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Assessing the Impact Fracture Method: Experimental Approach to the Functional Analysis of the Pointed Tools from the Mousterian Layers of Riparo Tagliente Rock Shelter

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Dottorando
Dott. Nikola Gavrilović

(firma)

Tutore
Prof. Dr. Marta Arzarello

(firma)

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Abstract

The aim of this research was to obtain an insight into the complex system of variables of impact fracture propagation without ignoring the non-impact damage. Using experimental approach, crucial data was collected that was necessary for the reliable interpretation of the damage that was further used for the interpretation of the damage identified on the pointed tools from Riparo Tagliente, and bringing up conclusions of their possible functionality.

By adapting the experimental variables as close as possible to the variables of the archaeological material from Riparo Tagliente, four experiments have been executed. The first experiment was a hunting simulation using Mousterian points that were hafted into the foreshaft using two hafting approaches, vertical and diagonal, and were propelled into the dead animal target. Obtained results enhanced the reliability of the interpretation of the damage and establishing its causation on the archaeological material.

Knapping damage was identified on the experimental points used in the first experiment, therefore the second experiment was established and executed in order to observe the variations and causations of the fractures that could be caused by knapping.

The third experiment was also a hunting simulation that was executed to obtain an insight of the impact fractures propagation using Levallois points with slightly different hafting approach than the one that was used in the first experiment. The reliability of the results obtained by the third experiment was questioned because of the modern equipment usage and the scarce number of the experimental samples.

Non-impact damage that was identified on the pointed tools from Riparo Tagliente was not ignored and the fourth experiment was executed for this purpose. The aim of the fourth experiment was getting an insight into the edge damage patterns that could be formed on the pointed tools by using them in cutting, scrapping and chopping activities. The results improved the interpretation of the edge damage patters identified on the pointed tools from the site of Riparo Tagliente.

Using all of the experimentally obtained data the possible functionality of the pointed tools from Riparo Tagliente was established. It is concluded that the pointed tools from Riparo Tagliente were used as multiple functionality tools. Furthermore this research proposed that it is necessary to improve the methodology of the impact fracture research in order to avoid the further confusion of the damage interpretation.

Riassunto

L’obiettivo di questa ricerca era ottenere un approfondimento all’interno del complesso sistema di variabili dell’impatto della propagazione delle fratture senza ignorare il danno da non impatto. Usando l’approccio sperimentale, sono stati raccolti i dati fondamentali che erano necessari per un’affidabile interpretazione del danno che sono stati ulteriormente usati per l’interpretazione del danno identificato sugli strumenti appuntiti proveniente da Riparo Tagliente, arrivando a conclusioni sulla loro possibile funzionalità.

Adattando le variabili sperimentali il più vicino possibile alle variabili del materiale archeologico proveniente da Riparo Tagliente, sono stati effettuati quattro esperimenti.

Il primo esperimento è consistito in una simulazione di caccia usando le punte Musteriane che erano fissate alla lancia, usando due approcci di fissaggio, verticale e diagonale, e che venivano lanciate mirando all’animale morto. I risultati ottenuti hanno evidenziato l’affidabilità dell’interpretazione del danno ed hanno stabilito la sua causa nel materiale archeologico.

Il danno da scheggiatura è stato identificato sulle punte usate nel primo esperimento, nel frattempo il secondo esperimento è stato stabilito ed eseguito in modo da osservare le variazioni e le cause delle fratture che potevano essere causate dalla scheggiatura.

Il terzo esperimento è consistito anche in una simulazione di caccia che è stata effettuata per approfondire l’impatto della propagazione delle fratture usando le punte di Levallois con un metodo di ancoraggio leggermente differente rispetto a quello usato nel primo esperimento.

L’affidabilità dei risultati ottenuti dal terzo esperimento è stata messa in discussione a causa della strumentazione moderna impiegata e della scarsa quantità di provini sperimentali.

Il danno da non impatto che è stato identificato sugli strumenti a punta provenienti da Riparo Tagliente non è stato ignorato e il quarto esperimento non è stato ignorato per questo motivo.

L’obiettivo del quarto esperimento è consistito nell’ottenere un’osservazione sui segni causati dai danni ai bordi che si sarebbero potuti formare sugli strumenti a punta usandoli nel taglio, nella frantumazione, nella tritura. I risultati hanno implementato l’interpretazione dei segni causati dai danni ai bordi identificati sugli strumenti a punta provenienti dal sito di Riparo Tagliente.

Usando tutti i dati ottenuti sperimentalmente è stata confermata la possibile funzionalità degli strumenti a punta provenienti dal sito di Riparo Tagliente. Si conclude che gli strumenti provenienti da Riparo Tagliente venissero utilizzati come strumenti multifunzionali. Inoltre

questa ricerca ha suggerito che fosse necessario migliorare la metodologia della ricerca sull’impatto delle fratture in modo da evitare ulteriore confusione sull’interpretazione del danno.

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Introduction

The unique Middle and upper Paleolithic rock shelter site of Riparo Tagliente has provided a lot of important information regarding the techno-economic, and the Neanderthal and early modern human behavior (Arzarello and Peretto, 2001; Arzarello and Peretto, 2005; Hohenstein, 2006; Fontana et al., 2009; Villa et al., 2009; Fontana et al., 2012; Hohenstein et al., 2018). The focus of this research are the pointed tool from the Middle Paleolithic from the site of Riparo Tagliente, i.e. from layer 52 to layer 25. The macrofractures identified on pointed tools from Riparo Tagliente site indicated their possible usage as a spear heads used as hunting weapons. In order to test that hypothesis, the experimental approach was mandatory (Soriano, 1998; Crombé et al., 2001; Pargeter, 2007; Yaroshevich 2010; Brindley and Clarkson, 2015). It is proposed that impact fracture analysis can be a reliable indicator of a certain stone tools usage as a weapon, but we can obtain a reliable interpretations only when we apply more than just microfracture analysis (Lombard 2005; Monnier et al., 2013, Rots 2016). Equifinality of impact fracture propagation presents an obstacle for our understanding and interpreting their causations (Schoville and Brown, 2010; Pargeter, 2013; Coppe and Rots, 2017). Using experimental data, this research will make an attempt to interpret the pointed stone tools functions as reliable as possible, i.e. to try to answer the question of what was the cause of the impact fractures. In order to avoid misinterpretation, four experiments have been executed. The first one, a hunting simulation using Mousterian points, in order to obtain information of which fracture types could be a result of "hunting" by using hand thrown and trusting spear hunting method. As it is known, impact fractures could occur in the initial phase of the certain stone tools manufacture (Pargeter 2011; 2013), the knapping of the stone tool. The second experiment had an aim to provide an insight into impact fracture propagation during the stone tools knapping in order to avoid their misinterpretation. Third experiment was another hunting-simulation, but using the Levallois points as hand-thrown spears. The final experiment was executed in order to get information about the other damage that was identified on the pointed tools from the site of Riparo Tagliente, such as striations and various types of edge damage. By using all of the experimental data combined, the functionality of the pointed tools from the Middle Paleolithic layers of the Riparo Tagliente rockshelter will be interpreted.

In the following chapters and subchapters, the history of impact fractures research will be presented, and the research history of the applying of impact fracture research in order to accomplish the reliable interpretations of the functionality of the certain pointed stone tools. Furthermore, the methodological approach of each experiment, the results and the conclusions after experimental data analysis will be presented. The presence of the impact and impact-like fractures on the whole lithic assemblage from the layers of 52-25b of the Riparo Tagliente site and the interpretation of the functionality of pointed tools using the experimentally obtained data together with the data of another research, will be presented. Finishing chapters, i.e. conclusion and suggestions for the future research will discuss the importance of the impact fracture analysis, other use-wear analysis and the reliability of the established interpretations.

1. Distinguishing the stone tools functionality – research history

Many researchers have tried, for a long time to establish a reliable method for identifying which stone tools were used as a weapon, or even if we could correlate certain stone tools to specific weapon technologies. Various methodological approaches were used in attempt to answer this complex question: use wear analysis (Wilkins et al., 2012; Knutsson et al. 2015; Fernandez-Marchena & Oll, 2016; Jayez and Nasab, 2016; Ollé and Vergès 2014; Stemp et al., 2016), residue analysis (Kooyman et al. 1992; Lombard, 2008; Monnier et al., 2013), ethnographical research (Churchill 1993; Churchill and Rhodes, 2009), various experimental researches (Moss and Newcomer, 1982; Barton and Bergman, 1982; Huckell, 1982; Bergman and Newcomer, 1983; Fischer et al., 1984; Odell and Cowan, 1986; Frison, 1989; Geneste and Plisson, 1990; Caspar and De Bie, 1996; Plisson and Beyries, 1998; Soriano, 1998; Crombe et al., 2001; Shea et al. 2001; O'Farell, 2004; Lombard et al., 2004; Pargeter, 2007; Sisk and Shea, 2009; Sano 2009; Yaroshevich, 2010; Schoville and Brown, 2010; Hutchings, 2011; Pargeter, 2011; Petillon et al. 2011; Lazuen et al., 2012; Wilkins et al., 2012; Pargeter, 2013; Roots 2013; Iovita et al., 2014; Iovita et al., 2016; Sano et al., 2016; Hutchings, 2016; Pargeter, 2016), morphometric analysis (Shea, 2006; Chacón, M. Gema, et al. 2016), morphological approach (Sisk and Shea, 2009; Shea and Sisk, 2010; Yaroshevich, 2010; 2013), functional analysis (Rots, 2009; Roots, 2011 Forssman, 2015; Wilkins, 2014) typological analysis and combination of two or more analyses (Rots, 2003; 2010; 2013; Rots and Williamson, 2004; Rots and Peer, 2006; Rots and Plisson, 2014, Goval et al., 2016). Multiple authors agree that, using just a single method or even the combination of multiple methods, we are incapable of reliably identifying certain hunting technologies (Iovita et al. 2014; Hutchings, 2016; Iovita et. al, 2016; Sano 2009; Sano et al. 2016). This research alongside many others will, using original data together with previously published, attempt to enhance our chances in solving this very complex puzzle. It will be attempted to establish a correlation between factors that influence impact fractures propagation and to gain insight into the reliability of the experimental approach.

From the early days of impact fracture research, it was concluded that fractures themselves are characteristic of nothing else than of a specific load and direction of pressure, damages that could occur as a result of any other cause instead of stone tools usage as a projectile (Committee, 1979; Fishcer et al., 1984; Coppe and Rots, 2017).

In the beginning, only two types of fractures, flute-like and burin-like fractures were considered diagnostic of impact (Withoft, 1968; Bergman and Barton, 1982; Moss and Newcomer, 1982; Bergman and Newcomer, 1983). After the experiments of Fischer and colleagues (Fischer et al., 1984), three new DIF categories were introduced: spin-offs, bifacial spin-offs and step terminating bending fractures. Hinge termination was introduced after the research of Odell and Cowan (Odell and Cowan, 1986). Feather termination was added to a DIF category after the paper of Caspar and De Bie (Caspar and De Bie, 1996). After those seven categories of damage were established, some of them were used in the future research as damage description. The description of damage varied in each research. The work of Lazuén and colleagues introduced the crushing fracture (Lazuén et al., 2012), but the crushing fracture still lacks a well-established description (Coppe and Rots, 2017).

1.1. Use-wear analyses

After Semenov's (1964) book was translated, the use-wear analysis started being gradually developed and it is still being developed even today. It is a well-established technique, and it provides us with a better understanding of the actual stone tools usage in the past. It is possible to differentiate the stages in the cycle of usage of each sample of excavated stone tool, the production, usage, hafting, retouching and de-hafting or re-hafting (Rots and Williamson, 2004). For each assemblage certain fractures/use-wear traces can vary based on the history of sites excavations. Each stone tool assemblage from a certain site carries variables of its own, and it is mandatory to experimentally analyze each assemblage separately (Olle and Vergés, 2014).

Use-wear analysis was executed on the 34 stone tools from the rockshelter of Oscurusciuto situated in southern Italy (Marciani et al., 2018). The traces were studied using microscopy at both low power and high power ranges. Interpretations of the macro use-wear, such as edge removals and edge rounding was carried out using low magnification. Using high magnification, micro edge-rounding, striations and polishes were interpreted. By using a combination of techno-functional and use-wear analysis it was concluded (Marciani et al., 2018) that each production-aim consisted of the several techno types that were used for different purposes. These analyses have also proven that the production aims could be correlated to a functional aim or that the large number of archaeological samples show the use-wear. Also, using the techno-functional and use-wear analyses is was proven that the tools with a specific structures were intended to be used to solve a specific task (Marciani et al., 2018).

The use-wear analyses were carried out (Lee and Sano, 2019) in order to test the hypothesis whether, the tanged points excavated from the site of Jingeuneul in Jinan-gun in Korea were used as spearheads or arrowheads. Their analyses provided the data showed that a considerable number of tanged points possess diagnostic impact fractures (DIFs). They have considered (Lee and Sano, 2019) that crushing, unifacial spin-offs larger than 6mm, bifacial spin-offs, feather-terminations, step-terminations, hinge terminations and burin-like fractures to be diagnostic of impact. It was hypothesized that TCSA and TCSP values of the tanged points possess the capability to identify delivery modes by distinguishing dart tips from arrowheads. The obtained results brought up a conclusion that the tanged points were used as mechanically delivered armatures, i.e. spear thrower darts or bows-and-arrows (Lee and Sano, 2019).

A unique combination of analysis was carried out (Caricola et al., 2018) in order to gain an insight into Early Upper Paleolithic flint knapping gestures and techniques, involving the usage of the macro-lithic tools. This research used a combination of use-wear, 3D and spatial analyses. Using experimental approach, the hammerstone traces were directly correlated to the ones excavated from the site of Fumane, i.e. by using both low and high power microscopy, the use-related wear that was identified on the hammer stones and retouchers were interpreted and compared by those excavated from the Fumane Cave. The conclusion implies the importance of the combination of qualitative, i.e. use-wear analysis and quantitative, i.e. GIS analysis, which could be applied to a various classifications of stone tools (Caricola et al., 2018).

1.2. Morphometric research

In pursuance of functional stone tool point as a hunting weapon, i.e. successful penetration of the preys hide, the value of the tip sectional area must be as low as possible (Hughes, 1998). The logic behind this argument is that a sharp point is concentrating the force in a small area and therefore reducing the energy needed to break a hole in the target. TCSP (Tip Cross Sectional Area) is calculated by using the following formula $4\sqrt{s}$; where s = (0.5 x maximum width)^2 + (0.5 x maximum thickness)^2 (Hughes 1998; Sisk and Shea, 2009).

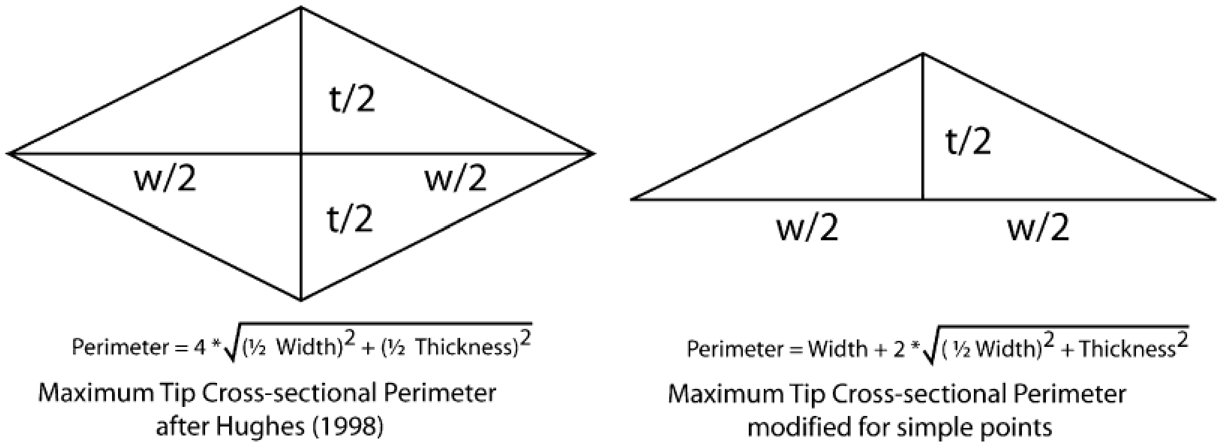


Fig. 1 – The two estimates of tip cross-sectional perimeter – Source: Sisk, Matthew L., and John J. Shea. "Experimental use and quantitative performance analysis of triangular flakes (Levallois points) used as arrowheads." *Journal of Archaeological Science* 36.9 (2009): 2044.

The experimental results carried out by Sisk and Shea (2009) have implied that the successful penetration of the prey is more tightly correlated to the point width and the cross sectional perimeter than to the point thickness or tip cross sectional area. It is also argued that the experimental results always suggest the possible not the probable outcomes.

One of the most significant analysis for distinguishing the stone tools function is the morphometric analysis carried out by Shea (2006). He has suggested that TCSA (Tip Cross Sectional Area) is a ballistically significant attribute that shows good results in distinguishing the spear thrower dart tips and arrowheads from spear points. TCSA is calculated by using the following formula – 0.5 x maximum width x maximum thickness. The mean TCSA values for spear heads is 168 mm^2 ± 89 mm^2, for arrowheads it is suggested to be 33 mm^2 ± 20 mm^2 and for dart tips 56 mm^2 ± 18mm^2. In his research Shea (2006) implied that those measurements do not prove that an individual pointed stone tool was used as a spearhead. Otherwise, if it is combined with other analysis such as residue analysis or use-wear analysis, TCSA could represent a significant argument in the interpretation of the certain stone tool point's function.

1.3. Ethnographical and skeletal morphology research

Due to difficulties in interpreting the stone tools record of hunting using macrofractures analysis Churchill (1993) carried out an ethnographic research that included the sample of 96 modern day hunters in order to obtain the information about the relation of hunting weapons, prey size and terrestrial hunting techniques. The result of his research (Churchill, 1993), suggests that there is an association between the hand thrown spear hunting technology and large-bodied prey, and that hunting techniques are dependent on physiographic features and the specific terrain types. It was also concluded that there is a slight correlation between the terrain types and atlatl-propelled spears and that the bow and arrow hunting technique is not dependent on the prey size or terrain type. The effective weapon distance range of various hunting technologies is suggested; for thrusting spear, at contact, for hand-thrown spear, up to eight meters, for spear thrower and dart, up to 40 meters, and for bow and arrow up to 26 meters (Churchill, 1993). Hand-thrown spears in terrestrial hunting were reported to had been used relatively rarely. The significant difference that Churchill (1993) had discovered was between the thrusting and hand-thrown spears. It was noted that both Tiwi and Tasmanians were using very light and thin spears for the thrown-spear hunting technology.

Rhodes and Churchill (2009) tested the hypothesis that was a product of the recent studies in the field of sports medicine that indicated that individuals who are engaged more often into the spear throwing such as professional spear throwers, have increased humeral retroversion angles in their throwing arms and greater percentage of bilateral asymmetry in retroversion angles than the individuals not engaged into habitual throwing. After the skeletal analysis of Neanderthal, Mousterian Early Modern Humans, Middle Paleolithic Modern Humans, Late Upper Paleolithic Modern Humans and today's professional sportsmen, they have concluded Neanderthals exhibit increased retroversion angles, i.e. decreased humeral torsion or a more posteriorly oriented humeral head, relative to the most modern human samples. In spite of this fact, the similarity appears to be more likely connected to the body form and overall activity levels than to habitual throwing (Rhodes and Churchill, 2009). But, the Neanderthal humeri that are preserved well enough to be measured are rare; only two males and one female show low levels of bilateral asymmetry in humeral retroversion, which brought on a suggestion that they were not performing throwing motions regularly. Furthermore, they brought up a conclusion (Rhodes and Churchill, 2009) that the use of throwing based projectile weaponry started being habitual only with the onset of the Middle Upper Paleolithic times. Another skeletal morphology analysis was carried out (Churchill and Rhodes, 2009) considering aspects of skeletal remains other than humeral torsion angles. In this research they have focused on the morphology of the scapular glenoid fossa and the ulnar supinator crest, which might help us obtain an answer regarding the origins of the projectile weaponry. The result of their research (Churchill and Rhodes, 2009) suggests that Neanderthals and Modern Human Mousterian foragers were not using throwing motions in their everyday activities and suggested that long-range projectile weaponry was not used by Mousterian hunters.

1.4. Experimental approach to the functional analyses (with a focus on impact fractures)

The first experiment executed in order to get a better insight into the impact fracture propagation was executed by Barton and Bergman (1982). They wanted to test the hypothesis whether the microlith points from the Mesolithic site of Powell were used as a tips and barbs for arrows. They used the copy of the Mesolithic 40 lbs long bow, a total of 17 experimental samples of non-geometric microlith points made of English chalk flint that were propelled into fallow-deer from the distances of four and eight meters. Types of impact fractures they used for description were only burin- like and flute-like fractures. No definitive comparisons could be made between their experimental material and the material from the archaeological sites.

Moss and Newcomer (1982) executed experiment in order to obtain a better interpretation on the traces found on the backed bladelets and Azilian points that belonged to the Magdalenian of the Paris Basin. The raw material they used was a chalk flint and the number of experimental samples was 15 backed bladelets and 16 Azilian points. Binding material they used was pine resin and beeswax. Points were propelled using the 45 lbs self-bow at the approximate distance of 3 meters. Their description of fractures is partial and the microwear description is scarce. Not long after, Bergman and Newcomer (1983) executed another experimental research with a goal to understand the fractures on the upper paleolithic arrowheads from the site of Ksar Akil (Douka et at., 2013) in Lebanon. They used 48 lbs a copy of Mesolithic long bow with a total number of 26 experimental samples. Raw material that was used was English and French flint. Ksar Akil-like points were binded using pine resin and beeswax. This is the first experiment where the artificial target was used, it was a meat and bone plate target. For the fracture description they used, same as Moss and Newcomer (1982), only flute-like and burin-like fractures.

The Fischer's (1984) experiment was one of the most important for the further development of impact fractures propagation research. He used both spear and 50 lbs laminated recurve bow. No shooting distance was described for his experiments. For both hunting technologies he used the experimental samples that were the copy of the late Paleolithic, Mesolithic and Neolithic. For the bow and arrow hunting technology he used a total of 135 experimental pieces that were representing various points such as small transverse arrowheads and Brommian points. As binding material, birch bark tar and fish glue with flax thread. All of the experimental samples were made of flint. He used eleven experimental pieces for the spear hunting technology. The Brommian points were binded into a shaft using flax thread. Targets that were used in Fischer's experiment were various: whole freshly killed wild boar, joints of pork with shoulder blades, boar head, boned leg of a boar, side of pork ribs, seven freshly killed sheep and four pikes. Various other experiments using bow and arrow and spear hunting technology were executed, such as: shooting on trunks, shooting on bushes, wet grass, soil and dense reed. For the impact fracture description, he used spin-off, bifacial spin-off and step-terminating fractures. He concluded that macro-fracture and micro-fracture method could be used independently, but by using both macro-fracture and micro-fracture analysis, we can obtain much better results.

Odell and Cowan (1986), executed an experiment with an initial concern of distinguishing the impact fractures between the damage from the "missile impact" and ones that can be caused by certain methods of flake manufacture, such as bipolar flaking. They used both 45 lbs bow and hand-thrown spear hunting technology. Shooting distance for hand-thrown spears was 4 – 5 meters and for bow and arrow hunting technology was 10 – 12 meters. For both hunting technologies the experimental samples were bifacially retouched points or unmodified or minimally modified flakes made of chert. The number of experimental samples for each hunting technology was 40 pieces. Projectile target was stacked dogs in both cases. As binding material, they used natural hemp and mastic or synthetic glue. For fracture description they have used burin-like fracture, flute-like fracture, step-terminating and hinge fracture.

Another experimental research of Frisson (1989) was highly unethical. He tested the functionality of the Clovis tools and weaponry assemblages using spear-thrower technology on dead or dying elephants in Hwange National Park in Zimbabwe. It was concluded that the Clovis weaponry could be used to inflict crippling or lethal wounding on the members of African elephant families on a regular and predictable basis. The projectile points were propelled to a target from te distances of 15, 17 and 20 meters. The spears weight was 400-1000 grams and they were made of obsidian, quartz and chert. As a binding material, sinew and pine pitch was used. Frisson did not provide any description of impact fractures, besides the figure representing the transverse impact break on a quartzite projectile point.

In order of better understanding of Solutrean shouldered points, Geneste and Plisson (1990) executed an experiment using 45-55 lbs long bow and calibrated crossbow. Shooting distances for long bow was 18 meters, and 9 meters for calibrated crossbow. The arrows weight was 40 grams for long bow and 150g for calibrated crossbow. Type of flint used for the experimental sample was the same one that was used at the site of Combe Sauniere (Castel et al., 2006). As binding material, they used pine resin, beeswax and ocher with or without sinew binding. Goats were used as a shooting target. They also executed a butchering experiment alongside other tasks but the fracture types are poorly described.

Caspar and De Bie (1996) experimentally tested the late Paleolithic arch-backed pieces using the bow and arrow technology. Their experiment was designed with an aim to obtain an insight into the degree of fragmentation of projectile heads in relation to the hafting technique and the shaft material. Arch-backed points made of flint were binded using pine resin with or without animal sinew. The hafted points were propelled into the animal carcasses. There is no data about the experimental sample size. Using the experimental assemblage, they were able to spatially differentiate the repair, manufacture and discard of the projectiles in the camp layout. They have used six types of impact fractures for the description of their experimental assemblage: burin-like, spin-off, bifacial spin-off, step-terminating bending fracture, hinge-terminating bending fracture and feather terminating-bending fracture.

An important experiment, regarding Levantine Mousterian was executed by Plisson and Beyries (1998). The experiment has been carried out in order to test the modes of usage i.e. functionality of the Levantine Levallois points. They have used the thrusting spear hunting technology. Levallois points made of flint from El Kown basin in Syria was binded into the hafting shaft using bitumen and ochre. Twelve experimental Levallois points were used. The spear weight ranged from 480 up to 900 grams, and young chamois was used as a target. Also, they have executed a butchering experiment. It was concluded that the Levantine Levallois points were both used as hunting and butchering tools, i.e. both as daggers and hunting spears. They presented a figure depicting the tip snap with impact burination and examples of microscopic butchering traces. It was suggested that the Mousterian hunters have systematically avoiding the contact against the bones, and targeted only the less dense tissue parts. The more interesting conclusion the have brought up based on their experiment is that, the Levallois points were not primarily used as a projectile armatures and judging by the high technicality of the Schöningen's spears (Thieme, 1997; 2000) that are made entirely of wood it could be suggested that the Mousterian hunters mainly used wooden and not stone-tipped spears (Plisson and Beyries, 1998).

Soriano (1998) wanted to test the hypothesis were the Upper Perigordian microgravettes from the site of Rabier (Samsel et al., 2016) used as projectile points by using both technological and experimental approach. Perigordian microgravettes were propelled using 28 lbs and 45 lbs long bow into the wild boar and sheep carcasses without viscera from the distance of 13 meters. Number of experimental sample was 80 pieces. Microgravettes were made of flint and were binded using sinew and natural glue made of pine pitch, ash and beeswax. Soriano (1998) implied that without preserved faunal material it is impossible to research on the hunting behavior on Perigordians hunting behavior, but after the execution of the experiment it was clear that the Perigordian microgravettes had a projectile tip function. The description of the fractures Soriano (1998) did on his own. Fracture types he used for the description were: orthogonal flat, oblique flat, orthogonal short bending, oblique short bending, symmetrical long bending, asymmetric long bending, burin-like, transversal bending, irregular, bifacial bending and non-determinable. Considering long and short fractures as he described them, he implies to longer than 2 centimeters and shorter than 2 centimeters.

In order to test the hypothesis whether the microliths found at the Mesolithic site of Verrebroek (Beugnier et al., 2005) in Belgium were used as hunting weapon Crombé and colleagues (2001) have carried out a hunting replicative experiment. With a total of 183 various microlithic experimental samples made of fine-grained flint the experiment was executed. Using 60 lbs walnut self-bow the arrows were propelled from 20 meters into a sheep carcass. The microliths were binded using pine resin as a single binding material. After obtaining the experimental results, Crombé and colleagues (2001) concluded that the vast majority of microliths excavated at the site of Verrebroek were used as a single-function tool for hunting. Also, their study implicated the close relation between the stone tool morphology and their function, so they have brought up a conclusion that the geometrical microliths were used as barbs, while the backed points and points with retouched base were used solely as tips. The fracture types that they have used for the description of their experimental assemblage were: feather-termination, hinge-termination, snap and cone fracture.

A controlled experiment was carried out by Shea and colleagues (2001) in order to reveal a connection between Levallois point (from Levantine Mousterian points context) morphology and their performance as a spear heads. Levallois points were hafted vertically using sloth and notch hafting approach and were binded using synthetic paving tar alone or with vegetal fibers. The total number of 45 experimental Levallois points made of israelian flint were propelled into the adult goats' carcasses. Their results implied that the Levallois points are closely corelated to spear head usage, but it does not necessarily mean that all of the Levallois points were used as hunting spear heads. Furthermore, they are suggesting that the typically large and elongated Levallois points where in fact designed to be used as knives.

In order to distinguish the causes of the macro-fractures produced by knapping, trampling and usage as a projectile on the Gravettian points from the site of Corbiac, O'Farell (2004) executed an experiment. Using experimental approach, O'Farell wanted to obtain a more reliable conclusions of her morphological, technological and functional analysis. Gravettian backed points made of flint were propelled from the distance of 9 meters using calibrated crossbow into a target that represented a Cow carcass. The weight of the experimental projectiles was 200 grams, and the total experimental sample size was 51 pieces. The binding material that was used was pine resin, beeswax and ocher. Using the results that were obtained in the experimental approach, O'Farell (2004) concluded that, the Gravettian backed points from the site of Corbiac were used as a projectile points. The fracture description types she used for interpreting the material were: spin-offs, bifacial spin-offs, step-terminating-bending fracture, hinge-termination and feather-terminating bending fracture.

Lombard and colleagues (2004) executed an experiment using convergent flakes in order to acquire better understanding of the fractures identified on the archaeological samples from the Sibudu cave. Also, they wanted to compare the results obtained on European flint tools, and to test could the concept of the diagnostic impact fracture types (DIFs) be applied to the local raw material and African MSA points. Thrusting and throwing spear hunting technologies were applied using 35 experimental samples. Convergent flakes made of chert, hornfels, mudstones and quartzite that were bound using sinew, leather or plant fibers were delivered into a forequarter of a wildebeest. Thrusting spears were projected into the target at contact while the hand-thrown spears were projected into a parts of wildebeest from 3-4 meters. Impact fracture types they have used for the description of their experimental material were: burin-like fracture, spin-offs, bifacial spin-offs and step-terminating bending fracture. The conclusion they brought was that using macro-fracture analysis combined with use-wear and residue analysis confirmed that the points from the Sibudu Cave were used as spearheads. They have also reported the notched hafts were not proven efficient, as the haft breakage occurred often.

Another experiment has been designed by Pargeter (2007) in order to test if the Howiesons Poort segments were used as a tip hunting weaponry. The 33 segments made of European flint were propelled using calibrated projectile machine from the distance of four meters into an impala without viscera that represented the "hunting target". The microlithic segments were binded using cyanoacrylate glue as a single binding material. The interesting thing about Pargeter's experiment is the hafting approach. He used four different hafting methods: vertical, diagonal, horizontal and back-to-back hafting method. The results obtained by this experiment, considering hafting methods were surprising. All of the hafting methodologies could have been used in the past, even the horizontal one, although the target penetration percentage was not as high as in those of other hafting approaches, it could be still used for causing blood loss. Furthermore, he concluded that the Howiesons Poort segments are functional as a projectile tips. Even though, he did not describe the fracture types, in his later work (Lombard and Pargeter, 2008) the fractures were described. The reported fracture types were: burin-like, spin-offs, bifacial spin-offs and step-terminating bending fractures.

Sisk and Shea (2009) performed two experiments using 51 Levallois points. The first one was designed in order to acquire an insight into an overall performance of the Levallois points against uniform density target. They executed the second experiment in order to test the durability of the Levallois points on the target that simulated an animal carcass. Slightly retouched Levallois triangular flakes made of Cenomanian and Turonian flint were binded using commercial adhesive. Using 40 lbs modern recurved bow the points were propelled from the distance of 4 meters into a leather covered archery target for the first experiment. For the second experiment the target into which the Levallois points were propelled from the distance of 4 meters was rack of ribs covered with goat skin. There are no descriptions of the fracture types except the ones that are presented in the figures. The conclusion they obtained using their experimental assemblage was that the successful penetration of the point into the target is more corelated with the points width and the tip cross-sectional perimeter (TCSP) than with thickness or tip cross-sectional area (TCSA).

Yaroshevich in his dissertation (2010) executed an experiment with huge number of experimental pieces that represented replicas of various microliths from Epipaleolithic Levant. The functionality of the microliths was tested, types and frequencies of impact fractures. Total number of 265 pieces were propelled into the targets using 35 lbs modern recurved bow from a shooting distances of 8-13 meters. Experimental microliths were made of flint and were binded using beeswax, resin, gypsum or ochre powder, fibre binding and commercial water-based glue. The targets he used for his experiment were a complete sheep carcass and encased skinned sheep thorax. Various types of fractures were used for description in this experimental research, fractures such as: step terminating bending fractures, spin-offs, cone-initiating fractures, snap-terminating bending fractures, feather-terminating bending fractures and hinge-terminating bending fractures.

An innovative experimental study was carried out by Schoville and Brown (2010). They have argued that the basic macroscopic and even microscopic analysis interpretation of the fracture types are useful but the majority of them possess a problem of equifinality, due to similar fracture is being formed on the individual stone tool as a causation of multiple activities. They used GIS to digitize and spatially reference the convergent flakes in order to standardize and quantify the edge damage. An attempt has been made to correlate their method to an assemblage of middle paleolithic convergent pointed flakes from the Pinnacle Point Cave 13B situated in South Africa. Convergent pointed flakes made of quartzite were binded into a hafting shaft using acacia karroo mastic and cow tendon. The 22 experimental samples were propelled into a Springbok carcass using calibrated crossbow that was set up to act as thrusting spear. The result they obtained lead to a conclusion that the convergent pointed flakes from the

Pinnacle Point Cave 13B were not used as a spear heads. Fractures have not been described, the authors only provided only the localization of the damage.

Hutchings (2011) carried out a large experimental research in order to test the fractures velocities when exposed to different "loading rates". He defines that the term "loading rate" refers to the characteristics of the contact between two objects, including. the rate of collision, the mechanical responses of the materials involved and the duration of contact. The further provided example is that during the production of the stone tool, the knapper's main goal is to control the removal of the flakes from the core. The knapper achieves that by manipulating the loading rate. For example, the loading rate is controlled by at least five methods (Hutchings, 1999;2011): selection of the hammer-stones of different densities, using the hammer-stones of different masses, controlling the angle of striking the platform, and the speed of the impact. Hutchings (2011) tested the influence of loading rate using four different hunting technologies. For all of the hunting technologies the calibrated crossbow was calibrated adequately. He used spear thrower darts, arrows, javelins, and spears. Total number of experimental Clovis points was 145. The binding material is not mentioned, and the target that was used was the several layers of fresh beef. Also, an accidental dropping experiment was carried out, majority of tips experienced tip damage, and only one was completely shattered. The conclusion after analyzing experimental results was that there is a clear indication that the different hunting technologies are influencing the lithic armatures in different loading rates. Mainly, the hand-thrown and thrusting spears are experiencing the alike fractures because they are exposed to a similar loading rate. The description of the fracture types obtained in his experiment are not provided.

Peillon and colleagues (2011) wanted to test the functionality of the Magdalenian osseous points. The experimental sample size was 18 antlers into which 51 microlithic elements made of flint were inserted. Using spear-thrower experimental samples were propelled from the distance of 12 meters into the juvenile female deer. Microliths and antlers were binded using beeswax, resin, ochre and birch bark pitch. The result led them to the conclusion that this kind of projectile points are extremely effective, as some of the experimental samples even pierced through the bone. For description of the fracture types they have used: step-terminating bending fracture, spin-offs, tip crushing, asymmetric notch, transversal snap and impact burination.

A new experiment was executed by Iovita and the colleagues (2014) in order to investigate the influence of speed on impact fracture propagation. Levantine Levallois points made of glass were hafted into shafts using beeswax as a single binding material. Using compressed air gun, a total of 234 experimental Levallois points were propelled from the shooting distance of 93 centimeters into an artificial target made of ballistic gelatin and bone-like plates that represented artificial ribs made of polyurethane. They could not find any relation between impact fracture types and speed. Also, they have concluded that step-terminating bending fractures should not be considered as diagnostic of weapon usage. Six categories of fracture types were used in their description of damage: flute-like, burin-like, transverse/snap, spin-off, tip crushing and microscopic i.e. very small fractures.

Pargeter (2013) had carried out a knapping experiment with a goal to investigate the rock type variability and the diagnostic impact fracture formation. In his work it was hypothesized that the knapping could produce the similar impact forces such as those that occur during trampling and that those two causers produce lower impact forces than those associated with weapon use. The experimental sample contained six rock types: heat-treated and un-heated silcrete, dolerite, milky quartz, obsidian and quartzite. Knapped flakes were later examined for the present of impact fractures. The results of his experiment are implying that questionable number of impact fractures could be eliminated from the analyses not by only identifying the impact fracture types, but also their patterns, locations on the stone tools and their relation to the retouch. He concluded that the location of impact fractures could possibly help us in distinguishing between taphonomical and weapon related impact fractures.

Brindley and Clarkson (2015), wanted to test were the Wardaman stone points used as a spear heads. They have performed an impact fracture based experiment. Total of 40 experimental samples were used out of which 17 were convergent points, 17 unifacially retouched and 6 bifacially retouched. Local raw material was used for manufacturing the experimental pieces, 21 points were made out of jasper and 19 points were made out of quartzite. Points were hafted using 160 centimeters long softwood hindshaft with 20 centimeters foreshaft and bound using spinifex resin. Compound bow fixed to a pine frame with a draw weight of 45 lbs was calibrated to imitate spear thrower. Points were propelled from 5 meters into a lamb carcass. The results of their experiment (Bradley and Clarkson (2015) suggest the possibility that the points were rarely used as a spear tips and were probably used as a multifunctional tools. Another possibility is that there are many unused points were found at the rockshelters of Nimji, Garnawala and Gordol-ya.

In order to test the methods of damage interpretation with focus on the hafting, Rots (2016) carried out series of experiments including thrusting spear, throwing spear and bow and arrow hunting technologies. For thrusting spear technology, 5 experimental Levallois points made of flint were thrusted into the deer carcass. Six Levallois experimental points made of flint were used for the throwing spear hunting technology. Spears were propelled into the deer carcass from the distance of 6-8 meters. Both thrusting and throwing Levallois points were binded using various adhesive material. Various microliths were used as projectiles that were propelled into the sheep carcass using 35 and 65 lbs bow from the distance of 18-20 meters. As a binding material, resin with or without ligature was used. The description of fracture type was detailed and extremely precise. Type of fractures Rots (2016) used for description of the experimental samples were: burination, step-terminating bending fracture, spin-offs, transversal fracture, feather-termination, scarring, crushed tip, notch and crushing fracture. The results of the experiments lead to a conclusion that no impact fracture is diagnostic of weapon usage until it could be associated to other damage identified on the same individual sample. Hunting technologies could be clearly distinguished based on fracture types, but only when experimental sample size is sufficient. Further, it is stated that currently, there is no experimental reference that allows us any reliable distinction of different projecting modes on the archaeological material.

Currently the typological system of impact fracture research in state of confusion. Fracture descriptions are defined specifically by each researcher. It is highly possible that the similar damage type is defined differently in by different authors. The current state of impact fracture typological system needs refinement and improvement in methodology of damage identification. The impact fractures typological system adapted from (Coppe and Rots, 2017) through time is presented in table (Table 1). An attempt has been made by Coppe and Rots (2017) to reduce the state of confusion and present an improved methodology for the identification of the damage that could be recognized on the projectile points by using their new experimental data. They suggest that the most important is to explain the fractures characteristics, i.e. attribute based terminology or simply said fracture types. Attributes that are included in the fracture descriptions are their initiation and termination. Considering the diagnostic impact fracture approach, they have decided to include next fracture as diagnostic of impact: step-terminating bending, feather-terminating-bending fractures, spin offs, and burination. Fractures such as flute-like and crushing are avoided because of their terrible level of definition. The result they obtained after experimental execution is that burin-like fracture is the most confusing one for description because they vary in the location of the initiation, the location of termination, type of initiation and termination. It is suggested that the higher level of precision in the fracture description and interpretation is necessary in order for the researchers to move forward in the development of the impact fracture research.

Werner and Willoughby (2018) designed an experiment in order to more reliably interpret the macro-wear of MSA points from the Magubike archaeological side that is situated in south Tanzania. After the experiment execution and analyzing the replicated stone tool points, they were able to distinguish which points were used for cutting/scraping and which were used for hunting, drilling or piercing purposes. Thirty unretouched points were knapped in order to test the damage distribution method in order to obtain the data necessary for differentiating the tip and marginal use modes. Obsidian was used as a single raw material for knapping the points. Ten out of thirty points were used to drill holes of ostrich eggshell. Also, ten out thirty points were used for scraping the bark from the tree limbs. The last ten points were used for "hunting". They haven't used the animal target, instead, the points that were binded to a wooden dowels using cotton string, were propelled into the trunk of a tree. By summing all the experimental results, they have concluded that the points from the site of Magubike had multiple functions including usage as a spear heads, cutting and scraping tools.

DIFs	Spin-offs	Bifacial spin-off	Burin-like	Step-terminating bending	Hinge-terminating bending	Flute-like	Feather-terminating bending	Crushing/Complex	Plunging fracture	Snap-termination	Cone	Impact notch
Witthoft, J., 1968			■			■						
Bergman, Barton, 1982			■			■						
Bergman, Newcomer, 1983			■			■						
Fischer et al., 1984	■	■		■								
Odell, Cowan, 1986			■	■	■	■						
Caspar, De Bie, 1996	■	■	■	■	■		■					
Titmus, Woods, 1986			■					■				
Crombe et al., 2001	■											
O'Farell, 2004	■	■		■	■		■					
Lombard, 2005	■	■	■	■								
Lombard, Pargeter, 2008	■	■	■	■								
Villa, Lenoir, 2009	■	■	■	■								
Sano, 2009	■	■	■	■	■	■	■					
Pargeter, 2011	■	■	■	■	■		■			■		■
Lazuén 2012			■	■	■	■	■	■				
Wilkins, et al., 2012	■	■	■	■								
Chesnaux, 2014	■	■	■	■	■		■					
Sano, Oba, 2014	■	■	■	■	■	■	■					
Weizel et al., 2014	■		■	■		■		■			■	
Iovita et al., 2016	■		■			■		■		■		
Coppe, Rots, 2017	■	■	■	■	■		■	■	■	■		
This research	■	■	■	■	■			■		■		■

Table 1 – Impact fractures description types used through time

2. Research Objectives, Materials and Methods

2.1. Research objectives

This study presents an experimentally based research of the stone tools from Mousterian levels from the site of Riparo Tagliente with focus on the pointed tools. Thirty pointed tools were identified from the Mousterian levels. The whole lithic assemblage from Mousterian levels, besides pointed tools was processed in order to identify impact fractures that could be formed during the initial phase of the stone tool manufacture, the knapping of the stone tool and possibly lead to misinterpretation of the pointed tool as a weapon. By analyzing the whole lithic assemblage, it will be possible to obtain more data about so called DIFs (diagnostic impact fractures), and to what extent do DIFs occur on the stone tools/flakes that are morphologically unusable as a weapon/spear.

If it is possible to distinguish specific causations by gathering information from experimental approach, is it possible to establish connections between factors? In other words, can we reliably interpret original material while one of the factors is missing, for example hafting shaft or hafting type, binding material? Finally, using the statistical approach, after summing up all the factors that influence the reliability of identifying certain weapon technologies, can we calculate the probability using all the variables, and describe the reliability of the interpretations?

While the experiments methodology was formed based on the material from the site of Riparo Tagliente in order to reduce the number of variables and to create the reliable conclusions, detailed insight of impact fractures variables was obtained. This study will not only present the basic interpretations of the impact fractures typology by experimental approach of the lithic material from the Mousterian layers of the Riparo Tagliente site, the study will make an attempt in establishing the limitations of the experimental approach, the reliability of the DIF (Diagnostic impact fractures) approach, the possibility of establishing modes of spear delivery (if any identified) and the methodology of impact fractures research in general.

There is an enormous amount of evidence which supports that the Neanderthals were able to hunt a very broad range of prey (Adler et al., 2006; Blasco, 2008; Böeda et al., 1999; Conard and Prindville, 2000; Fiore et al., 2004; Speth and Tchernov, 2001, 2002; Majkić et al., 2017; Mihailović, 2014). A part of this study will focus on the Neanderthal hunting technology and the functionality of the Mousterian points, i.e. were they actually used as a weapon, based on the fractures identified on the points.

Starting from the hypothesis that the knapping of the stone tools requires experience, and there is the possibility that the different level of "knapper's" experience could influence the formation of different types of fractures, i.e. possess different system of variables of impact fractures propagation. The goal of one of the experiments will be to test this hypothesis. Also, this experiment will provide the insight into the impact fractures that may occur during the knapping of the stone tool and enhance the reliability of the further impact fractures interpretations.

2.2. Materials studied (archaeological and experimental)

The material comes from the Mousterian layers from the site of Riparo Tagliente. More precisely, from the levels/cuts 52-31 and squares 9-15; and 534, 575, 594, 595, 614, 615, 616, 634 and 635, which means, both internal and external squares (Cremaschi, 1982; Bartolomei, 1982; Arzarello, 2004). Lithic material was obtained by the excavations in years of: 1974, 1976, 1979 and 1985. The complete lithic assembladge was processed in search for impact fractures, a total number of 19430 pieces. A total number of 30 points was processed, out of which 5 Levallois points, 15 Mousterian points, 8 pseudo-levallois points and 2 triangular flakes. In order to get insight into the impact fractures that are formed at the initial phase of stone tool manufacture - knapping, the whole lithic assemblage was processed, including the flakes equal or bigger than 20 mm (Fig. 118; 119).

Five reduction methods were identified in the Mousterian layers of the Riparo Tagliente: S.S.D.A, Levallois, Kombewa, volumetric laminar and Mousterian (Arzarello and Peretto, 2005). Impact fractures were identified on: Mousterian, Levallois, volumetric laminar and other small flakes that couldn't be identified. The pointed tools were the focus of this study, but the presence of the impact fractures on other flaked tools was also noted.

Each fracture that was identified as being caused by impact was analyzed both macroscopically and using a low-magnification stereoscopic microscope (Leica LAS EZ) at magnifications of 8-16x.

Experimental points were analyzed before the execution of the experiment in order to avoid misinterpretation of the impact fractures that could have occurred during the knapping. For both experimental and original material assemblages, every piece that expressed impact fracture was measured (weight, length, width, thickness), TCSA of the points was calculated, and knapping technology of the pieces was identified (if possible). Fracture termination types, sizes of fracture termination and the location/area of the impact fractures were recorded.

The descriptive statistical approach will be used for processing the experimental data, and therefore for establishing the conclusions of the executed experiments. Using the established conclusions, it will be attempted to interpret the impact fracture causations of the lithic material from the Riparo Tagliente site.

Impact fractures are the research focus of this thesis but the other identified use-wear traces have not been ignored. An experiment has also been carried out in order to understand the damage identified on the pointed tools from the site of Riparo Tagliente that are not diagnostic of impact.

2.3. Experimental approach to the impact fracture analysis

In order to develop a reliable interpretation of the causation of impact fractures, experimental study has to be executed with careful setup of variables. As equifinality of impact fractures represents a great problem, three experiments were executed in order to interpret the lithic material from the site of Riparo Tagliente as detailed and reliable as possible.

Impact fractures themselves are only typical of a specific load, and direction of pressure, and forces that could occur in circumstances other than projectile use (Coppe & Rots, 2017). That is the main reason that experimental approach is necessary in order to record every variable of the extremely complex system of impact fracture formation.

Experimental approach was chosen because it is the only method that can replicate the variables that are "invisible" to us, and cannot be obtained solely by studying the material obtained by excavations. Variables such as: distance between the "hunter and the prey", type of animal that is being hunted, hafting shaft length, the wood type of the hafting shaft, shaft weight, shaft diameter, hafting technology, binding material, penetration depth, angle of penetration, impact velocity of the spear, the end outcome of each spear that was propelled into the target. However, there are two substantial obstacles that we are completely unable to control. Firstly, the animal is not alive and running, so the hide resistance is not the same during the experiment. It is highly unethical to use alive animal in the experiments. Second, and very important variable that we are unable to control is the sole fact that we are not Neanderthals. The shoulder morphology plays an important role in throwing activities, and is not similar to shoulder morphology of Modern Humans (Schmitt et al., 2003; Churchill and Rhodes, 2009).

Four experiments have been executed:

1. The hunting replication experiment using Mousterian points – using two ways of delivery modes and two types of hafting approaches – An attempt of correlating the impact fracture type and cause.
2. Knapping experiment – identification of the impact and diagnostic impact fractures caused by knapping Mousterian points on experienced and. Inexperienced knapper's assemblages;
3. The hunting replication experiment using Levallois points – one way of delivery mode and one hafting approach – An attempt of correlating impact fracture type and cause on spears that penetrated the target.
4. Butchering, wood processing, antler processing experiment – this experiment was necessary in order to interpret the other damage other than impact fractures, identified on the pointed tools from the site of Riparo Tagliente

The detailed methodology of all of the experiments is presented in the chapters (3,4,5 and 6).

After the execution of all four experiments it was possible to establish the diagnostic impact fractures and to some extent the causation of the impact fractures propagation.

2.3.1. Impact fractures analysis - description

Five categories of damage were used for analyzing the experimental material (Coppe & Rots, 2017; Fischer et al., 1984; Iovita et al., 2014; Rots, 2014):

1. Burin-like fracture – Defined as a bending fracture resembling a burin spall and it is terminating in a 90◦ step, feather or hinge on the lateral part of the tools (Lombard 2005; Pargeter, 2011);
2. Crushing fracture – Damage that could be actually classified as a step fracture, considering that the impact force was directed into the stone tool at an angle that was not sufficient in order to remove a sizeable piece results in crushing (Odell and Cowan, 1986; Weitzel et al., 2014);
3. Impact notch;
4. Spin-off fracture – A secondary fracture type originating from bending fractures such as step or snap (Pargeter, 2011), or in other words, a fracture which initiates from a bending fracture and removes parts of the original surface of the stone tool (Fischer et al., 1984; Weitzel et al., 2014);
5. Step-terminating-bending fracture – A bending fracture terminating in a 90◦ step (Pargeter, 2011).

Nine categories of damage were used for analyzing the lithic material from the site of Riparo Tagliente:

1. Unifacial spin-off;
2. Bifacial spin-off;
3. Tip snap;
4. Tip crushing;
5. Impact notch;
6. Hinge termination;
7. Edge damage;
8. Burin-like fracture;
9. Crushing fracture.

Crushing fracture is not considered a DIF, but in this research it will be used for interpreting the damage. This fracture type was also used in the previous research (Titmus and Woods, 1986; Weitzel et al., 2014). Crushing fracture could be interpreted as a heavy damage followed by multiple variation of spin-offs and step-terminating bending fractures. This analysis carries another problem: which of these fractures used in this analysis could be considered a diagnostic impact fracture (DIF). As the current experimental researches propose (Coppe & Rots, 2017; Fischer et al., 1984; Iovita et al., 2014; Rots, 2014; Pargeter, 2011, Pargeter, 2013; Pargeter et al., 2016), there are three main DIF types. Step-terminating-bending fractures will be not considered as a DIF.

The results of the recent experiments brought to question impact fractures previously considered as most diagnostic of impact. For example, step-terminating bending fracture, considered as one of the most diagnostic impact fractures was brought into consideration and proposed to be discarded from a DIF category after recent experiments (Iovita et al., 2014, Pargeter 2016, Gavrilovic and Arzarello in press).

Currently the fractures that are diagnostic of impact, that are proposed by various authors (Coppe & Rots, 2017; Fischer et al., 1984; Iovita et al., 2014; Rots, 2014; Pargeter, 2011, Pargeter, 2013; Pargeter et al., 2016) are:

1. Spin-off fractures > 6 mm;
2. Bifacial spin-off fracture;
3. Impact burination.

2.3.2. Non-impact damage interpretation

The use-wear analysis is mandatory in order to create a powerful arguments for the reliable interpretations of the stone tools functionality (Evans et al., 2014; Rots, 2016). Since the translation of the Semenov's book (1964) the use-wear analyses are being developed systematically. Today, experimental research with the adapted variables for the reliable interpretation of the excavated artifacts became mandatory (Moss and Newcommer, 1982; Geneste and Plisson, 1990; Soriano, 1998; Lombard et al., 2004; Yaroshevich, 2010; Brindley and Clarkson, 2015; Rots, 2016). Ideally obtained results are those obtained by the application of two or more analyses (Lombard et al., 2004; Rots and Williamson, 2004; Rots and Peer, 2006; Monnier et al., 2013). In short, the use-wear analysis represents a comprehensive research that is based on the experimental data that is providing all of the necessary information to the researcher for the identification and interpretation of the certain use-wear damage on the stone tools (Pawlik 2001; Pawlik 2006).

The types of use-wear damages that could be identified on the stone tools are:

1. Edge damage – the first research considering the edge damage classification was carried out by Tringham and colleagues (1974). The results of their experiments implied that the longitudinal motions can produce damage on one side of the certain stone tool or bilaterally, depending on the working angle;

2. Micropolishes and polish – are defined as alterations visible on the natural surfaces that are increasing the reflectivity of said surfaces (Lozny and Abbott, 2004);

3. Striations – described as a small grooves of various length, width, and depth found on the polish surface and running parallel to the working direction (Pawlik, 2001, Lozny and Abbott 2004);

4. Rounding – helps in elimination of the possibly worked materials. For example, the wood sawing will probably produce light rounding, but when working on more dense materials such as bone, heavy rounding could occur (Keeley, 1980; Lozny and Abbott 2004);

Even though the damage identified on the stone tools can be the product of its usage in various manners, post-depositional processes can cause micropolishes and edge damage as well. The sedimentation process can cause various types of damage on the stone tool surface such as: patination, sediment polish or bright spots (Pawlik, 2001). There is not enough research dealing with this damage cause and that should be rectified in future.

2.3.3. Hafting of the stone tool

The hafting of the stone tool enhances its functionality and the efficiency of the certain task that the specific hafted tool is used for. Also, it enhances the working edge efficiency i.e. size and shape of the stone tool that is impossible to accomplish by hand-holding. Hafting itself, like the impact fractures propagation, has a complex system of variables of its own (Roots, 2003). Considering that the focus of this research are pointed tools and whether they were used as a spear or for other activities, hafting represents an important variable that can bring us one step closer to the conclusions and solving of this complex question.

Considering the experimental approach of this research, six stages of hafting were distinguished. Each of the stages carries a possibility for impact fracture formation. The first stage would be the selection of the tool. When the tool is selected it is possible that the impact fracture was already formed during the knapping of the tool. If the platform is not suitable for the desired way of hafting it has to be modified, and again, impact fracture could be formed as a cause of knapping. Hafting of the stone tool can create an impact fracture on the proximal part of the stone tool while it is being pushed into the shaft or while using sinew as one or as the only type of binding material. Next step would be the usage of the hafted stone tool. Possibly after the “hunt” is successful or the target has been missed, if the damage of the stone tool is not influencing its functionality, it becomes re-hafted into the same or another hafting shaft. Final step is discarding the hafted tool that cannot be used anymore.

If the hafting use-wear is present on the proximal part of the pointed tool, that is the possible indication that it was used as weapon. Also, if the impact fracture was identified on the distal part of the stone tool, it is becoming clear that the specific stone tool was used as a spear (Rots 2001; Villa 2009). Besides that the hafting-derived damage could answer to the above-mentioned questions, it also creates a lot of other questions that can attribute to the interpretation of the possible pointed tools usage: If strong evidence of hafting is present on the proximal part of the point, the TCSA values are in the range suitable for the spears (100-250 mm^2) and there is presence of impact fracture on the distal part of the point, the evidence is clear that the certain hafted point was used as a thrusting spear.

The recent discoveries from the caves of Fossellone and San’t Agostino have provided a strong suggestion that between the MIS 7 and MIS 3 that the hafting was the component of

Neanderthal behavior (Degano et al., 2019). This conclusion was brought up by residue analyses that unveiled that oil, waxes and pine resin were used as adhesives. The adhesive traces were located on the lateral and proximal sides of the stone tools (Degano et al., 2019).

