Groundbreaking technologies in the Middle Paleolithic of the Levant: High resolution and multi-scale functional analysis of Ground Stone Tools

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von

Eduardo Paixão

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Volume 1

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Dedicated to the memory of my grandfather

Nicolau Amândio

Abstract

The study of Ground Stone Tools (GST) is a powerful topic of research to understand key elements related to the evolution of human behavior across time and space. As a clear and direct evidence for past human daily tasks such as percussive activities, these artifacts are a testimony of the oldest, most persistent and durable technological strategy in human evolution. Their origin stretches from the earliest evidence of human activity to the present day, across a wide geographic distribution. By definition, this group includes any stone item that was primarily manufactured through mechanisms of abrasion, polish, or impact, or itself used to abrade, polish, or impact (Adams, 2002).

In the archaeological record, Ground Stone Tools diachronic and spatial distributions during the Middle Paleolithic of the Levant (ca. 250- 47 Ka BP) are mainly limited to mainly open-air sites, while their presence in caves and rock-shelters deposits is very rare. The reasons for these distribution patterns are still unknown. These patterns may be related to a research bias due to the difficulties in identifying these artifacts, or it can be related to the specific function that this material represented in each of the different location and type of site. From these contexts, in the literature a wide range of possible uses has been suggested for Ground Stone Tools, including the processing of organic materials (e.g., plants; faunal) and mineral products (e.g., ochres and bipolar lithic production). However, the correlation between different tool types, motions, and the processed material, and how these are represented in each site is still unknown.

In order to contribute to identify and characterize Ground Stone Tools in the Levantine Middle Paleolithic record, two main problems need to be resolved: a) the development of analytical units that, via experiment-based actualistic studies, aim to improve the identification and characterization of the different types and scale of damage patterns presented on the surfaces of these materials, and b), through this approach, recognize and understand the specific function/s of these materials and its correlation with the rest of the site assemblages.

To address these questions, this project follows a dedicated workflow characterized by 2 main research avenues: 1) technological and functional analysis using a high-resolution multi-scale approach, and 2) controlled experiments. The experimental program includes different types of Ground Stone Tools activities using limestone tools in a *controlled* environment. With the help of a mechanized system, a large number of variables can be controlled, resulting in numerical data to facilitate both the comparison of results and the replicability of the experiments. Functional

analysis combines a high-resolution and multi-scale low and high magnification approach, as well as an integrated approach focused on both qualitative and quantitative analysis. This allows the acquisition of multi-scale 3D data, which aims to qualitatively assess and quantify different types of use-wear traces.

In sum, this study presents groundbreaking research, contributing to the characterization of Middle Paleolithic populations behavior, addressing questions related to subsistence (e.g., food processing), technology and, possibly, symbolic behavior. The project also contributes to the methodological improvement of experimental and functional studies, by presenting a unifying methodology that contributes data for the comparison of Ground Stone Tools across time and space.

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1. Introduction

1.1. Brief introduction, research questions, and structure

The Levant region represents the main geographic corridor between Africa and Eurasia. This fact together with the abundant number of identified paleolithic sites, large artefactual assemblages and Human remains with exceptional good state of preservation, makes this area one of the main hotspots to investigate major and crucial topics on the study of Human Evolution. The Middle Paleolithic in the Levant (ca. 250- 47 Ka BP) (Mercier, 2003; Mercier et al., 2007; Rebollo et al., 2011; Valladas et al., 1999a; Valladas et al., 2013), has been strongly debated, since many researchers consider this region to be the most promising geographic area for the documentation and study of the earliest evidence of coexistence between Modern Humans and Neanderthals (Hovers, 2006). In fact, the possible interaction between these two human populations is very challenging to understand from the archaeological record, in part due to the fact that the artifacts left by both population cannot be easily distinguished (Hovers, 2006).

Nevertheless, during the last decades in this region, this area of research has been marked by the development of extensive studies on lithic knapping strategies (e.g., Levallois technology), faunal remains and human osteology. Several multidisciplinary studies have been established in the region, with the goal of understanding the human repertoires and behavioral dynamics that marked this step in the history of Humankind. However, regarding the variability of lithic technology during this period, some artefactual groups are still poorly known and discussed, like the case of the items commonly described as Ground Stone Tools (GST). By definition *Ground Stone Tools* is an artefactual group that includes any stone item that is primarily manufactured through mechanisms of abrasion, polish, or impaction, or itself used to abrade, polish or impact (Adams, 2014) (detailed terminology and definitions will be explained with more detail in section 1.2). During the last decades of archaeological research, Ground Stone Tools have been identified at multiple Middle Paleolithic sites. These tools represent a unique chance for understanding multiple aspects of daily routines of past human communities, specifically through the preservation of use-wear traces, that can be used as clear evidence for different tasks related with diet, technology and symbolic behaviour.

Earlier mentioned as one of the main problems in the study of Ground Stone Tools, the identification of these items within archaeological assemblages is not a simple and easy task, since, during the Middle Paleolithic, these tools were frequently used without prior preparation (e.g., flaking), which makes their identification in the archaeological record more difficult. This aspect makes the identification and characterization of these tools to be very dependent on multiscale and high-resolution use-wear studies. However, many of the raw materials (e.g., coarse-grained rocks such as limestone), have been under-explored in use-wear studies, and therefore, still lack an extensive reference collection against which the archaeological materials can be compared.

To tackle these issues, it is important to be aware of two main challenges related with paleoanthropological research on Ground Stone Tools that need to be addressed: a) the identification of these artifacts in the archaeological record, with special attention to the distinction between natural and anthropogenic evidences of tool use (macro and micro use-wear traces), and b) the comprehensive techno-typological and functional detailed characterization of this type of tools, which aims to understand their importance and their specific role among past paleolithic human populations.

Following these main objectives of research, this project explores the impact of Ground Stone tools technology during the Middle Paleolithic, with a focus on the geographic case study of the Levantine region, specifically by studying three case studies located in Israel. This work is based on the combination of a multi-scale and high-resolution analytical methodology, supported by experimental data. Here qualitative and quantitative analysis are combined, with the aim of reducing the analytical subjectivity and providing more precise and comparable data within and between assemblages.

In sum, this research is organized into three complementary and interrelated main goals:

a) To combine and develop high-resolution and multi-scale methodologies to support the analytical procedures, by increasing the application of quantitative approaches to better identify and compare patterns of the use-wear features,

b) To develop controlled experiments on limestone materials, to directly support the analysis of the case studies explored in this project, but also to be available to support other researchers studying use-wear on limestone and,

c) Provide new and detailed data and interpretations through the combination of archeological analyses and experiments for the characterization of the technology and functionality of Ground Stone Tools from the selected case studies, which directly contributes to understand its technological variability in the region.

During the first contact and visual inspection of the artifacts, the first question that raises should always be "*Is this a Ground stone tool?*". This first question should be followed by "*what was it used for?*" and "*how was it used?*". In other words, how and what for were these tools used by past human populations.

Although these may seem simple questions, in fact the process to answer them can be very complex and challenging from the methodological point of view, therefore a multidisciplinary approach is beneficial. In this sense, is important to characterize and describe these tools in as much detail as possible, concerning different aspects and features. For this detailed characterization it is fundamental that different scales of analyses are considered, such as exploring aspects such as raw materials, morphology, manufacturing process, type of use-wear traces, with all these related with the type of archaeological site and with the rest of the assemblages.

By exploring these different topics, data presented and discussed here sheds new light on the types of activities and technological behaviors previously unknown or poorly characterized for the Middle Paleolithic. The reported Ground Stone Tools from Middle Paleolithic sites are extremely rare and their diachronic and spatial distributions during the Middle Paleolithic of the Levant are mainly limited to open-air sites, while in caves and rock-shelters these tools seem to be so far very rare. The reasons for these distribution patterns are still unknown. It may be due to a research bias related to the difficulties in the identification of these artifacts or related to the specific function of this material and its association with human mobility and settlement patterns. To understand Ground Stone Tools it is fundamental a detailed characterization of the artifacts, including quantitative data acquisition which allows a detailed characterization of the Ground Stone Tools, and a precise comparison within and between assemblages. In contribution to this route, the investigation presented here explores the techno-typological and functional study of Ground Stone Tools assemblages of the following Middle Paleolithic sites: Nesher Ramla ~170-80ka BP (Centi & Zaidner, 2020; Prévost & Zaidner, 2020; Zaidner et al., 2018), Far'ah II, ~85-60ka BP (Gilead & Fabian, 1987; Goder-Goldberger et al., 2020) and Ein Qashish, ~66-64 ka BP (Been et al., 2017; Ekshtain et al., 2019a; Hovers et al., 2008; Malinsky-Buller et al., 2014b).

All archaeological artifacts were analyzed following a workflow that includes techno-typological and functional characterization, combining qualitative and quantitative 3D technologies and microscopic analysis (low and high magnifications). The analysis is supported by a reference collection developed through an experimental program that explored different types of motions and contact materials.

In sum the research presented in this thesis directly contributes new data and new workflows for a more complete and comprehensive interpretation of Ground Stone Tools technology in the Middle Paleolithic of the Levant, leading to a better understanding of past communities' behavioral dynamics.

Manuscript organization

This thesis is organized in two volumes, the **Volume 1** is presented into 7 main sections. In **section 1,** the goal is to present the foundations of the project, discussing the research questions, the main definitions used along the project, and to present the region where this study is dedicated. This section also introduces the main scientific debates concerning the Middle Paleolithic in the Levant, and specifically the debate concerning the topic of Ground Stone Tools. **Section 2** is dedicated to a brief history of the archaeological research on paleolithic contexts, firstly by discussing the main research phases of the Levant region in a chronological perspective, and secondly by briefly presenting some history of the use-wear approach and functional research on Middle Paleolithic lithic assemblages. In **section 3** the methods applied in the analysis of the materials are presented and explained in detail, as well as the methods and materials used for the development of experiments. **Section 4** is dedicated to presenting the main characteristics of the archaeological case studies (the sites of Nesher Ramla, Far´ah II and Ein Qashish) addressed in this research, focusing on aspects such as the site location, geology, and archeological assemblages. **Section 5** presents the results of this study, which are organized by: the outcomes of both experimental program and analysis of the archeological materials. Results are presented following the multi-scale approach, starting in the macro scale, and gradually zooming into the micro scale of the analysis. **Section 6** discusses the integration of the results of this research and debates their main contributions to the field. In **Section 7** the main conclusions of this investigation are presented, highlighting the contribution to the field and suggesting directions on further questions and avenues of research.

The two final parts of the manuscript are **section 8**, where all bibliography used in this work are listed, and **section 9**, which is dedicated to the appendixes (supplementary material). This section includes the equipment list and acquisition settings, summarized tutorials of the analytical workflows, and finally several extra data, including images and tables with information complementary to what is presented along the manuscript. The images, tables, and graphics that directly support the reading of the thesis appear directly along the text, while complementary images are listed in the dedicated sub-section within the section 9.

Volume 2 is strictly dedicated to the dissertation supplementary material, which includes the computational *R* and *Python* scripts used in this project, the configuration files used in the software *E4* for data input, and finally the confocal output data for all the analyzed samples micro surfaces.

1.2. Ground Stone Tool definition and terminology

The artefactual group addressed in this investigation is often classified and described by the scientific community through the use of different terminologies (e.g., percussive tools, macro lithics, non-knapped materials, Ground stone tools). I believe that every terminology, as a method used to categorize and classify objects, has its advantages and disadvantages, while clearly providing the archaeologists a baseline comparative language. In this case, some common terms are more specific for a type of activity, such as "percussive technology" (Benito-Calvo et al., 2018; Pop et al., 2018). In this case for example, the term exclusively defines a type of tools based on percussive marks. Others are more specific to morphometric aspects (e.g., macro-lithics) (Caricola et al., 2018). At the same time, other scholars often use terminology based on the fact that this type of artifacts in many cases have no evidence of intentional debitage prior to their use as tools (e.g., non-knapped materials) (Beaune, 2000) .

In this project, the adopted terminology is the generic term of "*Ground Stone Tools*". This is due to 2 main reasons: a) Ground Stone Tools is the most inclusive terminology, and b) it is a well established term, accepted, and used by most of the scientific community in this field (Adams, 2014).

By definition, Ground Stone Tools as an artefactual group includes any stone item that is primarily manufactured through mechanisms of abrasion, polish, or impact, or is itself used to abrade, polish or impact (Adams, 2002). This artefactual group includes several “families” of artifacts such as: processing tools, manufacturing tools, and symbolic items. Processing tools are defined as tools that were used to process products through impact or grinding motions, namely, to reduce particle sizes. This group includes tools such as: manos and metates, pestles and mortars, and anvils. These tools can be related with a large range of activities (e.g., grinding seeds, breaking fruit shells, breaking bones for marrow extraction). The manufacturing tools are the tools used to shape other items (e.g., retouchers and hammerstones for knapping). The Ground Stone Tools definition can also include symbolic items manufactured by pounding or abrasive motions (e.g., stone figurines, engraved plaquettes).

All these groups include many different types of artifacts that are typically classified mainly according to assumptions concerning the type of use, which ultimately can be tested through the identification and study of distinct use-wear traces.

Ground Stone Tools are a testimony of the most persistent and durable technological adaptation in human evolution, since their appearance stretches from the earliest evidence of human activity to the present day, across wide geographic areas around the world. Ground Stone Tools can preserve important evidence that allow the identification of a large variety of human actions. This aspect is very important to paleoanthropological research since these artifacts can preserve crucial information for the reconstructing, characterizing, and understanding the evolution of human behavior throughout time and space.

1.3. Geographic, chronological, and environmental context

As mentioned before, all case studies analyzed in this project are assigned to Middle Paleolithic contexts located in the Levantine region (fig.1). In this project, following Goring-Morris and colleagues definitions (Goring-Morris et al., 2009), the term Levant refers to a geographical region in the near East which is limited to the west by the Mediterranean Sea, east by the Zagros Mountains, south by the Sinai Peninsula, and north by the Anatolia Peninsula. This is one of the most accepted definitions for this geographic region and, therefore, the term used in this study.

The ecological characteristics of the Levantine region during the Middle Paleolithic had a major contribution in forming an exceptional setting marked by favorable conditions for human occupation in the territory. This area was characterized by a large diversity of natural environments in a relatively small area, including areas with levels of humidity favorable for the presence of very diverse flora and faunal resources.

Geographically, this region represents the main connection area between Africa and Eurasia, making this a favorable territory for the migration and contact between populations across the time. Its geographic location pushed this region to be considered by many authors as one of the main "hotspots" to be investigated and discussed in relation to human migrations, including migration during pre-historic times, namely during the Paleolithic periods. Those factors have been an element of attraction for many researchers along the years, aiming to study the possible contact between Neanderthals and Anatomically Modern Humans (AMH).

In terms of geology, the bedrock in the Levant is mostly composed by limestone, which creates conditions for the formation of many caves and rock shelters (Tomsky, 1991). These geological conditions also allowed many Middle Paleolithic sites to have relatively close access to abundant sources of flint. Other raw materials, such as basalt, are also available in some areas, for example in the fields of the Golan Heights, and the Nubia Sandstone (Shea, 2003a).

From the environmental point of view, this area today is very diverse, including Mediterranean climatic conditions in the western part, characterized by hot and dry summer, and cold humid winters, and large areas of deserted dry areas, such as the eastern zones (Blondel et al., 2010).

The vegetation present in the Levant is characterized by three major phytozones: a) Mediterranean woodland where the oak (*Quercus*) and terebinth (*Pistachia*) are dominant, b) Irano-Turanian steppe, characterize by the presence of wormwood (*Artemisia*) among other grasses, and c) Saharo-Arabian desert, where few sparse vegetation can be found (Zohary, 1972).

Paleoclimatic studies focused on pollen analysis suggest that the distribution of three phytozones followed the global climate alterations (Cheddadi & Rossignol-Strick, 1995; Horowitz, 1987; Weinstein-Evron, 1987). The beginning of glacial periods during the Pleistocene are associated with some increase in arboreal vegetation such as oak, pines and cypress, while the peak of glacial periods and interglacial are associated with an increase in herbaceous vegetation.

In terms of fauna, during the Pleistocene, the animal population in the Levant are composed by species from Africa and southern Asia, as result of approximately five million years of intercontinental faunal migrations (Tchernov & Tsoukala, 1997).

In present days only a tiny fraction of the animal diversity that occupied the area during the Pleistocene is still present. Nevertheless, it is still possible to find a relatively large population of animals such gazelles (*Gazella gazella*) and wild boars (*Sus scrofa*) today. The bird population are still considerably diverse, mainly due to the large number of migratory routes present in the region (Blondel et al., 2010).

Some of the largest animal species present during the Pleistocene in the Levant are already extinct, namely Aurochs and steppe rhino. Other large mammals, although not extinct, are no longer present in the region (e.g., elephant, hippopotamus, red deer, and hartebeest) (Blondel et al., 2010). Some large carnivores were also present in the region during the Middle Paleolithic, namely: leopard, lion, striped and spotted hyenas, and wolfs. In the Levantine Middle Paleolithic sites, it is also possible to find remains of other animals that still exist in the region (although in small populations), such as: ibex, wild boar, fallow deer, steppe ass.

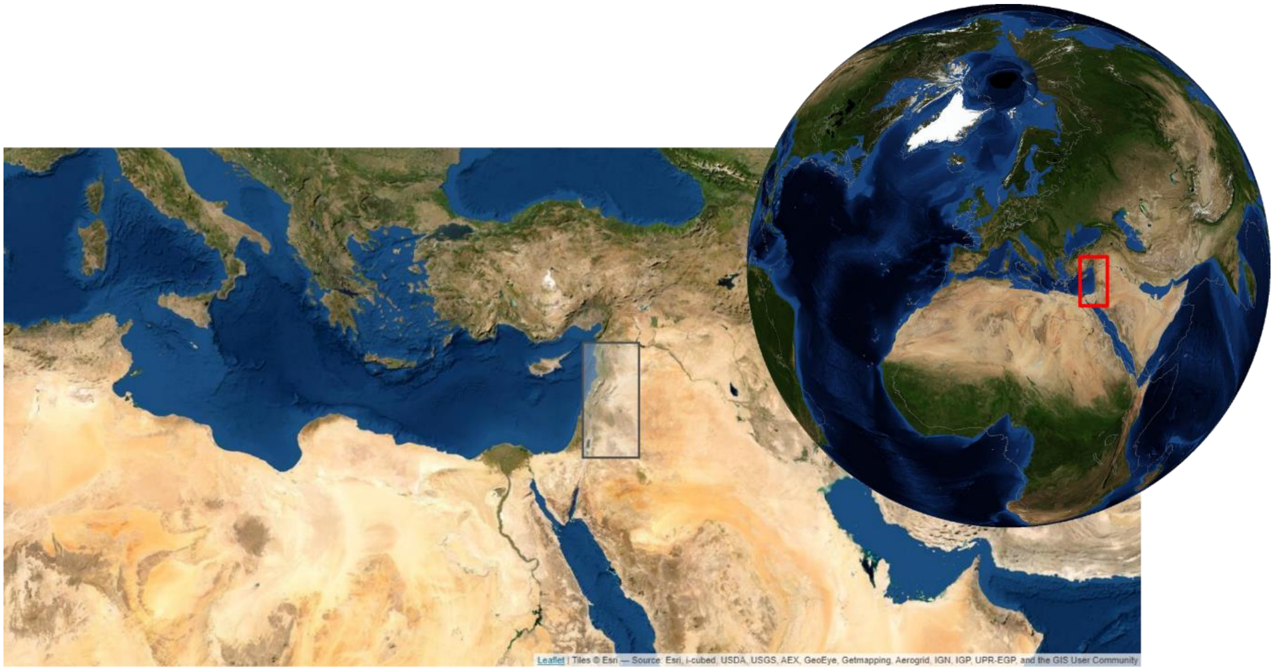


Figure 1: Geographic map indicating the Levant region.

1.4. The Middle-Upper Paleolithic transition: Neanderthals and Anatomically Modern Humans *meeting* in the Levant

The Levant is considered as the geographical area likely to have the earliest evidence of coexistence between Anatomically Modern Humans and Neanderthals. The possible interaction between these two populations is very challenging to decipher and understand from the archaeological record, in part due to the fact, that the artifacts left by both populations in the Levant cannot be easily distinguished as diagnostic evidence of one group or another. In addition, human skeletal remains with clear diagnostic features are present in only a very small fraction of the regions archeological record (Hovers, 2006).

The first discoveries of human remains in the cave of Zuttiyeh in Wadi Amud (Turville-Petre, 1927) together with the excavations in Tabun and Skhul caves in Mount Carmel (Garrod & Bate, 1937; McCown & Keith, 1939) were the trigger for a long debate about the co-existing occupation of the region by Neanderthals and Anatomically Modern Humans. The complexity of the research scenario in the region is as old as the first archeological interventions in the area, where European archeologists developed their first interpretations. Influenced by previous Middle Paleolithic European record and applying the French terminology for discoveries in the Levant. The results provided by the first excavations at Tabun cave brought a new perspective to the study, marked by a large level of complexity on the Middle Paleolithic discussion, where skeletons with physical characteristics similar with the European Neanderthals were discovered in *Tabun layer C*. However, a jaw with modern human characteristics was identified 90cm stratigraphically below, with this scenario in terms of stratigraphic order totally unexpected due to the previous experience with the stratigraphy of Middle Paleolithic European sites. In addition, the characteristics of this discovery was also associated with the remains found at Skhul cave. Conversely, the described sediments of Tabun C led to some interpretations of a possible burial from the posterior occupations. The controversy of the Tabun cave stratigraphy survived for decades.

In general, the first interpretations consider that archaeological deposits from Tabun and Skhul caves contain two different hominin groups (Neanderthals and Anatomically Modern Humans) that existed roughly contemporaneously. However, after a few years of excavations, McCown & Keith published the results, interpreting the human remains of the Mount Carmel excavation as being part of one Levantine species of “Neanderthals” considered to be distinct of the ones identified in

Europe. This findings were temporarily denominated as *Paleonthropus palestinensis* (McCown & Keith, 1939).

Nevertheless, the variability among these hominids, and the features associated to modern morphological aspects, led to the revised definition of that group as “proto-Cro-Magnons” (Howell, 1951; Vandermeersch, 1981a).

Contemporaneous excavations in Qafzeh cave also contributed to this discussion, bringing to light several human fossils with characteristics that were associated with the “classic Neanderthals” and modern Homo sapiens (Vandermeersch, 1981b).

Initially the human remain finds from Qafzeh and Skhul were presumed to be no older than 40ka BP or 50ka BP, an assumption based on “modern-looking” remains, and the possibility of the fossil having been buried in Mousterian deposits. However, during the decades of the 1980s and 90s, due to developments in radiometric dating techniques, new interpretations were drawn (Bar-Yosef, 1998; Bar-Yosef & Meignen, 2007). The remains associated with Tabun type C from Qafzeh and Skhul were actually dated prior to the Last interglacial, with Thermoluminescence dating giving results of approximately 102 Ka BP (Mercier et al., 1993), and the Neanderthals from Kebara and Amud dated between 70ka BP and 50ka BP. (Rebollo et al., 2011; Valladas et al., 1999)

The combination of controversial stratigraphic interpretations of Tabun cave stratigraphy, lithic interpretations based on typological assumptions, and discrepancies between dating results from different techniques were the main factors for multiple changes in the interpretations of the Middle paleolithic chronostratigraphic sequence and consequent human occupation in the region.

During the past decades, several major models had been proposed to explain the occupations in the region, such the Multiregional Hypothesis (Wolpoff et al., 1994) and the Out of Africa/ Replacement model (Hammer, 1995; Howells, 1976). The regional continuity model suggests that modern humans evolved in different regions through in-situ regional populations, which had locally grown following the Lower or Middle Pleistocene dispersals of *Homo erectus* from Africa (Clark & Lindly, 1989; Wolpoff et al., 1989, 1994; Wolpoff & Lee, 2001).

