hominins' exploitation of animal carcasses – whether hunted or scavenged is still a debated topic – was the most recurrent activity conducted at the site of Isernia. The use-wear and archaeozoological analyses highlighted the predominance of butchering activities, including all carcass processing phases, from meat to marrow extraction (Longo, 1994; Peretto, 1996; Peretto et al., 2004b; Thun Hohenstein et al., 2009; Pineda et al., 2020; Carpentieri et al., 2023a). The chert lithic assemblage perfectly reflects the performed activities, being characterised by the massive production of small-sized flakes – which many experimental works demonstrated to be highly efficient for butchering and cutting-oriented tasks – and small-sized tools in a minor portion (Crovetto et al., 1994; Yravedra et al., 2010; Boschian and Saccà, 2015; Mosquera et al., 2015; Venditti et al., 2019; Berruti et al., 2020b). The lower ratio of retouched tools compared to Notarchirico was also highlighted as one of the possible markers for the predominant role of meat processing activities. In this sense, the lithic corpus shares several similarities with other butchering sites of the Lower Palaeolithic, such as Ficoncella, Boxgrove and La Boella (Mitchell J. C., 1998; Smith, 2013; Mosquera et al., 2015; Aureli et al., 2016). From a technological perspective, the lithic industry of Isernia La Pineta has been initially described as unstructured and chaotic (Crovetto et al., 1994; Peretto, 1994), while recent works (Gallotti and Peretto, 2015; Carpentieri et al., 2023a) pointed out the presence of complex mental templates within the reduction sequences, including discoid and centripetal debitage but also significant employment of flakes as cores. This process allowed a global re-evaluation of the site of Isernia within the Middle Pleistocene Revolution, allowing some scholars to infer its possible relation with the Acheulean complex – which, as previously mentioned, features different innovative aspects besides the “mere” presence of handaxes – following the general increase in complexity witnessed during this chronological phase by other sites. Direct percussion and bipolar on-anvil techniques were equally employed, accounting for a codified choice from the hominins to overcome the local slabs’ morphology and quality, reflecting a well-known behaviour observed in other Lower Palaeolithic contexts, such as Pont de Lavaud, Vallparadìs, and Caune de l’Arago where bipolar on anvil held a predominant role (Barsky and de Lumley, 2010; Barsky, 2013; Garcia et al., 2013b; de Lombera-Hermida et al., 2016; Sánchez-Yustos et al., 2017; Despriée et al., 2018; Horta et al., 2022).

From this perspective, the experimentation conducted on the bipolar on anvil technique revealed that the accurate identification of these techniques within the lithic assemblage of Isernia La Pineta could be extremely challenging, as the range of overlapping between the traces left by direct and bipolar percussion is significant. Additionally, several similarities have been detected among the obtained products, further increasing the efficiency of these two debitage strategies for obtaining small-sized flakes. Within the present state of the art, several experimental and archaeological works re-evaluated the role of the bipolar on anvil within Lower Palaeolithic lithic assemblages – also from a complexity-wise perspective – which is nowadays considered one of the possible efficient reduction strategies employed by the hominins (Knight, 1991; de la Peña, 2015; Duke and Pargeter, 2015; Shott and Tostevin, 2015; Pargeter et al., 2019a; Gallotti et al., 2020; Horta et al., 2022). On the other hand, the possibility of distinguishing adequately the impact of the bipolar technique remains uncertain and highly connected to the morphology, quality, and lithology of the raw materials exploited (Bietti et al., 2010; Bradbury, 2010; Alonso, 2011; Vergès and Ollé, 2011; Eren et al., 2011a; 2013; De La Peña Alonso and Vega Toscano, 2013; Peña, 2015; Gurtov et al., 2015; Buchanan et al., 2016; Pargeter and Eren, 2017; Pargeter et al., 2019a; Delpiano et al., 2019).

Going back to Isernia La Pineta, all the knapping phases were recorded in the analysed layers, confirming that the hominids seemingly selected, used and abandoned the lithic artefacts in the same area. The presence of limestone artefacts was relatively inferior compared to the chert production and was primarily oriented to the production of percussion/battering tools and, in minor portions, medium and large-sized flakes. The absence, so far, of bifacial tools and LCTs raises significant questions about cultural or functional reasons. Other sites characterised by an almost exclusive butchery of herbivores provide ambivalence evidence. For instance, the Spanish site of La Boella exhibits an elephant carcass with many small-sized implements but also features two LCTs (Mosquera et al., 2015; Ollé et al., 2023). On the other hand, the Italian site of Ficoncella, where another elephant carcass associated with many small-sized lithic tools was discovered, does not feature any handaxe or LCTs (Aureli et al., 2016). Suppose we enlarge our sample, including La Noira and Notarchirico sites, which feature a “domestic” configuration (i.e., several activities are practised besides butchering). In that case, we see that, mainly for La Noira, bifacial tools were also employed for meat processing, while for Notarchirico, data are still preliminary (Hardy et al., 2018;

Moncel et al., 2023). It is plausible that, as hypothesised by many scholars, since bifaces were multi-functional tools (often compared to swiss-army knives) and since Isernia La Pineta is, seemingly, a single-functional area, the need for their realisation according to the hominins' purposes was lacking, rather than due to a behavioural inability (Solodenko et al., 2015; Viallet, 2016; Daura et al., 2018; García-Medrano et al., 2019; 2020; Zupancich et al., 2021). Eventually, the site of Isernia La Pineta, similarly to Notarchirico, represents a multifaceted context, offering a glimpse into the activities performed by the hominins during the Early Middle Pleistocene.

In the end, this work provided additional evidence to our knowledge of the European peopling during the initial phases of the Middle Pleistocene Revolution. Notarchirico and Isernia La Pineta emerge as essential steps for tracking the behavioural evolution of the Middle Pleistocene hominins after the severe climatic crises triggered at the end of the Lower Pleistocene. Their rich and variegated archaeological corpus offers critical insights into diversified aspects of life during the Lower Palaeolithic, allowing us to explore different responses regarding the arrival of the Acheulean techno-complex, the degree to which the activities performed in a context affect the lithic assemblage, land-use and resource management within open-air sites, and the relationship between the environment, the faunal communities and the human groups. The suitable climatic conditions affecting the Italian peninsula during interglacial and glacial stages make it an additional hot spot for Lower Palaeolithic archaeology, granting prolonged human occupation and offering diachronic and synchronic perspectives within human peopling and migration patterns. Future work will be needed to obtain a more homogeneous picture of the two sites. At Notarchirico, the material excavated by Piperno is the object of an ongoing multidisciplinary study to integrate the data from the new sequence, resulting in the reconstruction of almost 100 kya of continuous human occupation. At Isernia La Pineta, enlarging the sample analysed in this work and integrating it with the use-wear analyses would offer additional data over a larger area, allowing for a greater resolution within the activities of a butchering site. To conclude, technological analysis is still an efficient tool for comprehending the variety of human material culture and the evolution of hominins' behavioural complexity.

Chapter 7 References

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