2.3.4. Hafting methodology

Firstly, what is a hafting methodology? Based on which stone tool is intended to be hafted, the hafting methodology is formed. In the case of this assemblage, the stone tools that are intended to be hafted are Mousterian and Levallois points. The first part of the hafting methodology is the choice of which type of hafting shaft will be used. If the spear will be used as a thrusting spear, the hafting shaft has to possess higher morphometrical values i.e. be able to endure high level of stress without breakage. On the other hand, if the spear is intended to be hand thrown, the hafting shaft should possess lower morphometrical values, especially the shaft weight and diameter. After the suitable hafting shaft is chosen, the point has to be fixed to it, and therefore, the selected binding material and the type of hafting the point are being applied. Various fixation methods and binding materials were used in the other experimental research. Plisson and Beyries (Plisson and Beyries, 1998) used bitumen and ochre for fixing the Levallois points meant to be used as a thrusting spears; Shea (Shea et al., 2001), used synthetic paving tar with or without the vegetal fibers; Pargeter (Pargeter, 2007) used cyanoacrylate glue as a single binding material; Sisk and Shea (Sisk and Shea, 2009) used commercial adhesive as a single binding material; Yaroshevich (Yaroshevich et al., 2010) used bee's wax, resin, gypsum or ochre powder, fiber binding and commercial water based glue; Iovita (Iovita et al., 2013) used natural bee's wax as a single binding material. For this research the binding materials that were used in the experiments was natural bee's wax, sinew and in single case, animal intestine. In most of the experiments, the vertical hafting type was applied (Lombard, 2004; Pargeter, 2007; Hutchings, 2011; Iovita et al., 2013). Pargeter (Pargeter, 2007), used four types of hafting in his experiment: vertical, diagonal, back-to-back and horizontal. Hafting two Mousterian or Levallois points back-to-back would be highly inefficient, while horizontal hafting would be efficient, but not for spear use. Therefore, in the experiments of this research two types of hafting were applied: vertical and diagonal.

2.3.5. Hafting damage – variables and description

In other experimental research, it was discovered that various types of damage could be a result of hafting. The two leading types of damage are the product of the hafting-derived damage: scarring and some minor polish could be formed during hafting process alone, but the most of the damage is being formed due to a later usage (Rots, 2001; 2003; 2006). After the hafting experiment executions Rots (2001; 2003, 2006), claims that there are four variables that have the dominant influence on the propagation of the hafting damage:

1. Hafting arrangement (male and male split arrangement i.e. the stone tool is inserted into a cleft of the shaft);

2. Binding material (influences the morphology of the damage traces and polish);

3. The hafted tool usage;

4. Secondary variables (raw material, presence of retouch…).

This analysis, will interpret the hafting damage by using both its experimental results and the results of the other researchers.

2.4. Impact fractures – variables, problems and limitations of the experimental approach

We should observe impact fracture propagation as one huge sensitive system with a large number of variables, where the change of just one variable completely alters the obtained data. In order to better understand that system, we need to collect a vast amount of experimental data. It is mandatory to discover correlations between variables and not just focus on the fracture description, and to observe to what extent we can correlate experimental results with original data.

For better understanding of the complex system of variables, it is necessary to identify and record all the variables that could be part of the system. Most of the variables have a system of their own variables. If we begin from the initial phase of stone tools operational chain, the beginning would be the selection of raw material. Here we come to the fracture mechanics. Each type of raw material has its own fracture mechanic properties, which means the graininess of the rock and its elasticity. Therefore, each raw material type should be considered as a separate system with its own variables. A second phase would be the knapping of the stone tool. Knapping is one of the variables that also possess a complex system of their own. In past research (Pargeter, 2013; Gavrilović and Arzarello, in press), show the knapper's experience influences fracture propagation, and that a substantial number of DIFs could be identified on knapped assemblage. Bad striking angle was one of the main causers of the fractures on the proximal parts of the tool. The type of the hammer stone and the knapping approach are important variables: soft and hard hammer-stones produce different kind of damage to the striking platform. Also, the knapping technique is influencing the fracture formation (Putt, 2015). The morphology of the stone tool that is intended to be knapped may influence the fracture propagation, because the thin flakes tend to experience lateral damage while striking the ground or other knapped debris after being separated from the core. Another one of the knapping variables is retouching. It is possible to produce damage similar to those identified on hunting experiments samples, by a simple retouching of the stone tool (Pargeter, 2013; Gavrilović and Arzarello, in press). If the stone tool morphology is not suitable for hafting, the proximal part of the tool will have to be modified. While modifying the proximal part of the stone tool, a fracture could be formed.

Hafting is also one of the complex variables of fracture propagation. Hafting itself may also produce damage to the proximal and medial part of the stone tool, especially if a sinew is used for fixation. Type of hafting can be of great influence in the fracture formation. So far, four types of hafting were used in hunting experiments: diagonal, vertical, horizontal and back-to-back (Pargeter 2007; Iovita et al., 2014; Gavrilović and Arzarello, in press). In this research, differences in impact fracture propagation were noted in diagonally and vertically hafted Mousterian tools.

Hafting shaft morphology is one of the variables that require more attention in future research. Shaft diameter plays an important role in spear penetration efficiency. Also, shaft weight, length and the wood type used for crafting the hafting shaft should be considered as important variables.

The adhesive used for fixing the stone tool to the shaft plays one of the crucial roles for hunting efficiency, i.e. penetration depth and damage formation. Adhesives used in past experiments were various: beeswax, tar, a mixture of few adhesives with or without sinew, even commercial glue in some instances (Pargeter, 2007; Shea and Sisk; 2010; Iovita et al., 2014). Inefficient fixing can lead to hafting breakage that sometimes bring highly efficient hunting, i.e. the hafted point stays inside of the prey. Spears that experience haft breakage during the hunting are sometimes as efficient as those that do not break. If the point remains inside the animal, the death is inevitable and the hunt is successful.

The influence of hunting technology to the fracture formation is the variable that we tried to resolve for a long time. That makes the system of variables of fracture formation one of the most complex and demanding one. Various experiments, including thrusting spear hunting technology, low-velocity throwing spear, high-velocity throwing spear, and bow and arrow hunting technology were executed (Fischer et al., 1984; Pargeter, 2007; Lombard; 2004; Iovita et al., 2014). Based on the chronology and the stone tool morphology from the studied Paleolithic site, hunting technology was chosen for experimental approach. It is known that Neanderthals did not possess the capability for high-velocity spear usage due to their shoulder morphology (Schmitt et al., 2003; Churchil and Rhodes, 2009), therefore for example, if the studied material comes from site where Mousterian technology is identified, thrusting and low-velocity throwing spear hunting technologies should be used for execution of the experiment.

Depending on the faunal material, the animal target used in the experiment should be tailor made for the archaeological assemblage we are investigating. Therefore, usage of animals without internal organs, ballistic gelatin, or ballistic gelatin covered with animal hide, and ribcages bought from butchery shops give us some results, but how reliable are those results? Rigor mortis alone presents a great problem and hide resistance is considerably higher than when animal was alive. It would be ideal if live animals could be used in the experimental approach but this is of course highly unethical.

It is logical and has been experimentally proven that both impact velocity and impact angle influence fracture formation. Modern equipment could be used, but it is not mandatory for experimental research. The problem is that mechanically delivered spears do not replicate the approximate method of projecting used in the past. The results obtained that way are great for interpretation and establishing conclusions but the real question is how reliable are those interpretations and conclusions. The Paleolithic mode of projecting involves more uncontrolled variables, but with a higher number of samples the collected data is much more acceptable than "mechanically" obtained data. Another important variable is the outcome of the projected shot towards the target. If the target is missed, what kind of surface did it hit (wooden, stone, soil). Did it maybe rebound? Rebounding could be the repeating case because of *rigor mortis*. Which part of the animal did it hit when it rebounded? If it penetrated the target, what was the area of penetration and what was the penetration depth?

If Upper Paleolithic material is studied, we come across the problem of "hunting experience". Excluding the thrusting spear hunting technology, high-velocity hand thrown spears represent a great problem. Based on ethnological research, it is established that the effective range of high-velocity thrown spears is around 40 m (Iovita, 2016). Even the highly experienced hunter has a large chance of missing the target, and this is where the hunting replication experiments demonstrate lack of evidence. Mechanically propelled spears do not "miss" the target, i.e. the "hunt" is always successful and no attention is paid to impact fractures formed as a product of missing the target.

Finally, after finishing the experiment, a fracture analysis was conducted. Here again is another problem; fracture analysis is conducted differently by almost all of the authors. There is a high probability that the same fracture type is described differently in by different authors (Coppe and Rots, 2017). An established uniform methodology for fracture analysis is required:

methodology that could be precisely replicated and which would include exact fracture location, fracture size and type. Only then we could start moving forward into solving the complexity of impact fracture propagation.

2.4.1. Experimental sample size and modern equipment usage

Sample size of the past experimental fracture research varied from 7 - 265 pieces. Small experimental sample sizes were justified by being labeled as "highly controlled studies", which leaves fewer free variables. Therefore, those studies achieved high statistical power with smaller number of samples. The potential problem of those studies is that in order to control some of the variables, modern equipment had to be used. Usage of modern equipment produces highly questionable and possibly not reliable results. "Prehistoric mode of delivery" does leave considerable number of variables, but still, it is possible to control a high number of variables and with larger sample size, the results are more reliable.

2.5. Fracture velocity analyses – Fracture wings (Wallner lines)

Fracture velocity analyses are being carried out by measuring the plane fracture wings (FWs). The fracture wings are V-shaped and their apex is pointing in the direction of the fracture propagation (Thomenchuk, 1985; Ravi-Chandar, 2004; Hutchings, 2011; Sahle et al., 2013). The calculation of the fracture velocity for a stone tool made of raw material that posseses a known value of distortional wave velocity can be executed by measuring the angle of divergence of plane fracture wings that could be identified on the certain fracture (Hutchings, 2011). There are five stages of the fracture velocity analysis:

1. The raw material properties analysis of the pointed tools used by Middle Paleolithic inhabitants of the Riparo Tagliente site;

2. The microscopic analysis of the fracture surfaces found on the pointed tools;

3. Recording of the fracture's photomicrograph;

4. Measurement of the macrofractures features

5. Calculations of the fracture velocities.

The fracture velocity ($\dot{C}$) is demonstrated as a fraction of the certain material's distortional wave velocity (C_2). Mathematically, the velocity of the distortional wave (C_2) is expressed as (Blitz, 1967; Jaeger and Cook, 1976; Hutchings, 2011; Sahle et al., 2013):

C2 = $(\frac{G}{p})^{1/2}$ – where G is the modulus of rigidity, and p is the material density.

The modulus of the rigidity is expressed as:

G = E/2(1+*v*) – where E is Young's modulus, and *v* is Poisson's ratio. Young modulus (*E*) is expressed as:

E = $\mathbf{pv_s^2}$ – where v_s is the sonic velocity of the material (Hutchings, 1999; 2011).

The values for the distortional wave velocity of the certain flaked stone tool materials are presented in table (Table 2).

Material	p (10^3 N m^{-3})	E [pv_s^2] (10^{10} N m^{-2})	G [$E/2(1+\nu)$] (10^{10} N m^{-2})	ν	C_2 [$(G/p)^{1/2}$] (m s^{-1})	Data source
Chertsey flint (C)	2.52	5.516	2.224	0.24	2971	(1)
Chertsey flint (D)	2.55	5.516	2.224	0.24	2953	(1)
Chertsey flint (E)	2.58	5.516	2.224	0.25	2963	(1)
Rugen flint	2.63	7.45	3.45	0.08	3622	(1)
Edwards (Georgetown) flint	2.63	7.5	3.463	0.08	3629	(2)
Alibates flint (agatized dolomite)	2.62	7.6	3.503	0.08	3664	(2)
Chalcedonic chert	2.56	5.337	2.448	0.09	3092	(1)
Chert (dyke)	2.55	8.274	3.447	0.20	3677	(1)
Dolomitic chert (A)	2.63	3.544	1.648	0.001	2503	(1)
Dolomitic chert (B)	2.67	5.619	2.372	0.14	2981	(1)
Chalcedonic limestone	2.55	4.688	1.875	0.25	2712	(1)
Jaspelite (A)	3.39	10.34	4.826	0.07	3773	(1)
Jaspelite (B)	2.90	7.515	3.916	−0.04	3674	(1)
Modoc Calif. obsidian	2.45	6.56	3.03	0.08	3520	(1)
Lipari obsidian (A)	2.37	6.52	2.78	0.17	3425	(1)
Arnafels Iceland obsidian	2.37	7.18	3.03	0.18	3576	(1)
Glass Butte obsidian	2.546	8.9	3.794	0.17	3865	(2)
Opal	2.34	3.8	1.8	0.06	2774	(1)

Table 2 – Values for the distortional wave velocity of certain flaked stone tool materials. Source: Hutchings, W. Karl. "Measuring use-related fracture velocity in lithic armatures to identify spears, javelins, darts, and arrows." *Journal of Archaeological Science* 38.7 (2011): 1740.

Variables for the determination of the fracture propagation velocity ($\dot{C}$), expressed as a fraction of the distortional wave velocity (C_2), as determined from two configurations of Wallner lines (W) are presented in a figure (Fig. 2); a – Fracture propagation direction (indicated by C) is perpendicular to crack front as registered by fracture undulation (U).

Distortional wave propagation direction (C_2) indicated by SP, where S is the point of origin of the distortional wave, and P is the point of intersection of the generated Wallner line (W) and the fracture undulation (U); b – Boundary-reflected distortional wave disturbance resulting in the apparent convergence of two Wallner lines (W1 and W2 – one is the reflection of the other) with mutual angular displacement of 2φ (Cotterell and Kamminga, 1979, Kerkhof, 1975; and corrected from Thomenchuk, 1985;) - after Hutchings (2011).

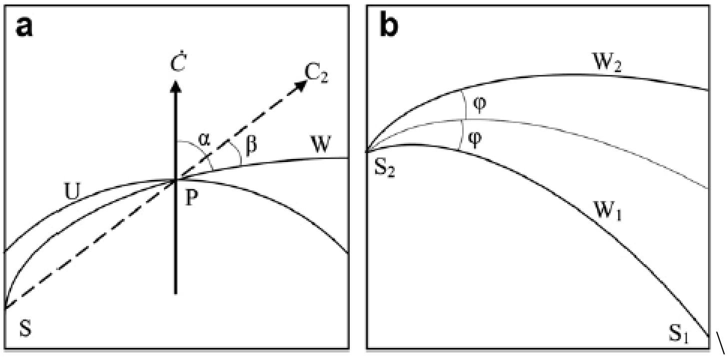


Fig. 2 – Variables for the determination of fracture propagation velocity. Source: Hutchings, W. Karl. "Measuring use-related fracture velocity in lithic armatures to identify spears, javelins, darts, and arrows." *Journal of Archaeological Science* 38.7 (2011): 1740.

Variables for the determination of the fracture propagation velocity ($\dot{C}$), expressed as a fraction of the distortional wave velocity (C_2), as determined from intersecting Wallner lines (W1 and W2). Two distortional wave disturbances (represented by (C_2) or S1P and S2P intersect at point P (Fig. 3); a – symmetric case; b – asymmetric case).

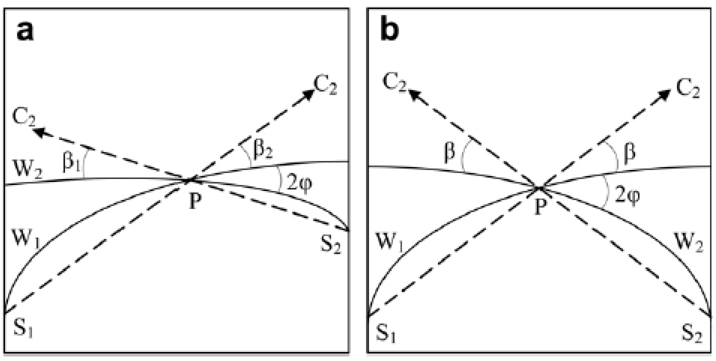


Fig. 3 – Variables for the determination of the fracture propagation velocity. Source: Hutchings, W. Karl. "Measuring use-related fracture velocity in lithic armatures to identify spears, javelins, darts, and arrows." *Journal of Archaeological Science* 38.7 (2011): 1741.

Variables for the determination of the fracture propagation velocity ($\dot{C}$), expressed as a fraction of the distortional wave velocity (C_2), as determined from the effective angle of divergence (ψ) of fracture wings (FW) (Fig. 4); a – Circular primary crack front (as indicated by fracture undulation) at point A and A'. The angle of divergence (ψ) is obtained from the intersecting tangents to the fracture wings at points A and A'; b – plane primary crack front. The angle of divergence is measured directly from the fracture wings (Thomenchuk, 1985; Kerkhof, 1975) – after Hutchings (2011).

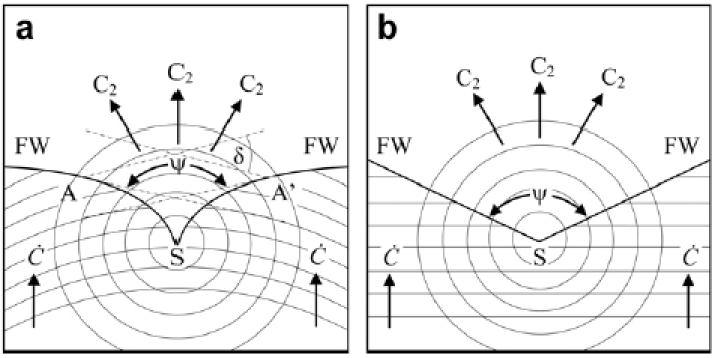


Fig. 4 – Variables for the determination of the fracture propagation velocity. Source: Hutchings, W. Karl. "Measuring use-related fracture velocity in lithic armatures to identify spears, javelins, darts, and arrows." *Journal of Archaeological Science* 38.7 (2011): 1741.

Instantaneous fracture velocity (C) of the fractures identified on the pointed tools from Riparo Tagliente were calculated using the values of the fracture wings (FW) angles using the equation $C = cos$ ([ψ/2]* C_2) – where ψ is the angle of divergence of a plane fracture wing (Hutchings, 2011; Sahle et al., 2013; Iovita et al., 2014).

The "loading rate" is explained as a characteristic of contact between two objects with minimal inclusion of the rate of collision, the mechanical responses of the materials involved and the duration of their contact (Hutchings, 2011). For example, while the stone tools are being knapped, the knappers' primary concern is the control of removal of the flakes from a core. The knapper is achieving the control by multiple methods. For instance, the selection of the hammer-stone with desired properties, striking angle or striking force. By changing the variables of some of these control methods the loading rate is being changed (Hutchings 1999; 2011). The loading rate scheme was modified (Stowe and Ainsworth, 1972; Tomenchuk 1985) by Hutchings (2011), and is defined for the archaeological needs as:

1. Quasi-static – described as the increasing contact force, that is somewhat correlated to the pressure knapping;

2. Rapid loading – could be realized by impact and could be correlated to a percussion knapping activities;

3. Dynamic loading – is also obtained by impact, but it cannot be closely correlated to the certain high velocity projectile hunting technologies (Hutchings, 2011).

The results of Hutching's (2011) experiment suggested a correlation between the loading range ranges that are associated to a stone tool knapping or use-wear damage type, and maximum instantaneous fracture velocities ($\dot{C}$) (Fig. 5).

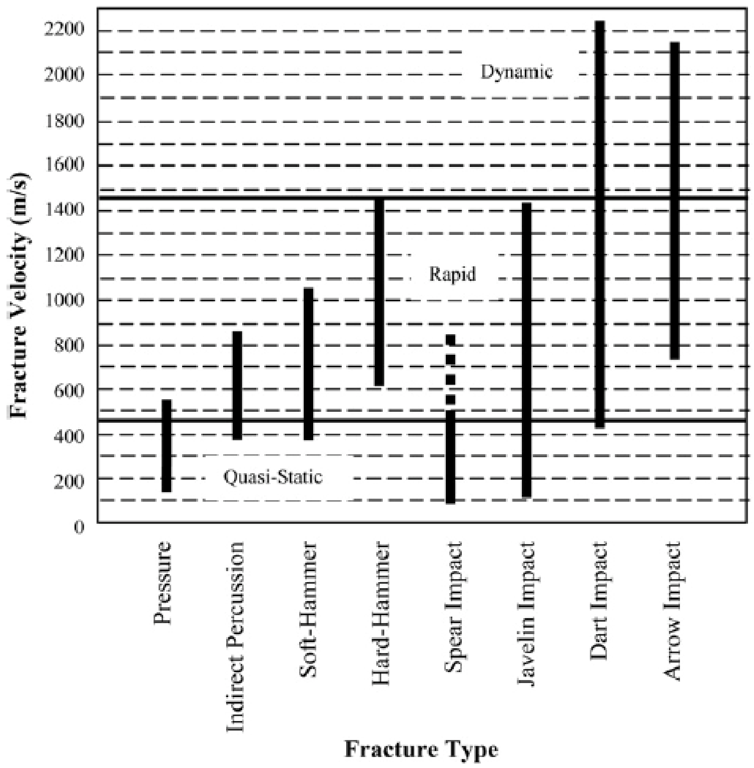


Fig. 5 – Comparison of loading rate ranges and experimental lithic fracture velocities associated with various reduction technologies and weapon armature impacts. Source: Hutchings, W. Karl. "Measuring use-related fracture velocity in lithic armatures to identify spears, javelins, darts, and arrows." *Journal of Archaeological Science* 38.7 (2011): 1742.

3. First experiment - The hunting simulation using Mousterian points

3.1. Research aims of the first experiment

This experiments methodology was formed based on the research of the site of Riparo Tagliente, so the impact fractures identified on the lithic material from the site could be reliably interpreted using obtained experimental results.

The experiment was executed in order to obtain answers to following research questions:

1. Is it possible to distinguish diagonal and vertical hafting technology by analyzing solely the impact fractures identified on the pointed tools?

2. Can we distinguish the spear delivery mode by analyzing only the impact fractures identified on the pointed tools?

3. Could we reconstruct the hafting shaft morphology (hafting shafts are exceptionally rarely preserved in archaeological record) based on the impact fractures identified on pointed tools?

4. Does the TCSA (Tip Cross Sectional Perimeter) influence the penetration, i.e. functionality of the spear?

5. Is it possible, and if it is to what extent, to identify the cause of the specific impact fracture type?

6. Does the hafting depth influence the functionality of the spear?

7. Is it sufficient to use the beeswax as the only binding material?

8. Does and to what extent the impact velocity influences the impact fracture formation?

9. Is it effective and functional to haft the Mousterian points vertically?

10. Is it effective and functional to haft the Mousterian points diagonally?

11. Can we establish a possible hafting depth, i.e. haft limit based on the hafting damage?

12. Is it possible to roughly interpret the hafting shaft morphology?

13. Using other variables, such as TCSA and impact fractures together in correlation with hafting damage, can we interpret the specific point's usage as a spear and furthermore the causation of the impact fracture?

3.2. Materials and methods

The raw material used in this experiment was chert, similar to the one that was used and could be found in the surroundings of the Riparo Tagliente rock-shelter. With help of archaeozoological studies we know that one of the hunted animals at the site was a wild boar (*Sus scrofa*), therefore, in one of the experiments, a dead wild boar was used as a target (Fig. 6). Morphology of the experimental Mousterian points was similar to those found at the site. Two types of hafting (vertical and diagonal) and two types of hunting technologies (throwing and thrusting) were applied (Fig. 7). There were four categories of spears used in the experiment: diagonal thrusting, vertical thrusting, diagonal throwing and vertical throwing spear. Retouched Mousterian points were hafted 1-3.4 *cm* deep into a homogenous wood shaft using only beeswax as a binding material. Beeswax was used as the only binding material in order to also test the functionality of this hafting approach. In previously published experiments, various fixing approaches were applied, using a single binding material or a mixture of two or more elements. Pargeter used Cyanoacrylate glue (Pargeter, 2007), Petillon and colleagues used a mixture of beeswax, resin, ochre and birch bark pitch (Petillon et al., 2011). Iovita and colleagues used only beeswax (Iovita et al., 2013), while Sisk and Shea used commercial adhesive (Sisk and Shea, 2009). Only one raw material type was used, chert, in order to reduce number of variables. Different authors previously used various raw materials in their experiments: (Yaroshevich et al., 2010), obsidian, (Hutchings, 2011), glass (Iovita et al., 2013), quartzite (Shoville and Brown, 2010), banded ironstone (Wilkins et. al., 2012). It was controlled as much as possible so that the place of impact was not repeated. IA (impact angle) and impact speeds were measured but they were not held constant. A photo of every stone tool was taken before and after each shot. Distance from the hunter to the prey was the only variable that was held constant. It is known from ethnographical research (Rhodes and Churchill, 2009) that the effective range of a hand thrown spear is no more than six meters. For this experiment, the distance that was chosen was four meters. Shafts were made of common hazel (*Corylus avellana*) 109 - 179 centimeters long. Shaft weights were 590-1700 grams, the diameter was 22-46 *mm*.

Point dimensions and TCSA (Tip Cross Sectional Perimeter) are presented in the table (Table 3-9). TCSA was calculated using the next formula: 0,5 x maximum width x maximum thickness (Shea, 2006).

In previous research, various authors (Schmitt et al. 2003; Churchill and Rhodes, 2009) found that Neanderthal skeletal evidence implies their inability of using high speed complex projectiles. Ballistic-inspired studies on the practicability of using Levallois and other Neanderthal made points as weapon tips (Sisk and Shea, 2009; Shea and Sisk, 2010) implies their usage as thrusting or low velocity throwing spears. It is argued that the Neanderthals did not possess the ability to use long-range weaponry, due to their skeletal morphology. The results of the past research regarding the subject (Schmitt et al., 2003) brought up the conclusions that the thrusting spear was the one of the main sources, if not the main source of osteogenic stimuli in Neanderthal and the Early Upper Paleolithic Modern Human male humeri. In contribution to the scarce material evidence of projectile weaponry usage in the late Middle Paleolithic period it is suggested that the long-range projectile weaponry did not become the principal hunting technology until the Upper Paleolithic, closely connected to the first discoveries of the spear-throwers (Schmitt et al., 2003). These statements were later confirmed by another research (Churchill and Rhodes, 2009) with the same conclusions that the osteological data, when entirely observed are implying that both Neanderthal and modern human Mousterian hunters were not habitually engaged in the forceful throwing, further implying that the long-range projectile weaponry was not a part of the Mousterian hunting technology. The same arguments, based on the archaeological evidence were brought up John

Shea (Shea, 2006). Due to these conclusions, two hunting technologies or delivery methods have been applied in this experiment: thrusting and hand-throwing.

It is convenient to reduce the number of variables as much as possible by controlling them and holding them constant, but due to the nature of this experiment, prehistoric type of projecting mode is probably the most suitable choice without the use of any modern technology. To control IA (impact angle) and the impact velocity is good in some cases, but the IA and impact velocity in prehistory could not possibly be constant. There are so many variables influencing macrofractures, for instance, the distance between the hunter and the prey, shaft morphology, speed of delivery, and the possibility that some of them were constant in Middle Paleolithic period is miniscule. In order to gather as much reliable data as possible, prehistoric type of projecting mode (Rots, 2013) was applied. Therefore, in this experiment the IA wasn't measured, but IA of every shot was approximately 20-24 degrees (calculated using basic trigonometry). Impact velocity for thrown spears was measured but it was not held constant. It was possible to observe and compare data that are unavailable or are found extremely rare in the archaeological record: hafting shaft length, weight and diameter, hafting depth, distance between hunter and the prey, penetration depth, area of penetration, speed or impact fracture cause. Each of these variables were carefully analyzed and compared in order to find even minimal connections between them.


Fig. 6 – Animal target used in the first experiment.

Vertically Hafted Thrown Spears TCSA		
N	Valid	10
	Missing	0
Mean		202.700
Median		154.500
Std. Deviation		120.73207
Range		350.00
Minimum		58.00
Maximum		408.00

Table 3 – TCSA values of vertically hafted Mousterian point used as hand-thrown spears.

Vertically Hafted Thrusting Spears TCSA		
N	Valid	10
	Missing	0
Mean		216.500
Median		212.500
Std. Deviation		93.40027
Range		356.00
Minimum		44.00
Maximum		400.00

Table 4 - TCSA values of vertically hafted Mousterian point used as thrusting spears.

Diagonally Hafted Thrown Spears TCSA		
N	Valid	10
	Missing	0
Mean		311.500
Median		294.000
Std. Deviation		78.17111
Range		203.00
Minimum		217.00
Maximum		420.00

Table 5 - TCSA values of diagonally hafted Mousterian point used as hand-thrown spears.

Diagonally Hafted Thrusting Spears TCSA		
N	Valid	10
	Missing	0
Mean		294.800
Median		261.500
Std. Deviation		136.46880
Range		444.00
Minimum		156.00
Maximum		600.00

Table 6 - TCSA values of diagonally hafted Mousterian point used as thrusting spears.

Point Length (mm)		Frequency	Percent
Valid	40.00	3	7.5
	41.00	1	2.5
	42.00	1	2.5
	47.00	3	7.5
	48.00	1	2.5
	49.00	2	5.0
	52.00	4	10.0
	53.00	1	2.5
	54.00	1	2.5
	55.00	3	7.5
	60.00	1	2.5
	61.00	2	5.0
	62.00	3	7.5
	63.00	1	2.5
	64.00	1	2.5
	66.00	2	5.0
	67.00	1	2.5
	68.00	1	2.5
	71.00	1	2.5
	73.00	1	2.5
	75.00	1	2.5
	76.00	2	5.0
	79.00	1	2.5
	82.00	1	2.5
	89.00	1	2.5
	Total	40	100.0

Table 7 – Length values of the experimental Mousterian points.

Point Thickness (mm)		Frequency	Percent
Valid	4.00	1	2.5
	5.00	1	2.5
	6.00	1	2.5
	8.00	1	2.5
	10.00	7	17.0
	11.00	2	5.0
	12.00	2	5.0
	13.00	2	5.0
	14.00	4	10.0
	15.00	1	2.5
	16.00	2	5.0
	17.00	4	10.0
	18.00	2	5.0
	19.00	1	2.5
	20.00	3	7.5
	21.00	1	2.5
	22.00	2	5.0
	23.00	1	2.5
	25.00	2	5.0
	Total	40	100.0

Table 8 – Thickness values of the experimental Mousterian points.

Point Width (mm)		Frequency	Percent
Valid	22.00	1	2.5
	23.00	2	5.0
	24.00	1	2.5
	26.00	3	7.5
	27.00	1	2.5
	28.00	2	5.0
	29.00	1	2.5
	30.00	3	7.5
	31.00	2	5.0
	32.00	2	5.0
	34.00	5	12.5
	35.00	1	2.5
	37.00	5	12.5
	38.00	1	2.5
	39.00	1	2.5
	40.00	2	5.0
	42.00	2	5.0
	43.00	1	2.5
	45.00	1	2.5
	48.00	2	5.0
	50.00	1	2.5
	Total	40	100.0

Table 9 – Width values of the experimental Mousterian points.

3.3. Stone Tipped Spears - functional perspective

The number of functional studies imply the importance of hafting in hunting technology of the Middle and Late Pleistocene (Rots, 2009; Roots, 2011; Wilkins et al., 2014; Forssman, 2015). Villa (2009) claims that there are definite advantages to hafting stone points to spear tips. For example, the stone point improves penetration and stopping power, and the breakage or loss of the point inside the body of the prey helps salvaging the wooden shaft because, the experiments of (Veil and Plisson, 1990) showed, the manufacture of the wooden spear takes is 5-20 times longer than the manufacture of a Middle Paleolithic stone artifact. Based on recent experiments results (Wilkins at al., 2014) it has been suggested that stone-tipped armatures are not more effective for dispatching game because they do not increase penetration depth. The advantage of hafting the stone tipped tools is, as stated in (Villa, 2009), that usually when the stone tool penetrates the hunted animal, hafting breakage occurs and the point remains inside. That outcome usually leads to a successful hunt.

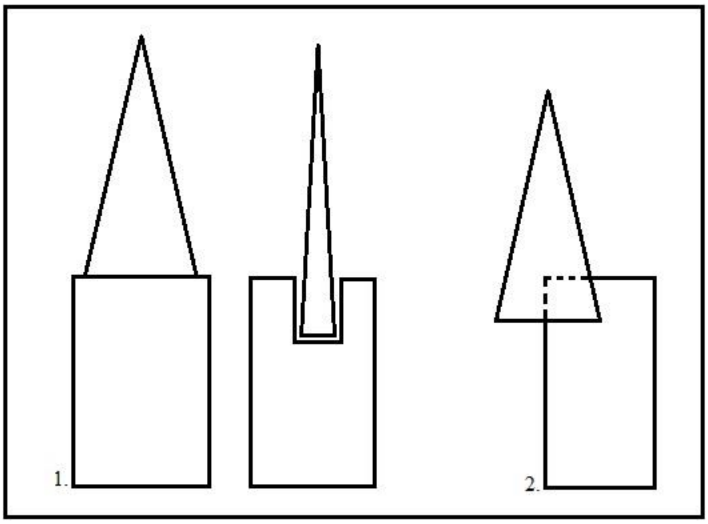


Fig. 7 – Hafting methods used in first experiment. 1 – Vertical hafting, 2 – Diagonal hafting method.

As stated in (Rots, 2014), there is a problem in the experimental approach when modern equipment, such as: calibrated crossbow, ballistic gelatin, superglue, mechanically modified spears, glass is used because the gathered results do possess statistical power, but are of highly questionable reliability. It is implied, that using modern equipment, we are merely accumulating huge amount of unreliable experimental data. The Paleolithic mode of projecting represents a more reliable way of obtaining data of impact fracture propagation. That way of projecting mode does leave more uncontrolled variables but, together with a larger number of experimental samples, the collected data is much more acceptable than "mechanically" obtained data.

3.4. The results of the first experiment

As it was expected, the most fractures occurred on the distal dorsal side of the points, while the fractures on the lateral, medial ventral and proximal ventral side of the point, have only one fracture each.

The research of Villa and colleagues (2009) found that about 40% of diagnostic impact fractures could be identified from kill sites. On this experimental assemblage, 67.5% experienced fracture, but how many of them could be classified as diagnostic impact fracture is highly questionable. Step terminating fracture was the most common fracture, while bifacial spin-off, edge damage, impact notch and tip snap were identified one example each. All identified impact fractures of both delivery and hafting methods are presented in (Fig. 8).

It was possible to hit three different types of surface at the experimentation site - gravel, target (wild boar), and wood. Out of the total experimental assemblage there were ten spears that missed the target and hit the gravel.

Step termination was identified on four points and four points did not experience fracture. One burin-like with step termination was identified and one point had edge damage.

Only in two cases, when the target was missed and the spear hit the wood surface, both hafted points experienced impact fractures - unifacial spin-off and burin-like with step termination.

Spears that penetrated the target and experienced unifacial spin-off fractures occurred in five cases, step terminating fractures in three cases and also three pieces did not experience impact fracture.

Spears that rebounded of the target, six out of eleven did not experience impact fracture. Step termination occurred in two cases, and burin-like, bifacial spin-off and impact notch had one example each.

Before hafting the Mousterian points into the shafts, they were examined for fractures that were a product of knapping incident. Burin-like with step termination fracture was identified on two points. Also, burin-like, step terminating, tip snap and unifacial spin-off had one example each.

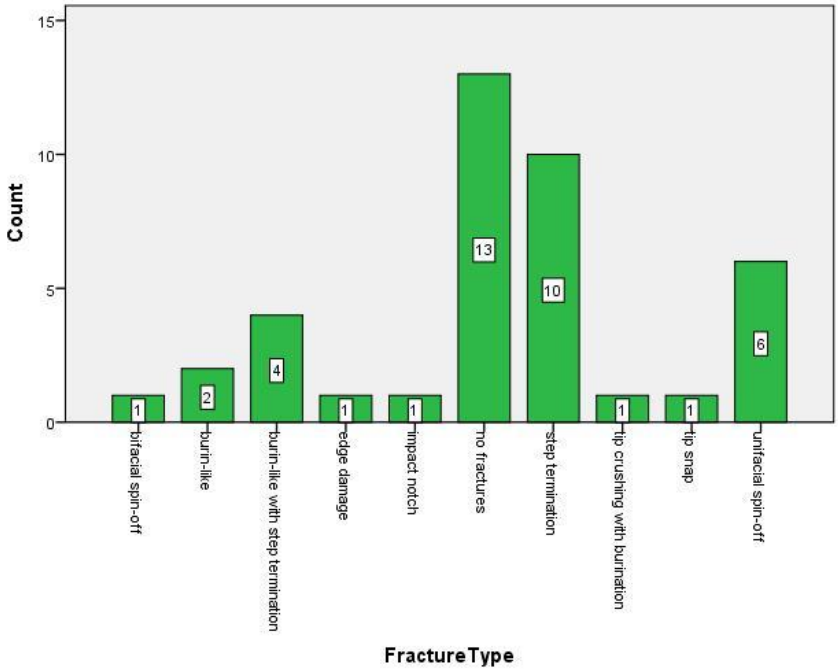


Fig. 8 – Fracture types present on the Mousterian points after the execution of the first experiment.

Descriptive statistical analyses were completed for each hafting and delivery method, in order to achieve an even more detailed insight into possible connections between variables. Step terminating fracture was identified in three cases in thrown spears with vertically hafted points (Fig. 25). Tip crushing with step termination, unifacial spin-off, edge damage, and burin-like fracture with step termination had one example each. Diagonally hafted thrown spears experienced burin-like fracture with step termination three times (Fig. 25). Step termination was identified on two points. Tip snap, unifacial spin-off and bifacial spin-off had one example each. There were no fractures on two points in this category of spears.

Vertically hafted spears used for thrusting experienced five examples of step terminating fractures, two unifacial spin-off fractures, one impact notch and two points had no fractures (Fig. 25).

The last category of spears, diagonally hafted used for thrusting experienced only four fractures. Two burin-like, one unifacial spin-off and one step terminating fracture (Fig. 25). All the processed experiment information of differently hafted Mousterian points could be found in (Fig. 16-19).

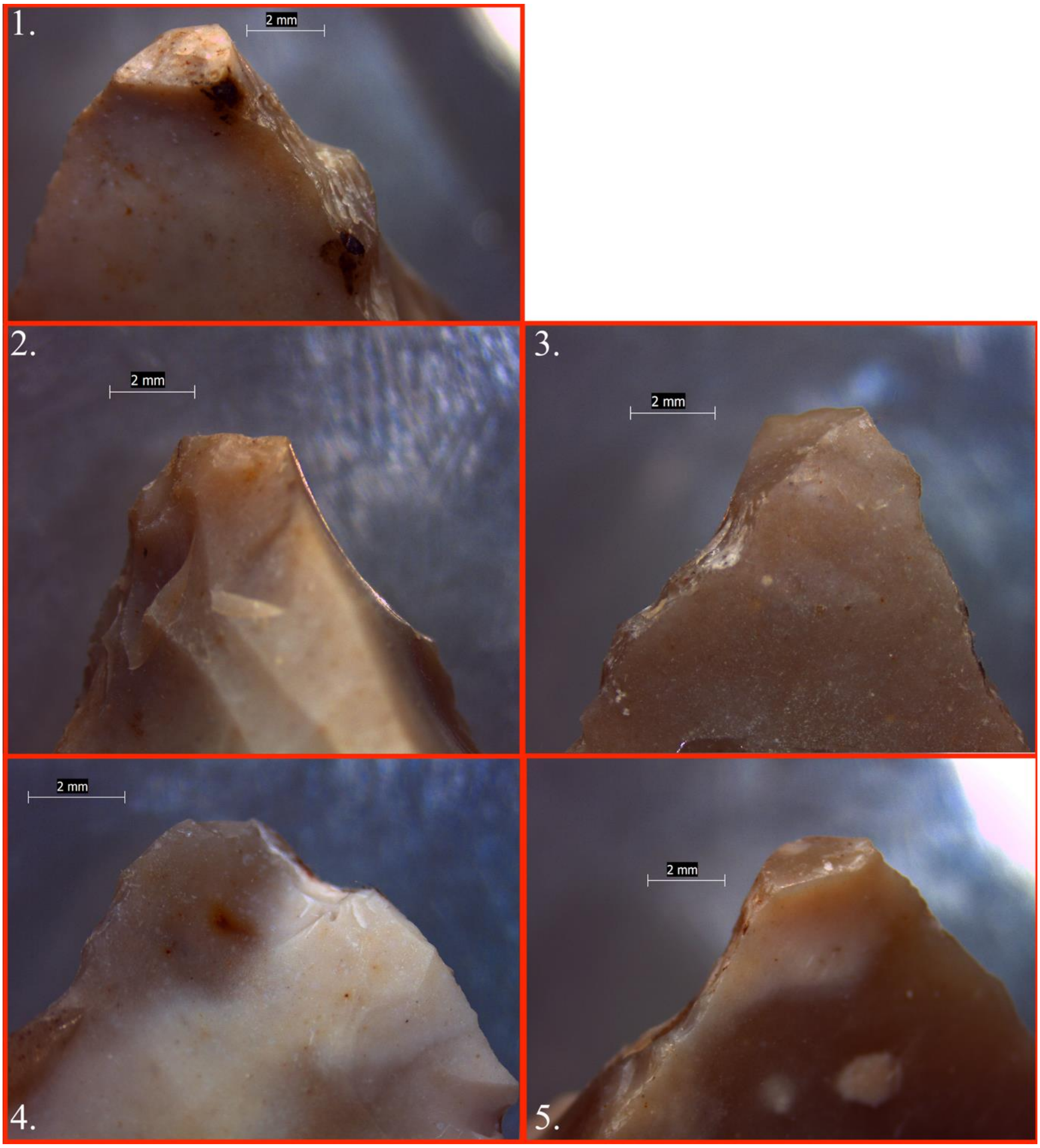


Fig. 9 – *Damage identified on diagonally hafted Mousterian points used for hand-thrown spear technology: 1) point a2 (ventral) – tip crushing and edge damage followed by striations, damage caused by missing the target and hitting the gravel surface; 2) point b3 (dorsal) – tip snap followed by spin-off and step-terminating-bending fracture, caused by rebounding of the the and hitting the gravel surface; 3) point b3 (ventral) – tip snap followed by spin-off (bifacial spin-off) and edge crushing damage made of multiple step-terminating fractures, caused by a knapping incident, rebounding the target and hitting the gravel surface; 4) point c1 (ventral) – spin off fracture followed by edge crushing, caused by missing the target and hitting the gravel surface; 5) point c2 (ventral) – tip snap and edge damage caused by a knapping incident.*

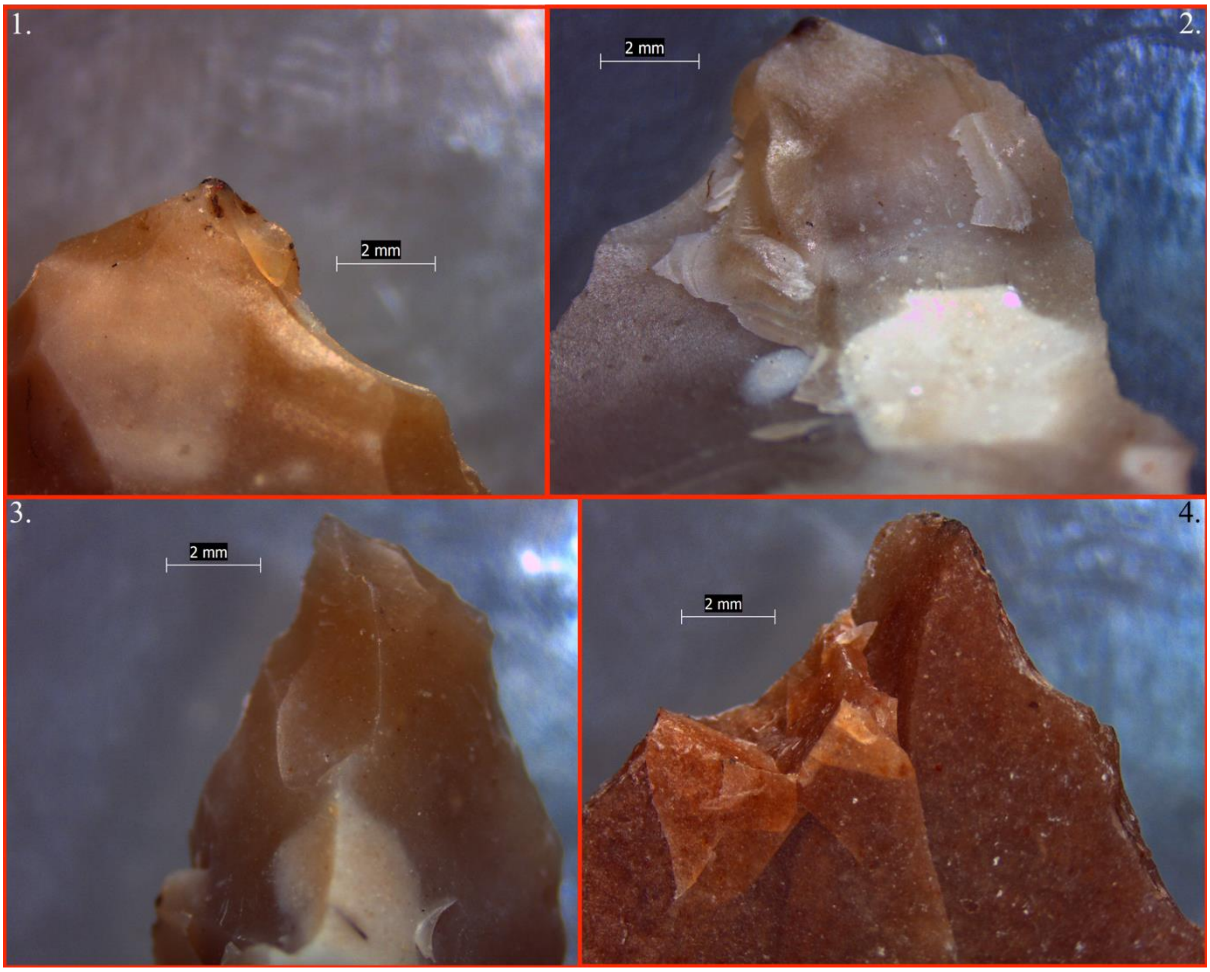


Fig. 10 - *Damage identified on diagonally hafted Mousterian points used for hand-thrown spear technology: 1) point c3 (dorsal) – tip damage and step-termination followed by burin-like fracture caused by knapping incident; 2) point c3 (ventral) – step-terminating bending fracture initialized from the lateral side, caused by a knapping incident; 3) point c10 (dorsal) – two unifacial spin-off fractures, the bigger one (left) was caused by a knapping incident, the second, smaller one (right) was caused by penetrating the target; 4) point d5 (ventral) – multiple burin-like fractures followed by step-terminating fractures caused by missing the target and hitting the wood.*

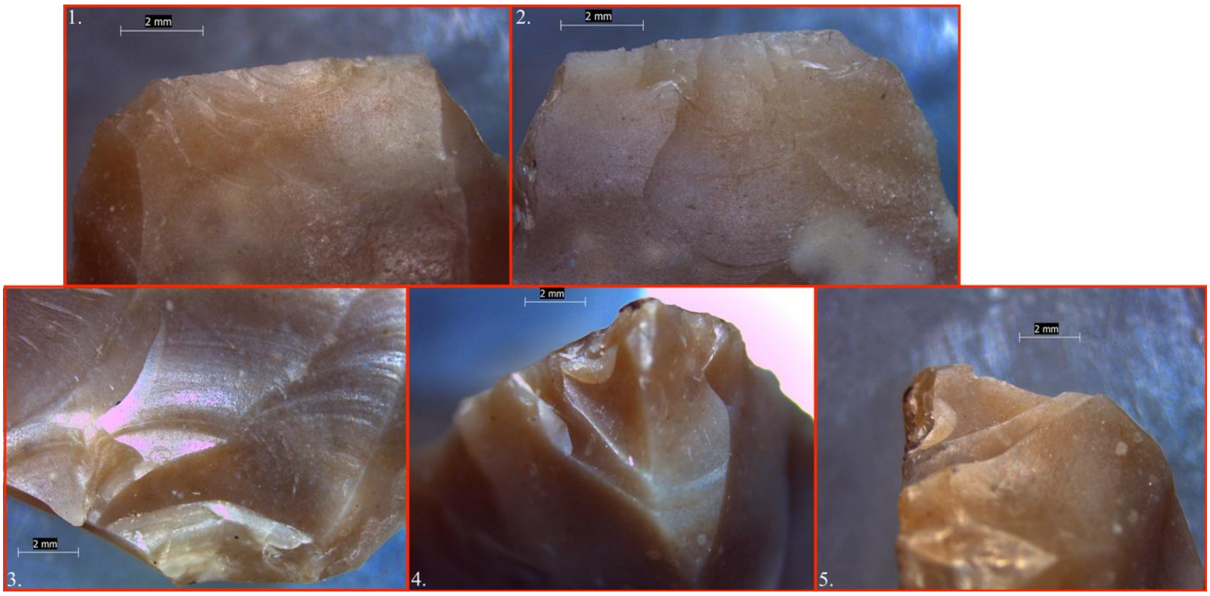


Fig. 11 - *Damage identified on vertically hafted Mousterian points used for hand-thrown spear technology: 1) point a3 (distal dorsal) – tip crushing caused by missing the target and hitting the gravel surface; 2) point a3 (dista) tip crushing followed by unifacial spin-off fracture caused by missing the target and hitting the gravel surface; 3) point a6 (proximal dorsal) hafting damage; 4) point a6 (distal dorsal) – tip crushing followed by burination and multiple step-terminating bending fractures caused by missing the target and hitting the wood; 5) point a6 (distal lateral) – tip crushing followed by burination and multiple step-terminating bending fractures caused by missing the target and hitting the wood.*

In previous studies (Newman and Moore, 2013; Clarkson et al., 2016) it was concluded that TCSA values are an unreliable factor. This experiment supports the previous studies, and Shea's (2006) classification of spears using TCSA method could not be applied on this experimental assemblage. Figure (Fig. 21) of correlations between TCSA and penetration depth confirms that the TCSA values are an unreliable factor, and it cannot be applied to this experimental assemblage. It would not be reliable to establish conclusions regarding a relationship between TCSA and penetration depth using this experimental data, since an obviously important variable such as impact velocity was not controlled. In the attempt to correlate shaft weight to fracture type in thrown diagonally hafted spears it could be certainly seen that step terminating fracture occur at shaft weight of ~ 800*g* and burin-like fracture occur in the wider range of shaft weights ~ 650-1000*g* (Fig. 22).