However, most of the recent nuclear and molecular studies seems not to support the Multiregional model (Clark & Lindly, 1989). Based mainly on genetic studies, the currently emerging picture for the late hominin populations suggests that at least over the last 250 ka, Anatomically Modern Humans and Neanderthals were all part of a single metapopulation, rather than as previously perceived as several competing species. This model has gained strength during the recent years, after studies on recent human remains from Denisova Cave led to the finding of another element of the metapopulation, named the Denisovans (Ackermann et al., 2016; Fu et al., 2015; Harvati et al., 2019; Hershkovitz et al., 2018; Kuhlwilm et al., 2016; Pääbo, 2015; Reich et al., 2010; Sankararaman et al., 2014; Sawyer et al., 2015; Zilhão, 2006).

To explain the identified cultural dissimilarities, different hypothesis has been suggested, such as the "Weak garden of Eden" hypothesis. This hypothesis assumes the possibility of a first separation of population groups, occurring around 100ka, with another episode of major growth occurring around 30ka. This hypothesis associates the isolation of populations with climatic events such as the eruption of the Toba Volcano at 73Ka BP (Gathorne-Hardy & Harcourt-Smith, 2003). Hence, the rapid expansion of isolated populations according to this hypothesis can be explained as the result of new cultural inventions and innovations due to different ecological conditions and constraints (Rampino & Self, 1992).

Following these ideas, the "Middle/Upper Paleolithic Revolution" is likely to not be related with biological changes, but rather with series of inventions and innovation that, due to demographic and ecological dynamics, led to a technological revolution.

For some authors, such as Bar Yosef (2000), if there is a clear discontinuity on the technological strategies on the production of stone tools between the Middle and Upper Paleolithic, then no biological continuity can be proposed. However, against this model, John Shea (2014) strongly criticizes the lithic approach as the main evidence when investigating hominin evolutionary processes in the context of the Later Middle Paleolithic of the Levant. To Shea, the approach adopted in terms of lithic analysis can lead to a misinterpretations of the social intimacy and evolutionary relationships between Neanderthals and Anatomically Modern Humans (Shea, 2014). Other point strongly criticized in this debate, is the use of a single site and its sequence (Tabun Cave) as a model for the characterization of the industries identified in the entire region. This is especially due to the fact, that Tabun Cave has been marked by several controversies in terms of the stratigraphic interpretation and dates.

Nevertheless, the major technological groups were created and apply for the whole Levant region based on the Tabun Cave stratigraphy. These include the Mousterian, organized in 3 main phases: Phase 1- Tabun D type, Phase 2- Tabun C type and phase 3- Tabun B type with this characterization mostly based on the distribution of lithic typology frequencies (Copeland, 1975). Tabun D is characterized by the production of elongated blanks, and short Levallois blanks, often of triangular shape. Tabun C type is characterized by the dominance of oval-rectangular short blanks, and the common production of sub-oval and sub-quadrangular flakes removed from Levallois cores through centripetal or bi-directional knapping strategy. The Tabun B type is mainly characterized by the production of sub-triangular short blanks, mainly flakes and points, mostly removed from unidirectional convergent Levallois cores (Bar-Yosef, 2000a).

The interaction between Neanderthals and Anatomically Modern Humans in the region is far from being fully understand, despite the multiple hypothesized scenarios proposed based on aspects of demography, ecology and biology, the fact is that the lack of skeleton remains from the Late Mousterian and Initial Upper Paleolithic represent a major obstacle to a direct interpretation of the link between the behavioral repertoire and the hominins.

Since in most archaeological contexts, the material remains are the most abundant footprint of past humans, it is our obligation to extract the maximum information from them, in order to contribute to a detailed characterization of past communities. This is in many cases the only bridge available to get closer to understanding the possible similarities and differences between the different hominins groups and interpreting the variability within and between lithic industries. Extracting the maximum information as possible from the artifacts means that technology and typology should be taken into consideration, as well as multidisciplinary approach focused on understanding tools function *per se* (i.e., use-wear studies). For investigating the routines of the populations, it is fundamental to characterize the tools used for daily tasks, and within this topic, Ground Stone Tools can play a major role since they can be in some cases the only testimony of different aspects of these societies, namely in terms of food resources management, technology, and symbolic behavior.

1.5. Subsistence and settlement patterns during the Middle Paleolithic

The subsistence patterns in the Levantine Middle Paleolithic are also an area of interest in current research. Phytoliths studies, such as those undertaken in Amud Cave, suggest that the exploitations of plants during the Middle Paleolithic was much more intensive than previously argued (Madella et al., 2002). Although evidence for plant consumption during the Middle Paleolithic is very rare, it is important to consider that the preservation of this type of evidence is usually dependent on very special preservation conditions, with this aspect easily leading to a biased interpretation of the archaeological record. Nevertheless, due to the recent developments in microscopic and residue analysis it is now possible to apply a new and holistic approach to lithic artifacts such Ground Stone Tools, which can represent a chance to observe evidence of vegetal exploitations even when only the lithics "survive" in the archaeological record (e.g., Madella et al., 2002).

Archaeological data from the sites located in the Levant has suggested well-developed large-game-hunting capabilities and strategy, related to the process of hunting, and transporting the meat to the sites, including differences in transportation methods according with different species. As an example, in Misliya Cave, evidence shows that humans systematically hunted prime-aged ungulates and transported to the site the complete carcass or not, depending on the size. At the site, humans roasted the meat, and cracked the long bones, in order to extract the marrow (Yeshurun et al., 2007).

Another major focus in current Levantine research is the regions occupation dynamics, namely the different patterns in terms of caves and open-air site occupations. Perfect location solutions are not absolute, since every environment is composed by many variables that represent advantages and disadvantages for human occupation and exploitation. Locations for occupation are determined in relation with the specific group demography, social structure, mobility options, and planned activities. These different locations leave settlement patterns that archeologists attempt to reconstruct from the material records (Hovers, 2017).

Ethnographic hunter-gatherers typically conduct diverse activities outdoors. Despite the fact that several activities can be conducted in caves, such as: habitation, socializing, food sharing, fire making, or production of tools, there is a range of activities that can only be performed in open landscape such as: harvesting and procurement of animals or plants for food, fuel for fireplaces, or raw materials for making tools (Binford, 1980; Habu & Fitzhugh, 2002).

Despite factors such as these that can be assumed to lead to more differences in the archeological record, in fact in some elements, such as technology, it can be very challenging to define distinctive patterns. For example, new data from sites such as Ein Qashish, show that a clear distinction from caves and open-air site function is not totally clear (Malinsky-Buller et al., 2014b). From the technological perspective, several characteristics are shared by both cave and open-air sites, namely the strategies for raw material management that combine provisioning on place with on-site knapping, transport of blanks and retouched items, and a relatively low investment in blank recycling (Malinsky-Buller et al., 2014b).

However, in this discussion, specific items such as Ground Stone Tools highlight that other complementary aspects should be explored in order to characterize the possible differences, since the frequencies of those findings are very different when comparing open-air and cave sites. While in cave sites it is very rare to find any Ground Stone Tools, in open-air sites the finding of some Ground Stone Tools is relatively common. However, lithic assemblages with large frequencies of Ground Stone Tools are very rare in both caves and open-air sites. In this context, the site of Nesher Ramla can be considered an exception, where a large number of Ground Stone Tools were discovered.

Ground Stone Tools, apart from other possible technological functions, are frequently associated with subsistence practices, namely in the form of tools used for processing food, animal and/or vegetal. In this scenario it is difficult to explain why this type of activity would not also be suitable with cave environments. However, in this stage of the research on the topic the possibility of some bias on the research should not be totally discarded as a possible explanation for those differences in terms of Ground Stone Tools frequencies.

1.6. Ground stone tools in the Middle Paleolithic of the Levant

In the Levantine Middle Paleolithic, Ground Stone Tools have been reported from multiple sites such as: Nesher Ramla, at ~170-80ka BP (Prévost & Zaidner, 2020; Zaidner et al., 2018), Far’ah II, at ~49-47ka BP (Gilead & Grigson, 1984; Goder-Goldberger et al., 2020) Ein Qashish, at ~70-55 ka BP (Been et al., 2017; Ekshtain et al., 2019a; Hovers et al., 2008; Malinsky-Buller et al., 2014b), Quneitra, (ca. 55 Zineni ESR in Goren-Inbar, 1990; Oron and Goren-Inbar 2014 for the TL), and Umm El Tlel (c. 70 BP. Boëda et al., 2008; Griggo et al., 2011). In the case of the open-air sites of Hummal and Quneitra, Ground Stone Tools have been interpreted as a tool used for knapping (Hauck, 2010) and animal bone processing (Hovers et al., 2008; Oron & Goren-Inbar, 2014). Recent studies at Qesem Cave have also shown that several limestone tools (i.e. spheroid) are associated with bone breaking activities at the site (Assaf et al., 2020).

Although some preliminary and general interpretations have been suggested, a detailed knowledge about the significance of the Ground Stone Tools variability and function in the Middle Paleolithic of the Levant is still very limited. In addition, the association of this artefactual group with different types of settlement lacks research, compromising a better understanding of the role of Ground Stone Tools in Middle Paleolithic human subsistence and settlement dynamics. One favorable aspect for the research on Ground Stone Tools in the Levant is the frequent good state of preservation of the archaeological record. This is also clearly evident from the lithics and faunal remains recovered at the different sites. This indicates the likely potential for good preservation of crucial evidence needed to reconstruct tool use, such as use-wear traces and eventually residue remains.

In general, from the archaeological record, Ground Stone Tools have been mainly recognized in open-air sites, while their presence seems to be very rare in caves and rockshelters. Nevertheless, the reasons for this distribution pattern are still unknown. It may either be: 1) due to a research bias related to the difficulty in the identification of these artifacts, which are mainly represented in coarse-grained materials and in many cases are not intentionally modified by knapping, or 2) related to the specific function of this material and their presence in association with different types of site, which is likely to reflect different human behavioral strategies.

To understand the complexity of the Middle Paleolithic in the Levant it is crucial not only that more sites can be dated with recent techniques but also, more functional studies in the different assemblages are needed, to allowed comparisons between sites that go further than the simple typological approach, to understanding tools functions that are crucial to characterize past communities.

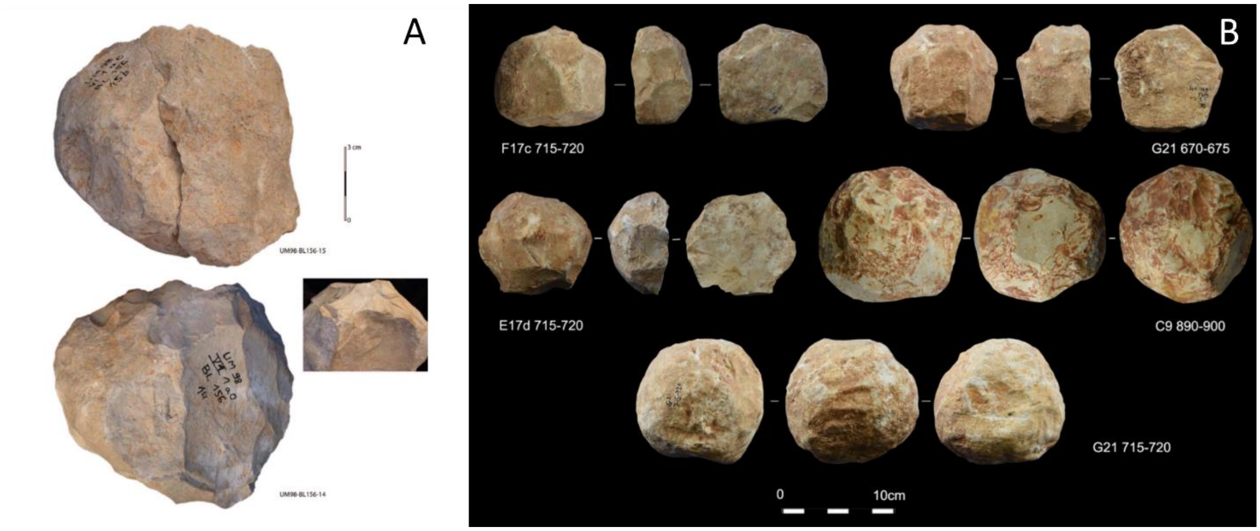


Figure 2: Examples of Limestone Ground Stone Tools tools found in the Middle Paleolithic of the Levant: A) Hammerstone, Umm el Tlel (photo from Griggo et al., 2011) *and b) Hammerstones, Qesem Cave (adapted from* Assaf et al., 2020*).*

1.7. Understanding lithic tool's function

Understanding a tools function has been always one of the main goals in prehistoric studies. In many of the prehistoric archaeological contexts, lithics are often the most abundant and, in some cases, the only testimony of past humans. This reinforces how important it is to understand their function to reconstruct past human behavior. Through human history, tools have been a key vehicle of hominin adaptation to the landscape (Foley & Lahr, 2003; Holdaway & Douglass, 2012; Stout et al., 2011).

The way archaeologists interpret lithics, and in particular their function/s, has gone through several transformations across time. For many years, functional interpretation relied deeply on assumptions based on artifact's morphology, and frequently, typologies were created where some tools were named in part according with specific assumed functions (e.g., scrapers, or points). However, the development of lithic tool typologies was crucial to organize and report the findings in a way that in most cases were understandable by the broader archeological community (Bordes, 1969; Tixier, 1963). Seeking to understand the mechanisms of tools production and their implication to the human evolution, for decades archeologists have been using typological systems to organize the lithic variability, but also in combination with technological analysis (Adams, 2002; Bicho, 1992; Boëda, 1993; H. L. Dibble et al., 2008; H. Dibble & Rolland, 1992; Goren-Inbar, 1990; Hovers, 2009; Malinsky-Buller et al., 2014b) and analysis of the raw materials procurement and management (Abrunhosa et al., 2019, 2020; Mangado Llach, 2002; Paixão et al., 2019; Pereira et al., 2016, 2017; Pereira & Benedetti, 2013).

Starting in the twentieth century, lithics studies gradually started to include the use of microscopic techniques to identify and document characteristic macro- and micro-alterations on the tools surfaces, that were explained as the result of the contacts with specific materials (Semenov, 1957). and this approach has remained in constant evolution during the current century (Bicho et al., 2015; Dubreuil et al., 2015; Dunmore et al., 2018; Marreiros et al., 2015). Through the years, microscopic techniques have evolved, allowing observation through higher magnifications, including equipment with much higher image quality , and later the possibility to also collect quantitative data through technologies such as 3D laser scanning methods (Evans & Donahue, 2008; Marreiros et al., 2020; Pedergnana et al., 2020; Pedergnana & Ollé, 2017; Stemp & Chung, 2011).

The application of microscopy on lithic studies has also been used as a tool to analyze different types of residue remains, that in combination with use-wear studies, is a powerful holistic method to reconstruct tool use and make inferences about past human behavior (Cnuts & Rots, 2017; Fullagar, 2006; Hayes, 2015; Rots et al., 2016).

Understanding tool functions is highly dependent on the development of experiments. In general, experiments seek to replicate different type of motions (e.g., impacts, grinding, scraping) in order to observe the physical alterations that those actions will generate on the surface of the tools. Additionally, the effect of different contact materials (e.g., flint, bone, plants) used in those actions can be studied. The characteristics of those alterations are used as proxy to analyze and characterize the use-wear present on the artifacts found in the archaeological record (Arrighi et al., 2020; Coles, 1979; de la Torre et al., 2013; Nonaka et al., 2010).

There are many different approaches on experimental archaeology, and the procedure should depend on research questions (Eren et al., 2016; Lin et al., 2018). Here, it is possible to divide archaeological experimentation on tool technology and function in two major groups: 1) manual or first-generation experiments and, 2) mechanical or second-generation experiments (*sensus* Marreiros et al., 2020).

In most cases, manual experiments aim to reproduce human actions to understand which major variables are involved in the formation of use-wear by and during different activities, including worked materials and motions. This approach also tries to understand the level of difficulty involved in the use of a determinate tool to perform a given task. This approach has many limitations in terms of variable control but is a crucial step to help to formulate more specific questions that will be fundamental to design mechanical or second-generation experiments.

Mechanical or second-generation experiments are an experimental approach that seeks to isolate and control the variables involved in some actions, in order to understand which specific factor is involved in the formation of wear. This approach normally uses mechanical devices to perform a specific task under controlled, and therefore reproducible, conditions. The two approaches should be complementary to bring solid data, which can be tested and reproduced. Solid experimental results are the foundation for the development of reference collections that play a crucial role concerning the functional analyses of archeological tools.

In this research, with the goal of understanding the tools function in the selected case studies, the artifacts were analyzed following a workflow that combines different scales of observation (macro and micro), and the combination of qualitative and quantitative analytical procedures. Use-wear analysis in this work was supported by an experimental reference collection developed specifically to understand use-wear traces formed on limestone materials, since it is the raw material that characterizes the large majority of the artifacts included in this study.

2. Brief history of research

2.1. The Middle Paleolithic research in the Levant

Archaeological research on the Pleistocene of the Levant has a long and complex story of investigations. The first projects in the region date back to the first half of the twentieth century. The large number of human fossils with an extraordinary level of preservation recovered in the early years of archaeological research in the region, namely at site such as Wadi Amud (Turville-Petre, 1927), Mount Carmel, Tabun cave, and Skhul cave (McCown & Keith, 1939), brought the attention of the scientific community to this region. These discoveries opened into multiple debates on the biological, technological, and cultural interactions between Neanderthals and Anatomically Modern Humans populations in the region. In this debate, during the last decades, two main possibilities have been discussed to explain major changes in the archeological record: either 1) local continuity and innovations of the hominin groups from Middle Paleolithic to Upper Paleolithic, or, 2) the arrival of new populations carrying new technological and consequential cultural input in the region.

In this discussion, Tabun Cave has an extraordinary importance to the history of the research in the Levant, since most of the lithic variability for the Paleolithic record in the region was classified according to the typologies observed in Tabun Cave (Tabun types), with the Tabun osteological remains a very active part of the debate about the contact and replacement of Neanderthals by Anatomically Modern Humans in the region, as mentioned previously in section 1.4.

It is important to mention that the interpretation on the chrono-stratigraphic sequence in Tabun cave has been very controversial, due to the possible earlier simplification of a much more complex stratigraphy. Discrepancies between dates obtained via different dating techniques have also contributed to and increased the difficulties of interpreting the different techno-complexes (fig.3).

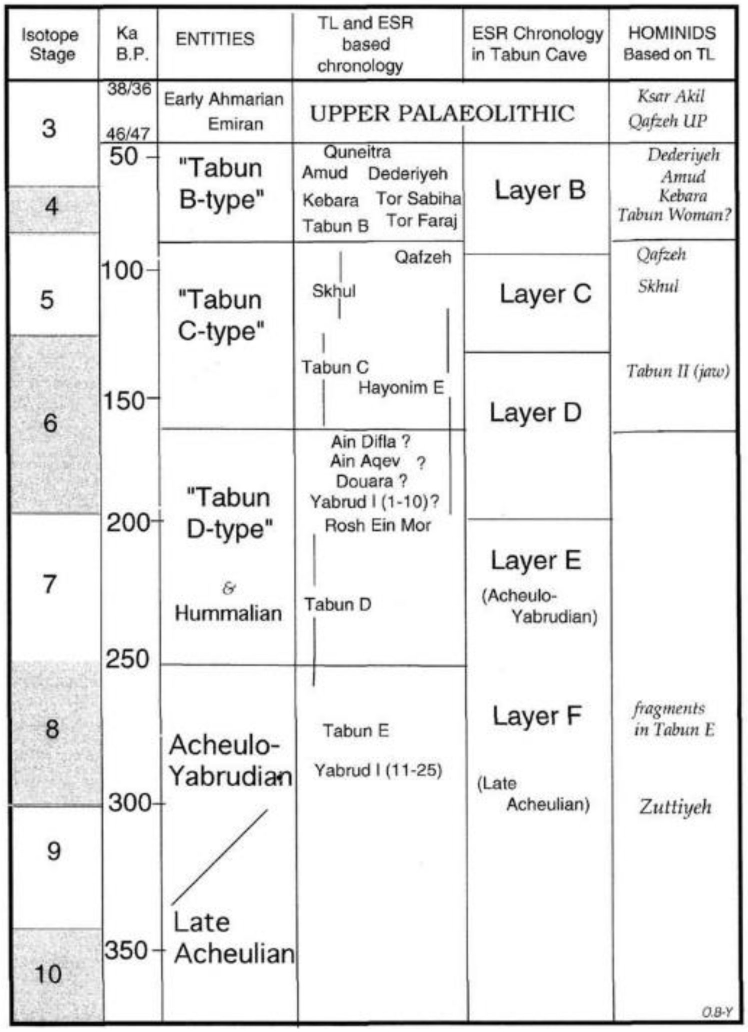


Figure 3: Chronological chart of the Paleolithic of the Levant (after Bar-Yosef, 2000).

After the Second World War, the rate of archaeological research in the Levant region increased considerably, namely with a large number of new excavations at sites such as Douara cave and Jerf Ajla in Syria (Akazawa, 1974; Hanihara & Sakaguchi, 1978; Julig et al., 1999), and also excavations in Adlun, Naam´e, and Ras el-Kelb in Lebanon (Copeland, 1998; Fleisch, 1970; Roe, 1983). During the same period, Israel witnessed numerous excavations of Middle Paleolithic sites, including the renewed excavation of known sites, such as Tabun cave (Jelinek, 1981), Amud (Chinzei, 1970; Suzuki & Takai, 1970), Kebara (Bar-Yosef & Meignen, 1988) and Qafzeh (Vandermeersch, 1981a).

After the decade of 1960´s, the research in the Levant increased, with renewed excavations in Qafzeh cave (Hovers, 2009) and Kebara Cave (Bar-Yosef & Meignen, 1988; Schick & Stekelis, 1977). New projects in Amud and Dederiyeh caves (Chinzei, 1970) also led to the discovery of new human fossils. During those decades, there was an increasing effort to recover larger proportions of the lithic and faunal remains, including small fragments that were often discarded by previous excavations (Shea, 2003b).

After the 80´s, new dating methods shed new light to the Levantine research, by systematically implementing a multidisciplinary approach, including lithic studies, faunal, and sedimentological studies, and also by adopting new methods, such on TL, ESR, and U-series techniques (Bar-Yosef, 2000b; Shea, 2003b). In this context, renewed excavations in Kebara cave between 1982 and1990 provided a new and large contribution to the research in the region, with clear goals focused on: 1) attaining new dates for the archaeological deposits, 2) studying in detail the stratigraphy and the formation processes of the site, and 3) analyzing extensively both lithic and faunal remains, including all evidence on taphonomic processes. During this period, the project at Kebara cave also focused on the study on the spatial distribution of different remains in the deposits, such as ashes, hearths, lithics, and bones, and looked to find more human remains in order to study their contexts in a detailed way (Bar-Yosef & Meignen, 2007) .

In the last years, several more sites have been discovered and excavated due to massive construction projects in northern Israel and natural resources exploitation, particularly open-air sites, such as the example of the open-air site of Nesher Ramla (Zaidner et al., 2018) and the site of Ein Qashish (Hovers et al., 2008).

In general, the methodological approach used at these sites has become gradually more multidisciplinary, with large research teams as result of international collaborations. This has allowed the development of diverse detailed studies in all sectors of the archaeological research, particularly in terms of sedimentology, faunal research and lithic studies, with this being focused not only on technology and typology, but also on tool function, and the application of use-wear and residue analyses in several cases.