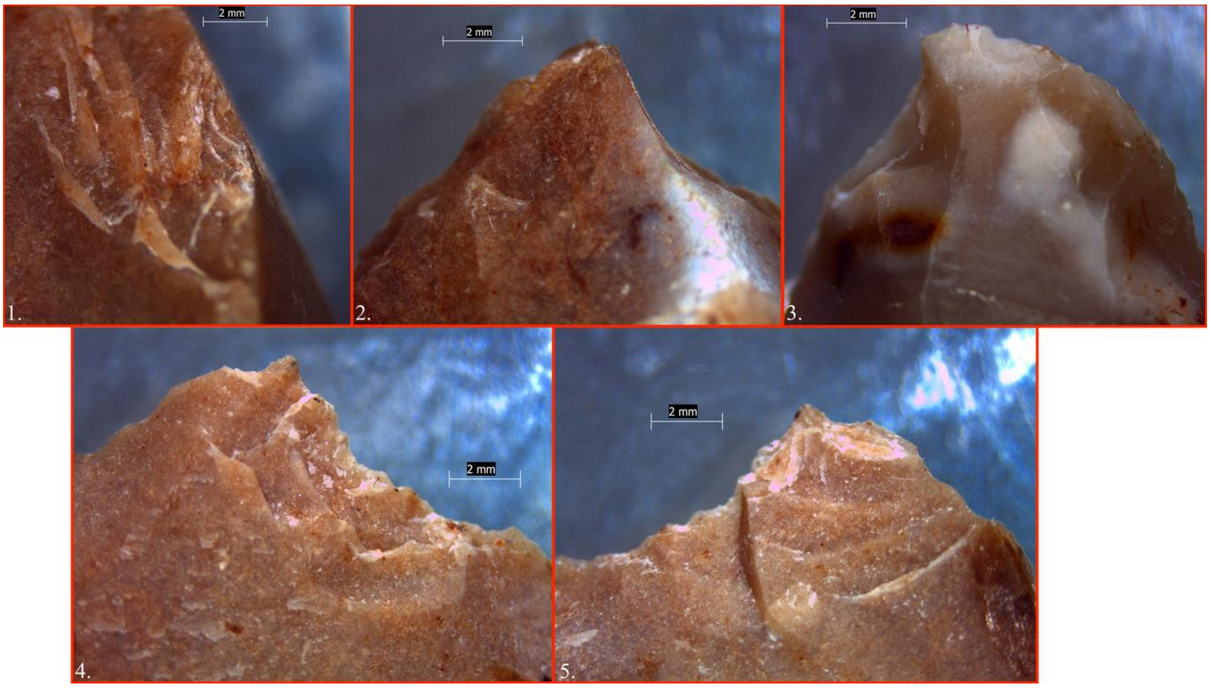


Fig. 12 - *Damage identified on vertically hafted Mousterian points used for hand-thrown spear technology: 1) point b5 (medial lateral) – edge crushing damage, caused by missing the target and hitting the gravel surface; 2) point b8 (distal dorsal) – burin-like with step-terminating bending fracture, caused by missing the target and hitting the gravel surface; 3) point d8 (distal dorsal) – step-terminating fracture on the distal lateral side of the point caused by missing the target and hitting the gravel surface; 4) point d9 (distal dorsal) – tip crushing followed by multiple step-terminating fractures, caused by missing the target and hitting the gravel surface; 5) point d9 (distal ventral) – tip crushing followed by multiple step-terminating fractures, caused by missing the target and hitting the gravel surface.*

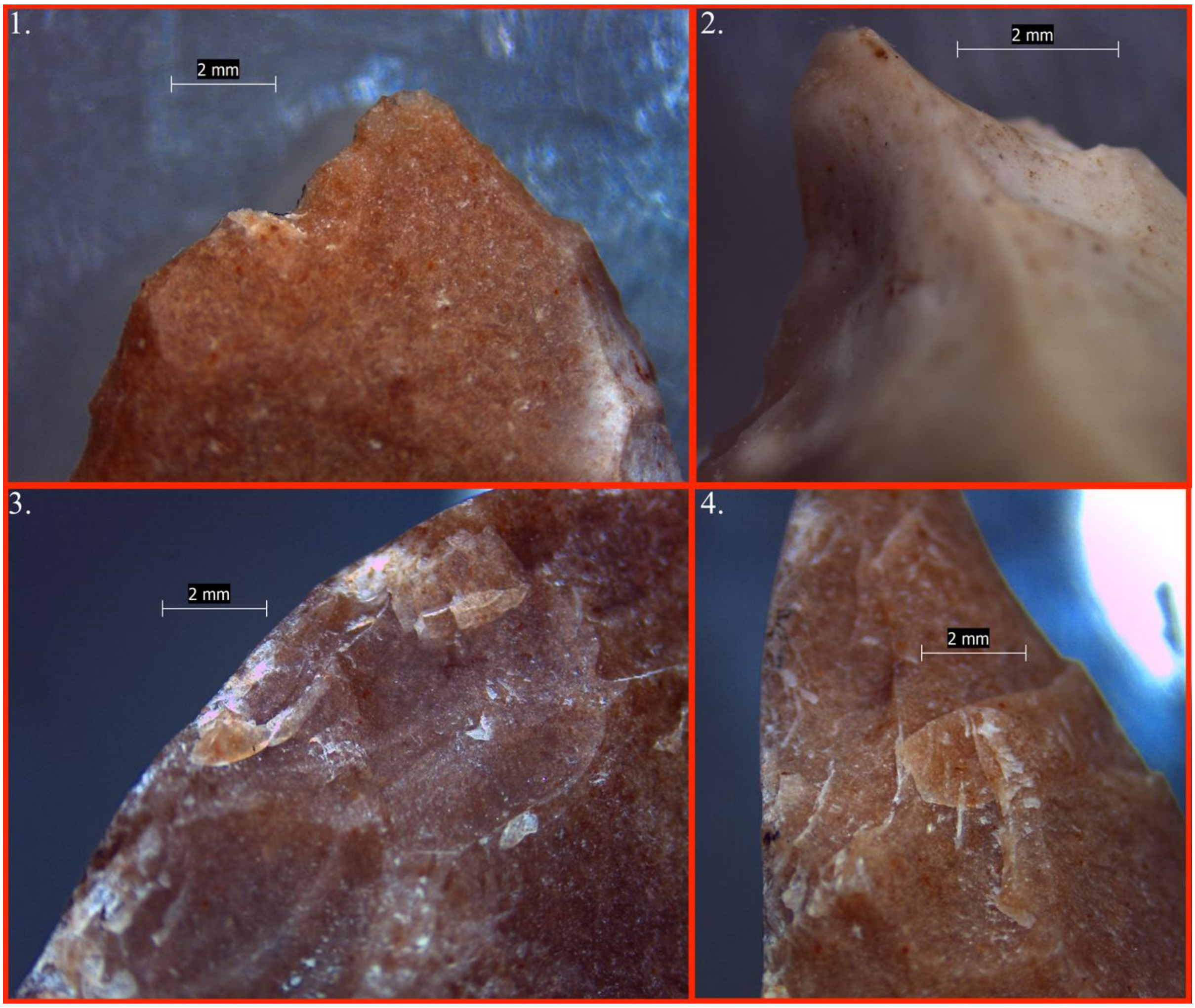


Fig. 13 - *Damage identified on diagonally hafted Mousterian points used in thrusting spear technology: 1) point a4 (distal dorsal) – two burin-like fractures, the burin-like fracture on the left was caused by the rebounding off the target, the burin-like on the right was caused by knapping incident; 2) point a10 (distal dorsal) – unifacial spin-off fracture caused by the penetrating the target; 3) point d7 (proximal-medial lateral) – hafting damage; 4) point d7 (distal lateral) – step termination followed by edge crushing damage, the damage was caused by penetrating the target.*

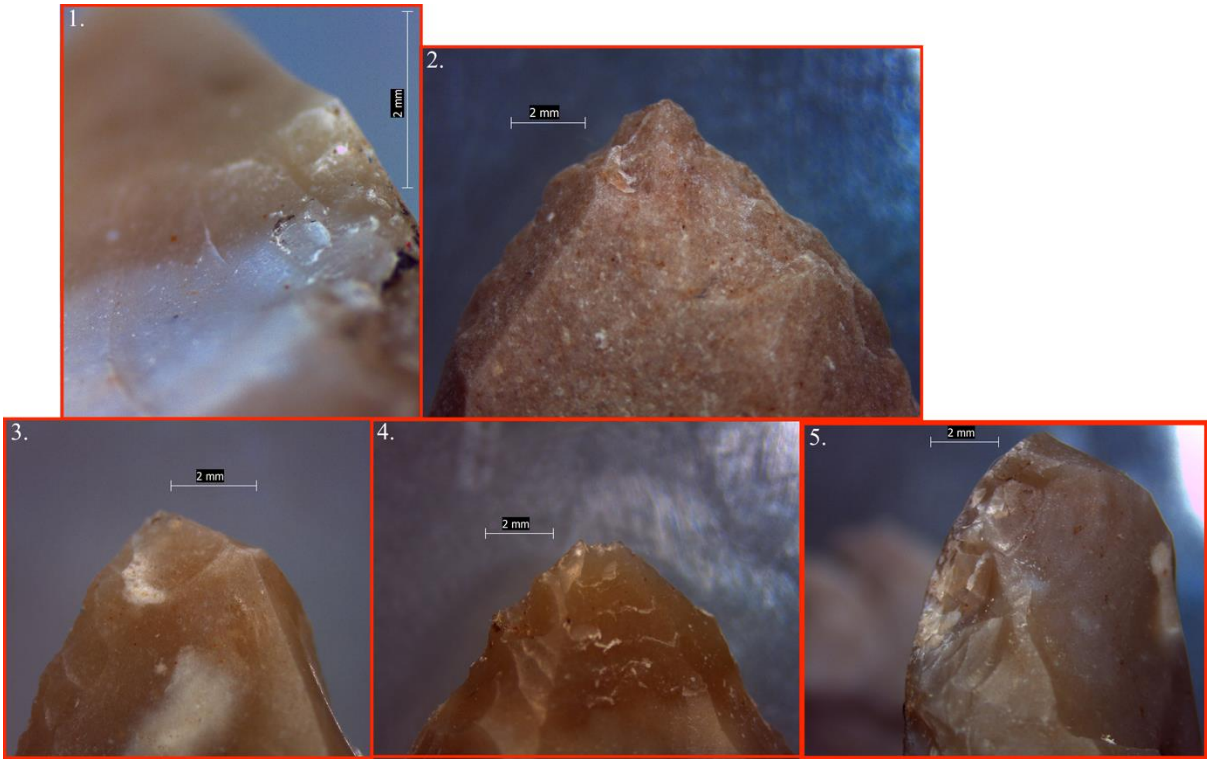


Fig. 14 - *Damage identified on vertically hafted Mousterian points used in thrusting spear technology: 1) point a5 (proximal lateral) – crushing damage followed by unifacial spin-off fracture, caused by rebounding off the target (hafting damage); 2) point a5 (distal dorsal) step-terminating fracture caused by rebounding off the target; 3) point a7 (distal dorsal) – tip snap followed by unifacial spin-off fracture caused by penetrating the target; 4) point a8 (distal dorsal) – striations caused by penetrating the target; 5) point b9 (proximal lateral) – hafting damage, caused by rebounding off the target.*

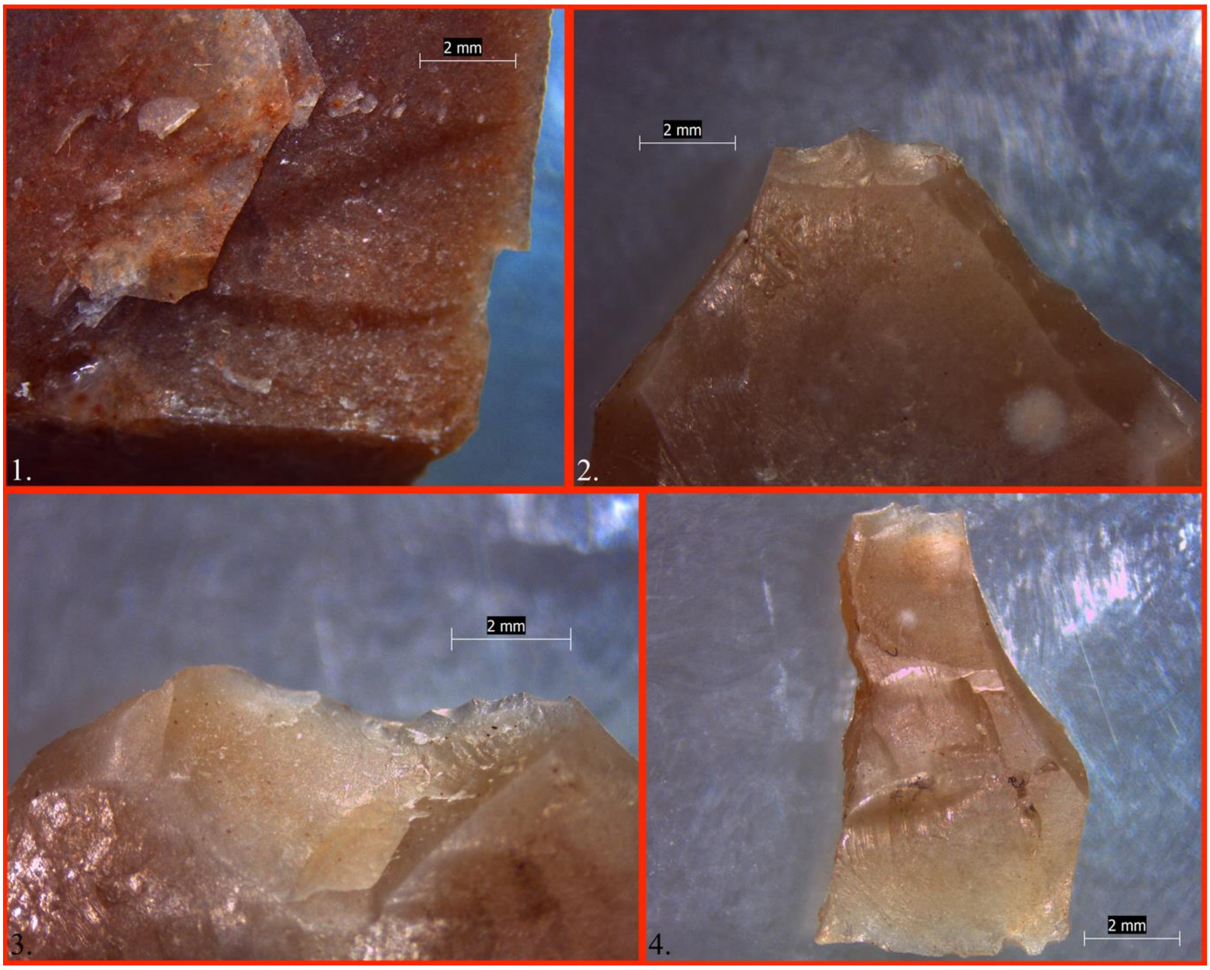


Fig. 15 - *Damage identified on vertically hafted Mousterian points used in thrusting spear technology: 1) point c5 (proximal ventral-lateral) - unifacial spin-off fracture followed by step-terminating bending fractures, hinge fracture and burin-like (hafting damage), caused by rebounding off the target; 2) point d4 (distal dorsal) – two unifacial spin-off fractures caused by penetrating the target; 3) point d6 (distal dorsal) – bifacial spin-off fracture caused by rebounding off the target; 4) refitted piece, a part of distal part of the point d6.*

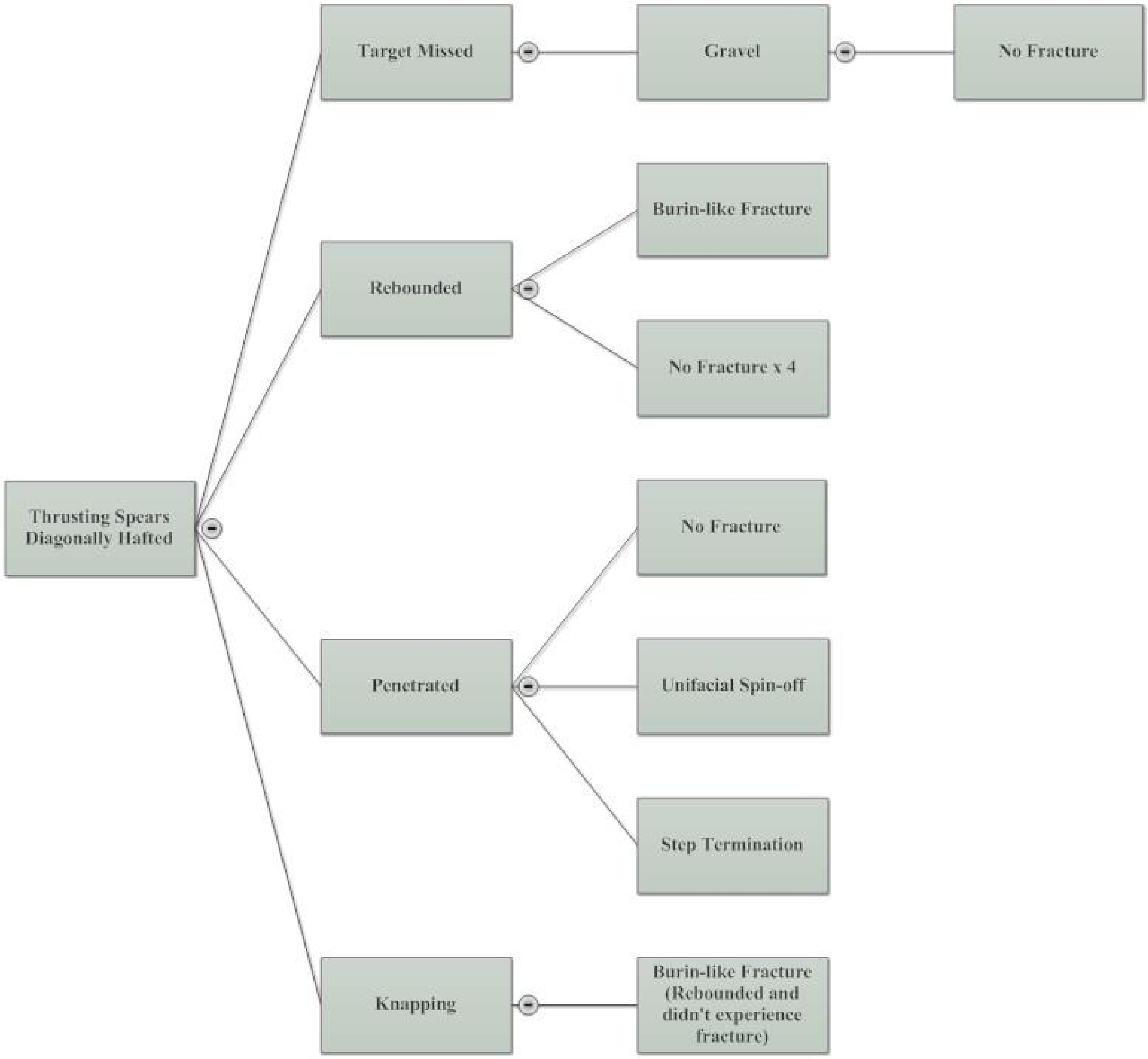


Fig. 16 – Diagonally hafted experimental Mousterian points used as thrusting spears – end point outcomes and identified fractures.

It was noted that burin-like fractures in the thrusting, diagonally hafted spears occurred only if shaft weight is greater than 1.1 *kg*, while spears that did not experience an impact fracture had wide range of shaft weight ~800-1400*g* (Fig. 10). Shaft weight as a factor of impact fracture propagation in both thrown and thrusting vertically hafted spears did not produce significant results (Fig. 21, 22).

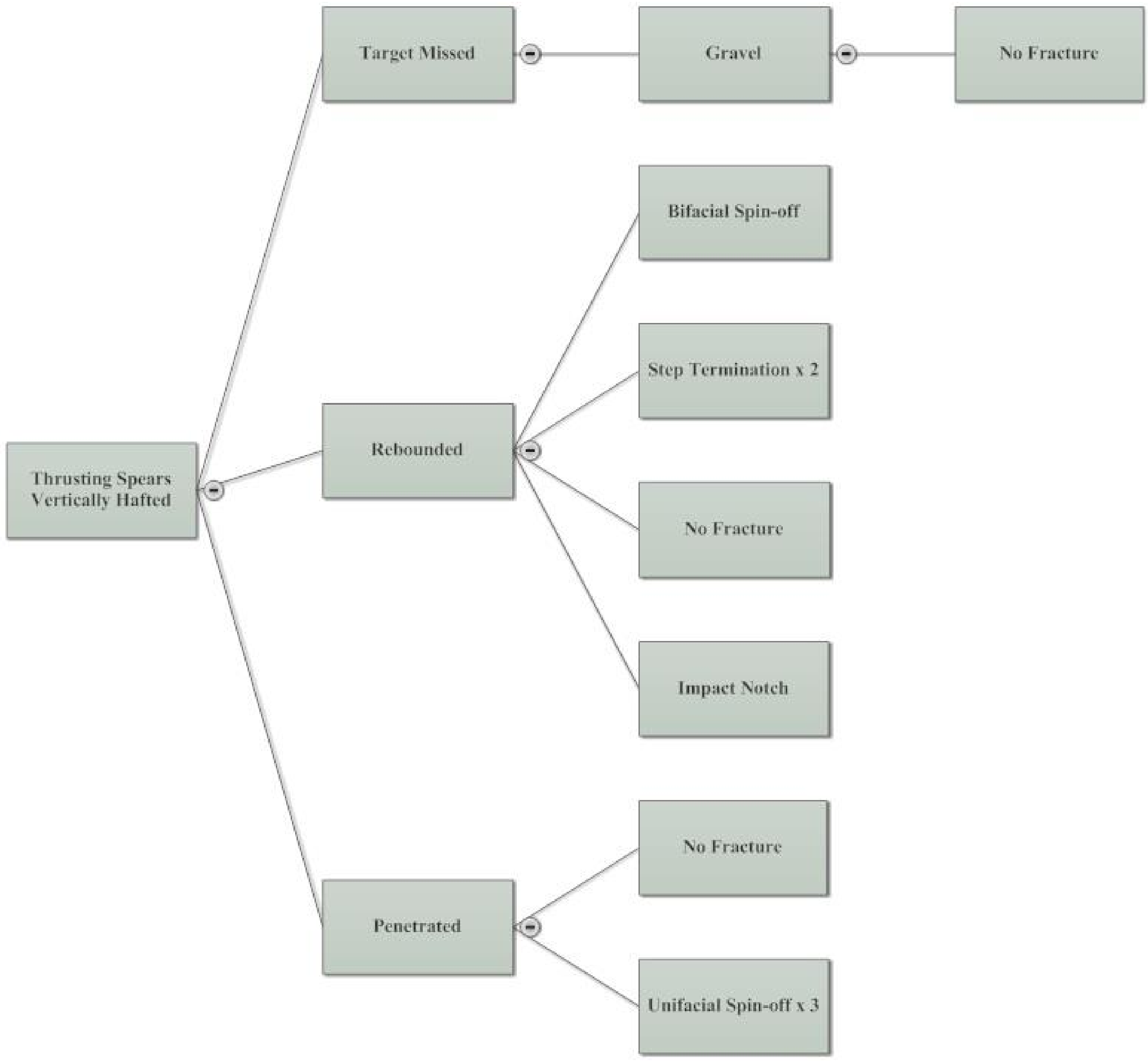


Fig. 17 - Vertically hafted experimental Mousterian points used as thrusting spears – end point outcomes and identified fractures.

The correlation of shaft diameter and fracture type produced interesting results. For diagonally hafted thrown spears, burin-like fracture with step termination occurred if shaft diameters were larger than 30 *mm*, while step termination occurred in shaft diameter of 20-30 *mm*. (Fig. 22). There is a problem in presenting the results of fracture propagation of diagonally hafted thrusting spears: the hafting approach was not appropriate for this type of delivery, i.e. all of the spears have experienced hafting breakage, therefore the results obtained are of questionable reliability (Fig. 22).

Vertically hafted thrown spear experienced step terminating fracture at the same shaft diameter range as diagonally hafted thrown spears, occurring at diameters larger than 30 *mm*. Other impact fractures occurred at the similar diameter range of ~28 *mm*. Vertically hafted thrusting spears experienced fracture if shaft diameter was larger than 30 *mm*. (Fig. 21). Diagonally hafted thrown spears experienced no fracture at the shaft length of ~130 *cm* (Fig. 22). Vertically hafted thrusting spears experienced unifacial spin-off fracture at shaft length of ~ 120-150 *cm* (Fig. 21).

No correlation of shaft length and fracture type could be identified on spears of other hafting and hunting approaches.

When considering impact velocity, it is logical that it has a relationship with impact fractures size. The comparison of fracture type and velocity also produced interesting results. The widest range of occurrences possessed a step terminating fracture, but in almost a similar range of fracture occurrences no fractures occurred (Fig. 20). The velocity in this case is not a diagnostic for correlation with fracture type. No pattern could be detected because there was the same chance for both fracture formation and its absence.

While comparing hafting depth and impact fracture type (Fig. 24), vertically hafted thrown spears experience step terminating fracture and no fracture at all at the hafting depth range of 15-20 *mm*. Burin-like fracture occurred on diagonally hafted thrusting spears at the hafting depth of 20-25 *mm*. Burin like fracture with step termination occurred at the hafting depth 15-17 *mm*, no fractures 18-19 *mm*, unifacial spin off ~27*mm*, step-terminating fracture at very wide ranges 17-27 *mm*. Vertically hafted thrusting spears experienced unifacial spin-off 11-14 *mm,* no fractures 16-19 *mm*, and step terminating fracture again at wide range 10-20 *mm*.

The comparison of hafting depth and penetration depth produced surprising results. Higher hafting depth doesn't result in higher penetration depth. For example, a spear with a hafting depth of 16 *mm*, penetrated 42 *mm* into the carcass, while a spear with a hafting depth of 27 *mm* penetrated 5 *mm* into the carcass (Fig. 21).

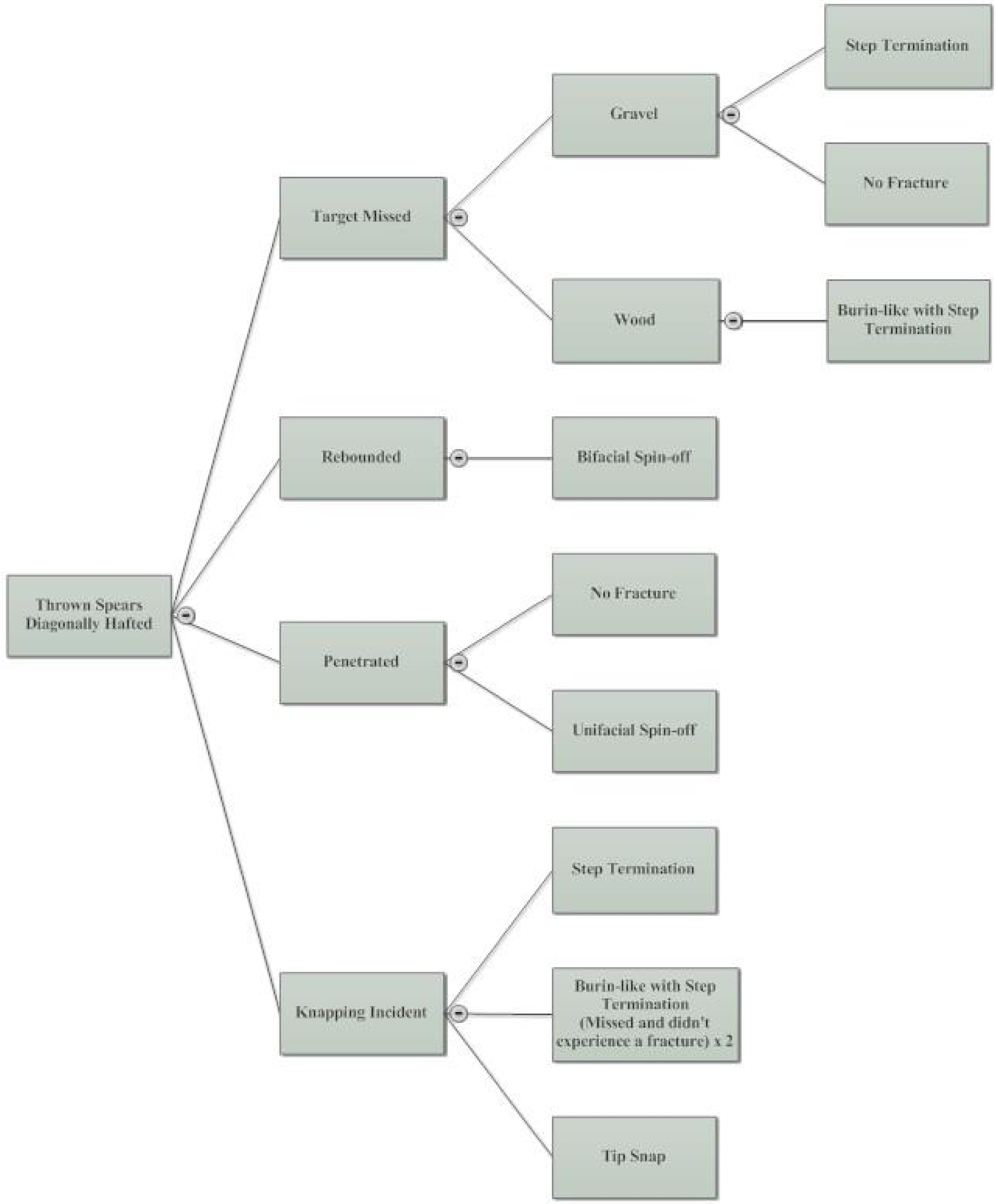


Fig. 18 - Diagonally hafted experimental Mousterian points used as hand-thrown spears – end point outcomes and identified fractures.

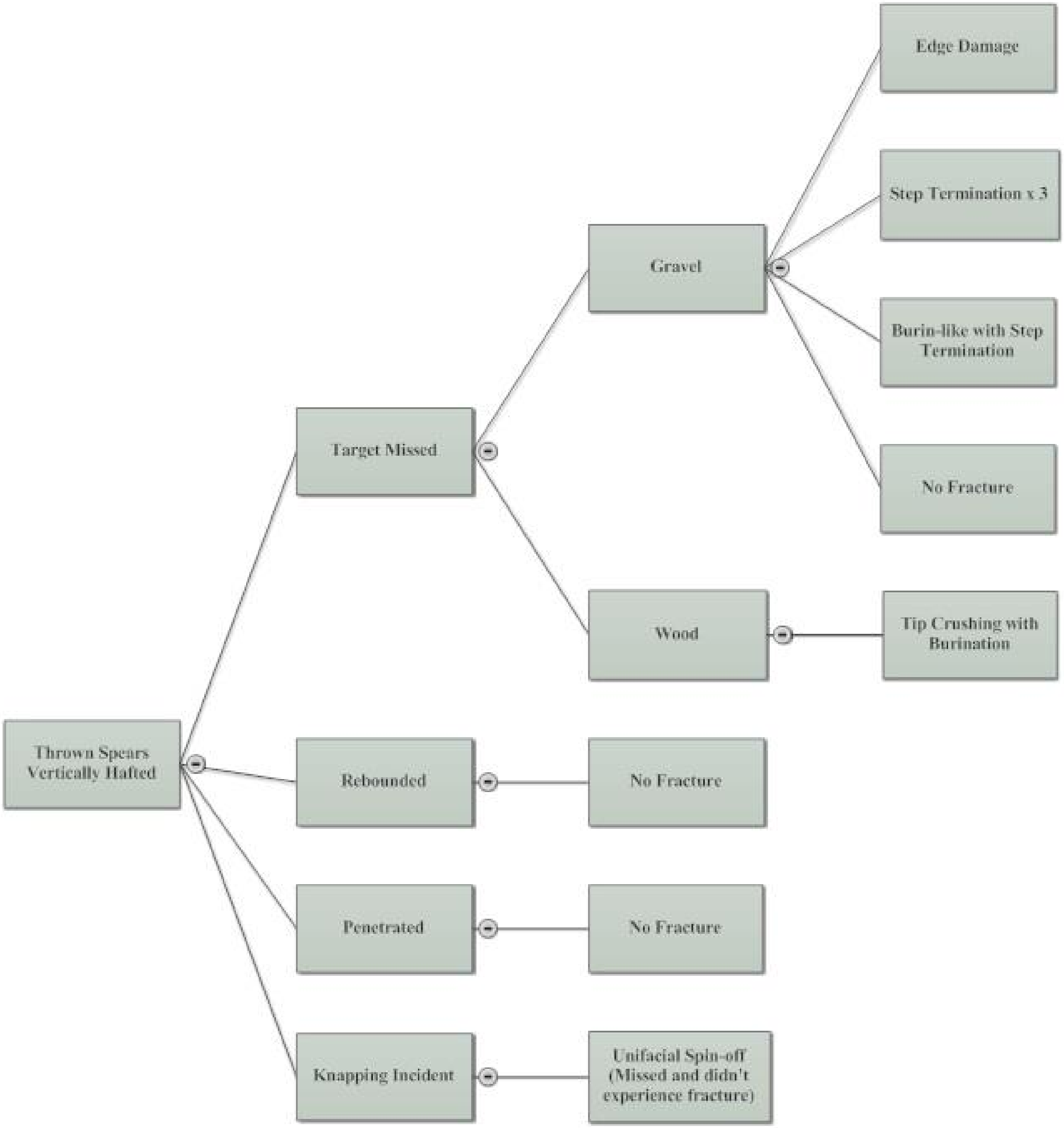


Fig. 19 - Vertically hafted experimental Mousterian points used as hand-thrown spears – end point outcomes and identified fractures.

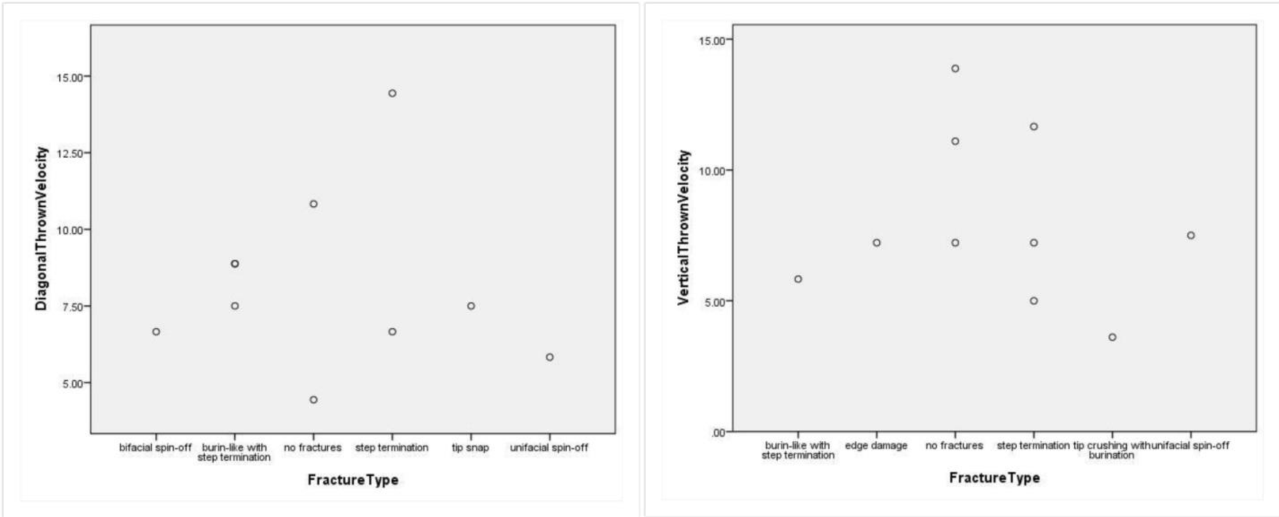


Fig. 20 – Comparison of impact velocities of diagonally (left) and vertically (right) hafted hand-thrown spears and fracture types.

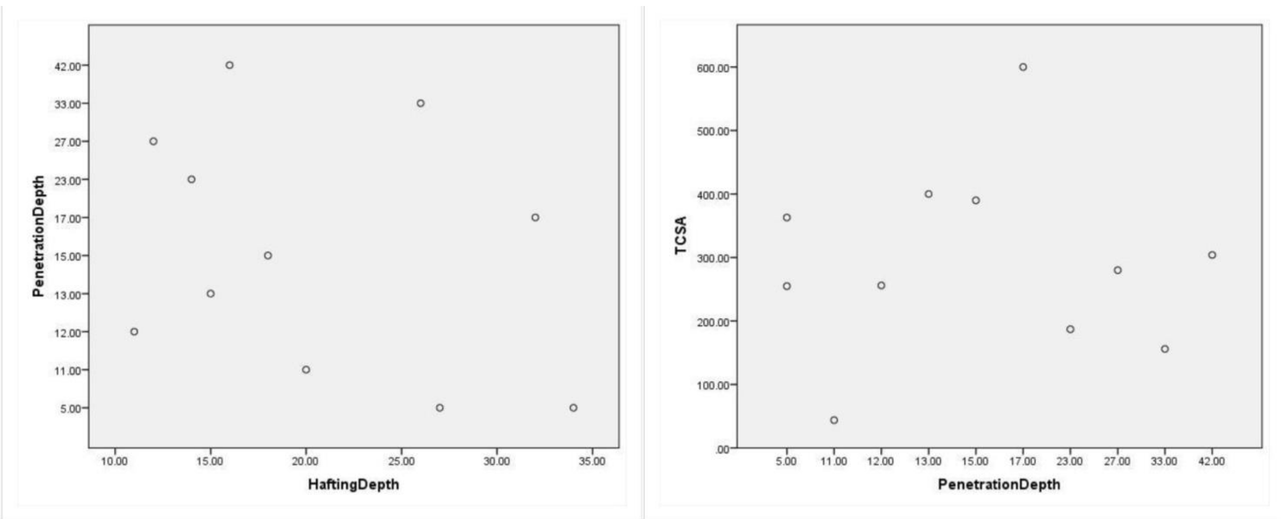


Fig. 21 – Comparison of penetration depth and hafting depth (left), and comparison of TCSA values and penetration depth (right).

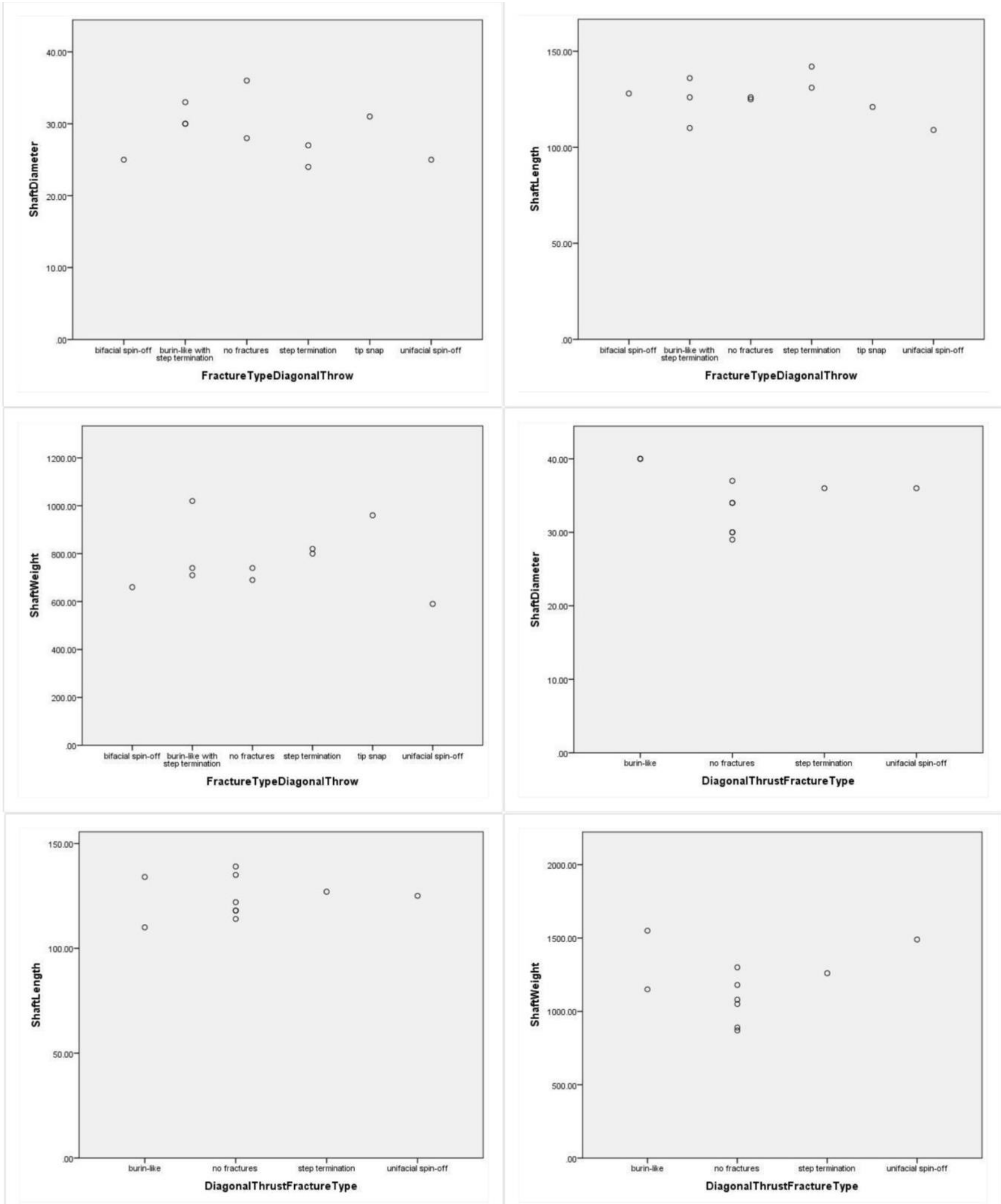


Fig. 22 – Comparison of shaft morphometric values and fracture types present on diagonally hafted spears.

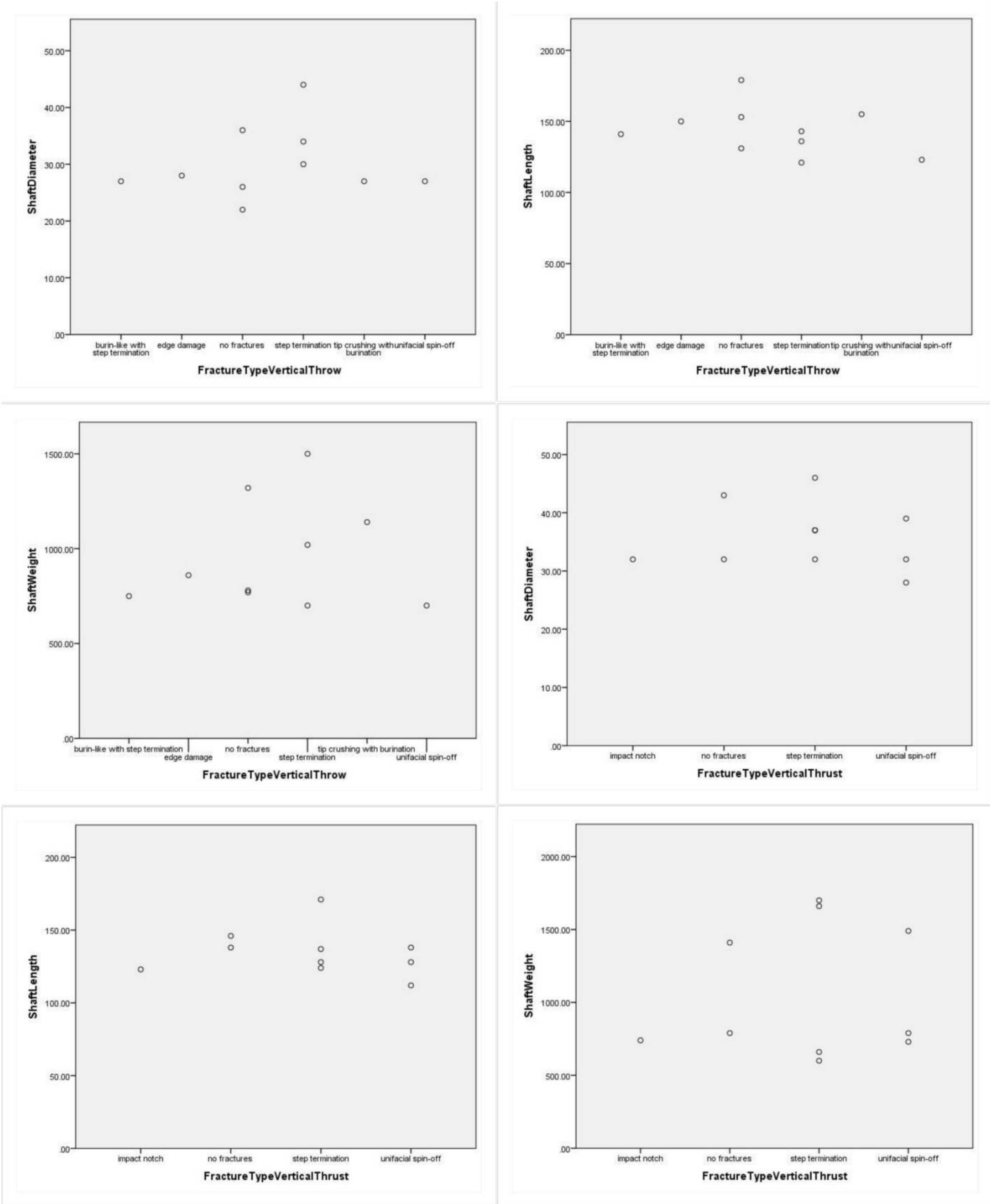


Fig. 23 - Comparison of shaft morphometric values and fracture types present on vertically hafted spears.

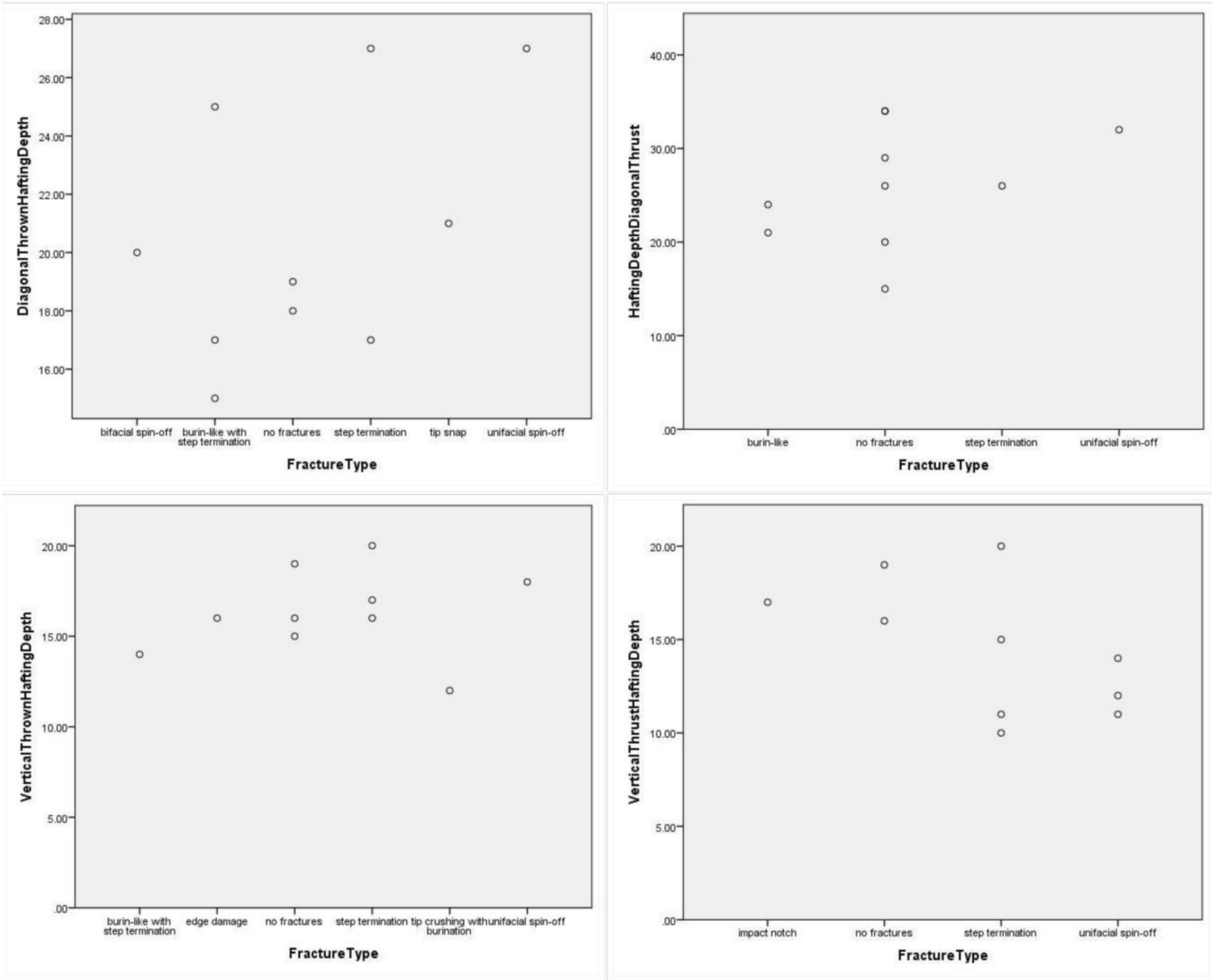


Fig. 24 – Comparison of hafting depth and fracture types present on diagonally and vertically hafted spears.

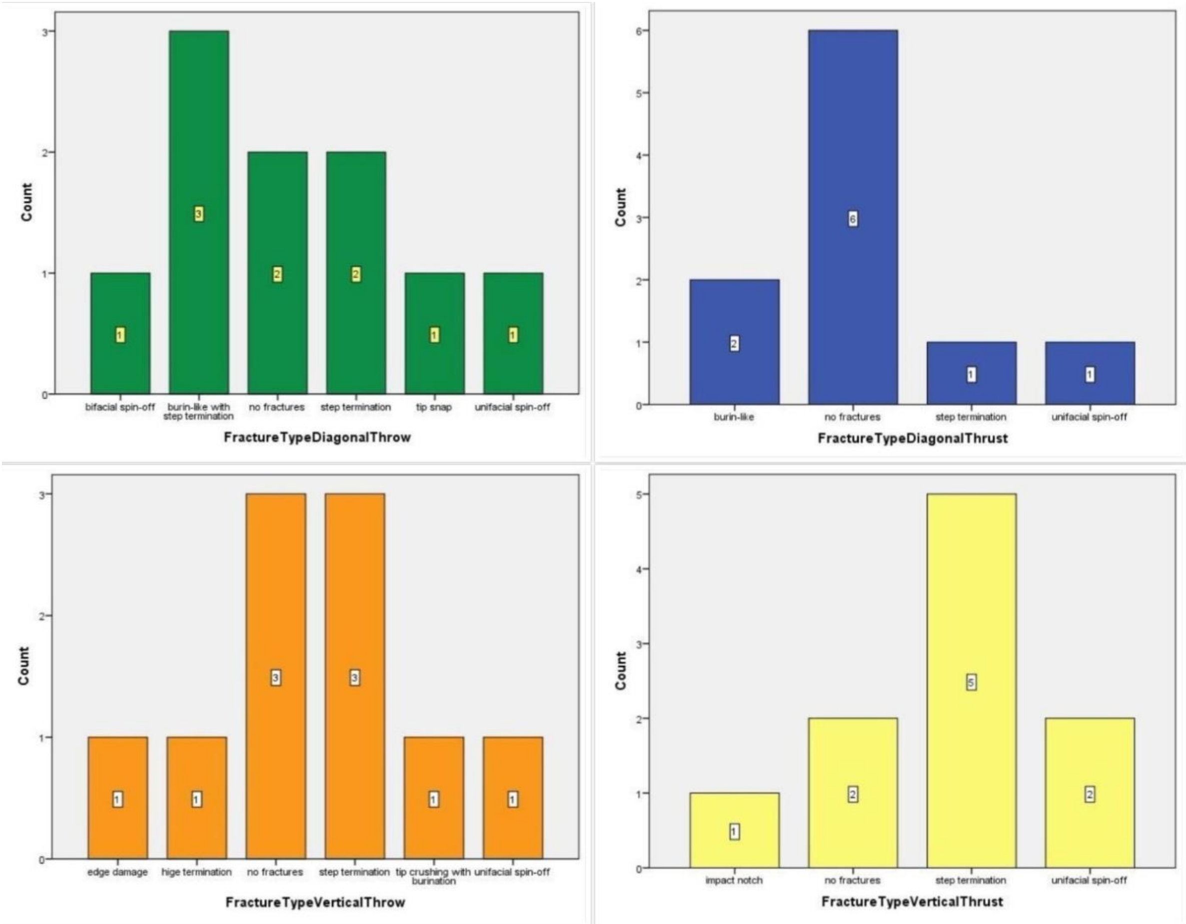


Fig. 25 – Fracture types present on diagonally hafted hand-thrown and thrusting spears and vertically hafted hand-thrown and thrusting spears.

3.5. Conclusions

Even though the experimental sample was very small for this type of research, it was possible to obtain through basic descriptive statistical analysis an insight into probable correlations between variables. The prey is hunted by either penetrating the vital organs or by causing severe blood loss (Frisson, 1978; Pargeter, 2007). Spears used in this experiment could be efficient only for causing severe blood loss. The fracture that is present in all possible outcomes is step terminating fracture, and therefore it presents a great problem in this research. Spin-off fractures, which are considered as one of the most distinctive diagnostic impact fractures (Fischer et al., 1984), are highly present on points that penetrated the target. This could mean, but taken with a high dose of caution, that if unifacial-spin-off fracture is identified on the original material, there is a great possibility that the spear actually hit the target. Also, the Pargeter's experiment (Pargeter, 2011) confirmed that spin-off fractures are the most diagnostic; only in one case was it noted in trampled and knapping assemblage. This experiment was not focused on trampling, but one case of spin-off fracture was also noted as a product of knapping incident. Forming of impact fractures when hitting wooden surface needs further research, because hitting the wooden surface occurred only twice during the experiment. In both cases impact fracture was identified- one unifacial spin-off and one burin-like with step termination. In Fischer's experiment (Fischer et al., 1984) two step terminating bending fractures were caused by hitting a wooden surface. In addition, an interesting result of the rebounded experimental spears showed that six out of eleven points did not experience impact fracture at all. This might be explained by the poor functionality of diagonally hafting the Mousterian point in both delivery methods. Rots' functional analysis (Rots, 2009) of Mousterian and Micoquian assemblage of Sesselfelsgrotte in Germany, described one specific use-wear trace as use scarring on the dorsal scraper-head, and it was stated that its causation was probably wood chopping. Similar damage was identified and classified as edge damage on one point of this experimental assemblage (Fig. 12/1). The point was hafted vertically and it was used as a thrown spear. The cause of edge damage was missing the target and hitting the gravel surface. Impact burination and unifacial spin-off were documented on the Pargeter's knapping experiment (Pargeter, 2011). The highest variety of identified fractures on this hunting simulation experimental assemblage was the product of a knapping incident.

As it was stated in various previous studies (Fischer et al., 1984; Lombard et al., 2004; Iovita et al., 2013), the correlation of hafting and delivery method with fracture type in this study needs further research with a greater number of samples used in the experiment. Although an appealing result was gained in searching for differences of impact fractures of vertically and diagonally hafted points, burin like fractures were identified only on vertically hafted spears, both in throwing and thrusting hunting technology. Vertically hafted thrown spear points experienced step terminating fracture on three out of ten samples, and the same number of samples did not experience any fractures. There is a problem with step terminating fracture because it was present in all of the hafting methods, it was also identified on five out of ten samples of the vertically hafted thrusting spear points. By fracture type it could be possible to reconstruct the possible shaft weight and shaft diameter for example, burin-like and step-terminating fracture (Fig. 22, 23), shaft length did not produce any significant result, another research is needed for that factor of impact fracture propagation.

Impact velocity was also a difficult factor for fracture propagation as there was an equal chance that fractures could either be formed or not at the same delivery speed, so this factor should not be taken as a standalone.

This study has demonstrated the complexity of the relationship between variables present in fracture formation. The formation of fracture can occur in the first phase of spear manufacture - the knapping of the stone tool. When the point is hafted and the spear is ready for usage, there are many variables that can influence the development of the fracture, for example: the delivery method, distance between the hunter and the prey, shaft morphology, hafting type, binding material, type of animal that is hunted, point morphology, raw material, speed of delivery, the end result (penetration, miss, rebound, surface type - if missed). Each of these variables will have to be studied separately through experimental approach in order to gain reliable results of correlation between them. All of the recent experiments that studied these variables had one problem in common: the sample size was too small for reliable results (Fischer et al., 1984; Plisson and Beyries 1998; Lombard et al., 2004; Pargeter, 2007; Sisk and Shea 2010; Schoville and Brown, 2010; Rots, 2013; Iovita et al., 2013).

Step terminating fracture needs more attention in future research because it was the most dominant impact fracture in this experimental assemblage and it is present in both hafting types and end result outcomes. Burin-like facture also produced intriguing results, it was identified in greater number in diagonally hafted points and if the shaft weight was 1.2 *kg*. or greater. Based on the previous studies, it was demonstrated that TCSA measures are highly unreliable indicators of performance in experiments (Newman and Moore, 2013; Clarkson et al., 2016). The results of this experiment confirmed the results of previous studies. It was expected that rebounded points would experience spin-off factures, similar to the points that penetrated the target, but this was not the case. The cause for this outcome could be that hafting approach was not suitable for thrusting spears.

Hafting depth could be one of the most important factors of both impact fracture and functional analysis. Based on the data of this experimental assemblage (Fig. 21), it can be concluded that the higher hafting depth doesn't result in higher penetration depth.

Another experiment should be completed in order to obtain an insight into the correlation between the impact fracture formation and wooden targets, since hitting the wooden target occurred twice during the experiment and both times an impact fracture was formed. The problem of this type of experiment is that there was no exact, i.e. sufficient number of pieces that should be used for experiment execution. This was the kind of experiment that should be repeated over and over again. The prehistoric mode of delivery indeed leaves many variables uncontrolled for, but the results are of higher reliability. On the other hand, when we do control variables as much as possible by using modern equipment in experiment execution, such as calibrated crossbow, air guns and artificial targets, we do get statistical power, but the problem of how reliable are those more powerful statistical results remains.

4. Second experiment – Searching for diagnostic impact fractures caused by the knapping of Mousterian points

When processing lithic material from Paleolithic sites, i.e. waste flakes, blades, points, scrapers, a substantial number of impact fractures, even the diagnostic ones (DIFs) could be identified (Goval, 2016; Lazuén, 2012; Lombard, 2005; 2007; Rots, 2009; 2013; Sano, 2009; Yaroshevich, 2013). A lot of those fractures are created by impact, but they don't necessarily have to be a signal that the stone tool was used as a weapon; they could have been formed during the knapping process.

After the execution of the first experiment, because of the conclusion that the highest variety of impact fractures was formed as a knapping incident, the second, knapping experiment was planned and executed.

4.1. The research aims of the second experiment

This experiment was executed in order to identify the types of impact-like fractures that occur on stone tools and flakes during the knapping of Mousterian points. Aside from an attempt of assessing the quantity of the macrofractures/diagnostic impact fractures in the knapping assemblage, the aim of this experiment was to have an experienced and inexperienced knapper knap five Mousterian points each and gain an insight into differences in the typology, quantity and causes of the impact fractures, the amount of time needed for knapping the points and the quantity of waste flakes produced that depended on the experience of the knapper.

The experiment was executed in order to obtain answers to following the research questions:

1. Which knapping variables are most likely to cause the formation of the impact fractures?

2. Which impact and diagnostic impact fractures could be caused by a knapping incident?

3. To what extent do the knapping experience influence the impact fracture formation?

4. Can we find a correlation between impact fracture type and cause – certain knapping variable (striking angle, retouching, platform preparation etc.)?

5. Which impact fracture that is considered as DIF could be identified a product of a knapping incident?

6. Could we "identify" the knapper's experience based on the impact fracture?

4.2. Materials and methods

Decorticated core sizes were approximately the same in order to reduce the number of variables: the inexperienced knapper used a 124x94x69mm core, while the experienced knapper worked on a 129x91x67mm core. Inexperienced knapper was the author of this dissertation, the experienced knapper was my PhD advisors. Chert was the only raw material used in the experiment in order to reduce the number of variables. Raw material presents an important role in fracture formation, but it is of less importance than use and taphonomy (Lombard et al., 2004; Pargeter, 2011, Pargeter, 2013). The same hard hammer-stone was used by both knappers. The only surface the flakes could fall on after being knapped from the core was a stone floor covered with a plastic wrap. Each flake was labeled and processed in order to identify the presence or absence of impact-like fractures. After each strike, the flakes were analyzed for damage in order to avoid confusion and misinterpretations of which knapping variable was the cause of the damage formation.

Each fracture that was identified as being caused by impact was analyzed both macroscopically and using a low-magnification stereoscopic microscope (Leica LAS EZ) at 8x magnification. Descriptive statistical approach was used for interpretation of identified damage.

4.3. The results of the second, knapping experiment

The number of flakes that the inexperienced knapper produced while knapping five Mousterian points was 385. Experienced knapper produced 213 flakes while knapping five Mousterian points. Fractures were analyzed macroscopically. Descriptive statistics were used for detailed analysis of fractures. Variables that this experiment focused on were impact fracture typology, size, area and fracture cause.

	Inexperienced knapper	Experienced knapper
Time needed	45 minutes	16 minutes
Flakes knapped (total)	385	213
Fractures present (total)	42	19
Fracture area (dominant)	Proximal dorsal	Lateral
Fracture cause (dominant)	Bad striking angle	Hitting the ground
Fracture type (dominant)	Step-terminating	Burin-like/ impact notch
DIFs (total)	8 (2,07%)	7 (3,28%)
Fractures present on the whole experimental assemblage	10,9%	8,92%

Table 10 – The results of a knapping experiment of both experienced and inexperienced knapper's assemblage.

Inexperienced knapper's assemblage had bigger percentage of fracture presence and it took him more time than the experienced knapper to knap five Mousterian points (Table 10, 12, 13, 16, 18). In the inexperienced knapper's assemblage the most present fracture is step-terminating fracture (31%) (Table 10), most of the fractures are formed on the proximal dorsal side (47,6%) of the flake (Table 16). Bad striking angle is the variable that caused most of the fractures (35,7%) (Table 13). Fractures are present on 10,9% of the inexperienced knappers assemblage (Table 10). Impact notch and burin-like fracture are the most common in the experienced knapper's assemblage, both having the same frequency (21.1%) (Table 10, 14). Most of the fractures were identified on the lateral side of the flake (52,6%) (Table 17). Flakes hitting the ground after being knapped from the core was the main cause of the fracture formation (47,4%) (Table 15). Fractures are present on 8,92% of the experienced knapper's assemblage (Table 1). Identified DIF-s are presented in Table 11.

While focusing solely on Mousterian points, a crushing fracture was identified in both knapper's assemblages. Fractures were not formed on two points on experienced knapper's assemblage (Table 19), while on one point knapped by inexperienced knapper fractures were not identified (Table 18). Both knapper's produced one example of spin-off fracture larger than 6 mm (Table 18, 19).

Detailed descriptive statistics have been executed in order to get a better insight into the variables. Fracture areas and fracture types for both knappers are presented in a figure (Fig. 26). Platform preparation was the cause of fracture sizes ranging between 4-6 mm for inexperienced and 2-7 mm for experienced knapper (Fig. 26).

For both knappers, impact notch was 2-5 mm. Step terminating-bending fracture was 1-10 mm for inexperienced and 6-10 mm for experienced knapper. On the experienced knappers assemblage spin-off was 2-11 mm and 5-13 mm on inexperienced knapper's assemblage (Fig. 28). Flake thickness was taken as an important variable of fracture propagation, because fractures are more likely going to occur on thinner flakes. Impact notch formed on flakes that were 5-10 mm thick for inexperienced and 2-5 mm for experienced knapper. Spin-off with step-terminating-crushing fracture formed on flakes that were 5-18mm for the inexperienced and 10-19 mm for experienced knapper. Step terminating fracture occurred on a wide span of flake thickness on inexperienced knapper's assemblage, 2-17mm, while 8-11 mm on experienced knapper's assemblage (Figure 29).

Comparison of fracture causes and fracture types are present in a figure (Fig. 30). Also, an important descriptive statistics of fracture area and fracture cause are presented in figure (Fig. 31).

Examples of fractures obtained in this experimental research from both knapping assemblages are presented in figures (Fig. 32, 33).

Fracture type	**Inexperienced knapper**	**Experienced knapper**
Spin-off fracture > 6 mm	4 (1,03%)	3 (1,4%)
Burin-like fracture	4 (1,03%)	4 (1,87%)
Bifacial spin-off	0	0

Table 11 – Diagnostic impact fractures present on the experimental knapped assemblage.

4.4. Knapping experiment – Bad striking angle as a fracture cause

Step-terminating fracture was the most present fracture in the inexperienced knapper's assemblage and the main cause of it was bad striking angle. In experienced knapper's assemblage crushing, burin-like fractures and impact notches were not identified as a cause of bad striking angle. Bad striking angle was one of the causes of formation of all fracture types used in this research, except for the impact notch in inexperienced knapper's assemblage. It is known that the flake angle determines the flake size, not the striking force (Dibble and Rezek, 2009). Due to the inability of the inexperienced knapper to control the angle of every single strike, fracture types varied considerably. Experienced knapper was able to control the striking angle much better, and only three types of fractures were identified: spin-off, spin-off > 6 mm and step terminating fractures.

4.5. Accidental dropping/ flakes hitting the ground as a fracture cause

Macrofractures on the flakes' lateral and distal sides were probably caused by hitting the ground. It was the only other possibility because fractures caused by retouching, bad striking angle and platform preparation were spotted on sight.

Burin-like fracture and impact notch are the two most present fractures in both knapping assemblages, while spin-offs and step-terminating-bending fracture were identified only once in each assemblage. One example of crushing fracture was identified in experienced knapper's assemblage. In the experiments of Hutchings (2011), it was reported that most of the damage was concentrated on the tip of the stone tools, one shattered, and on two of them burinated lateral margins were formed. The problem is that these two experiments could not be directly compared since the stone tools used in Hutchings's experiment were hafted as spear-thrower darts and it was not a knapping experiment.

4.6. Retouching as a fracture cause

Retouching the Mousterian points was the cause of one crushing, two step-terminating fractures, and one spin-off > 6 mm in inexperienced knapper's assemblage (Fig. 30). One crushing fracture, one spin-off and one spin-off > 6 mm were identified in the experienced knapper's assemblage, retouching was the cause of the formation of these fractures (Fig. 30).

		Frequency	Percent
Valid	burin-like	4	9.5
	crushing fracture	10	23.8
	impact notch	6	14.3
	spin-off	5	11.9
	spin-off > 6 mm	4	9.5
	step-terminating bending fracture	13	31.0
	Total	42	100.0

Table 12 - Macrofractures – Inexperienced knapper's assemblage.

		Frequency	Percent
Valid	bad striking angle	15	35.7
	hitting the ground	8	19.0
	platform preparation	6	14.3
	retouching	13	31.0
	Total	42	100.0

Table 13 - Macrofracture cause - Inexperienced knapper's assemblage.

		Frequency	Percent
Valid	burin-like	4	21.1
	crushing fracture	3	15.8
	impact notch	4	21.1
	spin-off	2	10.5
	spin-off > 6 mm	3	15.8
	step-terminating bending fracture	3	15.8
	Total	19	100.0

Table 14 - Macrofractures – Experienced knapper's assemblage.

		Frequency	Percent
Valid	bad striking angle	5	26.3
	hitting the ground	9	47.4
	platform preparation	3	15.8
	retouching	2	10.5
	Total	19	100.0

Table 15 - Macrofracture cause - Experienced knapper’s assemblage.

		Frequency	Percent
Valid	distal	4	9.5
	lateral	12	28.6
	medial	1	2.4
	proximal	2	4.8
	proximal dorsal	20	47.6
	proximal ventral	3	7.1
	Total	42	100.0

Table 16 - Macrofracture area - Inexperienced knapper’s assemblage.

		Frequency	Percent
Valid	distal	3	15.8
	lateral	10	52.6
	proximal dorsal	3	15.8
	proximal ventral	3	15.8
	Total	19	100.0

Table 17 - Macrofracture area - Experienced knapper’s assemblage.

		Frequency	Percent
Valid	crushing fracture	1	20.0
	no fractures	1	20.0
	spin-off > 6 mm	1	20.0
	step-terminating bending fracture	2	40.0
	Total	5	100.0

Table 18 - Mousterian points – Fracture types present on the inexperienced knapper’s assemblage.

		Frequency	Percent
Valid	crushing fracture	1	20.0
	no fractures	2	40.0
	spin-off	1	20.0
	spin-off > 6 mm	1	20.0
	Total	5	100.0

Table 19. Mousterian points – Fracture types present on the experienced knapper's assemblage.

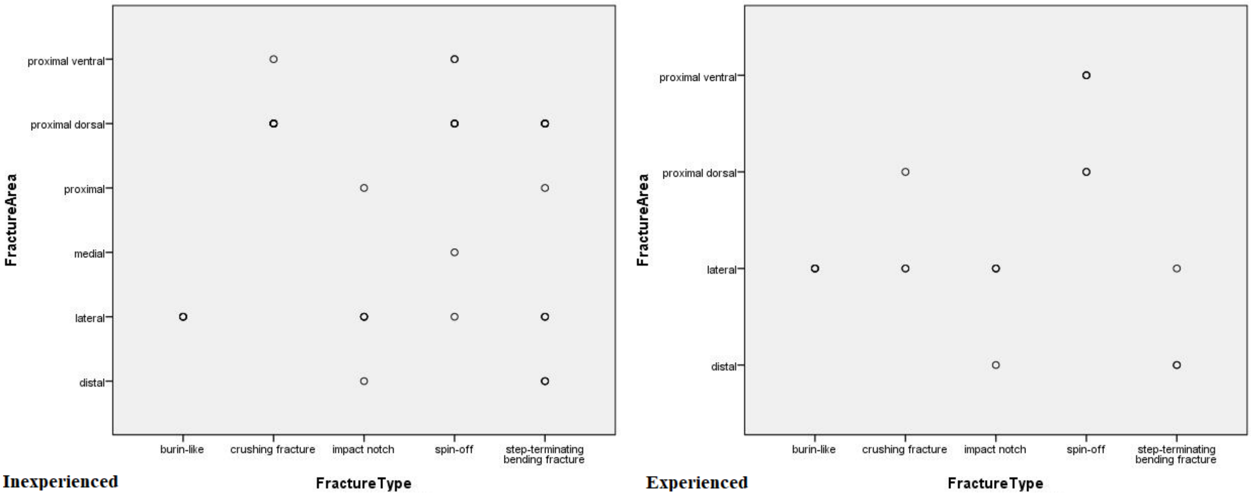


Fig. 26 – Comparison of the fracture area and fracture type for both knappers' assemblages.

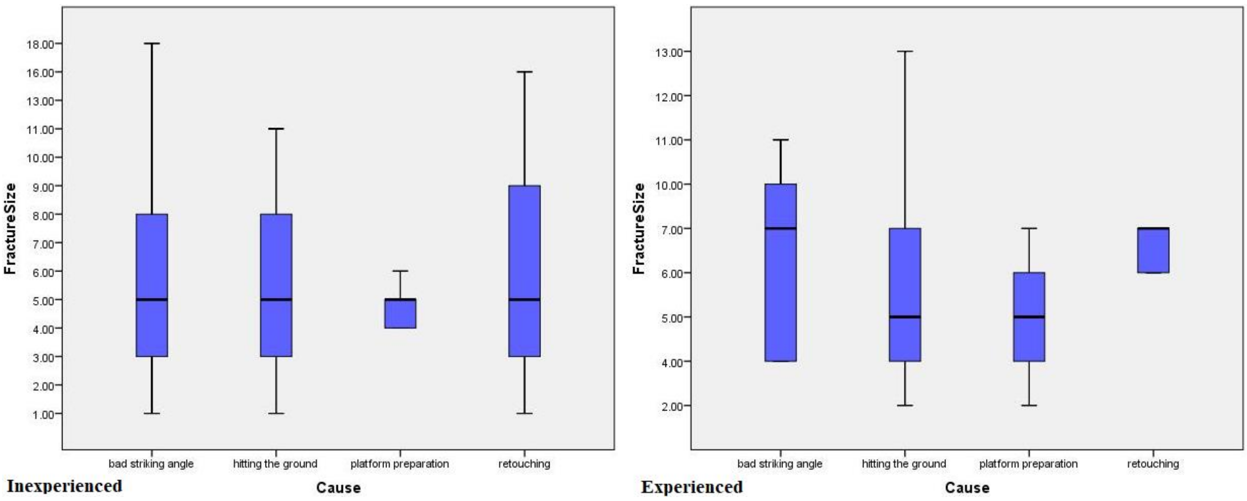


Fig. 27 - Comparison of the fracture size and fracture cause for both knappers' assemblages.

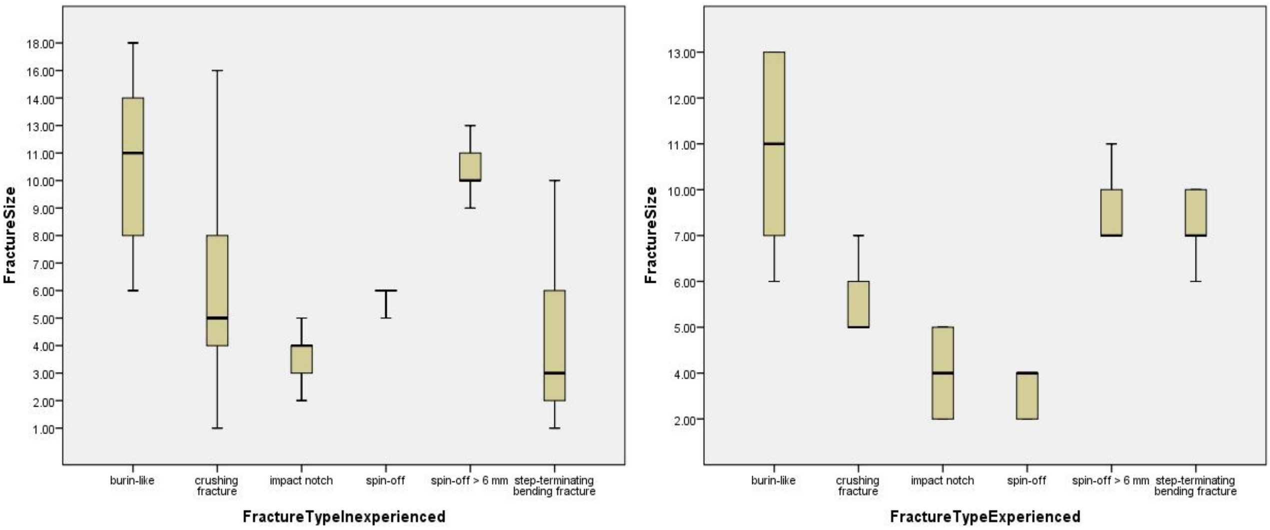


Fig. 28 - Comparison of the fracture size and fracture type for both knappers' assemblages.

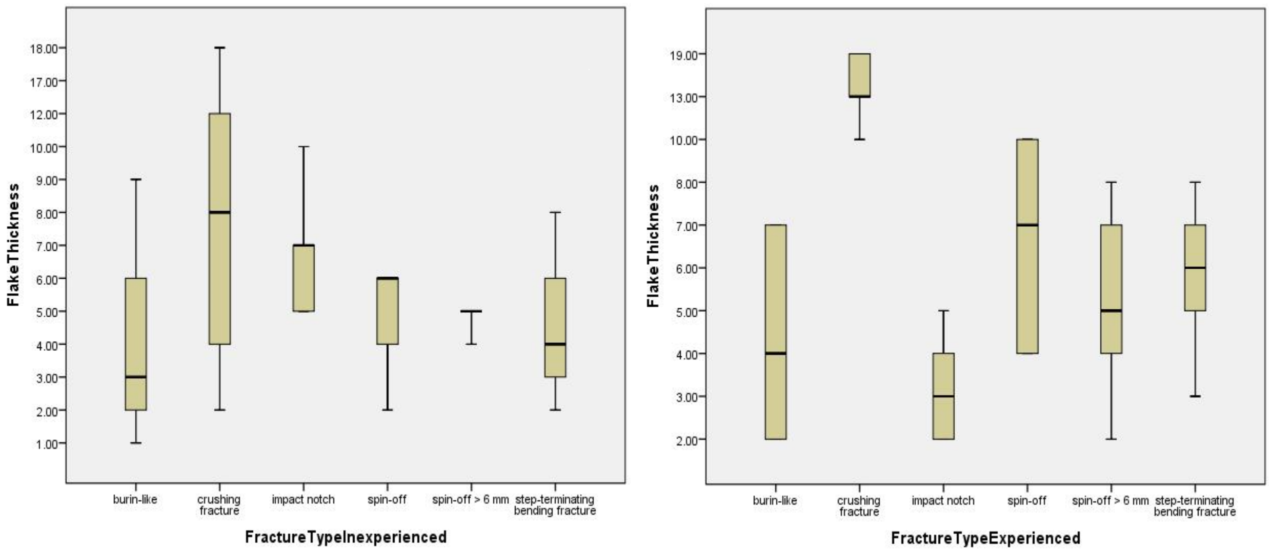


Fig 29. - Comparison of the flake thickness and fracture type for both knappers' assemblages.

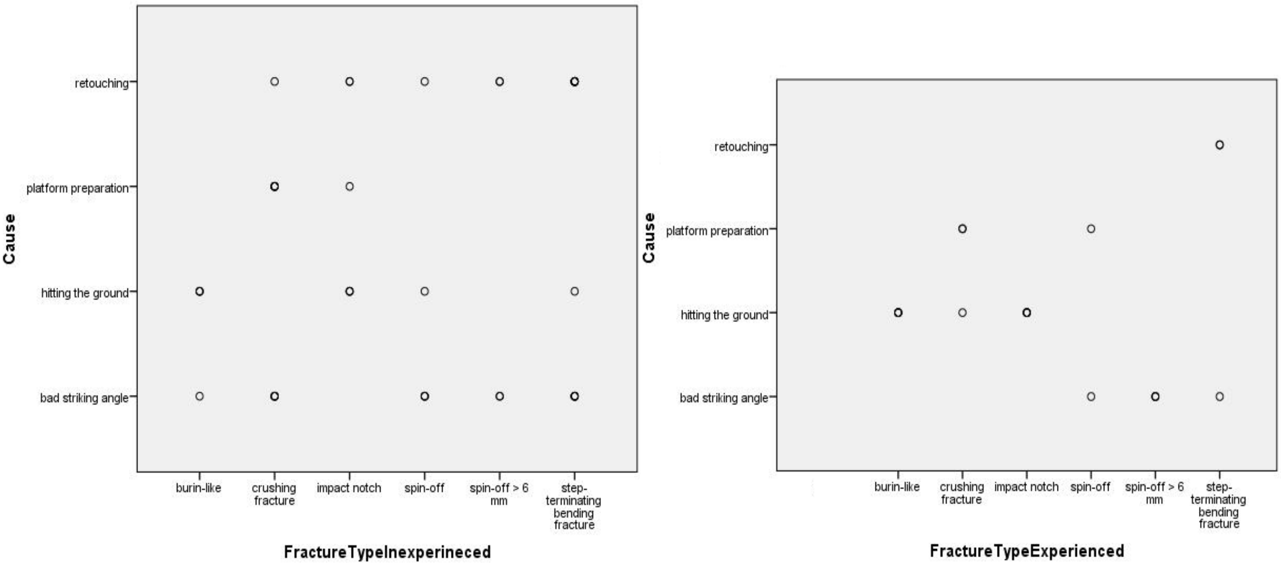


Fig. 30 - Comparison of the fracture cause and fracture type for both knappers' assemblages.

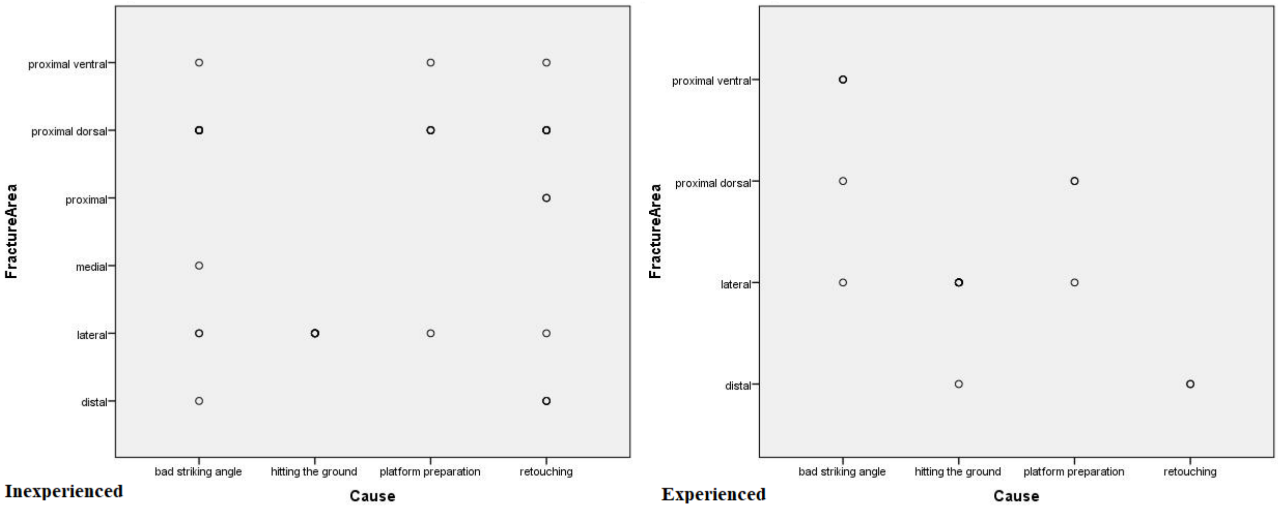


Fig. 31 - Comparison of the fracture area and fracture cause for both knappers' assemblages.

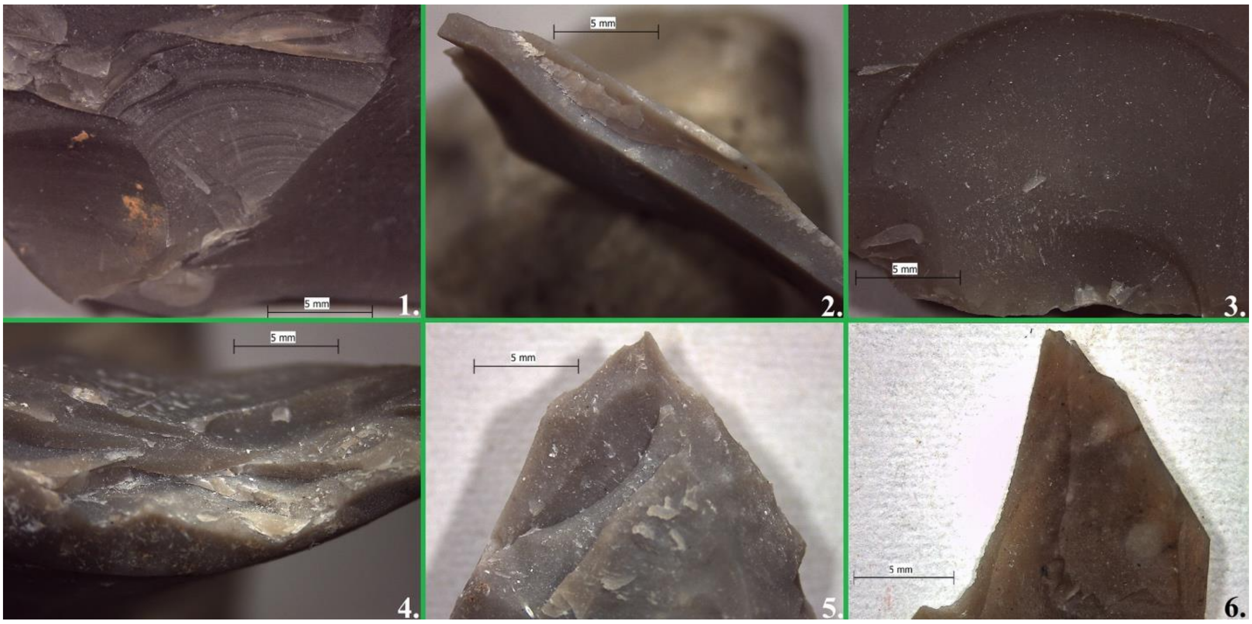


Fig. 32 – *Damage identified in Inexperienced knapper's assemblage: 1) Spin-off fracture > 6 mm with step-termination caused by a platform preparation; 2) Flake broken in half caused by a bad striking angle; 3) Spin-off fracture > 6 mm caused by platform preparation; 4) Crushing fracture caused by a bad striking angle; 5) Spin-off > 6 mm followed by step-terminating bending fracture caused by a bad striking angle while retouching; 6) Burin-like fracture caused by flake hitting the ground after being knapped.*

Fig. 33 – *Damage identified in experienced knapper's assemblage: 1) Crushing fracture caused by a bad striking angle; 2) Spin-off fracture caused by retouching; 3) Spin-off fracture > 6 mm caused by retouching.*

4.7. Conclusions

In Pargeter's (2011) experiments, 4% of diagnostic impact fractures were identified in knapped assemblage. In our experiment, 2,07% DIFs were identified in the inexperienced knapper's assemblage and 3,28% of DIFs in the experienced knapper's assemblage. Step-terminating fracture was not considered as a diagnostic impact fracture in these results. If step-terminating fracture was included, the percentage of DIFs in the inexperienced knapper's assemblage would be 5,45% and 4,69% in the experienced knapper's assemblage.

As it was expected, the inexperienced knapper needed more time to produce five Mousterian points than the experienced knapper. Also, inexperienced knapper produced more waste flakes which led to a higher number of macrofractures. The ratio of knapped flakes and macrofractures was not expected to be similar for both knappers. The percentage of all macrofractures that the inexperienced knapper produced was 10,9%, and 8,92% for the experienced knapper (Table 10).

In the inexperienced knapper's assemblage DIFs are present in greater number on proximal dorsal side of the flakes, and the cause of that was bad striking angle. On the experienced knapper's assemblage the fractures are mostly present on the lateral side of the flakes and the cause was flake hitting the ground after being knapped. This could be explained by different striking force and the angle of striking. As experienced knapper could more easily control the striking force and angle, the impact-like fractures would occur while knapped flake hits the ground rather than experiencing step-terminating or crushing fracture on the proximal dorsal side of the flake, which was the case for inexperienced knapper's assemblage due to bad striking angles.

The result of this experiment implies which fractures could be considered as a result of weapon use and which should be interpreted with caution. Step-terminating bending fractures were for quite some time considered "the simplest" DIF. They are formed as a result of longitudinal pressure from the distal and proximal ends of the stone tools (Fisher, 1984; Lombard, 2005). After experiments of Iovita and colleagues (Iovita et al., 2014), this claim was questioned. They argued that the use of step-terminating bending-initiated longitudinal fractures as diagnostic of impact is not entirely justified. The result of their experiment is that the fractures occur as a result of load that is distributed over a larger surface rather than concentrated in one point.

Equifinality is the biggest problem in our understanding of impact fractures propagation. Same fracture type can occur as a result of trampling, knapping, hafting or hunting damage (Fernandez-Marchena & Oll, 2016; Jayez and Nasab, 2016; Knutsson et al. 2015; Ollé and Vergès 2014; Pargeter et al., 2016; Stemp et al., 2016, Wilkins et al., 2012;). Step-terminating fractures are present in 3,37% in inexperienced knappers' assemblage and 4,69% in experienced knappers' assemblage. Due to this results and the results from previous experiments, step-terminating fractures should be completely disregarded as a DIF (Iovita et al., 2013; Pargeter, 2013).

Spin-off fractures, especially those > 6 mm are considered one of the reliable DIFs (Fischer et al., 1984; Lombard, 2005; Pargeter, 2013; Pargeter et al., 2016; Sano, 2009;). Variations of spin-off fractures > 6 mm, were identified on this knapped assemblage. In this research, spin-off fractures > 6 mm are present in 1,03% in inexperienced knapper's assemblage and 1,4% in experienced knapper's assemblage. Spin-off fractures are not as frequent as step-terminating fractures, at least, the area of fracture could help us distinguish the cause (Figure 1). Fractures that are not caused by hunting will probably occur on proximal parts of the stone tool (Villa et al., 2010), but again, there is a problem of hafting damage that occurs on proximal sides of the stone tools and could form a spin-off fracture (Rots, 2010, 2011, 2013, 2014). Burin-like fractures were identified on four flakes in both knappers' assemblages. In experienced knapper's assemblage 1,87%, and on 1.03% of the flakes in inexperienced knapper's assemblage. This fracture type was also identified in previous knapping experiments, and it seems that this fracture could be a reliable DIF only if another fracture is present on the same stone tool, (Pargeter, 2011, 2013). The results of this experiment lead to a conclusion that the only reliable DIF is bifacial spin-off fracture, as it was not identified in either knapping assemblage (Table 2).

During the past years, macrofractures, especially those formed by impact, gained a lot of research interest. After each experiment we are one step closer in deciphering impact fracture propagation. Fracture equifinality is one of the biggest problems, calculating the percentage of fracture types and fracture causation are valuable information but not enough to make solid,

final conclusions. There are a lot of variables, and in order to get reliable data, and move forward in impact fracture analysis, we need much more experimental data.
Step-terminating-bending fractures should be completely excluded from DIF category. Also, as step-terminating fractures are present in large numbers in almost all experimental assemblages, it should not be ignored completely, on the contrary, we should focus more on propagation of this fracture type.

After this experiment, even the spin-off fractures that are > 6 mm that were interpreted as one of the most reliable DIF, should be interpreted with great care in the future. For now, the one and only highly reliable DIF is bifacial spin-off fracture, because it was not identified in either knapping assemblage.

5. Third experiment – The hunting reconstruction using Levallois points

Considering that Levallois points with impact fractures were identified in the Riparo Tagliente's lithic assemblage, hunting reconstruction experiment was necessary for the better understanding and interpretation of those fractures.

5.1. The research aims of the third experiment

The research aims of the third experiment are somewhat similar to the research aims of the first experiment. The differences between the first and the third experiment is that the Levallois points are the subject of this time around, as opposed to previously used Mousterian points. Also, different hafting approaches were applied. In the first experiment, only beeswax was used as a single binding material while in the third experiment sinew (Fig. 35) and animal intestine (Fig. 36) were used as a binding material.

This experiment was executed in order to obtain answers to the following research questions:

1. Can we find the correlation between impact fracture type and cause on the Levallois points?
2. Do we obtain reliable results while using the modern equipment such as polyurethane plates in experimental research of impact fractures?
3. Is the hafting depth influencing the functionality of the spears?
4. Is using the sinew or animal intestine as a single binding material sufficient for the spears to be effective/functional?
5. Is the impact velocity influencing the fracture formation?
6. To what extent the hide resistance (thickness of the polyurethane boards) has the influence on the impact fracture formation?
7. Is the TCSA influencing the functionality of the spear, i.e. penetration depth?

5.2. Materials and methods

The raw material used in this experiment was chert. In this experiment the target was not a dead animal but polyurethane boards. A single polyurethane board was 50 mm thick. Same spears were propelled into the polyurethane plates two times. First round, only one polyurethane board was fixed onto the wooden board. After the first round all of the spears were examined for the presence of the impact fractures. For the second round, spears were re-hafted and another polyurethane board was added so the thickness of the complete target was 100 mm think with the additional 30mm of the wooden board. The distance from which the spears were propelled into the "target" was four meters (Fig. 34).

One type of hafting was applied on the spears from this experimental assemblage. All six spears were hafted diagonally. The binding material that was used on five of the spears was the animal's sinew. Only one point was hafted into the shaft using animal's intestine in order to see the functionality of this hafting approach. For the first round of the experiment, retouched Levallois points were hafted 15-30 *mm* deep into a homogenous wood shaft made of the common hazel (*Corylus avellana*). Shafts were 147-179 *cm* long (Table 22), their weight was 370-570 *g* (Table 23), and the shaft diameter was 30-35 *mm*. It was controlled as much as possible that the place of impact was not repeated. IA (impact angle) was measured and calculated using simple trigonometry. Impact speeds were measured and calculated using a basic physics formula. A photo of every stone tool was taken before and after each shot. Distance from the hunter to the prey was the only variable that was held constant. Point dimensions and TCSA (Tip Cross Sectional Area) are presented in the table (Table 20).

Fig. 34 – The setup of the third experiment

	Length (mm)	Width (mm)	Thickness (mm)	TCSA (mm2)
A1	53	39	10	195
A2	46	22	8	88
A3	38	25	7	88
A4	47	26	6	78
A5	55	34	7	119
A6	76	24	4	48

Table 20 – Morphometrical values of the experimental Levallois points used in the third experiment.

	Shaft weight (g)
A1	570
A2	450
A3	370
A4	540
A5	530
A6	380

Table 21 – Shaft weight values from the third experiment.

First Round	Shaft length (cm)	Hafting depth (mm)
A1	163	20
A2	179	22
A3	176	18
A4	171	12
A5	147	15
A6	172	30

Table 22 – Shaft length and hafting depth values from the first round of spear shooting from the third experiment.

Second Round	Hafting depth (mm)
A2	10
A3	12
A5	19

Table 23 – Hafting depth values from the second round of spear shooting from the third experiment.

Fig. 35 – Sample of Levallois point bound to the hafting shaft using sinew.

Fig. 36 - Sample of Levallois point bound to the hafting shaft using animal intestine.

5.3. Results

Before the first round of shooting the spears into the polyurethane board, the points were examined for the impact fractures that could have been formed as a knapping incident. On three points fractures were identified. One step-terminating-crushing fracture, one unifacial spin-off and one unifacial spin-off with step terminating fracture. Three points were not damaged during knapping (Fig. 41, 42).

After the first round of propelling the spears into the artificial target, one of the hafting shafts was damaged to the point of inability to re-haft a point onto it. Two of the points were snapped in half which was followed by a step-terminating fracture and therefore it was not possible to re-haft them for the second round of the experiment. For the second round of the experiment, three spears were used (Table 23). While analyzing the points after the first round of the experiment, impact fractures were identified on all of the six points. Two above mentioned, snapping in half that followed step-termination, one step-terminating crushing fracture, one step-terminating and one unifacial spin-off with step-terminating fracture.

Impact velocity varied from 10.8 m/s – 18.9 m/s. No correlation could be found between impact velocity and the fracture type. For example, step-terminating fracture could occur at any value of the impact velocity that was produced in this experiment. Also, no correlation could be found between the impact velocity and the fracture size. That can be confirmed by figure (Fig. 37) showing that both fracture size of one millimeter and nine millimeters may occur at the similar impact velocity.

During the experiment the target was never missed, so the cause of all the fractures was the penetration of the target (Fig. 37). No correlation between TCSA and the penetration depth was found (Fig. 38).

The first experiment produced the similar results considering the correlation between the hafting and the penetration depth. Higher hafting depth doesn’t mean higher penetration depth. This experiment produced some results that the first hunting reconstruction experiment did not. Taking into account the high caution, considering the small sample size, lower hafting depth may increase penetration depth (Fig. 38).

No correlation between shaft diameter, weight or length and fracture type could be found (Fig. 39, 40).

Data of the second round of the experiment is presented in table (Table 24). Crushing fracture was identified on all three of the spears. The fracture area of two samples was on the proximal dorsal side, while on one sample it was situated on the proximal ventral side. It was not possible to establish the correlation between the variables due to the small sample size of the second round of the experiment.

Fracture Type	**Fracture Area**	**Impact Angle (◦)**	**Penetration Depth (mm)**	**Impact Velocity (m/s)**	**Hafting Depth (mm)**
Unifacial spin-off followed by crushing fracture	Proximal dorsal	34	52	10.8	12
Crushing fracture	Proximal ventral	35	52	14.7	20
Crushing fracture	Proximal ventral	33	69	16.6	19

Table 24 – The results of the third experiment.

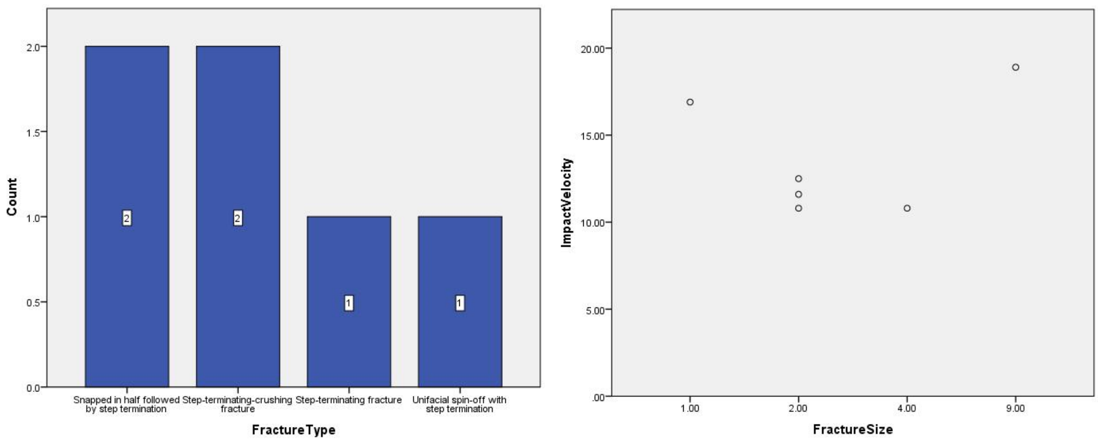


Fig. 37 - Fracture types present on the experimental Levallois points (left), and the comparison of impact velocities and the fracture sizes (right).

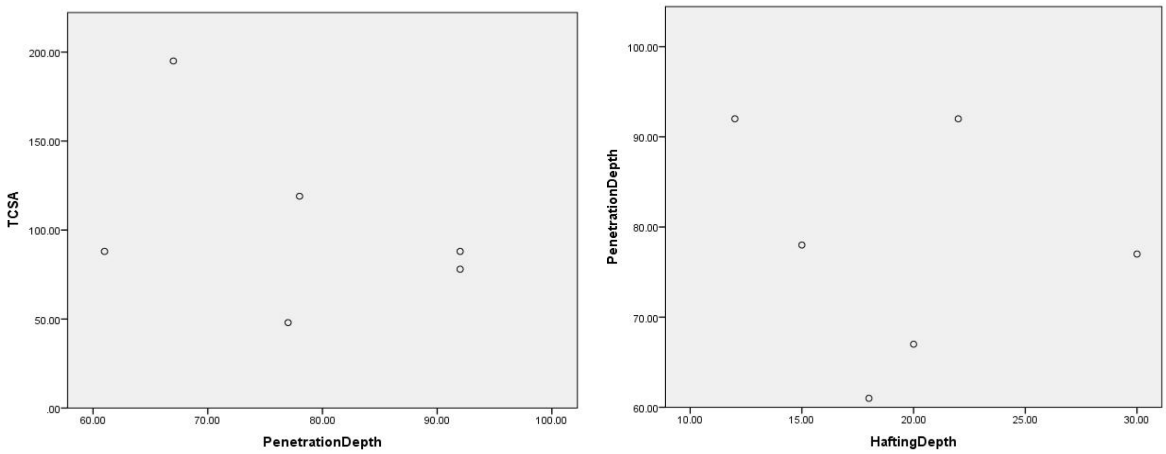


Fig. 38 – The comparison of TCSA values and the penetration depth velues (left), and the comparison of penetration depth values and hafting depth values (right).

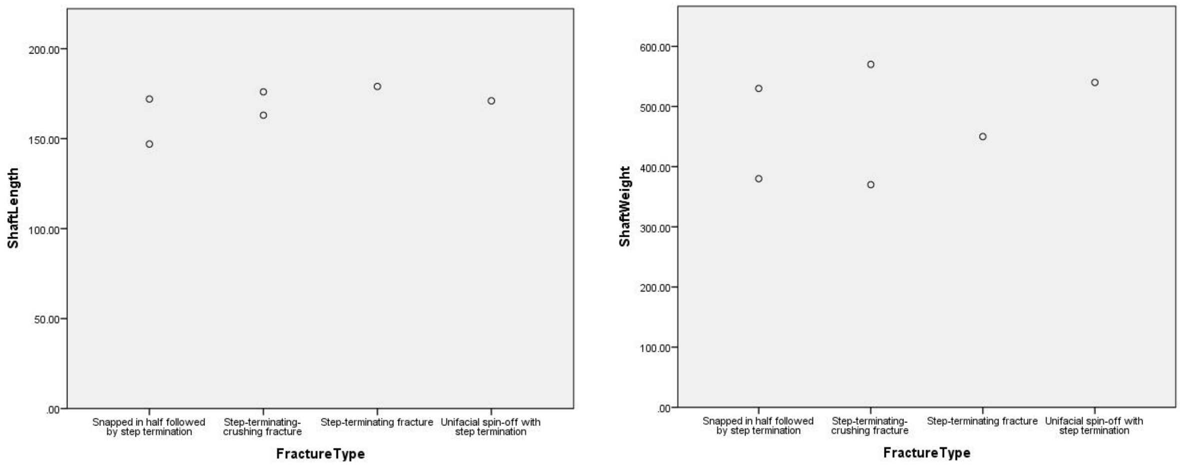


Fig. 39 - Comparison of shaft length values and fracture types (left), and the comparison of shaft weight values and fracture types (right).

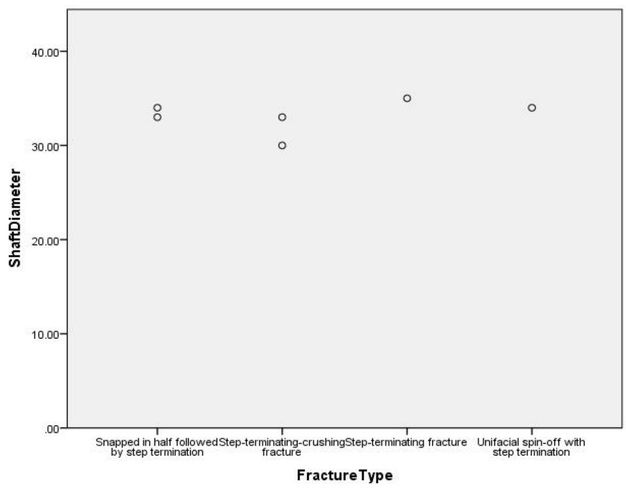


Fig. 40 – Comparison of shaft diameter values and fracture types.

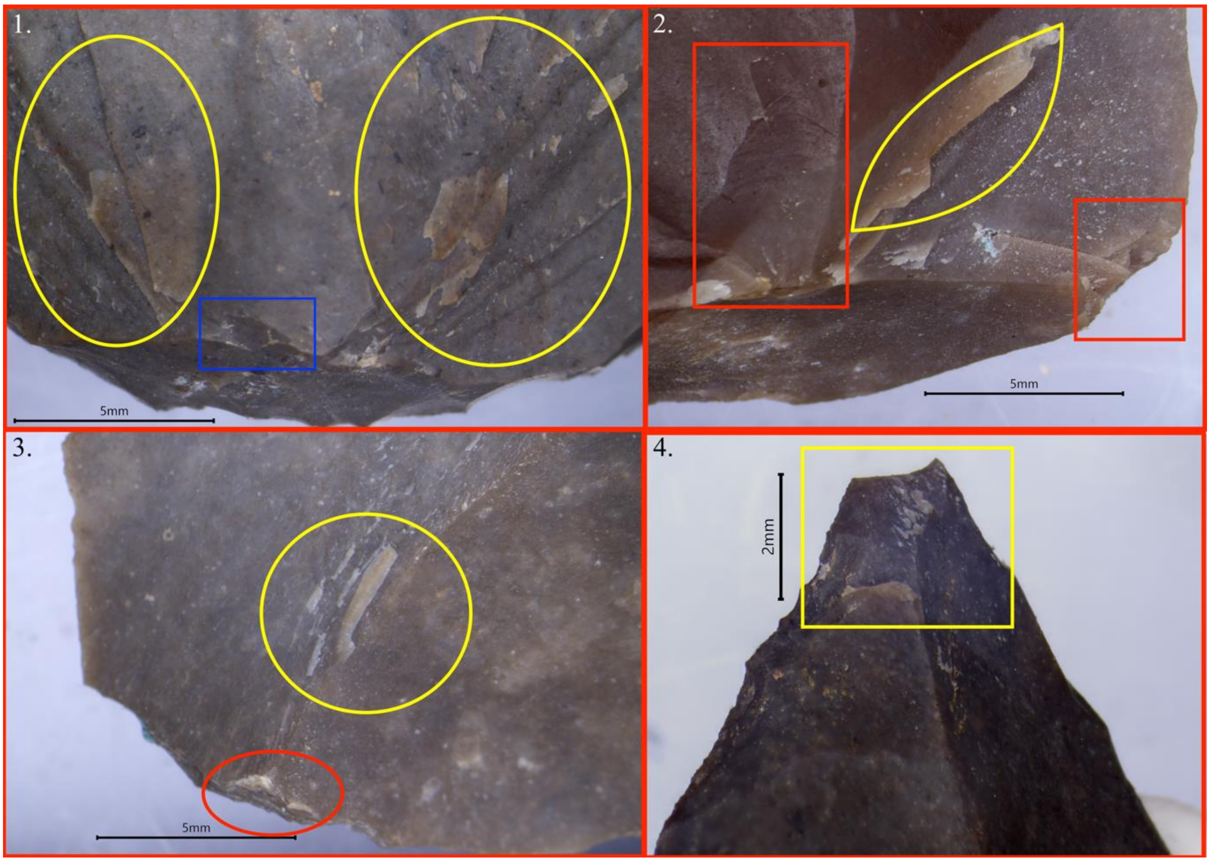


Fig. 41 – *Damage identified on the experimental Levallois points used in the third experiment (blue - knapping damage; yellow – damage after first round of propelling the spears into the target; red – damage after second round of propelling the spears into the target): 1) point a1 (proximal ventral) – unifacial spin-off, crushing fracture followed by multiple step-terminating fractures and striations (hafting damage); 2) point a2 (proximal ventral and lateral) – unifacial spin-off fracture followed by step-terminating fracture (proximal ventral), crushing damage (lateral) followed by a hinge termination (hafting damage); 3) point a3 (proximal dorsal) – striations and crushing damage caused by hafting shaft; 4) point a4 (distal dorsal) – tip snap followed by unifacial spin-off with step-termination.*

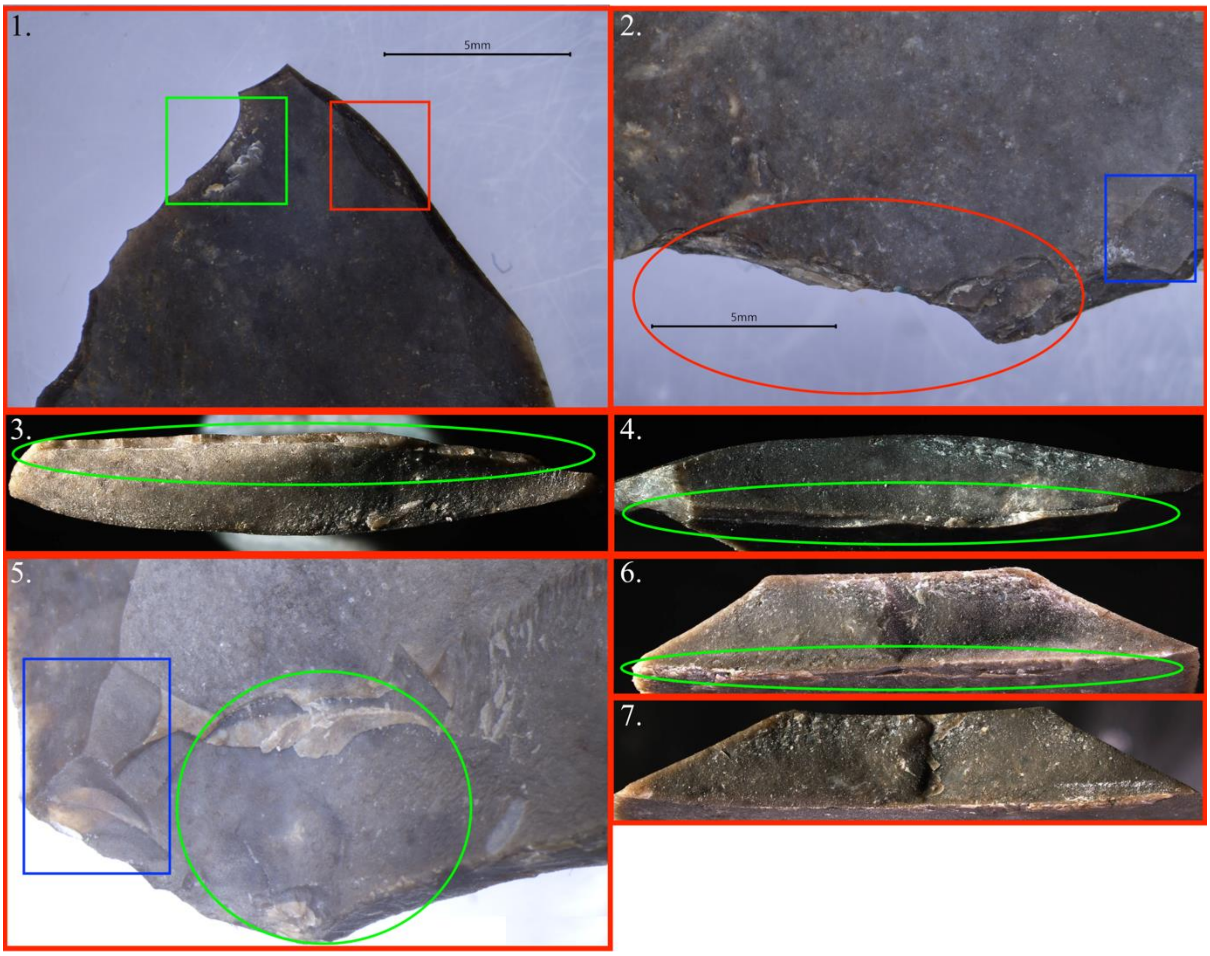


Fig. 42 - *Damage identified on the experimental Levallois points used in the third experiment (blue - knapping damage; yellow – damage after first round of propelling the spears into the target; red – damage after second round of propelling the spears into the target): 1) point a5 (distal/lateral ventral) – crushing fracture; 2) point a5 (proximal ventral) – hafting damage and unifacial spin-off caused by a knapping incident; 3) point a5 (proximal dorsal) – proximal part of the point after being snapped in half; 4) point a5 – distal part of the point – step-terminating fracture; 5) point a6 (proximal dorsal) – unifacial spin-off with followed by step-terminating crushing fracture, and unifacial spin-off fracture followed by step-termination caused by a knapping incident; 6) point a6 – proximal part of the point snapped in half; 7) point a6 – distal part of the point.*

5.4. Conclusions

This experimental assemblage could be used for the reliable correlation of fracture type and fracture cause, since all of the spears successfully penetrated the target i.e. the causation of all of the identified fractures was the penetration of the “target”. There is always a question of the reliability of the interpretation because the modern equipment was used and the target was artificial and the sample was tiny.

Hafting functionality could be established but with caution since the sample size was small. One of the spears that was hafted using sinew, and the single spear hafted using animal intestine experienced breakage. It could be concluded that the spears, hafted using only sinew are more efficient than those hafted with animal intestine, but considering that the sample size was small, this conclusion should be taken with caution. Does the impact velocity influence the fracture propagation? Again, the conclusion should be taken with caution considering the sample size. Impact velocity influences the fracture size. The data of this experiment provided an answer that if the impact velocity is between 10-15 m/s the expected fracture size would be 2 cm (Fig. 37).

The results of this experiment are implying that the previously discarded study (Newman and Moore, 2013; Clarkson et al., 2016) of the influence of tip cross-sectional area (TCSA) on the functionality of the pointed tool should be brought to consideration as the lower TCSA values means higher penetration depth (Fig. 38) based on the data of this experiment.

Problem of the usage of the modern equipment, such as artificial target made of polyurethane plates, that was used in this experiment, is leading to the question of reliability of conclusions brought up after observing the data obtained after execution of the third experiment. Considering that it is impossible to simulate the perfect conditions for experimental research of the impact fracture propagation, the only possibility that is left for our better understanding of the complex system of variables of impact fracture formation is repeatable execution of the simulation experiments.

6. Fourth experiment – edge damage patterns

6.1. Research aims of the fourth experiment

The fourth use-wear experiment's variables were adapted as close as possible to be similar to the excavated lithic material from the Riparo Tagliente site. The aim of this experiment was to get an insight into the edge damage that could be identified on the pointed tools from Riparo Tagliente and to achieve more reliable interpretations of the possible causes of certain damage types. Furthermore, it was possible to interpret the functionality of the pointed tools for certain activities that were carried out while using them. The research questions of the fourth experiment were:

1. Can we correlate certain damage type to a certain activity/cause?
2. Are points functional or non-functional for certain activities?
3. Do the morphometric values influence the functionality of the points?
4. What is the typical edge damage type for the certain activity: butchering, wood cutting, wood scraping, antler cutting?
5. Do certain activities cause the formation of the similar damage type, i.e. is there a fracture formation equifinality problem?
6. Would points be more efficient for the execution of certain activity while hand-held or hafted?
7. Does the duration of use or the number of strokes influence the fracture formation?
8. Could some of the fractures that are diagnostic of impact be formed on the pointed tools used for butchering, wood or antler manufacture?

6.2. Materials and methods

Fourteen Mousterian points made of chert were used in this experiment. The activities that were performed using the experimental points were: antler cutting, fresh walnut branch debranching, fresh walnut branch scraping and cutting, fresh pig's (*Sus Domesticus*) radius and ulnae butchering (meat cutting, skinning, bone cleaning, bone breaking, bone cutting) and dry walnut branch cutting, scraping, and debranching. Two of the points were used for antler cutting (Fig. 43; 44). For fresh wooden branch debranching, cutting and scraping, one point for each activity was used (Fig. 45). As for butchering activities, one point was used for meat cutting (Fig. 47), one for skinning (Fig. 47), and one for bone cleaning/scrapping (Fig. 48). Two of the points were used for bone breaking (Fig. 50). Two points were used for dry wood cutting and one for scraping (Fig. 46, 48, 49), and two for bone cutting (Fig. 49).

For each activity only one side (lateral-proximal-distal) of the point was used as the working side. All of the points were examined for the damage that could be caused by knapping. The photos of the points were taken before and after experiment. The number of strokes for each activity was counted, and the duration of the certain point's usage was measured. None of the points were hafted, all of them were used as a hand-held tool.

After the experiment has been carried out, the points were cleaned using only water in order to avoid possible damage formation. All of the points were examined both macroscopically and microscopically, using the 8x and 10x magnification of the W04 microscope (Fig. 53. 54).


Fig. 43 – Deer antler cutting.

Fig. 44 – Deer antler cutting.

Fig 45 – Fresh wooden branch scrapping.

Fig. 46 – Dry wooden branch scpapping.

Fig. 47 – Meat cutting (left), skinning (right).

Fig. 48 – Bone cleaning/scrapping (left), dry wood cutting (right).

Fig. 49 – Fresh wood cutting (left), bone cutting (right).

Fig. 50 – Bone breaking.

6.3. Results

Other that gaining an insight into the damage formation of the certain activities using Mousterian points, the information of the functionality of the Mousterian points for executing the certain activities was also mandatory. Furthermore, the interpretation of the functionality of modes of usage was necessary for the reliable interpretations of the archaeological material. As the activities using experimental points were carried out using only hand-held mode of usage, the conclusions of their efficiency for the certain activities using hand-held mode was established. It was experimentally shown that the Mousterian points were extremely efficient for the butchering activities in hand-held mode, further implying that hafting was not necessary for butchering activities except the bone breaking (Fig. 50). The experiment suggests that the Mousterian points are efficient for the bone cutting (Fig. 49) but not breaking. In three minutes and fifteen seconds, the experimental Mousterian point had cut 12 millimeters into the fresh pig ulna that was 34 millimeters thick, suggesting that the bone would be completely cut in less than 9 minutes.

Considering the wood manufacture, for this experiment, the idea of cutting, de-branching and scraping of the walnut branch had a goal to imitate the activities necessary for the hafting shaft manufacture. The experimental points proved extremely efficient for the hafting shaft manufacture for both fresh and dry wood. In 12 minutes, the Mousterian point had cut 15 millimeters into 35 mm thick fresh walnut branch, suggesting that the branch would be completely cut in less than 30 minutes. For the dry wood, in 5 minutes the point cut 11 mm into the 27 mm thick dry walnut branch.

The points have even displayed a short span efficacy for deer antler cutting. Experiment has shown that the points probably needed frequent re-sharpening for antler cutting activity as the edge was rounded and completely useless in 6 minutes for the first point and in 4 minutes for the second point that were used for experimental antler cutting. Using both points, it was cut 3 mm into the deer antler that was 29 mm thick in 10 minutes. These results suggest that it would be necessary to re-sharpen the two points ten times in order to cut the 29 mm thick deer antler, and in approximately 100 minutes we would be able to cut the deer antler completely.

Before the points were used for the experiment, they were examined for damage caused by their manufacture. Seven of the points were not damaged during their manufacture/knapping. Three points experienced crushing damage, two points experienced impact notch. Burin-like fracture was identified on one of the points, and the most interesting damage identified to be the cause of knapping were the striations on the ventral side on one of the points. The cause of the striations could possibly be the flake hitting the ground after it was separated from the core. All of the knapping damages are presented in a figure (Fig. 51).

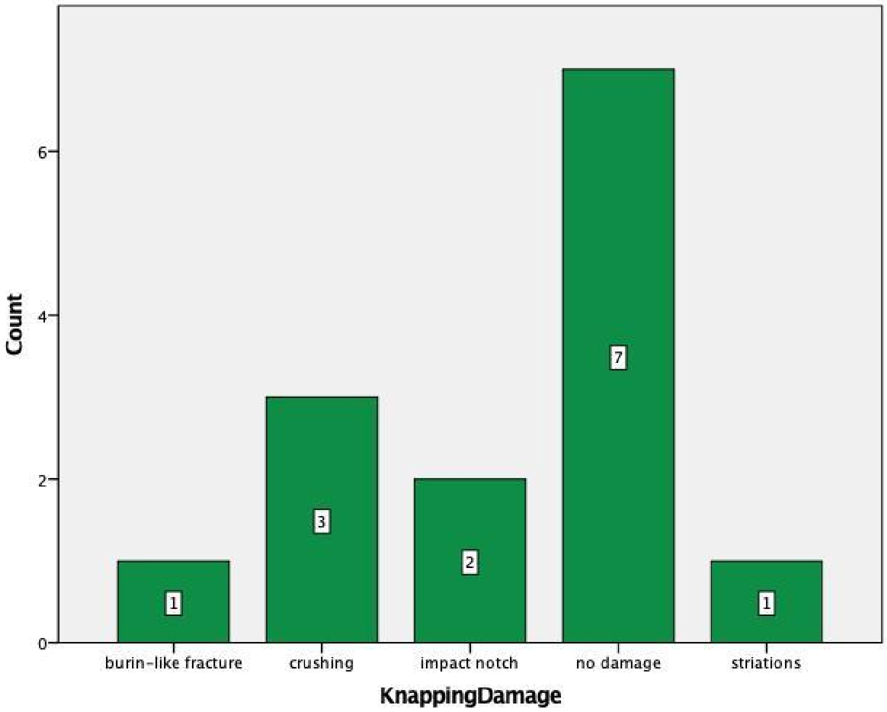


Fig. 51 – Knapping damage identified on the points used in fourth experiment

Various types of edge damages were identified on the experimental points: crushing damage, scaring, rounding, striations and even one fracture that is considered diagnostic of impact by some of the authors (Lombard, 2005; Villa et al., 2009; Pargeter, 2011; Iovita et al., 2016; Coppe and Rots, 2017), the burin-like fracture. It is clear that the rounding damage is connected to cutting activities, and that the intensity of the rounding damage is closely connected to the worked material's density. For example, the fresh bone cutting was the cause of the heavy edge rounding, while the dry walnut branch cutting produced mild/light rounding of the point's edge, i.e. lateral side. De-branching of the fresh walnut branch produced one burin-like fracture. While no damage was expected to be found on the points that were used for skinning, rounding was identified. Bone breaking was the cause of the fractures that are often used for description of damage that could be identified in hunting-reconstruction experiments, the crushing and step-terminating fractures. The activities carried out in this experiment and the damage they produced are presented in figure (Fig. 52).