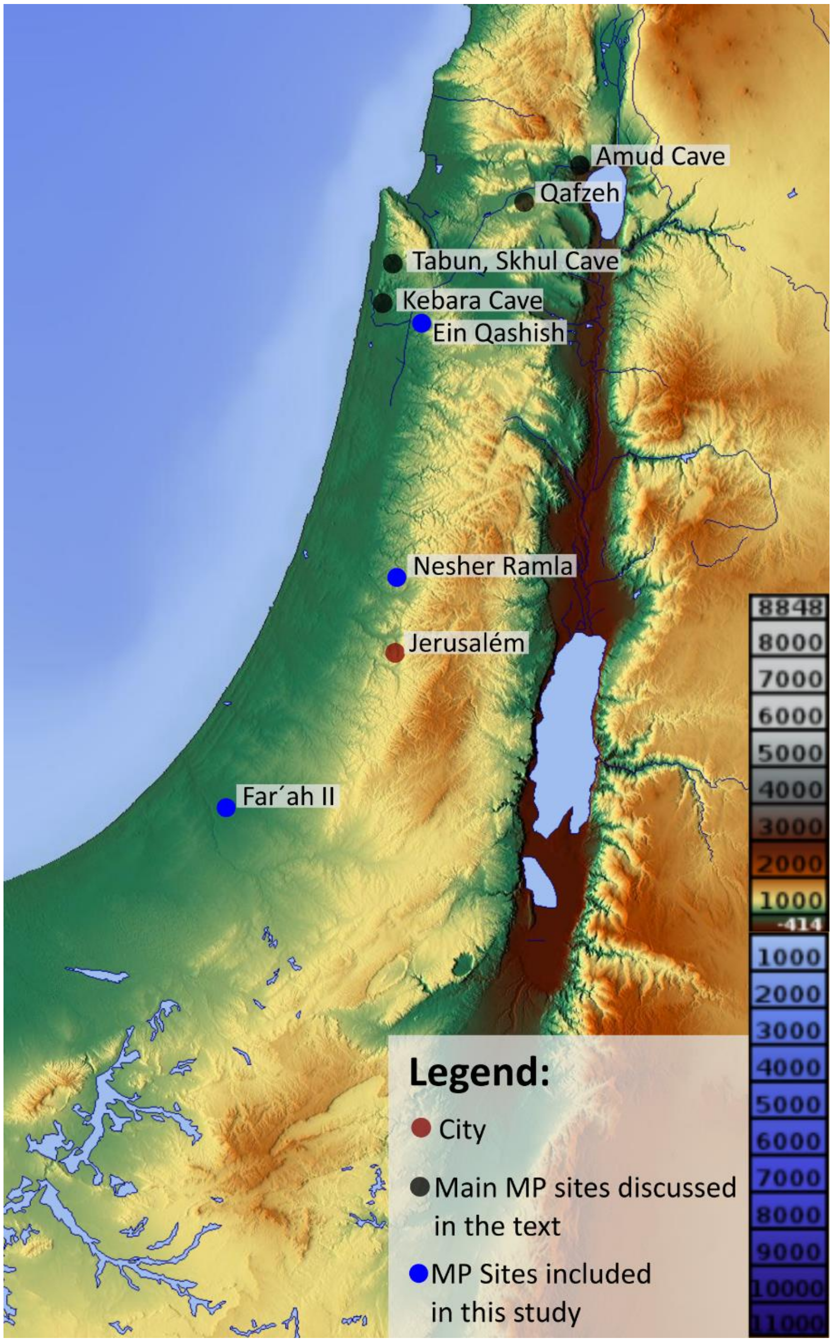


Figure 4: Map of the geographic area of study with the location of the main Middle Paleolithic sites discussed in the text.

2.2. The development of use-wear studies

Understanding how tool production and use change through time and space is one of the main research areas for investigating the evolution of human behavior. Through combining technological, use-wear, and residue analysis, it is possible to bring together major information about tool specific tasks, resource exploitation, and the patterns of human behavior (Dubreuil et al., 2015; Marreiroset al., 2020).

Although the recent years have brought great developments and changes to the use-wear discipline, it is important to keep in mind that all the methodological developments are "*standing on the shoulders of giants*", since the basis for attempt to infer about tools function has a long history on the archaeological research.

Some of the first functional interpretations of stone tools were made more than a century ago. In the late nineteenth century and beginning of twentieth century, some researchers started making the effort to identify and understand evidence of lithic tools function, mostly by describing the artifacts surfaces and analyzing macro use-wear traces. An example of this "genesis", which one day would become known as "functional analysis", was the work developed by researcher's in the end of 19th century and beginning of 20th century (Curvew, 1930; Evans, 1897; Pfeiffer, 1912).

In the 1930´s, Sergei Semenov started developing research that would become the "foundations" of functional analysis as we know it today. Semenov introduced new methods to describe the damage observed on the active areas of lithic and bone tools, thought the use of stereo microscopy (<100x optical magnification), and complemented with experimental reference collection, together with developments in terminology. This research culminated in his PhD thesis "Prehistoric Technology" (Semenov, 1957). The work developed by Semenov follows the Marxist perspective that characterized Russian archeology during the twentieth century (Trigger, 2006), that saw technological characterization of archeological artifacts as a fundamental proxy to understand the economic and social organization of the past populations (Childe, 1936; 1942).

Semenov's work was a major trigger for the exponential developments of functional analyses that relied strongly on the combination with the development of experiments as a fundamental proxy to interpret use-wear traces. The published work of Semenov was translated from Russian to English and brought to Western Europe during the decade of the 1960s (Semenov, 1964b). This is associated with the development of a new methodological perspective in the archeological theoretical agenda, named the "*New Archeology*", where interdisciplinary analytical methods were gaining strength, and the archeologist was seen as a social scientist, where one of the main objectives is to understand the human technology, economy, social behavior and organization, as reflected by the tools function (Binford, 1962). In this sense, the importance of use-wear analysis was increasing, since it was seen as a direct way to reconstruct the social and cultural past human behavior (Redman, 1973; Sterud, 1978).

The pioneering work of Semenov was an important methodological step in functional studies, by promoting the use of microscopes to analyze archeological tools. However during this time, studies were mainly focused on describing attributes such as edge angle and profile, edge damage, and some diagnostic fractures, through the use of stereo-microscopes where the magnifications in most cases do not reach more than 60x (Kamminga, 1982). It was in the beginning of the decade of 1980´s, that the high-power approach was introduced, where the microscopic observations reach a higher level of magnification (>100x) by adopting the use of reflected light microscopy (Keeley, 1980). This approach claimed that by using high levels of magnification in the analysis, it would be possible to go further into the identification of the type of material that was in contact with the tool during its use (e.g., wood, shell, bone). Beside the magnification of analysis, other issues were strongly debated during the last decades of methodological development in use-wear studies. One of the hot methodological topics is the need or importance of applying quantitative methods on use-wear analyses, with the main goal of reducing analytical subjectivity, and to produce data that can be statistically compared with a higher mathematical precision. The first big call of attention for this topic dates back to the 1970´s, and was the main topic discussed in the publication "Technique and methodology in microwear studies: a critical review" (Keeley, 1974a).

During the last years, it was possible to identify an exponential increase in research efforts to apply quantitative methods to the functional studies, both at the macro and micro scale of analysis. At the macro scale the development of technologies of light structured and laser scanning have been used by the archeologists in combination with GIS computing to analyze with a high level of precision the surfaces of the materials, by considering different surface parameters such as roughness and morphometry (Benito-Calvo et al., 2018; Caricola et al., 2018; Caruana et al., 2014; de la Torre et al., 2013; Zupancich & Cristiani, 2020).

At the micro scale of analysis, the use of 3D confocal microscopy have been adopted in order to characterize the micro texture of the tool surfaces, namely to identify and characterize the different types of micro polish formed by distinctive types of action and contact materials (Calandra et al., 2019; Evans & MacDonald, 2011b, 2011a; Marreiroset al., 2020; Martisius et al., 2018)

During the last decades, lithic studies has been marked by an exponential grow in functional studies that take in consideration the potential for use-wear preservation, but also the possibility for organic and inorganic residues preservation. These developments also have been marked also by a spatial attention to analyze the artifacts with high resolution approach and with an increasing application of quantitative methods at different scales. (Bordes et al., 2018; Dubreuil et al., 2015; Fullagar, 2006; Langejans, 2010, 2011; Pedergnana, 2020; Wadley et al., 2004; Zupancich et al., 2016).

The exponential growth of the archaeological community dedicated to use-wear studies is a very positive aspect that strongly contributes to continuous advances in the functional studies. This aspect is reflected in 3 major ways: a) an increasing number of publications in international scientific journals b) the increased contribution of use-wear topics in general international conferences, and c) an increasing number of participants in conferences organized by associations fully dedicated to topics related to use-wear (e.g., Association of Archaeological Wear and Residue Analysts, Association for Ground Stone Tools Research).

2.3. The Ground stone tool research

Ground Stone Tools are an artefactual group that play a major role in several of the major debates on the evolution of human behavior, particularly in its relation with the natural resources of the landscape. As mentioned before, this type of tools can represent a powerful source of information to explore evidence of use of many products that can be a direct link to understand major behavioral aspects.

From the chronological point of view, some types of tools, such as anvils, hammerstones and pounders, have been documented in several early prehistory contexts (Goren-Inbar et al., 2002; Leakey, 1971; Willoughby, 1987). Other types such as grinding elements (e.g., hand-stones), have their early appearance in the early Middle Stone Age in South Africa (Klein, 2009). Mortars and pestles have been documented in European Upper Paleolithic contexts (Klein, 2009) and from the Southwest Asian Early Epipaleolithic (Beaune, 2004; Semenov, 1964a). The general tendency is that the frequency within the assemblages and level of technological and morphometric standardization dramatically increase during the later periods (Cohen-Belfer & Hovers, 2005) .

Many researchers have demonstrated in their extensive studies dedicated to the topic of Ground Stone Tools, that this artefactual group can be very different in terms of the tools’ raw materials and in terms of use, depending on its chronology and geographic distribution (Dubreuil et al., 2015). In fact, some of the most extensive works dedicated to Ground Stone Tools include studies of archaeological assemblages from Asian contexts (Wright, 1991, 1992), America (Adams, 2002) and Europe (Beaune, 2000).

In terms of technology, it is crucial to mention the importance of these tools in the origin and developments of percussive technology. The well documented use of tools among primates has led some researchers to suggest that understanding this type of tool use by primates could be one of the keys to understanding the development of complex percussive techniques in human evolution (Benito-Calvo et al., 2015; Carvalho et al., 2008; Mercader et al., 2007).

Research on Ground Stone Tools is also fundamental to the in detail characterization of different aspects related with knapping activities, namely the management of hard hammerstones, lithic retouchers, and the origin of new knapping techniques such the bipolar debitage (Byrne et al., 2016; Vergès & Ollé, 2011)

The analysis of Ground Stone Tools has also been contributing major information about different aspects related to the diet of past human communities. In this topic, Ground Stone Tools studies play a major role in answering questions on the “*what*” and “*how*”. What products were consumed? How were those products processed? In many situations, Ground Stone Tools can preserve in their surfaces traces of use-wear and/or residues remains as the only evidence for consumption of perishable elements (e.g., vegetal remains) (Atchison & Fullagar, 1998; Florin et al., 2020; Hayes, 2015; Revedin et al., 2010). At the same time, Ground Stone Tools can also contribute to explaining how different products were exploited (e.g., marrow extraction from bones; nut cracking; grinding seeds) (Aranguren et al., 2007; Assaf et al., 2020; Goren-Inbar et al., 2002).

In same contexts, Ground Stone Tools can also bring information to identify and characterize the processing of ochre (Hodgskiss, 2020). In some cases the presence of ochre can be associated with technological aspects such processing hide (Dubreuil & Grosman, 2009), however in some specific cases, the identification of ochre processing can also be associated with symbolic behavior (Hovers et al., 2003).

In the last years, the studies focused on Ground Stone Tools have been crossing a phase of exponent development, partly due to the application of computer and automated technologies that have extended the application of quantitative methods. As an example of this new research phase there is exponential growth in terms of publications that include in their works-flows the application of 3D technology for the analysis of Ground Stone Tools (Arroyo & de la Torre, 2020; Benito-Calvo et al., 2015, 2018; Caricola et al., 2018; Caruana et al., 2014; Cristiani & Zupancich, 2020).

2.4. Experiments in Ground Stone Tools studies

Since use-wear studies need strong support from a reference collection, experimental archaeology has a crucial importance in this field. Different types of experiments have been developed since the beginning of studies on past human tools function, naturally with different research questions, but in general with the same common aim of generating data that supports the identification and interpretation of physical alterations in the archaeological materials. Experiments will generate data in different forms such as: materials, images, or residues. This set of data is commonly called “reference collection” or “reference libraries”(Hayes et al., 2018).

Reference collections focus on the physical alterations that can be associated with different types of activities and contact with different materials, but can also be more focused on the effects of post depositional factors, namely the influence of chemical processes such as dissolution (Mansur, 1997), or physical processes such as the influence of post depositional mechanisms (Dubreuil, 2002).

Different types of experimental approaches have been developed through this time, including manual and mechanized, or exploratory and systematic (Adams, 2014; Dubreuil, 2002; Richard Fullagar et al., 2012; Keeley, 1980; Xie et al., 2019). The large majority of experiments that focused on Ground Stone Tools until now, were manual experiments that made efforts not only to generate experimental use-wear that can be compared with archaeological data, but also to evaluate the efficiency of the tools to perform a certain task (Samuel, 2010; Valamoti et al., 2013). Although manual experiments can lack in the quantification some important data, they provide a qualitative assessment that are, in most of the cases valid and crucial to explore the past technical systems that past communities developed to process different types of products (e.g., cereals, ochres, and bones).

The mechanical approach has been developed in recent years and assumes a huge importance to generate quantitative and reproducible data while also understanding the specific mechanisms involved in the use-wear formation. Several experimental programs have already started developing this area, making efforts to control and isolate variables and generate quantitative comparable data (Delgado-Raack et al., 2009; Iovita et al., 2014; Marreiros, Pereira, et al., 2020; Pereira et al., 2017; Procopiou, 1998; 2004, Paixão et al., 2021). In this debate, different approaches to archaeological experimentation are not organized in hierarchical levels of importance, instead they should be adopted according to the specific question, and complementary for a better understanding of the different aspect related with use-wear.

To understand Ground Stone Tools function, beside the need to consider the possible natural processes that can generate alterations on the surfaces of the materials, it is also important to distinguish the traces related with manufacture or preparation, as well as traces related with tool use.

In what concerns experimental studies directly focused on Ground Stone Tools, it is important to mention that several researchers have been making significant efforts on developing large reference collections around the world, namely in North America where a large amount of experiments performed by Adams have directly contributed to the production of one of the essential manuals in Ground Stone Tools studies (Adams, 2014; 2002). In other regions of the world, several other projects have dedicated an important part of their time to developing experiments (Adams et al., 2009; Beaune, 2000; de la Torre et al., 2013; Dubreuil, 2002; Dubreuil et al., 2015; Hayes, 2015; Wright, 1991; 1992).

Although significant progress has been made in this field during the last year, there are many gaps of knowledge that still need to be on this topic, namely: a) many raw materials are still poorly included in experiments, b) the level of standardization should be improved, in order to generate comparable data, and c) the use-wear formed by many worked materials is still poorly explored, namely organic materials such as wild plants, among other perishable organic elements.

Of course, no project develops enough experiments to answer all the questions and test all the hypothesizes, and we should highlight the importance of establishing collaborations between researchers, projects, and institutions, to optimize efforts and bring a better contribution to the field. In this sense, it is extremely beneficial to the field of Ground Stone Tools research that the scientific community working on use-wear and residue analyses follow the general recent scientific tendency to adopt the policy of making data as available and easy to access as possible, using strategies such as storage in online repositories with free access.

3. Methods

3.1. Methods and brief main tasks description

This project were developed using an high-resolution approach to study Ground Stone Tools from the Middle Paleolithic sites of Nesher Ramla (layer 5 - late MIS6-early MIS5), (Zaidner et al., 2018), Far'ah II, ~85-60ka BP (Gilead & Fabian, 1987), Ein Qashish, ~66-64 ka BP (Been et al., 2017). The study uses a methodological agenda that combines techno-typology and use-wear analysis, through a multi scale approach, that generates and combines both qualitative and quantitative data.

In this study, to preserve samples for the possibility of future analysis, the probability of residue preservation is taken in account by following standard protocols in the discipline. During the cleaning process of both archaeological and experimental samples, residue samples are collected using the pipette extraction method (Cnuts & Rots, 2017; Hayes, 2015).

Being aware of the importance of combining qualitative and quantitative data (Marreiros et al., 2020) this projects presents a combination of quantitative and qualitative data analysis of the archeological case studies, and in parallel develops an experimental program focused on controlled experiments with the aim of building a reference collection to support the archeological interpretation.

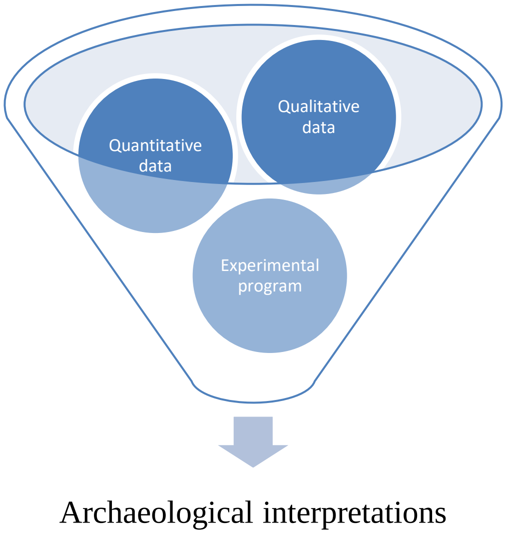


Figure 5: Schematic diagram showing the adopted methodological approach and organization.

The workflow is organized into five main sets; 1) sorting and sampling the archeological materials within the entire assemblage; 2) sampling for residues and cleaning; 3) use-wear analysis at macro and micro scale; 4) 3D documentation and analysis; and 5) the development of experiments with a focus on mechanized experiments for percussive and grinding activities.

3.1.1. Sorting and sampling

The sorting phase was necessary in the case of assemblage from Nesher Ramla since the materials were stored in large containers, in which the artifacts were not yet separated from natural stone fragments. For the case of materials from Far´ah II and Ein Qashish, the Ground Stone Tools were already sorted and stored individually.

Concerning the analysis of the Nesher Ramla assemblage, all flint and limestone artifacts (excluding debitage by-products) collected from Unit V during the excavations, were sorted and preliminarily examined for the identification of surface preservation and possible anthropic alterations. This first phase was executed through the combination of naked eye and stereo-microscope observations. The techno-typological and functional analysis included all the materials that at a naked-eye scale showed surfaces with clear evidence of use-wear or show surfaces that are suitable for the preservation of micro use-wear traces. Here, all the materials that do not occur naturally in the site were selected for detailed inspection (e.g., river pebbles), excluding the nary rock fragments that form the natural composition of the eroded bedrock and therefore could be present at the archeological horizons due to gravitational transport from the surrounding areas.

Figure 6: Sorting Nesher Ramla Ground Stone Tools (Hebrew University of Jerusalem, Israel, Photo: Eduardo Paixão).

3.1.2. Residue sampling and cleaning procedure

Before cleaning, all typological categories were sampled for further residue analyses followed a standard protocol for residue sampling on stone tools, consisting of the located micro-pipette extraction method (Hayes, 2015). Analysis of the residue samples is beyond of the scope of the presented PhD project, however their preservation for future work was guaranteed. This non-destructive sampling method was applied for all the sites included in this research project. For most cases the cleaning of the artifacts was made only with running tap water, without the use of any type of abrasive tool (Pedergnana et al., 2020). The samples selected for laser confocal microscopy were also cleaned in an ultrasonic bath for 10 minutes, and the analyzed polished areas of the tool were then cleaned with ethanol.

Figure 7: Sampling extraction method for residues (Photo: Eduardo Paixão).

3.1.3. Use-wear analysis

The use-wear analysis was carried out with the combination of qualitative and quantitative analytical approaches and with the use of low and high-power microscopy (Adams et al., 2009; Dubreuil & Savage, 2014; Fullagar, 2014; Hayden, 1979; Keeley, 1974b; Rots, 2013). The first phase was based on both macro-observations using a stereo microscope (ZEISS Stemi 305) and microscopic observation using a portable digital microscope (Dino-Lite Edge AM7915MZT) (acquisition settings in section 9). This phase of the workflow was focused on the preliminary analysis and documentation of the surfaces (natural/anthropic alterations) of the materials, as well as a general description of raw material properties. This process was critical to evaluate the entire Ground Stone Tools assemblage and identify tools with use-wear preservation that would require further investigation (e.g., through the use of higher magnification).

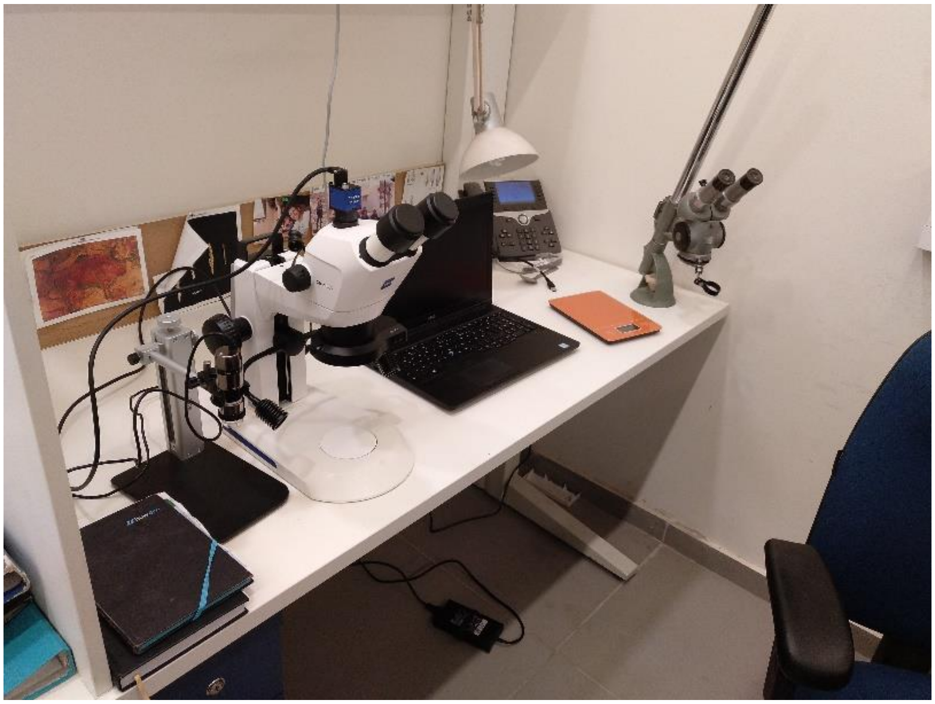


Figure 8: First phase of artifacts observation: Dino-Lite Edge AM7915MZT and ZEISS Stemi 305 (Archaeology laboratory, Ben-Gurion University of the Negev, Israel. Photo: Eduardo Paixão).

In order to primarily register the location of the observed macro wear traces on the tools, an artificial grid divided in 9 squares for both surfaces of the tool were created (face A and B). Here the tool was orientated based on its longitudinal axis (fig. 9).

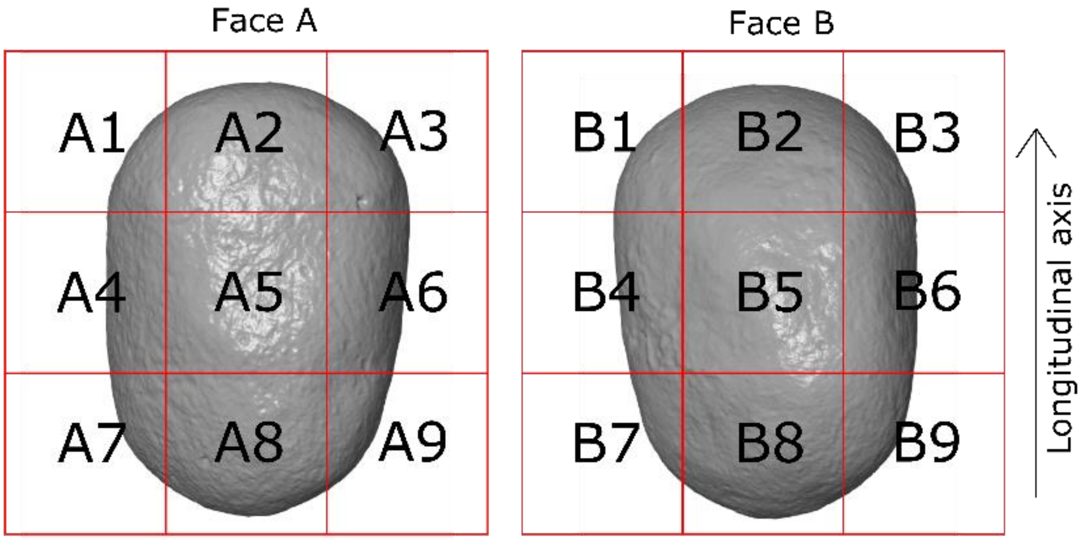


Figure 9: Schematic representation of grid for record use-wear location.