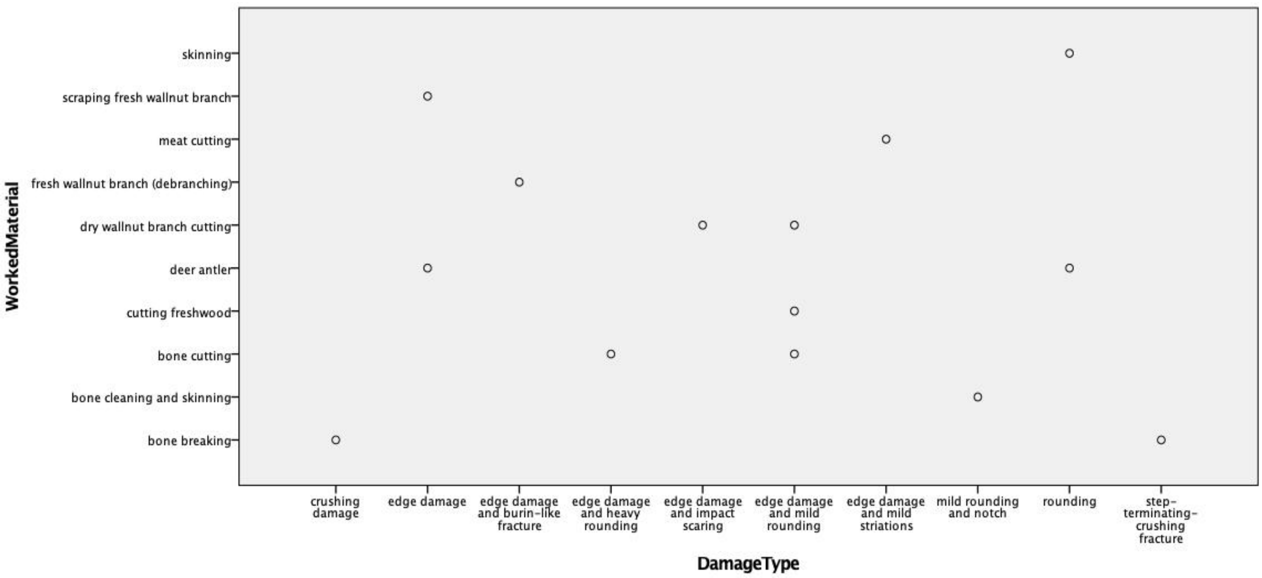


Fig. 52 – Correlation of the worked material and the damage type

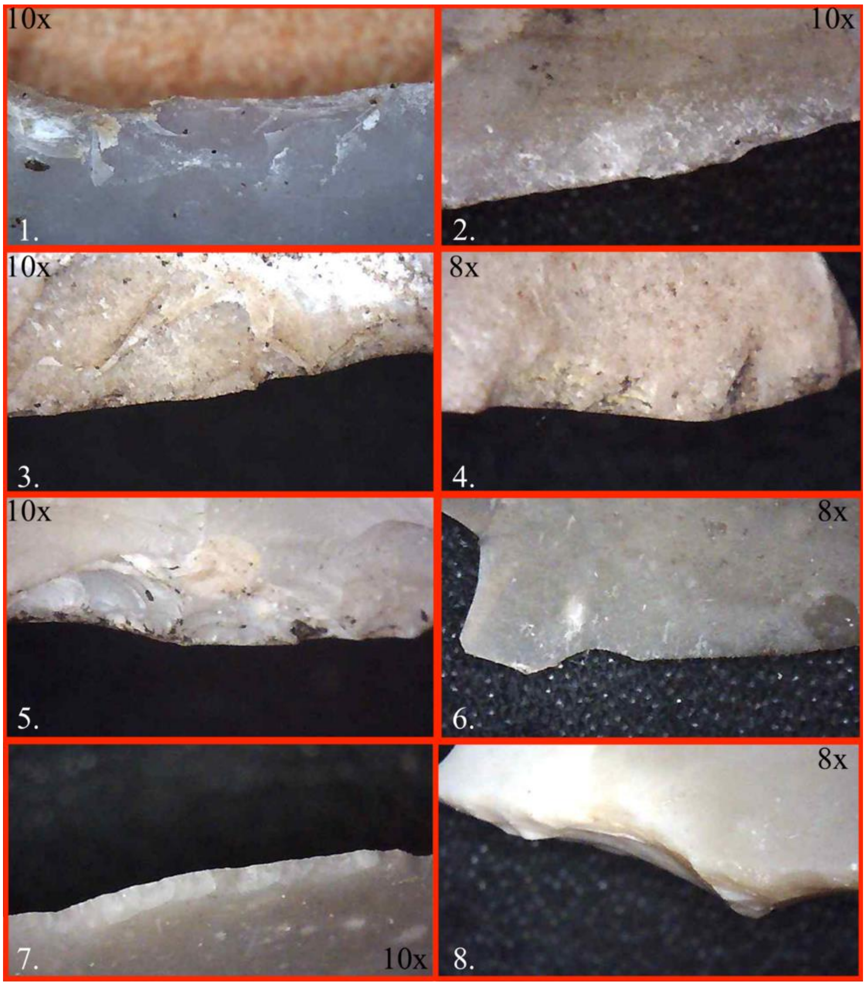


Fig. 53 – *Edge damage patterns of the fourth experiment: 1 and 2) antler cutting; 3) fresh wood debranching; 4) scraping fresh wood; 5) fresh wood cutting; 6) meat cutting; 7) deskinning and meat cutting; 8) bone cleaning and skinning.*

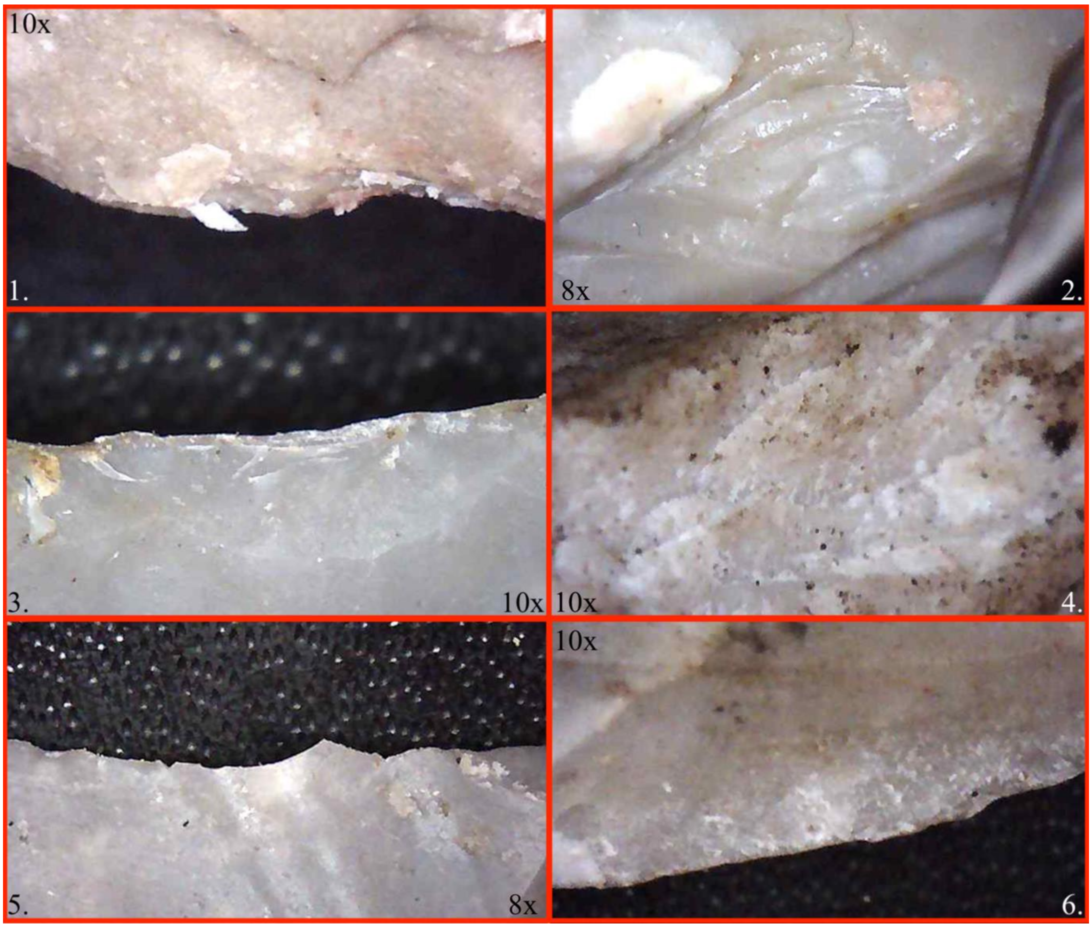


Fig. 54 – *Edge damage patterns of the fourth experiment: 1 and 2) bone breaking; 3 and 4) dry wood cutting; 5 and 6) bone cutting.*

6.4. Conclusions

The answer to the question of the functionality of the Mousterian points for executing certain activities could be established after processing the results of this experiment. It is clear that the experimental Mousterian points were highly efficient for butchering activities in hand-held mode, while for the bone breaking and de-branching the wooden branch they would have been more efficient if they were hafted. This conclusion was brought up during the experiment. It was impossible to obtain good striking angle for de-branching in hand-held mode and the striking force for the bone breaking was not sufficient in hand-held mode for successful execution of the activity. Points were even efficient for the antler processing, but frequent re-sharpening would be necessary as the edges get rounding damage quickly. Rounding damage was also a problem for wood processing activities, but it was not so intense as for antler and bone cutting activities. Edge damage patterns could provide a better insight into the edge damage that can be identified on the archaeological material. Since the damage equifinality represents a great problem of use-wear studies, using the edge damage for the interpretation of the certain activities that could have been carried out with the archaeological pointed tools, might not be highly reliable but rather suggestive. One of the reliable damages for interpretation of the archaeological material might be the rounding damage. Considering the results of this experiment, the degree of edge rounding implicates the density of the worked material, i.e. the heavier rounding damage could mean that the denser material was processed using the certain stone tool.

7. Riparo Tagliente

7.1. History of research

Riparo Tagliente site was discovered by Francesco Tagliente in the year of 1958. The rock-shelter is situated on the left side, i.e. west slope of the Valpantena, 250 meters above the sea level, in one of the main valley-bottoms of the pre-Alpine Monti Lessini massif, in the municipal land of Grezzana, East of Stallavena village, in Verona province.

The first excavations of Riparo Tagliente started in 1962 and finished in 1964. Not long after, excavations have been undertaken again in 1967 by the University of Ferrara and are still in progress. Two huge deposits were uncovered by the excavations of stratigraphic sequence of approximately 4.6 meters. According to paleo-environmental data, the first deposit has been correlated to the lower and middle Würmian tardiglacial, which contained Mousterian and Epigravettian industries. At the end of the Würmian tardiglacial, it seems that Riparo Tagliente was not occupied. The deposits were covered by clay sediments from the slopes of the valley. This caused an almost total disappearance of the shelter. The rock-shelter was visible only through one narrow fissure that was formed during the medieval period that almost led to a total destruction of the Mousterian and Epigravettian layers.

7.2. Archaeological deposits and chronology

The oldest deposit cuts 52-25b is represented by Mousterian industries. Aurignacian industries have been identified in the cut 25. Mousterian industry is represented by the high percentage of Levallois artifacts (Arzarello, 2004). Epigravettian layers are represented by the cuts ranging from 18 to 4 (Fig. 55).

Huge difference in layer thickness has been detected between the inside and the outside of the shelter. Moving away from the rock-shelter wall the layers differ up to 2 meters in thickness. This difference is explained by the different sedimentation modes of the internal and external area of the shelter.

Even though the site of Riparo Tagliente still lacks absolute dates, based on the substantial quantity of conducted research, it could be placed in the chronological span from 60 000 - 12 000 BP.

7.3. Internal and external excavations

The excavation of the internal survey was carried out during the 1976 campaign and has covered the entire succession including the Mousterian occupation. The operational layers from 52 to 25 represent the Würmian deposits, within which those between 52 and 31 (square 635, 634, 615, 614) are represented by Mousterian industries while 25 represent Aurignacian industries (Bartolomei et al., 1982). The upper operational layers of the middle Paleolithic sequence are disturbed by the material from subsequent levels, i.e. mixed. The deposits have been disturbed by various post-depositional processes, such as fluctuation and bioturbation. The number of finds are providing the conclusion that not all of the layers could be correlated to an actual human activity. Particularly, the operational layer from 49 to 45 and from 41 to 39 are showing non-constant occupation of the shelter. That increases considerably starting from operational layer 37. The operational layers that shows the high presence of human activity are from 34 to 37, 44 and 42, and, to a lesser extent, from 50 to 52 (Arzarello, 2004).

The Mousterian levels of the external excavations are located in the squares 7, 8, 9, 11, 12 and 13, those squares have been excavated between 1979 and 1999, the year in which the bedrock was uncovered. Recent analysis of electrical tomography (Prof. Santarato and Dr. Abu-Zeid, University of Ferrara) have proposed (Bianchi, 2011), that in fact the bedrock could be the actual rock that collapsed from the top of the shelter, that is possibly blocking the further excavation of the possible continuous Mousterian layers (Arzarello, 2004). Because of this fact, the upper levels are contaminated by the Epigravettian material from the upper layers and bioturbation just added to a bigger layer disturbance. After the analysis of the lithic material found in squares 11, 12 and 13, it could be concluded that there is a correspondence of lithic material from those squares and the ones found in operational layers from 34 to 37 and in operational layer 42. The reliable element of comparison comes from the operational layer 37 because of the presence of the laminar debitage. Furthermore, the material found in the operational layer 40 presents a high concentration of material that could not be correlated to the internal area; this could be explained by the spatial reasons or a real non-correlation between the series. Analogies and differences could be linked to the deposit formation, to the actual non-correspondence of the series or, less probably, to the different spatial use of the areas by the humans that occupied the shelter. It could be concluded that the human activity was lower in the lower layers, while in the upper ones it was contrary (Arzarello, 2004).

7.4. Mousterian layers

Mousterian occupation of the Riparo Tagliente site has provided an abundance of data crucial for the techno-economic reconstruction research. Two most represented reduction methods are the opportunistic one i.e. S.S.D.A (Forestier, 1993; Arzarello et al., 2011), and the Levallois method, centripetal recurrent is the dominant one in the lower layers, while in upper ones unipolar recurrent Levallois is the most present method (Arzarello and Peretto, 2005). Apart from centripetal recurrent and unipolar recurrent methods, discoid method is also identified as being used as a way of reduction of Levallois cores. Kombewa method of reduction has also been identified and in is present in almost all of the middle Paleolithic levels. The most interesting thing about lithic assemblage is the presence of volumetric laminar debitage that was identified initialing from level 37. The dominant raw material in the Mousterian layers is chert. This type of raw material is abundant in the surrounding of the site.

Regarding paleoanthropological material, one phalanx, one upper right second deciduous molar and lower left deciduous canine were found in the Mousterian levels 36 and 37. The molar and the canine were attributed to *Homo neanderthalensis*. The radiometric dating is not available for the two teeth, but the stratigraphic and cultural information correspond to MIS 3 and MIS 4 (Arnaud et al., 2016).

The archaeozoological research was carried out on the faunal remains from the Mousterian layers. The taphonomical analysis has been executed on the bone fragments larger than 2 cm; 406 from level 35, 1162 from level 36, 773 from level 37 and 1053 from level 44-52. (Thun Hohenstein, 2001; Thun Hohenstein and Peretto, 2005).

The taphonomical research proved once more that Neanderthals were able to hunt across the broad range of prey. A total of 20 animal species were identified, out of which roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus*), alpine ibex (*Capra ibex*) and alpine marmot (*Marmota marmota*) were the dominant ones (Thun Hohenstein and Peretto, 2005).

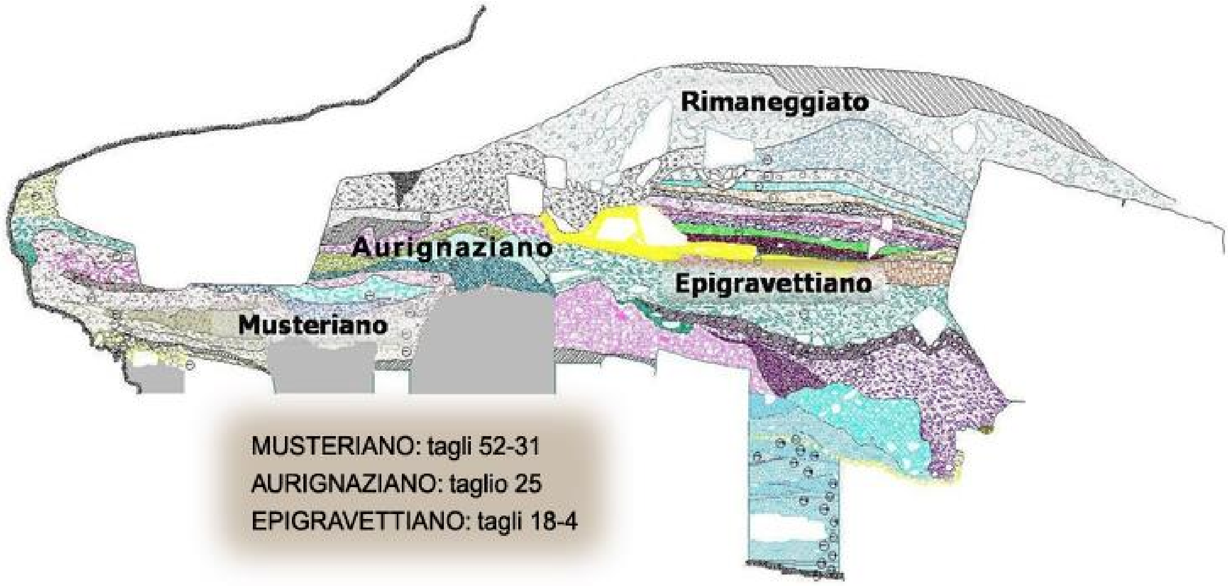


Fig. 55 - Stratigraphical transversal section of the deposit. Source: www.unife.it/dipartimento/biologia-evolucione/strutture/riparo-tagliente/il-sito/il-giacimento

7.4.1. The climate aspect of the Mousterian layers

The lower stratigraphic unit is 2.8 meters deep on the inside of the of the shelter. The content of the base is the rocky substrate and the upper part represents the surface of the erosion. It is possible to distinguish two subunits (Cremaschi, 1982).

- Unit 1a – spans from the operational layer 52 to 44. At the base there are coarse breccia layers which contain silty clayed red soil of colluvial origin formed by the erosion of the slopes and soil outside the shelter. They are colliding with the thin anthropogenic sediments and are slightly inclined towards the outside (Cremaschi, 1982). On top the clay disappears and the sediment changes to become full of limestone fragments incorporated in the sediment which could lead to the conclusion that the process of thermoclastism occurred (Cremaschi, 1982). Thermoclastism is defined as the phenomenon of rock disintegration and the thermal action of solar rays. In practice the dark minerals absorb more heat and therefore heat up and expand more than the lighter in color – thermoclastism causes the rock to flake off, i.e. the rock becomes fragmented

(Huggett, 2016). Therefore, these levels indicate the climate change, characterized by the cold and rainy winters and hot and dry summers, the climate that is characteristic for the beginning of the first part of the glaciation (Bartolomei, 1982).

- Unit 1b – spans from the operational level 43 to 25. At the initiation of the operational layers from 43 to 40 large masses of boulders were uncovered, the collapsed material and cryoclasts are the results of the deterioration of shelters walls and ceiling. This could be placed within peak of the initialized glacial (Guerreschi, Peretto and Thun Hohenstein, 2002). The large masses of boulders are joined by the biconvex layers that are slightly inclined towards the outside of the shelter and are created of clayish sediments and sediments with high presence of calcareous fragments which are intercalated with anthropomorphic sediment accumulation (Cremaschi, 1982; Bartolomei, 1982). These operational layers are followed by an almost sterile loess sediment, the operational level 39, in which the gravel is almost completely absent which implies to the arid phase. The content of the operational levels from 30 to 25 poses almost the same characteristics, but the upper part is erosive and is closely correlated to the river influence with the high accumulation of pebbles (Cremaschi, 1982; Bartolomei, 1982).

7.5. The study of lithic technology

7.5.1. Levallois technique

Levallois, the prepared-core technology method, can be identified in certain Acheulian and Mousterian facieses (Bordes 1961; Böeda 1993, Debénath and Dibble, 1994). The Levallois technique was starting to be applied as a core reduction method during the lower and throughout the whole Middle Paleolithic period. Certain artifacts forms are being modified by centripetal knapping and it is not obtained by its modification after being separated from the core (Bordes 1961; Böeda 1993; Chazan, 1997; Sangathe, 2005). The striking platform is being prepared by faceting. Levallois debitage is obtained by the usage of the direct percussion with a stone hammer, but certain finds implied the usage of a soft hammer (Böeda 1993; Inizan et al., 1999).

There are a few variations of Levallois reduction:

1. Levallois centripetal – it is being carried out by centripetal reduction of the core, after which the core gets the continuous circular percussion traces along the perimeter (Böeda 1993, Debénath and Dibble, 1994);
2. Levallois recurrent – the goal of this Levallois method is to produce several blanks in order to form a knapping surface (Dibble and Bar-Yosef, 1995);

Levallois preferential – this method has a goal to produce a single blank per prepared surface (Dibble and Bar-Yosef, 1995).

Levallois modes of reduction that were identified at the site of Riparo Tagliente are:

1. Bipolar recurrent;
2. Centripetal recurrent - the most frequent one in the lower levels;
3. Unipolar recurrent – dominant in the upper levels of Riparo Tagliente (Arzarello and Peretto, 2005).

7.5.2. Discoid technique

Discoid method is considered to be a more simplistic method than the Levallois, and it has been common since the Lower Paleolithic (Stout et al., 2010; Picin and Vaquero, 2016). The differences involves the non-hierarchical relation of the surfaces and the direction of production that is secant in comparison with the plane of intersection of the two surfaces (Picin and Vaquero, 2016). There are two modalities recognized in the discoid reduction strategy, such as *sensu lato*, where the objectives vary, and *sensu stricto*, where the sequence is single-focused on the production of pseudo-Levallois points and core-edge removal flakes (Mourre, 2003; Bianchi, 2011; Picin and Vaquero, 2016).

7.5.3. Kombewa technique

The Kombewa flaking technique belongs to the prepared core techniques. The initial sequence is the production of the flake with the big bulb of percussion, which is afterwards being flaked in order to obtain circular or semi-circular flake. On the obtained Kombewa flake, the remains of the platform of the previous flake are often preserved. Flakes obtained using this method are sometimes called Janus flakes (Debénath and Dibble, 1994; Tixier and Turq, 1999; Dibble and McPherron, 2006).

7.5.4. SSDA flaking method

This method is usually called the opportunistic method because of its high adaptability and the possibility of adaptation of the obtained flake in order to enhance its functionality for the certain task. Flaking scheme of the SSDA method is presented in a figure (Fig. 56).

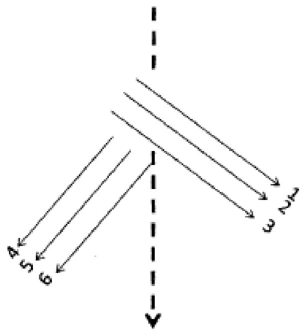


Fig. 56 –SSDA knapping scheme. Source: Arzarello, M., Fontana, F., Peresani, M. Manuale di tecnologia litica preistorica. Concetti, metodi e tecniche. Carocci editore, Roma, 2011.

7.5.5 Levallois points

Debénath and Dibble (1994) have used the Tixier's (1960) definition in order to explain the term "Levallois point" that was established by Bordes (1953), they have defined it as a triangular flake with a central or medial ridge, that sometimes may contain a triangle form at the base caused by the previous removal of a small flake. The medial ridge guides the removal and sets the triangular form (Debénath and Dibble, 1994). Even though Bordes (1953) did not provide the number of different types, he made a distinction between the "first-order" Levallois points, which exhibit only the central ridge, and "second-order" Levallois points, which show also the triangular negative scar near the base left by the removal of an earlier first-order point (Debénath and Dibble, 1994).

7.5.6. Pseudo-Levallois points

Due to their triangular shape, the pseudo-Levallois points can lead sometimes be misinterpreted as Levallois points. The actual distinction of these two morphological types is that the pseudo-Levallois point is not obtained by using Levallois reduction method but by using the discoid method. Pseudo-Levallois point's axis is defined by the distal point, and are oblique relative to their axes of flaking – generally the difference between two axes is greater than 45 degrees (Debénath and Dibble, 1994).

7.5.7. Mousterian points

Mousterian points can be formed on any Levallois flake or blade, including the Levallois points and it is usually of triangular form and it is retouched partially (only the tip) or bilaterally (Debénath and Dibble, 1994). The Mousterian point's definition is that the stone tools point itself must be formed by retouch combined with the bilateral heavy retouch. Shea and colleagues (2002) have suggested that the morphological variabilities are a reliable factor for distinguishing the Levallois and Mousterian points. They also suggest that the variable of the Mousterian points that should be considered is their more or less longitudinal flatness aspect, and that they often possess the traces of thinning on one edge or bilaterally.

7.5.8. Triangular flakes

The research carried out by Goval and colleagues (2015) had a goal to understand the functionality of the triangular flakes unearthed in Normandy and Flemish plains. Similar flakes could be found in the lithic assemblage of Riparo Tagliente. Odell and Cowan (1986) proposed that the triangular flakes could have been used as projectile points. Later, Sisk and Shea (2009) have used triangular flakes made of Cenomanian and Turonian flint for their experimental research and have concluded that their results do not confirm the triangular flakes usage as an arrowhead.

8. Results and Discussion – Riparo Tagliente pointed tools

How do we know if the point was used as a hunting weapon? It doesn't necessarily have to mean that all of the stone tools that morphologically look like a point were indeed used as part of hunting weaponry. To test the hypothesis whether the certain pointed tool was used as a weapon, certain criteria has to be established. Here, the impact fractures play one of the important roles in answering this complex question. If the point was used as a spear, it must show the next criteria (Rots, 2002; Villa et al., 2009; Shea and Sisk, 2010):

1. Point has to possess an impact fracture;

2. Point must possess certain morphometric values: the sharp tip, TCSA value (Shea, 2006) of the (100-250 mm^2), platform suitable for hafting;

3. The presence of evidence of hafting.

After the points have been processed using these criteria, using experimental data, it was attempted to interpret the pointed tools from Riparo Tagliente. The questions which will be tried to provide an answer to are:

1. Which type of hafting was used? – This question will be answered using the data obtained after the execution of the first experiment.

2. What is the cause of the identified impact fracture type? – Answered by using the data of all four of the experiments.

3. What were the possible morphometric values of the hafting shafts? – It will be attempted to answer using the data of the first and the third experiment.

4. What were the values the possible impact angle and impact velocity that influenced the impact fracture, while the focus will be on the impact fracture size? – Answer will be provided using the first and third experiment.

5. For which hunting technology the point was used? Was it used as a part of the thrusting or throwing spear? This complex question will be answered using the data from the first and the third experiment. The focus will be on the point's morphometric values, i.e. TCSA value, platform thickness and impact fractures type and size.

6. Are impact fractures present in higher number in certain layers?

The focus of this research are the impact fractures, but other damage that was identified on the pointed tools from Riparo Tagliente was not ignored. By interpreting the edge damage and other damage identified on the pointed tools, using the data obtained by the fourth experiment, other three experiments and other author's experimental research data, it will be attempted to establish the interpretation of the activities that were carried out using the certain pointed tools from Riparo Tagliente. The questions that will be attempted to answer using this analysis are:

1. What was the worked material?

2. Was the point hafted or used in hand-held mode?

3. Was point used or not? If it was used, what was the working edge?

4. What was the point's function?

5. Could the possible residues of a binding material be identified?

6. Is it possible to identify fracture wings and calculate the fracture velocity?

7. Is it possible to provide highly reliable interpretations of the damage identified on the points from Riparo Tagliente by using experimental data?

8.1. Results of the functional/ macrofracture analysis – damage interpretation

A total of thirty pointed stone tools have been analyzed, out of which, two were triangular flakes (Fig. 73, 81, 82), eight pseudo-Levallois points (Fig. 61, 68, 71, 72, 77, 78, 83 – 85, 99, 100), fifteen Mousterian points (Fig. 57-60, 62-67, 69, 70, 74, 79, 80, 88-91, 96, 98, 101 - 104), and five Levallois points (Fig. 75, 76, 86, 87, 94, 95, 97).

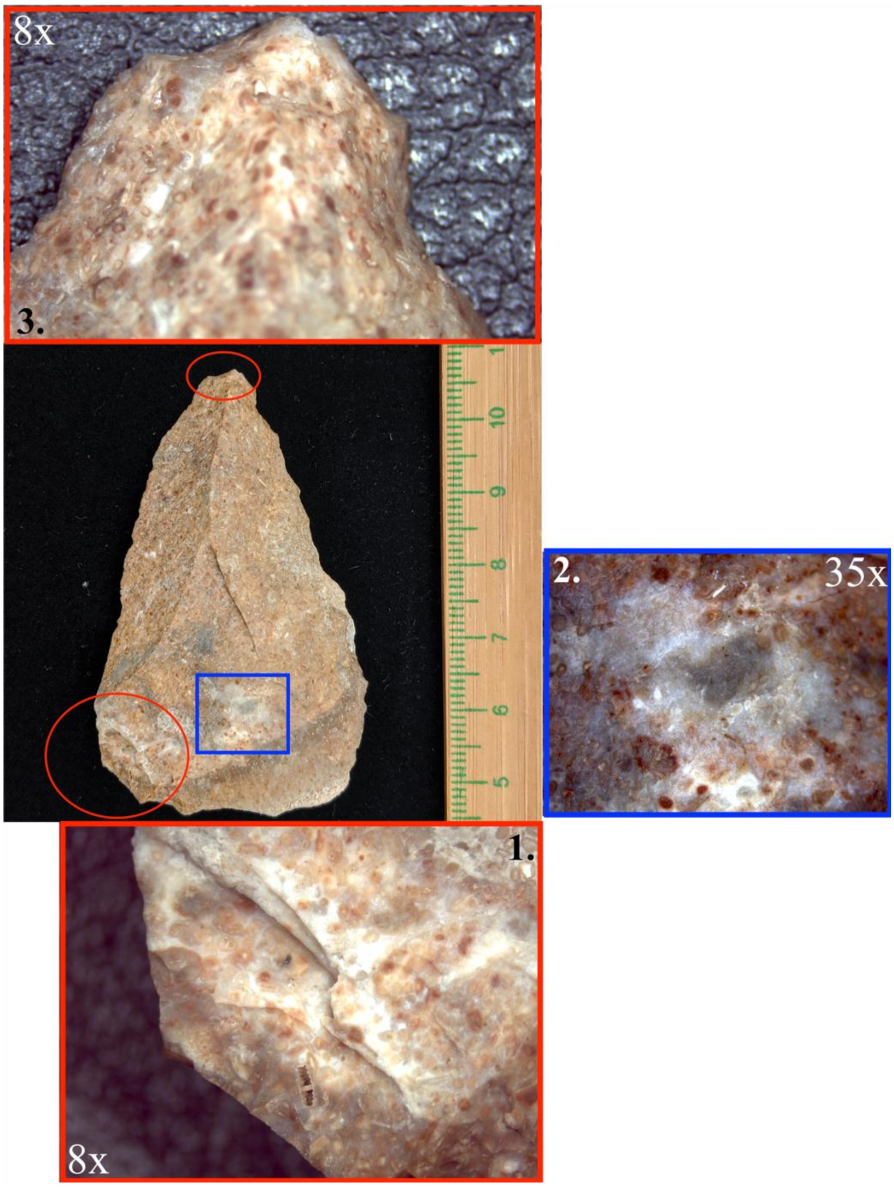


Fig. 57 – R.T. 32 – dorsal – *1) Step-terminating crushing fracture followed by step-terminating bending fracture and polish (Werner and Willoughby, 2018). The possible cause of this fracture could be hafting or more precise the damage influenced by the pressure of the hafting shaft; 2) possible residues; 3) Tip snap and crushing followed by a spin-off fracture (Iovita et al., 2014).*

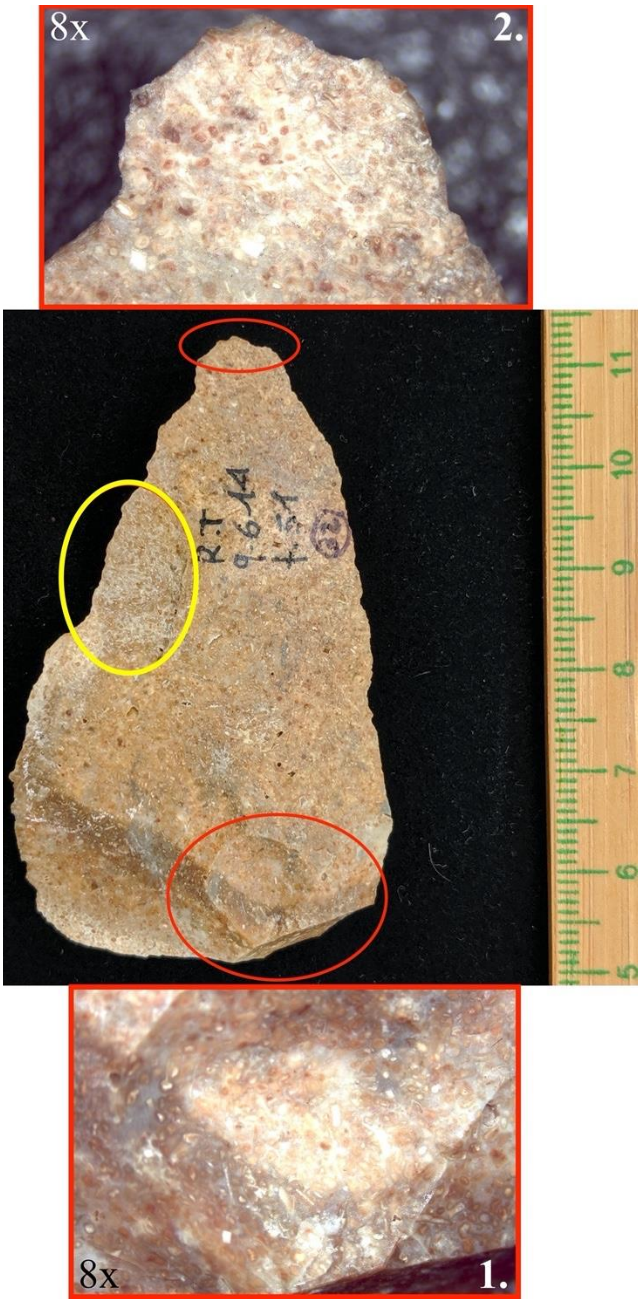


Fig. 58 - R.T. 32 – ventral – 1) *Spin-off fracture with bending termination that possibly represents the intentional removal of the bulb of percussion (hafting modification) (Brindley, 2015); 2) tip crushing. Yellow marked area represents the heavy rounding and micro-notches of the point's lateral side followed by spin-off and step-terminating fracture, based on the 4th experiment it has been shown that cutting the material with high density produces heavier rounding (Fig 53, 54).*

Fig. 59 - R.T. 166 – dorsal – *1) Step-terminating crushing damage (Iovita et al., 2014) possibly caused by the hafting shaft (Fig. 15/1; 41/1; 42/2) or knapping (Fig. 32/4; 36/1); 2) Polish damage that could be correlated to hafting (Rots, 2005); 3) Step-terminating bending fracture followed by a spin-off fracture and step-terminating fracture (Lombard, 2005), the cause of this set of fractures, found on the tip of the point can be interpreted as its usage as a spear-head; 4) diagnostic hafting damage, followed by polish that was probably also caused by hafting (Rots et al., 2001).*

Fig. 60 – R.T. 166 – ventral – *1) polish that could be correlated to hafting (Rots, 2005); 2) Spin-off initialized from tip crushing and followed by a small burin-like fracture and step-terminating bending fracture, when correlated to spin-off fracture on the dorsal side of the points and interpreted as bifacial-spin off fracture. Edge damage is present on both lateral sides of the point as a low rounding damage and presence of the micro-notches, the cause of the edge damage is probably cutting of the low density material. This sample represents a unique example that possesses a strong evidence of usage as a spear-head.*

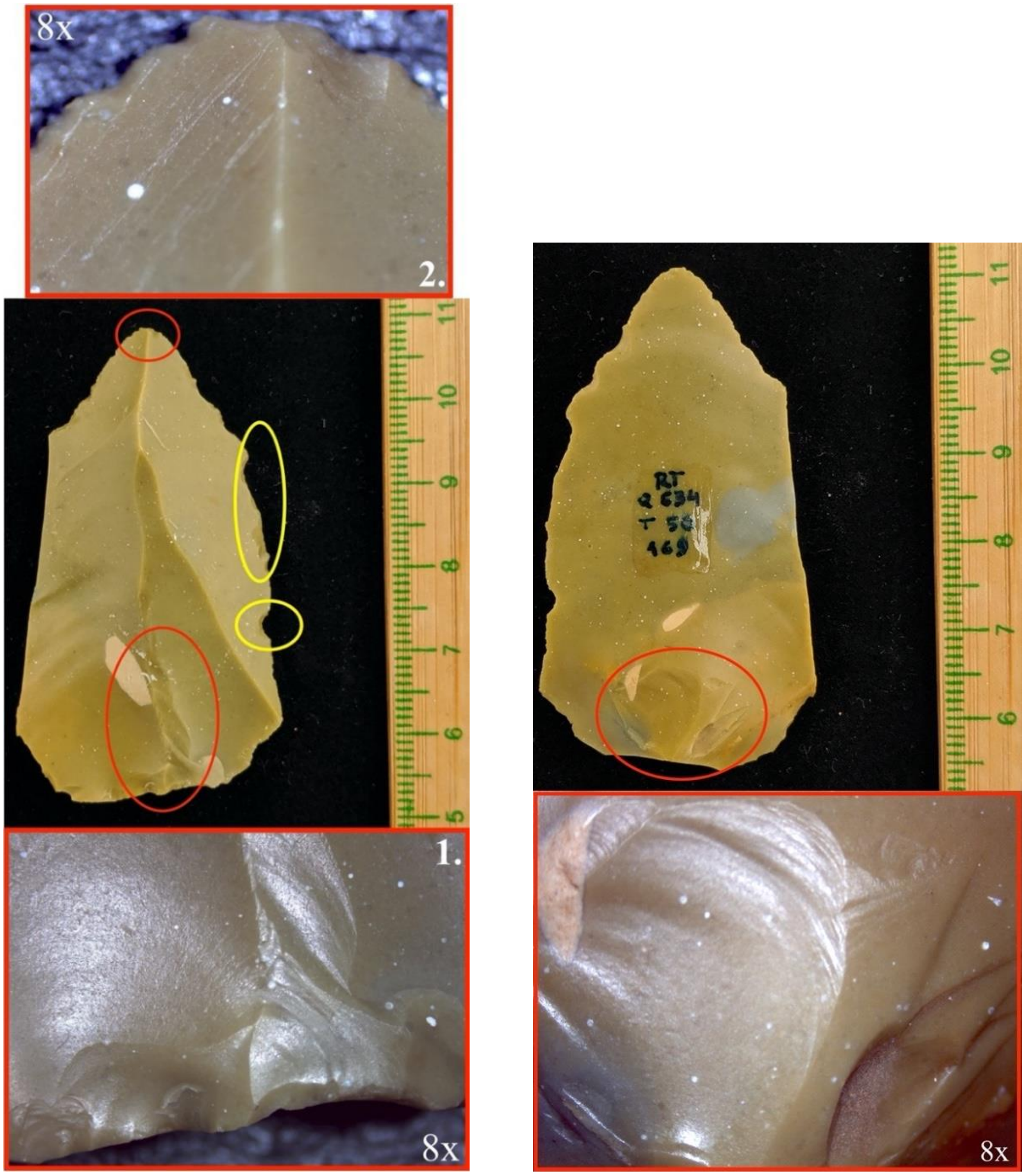


Fig. 61 – R.T. 169 – dorsal and ventral – *1) crushing fracture (Iovita et al., 2016) that has further initialized a spin off that was possibly caused by either knapping incident or hafting shaft; 2) Striations, tip snap followed by a spin-off fracture (Lozny and Abbott, 2004; Pawlik 2001; 2006). On the proximal ventral side of this point, large spin-off fracture is present and same like the fracture on the proximal dorsal side of the point it could be interpreted either as a hafting shaft damage or a knapping incident. The lateral side (marked with yellow ellipses) shows clear evidence of cutting activities (Fig. 53/6; 54/5) in form of light edge rounding, notch and micro-notches. The notch marked with yellow ellipse could also represent a possible hafting damage. (Rots et al., 2001). By the degree of the edge rounding it could be concluded that the light density material was processed using this point.*

Fig. 62 – R.T. 205 – dorsal – *1) Heavy crushing damage (Fig. 53/3, 54/2), possibly caused by heavy butchering activities. Considering the huge spin-off fracture with step-termination (yellow) and the data obtained by the fourth experiment that implied that the hand held mode for the heavy butchering activities such as bone breaking, or other activities such as debranching, is not functional. Therefore, considering the heavy crushing damage along the lateral side of this Mousterian point implies that this piece was hafted and used for breaking the dense material.*

2) Multiple spin-off fractures that are possibly caused by retouching.

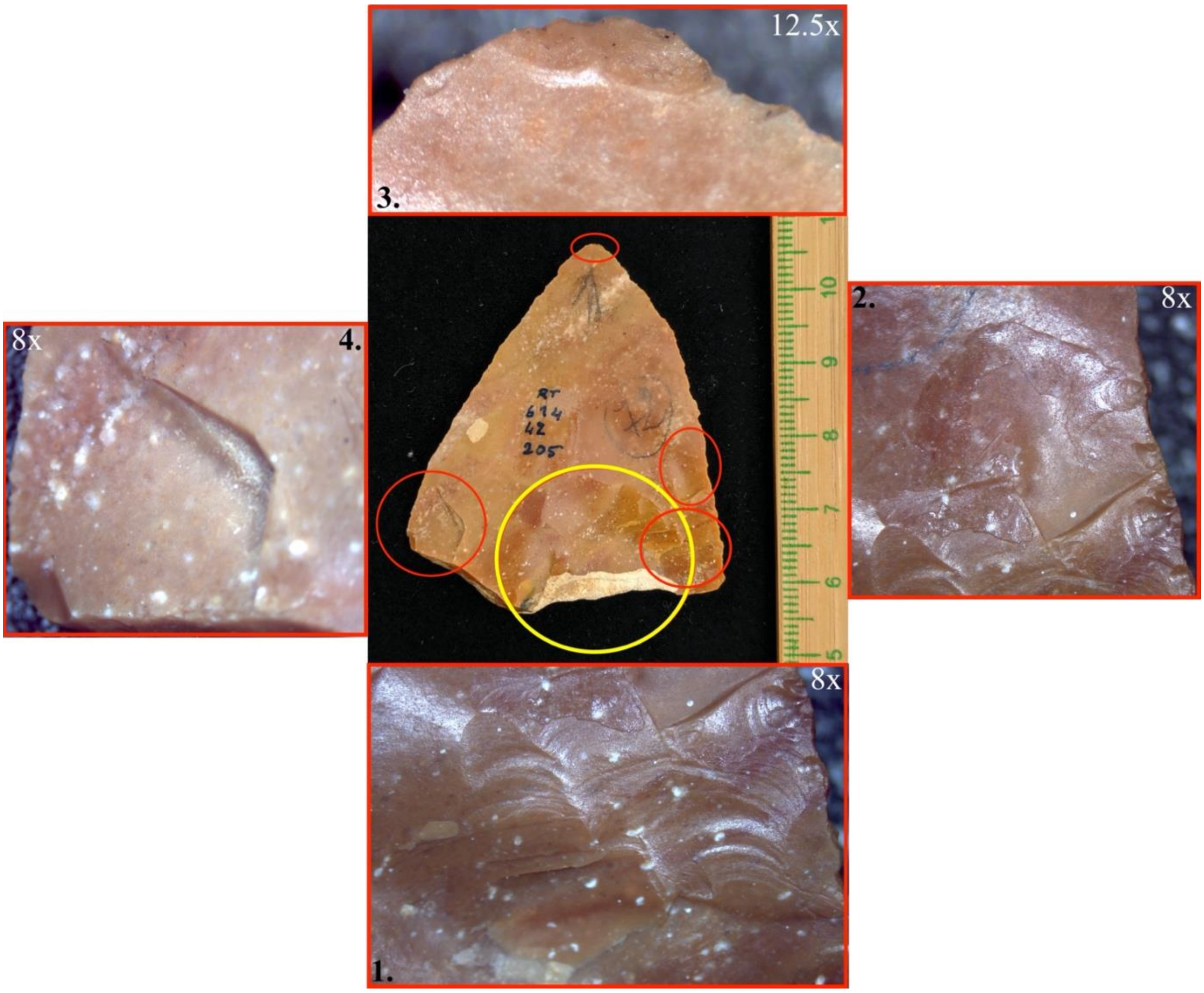


Fig. 63 - R.T. 205 – ventral – *1) multiple spin-off fractures with step-terminating-bending fractures that correspond to the large spin-off fracture on the dorsal side of the flake and strengthen the interpretation that this triangular flake was hafted. 2) Spin-off fracture with step-terminating bending fracture, parallel to another spin-off fracture with step-terminating bending fracture (4) (Rots et al., 2001). These two parallel fractures are confirming that this triangular flake was hafted. 3) Tip crushing with two unifacial spin-off fractures with bending termination. The possible cause of these fractures located on the tip of this point could possibly represent even this point's usage as a spear-head. Similar damage was identified after the execution of the first experiment and the experimental Mousterian point was used as a thrusting spear-head that was vertically hafted (Fig. 18/2).*

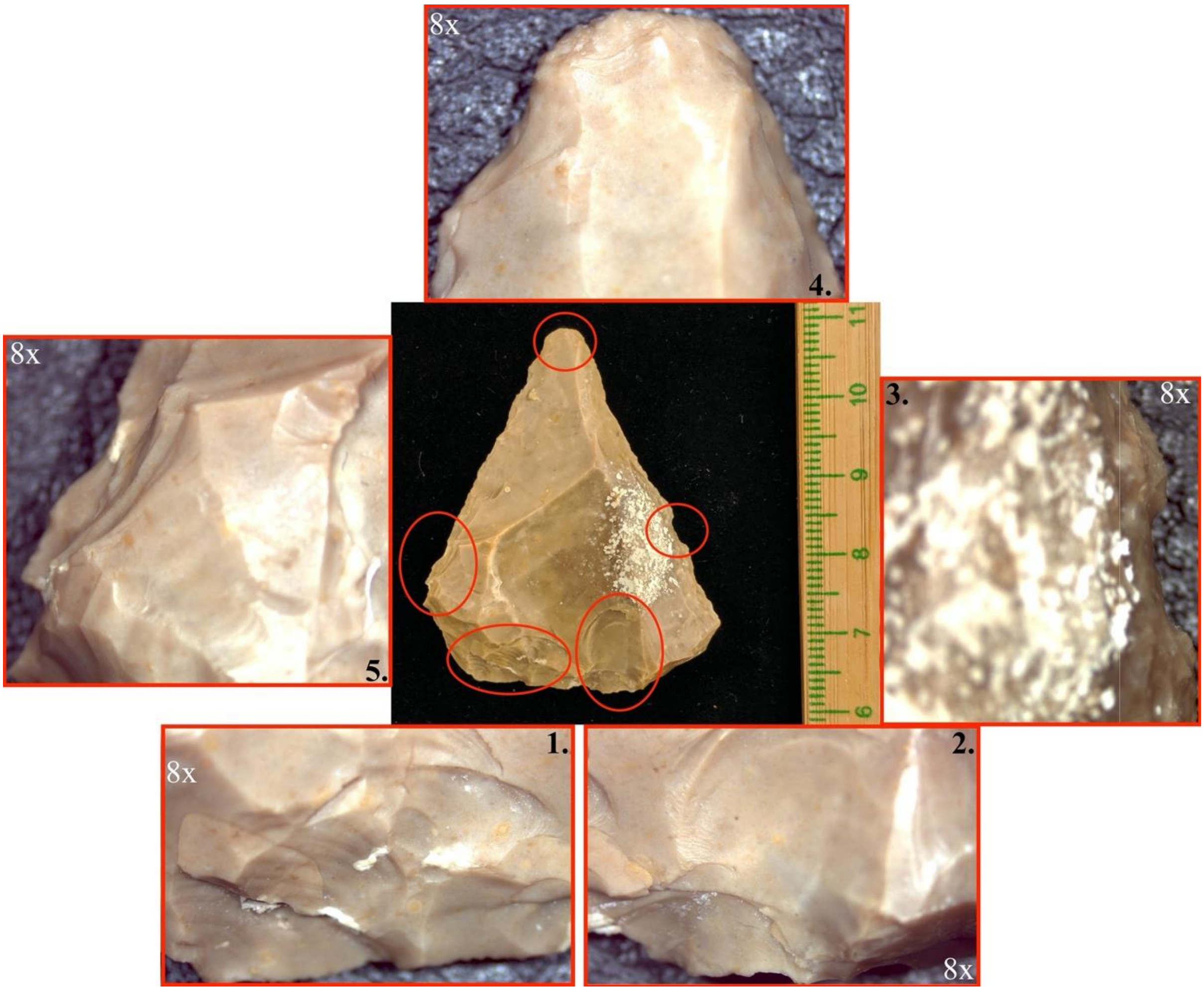


Fig. 64 – R.T. 212 – dorsal – *1) Crushing fracture (Odell and Cowan, 1986; Weitzel et al., 2014) from which the spin-off fracture was initialized; 2) Crushing fracture rom which the spin-off fracture was initialized. The possible causes of the fractures (1; 2) are either knapping incident (Fig. 32/4; 33/1) or a hafting shaft (Fig. 11/3; 15/1). 3) Impact notch, possibly caused by hafting or knapping.*

4) Tip crushing rom which a small spin-off fracture was initialized. 5) Crushing damage that could be interpreted as either knapping or hafting damage.

Fig. 65 – R.T. 212 – ventral – *1 and 2) Multiple spin-offs and step-terminations possibly caused by knapping (Fig. 32/4) or hafting (Fig. 11/3). 3) Edge damage that could be correlated to a wood cutting activities, based on the fourth experiment's data (Fig. 53/5; 54/3,4). 4) Tip crushing from which a spin-off fracture and striations were initialized. It was possible to identify fracture wings (5.) on plane of the spin-off fracture and calculate the fracture velocity (171 m/s) of the fracture which means it belongs to the quasi-static load range. The knapping incident in this case could be excluded, since by the experimental research (Hutchings, 2011) it was established that the soft-hammerstone and hard-hammerstone produce the fracture velocities higher than 400 m/s (Fig. 5). Fracture velocity of this point (R.T. 212) of 171 m/s can be interpreted as a spear impact.*

Fig. 66 – R.T. 216 – dorsal – *1) Multiple step terminating bending fractures and a crushing fracture, the possible cause of these fractures could either be a knapping incident (Fig. 31/1, 4; 32/1) or hafting (Fig. 11/3; 15/1). 2) Multiple spin-off and step terminating fractures possibly caused by knapping or breaking the dense material. 3) Edge damage – rounding and notches, possibly caused by dense material cutting or retouching (Fig. 53/3; 54/1, 2). 4) Tip crushing followed by a small spin-off fracture. 5) Edge damage, crushing and micro notches caused by cutting and breaking of the dense material and also retouching (Fig. 53/3; 54/1, 2).*

Fig. 67 – R.T. 216 – ventral – *Area marked with yellow circle, marks the large spin-off fracture with step termination that could be correlated to either the hafting modification or hafting damage (Fig. 11/3; 15/1) or even maybe knapping incident (Fig. 32/ 3). 1) Edge damage, crushing and rounding, possibly caused by cutting and breaking the dense material (Fig. 53/1, 3; 54/1, 2, 3). 2) It was possible to locate the fracture wings on this Mousterian point, and they were used to calculate the fracture velocity and therefore the loading rate. The fracture velocity of the large spin off fracture (4) that was initialized from the crushing damage on the tip of the point is 972 m/s which places it in the rapid loading rate category which means that there are various causations of this fracture. Based on its location, the knapping incident by using the soft or hard-hammer could be excluded as a possible cause. Value of the fracture velocity implies to points usage as a spear-head for the hand-thrown spear hunting technology (Fig. 5).*

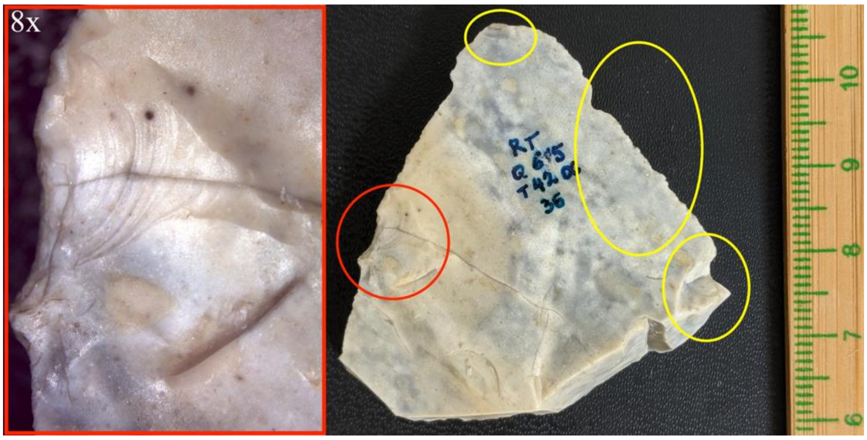


Fig. 68 –- R.T. 36 - *Ventral side of the pseudo-Levallois point. Area marked with the red circle represents a crushing damage from which the two spin-off fractures and a step-termination were initialized. The areas marked with yellow circles represent a crushing fracture (Distal – tip), edge rounding and micro-notches (lateral), and impact notch with the step-terminating bending fracture (proximal-lateral). Based on the locations and the types of the damage, this pseudo-Levallois point was probably used for medium-high density material processing (Fig. 53/2, 7; 54/ 6).*

Fig. 69 – R.T. 547 – dorsal – *1) Small crushing fracture from which multiple step-terminating-bending fractures were initialized, possibly caused by a knapping incident (Fig. 32/1; 33/1) or hafting (Fig. 11/3, 15/1). 2) Burin-like fracture from which multiple spin-off fractures with step termination were initialized, these fractures were probably caused by retouching and/or cutting the high density material (Fig. 53/5). 3) Edge rounding, crushing damage, multiple spin-offs. This damage was caused by cutting the high density material (Fig. Fig. 53/5; 54/3) and re-sharpening/knapping the edge.*

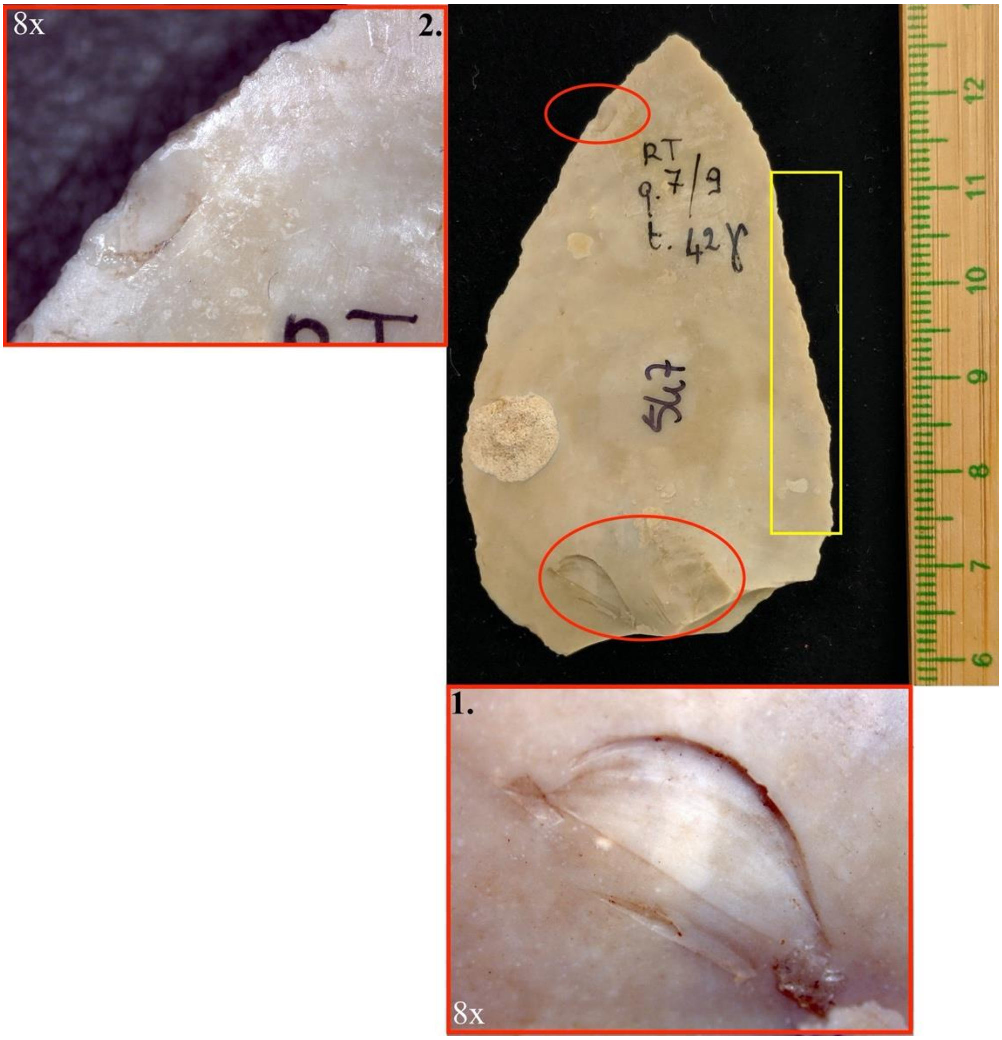


Fig. 70 – R.T. 547 – ventral – *1) Step-terminating fracture and a possible residue remains. Possible cause of this fracture is hafting. Area marked with yellow rectangle is the edge rounding damage and micro-notches that could be related to cutting the medium-high density material (Fig. 53/1, 2; 54/5). 2) Spin-off fracture with step-termination, caused by cutting or breaking the medium-high density material (Fig. 53/3; 54/3, 6).*

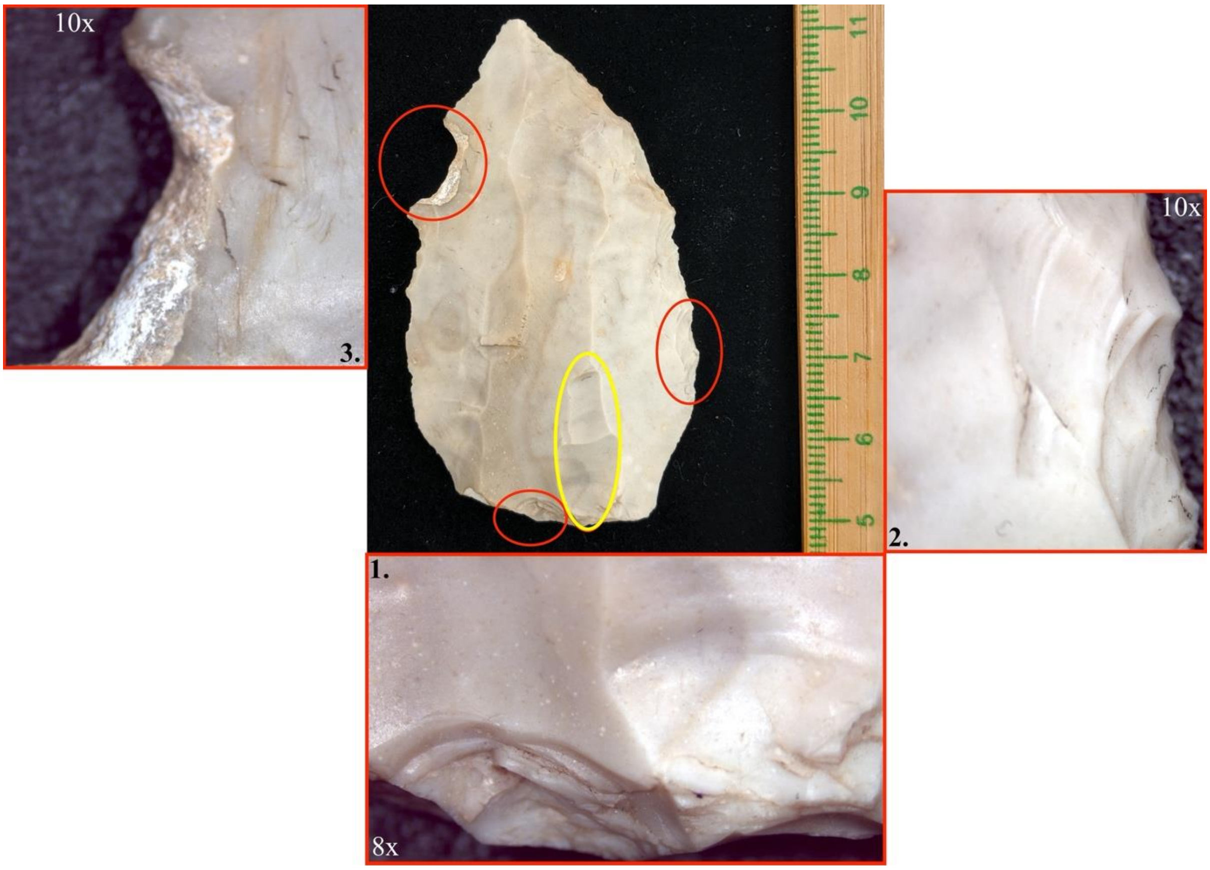


Fig. 71 - R.T. 201 – dorsal – *1) crushing damage that could be correlated to knapping incident (Fig. 32/3; 33/1) or hafting-derived damage (Fig. 11/3, 15/1; 41/2; 42/2). Area marked with yellow ellipse represents a spin-off fracture with step-termination possibly caused by hafting (Fig. 11/3, 15/1).*

2) Heavy edge rounding and crushing, possibly caused by multiple causes, for instance dense material cutting and breaking or re-sharpening (Fig. 53/1, 3; 54/1, 3). 3) Patinated impact notch that could have been caused by numerous activities or it could have been created intentionally.

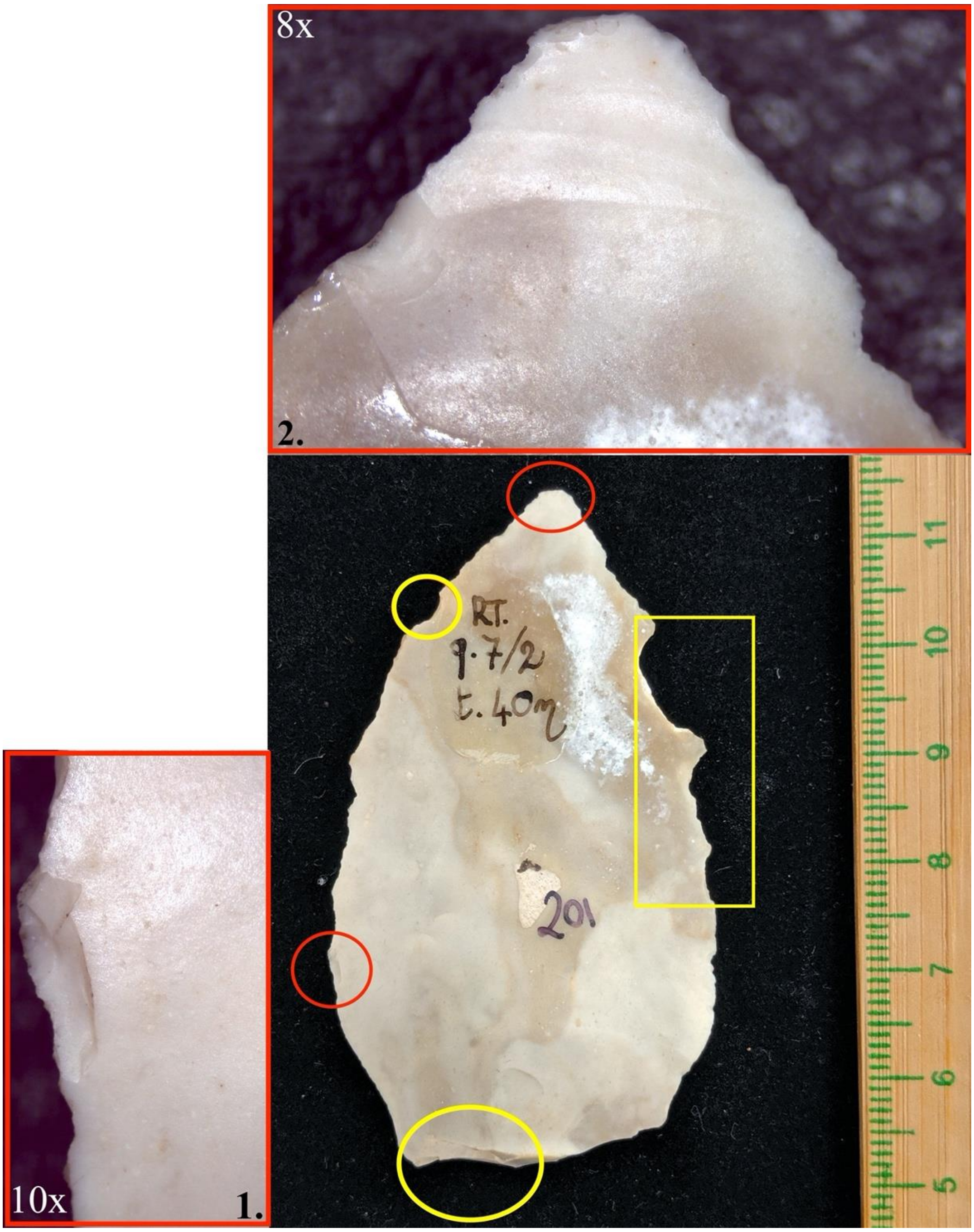


Fig. 72 – R.T. 201 – ventral – *1) Spin-off with step-termination that possibly represents a hafting-derived damage (Rots et al., 2001). The areas marked yellow are crushing damage (base) possibly caused by knapping or hafting, edge rounding (lateral-right) that could have been caused by cutting the low-medium dense material, and notch (lateral-left) that was possibly caused by retouching incident, cutting or scraping the medium-density material or it was created intentionally. 2) Spin-off fracture initialized from the lateral side of the tool and was possibly caused by retouching (Fig. 32/5, 33/3) incident or cutting activities (Fig. 54/3).*

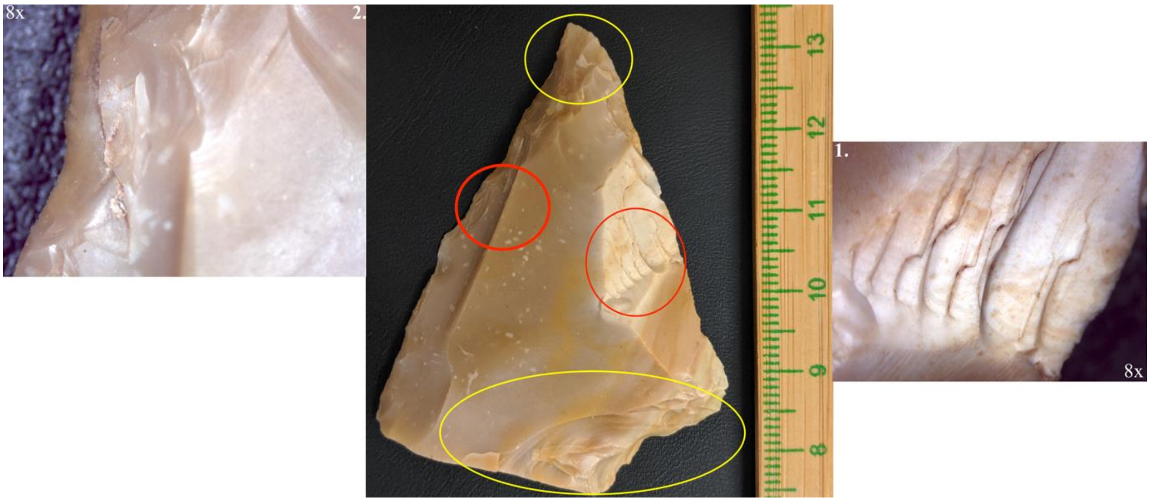


Fig. 73 – R.T. 280 – dorsal – *Area marked with yellow ellipse represents a large crushing damage with step termination (base) that either represents a hafting-derived damage (Fig. 11/3, 15/1; 41/2; 42/2) or a retouching/ re-sharpening (Fig. 32/3; 33/1), and crushing and spin-off fractures (distal-tip) that could have been caused by points usage as a spear-head .*
1) Numerous step-terminating fractures and striations that were possibly caused by post-depositional processes or knapping (Fig. 33/1). 2) Edge rounding with step termination and hinge termination caused by medium-high density material processing (Fig. 53/3, 54/1) and/or retouching (Fig. 32/5; 33/3).

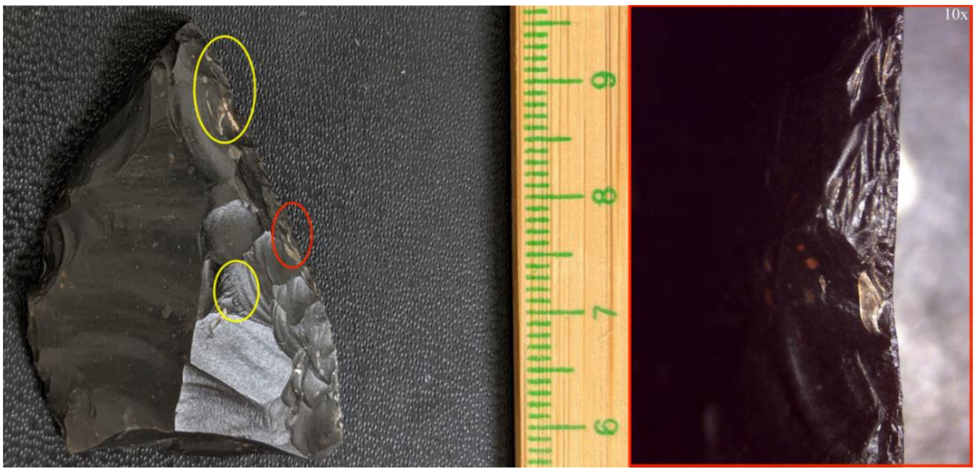


Fig. 74 – R.T. 12 – dorsal – *Area marked with yellow ellipse represents a striations (medial) and edge crushing (distal-lateral). Striations were probably the result of the post depositional processes or by a contact with the high density material (Lozny and Abbott, 2004; Pawlik, 2001). Area marked with red ellipse represents edge crushing and rounding caused by retouching, breaking and cutting activities (Fig. 53/1, 3; 54/1, 2, 3). It seems that this Mousterian point was re-sharpened up to the point where it was impossible to re-sharpen it again, so it was discarded.*

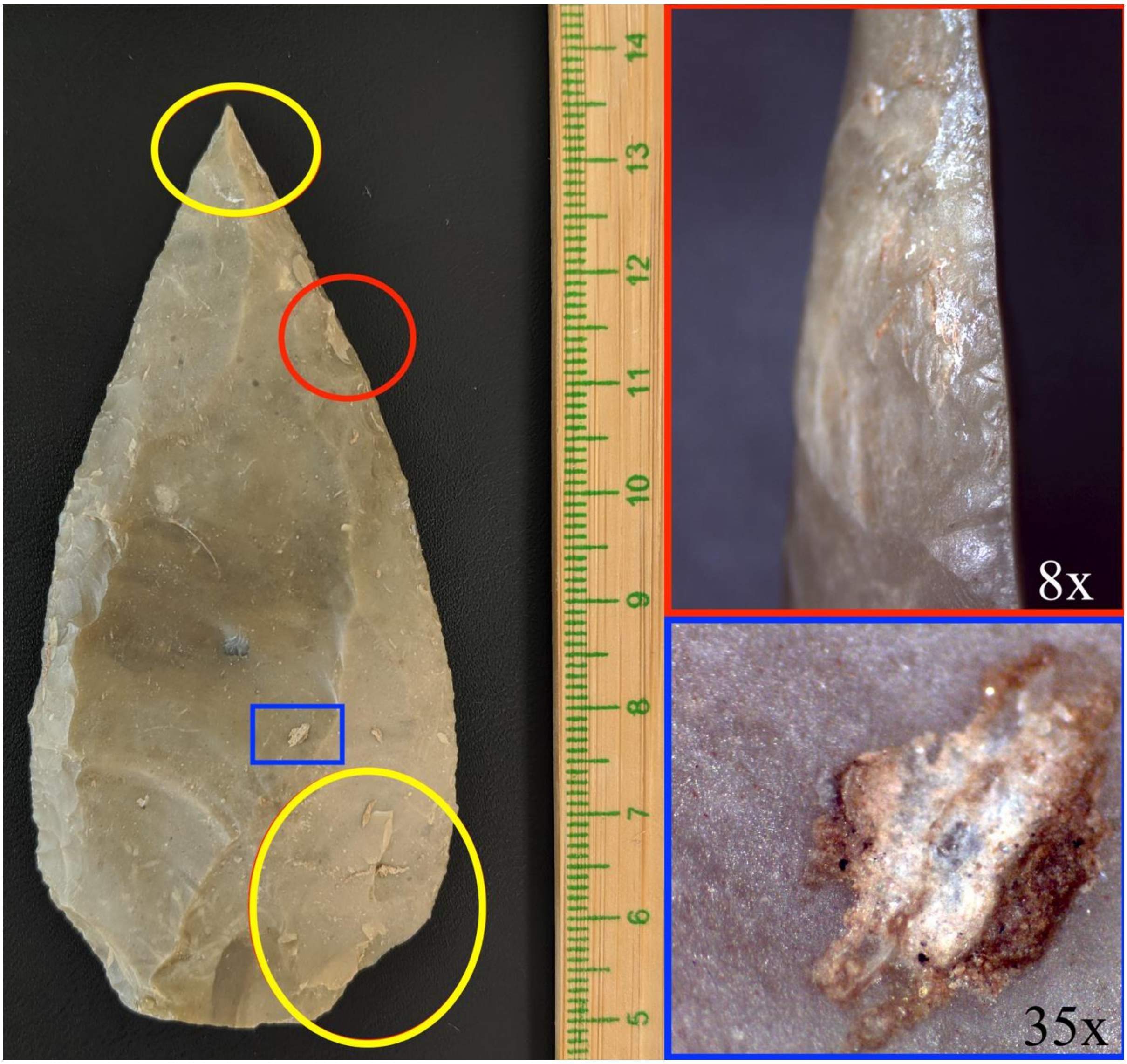


Fig. 75 – R.T. 448! Q. 13/2; t. 37α - dorsal - *Area marked with yellow ellipse – crushing and scarring damage (proximal) that could be correlated to a hafting-derived damage (Fig. 41/2). Crushing-like damage (distal -tip) that could be correlated to retouching in order to obtain point. The area marked with blue rectangle represents a possible residue traces that are currently under analysis. Area marked with red ellipse represents edge rounding caused by medium density material processing (Lozny and Abbott, 2004), (Fig. 53/5, 7; 54/3). Also, retouching crushing damage could be identified.*

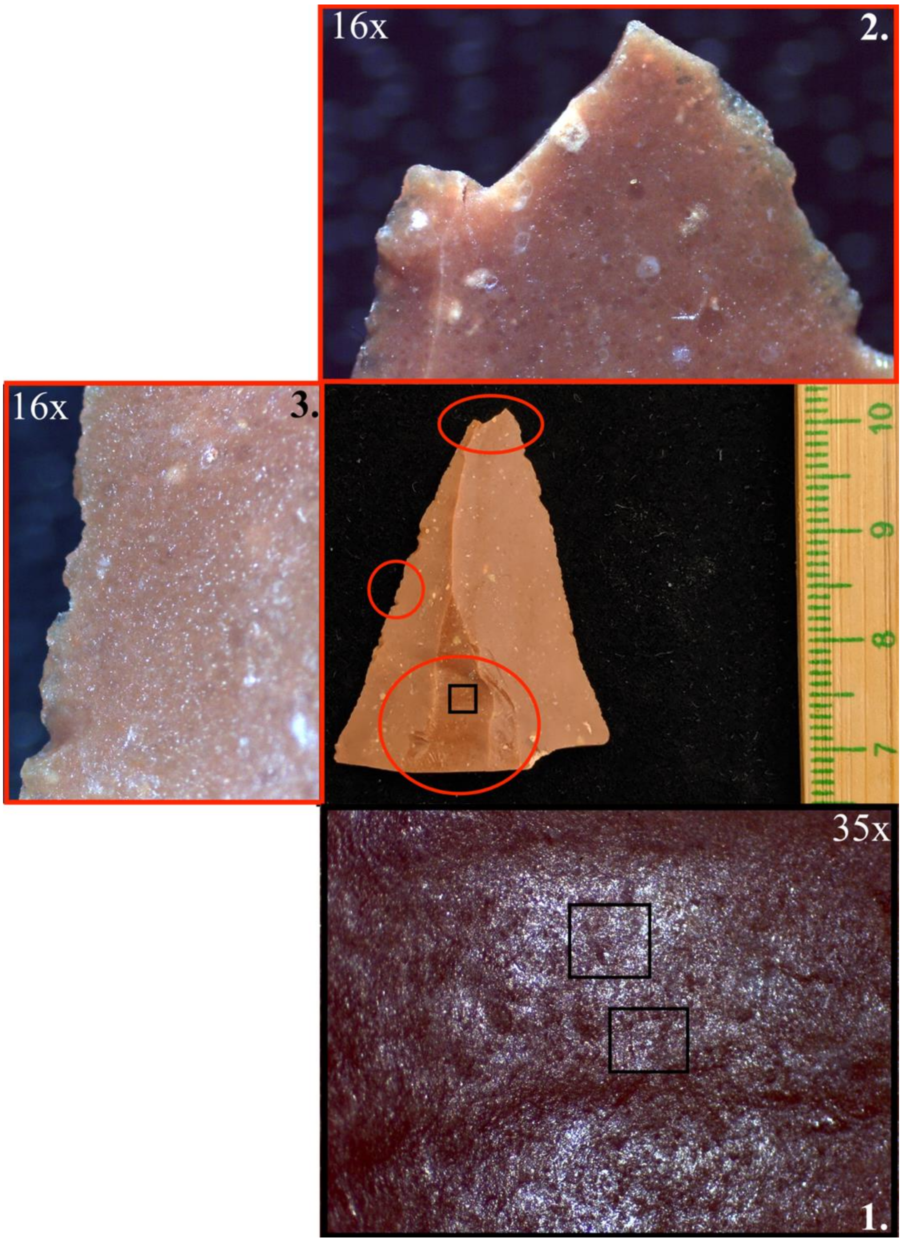


Fig. 76 – R.T. 477 – dorsal – *1) Large spin-off fracture with bending termination initialized from the points breakage in half, the black rectangles represent the fracture wings (Hutchings, 2011; Sahle et al., 2013) used to calculate fracture velocity. The fracture velocity of this fracture is 707 m/s which places it in rapid-loading category which implies that the cause of the fracture could be the point's usage as spear-head used in thrusting or hand-thrown hunting technology (Fig. 5, 42/4, 6, 7). Also, it is rare but the flake breaking in half could also be caused by knapping using the hard hammerstone (Fig. 32/2). 2) Burin-like fracture that could have been the result of point's usage as a spear-head, but the tip of this point is extremely fragile, and the thickness is just 2 mm, so the burin-like fracture could have been caused by multiple factors. 3) Edge rounding and micro-notches that could be possibly caused by cutting the low and medium density material (Fig. 53/7, 54/5).*

Fig. 77 – R.T. 51 – dorsal – *1) Base crushing and striations, possibly caused by knapping (Fig. 32/3; 33/1) or hafting (Fig. 41/2). 2) Tip snap from which the spin-off and bending fracture were initialized could have been caused by numerous activities. 3) Crushing damage and striations, the cause of this fractures could be interpreted as a post-depositional damage or hafting-derived damage (Roots et al., 2001; Pawlik 2004). Area marked with yellow rectangle represents edge rounding and multiple micro-notches that could have been caused by cutting the medium-high density material (Fig. 53/1, 54/5).*

Fig. 78 – R.T. 51 – ventral – *Red circle represents heavy edge rounding caused by cutting and/or scrapping medium-high density material (Fig. 53/2, 4; 54/6). The yellow rectangles are marking the large spin-off fracture with bending termination (proximal) possibly caused by knapping (Fig. 32/1, 3) or hafting , and one of the diagnostic hafting-related damage (lateral) (Rots et al., 2001; Rots, 2004).*

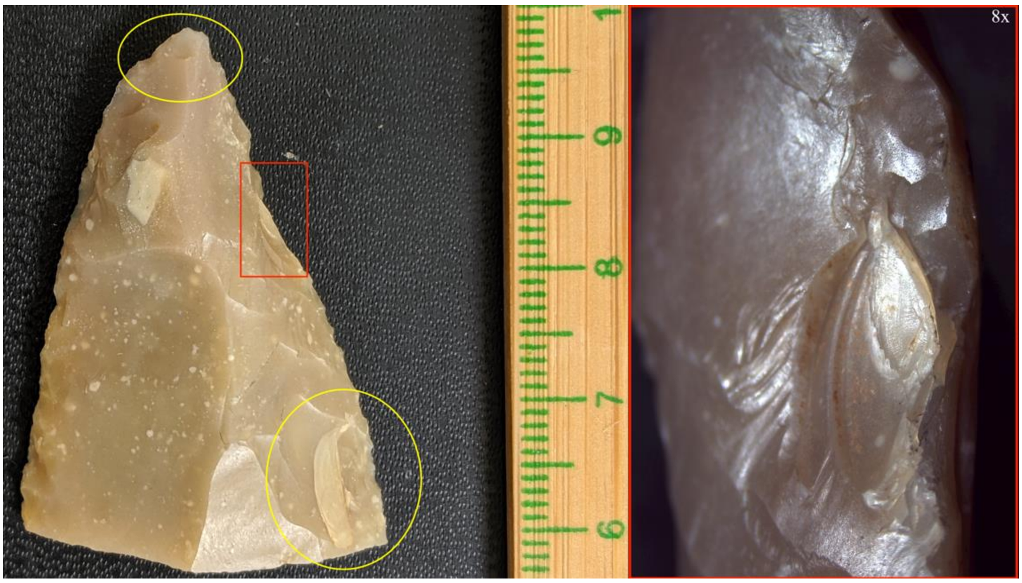


Fig. 79 – R.T. 618 – dorsal – *Area marked with yellow ellipse (lateral) – crushing damage and heavy edge rounding, tip crushing from which a spin-off and burin-like fracture were initialized (distal). Red rectangle represents an edge rounding and crushing damage that could be correlated to breaking the high density material, retouching or probably the combination of thereof (Fig. 53/3; 54/1, 3).*

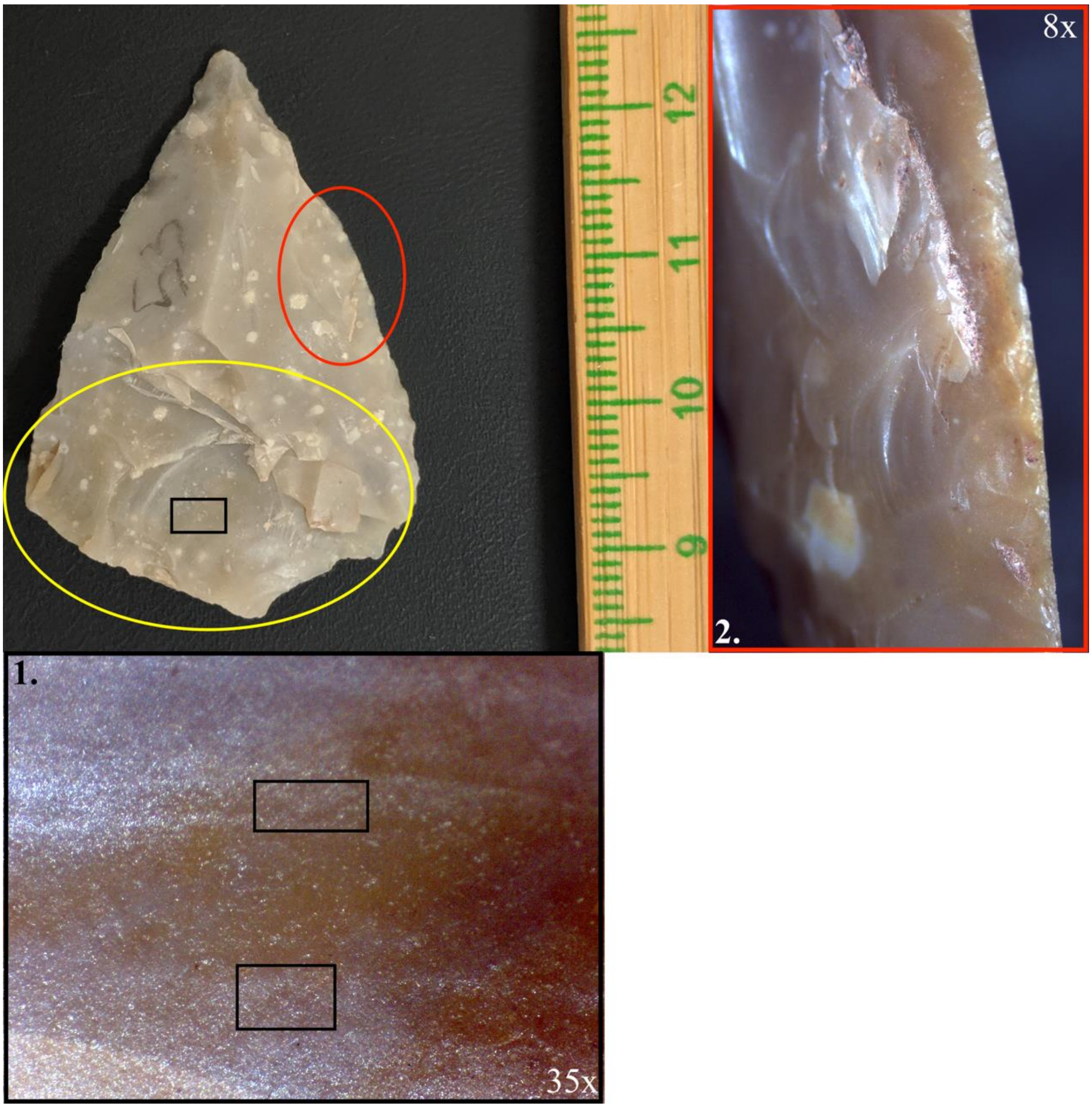


Fig. 80 – R.T. 612 – dorsal – *1) Fracture wings used to calculate the fracture velocity and loading rate (Hutchings, 2011; Sahle et al., 2013). The fracture velocity value of this spin-off fracture with multiple step-terminating crushing fracture and hinge termination is 971 m/s which places it in the rapid load category (Fig. 5). This fracture could have been caused by either knapping using the hard hammerstone or hafting-derived damage of points usage as spear-head. 2) Heavy edge rounding and crushing damage possibly caused by cutting and breaking medium-high density material and retouching/ re-sharpening (Fig. 53/3; 54/ 1, 2).*

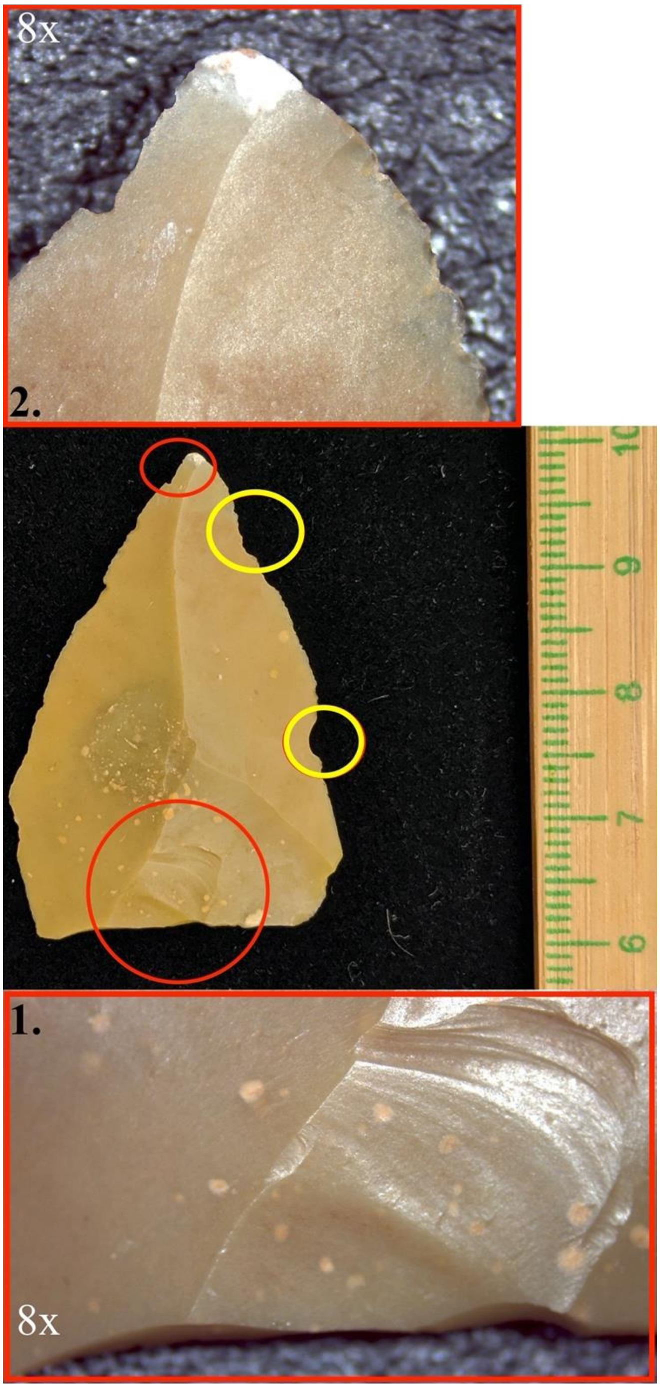
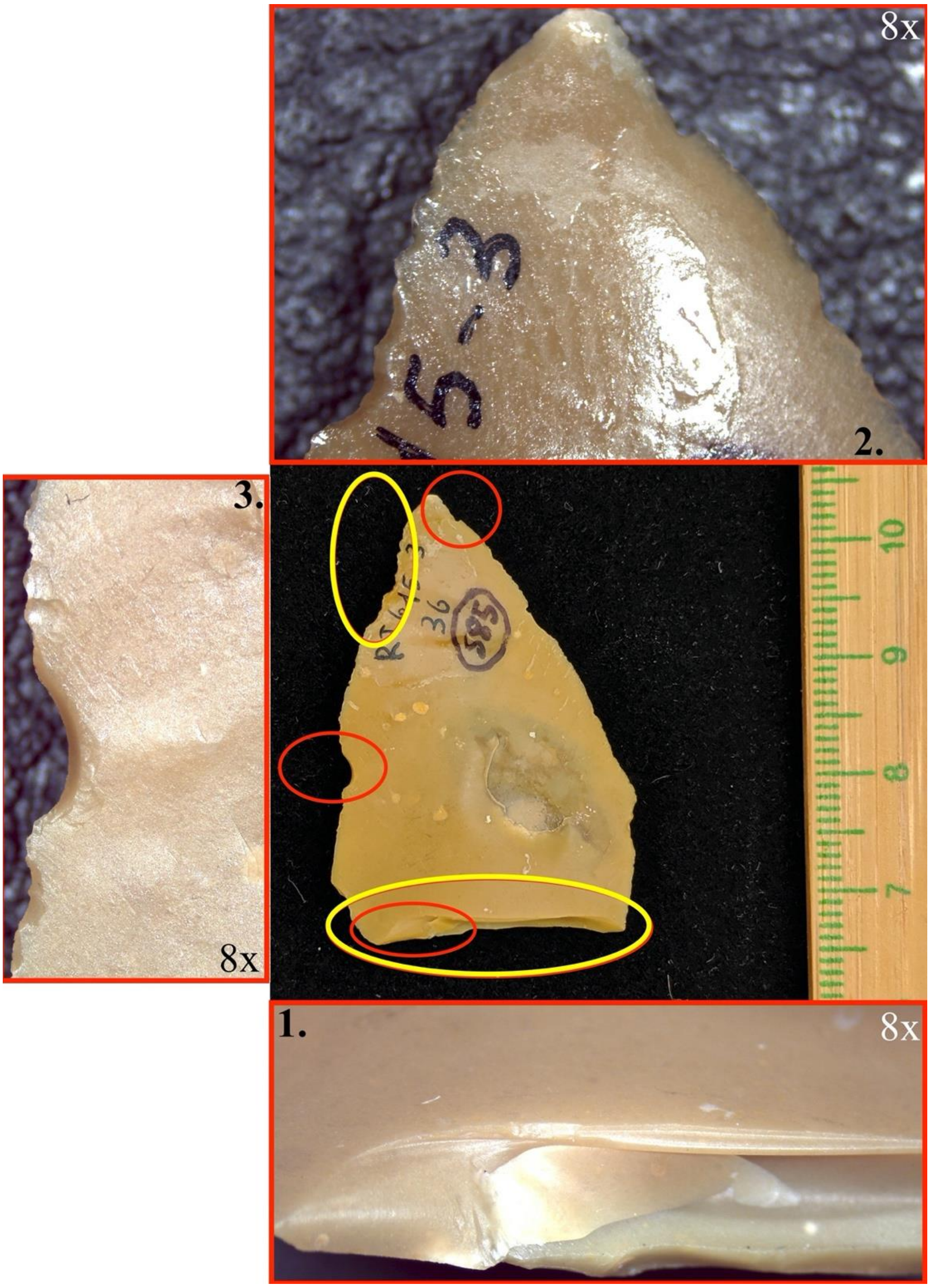


Fig. 81 - R.T. 585 – dorsal – *1) Spin-off fracture with step-termination that was initialized from transversal fracture and caused probably by hafting shaft pressure. 2) Burin-like fracture that was not caused by impact but by using the edge for cutting activities, this conclusion could be established because of the presence of the edge rounding and micro-notches (Fig. 49; 53/1, 6; 54/3, 6). Area marked with yellow ellipse represents edge rounding, notches and micro-notches caused by cutting activities (Fig. 53/ 6; 54/ 6).*



Fig, 82 – R.T. 585 – ventral – *1) transversal fracture. 2) Burin-like fractures caused by cutting activities (Fig. 49). 3) Notch with step-terminating bending fracture that possibly represents hafting damage (Rots et al., 2001).*

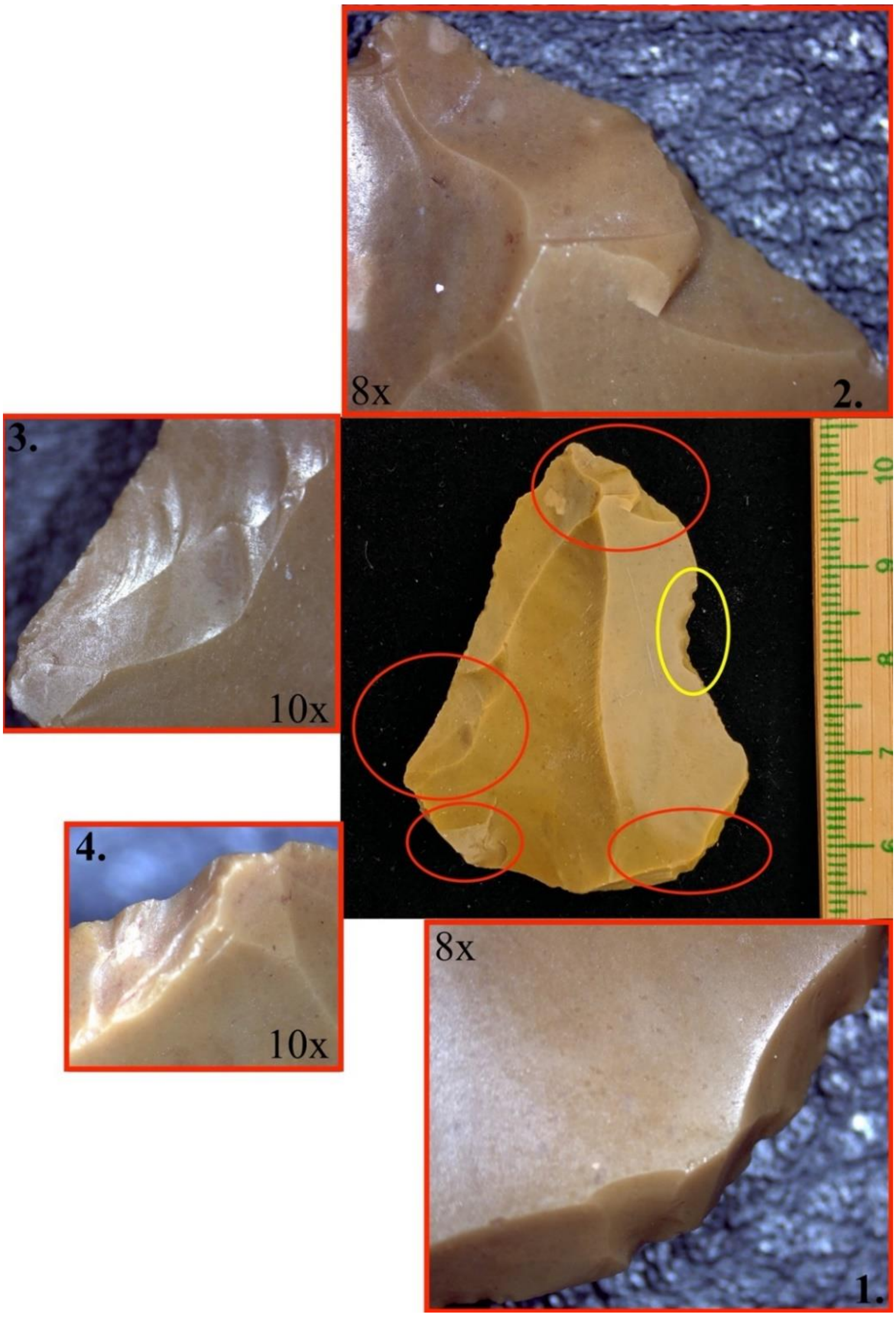


Fig. 83 – R.T. 586 – dorsal – *1) Edge rounding/polish, which possibly represents hafting-derived damage (Rots, 2004). 2) Tip crushing that initialized a small spin-off, burin-like fracture and a step-terminating bending fracture. These fractures could have been caused by this pseudo-Levallois point usage as a spear-head (Fig. 111/4, 5). 3) Two small spin-off fractures with step-terminating bending fractures that probably represent a hafting-derived damage. 4) Crushing damage that could have been caused by knapping (Fig. 32/4; 33/1) or possibly represents a hafting damage (Fig. 41/3). Yellow marked area represents a heavy rounding damage possibly caused by high density material cutting or/and scrapping (Fig. 53/2, 4; 54/6).*

Fig. 84 – R.T. 586 – ventral – *1) Platform Crushing and spin-off fracture that could have been caused by knapping or hafting 2) Tip crushing and burin-like fracture that was caused by points usage as a spear-head or by cutting/butchering activities.*

Fig. 85– R.T. 40 – *Crushing fracture with step-terminating fracture probably caused by knapping.*

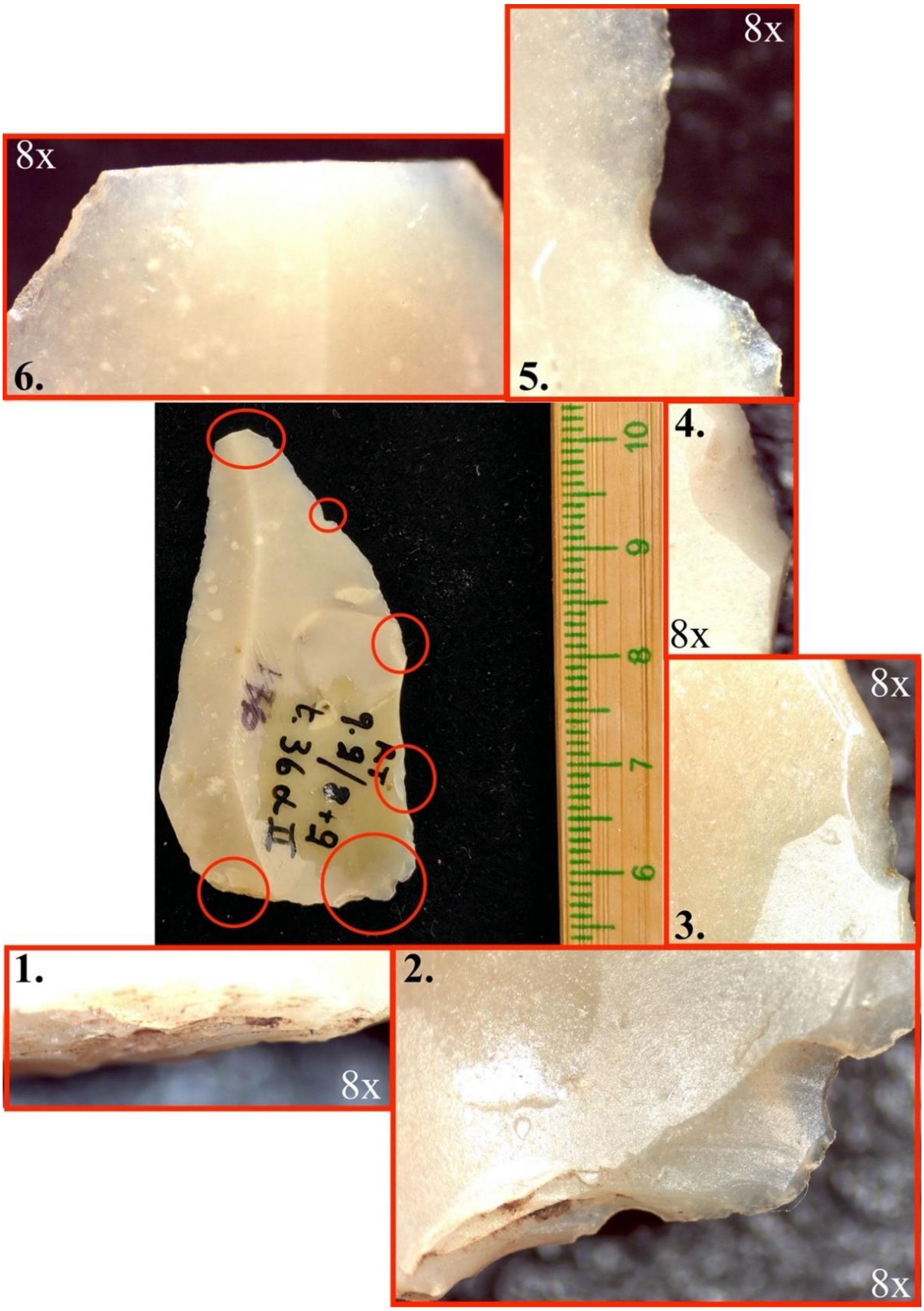


Fig. 86 – R.T. 176 – dorsal – *1) Platform crushing caused by either knapping or hafting (Fig. 11/3, 15/1; 32/4; 41/2; 42/2). 2) Bending fracture and step-termination that possibly represents hafting damage (Fig. 11/3). 3) Bending fracture with polish damage that could represent the hafting-derived damage (Rots, 2004). 4) Edge rounding and bending fracture possibly caused by cutting activities (Fig. 53/1, 6; 54/3, 6). 5) Edge rounding and notch that was possibly formed by using this pseudo-Levallois point for cutting activities. 6) Tip snap, damage that could have been caused by various activities.*

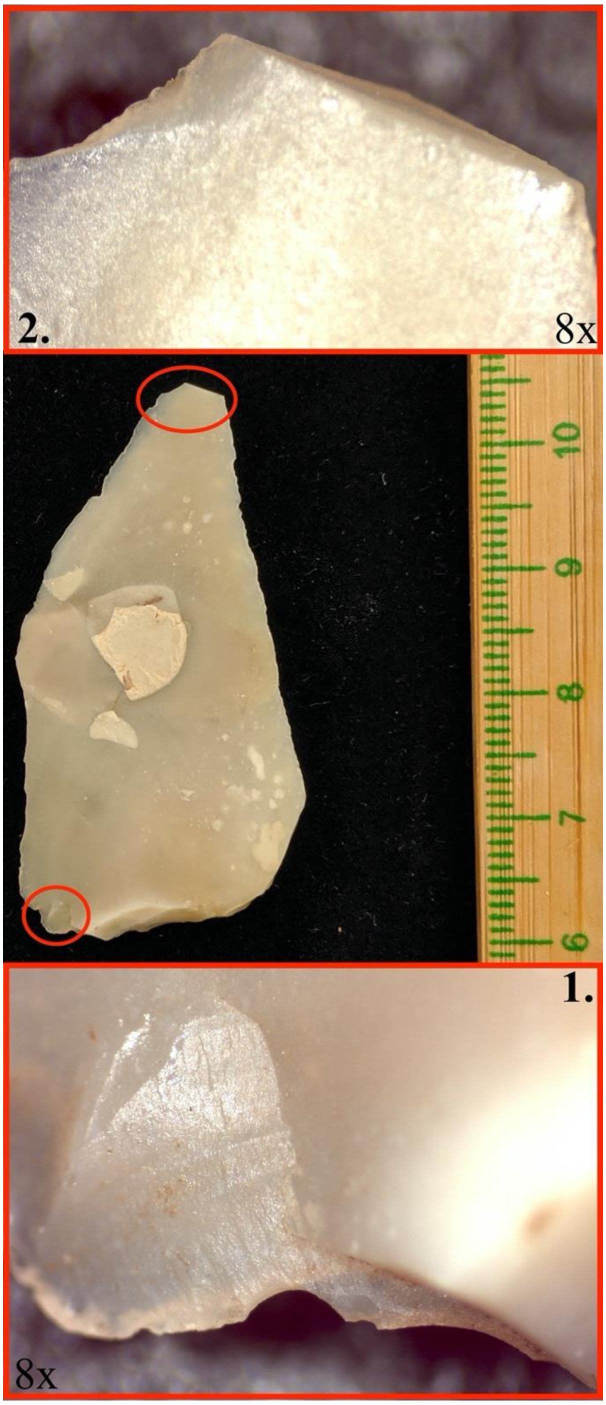


Fig. 87 – R.T. 176 – ventral – *1) Impact notch and bending and spin-off fracture that was caused either by knapping or represents hafting-derived damage. 2) Tip snap and bending fracture that could have been caused by various activities.*

Fig. 88 – R.T. 447! Q13/6; t. 36β - dorsal – *1) Crushing damage that could have been caused by hafting (Fig. 11/3; 15/1) or knapping (Fig. 32/1; 33/1). 2 and 4) Parallel crushing damage that probably represent the hafting limit and was caused by hafting (Roots et al, 2001; Rots, 2004). 3) Striations that could have been formed by various causes. Yellow marked area represents an edge rounding and impact notch.*

Fig. 89 – R.T. 447! Q13/6; t. 36β - ventral – *Crushing damage that is possibly a product of knapping (Fig. 32/1; 33/1) or hafting (Fig. 11/3; 15/1). Yellow marked area represents parallel crushing damage that probably represent the hafting limit and edge rounding and impact notch (distal lateral).*

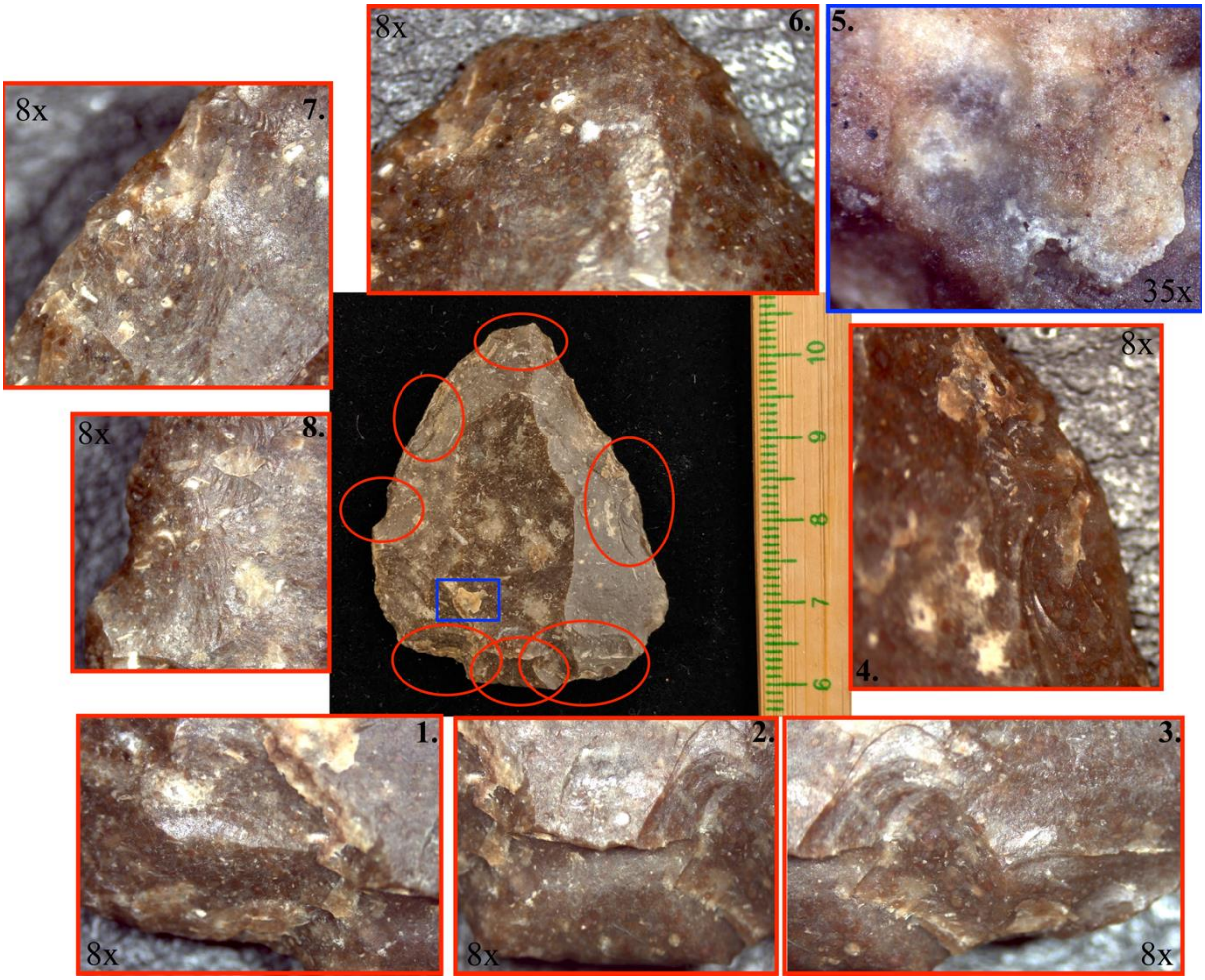


Fig. 90 – R.T. 342 – dorsal – *1) Crushing damage with spin-off and step-terminating bending fracture, 2) hinge-terminating bending fracture, 3) Crushing damage and spin-off with step-termination. The fractures presented in these three pictures represent either hafting or knapping damage or even possibly the combination of both (Fig. 11/3; 15/1; 32/1; 33/1; 41/1; 42/2, 5). 4 and 7) Edge rounding and crushing caused by cutting and breaking activities (Fig. 53/5; 54/3, 6). 5) Possible residues of binding material. 6) Tip snap from which a spin-off fracture was initialized and could have been caused by using this Mousterian point as a spear-head (Fig. 11/1, 2).*

8) Edge rounding and notch with bending termination that probably represent a haft-limit damage (Rots et al., 2001).