For a more detailed characterization and imaging of the use-wear at a macro scale, a digital camera was used (Nikon DSLR camera, model D610 with a Nikon AF-S VR Micro-Nikkor 105 mm f/2.8G IF-ED lens.). A 3D digital automated microscope ZEISS Smartzoom 5 (equipped with a PlanApo 1.6×/0.1 objective, and an integrated segmented LED ring light) was used to image larger areas with low magnification. For the micro analysis of the areas with polish formation a reflected light microscope (ZEISS Axio Scope.A1 MAT) was used. During the analysis, all pictures were acquired using the dedicated software ZEISS Zen Core, including the use of the image Extended Depth of Focus (EDF) stacking module to generate in-focus images (the image equipment and acquisition settings are listed in detail in the appendix section 9.4).

After acquisition, when needed, digital images (including overviews, areas of interest and particular macro features) were edited using GIMP (free open-source image editor, available at *https://www.gimp.org/*, v.2.10.18). All edited and original images were later combined and processed using Inkscape (free and open-source vector graphics editor, available at *https://inkscape.org/*, v.0.92.4).

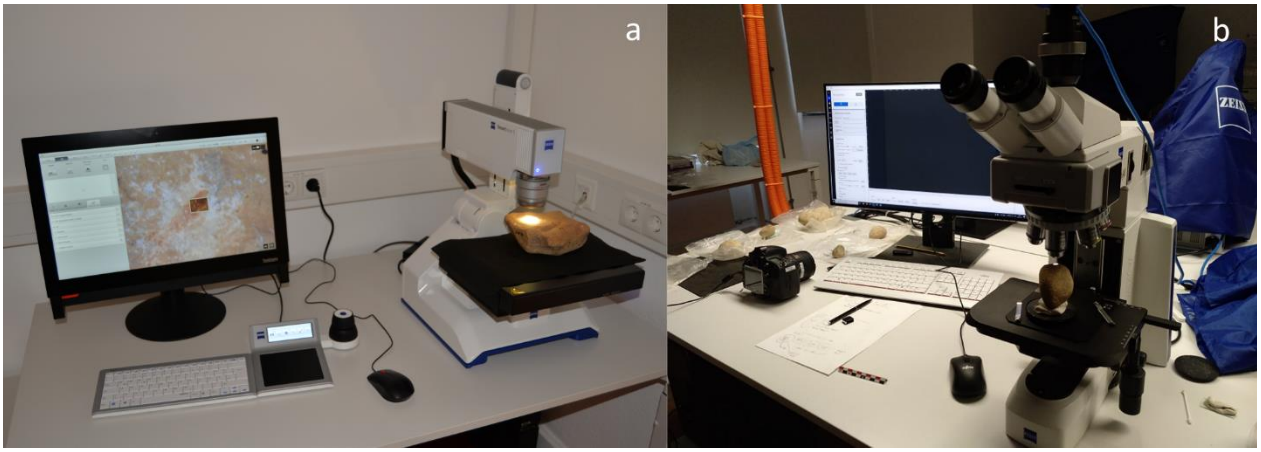


Figure 10: Microscopic analyses: a) ZEISS Smartzoom 5 b) ZEISS Axio Scope.A1 MAT (TraCEr-Monrepos, Photo: Eduardo Paixão).

The qualitative description of the micro traces followed the criteria commonly adopted in Ground Stone tools studies (Adams, 2014; Dubreuil et al., 2015). This includes, when possible, the description of the polish in terms of distribution, density, microtopographic context, texture, contours, brightness, and the registration of any other features, such the presence of striations or abrasive tracks. The data input to construct the analytical database was made using a dedicated configuration in the software *E4* (available at www.stoneage.com). All the configurations used during this project are available in the volume 2 of this work and are available to be used by other researchers that find it a useful resource to support their data input.

Table 1: Qualitative micro wear criteria (*adapted from* Dubreuil et al., 2015).

Criteria	Variability			
Distribution (on the surface) 50x	sparse	covering	concentrated	
Density (Mesh)	separated	closed	connected	
Microtopographic context	only on high	penetrating on low	high and low	
Morphology in cross section	domed	sinuous	flat	
Texture	rough	fluid	smooth	
Contours (or limits)	sharp	diffuse		
Brightness	high	medium	low	
Special features	abraded area	pits	striations	abrasive track

In order to combine the qualitative approach with micro quantitative data confocal microscopy was used, since other works have previously demonstrated that this technology is a valuable and accurate tool on the micro surface texture characterization (Calandra et al., 2019; Evans et al., 2014; Evans & Donahue, 2008). Therefore, to quantitatively characterize the micro topography of the polish present in the assemblage, a sample of 12 polished areas from four tools identified in the Nesher Ramla assemblage were selected for confocal analysis. The selection of samples for confocal microscopy was made to represent the variability observed in the assemblage. Beside the archeological samples, the experimental materials were also sampled for confocal analysis, to quantitatively characterize the type of polish formed by each type of activity and contact materials. All micro surface texture acquisitions were done using a 3D Laser Confocal microscope ZEISS LSM 800, objective C Epiplan-Apochromat 50×/NA = 0.95/WD = 0.22 mm. The resulting 3D surface data were processed in batch in ConfoMap v8.1.9286 (a derivative of MountainsMap Imaging Topography developed by Digital Surf, Besançon, France). All surface processing and analysis was done using templates adapted from Calandra et al 2019 and Schunk et al. in preparation for the surface roughness standard following ISO 25178 (ISO, 2005), the analysis workflow is detailed in a dedicated sub-section within section 9. A total of 13 different surface texture parameters were analyzed to quantitatively characterize the polish areas (fig.11 and table.2).

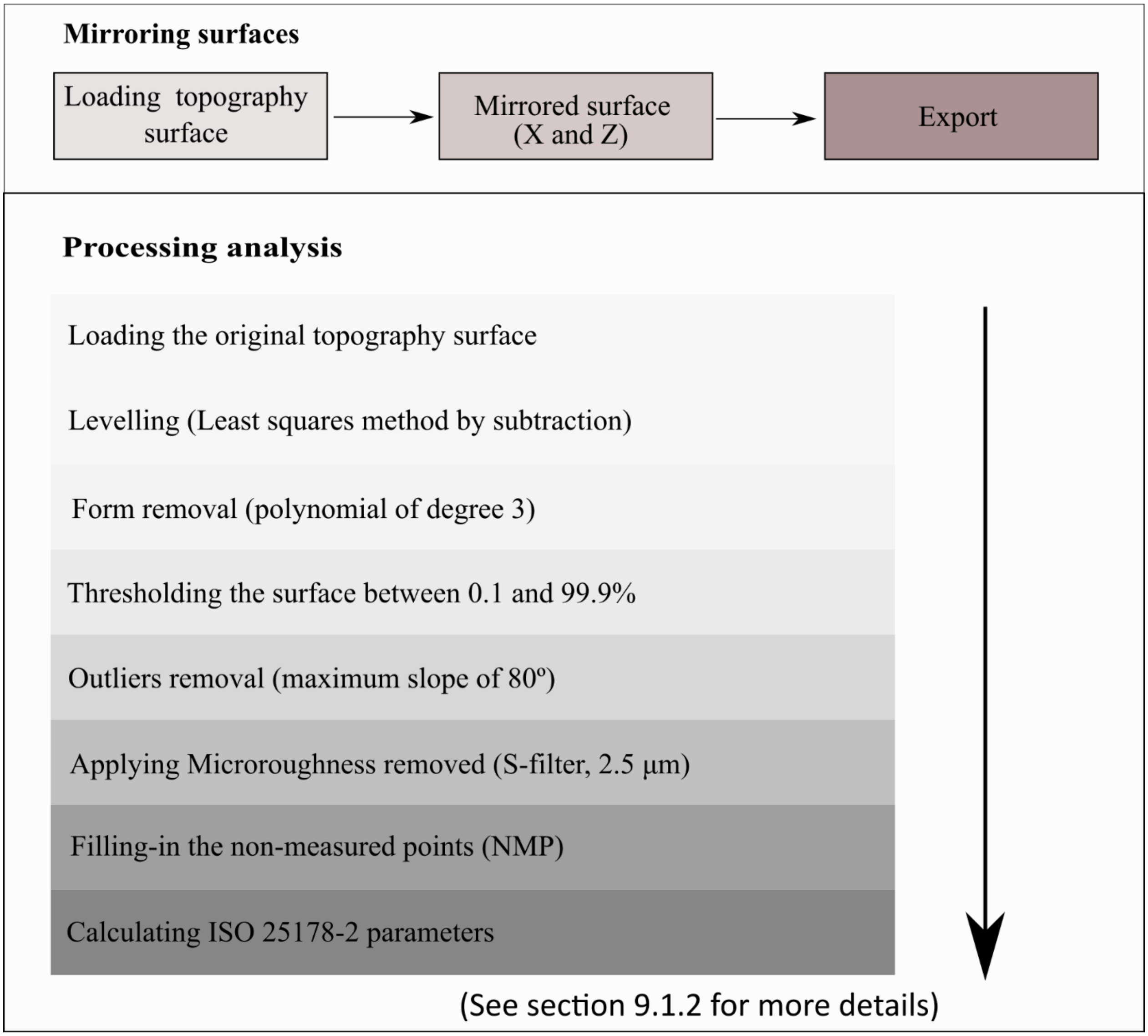


Figure 11: Confocal processing workflow

Table 2: List of parameters for micro surface texture analyses (*Adapted from ISO 25178-2*, 2012; Calandra, 2011; Calandra et al., 2019b; Schulz et al., 2013; Scott et al., 2006).

Scale type	Standard	Category	Parameter	Description (condition)	Unit
Length-scale (profile)	ISO 4287 (1984-1996)	Amplitude	Rt	total height of the profile	
			Rp	Maximum profile height	
			Rv	Maximum profile valley depth (Rm 1984)	
			Rz	Maximum height of the profile (Ry 1984)	
			Ra	Arithmetical mean deviation of the assessed profile	
			Rq	Root mean square deviation of the assessed profile	
			Rsk	Skewness of the assessed profile (Sk 1984)	
			Rku	Kurtosis of the assessed profile (Amendment)	
			Rc	Mean height of the profile	
		Spatial	RSm	Mean width of the profile elements (Sm 1984)	
		Hybrid	Rdq	Root mean square slope of the assessed profile	
			RPc	Peak count number (Amendment)	
		Functional	Rmr	Material ratio of the profile	
			Rdc	Profile section height between two material ratios (Amendment)	
	ISO 12085	Motif	nmoti	number of motifs	no unit
			meh	mean Height	µm
			mea	mean Area	µm2
			mev	mean Volume	µm3
Area-scale	ISO 25178	Height	Sq	standard deviation of the height distribution, or RMS surface roughness	µm
			Ssk	skewness of the scale limited surface	no unit
			Sku	kurtosis of the scale limited surface	no unit
			Sp	maximum peak height	µm
			Sv	maximum pit height	µm
			Sz	maximum height of the scale limited surface	µm
			Sa	arithmetical mean height or mean surface roughness	µm
		Spatial	Sal	auto-correlation length (s = 0.2)	µm
			Str	aspect ratio (s = 0.2)	no unit
			Std	direction	°
		Hybrid	Sdq	root mean square gradient of the scale limited surface	no unit
			Sdr	developed interfacial area ratio of the scale limited surface	%
			Smr	areal material ratio function of the scale limited surface (c = 1 µm under the highest peak)	µm
			Smc	areal material ratio function of the scale limited surface (p = 10%)	
		Function and related parameters	Sdc	Surface Section Difference (extension of the Rdc)	
			Sxp	peak extreme height difference in height between p% and q% (p = 50%, q =97.5%)	µm
			Vm	material volume at a given height (p = 10%)	µm3/µm2
			Vv	void volume at a given height (p = 10%)	µm3/µm2
			Vmp	material volume of peaks (p = 10%)	µm3/µm2
			Vmc	material volume of the core (p = 10%, q =80%)	µm3/µm2
			Vvc	void volume of the core (p = 10%, q =80%)	µm3/µm2
			Vvv	void volume of the valley (p = 80%)	µm3/µm2

		Related to segmentation	Spd	density of peaks	1/µm2
			Spc	arithmetic mean peak curvature	1/µm
			S10z	ten-point height of the surface	µm
			S5p	five-point peak height	µm
			S5v	five-point peak height	µm
			Sda	mean dale area	µm
			Sha	mean dale area	µm
			Sdv	closed dales volume	µm3
			Shv	closed hills volume	µm3
	ISO 12781	Flatness	FLTt	peak to valley flatness deviation of the surface (Gaussian Filter, 0.025mm)	µm
			FLTp	peak to reference flatness deviation (Gaussian Filter, 0.025mm)	µm
			FLTv	reference to valley flatness deviation (Gaussian Filter, 0.025mm)	µm
			FLTq	root mean square flatness deviation (Gaussian Filter, 0.025mm)	µm
	Other param.	Furrow analysis	madf	maximum depth of furrows according the = vectorisation of the micro-valley network	µm
			metf	mean depth of furrows	µm
			medf	mean density of furrows	cm/cm2
		Direction	Tr	direction isotropy	%
			Tr1R	first Direction	º
			Tr2R	second Direction	º
			Tr3R	third Direction	º
		Isotropy	IsT	isotropy	%
		Scale Sensitive Fractal Analysis		Smooth-rough crossover	
				Maximum relative length/area (Sdr on a surface)	
				Fractal dimension	
				Complexity (Similar to Sdq)	
				Scale of maximum complexity	
				Regression coefficient R²	
				Heterogeneity of complexity	

When possible, three different spots representative of the same micro polished area were measured. For some of the tools this was not possible due to the low degree of polish formation or unclear and non-diagnostic classification of the polished area.

Figure 12: ZEISS LSM 800 (TraCEr-Monrepos, Photo: TraCEr).

3.1.4. 3D scanning and spatial GIS analyses

During the last years, several studies have highlighted the potential of 3D scanning technology when applied to the Ground Stone Tools research. Different types of computation from digital elevation models have provided a great improvement concerning artifact analysis, contributing quantitative data for this field (e.g., Benito-Calvo et al., 2015, 2018; Caricola et al., 2018; de la Torre et al., 2013; Zupancich et al., 2019). All artifacts included in this study were scanned with a portable scanner (HP 3D Structured Light Scanner Pro S3 DAVID SLS-3). The 3D models were used for documentation, morphometric analyses, and to generate *raster files* to be processed using GIS analysis methods (*QGIS software*), creating digital elevation models (DEM) and digital surface models (DSM), to compute the Slope and TRI (Terrain Ruggedness Index). The combination of different computations allows us to quantitatively describe different characteristics of the artefact surfaces with a very high level of precision and detail.

The workflow in terms of 3D data acquisition and analysis can be divided into 3 main phases (Scanning, 3D model preparation, GIS analysis), with each incorporating different steps. The settings of each step should be as standard as possible, but adaptable according to the specific characteristics of the tools (e.g., size, reflectivity).

3D Scanning

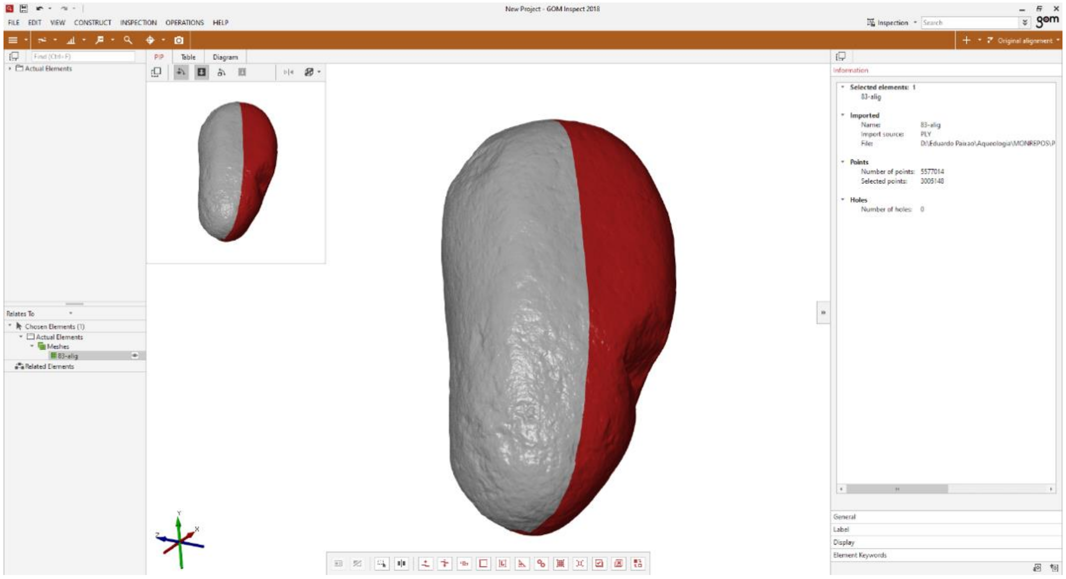
As mentioned before, in this study a Structured Light Scanner was used. This equipment consists in the combination of a projector, a camera, and a computer. The projector projects multiple patterns in the form of parallel lines and stripes over the object. These lines when meeting the object will naturally present some distortion. The camera will capture images of the distorted pattern and send it to the *software* running in the control station computer. The algorithms run by the software use the method of triangulation to calculate surface information. Multiple scans must be done from different angles of the object with some portion of overlap between them, with the software automatically orientating and collapsing all the scans to generate a 3D model.

The artifacts sit on a round turntable and make 8 single scans of each surface using a field of view (FOV) up to 120mm and a resolution up to 0.06mm. A total of 16 individual scans were aligned and merged using the HP software. At the end of this process the 3D model was exported in a polygon file format (.PLY).

Figure 13: 3D scanning (HP 3D Structured Light Scanner Pro S3 DAVID) at the Hebrew University archaeological lab (Photo: Eduardo Paixão).

3D Model processing and preparation

Before the GIS analyses the data needs to be prepared before importing into the GIS software. This preparation consists in 2 main tasks, aligning the position and cutting the model in two surfaces. For this process, the software GOM inspect v2.0.1 was used. The .PLY file was imported into this software and then the operation of manual alignment was used, to position the tool in the orientation according with the longest axis. After this step, the cutting tool was used to divide the model into two opposite surfaces (A and B). Both surfaces were exported as an .ASCII file (American Standard Code for Information Interchange). This consists of a table with thousands of points, where each point has a different coordinate (XYZ) precisely representing the objects surface. This file contains all the data that is needed to import the model point cloud into the GIS software.



Selected elements: 1
83-alig

Imported
Name: 83-alig
Import source: PLY
File: D:\Eduardo Paixao\Aqueologia\MONREPOS\P

Points
Number of points: 5577014
Selected points: 3005148

Holes
Number of holes: 0

Figure 14: Cutting a 3D model in GOM Ispect.

GIS processing

For the GIS analysis, the software QGIS Version 3.14.16 was used. The first step was to import our data file as a delimited text layer. This file contains the data to project the points cloud that represents the topography of the object. Before the surface analysis, the points need to be transformed into a triangulated surface (DSM). For that it was used the Triangulated Irregular

Network (TIN) algorithm, and later, the processed surface was saved as a raster file. After that, the followed computations were applied:

Hillshade

The hillshade function outputs a raster file with a virtual shaded relief effect on the surface. Hillshading creates a three-dimensional effect that provides a sense of visual relief, and a relative measure of incident light. It is very useful way for visualizing the surface and identifying areas of interest for extraction, since it will highlight the alterations and irregularities on the surface. It is possible to optionally specify the azimuth and altitude of the light source, a vertical exaggeration factor, and a scaling factor to account for differences between vertical and horizontal units. The algorithm is derived from the *GDAL DEM utility*.

Slope

This computation outputs a raster file with the information of the incline and steepness of a surface. Slope can be measured in degrees from horizontal **(0–90)**. The slope for a cell in a raster is the steepest slope of a plane defined by the cell and its eight surrounding neighbors. The computational algorithm is derived from the *GDAL DEM utility*.

TRI, *Terrain Ruggedness Index*

The Terrain Ruggedness Index (TRI) can be defined as the mean difference between a central pixel and its surrounding cells. Using this tool, terrain heterogeneity can be calculated. This provides a relative measure of elevation changes between a specified grid cell and neighbors. *TRI* is based on the algorithm proposed by Riley and colleagues and calculates the sum change in elevation between a grid cell and its neighborhood. In the resulting index, a TRI value of **0 represents the minimum degree of roughness** (i.e. homogeneous surface), with the number increasing together with the heterogeneity of the analyzed area (Riley et al., 1999).

Contour / Polygon

Contour computation generates several Isolines in a predetermined interval to represent the value distribution of one parameter. An Isoline is a line on a map with a constant value. Those lines never cross each other. Contour lines were used to create polygons to delimitate areas with common values. This makes it possible to quantify and compare the distribution of values generated by previous computations on the surface (e.g., TRI, TPI, Slope). Examples of the different computations were exported as images where the different values of the computations were classified by colors. For statistical processing, the numerical data that results from the computations was compiled in a table exported as a CSV file.

All the GIS detailed workflow and scripts for automatization and processing data are available in the section 9.

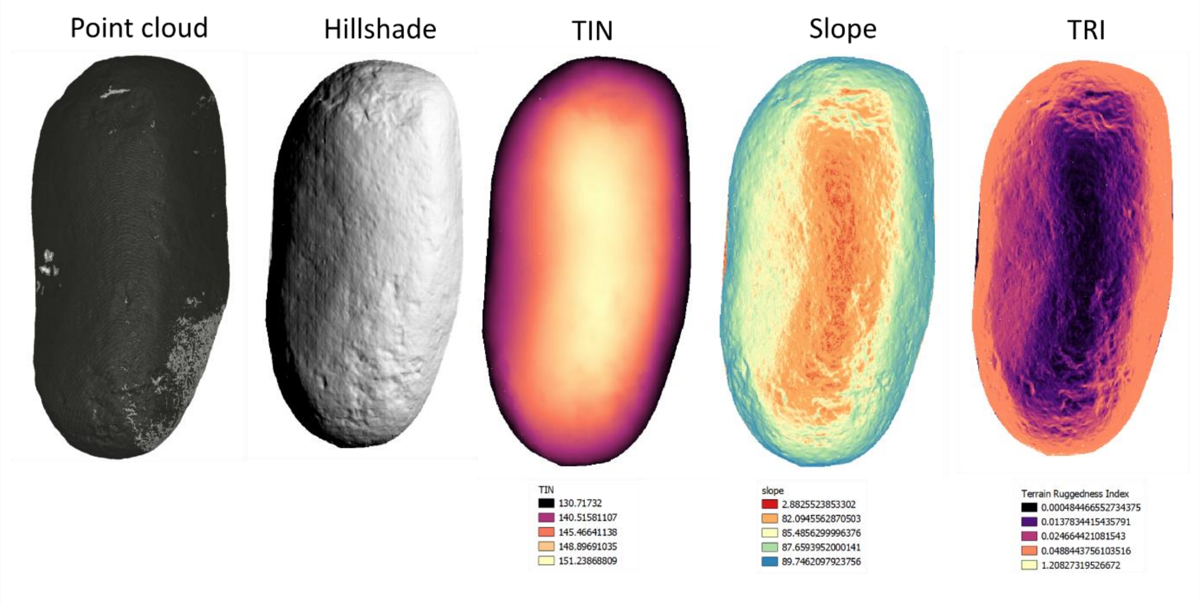


Figure 15: DSM computation visualization (example of each parameter used in this study).