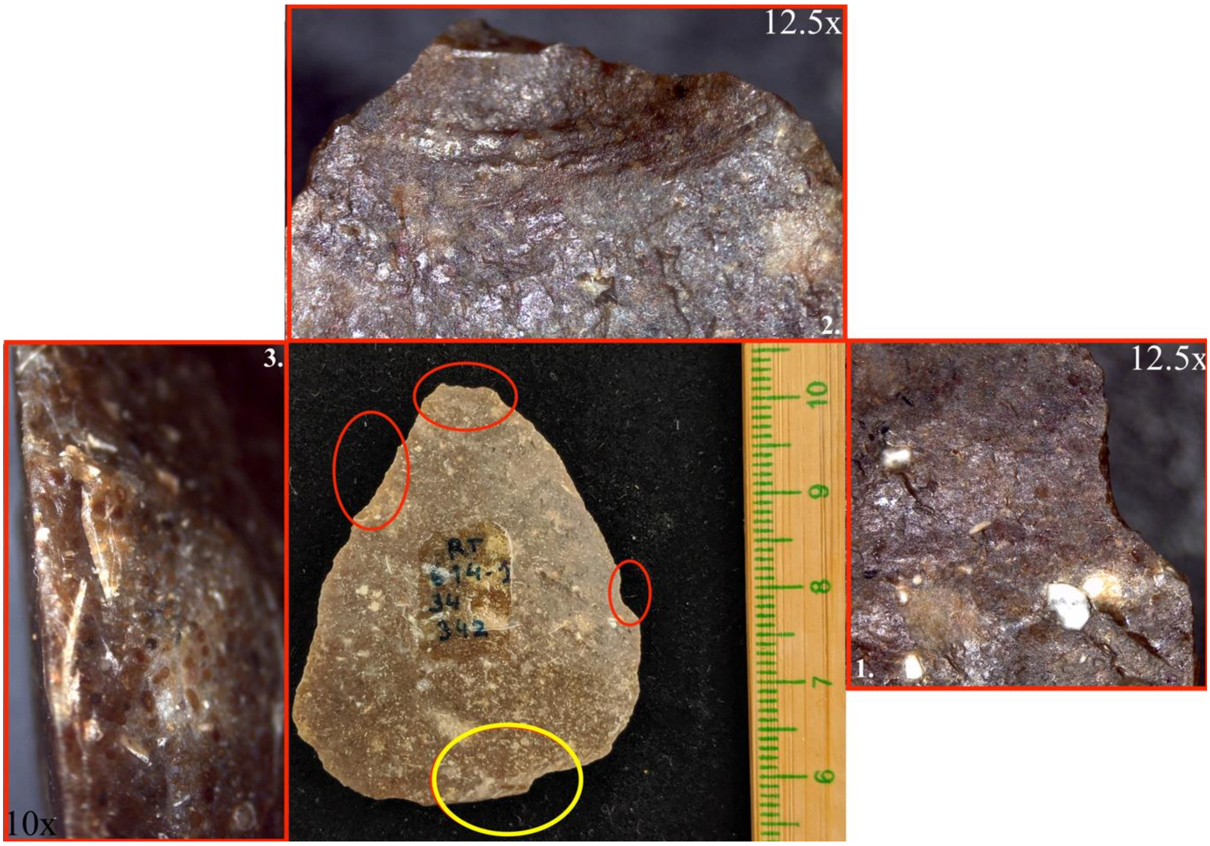


Fig. 91 – R.T. 342 – ventral – *1) notch and polish that probably represent a hafting damage. 2) Tip crushing and spin-off fracture with bending termination that could have been caused as points usage as a spear-head (Fig. 12/5; 14/3; 15/3). It was not possible to locate fracture wings due to post-depositional damage. 3) Edge damage – crushing and rounding, possibly caused by cutting and breaking activities or retouching or combination of thereof (Fig. 53/1, 3; 54/1, 2, 3). Yellow marked area represents crushing damage that could be correlated to knapping or hafting*.

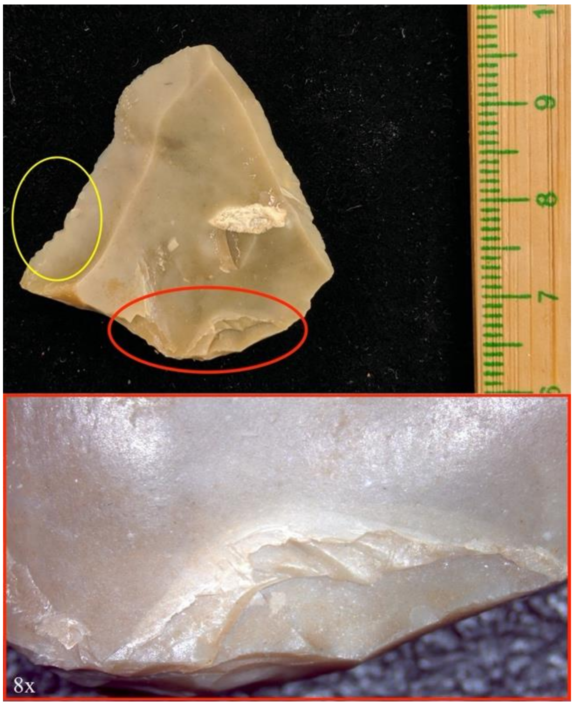


Fig. 92 – R.T. 7 – dorsal - *step-terminating crushing damage that was probably caused by knapping (Fig. 33/1; 41/1; 42/5). Yellow marked area represents edge rounding and micro-notches, caused by cutting activities (Fig. 53/ 6; 54/ 6).*

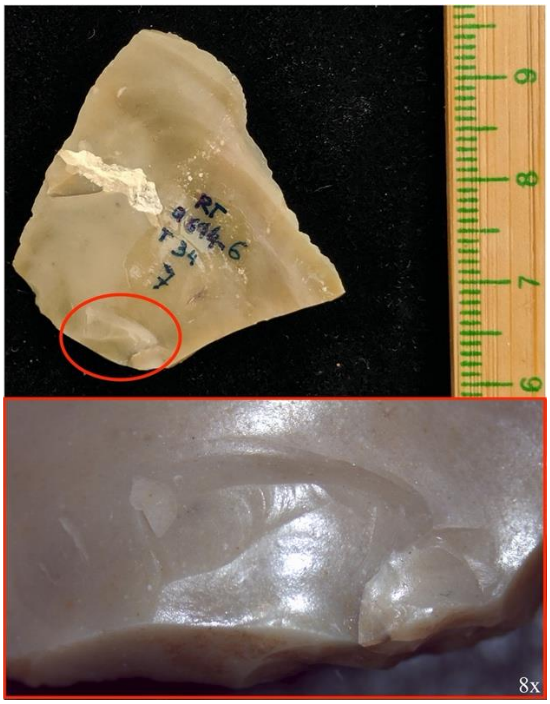


Fig. 93 – R.T. 7 – ventral - *spin-off fracture with bending termination possibly caused by knapping (Fig. 32/1; 42/5).*

Fig. 94 – R.T. 343 – dorsal – *1 and 2) Step-terminating crushing fractures caused by either knapping (Fig. 32/1; 42/5) or hafting (Fig, 11/3; 41/2; 42/2). 3) Notch with bending termination possibly caused by scraping or cutting activities (Fig. 53/1, 6; 54/5). 4) Tip crushing with bending termination, a damage that could have been caused by multiple activities, point's usage as a spear-head is one of the possibilities (Fig. 9/1). 5) Edge rounding and crushing with multiple step-terminating bending fractures caused by the cutting of medium-high density material (Fig. 53/1; 54/3).*

6) Pits and striations that could have been caused by post-depositional activities.

Fig. 95 – R.T. 343 – ventral – *1) Step-terminating bending fracture with spin-off and striations, these fractures could represent a knapping or hafting damage. 2) Striations and crushing damage, possibly caused by hafting (Fig. 41/1 3; 42/5). 3) Edge rounding and crushing with spin-off fracture caused medium-high density material cutting (Fig. 53/1; 54/3) or retouching (Fig. 33/2, 3). 4) Tip crushing from which multiple small spin-off fractures were initialized, this fracture could have been caused by various activities. Yellow marked area represents striations possibly caused by post-depositional processes.*

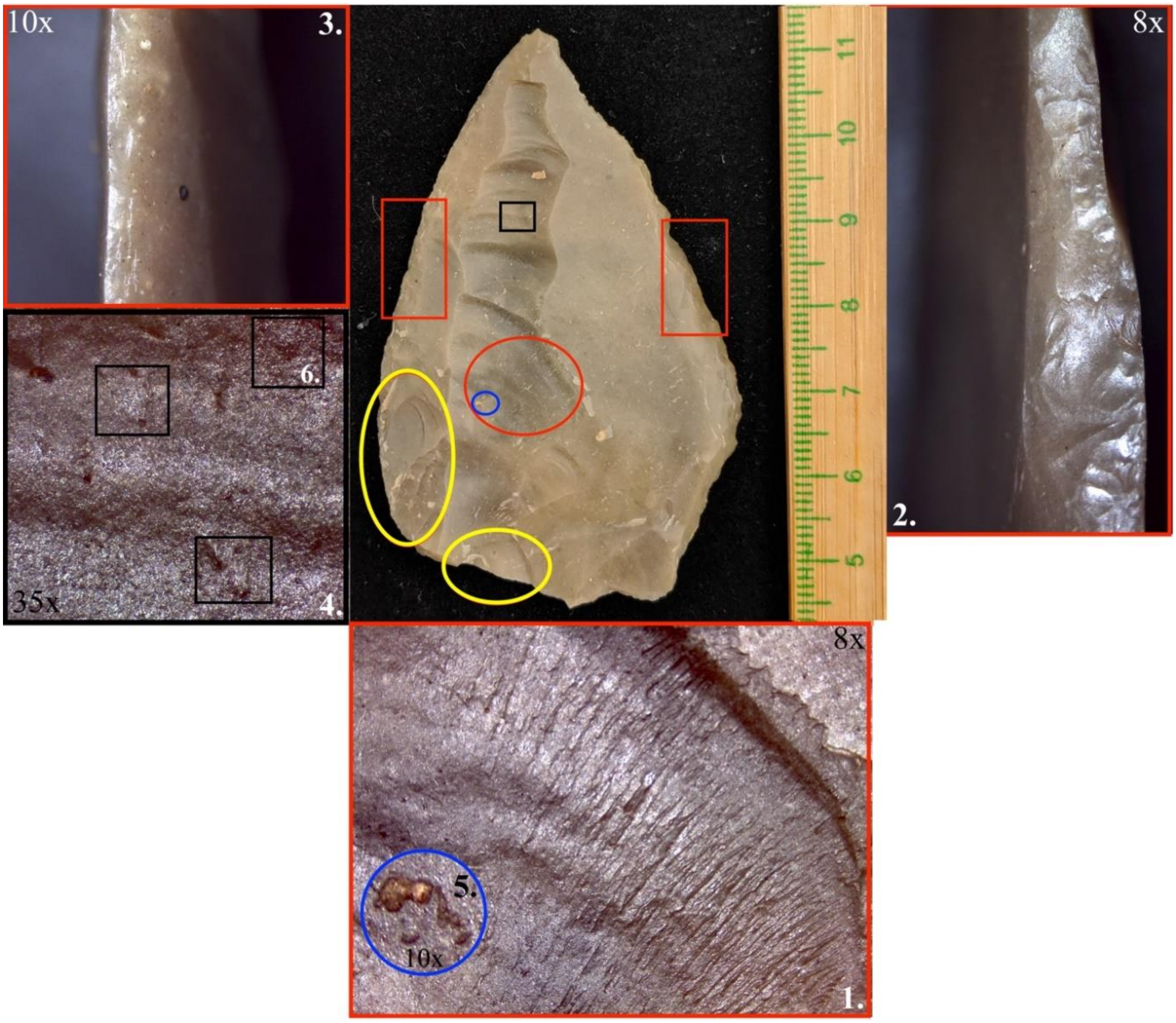


Fig. 96 – R.T. 60 – dorsal – *1) Spin-off fracture with step-termination and striations possibly caused by knapping or hafting (Fig. 32/1, 3; 41/2; 42/5). 2) Heavy edge rounding and crushing, caused by cutting and breaking medium-high density material and re-sharpening/retouching (Fig. 53/1; 54/3). 3) Edge rounding caused by cutting the medium density material (Fig. 53/5, 7; 54/3). 4 and 6) Fracture wings used for calculation of fracture velocity and loading rate. The fracture velocity of the large spin-off fracture is 433 m/s which places it in the quasi-static loading rate category (Fig. 5). This value of fracture velocity could be the result of the pressure flaking, soft hammerstone knapping, or the point's usage as a spear-head for hand thrown and thrusting spear hunting technology. Based on fractures location the possible cause could be the points usage as a spear-head and unintentional pressure flaking initialized by the hafting shaft while the point was used for cutting activities or as a spear-head. 5) On the figure (96/1) possible residues of binding material are marked with blue circle. Area marked with yellow ellipses represent crushing damage with spin off possibly caused by knapping or hafting (base) and edge rounding and spin-offs (lateral) caused by cutting/breaking the medium density material or retouching.*

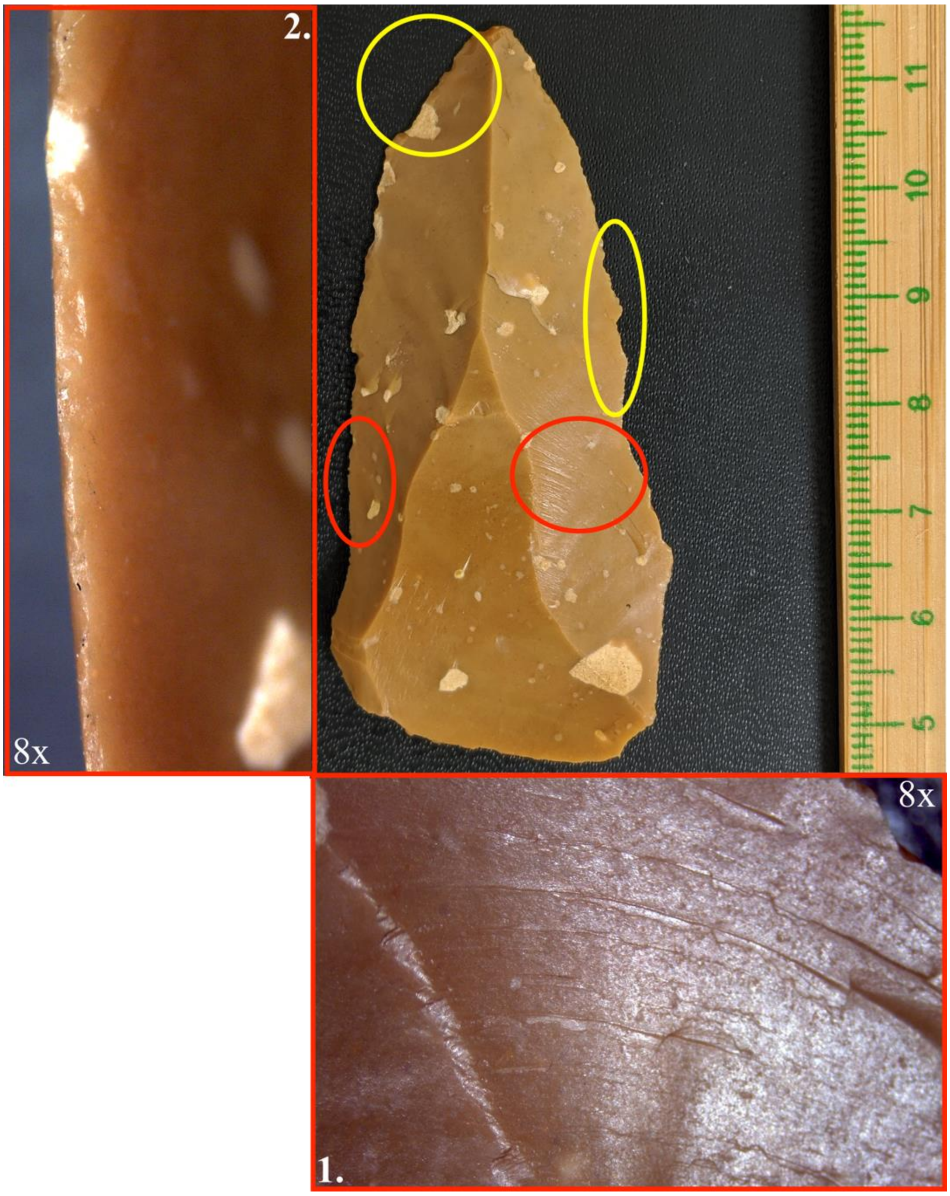


Fig. 97 – R.T. 10 – dorsal – *1) Striations that could have been caused by various activities. 2) Edge rounding caused by cutting the low-medium density material (Fig. 53/1, 7; 54/;3). Area marked with yellow ellipse represents edge rounding and micro-notches caused by cutting activities (Fig. 53/ 6; 54/ 6). Yellow circle represents the burin-like fracture not caused by impact but as a points usage as a knife.*

Fig. 98 – R.T. 446! Q. 615-8; t. 33 – dorsal – *1) Edge rounding and crushing with multiple spin-off fractures and step-terminations, caused by multiple activities such as scraping, cutting, breaking of medium-high density material and retouching/re-sharpening (Fig. 53/3; 54/ 1, 2). 2) Edge rounding and multiple spin-off fractures with step-terminations that could have been caused by cutting or breaking activities or retouching/re-sharpening (Fig. 53/3; 54/5).*

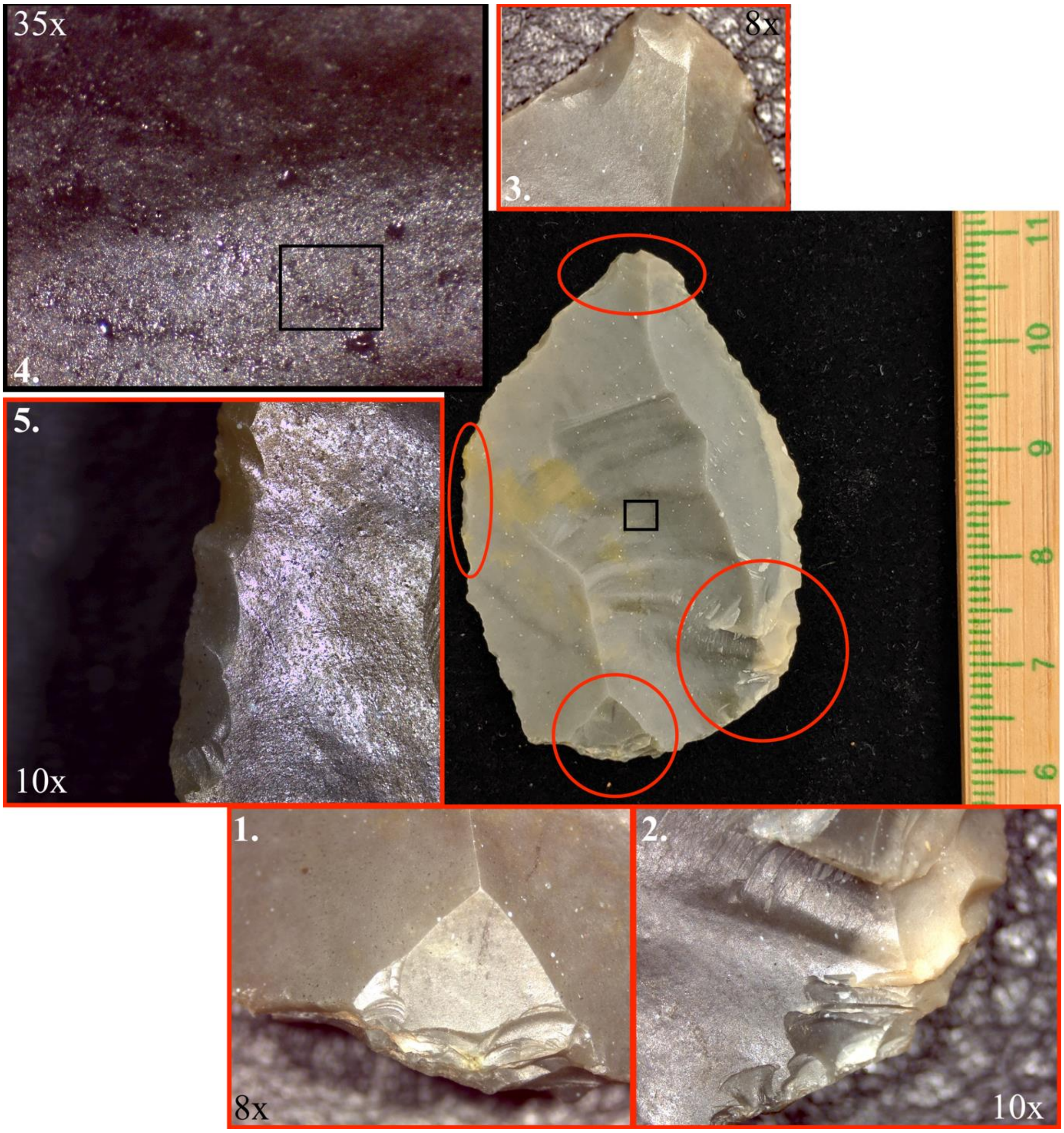


Fig. 99 – R.T. 8 – dorsal – 1) *Crushing fracture caused by either knapping (Fig. 32/1; 33/1) or hafting (Fig. 15/1; 41/1, 2; 42/2, 5). 2) Crushing fracture with step-terminating bending and hinge fracture, these fractures are possibly representing a hafting-derived damage (Fig. 15/1). 3) Tip bending that could have been caused by various type of activities. 4) Fracture wing (Hutchings, 2011; Sahle et al., 2013) used to calculate the fracture velocity of the large spin-off fracture with step-termination. The fracture velocity value, given the presented fracture wing is 760 m/s which places this fracture in the rapid loading rate category (Fig. 5). Considering the value of the fracture velocity and the loading rate, this fracture could have been caused by indirect percussion, knapping by using soft or hard hammerstone. 5) Heavy edge rounding caused by cutting or scrapping the medium-high density material (Fig. 53/2; 54/6).*

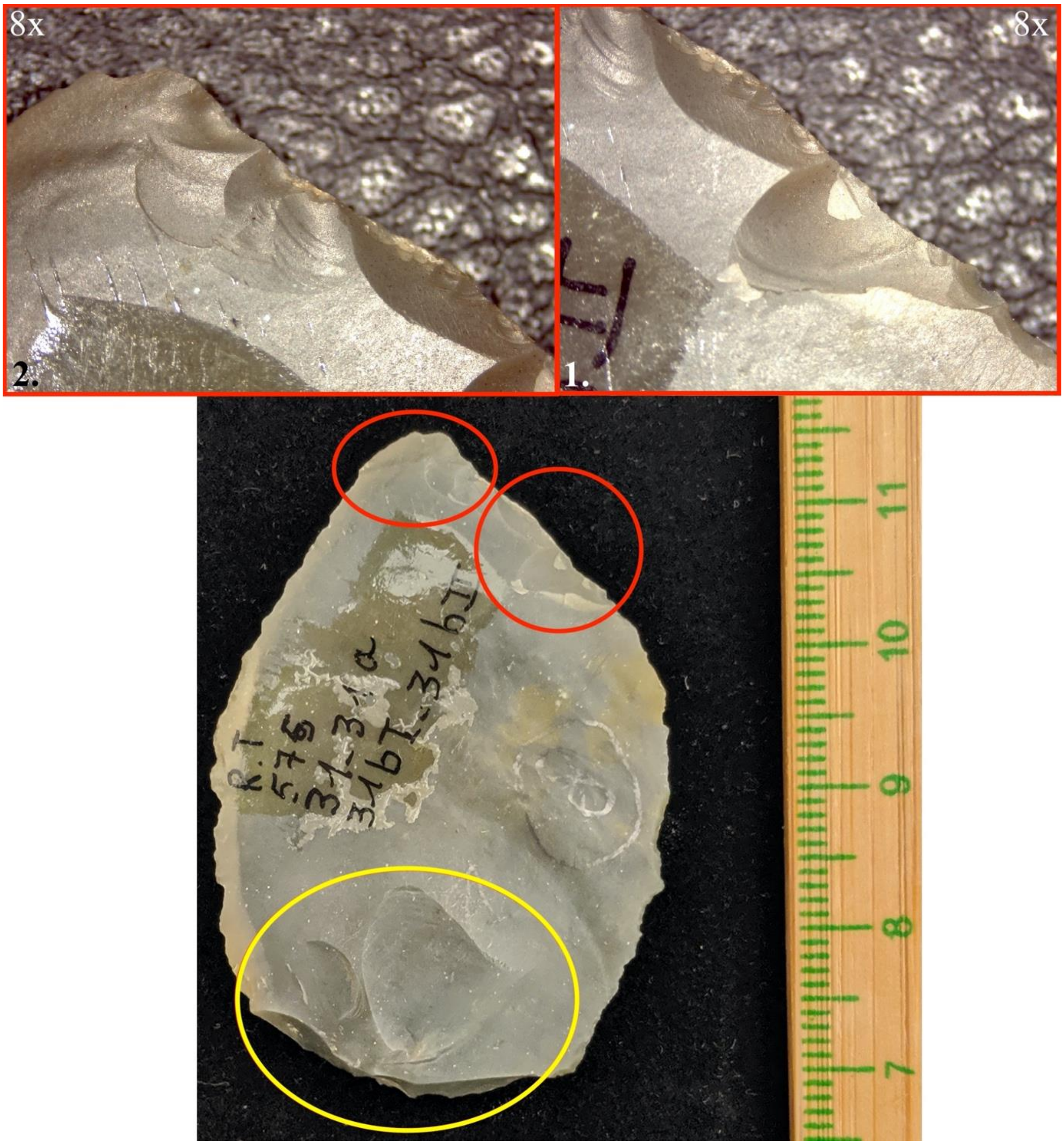


Fig. 100 – R.T. 8 – ventral – *1 and 2) Edge rounding and multiple spin-off and step-terminating bending fractures that were possibly caused by cutting the medium density material and retouching/re-sharpening (Fig. 33/2, 3; 53/5; 54/3). Area marked with yellow ellipse represents the pits/bending fractures that could have been caused by hafting shaft.*

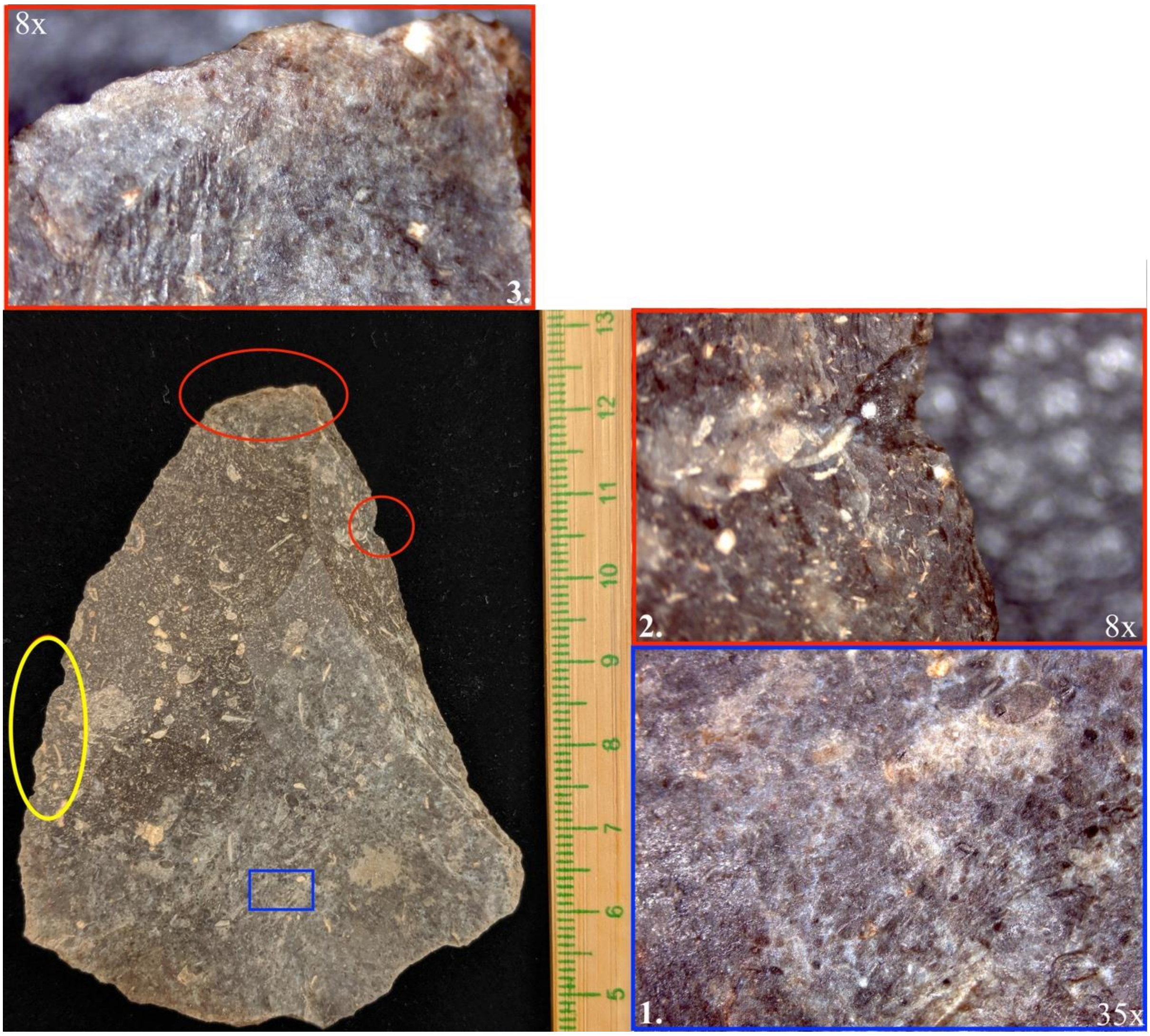


Fig. 101 – R.T. 444! Q.14/6; t. 31µ - dorsal – *1) Possible binding material residues and striations. 2) Edge rounding and impact notch with bending termination possibly caused by cutting or scraping the medium-high density material (Fig. 53/4, 5; 54/ 3). 3) Tip rounding possibly caused by cutting or scraping activities. The area marked with yellow ellipse represents the edge rounding, notches and micro-notches that were possibly caused like the damage presented in the figure (2) by cutting or scraping the medium-high density material.*

Fig. 102 – R.T. 444! Q.14/6; t. 31µ - ventral – *1) Multiple step-terminating bending fractures. Considering the polish that could be easily spotted on the proximal-medial part it could be concluded that this damage was caused by hafting (Rots et al., 2001; Rots, 2004). 2) Tip rounding and two bending fractures that could have been caused by cutting the medium-high density material (Fig. 43/2; 54/6).*

Fig. 103 – R.T. 445! Q.14/6; t. 31μ - dorsal – *1) base crushing – possibly caused by platform preparation or hafting (Fig. 42/2). 2) Burin-like fracture and edge rounding that was probably the result of the cutting activities or even maybe point's usage as a spear-head (Fig. 13/1; 53/1, 6; 54/3, 6).*

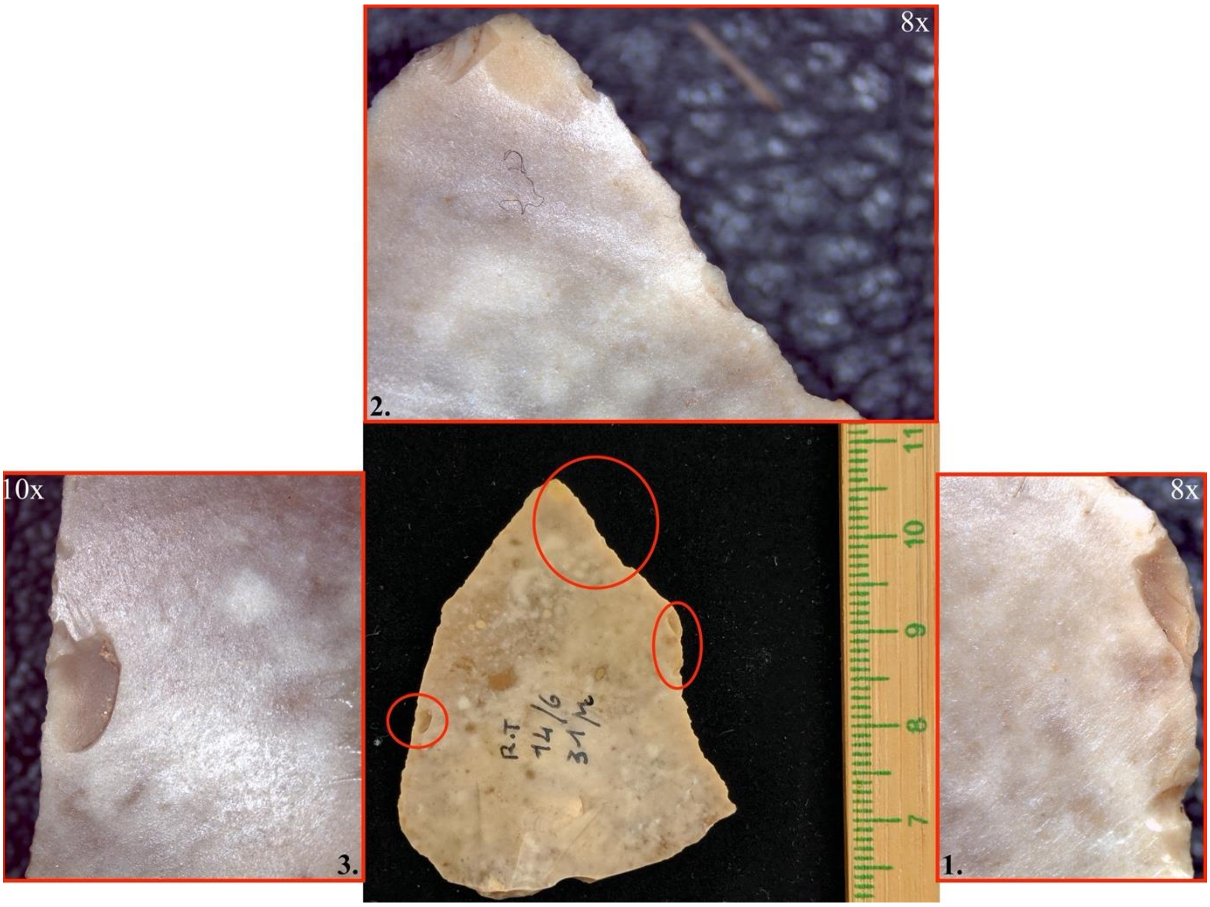


Fig. 104 – R.T. 445! Q.14/6; t. 31μ - ventral – *1) Edge rounding, striations and bending fractures that could have been caused by medium-high density material cutting or scraping (Fig. 53/5; 54/3). 2) Burin-like fracture caused by edge rounding and possibly cutting activities and spin-off and bending-terminating fractures caused by the pressure while using this pseudo-Levallois point in cutting activities or it's usage as a spear-head (Fig. 13/1; 53/1, 6; 54/3, 6). 3) Spin-off fracture that possibly represents retouching damage (Fig.33/2, 3) or hafting-derived damage considering the striations and polish damage (Rots et al., 2001; Rots, 2004).*

PointID	PointType	Layer	Square	UnifacialSpinOff	BifacialSpinOff	StepTerminatingBending	Crushing	BurinLike	SnapTermination	HingeTermination	ImpactNotch	EdgeDamage	Striations	Polish	EdgeRounding	PossibleFunction
8	Pseudo-Levallois	31-31α/31β1/31/β2	575	1.00	.00	1.00	.00	.00	.00	.00	.00	1.00	.00	1.00	1.00	knife/scraper
444!	Mousterian	31μ	14/6	.00	.00	.00	.00	.00	.00	.00	1.00	1.00	1.00	.00	1.00	knife/scraper
445!	Mousterian	31μ	14/6	1.00	.00	1.00	.00	1.00	.00	.00	.00	1.00	.00	.00	1.00	multifunctional
446!	Mousterian	33	615-8	2.00	.00	2.00	1.00	.00	.00	1.00	.00	1.00	1.00	.00	1.00	knife/scraper
342	Mousterian	34	614-1	1.00	1.00	.00	2.00	.00	.00	.00	.00	1.00	.00	.00	1.00	knife/spear-head
7	Pseudo-Levallois	34	614-6	.00	.00	1.00	.00	.00	.00	.00	.00	1.00	.00	.00	1.00	knife
343	Levallois	34	614-3	2.00	.00	2.00	3.00	.00	.00	.00	.00	1.00	1.00	.00	1.00	multifunctional
60	Mousterian	34	574	1.00	.00	.00	1.00	.00	.00	.00	.00	1.00	.00	.00	1.00	multifunctional
10	Levallois	34	615	.00	.00	.00	.00	1.00	.00	.00	.00	1.00	1.00	.00	1.00	knife
477	Levallois	36	614-2	1.00	.00	1.00	.00	1.00	1.00	.00	1.00	1.00	.00	.00	1.00	knife
51	Pseudo-Levallois	36	574	1.00	.00	1.00	.00	.00	1.00	.00	.00	1.00	1.00	.00	1.00	knife
618	Mousterian	36	634-4	1.00	.00	.00	1.00	1.00	.00	.00	.00	1.00	.00	.00	1.00	multifunctional
612	Mousterian	36	634-1	.00	.00	1.00	1.00	.00	.00	.00	.00	1.00	.00	.00	1.00	knife
585	Triangular flake	36	615-3	1.00	.00	1.00	.00	1.00	.00	.00	.00	1.00	1.00	.00	1.00	knife
586	Pseudo-Levallois	36	615-6	3.00	.00	3.00	.00	1.00	.00	.00	.00	1.00	.00	.00	1.00	multifunctional
40	Pseudo-Levallois	36	615-6	.00	.00	.00	.00	.00	.00	.00	.00	1.00	.00	.00	.00	knife
176	Levallois	36α2	9.9/8+9	.00	.00	1.00	.00	.00	2.00	.00	1.00	1.00	1.00	.00	1.00	knife/spear-head
447!	Mousterian	36β	13/6	.00	.00	.00	.00	.00	.00	.00	1.00	1.00	1.00	.00	1.00	knife/spear-head
280	Triangular flake	37	634-3	1.00	.00	1.00	1.00	.00	.00	1.00	.00	1.00	1.00	.00	1.00	knife/spear-head
12	Mousterian	37α	554	.00	.00	.00	1.00	.00	.00	.00	.00	1.00	.00	.00	1.00	knife/scraper
448!	Levallois	37α	13/2	.00	.00	.00	.00	.00	.00	.00	.00	1.00	.00	.00	1.00	knife/spear-head
201	Pseudo-Levallois	40μ	7/2	.00	.00	.00	.00	.00	.00	.00	1.00	1.00	.00	.00	1.00	knife/scraper
205	Mousterian	42	614	1.00	.00	.00	1.00	.00	.00	.00	.00	1.00	.00	.00	1.00	multifunctional
212	Mousterian	42	614	1.00	1.00	1.00	1.00	.00	.00	.00	1.00	1.00	.00	.00	1.00	knife/spear-head
216	Mousterian	42	634	2.00	.00	2.00	1.00	.00	.00	.00	.00	1.00	.00	.00	1.00	multifunctional
36	Pseudo-Levallois	42α	615	.00	.00	.00	1.00	.00	.00	.00	1.00	1.00	.00	.00	1.00	knife/scraper
547	Mousterian	42γ	7/9	2.00	.00	2.00	.00	1.00	.00	.00	.00	1.00	1.00	.00	1.00	knife/scraper
166	Mousterian	50	634	1.00	.00	.00	1.00	1.00	1.00	.00	.00	1.00	1.00	.00	1.00	knife/spear-head
169	Pseudo-Levallois	50	615	1.00	1.00	3.00	1.00	1.00	.00	.00	.00	1.00	.00	.00	1.00	knife/spear-head
32	Mousterian	51	614	1.00	.00	1.00	1.00	.00	1.00	.00	.00	1.00	.00	.00	1.00	knife/spear-head

Table 25 – Pointed tools from the Mousterian level of Riparo Tagliente – damage types caused by the pointed tools usage.

PointID	PointType	Layer	Square	UnifacialSpin Off	BifacialSpin Off	StepTerminating Bending	Crushing	BurinLike	SnapTer mination	HingeTer mination	Impact Notch	EdgeDa mage	Striations	Polish	EdgeRoun ding
8	Pseudo-Levallois	31-31α/31β1/31	575	1.00	.00	1.00	2.00	.00	.00	1.00	.00	1.00	.00	.00	.00
444!	Mousterian	31μ	14/6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
445!	Mousterian	31μ	14/6	.00	.00	.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
446!	Mousterian	33	615-8	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
342	Mousterian	34	614-1	1.00	.00	2.00	2.00	.00	.00	1.00	.00	.00	.00	.00	.00
7	Pseudo-Levallois	34	614-6	1.00	.00	2.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
343	Levallois	34	614/3	1.00	.00	2.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
60	Mousterian	34	574	2.00	.00	1.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
10	Levallois	34	615	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
477	Levallois	36	614-2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
51	Pseudo-Levallois	36	574	1.00	.00	1.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
618	Mousterian	36	634-4	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
612	Mousterian	36	634-1	.00	.00	1.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
585	Triangular flake	36	615-3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
586	Pseudo-Levallois	36	615-6	.00	.00	1.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
40	Pseudo-Levallois	36	615-6	.00	.00	.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
176	Levallois	36α2	9.9/8...	1.00	.00	1.00	1.00	.00	.00	.00	1.00	.00	.00	.00	.00
447!	Mousterian	36β	13/6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
280	Triangular flake	37	634-3	.00	.00	1.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
12	Mousterian	37α	554	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
448!	Levallois	37α	13/2	.00	.00	.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
201	Pseudo-Levallois	40μ	7/2	.00	.00	.00	1.00	.00	.00	.00	1.00	1.00	.00	.00	.00
205	Triangular flake	42	614	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
212	Mousterian	42	614	3.00	.00	2.00	2.00	.00	.00	.00	.00	1.00	.00	.00	.00
216	Mousterian	42	634	1.00	.00	2.00	1.00	.00	.00	.00	.00	1.00	.00	.00	.00
36	Pseudo-Levallois	42α	615	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
547	Mousterian	42γ	7/9	.00	.00	1.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
166	Mousterian	50	615	.00	.00	1.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
169	Pseudo-Levallois	50	634	2.00	.00	1.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
32	Mousterian	51	614	1.00	.00	1.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00

Table 26 - Pointed tools from the Mousterian level of Riparo Tagliente – damage types caused by a knapping incident.

PointID	PointType	Layer	Square	UnifacialSpinOff	BifacialSpinOff	StepTerminatingBending	Crushing	BurinLike	SnapTermination	HingeTermination	ImpactNotch	EdgeDamage	Striations	Polish	EdgeRounding	PossibleResid...	Hafted
8	Pseudo-Levallois	31-31α/31β1/31	575	1.00	.00	2.00	2.00	.00	.00	1.00	.00	.00	.00	.00	.00	no	yes
444!	Mousterian	31μ	14/6	.00	.00	1.00	.00	.00	.00	.00	.00	.00	1.00	1.00	.00	yes	yes
445!	Mousterian	31μ	14/6	1.00	.00	.00	1.00	.00	.00	.00	.00	1.00	1.00	1.00	1.00	no	yes
446!	Mousterian	33	615-8	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.00	.00	.00	no	no
10	Levallois	34	615	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.00	.00	.00	no	yes
60	Mousterian	34	574	2.00	.00	1.00	1.00	.00	.00	.00	.00	1.00	1.00	.00	1.00	yes	no
343	Levallois	34	614/3	1.00	.00	2.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00	no	possibly
7	Pseudo-Levallois	34	614-6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	no	yes
342	Mousterian	34	614-1	1.00	.00	2.00	2.00	.00	.00	1.00	1.00	1.00	.00	1.00	1.00	yes	possibly
618	Mousterian	36	634-4	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	no	possibly
612	Mousterian	36	634-1	.00	.00	1.00	1.00	.00	.00	.00	.00	1.00	.00	.00	.00	no	yes
51	Pseudo-Levallois	36	574	1.00	.00	1.00	1.00	.00	.00	.00	.00	1.00	.00	.00	.00	no	yes
477	Levallois	36	614-2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	no	possibly
585	Triangular flake	36	615-3	1.00	.00	1.00	.00	.00	.00	1.00	.00	1.00	.00	.00	.00	no	yes
586	Pseudo-Levallois	36	615-6	1.00	.00	2.00	1.00	.00	.00	.00	.00	.00	1.00	1.00	1.00	no	yes
40	Pseudo-Levallois	36	615-6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	no	no
176	Levallois	36α2	9.9/8+9	1.00	.00	2.00	1.00	.00	.00	.00	1.00	1.00	1.00	1.00	1.00	no	yes
447!	Mousterian	36β	13/6	.00	.00	.00	2.00	.00	.00	.00	1.00	1.00	1.00	.00	.00	no	yes
280	Triangular flake	37	634-3	.00	.00	.00	1.00	.00	.00	.00	.00	.00	1.00	.00	.00	no	possibly
12	Mousterian	37α	554	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	no	no
448!	Levallois	37α	13/2	.00	.00	.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00	yes	yes
201	Pseudo-Levallois	40μ	7/2	2.00	.00	1.00	2.00	.00	.00	.00	.00	1.00	.00	.00	.00	no	yes
205	Mousterian	42	614	3.00	.00	3.00	1.00	.00	.00	.00	.00	1.00	.00	.00	.00	no	yes
212	Mousterian	42	614	3.00	.00	2.00	2.00	.00	.00	.00	1.00	1.00	.00	.00	.00	no	possibly
216	Mousterian	42	634	1.00	.00	2.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00	no	possibly
36	Pseudo-Levallois	42α	615	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	no	no
547	Mousterian	42γ	7/9	.00	.00	1.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00	yes	yes
166	Mousterian	50	615	1.00	.00	2.00	1.00	.00	.00	.00	.00	1.00	.00	1.00	.00	no	yes
169	Pseudo-Levallois	50	634	1.00	.00	1.00	1.00	.00	.00	.00	1.00	1.00	.00	.00	.00	no	possibly
32	Mousterian	51	614	1.00	.00	1.00	1.00	.00	.00	.00	.00	1.00	.00	1.00	1.00	yes	yes

Table 27 - Pointed tools from the Mousterian level of Riparo Tagliente – hafting-derived damage types.

PointID	PointType	Layer	Square	UnifacialSpin Off	BifacialSpin Off	StepTerminating Bending	Crushing	BurinLike	SnapTermin ation	HingeTermi nation	ImpactNotch	EdgeDamage	Striations	Polish	EdgeRoun ding
8	Pseudo-Levallois	31-31α/31β1/31	575	1.00	.00	1.00	.00	.00	.00	.00	.00	1.00	.00	.00	.00
444!	Mousterian	31μ	14/6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
445!	Mousterian	31μ	14/6	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
446!	Mousterian	33	615-8	2.00	.00	2.00	1.00	.00	.00	1.00	.00	1.00	.00	.00	.00
10	Levallois	34	615	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
60	Mousterian	34	574	1.00	.00	.00	1.00	.00	.00	.00	.00	1.00	.00	.00	.00
343	Levallois	34	614/3	1.00	.00	.00	1.00	.00	.00	.00	.00	1.00	.00	.00	.00
7	Pseudo-Levallois	34	614-6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
342	Mousterian	34	614-1	.00	.00	.00	1.00	.00	.00	.00	.00	1.00	.00	.00	.00
618	Mousterian	36	634-4	.00	.00	.00	1.00	.00	.00	.00	.00	1.00	.00	.00	.00
612	Mousterian	36	634-1	.00	.00	1.00	.00	.00	.00	.00	.00	1.00	.00	.00	.00
51	Pseudo-Levallois	36	574	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
477	Levallois	36	614-2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
585	Triangular flake	36	615-3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
586	Pseudo-Levallois	36	615-6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
40	Pseudo-Levallois	36	615-6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
176	Levallois	36α2	9.9/8+9	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
447!	Mousterian	36β	13/6	.00	.00	.00	3.00	.00	.00	.00	.00	1.00	.00	.00	.00
280	Triangular flake	37	634-3	1.00	.00	1.00	1.00	.00	.00	.00	.00	1.00	.00	.00	.00
12	Mousterian	37α	554	.00	.00	.00	1.00	.00	.00	.00	.00	1.00	.00	.00	.00
448!	Levallois	37α	13/2	.00	.00	.00	1.00	.00	.00	.00	.00	1.00	.00	.00	.00
201	Pseudo-Levallois	40μ	7/2	1.00	.00	1.00	1.00	.00	.00	.00	1.00	1.00	.00	.00	.00
205	Triangular flake	42	614	1.00	.00	.00	.00	.00	.00	.00	.00	1.00	.00	.00	.00
212	Mousterian	42	614	.00	.00	1.00	.00	.00	.00	.00	.00	1.00	.00	.00	.00
216	Mousterian	42	634	.00	.00	.00	1.00	.00	.00	.00	.00	1.00	.00	.00	.00
36	Pseudo-Levallois	42α	615	2.00	.00	2.00	1.00	.00	.00	.00	1.00	1.00	.00	.00	.00
547	Mousterian	42γ	7/9	1.00	.00	2.00	1.00	1.00	.00	.00	.00	1.00	.00	.00	.00
166	Mousterian	50	615	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
169	Pseudo-Levallois	50	634	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
32	Mousterian	51	614	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

Table 28 - Pointed tools from the Mousterian level of Riparo Tagliente – retouching/re-sharpening damage types.

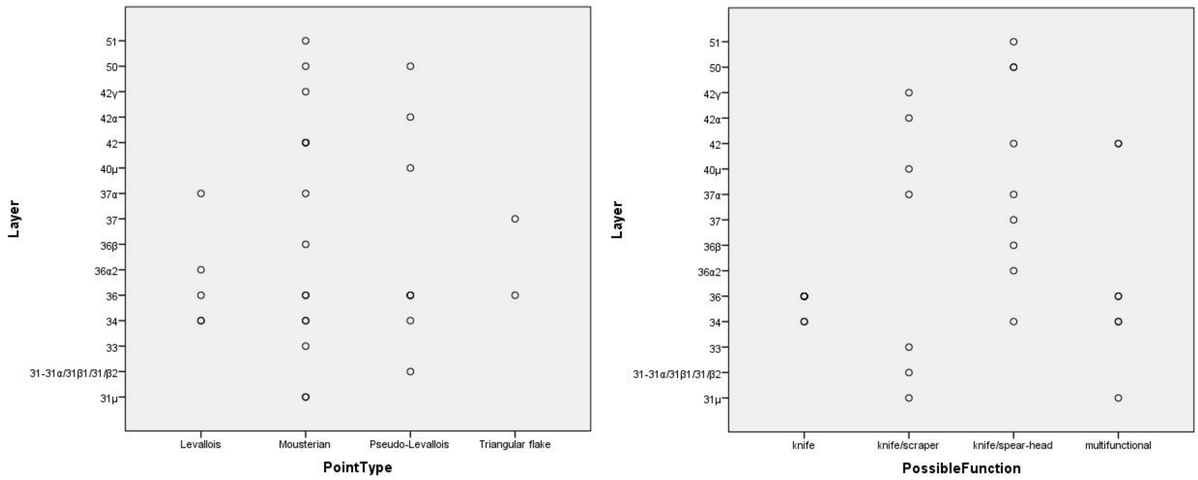


Fig. 105 – Comparison of operation layer and the point types (left), the comparison of the operational layer and the possible function of the pointed tools (right).

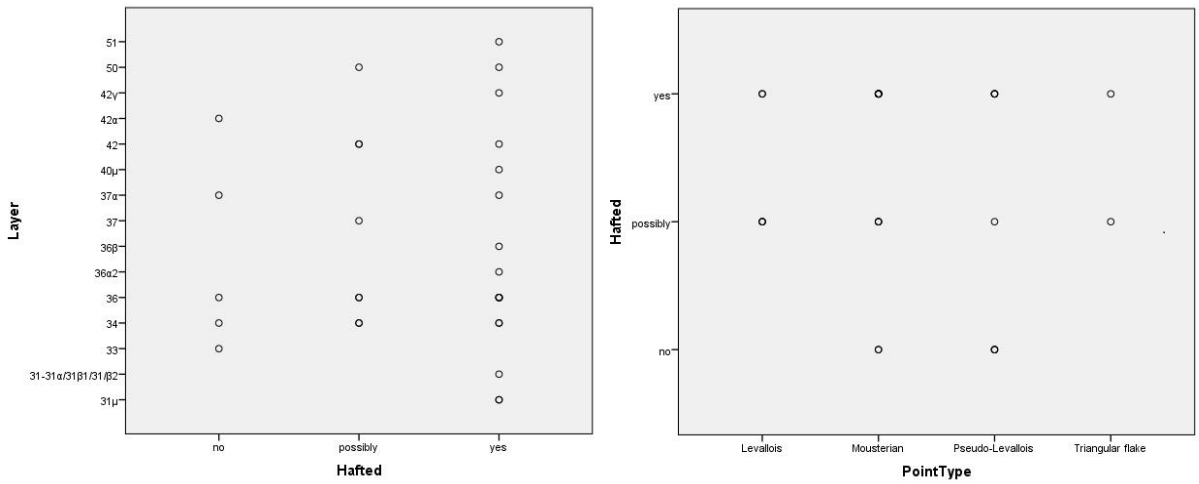


Fig. 106 – Comparison of the operational layer and the presence of hafting traces on the pointed tools (left); Comparison of the points types and the presence of hafting traces (right).

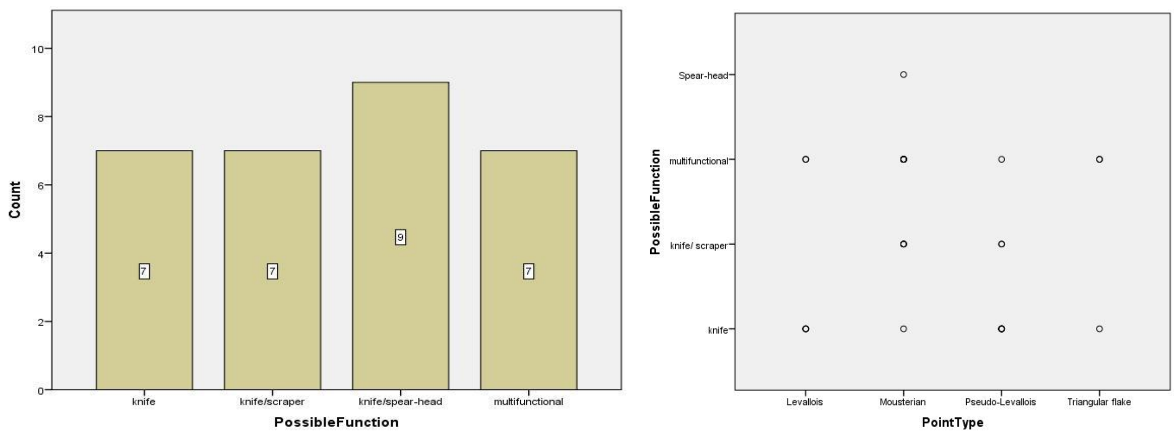


Fig. 107 – The possible functions of the pointed tools.

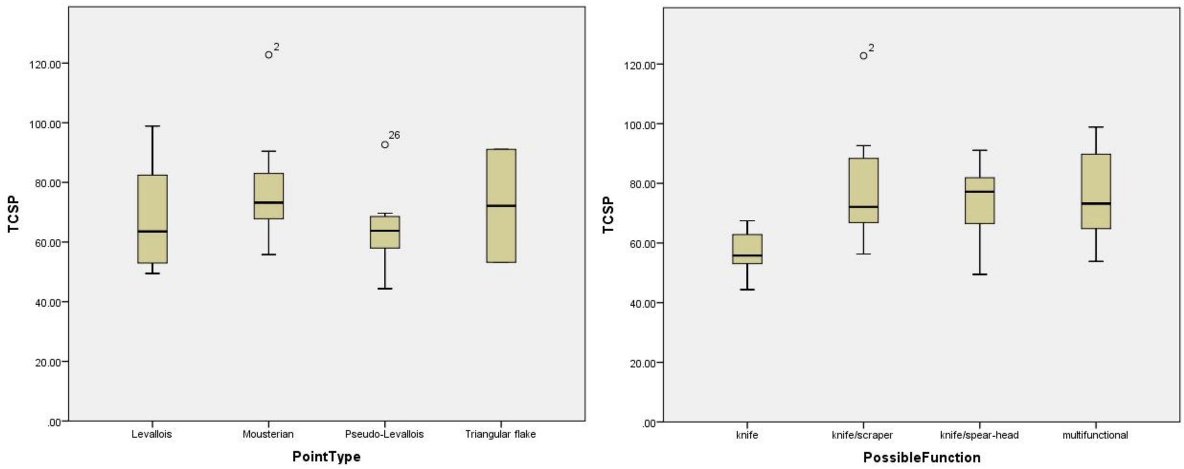


Fig. 108 – Comparison of TCSA values of the pointed tools and point types (left); Comparison of TCSP values of the pointed tools and point types (right).

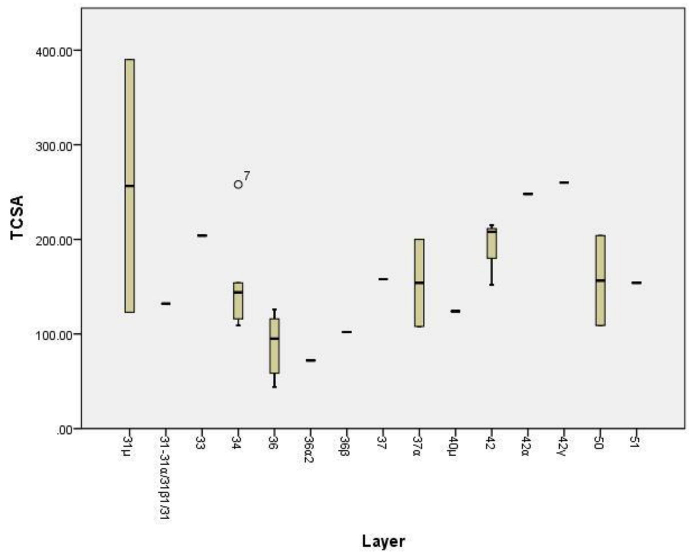


Fig. 109 – Comparison of TCSA values of the pointed tools and operational layers.

PointID	TCSA	TCSP
8	132.00	69.67
444!	390.00	122.78
445!	123.00	71.38
446!	204.00	72.11
342	144.00	66.52
7	116.00	67.46
343	258.00	98.89
60	154.00	89.10
10	109.00	63.56
477	65.00	52.95
51	120.00	62.09
618	112.00	58.24
612	95.00	55.78
585	52.00	53.20
586	126.00	53.85
40	44.00	44.36
176	72.00	49.47
447!	102.00	69.05
280	158.00	91.08
12	108.00	56.32
448!	200.00	82.46
201	124.00	64.03
205	215.00	90.42
212	152.00	77.66
216	208.00	73.23
36	248.00	92.64
547	260.00	84.11
166	204.00	77.20
169	109.00	63.56
32	154.00	81.90

Table 29 – TCSA and TCSP values of the pointed tools.

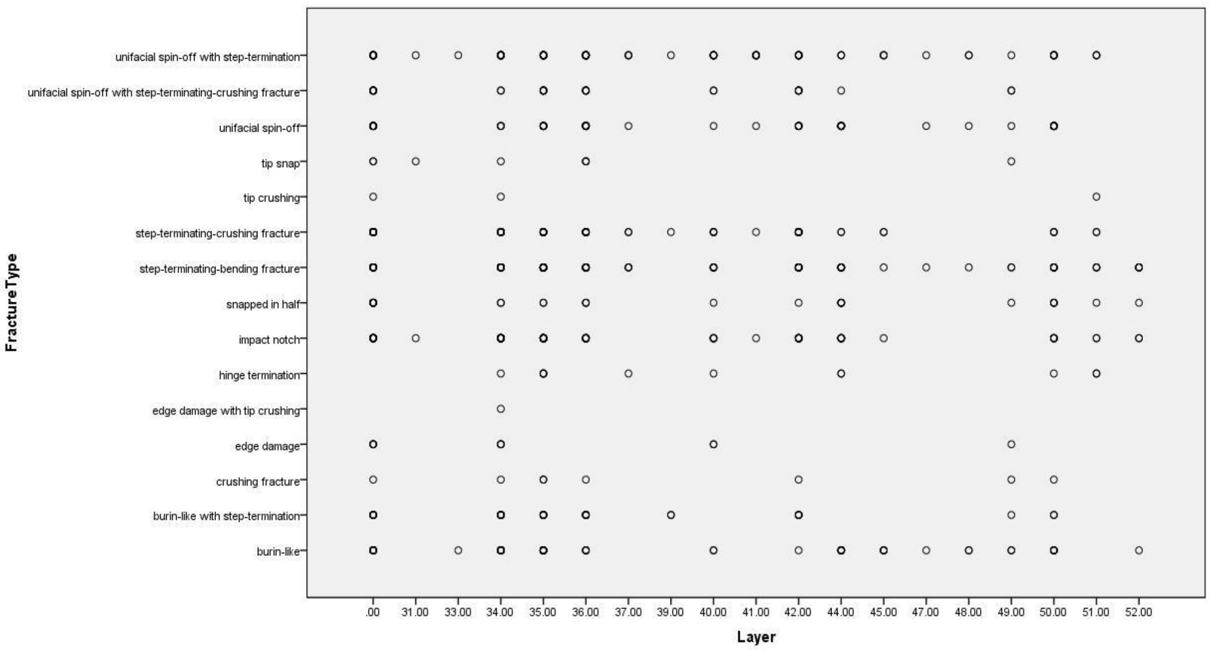


Fig. 110 – The comparison of the fracture types present on the flaked stone tools from the Mousterian levels and operational layers.

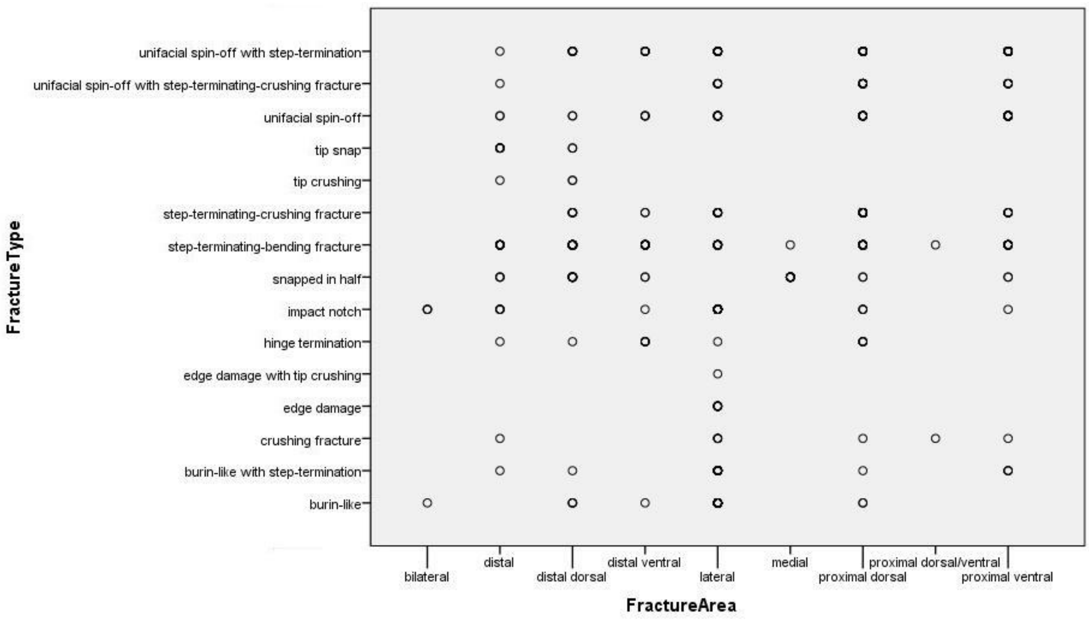


Fig. 111 - The comparison of the fracture types present on the flaked stone tools from the Mousterian levels and fracture locations.

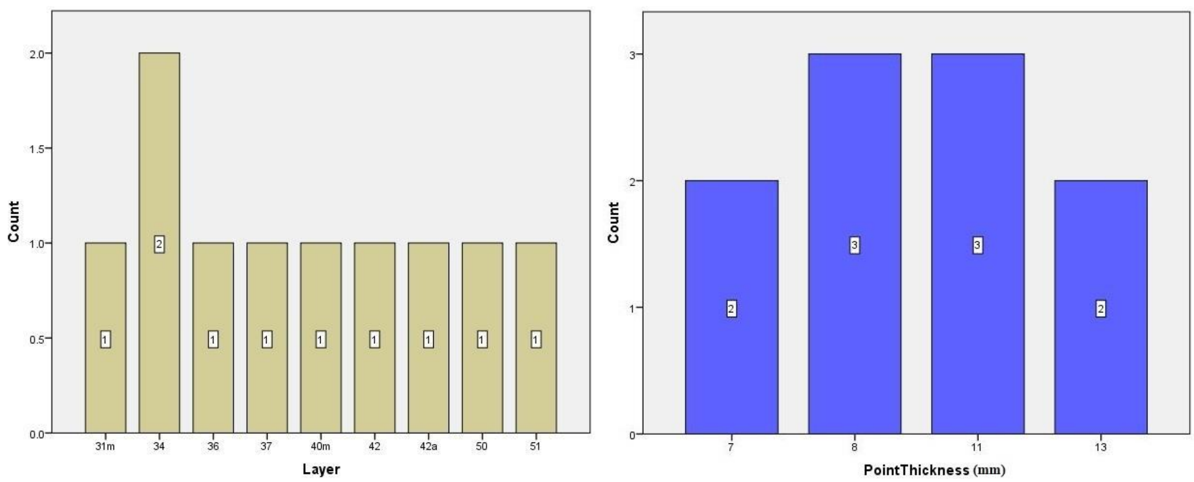


Fig. 112 - Presence of patina on pointed tools.

The possible functions of the certain pointed tools were established by careful observations of all of the variable values, such as: the type of the impact fracture or other macrofracture, the fracture location and the possible cause of the certain fracture. No fracture was ignored and if multiple diagnostic of impact or other fractures were present on the same pointed tool, they were all noted and processed either as a product of use, production, hafting, retouching or other activities. The fractures were placed in the certain category of the possible cause by using the data obtained by the four experiments and by using other author's experimental research (Fischer et al., 1984; Rots et al., 2001; Rots, 2004; Iovita et al., 2014; Cope and Rots., 2017).

Based on the experimental research, the interpretation of the damage identified on the pointed tools from Riparo Tagliente led to an interpretation of their possible functionality. Out of 30 points, 7 were used as a knife, 7 were used both as a knife and scraper; 9 were used both as a knife and a spear-head and 7 were a multifunctional tools (Fig. 107). Whole assemblage from the Mousterian levels of Riparo Tagliente was processed in order to get an insight into the impact damage that could be formed as a result of knapping and post depositional processes. Total of 19430 flakes were processed and the impact damage possibly caused by a knapping incident or post depositional processes was identified on 1129 flakes (5.81%) (Fig. 110; 111).

In past research, it was discovered that the certain quantity of edge damage that could be found on stone tools is caused by the movement of the stone tools through the gravelly sediment and it could lead to misinterpretation. Also, it is noted that the micropits present on the artifacts represent the post depositional damage (Sala Irene Levi, 1986).

It is known that the long and sometimes even minimal exposure of flint to a sodium hydroxide (NaOH), that is present in clayish sediments, can patinate stone tools (Sala Irene Levi, 1986). Patina was identified on ten out of twenty pointed tools (Fig. 112). The presence of patina was identified on the points which with thickness of 13 or less millimeters (Fig. 112). Some of the use-wear traces on the edges of certain pointed tools are patinated and therefore the possible cause could not be interpreted in details (Fig. 58, 71, 90, 101).

In past research it is stated that the movement of the artifacts through the sediments of archaeological sites, such as cryoturbation, fluctuation, bioturbation, gelifluction, etc., causes use-wear-like damage that could lead to misinterpretation of the certain artifacts functionality (Keeley, 1980; Sala Irene Levi, 1986). Considering that at the site of Riparo Tagliente the evidence of post depositional processes were present in large quantities, the identified use-wear traces interpretation should be treated with great caution (Bartolomei, 1982; Arzarello, 2004).

8.1.1. Layer 31-31α/31β1/31β2

The layer 31-31α/31β1/31β2 contained only one pseudo-levallois point, R.T. 8 (Fig. 99, 100). Damage that was caused by the point's usage (Table 25) consisted out of spin-off fractures and step-terminating bending fractures on the point's distal-lateral side. Edge rounding followed by a polish damage implied to a point's usage as a knife and/or scraper (Fig. 53/2; 54/6). There are few possibilities of the interpretation of the damage on the base and proximal-lateral side of the R.T. 8. Unifacial spin-off fracture that was initialized from the crushing fracture (proximal/base) and crushing fracture from which the hinge-terminating fracture was initialized could have been caused by either knapping incident (Fig. Fig. 32/1; 33/1; Table 26; 27) or the hafting shaft (Fig. 15/1; 41/1, 2; 42/2, 5). Retouching or re-sharpening could be the cause of the unifacial spin-off fractures and step-terminating bending fractures on the distal-lateral (ventral) side of the point (Table 28).

8.1.2. Layer 31μ

Two Mousterian points were found in the layer 31μ. Both of the points did not have the id number, therefore they were labeled as R.T. 444! and R.T. 445!. It could have been noted that the point 444! was retouched but the post depositional damage completely covered the edges of the point, therefore just some of the fractures could have been described. Edge rounding, tip rounding, notches and micro notches implies to a conclusion that this point was used as a knife and/or scraper. Damage that could have been caused by the knapping incident was not identified on this point (Table 26). Hafting damage was identified on the proximal-medial part on the ventral side of the point (Fig. 101, 102). The polish damage could be easily identified, that could be correlated to striations on the proximal part on the dorsal side of the point (Fig. 101; Table 27). Next to the striation damage possible residues of the binding material were identified (Fig. 101/1).

Second point from the layer 31μ labeled as R.T. 445! represents another Mousterian point that could have been used as a spear-head as one of the functions. Burin-like fracture on the distal-lateral side of the point implies to its possible function as a spear-head (Fig 103, 104; Table 25). The problem is, even this type of fracture is considered as a diagnostic of impact, after the execution of the fourth experiment it was shown that this type of fracture could also be formed if the point is used for cutting the high density material (Fig. 49). Another impact fracture implies to this point's usage as a spear-head, it is a spin-off fracture with bending fracture that could be identified on the tip of the point on the ventral side (Fig. 104/2). Edge rounding and striations with bending fractures are leading to a conclusion that this point was also used for cutting and scraping activities. One unifacial spin-off fracture with step-termination could have been caused by re-sharpening/ retouching (Fig. 104/3; Table 28). A small unifacial spin-off fracture with crushing (base) could either be correlated to a knapping or hafting incident (Fig. 103; Table 26; 27). After summing up all the identified damage, it could be concluded that this point was used as a multifunctional tool.

8.1.3. Layer 33

From the layer 33, one Mousterian point was identified (Fig. 98) R.T. 446!. All of the identified damage is present on the dorsal side of the point and it implies its usage as a knife and scrapper. Heavy edge crushing and rounding with multiple step-terminations (Fig. 98/1) represent a scraping, cutting and even breaking the high density material (Fig. 50; 53/3; 54/2; Table 25). Hafting damage is not present on this point, except the striations that could have been caused by post depositional processes (Table 27). No damage that could be associated to knapping incident was identified on this point (Table 26). Damage situated on the tip of the point, multiple step-terminations, edge rounding, spin-offs and micro-notches could possibly represent the retouching or re-sharpening damage (Table 28). Considering all of the identified damage, it could be concluded that this point was used for cutting, scraping and breaking activities.

8.1.4. Layer 34

Five points were uncovered in the layer 34. Two Levallois, two Mousterian and one pseudo-levallois point. Point R.T. 10, morphologically represents a Levallois blade, but the use-wear damage focused on both distal-lateral sides created a point. Edge damage and rounding (Fig. 53/1, 7; 54/3) implies to this tools usage as a knife. Burin-like fracture situated on the distal lateral side of the point does not represent the impact damage but the damage caused by cutting activities (Fig. 49; Table 25). Damage that could have been caused by retouching or knapping incident were not identified on this point (Table 26; 28). The only damage that could possibly imply that this stone tool was hafted are the striations situated on the proximal-medial part on the dorsal side of the stone tool (Fig. 97; Table 27).

Mousterian point R.T. 60 possesses two unifacial spin-off with step-terminating bending fractures. One of the unifacial spin-off fractures with step-termination represents either a knapping incident damage (proximal dorsal) or a hafting-derived damage (Fig 96/1, Table 26; 27). Edge rounding and crushing represents a cutting and scraping damage (Table, 25). It seems that this point was re-sharpened multiple times (Fig. 96/2). Multiple examples of the identified damage implies to the conclusion that this point was hafted. The unifacial spin-off fracture with step-termination, striations damage on the proximal-medial part of the point on the dorsal side next to which a possible residues of the binding material could ne associated to the hafting damage (Table 27). Fracture wings could be found on the large spin-off fracture with step-termination that was initialized from the base of the point. Considering that this fracture was not initialized from the tip of the point, the interpretation that this point was used as a spear-head becomes less probable but not completely excluded. The impact velocity of the large spin-off fracture is 433 m/s which places it in the quasi-static loading rate category (Fig. 5). This data allows an interpretation that this fracture is either a result of the pressure flaking, soft hammerstone knapping or usage of this point as a spear-head. If the fact that the fracture was initialized from the base of the point, its usage as a spear-head could be excluded, which leaves the interpretation that the cause was knapping by using the soft hammerstone or pressure flaking. The morphology of the fracture implies that it was indeed the product of pressure, but not intentional. It seems that while the point was used for cutting or scraping the high density material Fig. 53/1; 54/3, the pressure of the hafting shaft caused this large fracture. Crushing damage on the edge of the point could also be interpreted as a retouching incident (Fig. 32/4; Table 28). Using all of the data, this point could be interpreted as a multifunctional tool.

Levallois point R.T. 343 was possibly hafted, considering the crushing and step-terminating bending damage on the proximal dorsal side and multiple step-terminating bending fractures with unifacial spin-off on the proximal ventral side of the point (Fig. 94; 95; Table 27). Notch with bending termination, edge rounding with bending initiations and crushing possibly represents a damage caused by cutting and scraping the high density material (Fig. 94; Table 25). Some of the fractures situated on the proximal ventral and dorsal side of the point could also, besides hafting-derived, represent the production related damage (Table 26). The pits with striations situated on the medial-distal part on the dorsal side of the tool could possibly represent the post-depositional damage. Some of the unifacial spin-off fractures and crushing damage situated on the lateral side of the tool could possibly represent a damage caused by retouching/ re-sharpening (Fig. 94; 95; Table 28). This point represents a multifunctional stone tool.

R.T. 7 is a pseudo-levallois point that possess edge damage (Fig. 92, 93) in shape of micro notches that possibly represents cutting activities damage. The crushing damage with a unifacial spin-off fracture and two step-terminating bending fractures could be associated with production related damage (Table 26). No retouching and hafting damage could have been identified on this pseudo-levallois point. Considering the edge damage, this point was used for cutting activities.

R.T. 342 is a Mousterian point that possesses damage types that could imply that is was hafted and possibly used as a spear-head and for cutting and scraping activities. Crushing damage, unifacial spin-off, hinge termination and step-terminating bending fractures on the proximal dorsal side of the point possibly represent a hafting-derived damage and damage that could have been caused in the initial phase of the stone tool manufacture, knapping (Fig. 90/1, 2, 3; Table 26; 27). The notch with visible polish (Fig. 91/1; Table 27) represents a diagnostic hafting damage (Rots et al., 2001). Considering all of the identified hafting-derived damage and the possible residue of a binding material (Fig. 90/5) it is clear that this point was hafted. The presence of a tip crushing damage with unifacial spin-off with bending termination (Fig. 91; Table, 25) strengthens the conclusion that one of the functions that this point had was its usage as a spear-head. Unfortunately the post-depositional processes in this case represent a great obstacle in identification of the fracture wings and calculation of the fracture velocity on the plain of the spin-off fracture with bending termination located on the ventral distal side of the point. Edge rounding and crushing was possibly caused by cutting and scraping of the high density material (Fig. 53/5; 54/3, 6); Table 25). The cause of the crushing fracture could have been the point's usage as a spear-head for the hand-thrown spear hunting technology with missing the hunting target as an more specific cause. Similar damage was identified on the experimental Mousterian point after the execution of the first experiment (Fig. 14/1). After taking into account all of the interpreted damage, it could be easily concluded that this point was used as a spear-head and as a knife for cutting the high density material.

8.1.5. Layer 36

Layer with the highest number of pointed tools is layer 36. Seven points were uncovered, out of which three were pseudo-levallois points, two Mousterian points, one Levallois point and one triangular flake. Point R.T. 477 in fact represents the distal part of a Levallois point (Fig. 76). The burin-like fracture located on the tip of the point could have been caused by various activities because the tip is extremely fragile, its thickness is just 2 *mm*. Fracture wings were identified on the plain of the large unifacial spin-off fracture that was initialized from the transversal fracture, the fracture velocity is 707 m/s which places it in rapid-loading category. Possible cause of the fracture could be the point's usage as spear-head used in thrusting or hand-thrown hunting technology (Fig. 42/3, 4, 6, 7). Problem with this certain point is its morphometric values, the maximum thickness of this point is 5 *mm* and there could be numerous causes of its breakage in half. Certain fact about this point is that the edge damage, notches, micro-notches and rounding imply that it was used for cutting the low density material (Fig. 53/7, 54/5; Table 25).

Another point from the layer 36 is the R.T. 51, a pseudo-levallois point that was hafted and used as a knife. Base crushing and striations, besides hafting-derived (Fig. 77; Table 27) it could also represent a knapping damage (Table 26). Tip snap with small unifacial spin-off fracture and bending fracture could have been caused by numerous activities considering that the tip of this certain point is extremely fragile. Crushing damage and striations on the medial part of the point could represent a hafting damage, considering that the diagnostic hafting damage was identified on the proximal-lateral side of the point, 17 mm below the crushing fracture with striations (Fig. 77; 78). On the lateral side of the point, damage that is diagnostic of cutting, edge rounding and micro-notches were identified. Heavy edge rounding that is located on the ventral-lateral side of the point (Fig. 78) represents the cutting and scraping damage (Fig. 53/2, 4; 54/6). Considering all of the damage it could be concluded that this point was hafted and used as a knife.

R.T. 618 is a Mousterian point that was used as a multifunctional tool. Both lateral sides of the point possess a heavy crushing damage (Fig. 79). Crushing damage could have been caused by breaking the dense material or retouching/ re-sharpening (Fig. 54/2; Table 25; 28). From the crushing damage on the tip of the point, a small unifacial spin-off and a burin-like fracture were initialized. This type of the damage could be associated with this point's usage as a spear head, or more precisely, based on the data of the first experiment as a vertically hafted point used in thrusting spear hunting technology (Fig. 14/2). It seems that the point is not complete, i.e. the proximal part is missing (Fig. 79). The problem is, there are no fractures on the base of the point to confirm that conclusion, like those from the third experiment (Fig. 45). Crushing damage on the proximal – lateral sides of the point could, in fact, besides retouching damage, represent a hafting damage. After the observation of all of the fractures, edge crushing and rounding, and the damage associated to the tip of the point, it could be concluded that this point was used a multifunctional tool.

Mousterian point R.T. 612 possesses a huge unifacial spin-off fracture with multiple step-terminating bending fractures, crushing and hinge-terminating fracture. All of these fractures are concentrated on the proximal-medial part on dorsal side of the point (Fig. 80; Table 25-28). The fracture wings on the plane of the unifacial spin off fracture with step, hinge and crushing termination were identified and were used to calculate the fracture velocity (Fig. 80/1). Fracture velocity is 971 m/s which places it in the rapid load category (Fig. 5). The cause of these complex fractures could be the knapping incident, using the hard hammerstone (Fig. 32/4; 33/1) or less possibly the hafting-derived damage caused by points usage as spear-head. Considering that the tip of the point shows no damage that could be diagnostic of its usage as a spear-head, the hafting-derived damage could be excluded and the knapping damage could be confirmed. Even so, considering the step-terminating fracture on the proximal-lateral dorsal side of the point, it could be presumed that the fractures present on the proximal-medial dorsal side of the point could also represent a hafting modification and that the step-terminating fracture on the proximal-lateral side confirms that statement. By the observation of all the fractures and the edge damage and rounding, it could be concluded that this point was used as knife and it could be clearly seen that the edge damage (Fig. 80/2) besides cutting damage (Fig. 53/3; 54/ 1, 2) also represents a retouching/ re-sharpening damage (Fig. 32/5; 33/2, 3).

Levallois triangular flake R.T. 585 was hafted and possibly used as a knife or even as a spear-head, considering the bilateral burin-like fractures that could have been caused by both cutting activities and tools usage as a spear-head (Fig. 81; 82). Transversal fracture located on the base of the triangular flake from which the unifacial spin-off fracture with step-termination was initialized, was caused by hafting shaft while the tool was used as a knife (Fig. 42/3, 4, 6, 7, Table 25). Notch with step-terminating bending fracture, is one of the diagnostic hafting-derived damage, when correlated to a transversal fracture it strengthens the conclusion that it was hafted. Edge rounding, and micro notches confirm that this triangular flake was used for cutting activities.

Pseudo-levallois point R.T. 586 possesses a possible hafting damage on the proximal-lateral, two unifacial spin-off fractures with bending termination and on the proximal-basal area, a crushing damage with polish (Fig. 83; 84, Table 25-28). Considering the damage located on the tip of the point, the conclusion that one of the functions this pseudo-levallois point had was its usage as a spear-head. Tip crushing with from which the small spin-off fracture was initialized together with burin-like and step-terminating bending fracture are strengthening the conclusion that this point was used as a spear head (Fig. 83/2). Similar to the damage situated on the tip of this point was identified after the execution of the first experiment on the point that was vertically hafted and used in hand-thrown spear hunting technology (Fig. 11/4, 5). On the proximal ventral side of the point, a crushing fracture from which unifacial spin-off fracture with bending termination was initialized. These fractures were caused either by knapping or are hafting-derived damage. Unfortunately no fracture wings were located on the plane of the bending fractures located on the tip of the point which would even more strengthen the conclusions of the certain fracture causations. The striations on the medial part on the dorsal side of the point are most likely representing a hafting-derived damage (Table 27). Edge rounding on the right lateral side of the point, which could be seen from the dorsal side represent the cutting and scraping damage (Fig. 53/2, 4; 54/6; 83). After summing up all of the damage that was identified on this point, it could be easily concluded that this point represents a multifunctional tool, or more precisely, a spear-head, knife and a scraper.

On the point R.T. 40, a pseudo-levallois point, only one crushing fracture with step-termination was identified (Fig. 85). The cause of the fracture s located on the proximal ventral side of the point was most likely caused by knapping (Fig. 41/1; 42/2). The micro notches that could be identified on the right lateral side of the point are caused by cutting the low density material. Considering the damage identified on this point, it could be concluded that it was used as a knife for cutting the low density material.

8.1.6. Layer 36α2

Only one Levallois point was uncovered from the layer 36α2 (R.T. 176). Hafting-derived damage was identified on the base (platform crushing and bending fracture with step-termination), on the dorsal medial part (striations) and on the proximal-lateral side (notch with bending termination) of the point (Fig. 86/1, 2). Edge rounding, notches and micro-notches are implying that this point was used for cutting activities (Fig. 53/1, 6; 54/3, 6, Table 25). The tip snap with bending termination that could be identified on the ventral side of the point could have been caused by the point's usage as a spear-head (Fig. 87/2). Base crushing could have been also caused by knapping (Fig. 41/1; 42/5, Table, 26). By taking into the account all of the identified damage, it could be concluded that this Levallois point was used as a multifunctional tool, or more closely both as a knife and as a spear-head.

8.1.7. Layer 36β

Only one Mousterian point (R.T. 447!) was uncovered from the layer 36β. Two parallel crushing damages that are located on the both proximal-lateral sides and striations on the dorsal medial part of the point are clearly representing a hafting damage (Fig. 95; 96). The crushing damage that is present on both proximal dorsal and proximal ventral sides of the point were caused either by knapping (Fig. 32/1; 33/1) or hafting shaft (Fig 11/3; 15/1; 42/2, 5). Edge rounding, and micro notches clearly indicates the cutting activity. Intense retouching/ re-sharpening could be the cause of some of the crushing damage present on both lateral sides. No fractures were located on the tip of the point that could lead to a conclusion that one of its function was usage as a spear-head, but also, after the execution of the first experiment, 13 out of 40 points did not experience damage (Fig. 8). Taking into the account that the TCSA (Table 29) value ($119mm^2$) is applicable for this point's interpretation as a spear-head. It could be concluded that this point was most likely used both as a knife and as a spear-head.

8.1.8. Layer 37

Triangular flake R.T. 280 is the only pointed tool uncovered from the layer 37 (Fig. 73). Crushing damage located on the base of the flake is most likely caused by the knapping incident (Fig. 32/3; 33/1). Damage situated on the tip of the triangular flake, crushing damage from which the unifacial spin-off fracture with bending termination was initialized represents a retouching damage and also possible, but with lower probability, the flakes usage as a spear-head. Edge rounding and bending fractures on the left lateral side represents a cutting damage (Fig, 53/3, 54/1; 73). On the right lateral side of the flake, numerous step-terminations were identified. This type of damage could either be interpreted as a knapping damage (Fig. 32/3; 33/1) or a post-depositional damage. Considering all of the damage that was identified on this flake, it could be concluded that it was used as a knife or a spear-head. Based on the TCSA value (Table 29) of this flake (158 mm^2) the possibility of its usage as a spear-head is present, but without the strong supporting hafting evidence, the conclusion of flakes usage as a spear-head is highly questionable.

8.1.9. Layer 37α

Mousterian point R.T. 12 was used for cutting the high density material, that conclusion is being confirmed by the heavy edge damage and rounding. There are no visible traces of hafting (Fig. 74, Table 7. The most reliable interpretation of the crushing damage on both lateral sides of the point besides usage for processing the high density material (Fig. 53/1, 3; 54/1, 2, 3) and/or retouching/ resharpening (Fig. 32/4; 33/1). This point was re-sharpened to the point of inability for further re-sharpening so it was discarded. Damage on the both lateral sides lead to a conclusion that this point was used both as a knife and a scraper.

Another point from the layer 37α, R.T. 448! is a Levallois point. Morphologically there is no more perfect point in the whole assemblage (Fig. 75). Unfortunately the only damage associated to the tip of the point is a small crushing damage that represent a retouching damage. There is a strong evidence of hafting on the proximal dorsal side of the point (Fig. 42/ 2, 5; 75). The point is bilaterally retouched and there is a crushing damage on the distal lateral part that could be correlated to retouching damage. Edge rounding indicated that this point was used as a knife. TCSA value (200mm^2) implies that this point also had a function as a spear-head, but without the further supporting evidence it only stays a possibility.

8.1.10. Layer 40μ

The pseudo-levallois point R.T. 201 (Fig. 71, 72) possesses a hafting damage and was probably used as a knife and a scraper. Crushing damage that is situated on the base of the point represents either a knapping (Fig. 32/3; 33/1) or a hafting damage (Fig 11/3, 15/1; 41/2; 42/2). Unifacial spin-off with step-termination located on the right lateral-proximal side of the point represents a diagnostic hafting damage (Fig. 71/ 2). One more fracture strengthens the conclusion that this point was hafted, it is a unifacial spin-off fracture with step-termination located on the proximal dorsal side of the point. The edge rounding and crushing was caused by cutting and scraping activities (Table 25). More precisely, the patinated notch that is located on the left distal-lateral side of the point clearly indicates that it was caused by scraping activities. Striation damage associated to this notch confirms the conclusion that the notch was caused by scraping. Unfortunately, even more precise description of the notch is not possible due to patination. After taking into consideration all of the damage identified on this pseudo-levallois point, it could be confirmed that it was used both as a knife and a scraper for processing the high density material.

8.1.11. Layer 42

Three pointed tools were uncovered from the layer 42, and all three of them are Mousterian points. Point R.T. 205 was possibly hafted, considering the crushing damage on the proximal ventral side of the point, and almost parallel unifacial spin-off fractures with bending termination located on the both proximal lateral part and ventral side of the point (Fig. 62; 63). Heavy crushing damage is completely covering both lateral sides (Table 25-28). It could be concluded that the crushing damage was caused either by breaking the high density material (Fig. 50; 53/3; 54/1, 2) or intense retouching/ resharpening. Tip crushing from which two unifacial spin-off fractures with bending termination have initialized possibly implies that one functions this point had was its usage as a spear-head. Similar damage was identified after the execution of the first experiment on the tip of an experimental Mousterian point that was vertically hafted and used for thrusting spear technology. The cause of the damage identified on the experimental Mousterian tool was the penetration of the target (wild boar). Taking into the account all of the damage identified on the R.T. 205 point, it could be concluded that it was used as a multifunctional tool, or more specifically, as a knife, scraper and even spear-head used in thrusting spear hunting technology.

Mousterian point R.T. 212 (Fig. 64; 65) possesses a multiple unifacial spin-offs and step-terminating bending fractures alongside crushing damage on the base and on the both proximal dorsal and proximal ventral side. Possible causation of these fractures is the combination of knapping and hafting damage (Fig. 32/4; 33/1; 42/5). The edge damage and rounding (Fig. 65/3) clearly indicate that the point was used for cutting activities. Tip crushing from witch the unifacial spin-off fracture with step-termination was initialized represent the damage caused by this point's usage as a spear head. It was possible to locate fracture wings on the plain of the unifacial spin-off fracture located on the distal ventral part of the point, and therefore calculate the fracture velocity. The value of the fracture velocity of 171 m/s indicates that the cause of this unifacial spin-off fracture with step-termination was indeed the point's usage as a spear-head (Fig. 5). First experiment produced similar unifacial spin-off fracture with step-termination and the causation was experimental Mousterian point's usage as a vertically hafted spear-head used in thrusting spear hunting technology (Fig. 11/2). It could be concluded with high reliability that this point was used both as a knife and a spear-head.

Point R.T. 216 could in fact be both interpreted as a Mousterian point and convergent scraper (Fig. 66; 67). Multiple step-terminations and crushing damage on the proximal dorsal side of the tool represent possible hafting or knapping damage (Fig. 31/1, 4; 32/1; 11/3; 15/1). Numerous unifacial spin-off and crushing damage that is present bilaterally represents the retouching and breaking damage, similar damage was obtained on the experimental points used in the fourth experiment for bone breaking and debranching (Fig. 53/3; 54/1, 2). Considering the crushing damage on the proximal dorsal side and unifacial spin-off fracture from which multiple step-terminations were initialized, it could be concluded that this point was possibly hafted (Fig. 11/3; 15/1). Edge rounding, micro-notches and the "pseudo-burin-like" fracture that could be identified on the distal right lateral side of the point are clearly indicating that it was also used for cutting and scraping activities (Fig. 67/1). The crushing damage from which the unifacial spin-off and step-termination were initialized, located on the distal ventral side (Fig. 67/3) could lead to the conclusion that this point was used as a spear-head. Fortunately, it was possible to locate the fracture wings on the plain of the unifacial spin-off fracture and calculate the fracture velocity (972 m/s). This fracture could be placed in the rapid loading rate category (Fig. 5) which furthermore implies that the possible cause of this fracture cold be the knapping by using the both soft and hard hammerstone and even the point's usage as a spear-head used in hand-thrown hunting technology. Similar fracture was identified after the execution of the first experiment on the experimental Mousterian point that was used as a vertically hafted spear-head used in hand-thrown hunting technology, and the fracture cause on the experimental point was missing the "hunting target" and hitting the gravel surface (Fig. 11/2). Reliable conclusion could be brought us after summing up all of the identified damage that this point represents a multifunctional tool that was used as a knife, scraper and even spear-head.

8.1.12. Layer 42α and 42γ

Pseudo-levallois point R.T. 36 from the layer 42α (Fig. 68) possess no damage that could have been caused by hafting. No damage was identified on the dorsal side of the point. On the ventral side of the point, crushing damage from which unifacial spin-off fracture and step-termination were initialized could be identified on the right lateral side of the point. This damage was caused by scraping the high density material (Fig. 68). Impact notch with step-terminating bending fracture was identified on the left proximal-lateral side of the point and could be correlated to a knapping or retouching damage (Table 25-28). Edge rounding with notches and micro-notches represent a cutting damage (Fig. 53/2, 7; 54/ 6). The crushing damage with step-termination located on the tip of the point could have been caused by numerous activities, but it is clear that it was not caused by this point's usage as a spear-head. It could be concluded that this point was used as a hand-held tool for cutting and scraping activities.

R.T. 547 is a Mousterian point from the layer 42γ (Fig. 69, 70). Considering the unifacial spin-off fracture with multiple step-terminations on the proximal dorsal side, the striations on the proximal-medial side of the tool and the step-termination with possible residue of the binding material on the proximal ventral side of the tool it could be concluded that this point was hafted. Heavy edge crushing and rounding with presence of micro-notches and unifacial spin-off fracture with step-termination on the right distal-lateral side of the point were caused by cutting and scraping activities (Fig. 53/5; 54/3). TCSA value (260 mm^2) of this point (Table 29) is too high, so the possibility of this point's usage as a spear-head could be excluded. Therefore, the burin-like fracture with bending termination from which the multiple unifacial spin-off fractures with step-termination were initialized could be correlated to either cutting (Fig. 53/5) or retouching damage (Fig. 32/5; 33/2, 3). By taking into the account all the damage data that was obtained by processing this point, it could be concluded that it was hafted and used as a scraper and a knife.

8.1.12. Layer 50

Mousterian point R.T. 166 from the layer 50 possesses the most diagnostic hafting damage. Notch with step-terminating bending termination on the left proximal-lateral side of the point with polish that can be identified from the fracture initiation across the medial and opposite lateral side, and also on the proximal ventral side (Fig. 59; 60) of the point represents the most diagnostic hafting damage (Rots et al, 2001; Rots, 2004). Crushing damage located on the base of the point, represents either a knapping (Fig. 32/4; 36/1) or hafting damage (Fig. 15/1; 41/1; 42/2). The crushing and bending fractures with small unifacial spin-off fracture and step-terminations represent a clear damage diagnostic of this point's usage as a spear-head (Lombard, 2005; Paergeter, 2011; Iovita et al., 2014). Huge step-terminating bending fracture situated on the distal right lateral ventral side of the point, confirms that this point was indeed used as a spear-head. TCSA value (204 mm^2) also confirms the very high possibility that this point was used as a spear-head. Similar damage was identified on the experimental Mousterian points that were vertically hafted and used as a hand-thrown spears (Fig. 12/4, 5). Presence of edge rounding and micro-notches indicates that this Mousterian point was used, besides as a spear-head, also for cutting activities.

Another point from the layer 50 is a pseudo-levallois point R.T. 169 (Fig. 61). Presence of hafting damage was identified both on proximal (crushing damage with unifacial-spin off and bending termination) dorsal and ventral (unifacial spin-off with bending termination), and right lateral part of the point (notch with bending termination). Edge rounding, notches and micro-notches indicate that this pseudo-levallois point was used as a knife. There is also a small possibility that this point was also used as a spear-head. Tip crushing from which the unifacial spin-off fracture was initialized and striations could represent the damage caused by point's usage as a spear-head. Considering the striations on the distal dorsal part of the point, the similar damage was identified on the point used as a vertically hafted spear-head, used for thrusting spear hunting technology (Fig. 14/2). Considering all of the identified damage it could be concluded that this point was used as a knife and possibly even as a spear-head.

8.1.13. Layer 51

Mousterian point R.T. 32 (Fig. 57; 58) represents another example of the points from the site of Riparo Tagliente with possible usage as a spear-head. The polish on the proximal dorsal side of the point, the removal of the bulb of percussion and the step-terminating crushing damage on the left proximal lateral side represent a hafting-derived damage. Furthermore, on the proximal dorsal side of the point, the possible residue of a binding material could be identified (Fig. 57/2). Crushing and bending fractures with unifacial spin-off fracture, that could be identified on the tip of the point are indicating that this point was used as a spear-head. Similar damage was identified on the experimental Mousterian point that was vertically hafted and used in a thrusting spear technology (Fig. 14/2). Heavy edge rounding and step-terminating fracture initialized from the crushing damage on the right lateral side of the point could have either be caused by cutting the dense material or points usage as a spear-head. Huge burin-like fracture could be identified on the right lateral side of the point, but considering the edge rounding and micro-notches, it seems that it was not caused by impact but by cutting activities. It could be concluded that this Mousterian point was used for cutting activities and as a spear-head.

9. Conclusion

Each specific stone tool assemblage from the studied archaeological site needs a support of the experimental research with the adapted system of variables in order to provide the important information about fracture propagation and their further reliable interpretations (Pargeter, 2007; Lombard and Pargeter, 2008; Gi-Kil and Sano, 2019).

The first, hunting replicative experiment was executed in order to provide answers to a multiple complex questions. After the experiments execution it was possible to obtain sufficient amount of data that was used for providing the answers and possible interpretations of the functionality of the pointed tools from the site of Riparo Tagliente. The equifinality in the fracture formation represented a great problem both in previous (Pargeter, 2011; Hutchings, 2016; Milks et al., 2016; Wilkins and Schoville, 2016) and also this research. Even due to the problems of equifinality some conclusions could have been established. In the first experiment using the experimental Mousterian points, the variations of the step-terminating fractures represented problem because they were present in all of the possible hafting and delivery methods and outcomes (Fig. 9-19). Even though, some of the impact fractures type formation provided an appealing result, such as the high presence of unifacial spin-off fractures on the Mousterian points that hit the target (wild boar), and burin-like fractures that are present in high percentage on the diagonally hafted experimental Mousterian points. The most surprising result of the first experiment is that hafting depth does not influence the penetration depth (Fig. 21). Some studies discarded Shea's (2006) proposed TCSA values for spear and arrow points, and proclaimed that TCSA values are an unreliable factor (Newman and Moore, 2013; Clarkson et al., 2016). It is true that also in this research, the first experiment results did not show the relations between TCSA values and the penetration depth (Fig. 21), but, considering the small sample, it does not necessarily mean that the Shea's (2006) TCSA research should be completely discarded. TCSA values, to the certain extent did help in the interpretation of the pointed tools from the side of Riparo Tagliente. If there were a few possibilities for the interpretation of the certain set of fractures on the same point, TCSA value could narrow the variety of interpretations of the point's functionality to a certain extent. Fracture types that were identified after the execution of the first experiment provided a possibility for a direct comparison of the fractures identified on the points from Riparo Tagliente. For example, the tip crushing with bending termination that was identified on the Levallois point R.T. 343 (Fig.

94/4, 95/4, or the unifacial spin-off fracture with step-termination that was identified on the Mousterian point R.T. 212 (Fig. 64/4, 65/4).

The damage that was identified on the Mousterian experimental points used in first experiment before the points were actually used, was classified as a damage that was caused during the knapping phase. That conclusion led to a second, knapping experiment set-up and execution. Impact fractures could be formed, as they name indicates, by any activity that involves impact action (Pargeter, 2011; Hutchings, 2016; Coppe and Rots, 2017). Knapping process is based on impact between the hammerstone and the raw material that is being manufactured, therefore, many of the fractures that could be identified on the stone tools could actually be formed during the production phase. Second, knapping experiment was executed in order to get a closer insight into the formation of the impact fractures and diagnostic impact fractures that could occur during the knapping phase. Also, it was attempted to get an insight if there is any difference in fracture propagation based on the level of experience of the knapper. Considering that the difference between the percentage of the macrofractures that were identified on the experienced (10,9%) and inexperienced knappers (8.92%) is low (Table 10), i.e. it is not significant for establishing the reliable conclusions. The important results that second experiment provided, are the fractures that could be located on the proximal dorsal and ventral side of the tool that could also be caused by hafting shaft when the certain tool is being used (Lombard 2004, 2016; Rots, 2013). One of the most diagnostic impact fracture, the unifacial spin-off that is larger than 6 *mm* (Lombard, 2005; Pargeter, 2011; Iovita et al., 2014) was identified on the both inexperienced and experienced knapper's assemblage. Considering the fact that diagnostic impact fractures could be formed during knapping processes (Fig. 32; 33), the location and the morphology of the fracture represents an important data in order to avoid their misinterpretation. The fractures caused by a knapping incident tend to occur in high percentage on the proximal (platform preparation, and separation from the core) and lateral sides (retouching, striking the ground after being separated from the core) of the stone tool (Fig. 31). Low percentage of the knapping incident fractures could be formed on the distal part of the pointed tool, and they are being caused by the bad striking angle, i.e. failed attempt to modify the distal part of the tool in order to produce a point (Fig. 32, 33). In fact, this kind of fractures are represented by crushing damage and unifacial spin-off fractures, but this is a different type of unifacial spin-off fracture, or "pseudo unifacial spin-off". The spin-off fracture by definition are a secondary fracture types that are originating from other fractures, such as step, bending, snap, notch or crushing fractures (Sano, 2009; Pargeter, 2013). Objectively, if the recent and most reliable detailed and exact fracture description that is provided by the research of Cope and Rots (2017) is taken into consideration, almost all of the present descriptions of the fractures could be to some extent interpreted, as for example: 1) Crushing initiation with spin-off propagation and step termination; 2) Snap initiation with spin-off propagation and bending termination; 3) Impact notch initiation with bending propagation and step-termination. These examples are indicating, just like the research of the Cope and Rots (2017) the state of the confusion that impact fracture research is in. Also, it is not strange to find the different description of the similar fracture types in various research. It is true, that even when other types of research are being executed that the interpretation of the certain variables are in most of the cases subjective in nature. Furthermore, for example, various researchers (Fischer et al., 1984; Lombard, 2007; Villa et al., 2009; Wilkins, 2012; Gavrilović and Arzarello, in press) are seeing and interpreting similar fractures subjectively.

Third hunting replicative experiment using Levallois points provided an clear insight into the causations of some fractures even the sample size was small (Plisson and Beyries, 1998; Rots, 2013; Rots and Plisson, 2013). The data that was obtained when combined with first experiment confirmed the conclusion of the interpretation of some fractures. For example the hafting damage (Fig 15/1; 41/2). And even the similar fractures were identified on the second knapping experiment and the knapping damage of the third experiment (Fig. 32/1; 33/1; 41/1, 2; 42/5). Furthermore, it provided a more detailed information of the transversal fractures, i.e. the causations of the tool to break in half. It is true that tools breaking in half could be caused by various causations: knapping (Fig. 32/2), dropping (Hutchings, 2011), trampling (Pargeter, 2011; McPherron et al., 2013); usage as a spear-head (Fig. 42/3, 4, 6, 7). Also, it provided the reliable interpretations of the fractures that could be caused by the spear successfully penetrating the target, i.e. “successful hunt” considering that the all of the experimental spears penetrated the artificial target (Fig. 37). It is known that the impact velocity influences the fracture size (Hutchings, 2011; Iovita et al. 2014), the third experiment provided data that if the impact velocity of the hand-thrown spear was between 10-15 m/s the possible fracture size will be approximately 2 cm (Fig 37). Furthermore, the data of the third experiment has shown that the lower TCSA values means higher penetration depth (Fig. 38), which supports the Shea’s (2006) research. Since the sample size was small to establish reliable conclusions about hafting functionality, the next statements should be taken with caution. The Levallois point that was hafted using animal intestine experienced hafting breakage and the point stayed inside of the “target”. Therefore, it could be concluded if the hunter’s intention was to make the point stay inside of the target, this hafting approach would be used. Also, it could be concluded that the hafting approach using sinew possesses higher functionality.

Since the damage that is not diagnostic of impact was identified on the pointed tools from Riparo Tagliente, that damage was not ignored and the fourth experiment was executed in order to provide interpretation of certain stone-tools functionality by identifying the damage cause as reliable as possible. The first idea about the interpretation of the pointed tool that we get in most of the cases is that they have been possibly used as a spear-heads. Edge damage patterns obtained in the fourth experiment (Fig. 53, 54) in most cases indicated that numerous pointed tools from Riparo Tagliente were, besides their usage as a spear-head, used as a multifunctional tools. Fourth experiment also confirmed the conclusions about the edge rounding from the previous research (Tringham et al., 1974; Keeley, 1980; Pawlik 2001; 2006; Lozny and Abbott, 2004), that the intensity of the rounding damage is growing accordingly to the density of the worked material. Edge crushing, besides its possible causation of certain pointed tool usage as a spear-head, also could occur in other impact-related activities, such as debranching or heavy butchery such as bone breaking activities (Fig, 53/3; 54/1, 2). Importance of the final experiment in this research is perfectly presented in the case of the Levallois blade, R.T. 10 (Fig. 97) where the blade could be interpreted also as a point because the use-wear damage is the cause why this stone tool is pointed. This conclusion was brought up, because the R.T. 10 does not have any of impact damage or diagnostic impact damage and the edge damage patters clearly show the damage caused by cutting activities (Fig. 53/ 6; 54/ 6; 97).

The questions that the four of the experiments were created to answer, could be partially answered. Which type of hafting was used? It is possible to partially answer this question. Considering the first experiment, or more precisely the results of the spears that rebounded off the target, the most of the spears that rebounded were diagonally hafted (Fig. 9, 10, 13; 16; 18). There are a few pointed tools from the Riparo Tagliente that possibly show the damage caused by hafting them diagonally (Fig. 61; 77; 83; 99). Based on the first experiment, their function as spear-head is less probable, and the most reliable interpretation is their function as a knife, scraper or the combination of thereof. Currently, based on the data that was obtained by the first and third experiment, it is not possible to experimentally reconstruct a possible morphometric values of the hafting shaft, since no relation between hafting shaft morphometric values and fracture types was discovered (Fig 23, 24, 39, 40; Table 21; 22). The correlation of morphometric values to a fracture type and correlation of hafting and delivery method with fracture type needs another research with much greater number of experimental samples (Fischer et al., 1984; Lombard et al., 2004; Iovita et al., 2014). No relation between point types and the layers of Riparo Tagliente could be found (Fig. 105). Also, no relation between the possible function of the points and the layers could be found (Fig. 105). No relation between hafted tools, point types and layers could be found (Fig. 106). This could be possibly explained by the high levels of disturbance caused by post depositional processes that damaged the stratigraphy of Riparo Tagliente (Bartolomei, 1982; Cremaschi, 1982).

The biggest problem of impact fracture analyses is the equifinality of the fracture formation (Wilkins et al., 2012; Knutsson et al. 2015; Stemp et al., 2016; Pargeter et al., 2016). We are able, through experimental approach, to "observe" and even control some of the numerous variables of the complex system of fracture formation. Still, there are countless variables that represent obstacles and therefore are reducing the reliability of the obtained data. After the execution of four different experiments that are presented in this research, it is possible to some extent to differentiate the fractures caused by knapping, point's usage as a spear-head, cutting, chopping or scrapping tool (Fig 107). Nevertheless, those interpretations are still questionable and possible, not final. As said by Cope and Rots (2017), fractures themselves are implying that the specific load and direction of the pressure to the certain area of the tool can occur as a result of any other cause instead of stone tools usage as a spear-head/projectile. Similar conclusion was brought after the execution of the experiments of this research, and many of the damage types that were identified on the pointed tools from the Mousterian layers of the Riparo Tagliente site were interpreted as being caused by multiple possible activities (Table 25; Fig. 62; 66; 70; 83; 94; 96; 103).

Another problem of experimental research is the question of reliability of our methodology of "replication" of the damage. As it was already mentioned, we cannot possibly "replicate" some of the variables such as the hunting itself, the prey is not alive and running, and in some of the experiments the authors (O'Farell, 2004; Pargeter, 2007; Iovita et al., 2014; Coppe and Rots, 2017) do not even pay attention to some of the important variables such as missing the target and if the target was missed what was the surface the stone tool was in contact with. In their experiments (O'Farell, 2004; Pargeter, 2007; Iovita et al., 2014; Coppe and Rots, 2017) the hunt is always successful, i.e. the target was penetrated by the spear and never missed. It is clearly shown after the execution of the first experiment of this research that missing the target was an important variable. For example, the functional analysis carried out by Rots (2009) of Mousterian and Micoquian assemblage of Sesselfelsgrotte in Germany, described a damage on the edge of the scraper as being caused by wood chopping, similar damage was identified on the experimental Mousterian point that was vertically hafted and used as a thrown spear. Damage identified on the experimental Mousterian point was caused by spear's missing the target and hitting the gravel surface (Fig. 12/1).

Furthermore, there is a great confusion in the fracture descriptions (Coppe and Rots, 2017). It is possible that the similar fractures are described differently by different authors. In order to avoid such confusion, Coppe and Rots (2017) proposed a methodology for detailed and precise fracture description. More specifically, the location of the fracture initiation, the location of the termination, the type of initiation, the type of termination and the locus of the fracture (Coppe and Rots, 2017). One of the important fracture attributes that needs more attention in the future research is the fracture propagation. The types of fractures initiation and terminations are important, but also, the description of fracture plain, i.e. the area between the fracture initiation and termination is usually left out. It was demonstrated by a few authors that the fracture plain possibly carries very valuable information, the fracture wings (Hutchings, 2011; Sahle et al., 2013). By identifying the fracture wings on the fracture plain, we can calculate the fracture velocity which is an extremely valuable information for the interpretation of the fracture causation (Hutchings, 2011).

The experimental research that was executed in order to better understand the damage that could have been caused by impact, has provided a valuable results for our better understanding of fracture propagation and their causation, and also for the more reliable interpretation of the pointed tools from the Mousterian levels of Riparo Tagliente.

Even the experimental sample size was small in all four of the experiments, it was possible to establish reliable conclusions for some of the variables. The most significant conclusions that could be established after the execution of the first experiment were:

1. The burin-like fracture will more likely be formed on the points that are diagonally hafted to the shaft independently of the delivery method;
2. Step-terminating fracture could be formed by using any hafting approach, delivery method and in all of the possible end-point outcomes and therefore it should be excluded from the DIF category. This is conclusion was confirmed by observing the data obtained by the first, second and third experiment;

3. Impact velocity is a complex variable of fracture propagation, because the fractures could be formed or not at the same delivery speed;
4. There is a high probability that if the spin-off fracture is identified on the pointed tool, it was probably caused by the penetration of the hunted target.

Second, knapping experiment, besides providing an insight into which knapping variables influence the impact fracture propagation it also provided important data of influence of the knappers experience to the fracture formation. The lower the level of knapping experience is, the higher the number of waste flakes are being produced and therefore the higher variability and quantity of the fractures are being formed. Fractures situated on the proximal sides of the points if not being caused by hafting shaft, they are being caused by a bad striking angle when the flake is being separated from the core. Resulting fracture type caused by a bad striking angle is in most of the cases the step-terminating or crushing fracture. The location of the fractures could help greatly in distinguishing their cause. The problem is, that in some cases, even the fracture that is caused by knapping it could be misinterpreted as being caused by using the certain point as a weapon. There is a perfect example of the experimental point (Fig. 32/5) that experienced a unifacial spin-off fracture > 6 mm with step-terminating bending termination on the distal proximal side, i.e. area with the highest occurrence of fractures that are diagnostic of weapon use. Knapping experiment let to another important conclusion. Even the spin-off fractures > 6 mm, one of the most diagnostic impact fractures should be interpreted with caution in the future research because it can be also caused by a knapping incident. Also, it could be concluded that the most diagnostic impact fracture is the bifacial spin-off fracture because it was not identified in the experimental knapped assemblage.

Besides the fracture propagation and causation, the functionality of the pointed tools for the various activities have been experimentally tested. For example, it was shown that the TCSA values do not influence the penetration depth in the first experiment, but in the third experiment the results were completely opposite, the lower TCSA values caused higher penetration depth. Furthermore, it was shown that the hafting depth does not influence the penetration depth. The spears that were used in first experiment could be efficient for causing severe blood loss of the prey, while the spears used in the third, hunting simulation experiment demonstrated the high functionality of Levallois points as a spear heads used in hand-thrown spear hunting technology. All of the spears successfully penetrated the target 61-93 mm. Due to a small sample size, the conclusions that were brought up should be taken with caution. There is no relation between the hafting shaft morphology and the fracture type. Also, the third hunting simulation experiment confirmed the conclusion brought up after the execution of the first experiment, there is no correlation between hafting depth and penetration depth.

The first association when the pointed tools are being studied, is their usage as a hunting weapons. This research has clearly demonstrated that the pointed tools from the site of Riparo Tagliente in fact, represent multifunctional tools, and one of their possible function is their usage as a hunting weapon, i.e. spear-heads used for both thrusting and hand-thrown spear hunting technology. Pointed tools were also used as knifes, scrappers and in some cases even as a chopping tools. No correlations could have been established between the knapping technology of the point and their possible function, i.e. all of the identified point types were used as either knife, scraper, spear-head or in some cases as multifunctional tool. Also, no significant conclusions of the change in the functionality or point manufacture by the layers could have been established.

It can be concluded that the pointed tools from the Riparo Tagliente were used as a multifunctional tools, and also weapons. The scarce number of the pointed tools used as a spear-heads could be explained by the usage of wooden spears.

Future work

The future work should be focused on improving of the research methodology of impact fractures and other damage that could be identified on the stone tools as being caused by their manufacture, usage or post-depositional processes. By improving the methodology, the reliability of the damage interpretation will also be improved. Still, some of the impact fracture types lack of detailed description (crushing fracture) and are in need of redefinition in order to reduce the confusion and misinterpretation of the certain fracture types. Important variables should be established and no damage should be ignored while interpreting both experimental and archaeological samples.

Firstly, archaeological material should be processed and variables should be adapted as close as possible in order to enhance the reliability of the experimentally obtained results. By using modern equipment in the experimental research, we do control certain amount of variables, but how reliable are the results obtained “modern way”. Fracture types should be described into details and all of the information about the experimental approach (setup, equipment, stone tool manufacture, hafting methodology, end-point outcomes…) should be described into details.

Fracture wings have proven to be a powerful tool for interpretation of the fracture propagation (Hutchings, 2011; Sahle et al., 2013), i.e. calculation of fracture velocity and therefore establishing the possible causation. The problem is, they cannot be identified on each stone-tool (Hutchings, 2011). Fracture wings (Wallner lines) should be included as a mandatory part of macrofracture analyses, i.e. for both experimental and archaeological material processing.

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