3.1.5. Experiments

The activities included in the experimental program are based on two main types of movements: grinding and impact motions. The grinding activities were performed by grinding acorn seeds in circular movements, and the impact activities were performed by the breakage of bones and flint knapping. The samples used to perform the experiments consisted of limestone river cobles collected in Israel, which matches the raw material identified in the archaeological assemblages studied here. The experimental program developed in this project focused on mechanized/controlled experiments, but manual experiments are also included as a first approach. During the manual experiment phase, the activities are recreated manually using the same raw materials found in the archaeological record. In this type of experiment, the main goal is to understand the major factors involved in the activity, to develop with better precision, the specific research question, and help to design the following controlled experiments.

With controlled experiments, it is possible to isolate the variables to better understand the cause/effect of major factors involved in the process. Aside from isolating variables, this experimental approach is also crucial for providing reproducible data for major parameters involved in the actions and that may potentially affect the final results (e.g., force, speed, position) (Calandra et al., 2020).

In this study, controlled experiments were performed using the SMARTTESTER machine. This mechanical device allows the control of a large number of variables during the experiments. In this phase the experiments are automatically reproduced by the machine, which controls the velocity, force, angle of work, and number of movements.

All the experimental samples were 3D scanned (Light 3D-Scanner Pro S2), before and after the different experimental cycles. After the execution of the experimental activities all the tools were analyzed following well established use-wear methods, from which results were organized into two main scales of observation: macro and micro wear traces. Wear traces were documented following the common terminology on ground stone tools studies (Adams, 2014; 2002; Adams et al., 2009; Dubreuil et al., 2015; Dubreuil & Savage, 2014). Use-wear traces were organized into three main categories: abrasive (e.g., striations), impact (surface macro fractures) and micro polish (i.e. sheen). For the micro polish analysis, these traces were characterized, taking into consideration the distribution of the mesh, the level of penetrations in the micro-topography, the morphology of the cross section, the texture, contours of the polish, and the presence of other features such as striations and abrasive tracks.

Apart from the qualitative characterization described above, samples of each type of activity were also selected to be scanned with Confocal Laser scanning microscope (LSM). On the samples selected for LSM, a minimum of 3 spots were scanned for each tool. The confocal technique was used to analyze 13 different parameters of surface texture analyses according with the International Organization for Standardization (ISO 25178, 2005). Each parameter is described in section 3.1.3.

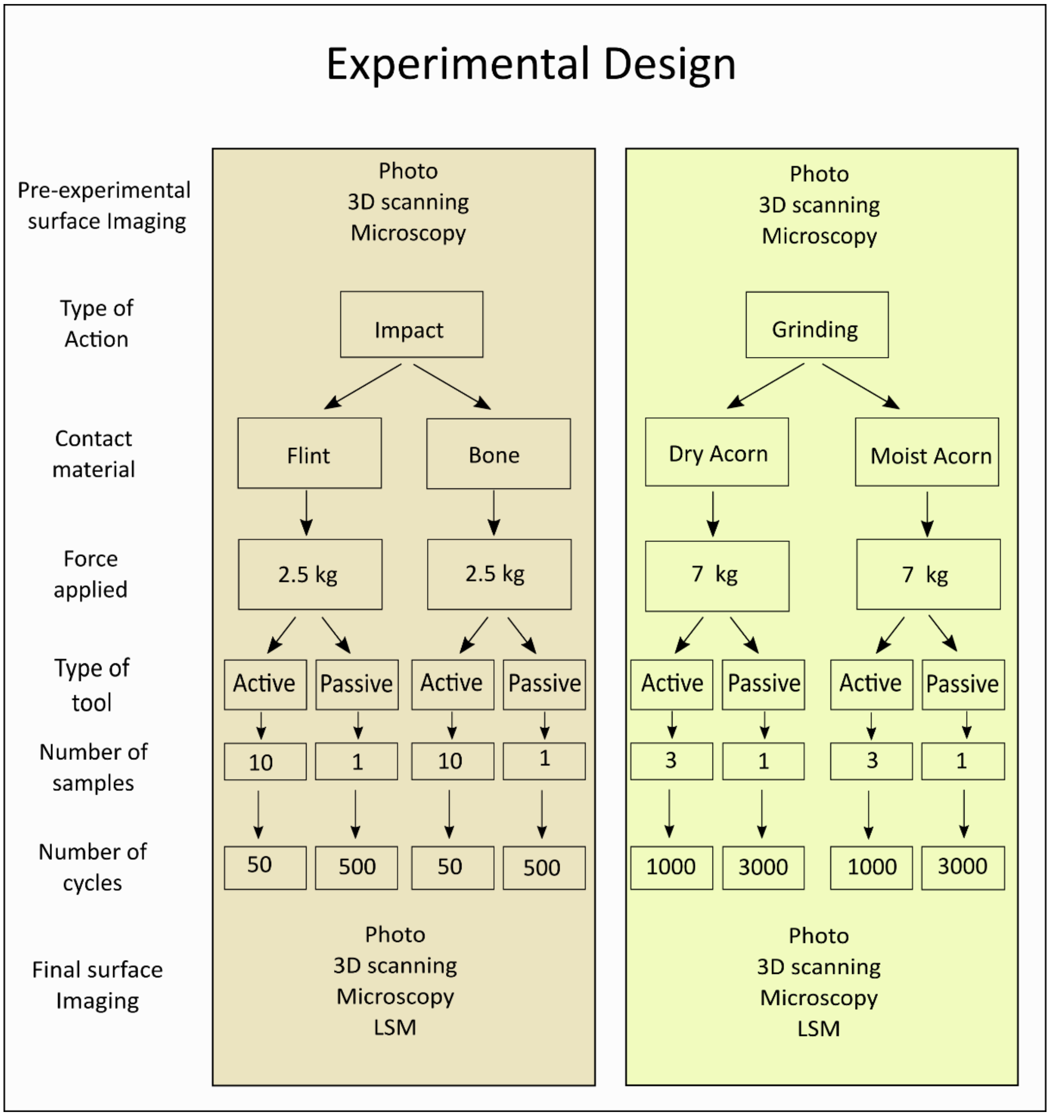


Figure 16: Summary of the experimental design.

3.1.5.1. ***Percussive experiments***

Bone breaking and flint knapping activities are two of the most straightforward assumptions to account for the large accumulation of Ground Stone Tools at the site of Nesher Ramla. The significance of these activities is indicated by both the macroscopic identification of impact marks and the characteristics of the archaeological unit composition, which is rich in knapped materials, and fragmented bones (Gershtein et al., 2020). This type of activity is also a reasonable hypothesis to explain the presence of large tools with impact marks in other contexts, in which they are often associated with bones and thousands of lithic debitage products. However, there is a lack of a suitable reference collection to support the identification of use-wear on pebbles and cobbles formed by bone processing and flint knapping, with a specific focus on identifying the diagnostic traces of both activities, to clearly differentiate their macro and micro traces during the analysis. Consequently, this project prioritized experimental replication of both activities to build a comparative ‘library’ for documenting diagnostic use-wear features limestone pebbles. This will be useful for the analyses of the materials of the sampled sites in this project, and will also be available in the future for other researchers to use to support their investigations on the topic.

3.1.5.1.1. Manual (1º Generation)

Although the manual experiments are not the main scope of the approach adopted in this project, some trial experiments were performed before the design of the mechanical experiment. This set of experiments were developed in collaboration with students from the Hebrew University of Jerusalem, and the Professor Yossi Zaidner. These first experiments consisted of breaking bones with limestone cobles with and without the use of an anvil, which aimed to understand which motions and gestures seem to be most efficient to successfully conclude the task. This exercise also allowed a first impression on the main variables and factors involved and required in the process (e.g., force, number of impacts). Here, a total of 10 tools were used, which were scanned before the experiments. During the activity the number of impacts and the time duration of the activity was recorded.

Figure 17: Manual experiments on bone breaking without passive stone (Hebrew University of Jerusalem, Photo: Eduardo Paixão).

3.1.5.1.2. Mechanical (2º Generation)

The mechanical experiments in this project were developed using a mechanical device (SMARTTESTER®, manufactured by Inotec AP GmbH with adaptations made by Walter Gneisinger (see fig 19 and 20) that allowed us to control and record a number of parameters (Calandra et al., 2020). This machine is a modular test rig primarily developed for industrial use to assess product durability. The machine is designed to perform standard and consistent movements and registers the activity parameters in a central computer. It allows us to predefine the type of movement (e.g., linear, circular, impact), the number of repeats, and to record the force involved in the action by using force sensors.

The mechanized percussion experimental program was designed to develop a set of controlled experiments that consist in impact activities on bone (*bone breaking*) and flint (*flint knapping*) under controlled conditions. The experiment was performed by applying a standardized number of impacts, while the previously defined main variables were kept constant throughout the entire duration of the activities, namely the impact force, number of impacts, and the position of the sample.

Prior to the start of the experiment, a bone was manually broken with a hammerstone, while a sensor located under the anvil recorded the impact force of each stroke. This permitted us to find an average value as an internally valid reference for setting up the mechanical apparatus and the experimental design. Dead weights were then applied to the sample holder on the mechanical device until an approximation of the previously observed value (2.5 Kg) was reached. The samples were cut through the surface opposite to the active area to make a flat surface on which a small groove was cut to install a metallic piece that permits the sample to be positioned in the sample holder in a standard and stable position. This solution also allows the sample to be removed and relocated in the exact same position between different experimental cycles.

Figure 18: Sample preparation for mechanized experiments: a) cutting a surface opposite to the active area b) marks to cut the grove c) sample installation in the sample holder d) fixing the metallic adaptor to the tools (Photos: Eduardo Paixão).

In this experiment, a total of 23 samples were used. Twelve tools were used for bone breaking, and eleven tools for flint knapping. Using a specifically designed mechanical setup, the hammerstones was attached to a vice on the sample holder carriage in a standard position (60 cm from the contact material in a vertical axis). The impact force for all the samples was standardized by using the same drop distance and the same added heights (2.5Kg). A total of 15 pieces were used during 50 impacts, and the others were used during a more extensive number of impacts (up to 500). One anvil was used per contact material (flint, bone). This set of experiments allowed us to clearly identify and measure distinctive elements for each contact material in terms of use-wear, both at macro and micro scale. (Paixão et al., 2021).

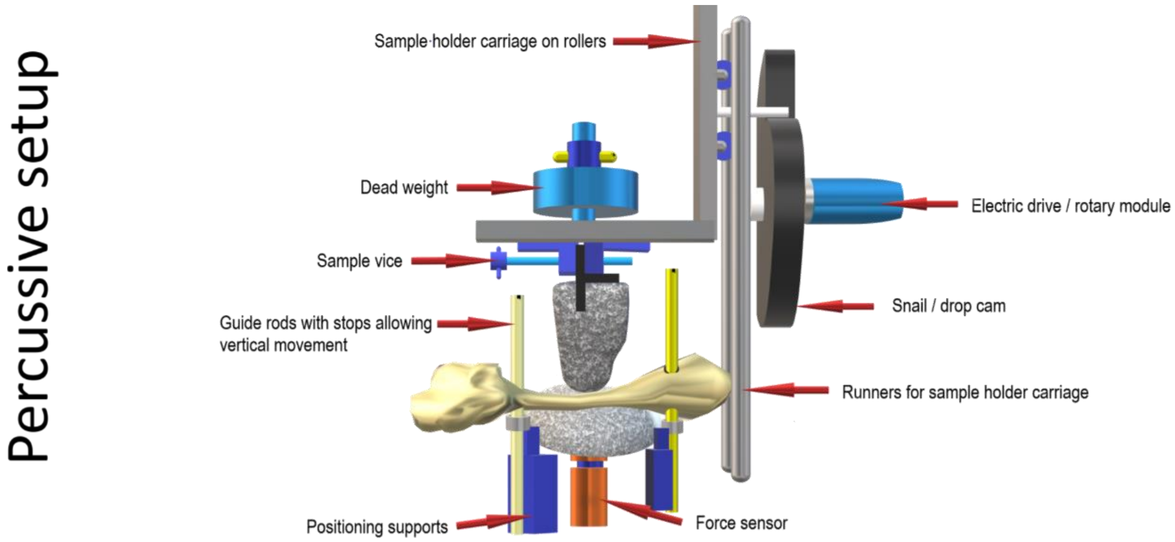


Figure 19: Percussive setup (Drawing by Walter Gneisinger).

Figure 20: Mechanical experiments setup for percussive activities (Photos: Eduardo Paixão).

3.1.5.2. ***Grinding experiments***

One of the most debated topics in the use of Ground Stone Tools among paleolithic communities is the possibility for those artifacts to preserve traces that reveal the manipulation and consumption of vegetal products. Grinding activities can be involved in the processing of many products, that for some reason requires a reduction of their particles size. To test the development of use-wear traces on limestone caused by grinding activities, this project developed a set of experiments, involving the grinding of acorn (*Quercus robur*). These experiments included the grinding of both dry and moist acorn seed, ground in circular motions under the same controlled condition using a mechanical device adapted specifically for the purpose of this experiment. The main goal of using the mechanical device was to make sure that all samples and both states of humidity level of the acorn seed were processed under the same conditions, in terms of number of turns, speed, and force applied.

3.1.5.2.1. Manual (1º Generation)

A manual experiment for the grinding acorns was a "preparation experiment", that had the main goal of understanding the range of force values needed to grind the material, in order to find a value within that range to set up the mechanized experiment. The experiment was carried out with the passive stone positioned on top of a force sensor, with this used to measure the range of force used in grinding the acorns. That value was then used to set up the constant force used during the mechanical experiments. This same procedure was executed for both conditions of acorns (dry and moist) (fig.17).

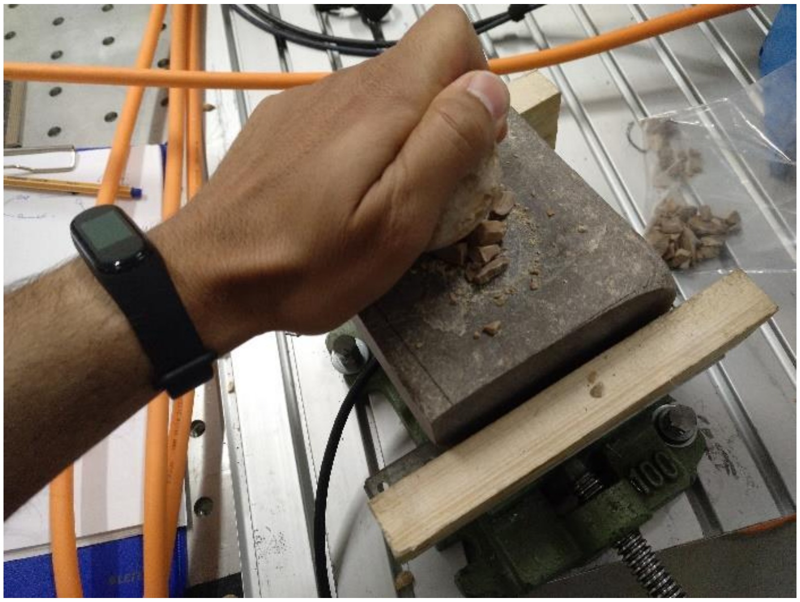


Figure 21: Manual grinding of acorns (Photo: Eduardo Paixão).

3.1.5.2.2. Mechanical (2º Generation)

For the grinding experiments, the machine was adapted to perform circular movements. The rotary drive module was mounted to rotate a flywheel via a toothed drive belt. The top stone is fixed in the vice of the sample holder that is attached to the rotating flywheel in order to move the top stone in a circular grinding motion. The sample holder carriage on rollers is limited in its vertical movement by an adjustable stop on the runners to avoid stone-to-stone contact. The base stone was mounted inside a bucket under a funnel where the acorns are deposited for grinding. The acorns are fed towards the center of the bottom stone with the help of a brush which is attached to the flywheel. The bottom of the bucket was filled with a reversible plaster fill and a base plate to create a flat surface for the contact with the force sensor. The bucket itself was held in position, as for the percussive setup, to allow for vertical motion enabling the sensor to generate readings. As before, any sensor readings serve only as an internal reference value. A total of eight limestone samples were used to perform this experiment, with three active stones per contact materials, and one passive stone per contact material. Each active stone performed 1000 rotations, and each passive stone performed 3000 rotations, always in a standardized speed and pressure.

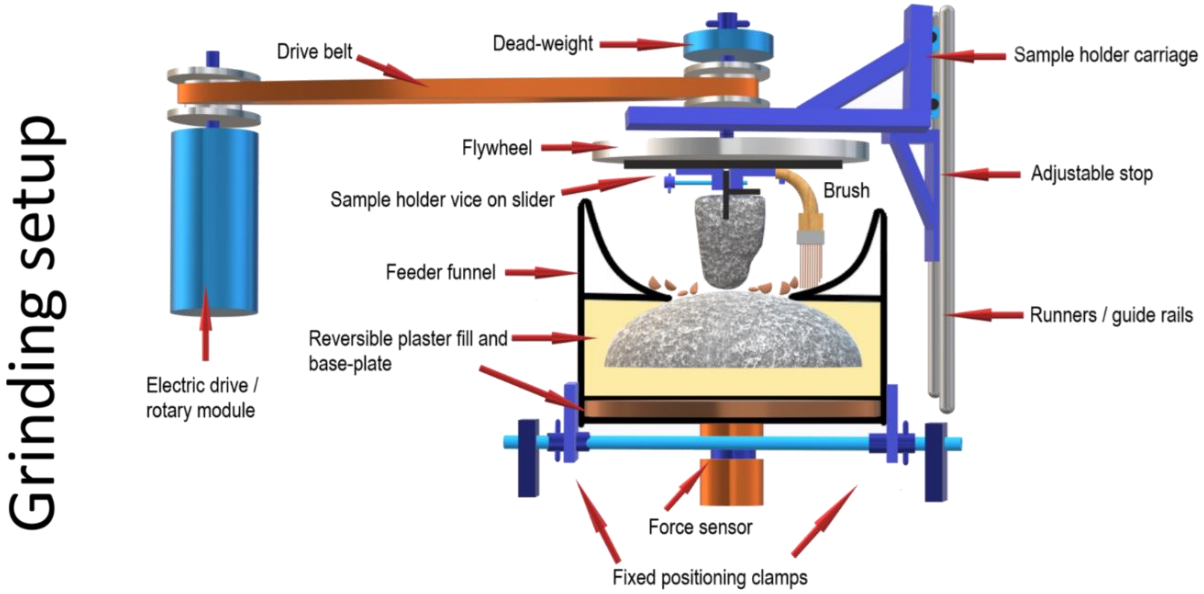


Figure 22: Grinding setup (Drawing by Walter Gneisinger).

Figure 23: Grinding experiment setup (Photos: Eduardo Paixão).

4. Archaeological sites: selected case studies

As mentioned before, all the case studies included in this project are situated in the Levant region. The northern site of Ein Qashish is located within the Yizra’el Valley, east of Mt. Carmel. In the center there is the site of Nesher Ramla, near the city of Ramla. The southern studied site is Far´ah II, located in the eastern bank of Wadi Besor in the north-western Negev desert. (fig.24)

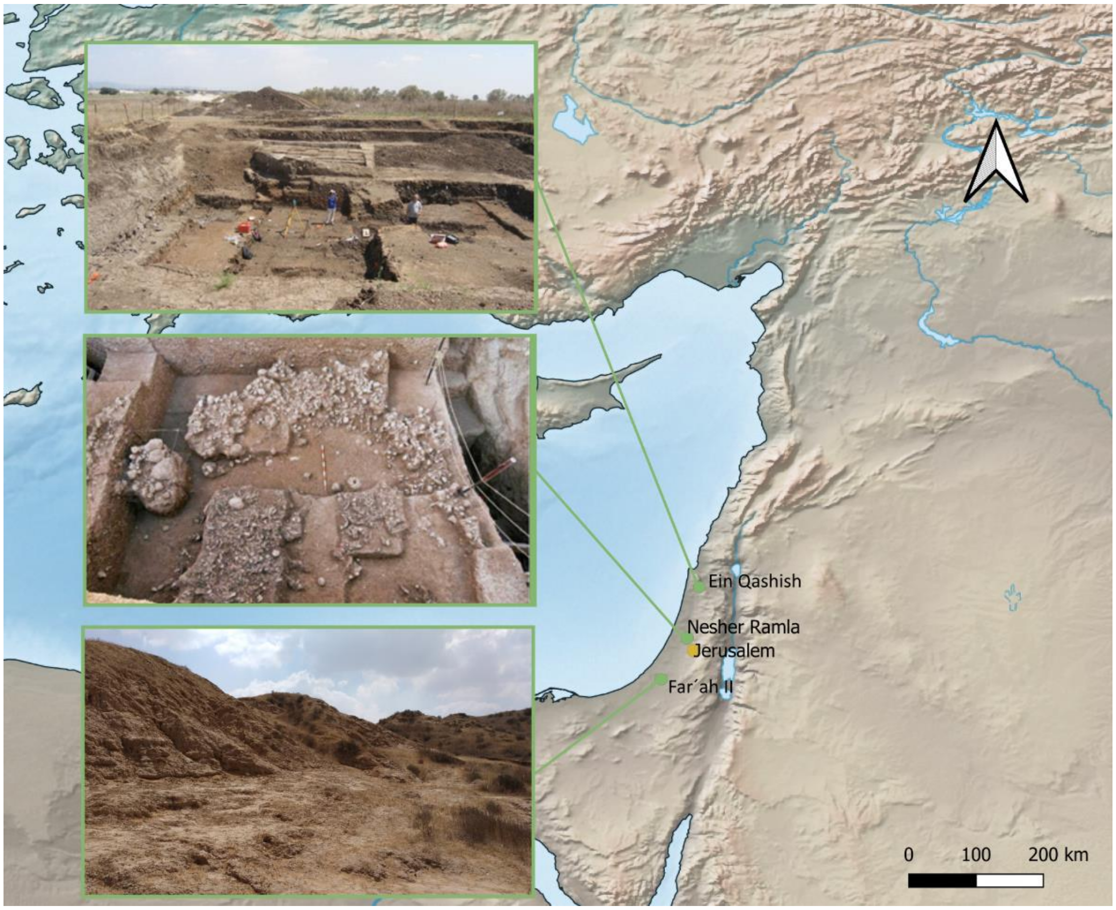


Figure 24: Map showing the location of all sites included in the study. Site photos: courtesy of Ariel Malinksy-Buller, Yossi Zaidner and Mae Goder-Goldberger).

4.1. Nesher Ramla

4.1.1. Site presentation

Nesher Ramla is an open-air site located on the western slopes of the Judean hills bordering the Mediterranean coastal plain, in central Israel. The site was discovered following quarrying activities by the “Nesher cement factory”. After the removal of approximately 12m of clays, the site was exposed in a deep depression formed within the chalk bedrock. The site was intensively excavated during two seasons between 2010 and 2011, for a total of 12 months, under the supervision of Dr. Yossi Zaidner. More than 450m^3 of sediments were removed, which represents almost the entire extension of the known archaeological deposits. Nesher Ramla presents a large lithic and faunal assemblage, showing a very good state of preservation, with remains attributed to the Middle Paleolithic period (Zaidner et al., 2014; 2018).

A series of optically stimulated luminescence (OSL) dates from the different stratigraphic units identified at the site gave an estimation between 160 and 80ka BP (Zaidner et al., 2014). Several burnt flints analyzed by thermoluminescence (TL) method place the hominin occupations at the end of MIS 6 and beginning of MIS 5 (Guérin et al 2017). Large number of lithic artifacts, including more than one hundred Ground Stone Tools, faunal remains, and several combustion features were found, revealing *in situ* evidence of human activities. Due to the good state of preservation and extraordinarily large number of tools when compared with most Middle Paleolithic sites in the region, Nesher Ramla is an ideal case study for a comprehensive study of Ground Stone Tools. This study focuses on the analysis and discussion of the Ground Stone Tools from Unit V, dated to the beginning of MIS5.

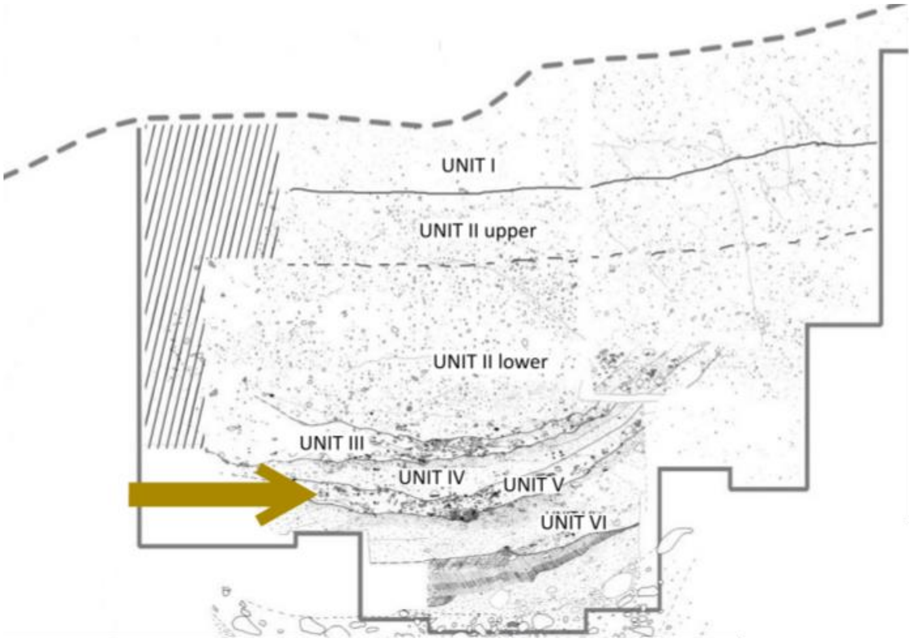


Figure 25: Nesher Ramla excavation profile (courtesy of Y. Zaidner).

Figure 26: Unit V of Nesher Ramla (courtesy of Y. Zaidner).

4.1.2. Geographic and geological context

Geologically, Nesher Ramla can be defined as a sinkhole, formed by the sagging and deformation of the bedrock and sediments after the collapse of an underground karstic void (Frumkin et al., 2015; Zaidner et al., 2014). The archaeological deposits were found in the middle of the sinkhole, which is about 34 m deep. The Middle Paleolithic sequence is 8 meters thick and is divided into six main archaeological units (I-VI). The diameter of the sinkhole where the archaeological sequence starts is approximately 20m and reduces slightly with depth. In the surrounding area other depressions were identified, and interpreted as karst sinkholes (Frumkin et al., 2015).

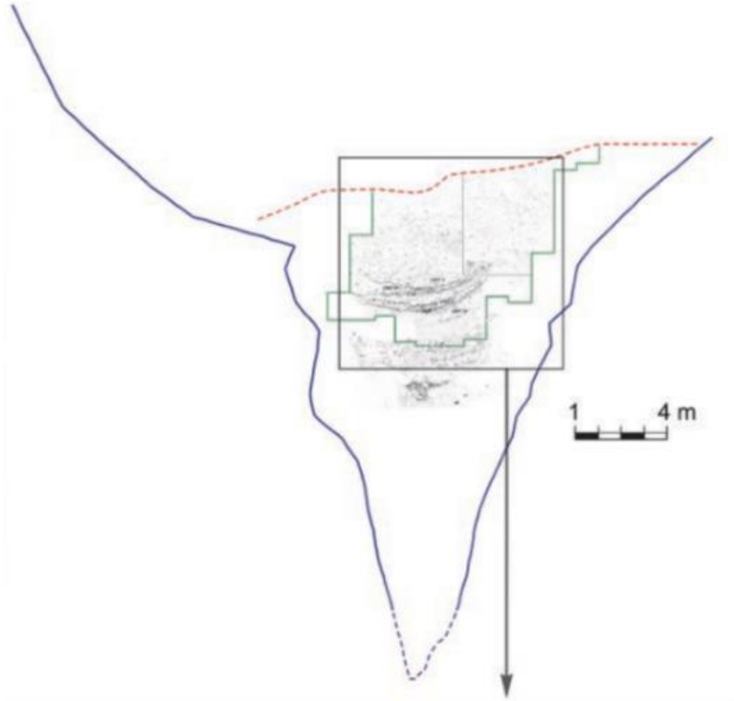


Figure 27: Nesher Ramla, sinkhole drawing (after Zaidner et al., 2018).

4.1.3. Archaeological context

All archeological units contain lithic and faunal remains attributed to the Middle Paleolithic, but with some variation in terms of the frequencies between strata. Unit III and V show the highest density of materials, including Ground Stone Tools and manuports, while units I and II are the ones that reveal a lower number of materials (Centi & Zaidner, 2020; Prévost & Zaidner, 2020; Zaidner et al., 2018).

In general, the knapped lithic assemblages are mainly characterized by a high frequency of Levallois products, focused on the flake production. The Levallois centripetal flaking method is the major technological characteristic, identified by both the by- and end-products (i.e., core trimming elements, flakes and cores). The assemblage also has a considerable presence of intensively retouched tools, namely scrappers and tools with lateral tranchet blow (Prévost & Zaidner, 2020). Nesher Ramla also presents the largest assemblage of lithic bulb retouchers known in the Middle East for Middle Paleolithic contexts (Centi & Zaidner, 2020). In terms of raw materials exploitation, as any other Middle Paleolithic site in the Levant, the lithic assemblage is dominated by flint, but also with considerable frequencies of limestone materials. The most represented flint corresponds to local Campanian flint of Mishash formation (Avni, 2018), although there is also a considerable presence of flint from indeterminate sources. Local limestone was also collected and brought to the site (Prévost & Zaidner, 2020). In terms of faunal remains, all units are characterized by large accumulation features located in different areas within the site, dominated by aurochs, equid, and tortoise (Gershtein et al., 2020; Zaidner et al 2014).The site is also rich in terms of multiple well-preserved combustion features composed by ashes and charcoal (Friesem et al., 2014).

Unit V (170±12 ka, OSL) of Nesher Ramla is characterized by approximately 20-30 cm of sediment thickness and is extended in an area of 50-60m^2 (Zaidner et al., 2018). From a sedimentological perspective, this layer is composed by a brown-gravelly clay. From the archaeological point of view, this layer is characterized by the presence of large artifact concentrations of animal bones, limestone pebbles and boulders (e.g., anvils, hammerstones, manuports), knapped lithic artifacts (e.g., flake, retouched tools), and combustion features.

Similar to the other archaeological deposits at the site, Unit V has the highest density of faunal remains in the site, including aurochs, equid bones with high level of fragmentation (Gershtein et al., 2020). There is also the presence of some features associated with combustion including a considerable presence of burned bones and wood ash (Friesem et al., 2014).

The lithic assemblage of Unit V is still under analysis, but it is possible to recognize a very high density of flint knapped tools, characterized by the presence of Levallois elements (Prévost & Zaidner, 2020). In this Unit, nearly 500 non-knapped stone items were identified, categorized as pebbles, cobbles, and boulders. These artifacts do not occur naturally at the site, and therefore were intentionally carried into the site. Initially they appear distributed through the entire unit, but it was possible to identify some areas of some materials concentrations. This study is focused on the characterization of these artefactual group, exploring their variability and function.

4.2. Far´ah II

4.2.1. Site presentation

Far´ah II is a Late Middle Paleolithic open-air site located in the Southern Levant, in the badlands of the main channel of Nahal Besor, the largest drain system of the Northern Negev, in the semi-arid part of Israel. The site was discovered and excavated in 1972-1973 by the British Western Negev Expedition (Price Williams, 1973, 1975), and in 1976-1978 by Isaac Gilead (Gilead & Grigson, 1984). Renewed excavation took place in 2017, with the main goals on re-dating the archaeological horizons with more accuracy, using Optically Stimulated Luminescence and ^{14}C. This new work at the site also collected samples for paleoclimatic study.

In terms of dating, initially interpolations based on sedimentological rates, pointed to 45-40 Ka (Gilead & Grigson, 1984). During the 1990s dating by Electron Spin Resonance (ESR) was applied, pointing to a date of 60-50 Ka BP (Schwarcz & Rink, 2002). The most recent dating results from OSL on quartz and C14 on charcoal point to 49-47ka BP (Goder-Goldberger et al., 2020).

This site is composed by two *in situ* archeological layers with a clear concentration of bones and lithics, the latter showing a large degree of technological variability. Within this assemblage from the 1976-79 excavations, an assemblage of limestone Ground Stone Tools in a good state of preservation were also found.

Figure 28: Loess deposits in vicinity of Far´ah (Photo: Eduardo Paixão).

4.2.2. Geographic and geological context

Far´ah II is located in the Negev Quaternary loess deposits (Crouvi et al., 2017). Some older studies in the region have identified three moments of fluvial loess deposition. This identification was based mainly on ^{14}C dates divided in 70-60Ka, 40-22Ka and 15-10Ka BP (Bruins & Yaalon, 1979; Goldberg, 1986; Williams, 1975). More recent studies, based on OSL dates, indicate that main interval of fluvial loess deposition happen at 71-22Ka BP, and that period was followed by deposition of coarse gravels at 22-10Ka, with another interval in loess deposition happening around 13-10Ka BP (Avni et al., 2017; Avni et al., 2006; Faershtein et al., 2016). The loess deposits that cover most of the northern Negev represent a major sedimentological and hydrological event that occurred in the Negev during the Quaternary.

Figure 29: Far´ah II profile (Photo: Eduardo Paixão)

4.2.3. Archaeological context

The archaeological layers consist of two horizons of 5-15 cm thick, with patches of grey color due to ash. The recovered assemblage is composed of artifacts made of flint and limestone, animal bones (including bone fragments), and charcoal fragments. The lithic assemblage is very large (n= >3720), and most of the artifacts come from the upper horizon, as shown by the lithic refitting within this layer (Goder-Goldberger et al., 2020).

The lithic debitage assemblage is well preserved and mostly composed of flint artifacts with sharp edges, slightly or not patinated. The presence of Levallois elements is very low (approx. 5%) and retouched tools are very rare within the assemblage (less than 1%). As mentioned, limestone cobles were also recovered in the archaeological deposit. These materials were transported to the site by human action, probably from the riverbed that is located around 100m to the west. This type of materials does not occur naturally in loess deposits at the elevations where the site is located.

The faunal assemblage is very rich, including: wild camel *(Camelus cf. thomasi),* Aurochs *(Bos primigeniu),* hartebeest *(Alcelaphus bucelaphus),* Equids *(Equus sp.) hemionusl asinus,* goat *(Capra sp.),* gazelle *(Gazella sp.),* and possibly hippopotamus (*Hippopotamus amphibious).* *Ostrich egg shell fragments w*ere also recovered (Gilead & Grigson, 1984). Some bone fragments exhibit damage features associated with percussion activities (Gilead & Grigson, 1984).

4.3. Ein Qashish

4.3.1. Site presentation

Ein Qashish is a Middle Paleolithic open-air site dated to ~60 Ka BP (Ekshtain et al., 2019b; Hovers et al., 2008). The site was discovered in 2004 by a team from the Israel Antiquities Authority during a survey in the area of the Yoqne´am junction, located in Northern Israel. This is situated relatively close (less than 30 km) to some of the major cave sites in northern Israel, such as: Kebara Cave, Raqefet Cave, and the Nahal Me'arot site complex. The site is composed of a large number of lithics and faunal remains, from an area of approx. 1300m^2, out of which 600 m^2 have been excavated (Been et al., 2017; Ekshtain et al., 2019b; Hovers et al., 2008; 2014; Malinsky-Buller et al., 2014b; Sharon et al., 2014). Beside the well preserved and abundant number of archeological artifacts, Ein Qashish has also become a site of extraordinary importance for the study of human evolution, due to the recovery of the first diagnostic Neanderthal remains from an open-air site in the region (Been et al., 2017). The Ground Stone Tools explored in this study were recovered from the same unit (3B). In general, this archaeological unit is the one that reveals most of the artifacts with a higher level of preservation.

Figure 30: Ein Qashish, excavation work at the site (Photo: courtesy of E. Hovers).

4.3.2. Geographic and geological context

Ein Qashish is located in close proximity to the eastern slopes of Mt. Carmel, on the Pleistocene floodplain of the Qishon stream in Jezreel Valley, approx. 3.5 m below the present-day surface. The site stratigraphy consists of six sedimentary layers composing four human occupational horizons (Stahlschmidt et al., 2018). The sediments are composed mainly of black heavy clays and coarse cobbles transported by the short, steep, fast-flowing streams off the eastern flanks of Mount Carmel. The site sequence was dated through optically stimulated luminescence (OSL) to ca. 70–60 ka BP.

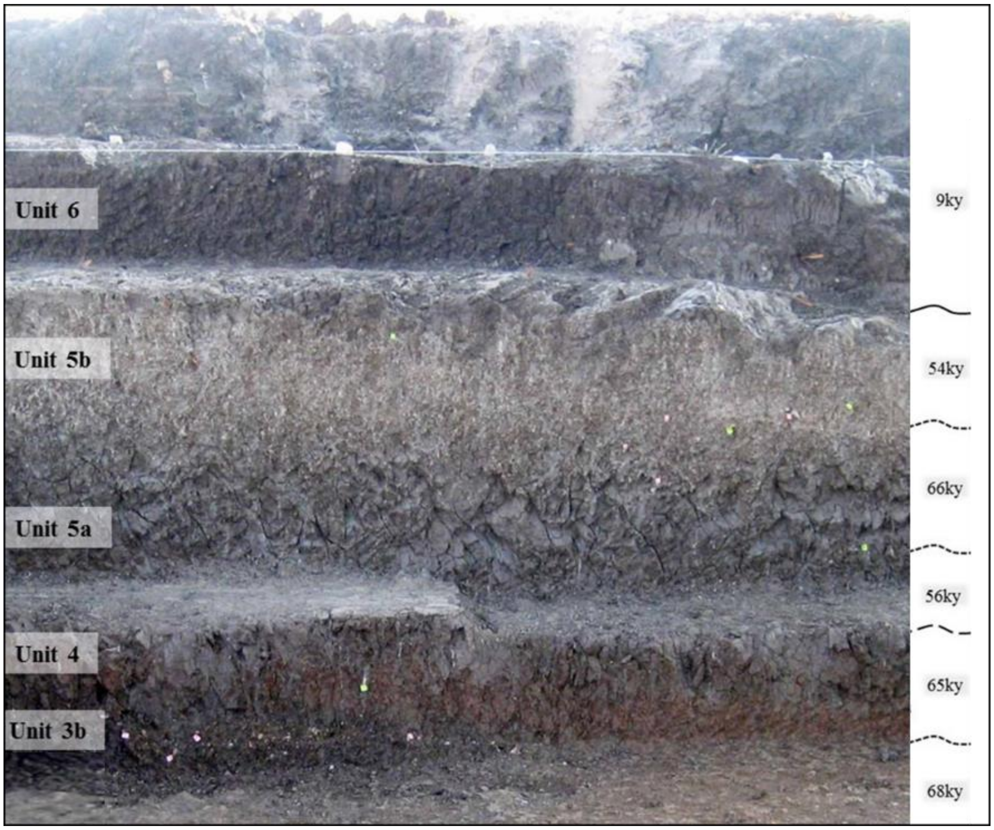


Figure 31: Chrono-stratigraphic profile from the site of Ein Qashish (Stahlschmidt et al., 2018).

4.3.3. Archaeological context

The archaeological context at Ein Qashish is characterized by a high density of lithics and faunal remains, with three different layers also yielding hominin remains, namely a skull fragment, an upper third molar, and five lower limb bones - a femur, two tibiae, and two fibulae (Been et al., 2017).

The lithic materials recovered from the site consist of knapped artifacts produced in flint (n=6281), some limestones manuports, and a relatively small number of Ground Stone Tools (n=8). Lithic analysis reveals the presence of three main technological systems at the site, Levallois, cores-on-flakes, and blade/bladelet production. In general, the assemblage is orientated to flake production, while points and cores for points production are rarely identified (Malinsky-Buller et al., 2014a).

In terms of faunal remains, a large number of highly fragmented bones were found, including *Bos, Dama, Capra, Gazella, Equus and Sus.* No remains of smaller mammals, birds, reptiles, or fish were found at the site (Ekshtain et al., 2019a; Hovers et al., 2014).

The hominin remains consist of three individuals, which were discovered in three distinct layers. One specimen consists of a non-diagnostic skull fragment, associated with layer 1. The second specimen is an upper third molar from the Layer 5a and was discovered close to flint and faunal remains. The third group and best-preserved hominin remains consist of a femur, two tibiae, and two fibulae. These remains were recovered from layer 3b, which was also composed of flint artifacts, faunal remains, and the limestone artifacts that are part of the research presented and discussed in this dissertation.

5. Results

5.1. Experimental results

A total of 31 samples were used in the mechanic experimental program (river cobbles). Twelve samples were used for bone breaking activities, eleven for flint knapping activities, four for grinding dry acorns, and four for humid acorns (Table 3).

Table 3: Mechanical experiments inventory.

Sample ID	Raw material	Type of experiment	Contact Material	Type of movement	Weight applied	Number of movements
3-7	Limestone	Mechanical	Fresh Bone	Impact	2	100
anvil-flint	Limestone	Mechanical	Fresh Bone	Impact	2.5	900
anvil-bone	Limestone	Mechanical	Flint	Impact	2.5	970
3-3	Limestone	Mechanical	Flint	Impact	2.5	50
3-8	Limestone	Mechanical	Fresh Bone	Impact	2.5	50
2-11	Limestone	Mechanical	Fresh Bone	Impact	2.5	50
3-11	Limestone	Mechanical	Fresh Bone	Impact	2.5	50
3-1	Limestone	Mechanical	Fresh Bone	Impact	2.5	85
3-9	Limestone	Mechanical	Fresh Bone	Impact	2.5	50
3-5	Limestone	Mechanical	Fresh Bone	Impact	2.5	50
2-6	Limestone	Mechanical	Fresh Bone	Impact	2.5	200
3-4	Other	Mechanical	Fresh Bone	Impact	2.5	50
3-10	Other	Mechanical	Fresh Bone	Impact	2.5	50
3-6	Limestone	Mechanical	Fresh Bone	Impact	2.5	500
4-1	Limestone	Mechanical	Flint	Impact	2.5	6
2-12	Limestone	Mechanical	Flint	Impact	2.5	50
2-1	Limestone	Mechanical	Flint	Impact	2.5	50
2-2	Limestone	Mechanical	Flint	Impact	2.5	50

2-9	Limestone	Mechanical	Flint	Impact	2.5	50
3-12	Limestone	Mechanical	Flint	Impact	2.5	50
2-10	Limestone	Mechanical	Flint	Impact	2.5	7
2-7	Limestone	Mechanical	Flint	Impact	2.5	50
2-5	Limestone	Mechanical	Flint	Impact	2.5	50
6-5	Limestone	Mechanical	Humid Acorn	circular	7	1000
6-2	Limestone	Mechanical	Dry Acorn	circular	7	1000
6-1	Limestone	Mechanical	Dry Acorn	circular	7	1000
6-6	Limestone	Mechanical	Dry Acorn	circular	7	1000
6-7	Limestone	Mechanical	Humid Acorn	circular	7	1000
6-3	Limestone	Mechanical	Humid Acorn	circular	7	1000
6-10	Limestone	Mechanical	Humid Acorn	circular	7	3000
6-12	Limestone	Mechanical	Dry Acorn	circular	7	3000

5.1.1. Percussive experiments

The set of percussive experiments allow a clear characterization of the macro and micro wear traces generated during contact with bone and flint. Using a controlled setup to compare both materials under the same conditions (e.g., impact force, number of impacts, position), it was possible to identify clear differences in terms of use-wear formation on the tools' surface. The difference in the physical alterations of the surface developed by the activities can be observed both at macro and micro scale.

Figure 32: Samples used for percussive experiments after cleaning (Photo: Eduardo Paixão).

5.1.1.1. ***Bone breaking***

At a macro scale, bone breaking activities produce a very low level of surface alterations on limestone. After 50 impacts, surface alterations were practically invisible at naked eye, revealing a major contrast when compared with the results of the flint knapping, under the same number of impacts. This absolute contrast raises the need to test if those differences could disappear after intensive use (i.e., high number of impacts). In other words, it was important to know if by increasing the number of impacts, the macro surface alterations would get to a stage where would it be impossible to distinguish from the results on flint experiment. To test this hypothesis, one sample was tested and evaluated over an extra number of impacts. In this study, sample 3-6 ran for 500 impacts on bone, which provide a convincing answer by showing then even when its used for considerably higher number of impacts, the macro surface alterations still totally distinguishable of the alterations produced by flint knapping.

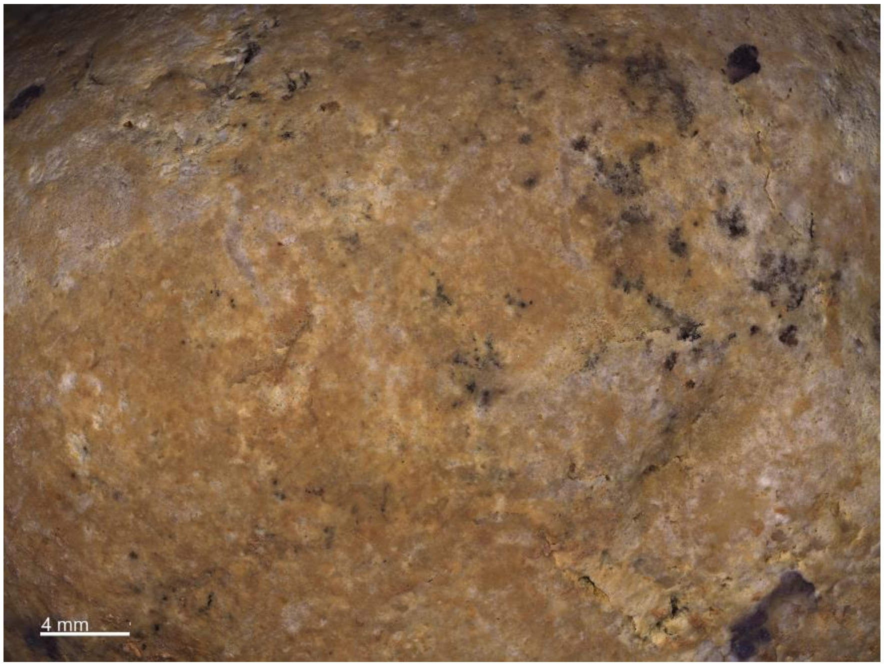


Figure 33: Sample 3-5 (used for 50 impacts on bone).

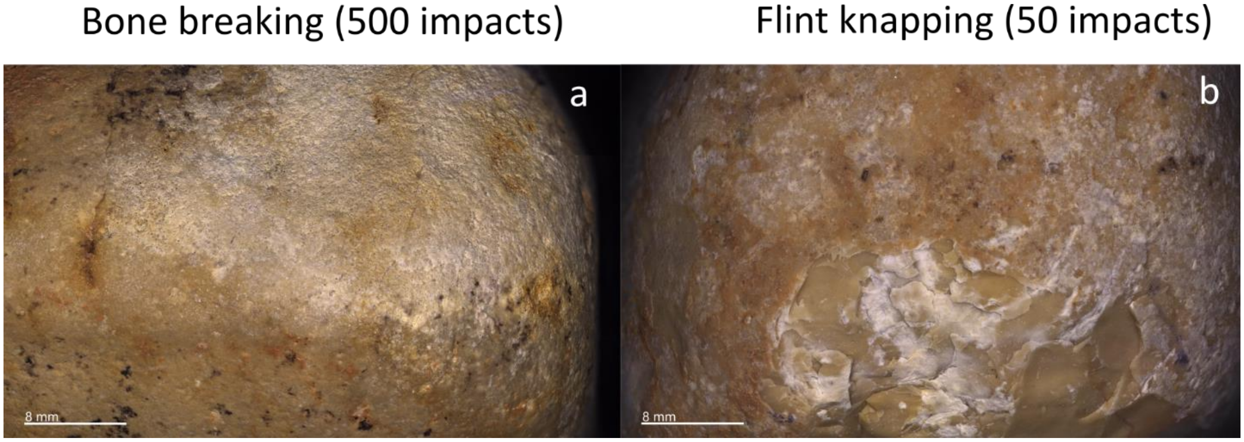


Figure 34: a) Sample 3-6 (used for 500 impacts on bone), and b) sample 3-12 (used for 50 impacts on flint).

Although in most cases the surface alteration produced by the bone contact during these experiments are difficult to detect at low magnification, the scenario changes completely when high magnification is applied. At the micro scale, it was possible to clearly identify polish, which is generally characterized by a fluid texture, domed cross sections, and partially penetrating on the low micro topography (fig. 31).

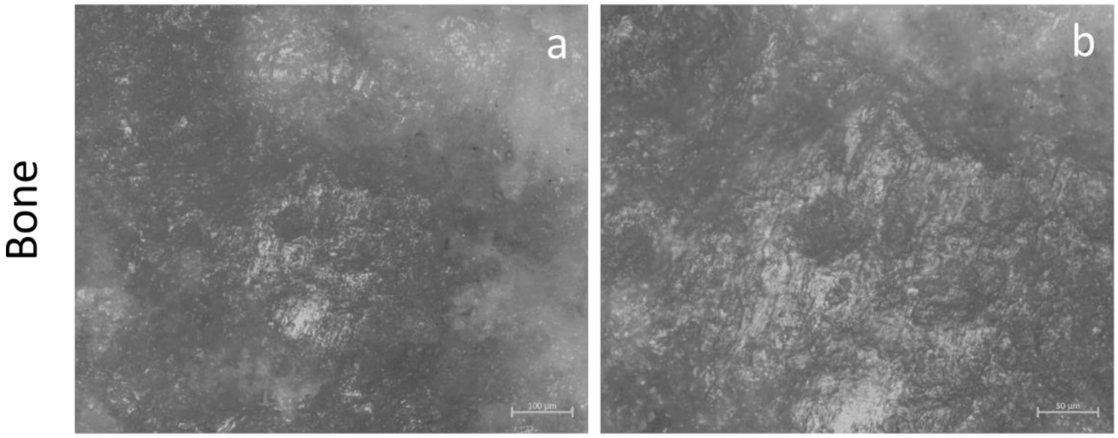


Figure 35: Metallographic microscope image of a polish formed by experiment with bone: a) 10x image of polish area and b) 20x image of a polish area.

5.1.1.2. ***Flint knapping***

When compared with the bone breaking motion, flint knapping activities produce major alterations both at macro and micro scale. At a macro scale it is possible to observe high levels of mineral crushing, fracturing, and formation of macro striations in the contact areas even after only a few impacts. This activity also often results in some level of flaking of the active area. The sample reached a level of damage too high to proceed with the experiment in only one case, where sample 2-10 broke after the seventh impact.

Figure 36: Flaking during knapping experiment.

Figure 37: Smart zoom microscope image: Sample 3-3 (used for 50 impacts on flint).

At micro level. it is possible to identify some polish areas generally characterized by flat cross-sections, rough texture, sharp contours, and frequent formation of deep abrasive tracks and multiple parallel striations. The polish in most cases is formed only on the high microtopography of the surface (fig.34).

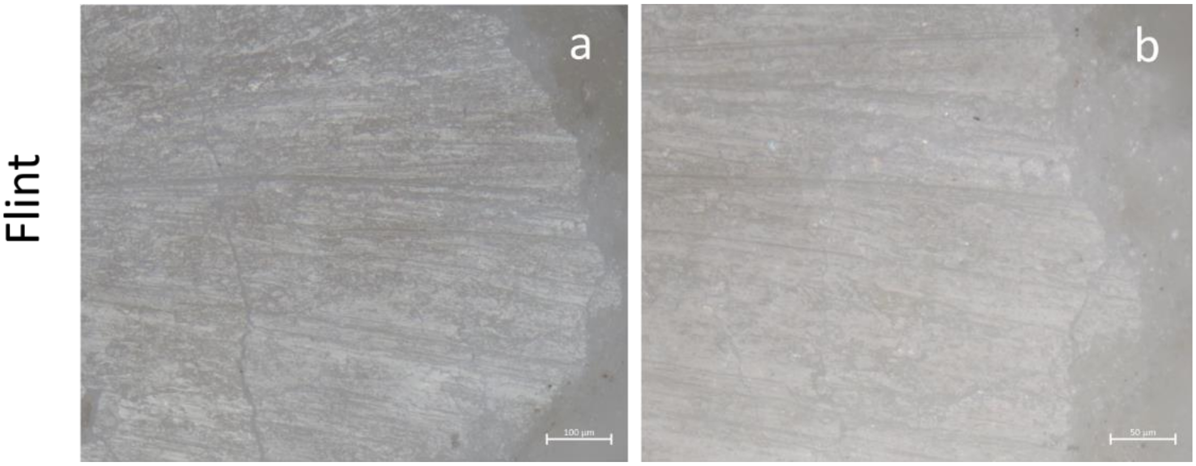


Figure 38: Metallographic microscope image of a polish formed by experiment with flint: a) 10x image of a polish area b) 20x image of a polish area.

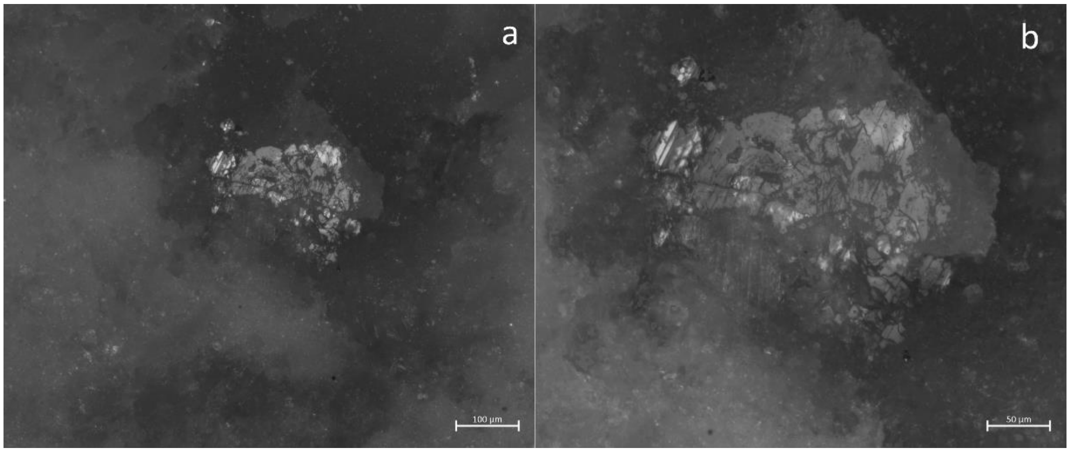


Figure 39:Metallographic microscope image of a polish formed by experiment with flint: a) 10x image of a polish, b) 20x image of a polish area.

5.1.2. Grinding Experiments

The set of experiments regarding grinding activities was dedicated to exploring the formation of use-wear traces on limestone as a result of the contact with acorn. The experiments were based on grinding acorn in a controlled environment. This experiment incudes acorns at two different levels of humidity (dry and moist), to investigate if this aspect can influence the physical alteration on limestone macro and micro surface texture.

Figure 40: Samples for grinding experiments (Photo: Eduardo Paixão).

5.1.2.1. ***Acorn processing***

The results from the acorn processing experiments reveal a very low level of surface alteration at a macro scale. In both conditions, the acorn activities did not produce surface alterations easily detectable by naked eye observations or even by low magnification microscopy (fig. 36).

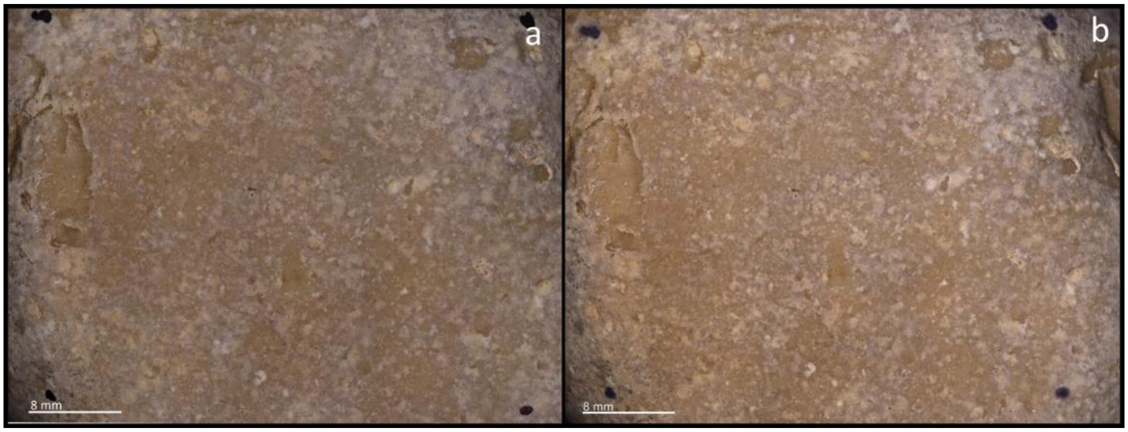


Figure 41: Smart zoom microscope image (34x): a) Sample 6-1 (before the experimental activity) b) Sample 6-1 (used for 100 rotations grinding dry acorn).

However, when observed at a micro scale, it is possible to observe the presence of micro polish developed. Both wet and dry acorn reveal micro polish formation, however, with different characteristics. While the polish formed by wet acorn tend to be more disperse, with diffuse contours and free or very low level of striation, the polish formed by dry acorn tends to reveal much more abrasive traces, being more compact, with sharp contours, and a high level of striation (fig. 42).

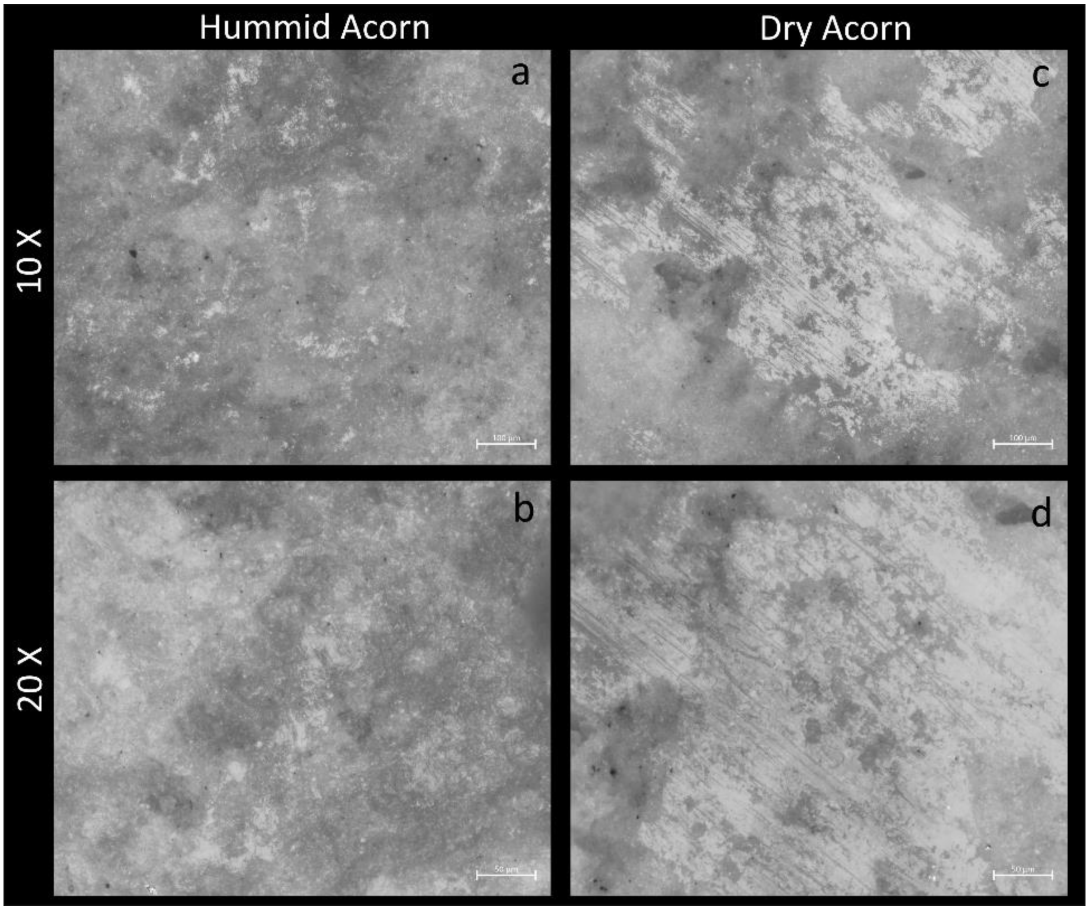


Figure 42: Polish formation by grinding acorn: a) sample 6-7 10x b) sample 6-7 20x c) sample 6-6 10x d) sample 6-6 20x.

The differences in the micro texture of the polish formed by these two conditions of the acorn were also measured using confocal microscopy. Results from the 3D micro texture analysis show clear differences, which can be seen in most of the analyzed micro surface analytical parameters (see sub-chapter 5.1.3).

5.1.3. Experimental summary and quantitative approach

Together with the multi-scale approach for observation on the experimental results presented above, also quantitative methods were applied, for two different scales of analyses: a) use of 3D models to generate Digital Elevation Model (DEM) for different surface/terrain analysis and b) 3D Laser Confocal microscopy to micro surface texture analysis of the micro polishes.

In terms of the analysis of the data from the 3D models, it was possible to verify that when comparing before and after experimental cycles, the experiment with flint is the one that shows significant changes in both slope and roughness. In this case, slope data shows a clear tendency for surface areas with lower slope values to increase after the experiments.

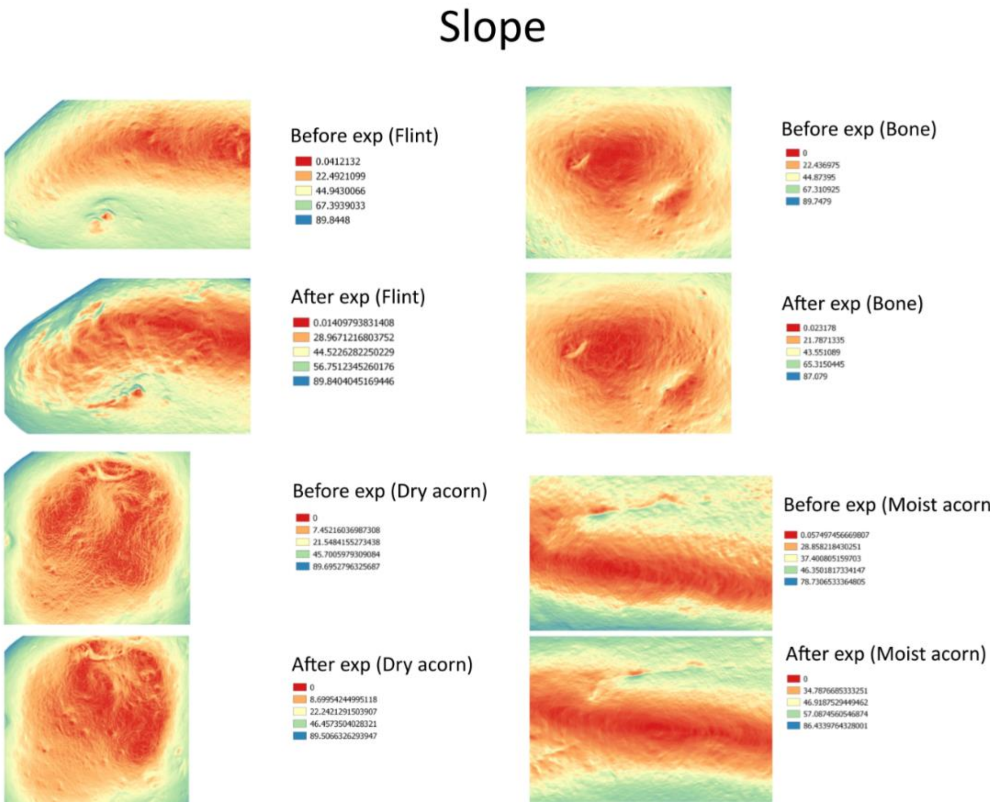


Figure 43: Slope projection on active areas of experimental tools.

In figure 44 it is possible to see how the different experiments modify the surface in terms of slope. Samples 3-3 and 2-5 (used for flint knapping) show an intense alteration when compared with the samples 3-8 and 3-9 (used for bone breaking). For the last three, the alterations are poorly detectable at this scale of analyses.

Flint experiments also produced surface alterations that are clearly detected and measured by the quantification of slope. These are marked by a clear increasing in the percentage of areas with lower inclination angles. This means that the normal curvature of the stone was reduced by the impacts, generating an increase of flattened areas. In sum, is possible to conclude that the activities involved in impact motions leave marks on the surface that are detectable and possible to measure, by calculation of the slope. However, the same computation did not detect significant alteration when applied to the sample used for grinding experiments. As it is possible to verify in fig.44 and 45, in this case, the distribution of the slope values, did not change significantly after the experiments.

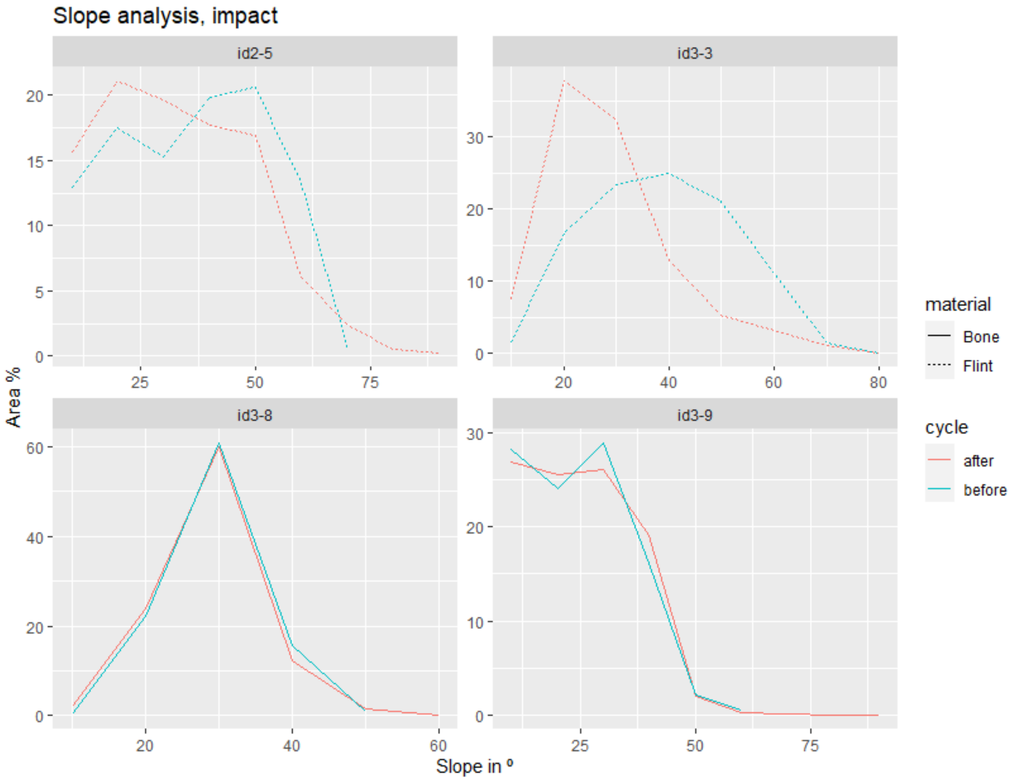


Figure 44: Projection of slope values on experimental samples for impact experiments (% of area).

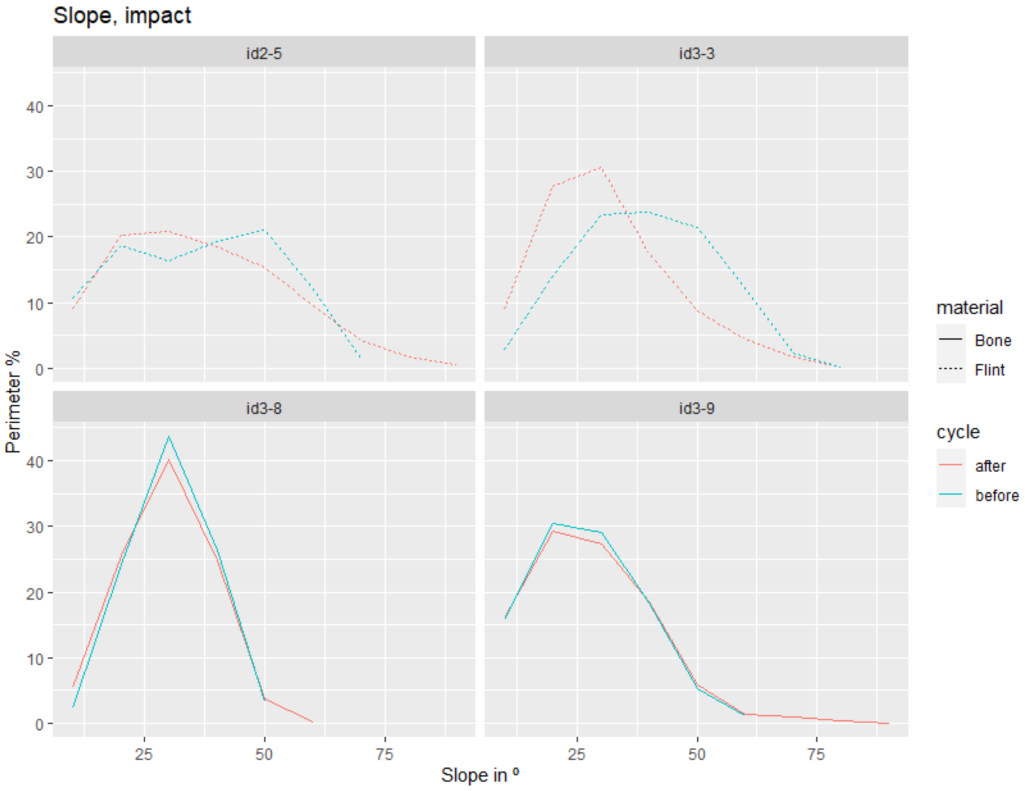


Figure 45: Projection of slope values on experimental samples for impact experiments (% of Perimeter).

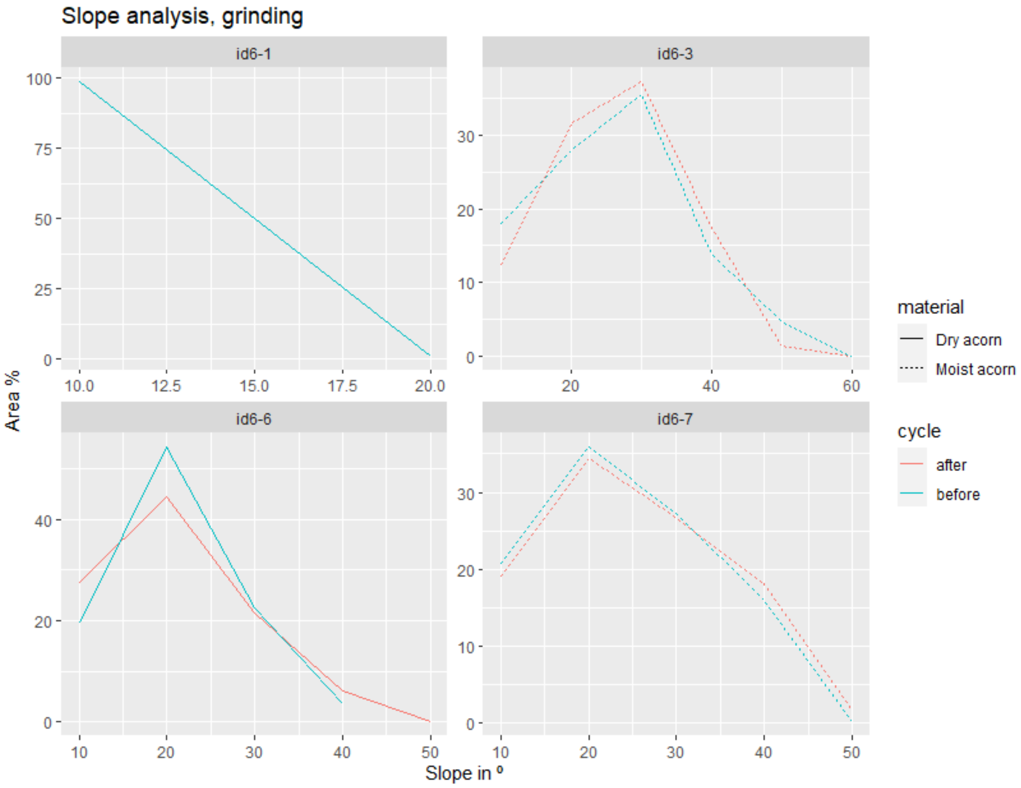


Figure 46: Projection of slope values on experimental samples for grinding experiments (% of area).

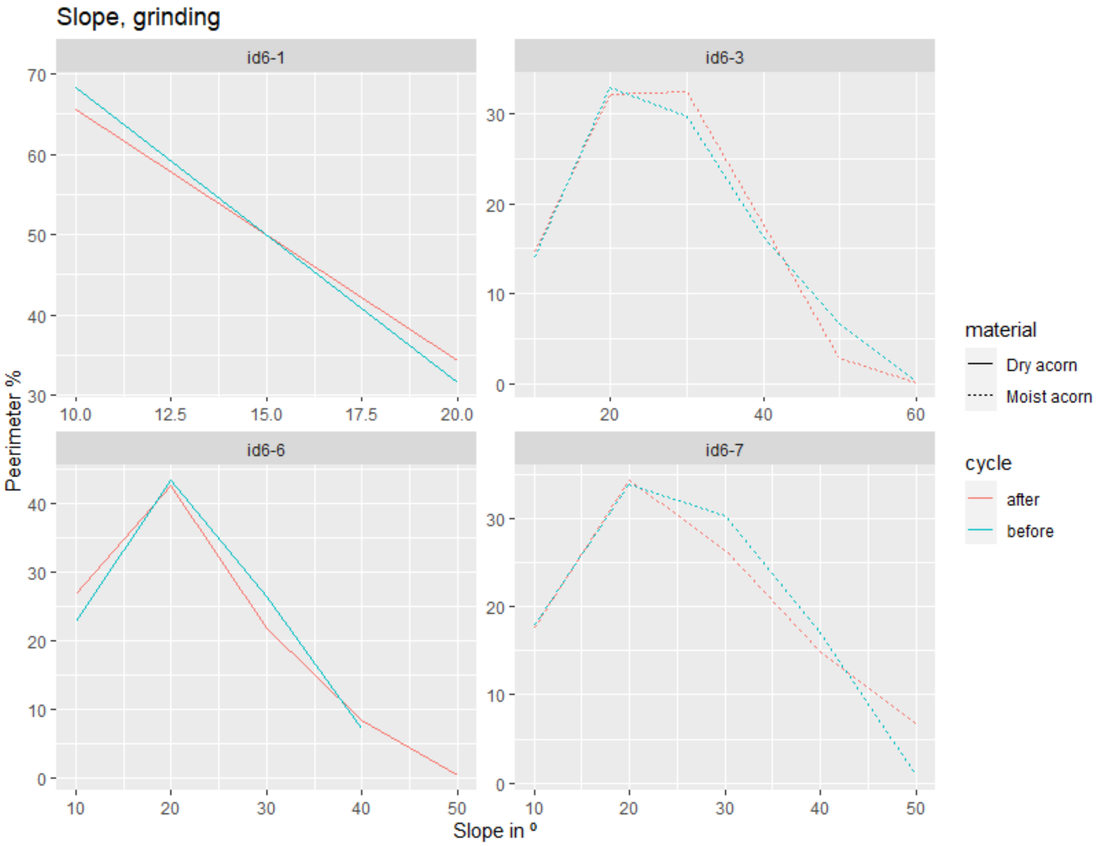


Figure 47: Projection of slope values on experimental samples for grinding experiments (% of perimeter).

Concerning the Terrain Ruggedness Index (TRI), all percussive experiments tend to increase the values, both absolute values, area, and perimeter, which illustrates an increase in macro surface roughness. However, the different materials did not form diagnostic patterns detectable at this scale by this computation. The TRI differs from the slope computation, as with the TRI it is also possible to identify changes in the surfaces of the tools used for grinding experiments. In this case it is possible to verify a tendency for a reduction in surface complexity, where the values tend to converge (fig. 48 to 51).

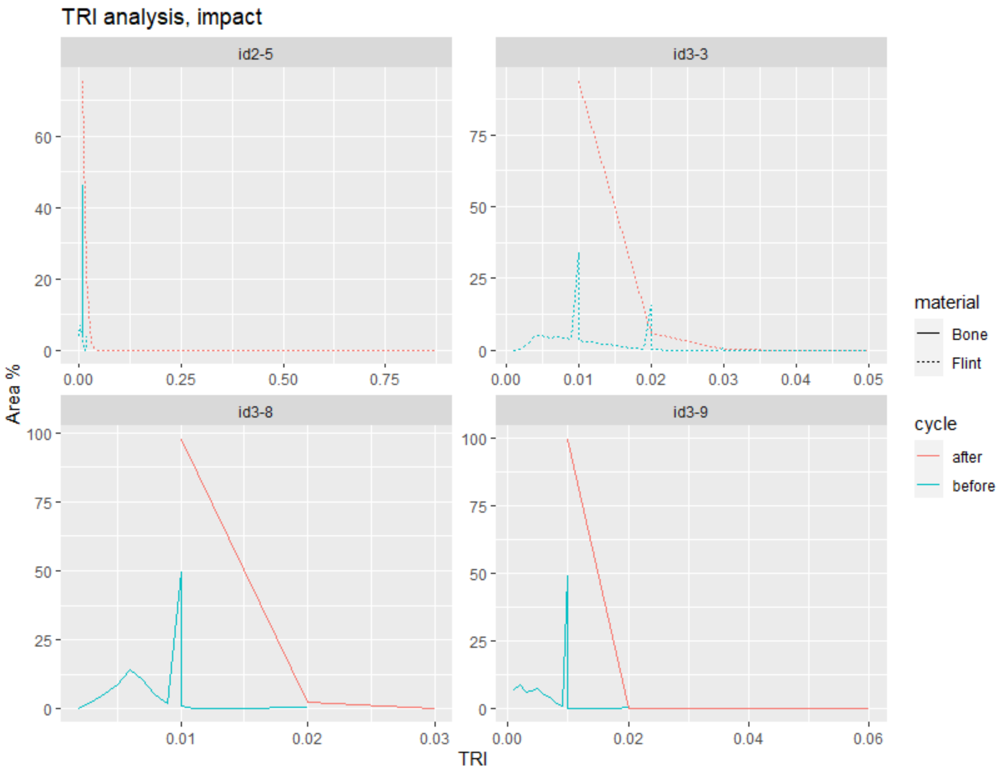


Figure 48: Projection of TRI values on samples used for impact experiments (% of area).

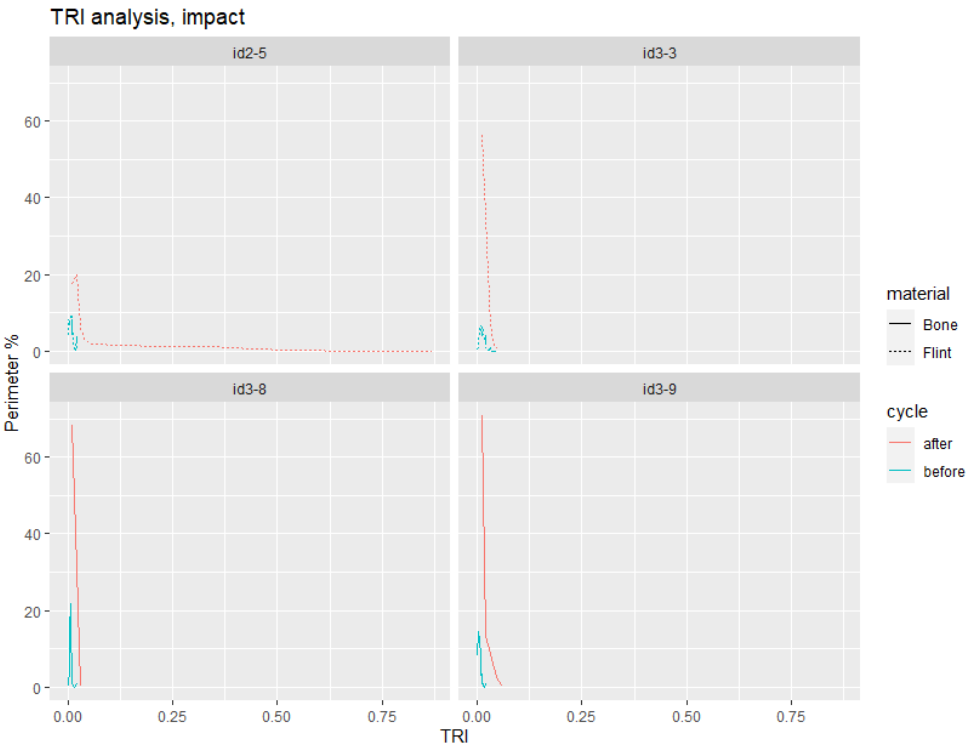


Figure 49: Projection of TRI values on samples used for impact experiments (% of perimeter).

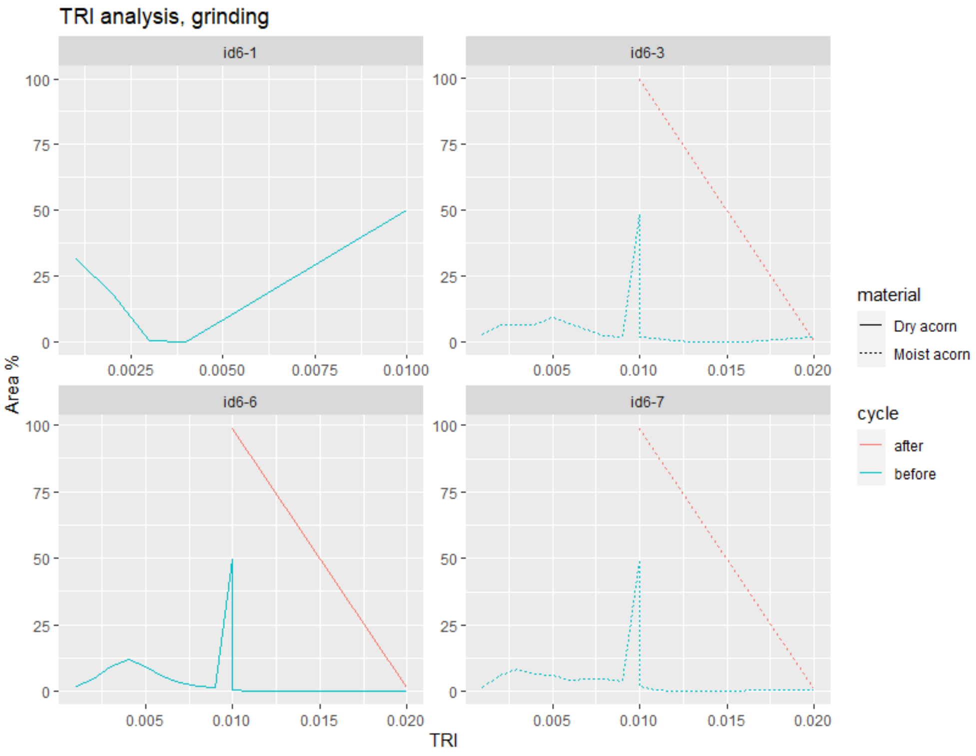


Figure 50: Projection of TRI values on samples used for grinding experiments (% of area).

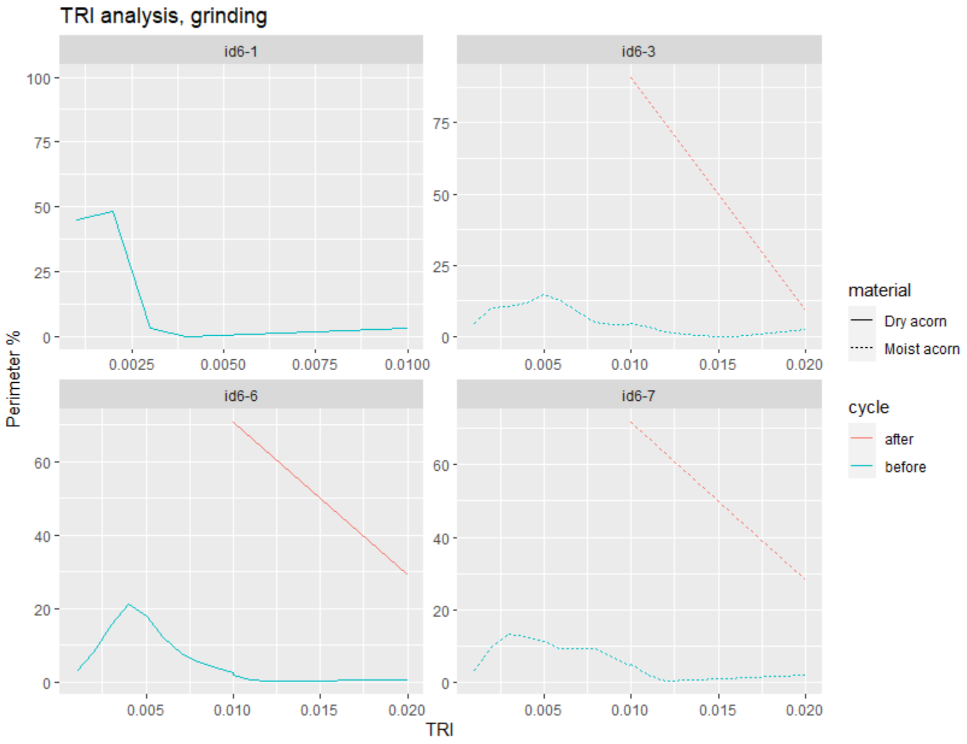


Figure 51: Projection of TRI values on samples used for grinding experiments (% of perimeter).

At the micro scale, a quantitative comparison of the polish developed by the different experiments was applied, using laser scanning microscopy. This method aimed to get quantitative data based on the analysis of Area-scale parameters ISO 25178 for surface texture, including area and volume parameters.

Through the analysis of the contact material individually, it is possible to verify that in the grinding experiments the dry acorn tend to form a more consistent range of values between measurements from each group, however without overlap between them, except for one single parameter (Sku) (fig. 52). An opposite scenario occurs with the moist acorn where the variation of values tends to be higher for most of the parameters.

Within the group of the impact experiments (flint / bone), is interesting to verify that most of the parameters manage to show a distinctive signal between bone and flint. While the flint results tend to present a higher spectrum of values, the bone contact tends to present less variation in the values.

Although there are some values for some parameters that overlap between the polish formed by these different activities, through the analyses of the density of furrows it is possible to see a clear distinctive pattern between both the type of activity, and contact materials. The polish formed by percussive activities tends to present considerably higher values (fig. 56).

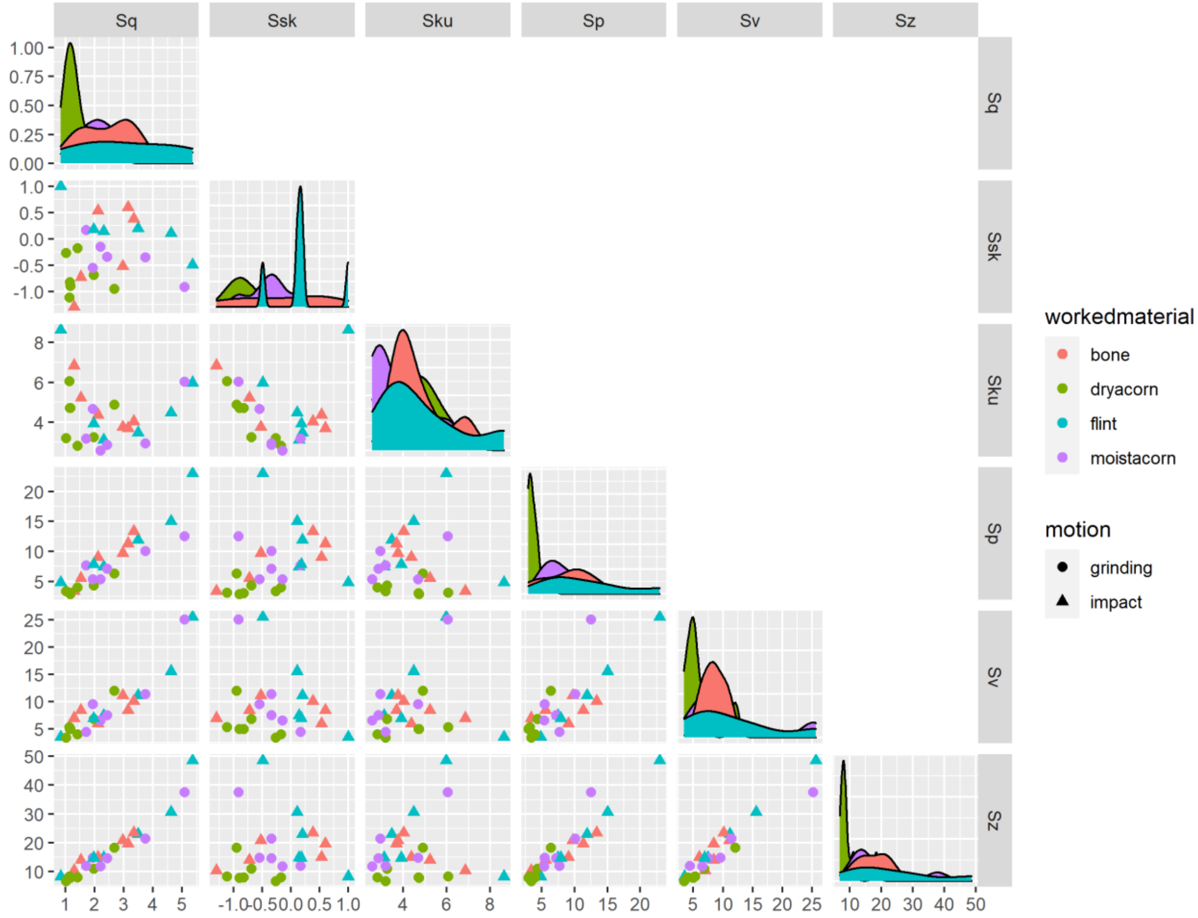


Figure 52: Texture surface analyses for experimental results (area parameters).

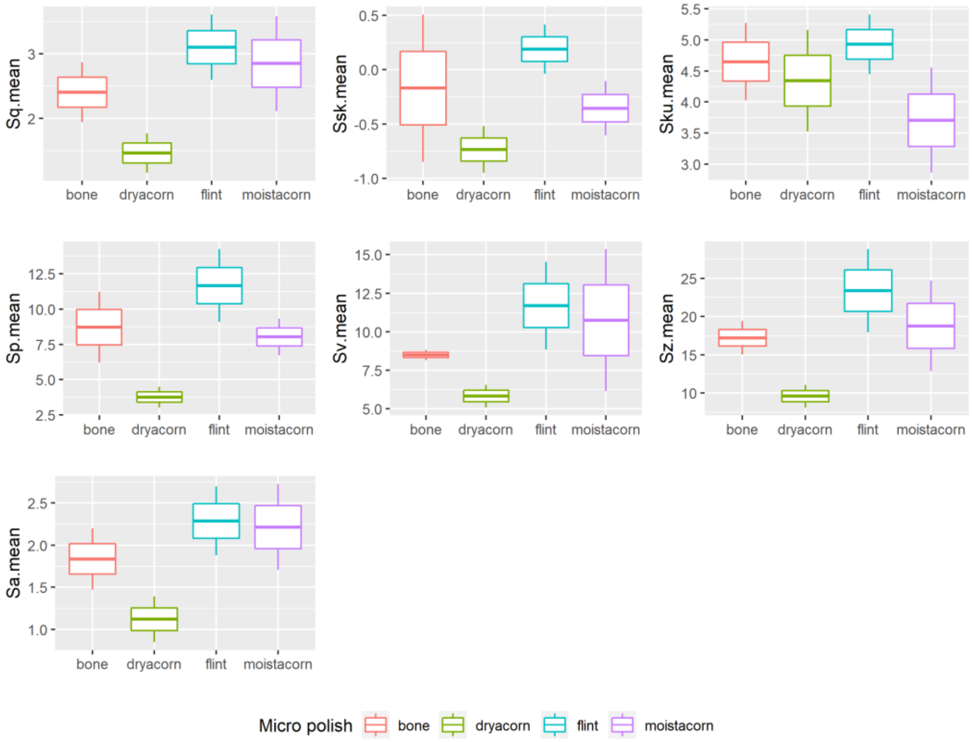


Figure 53: Box plots with texture surface analyses of experimental results (area parameters).

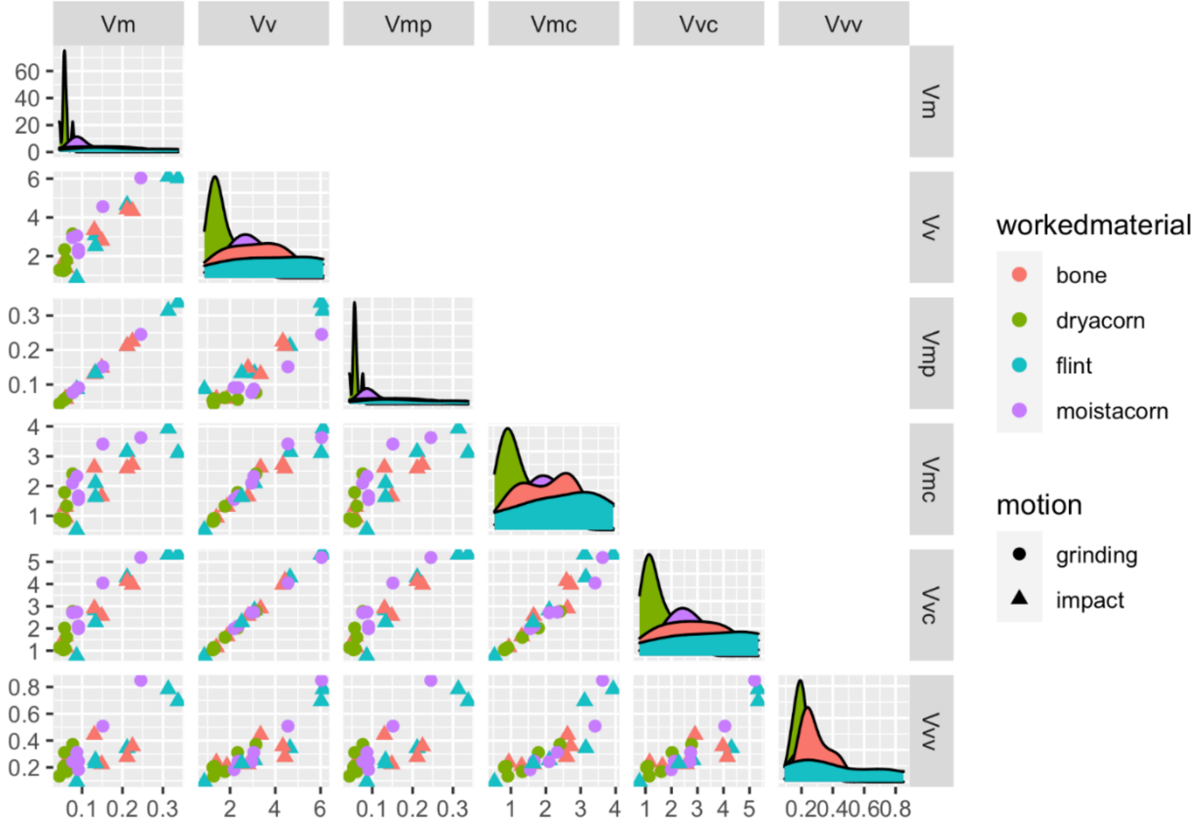


Figure 54: Texture surface analyses for experimental results (volume parameters).

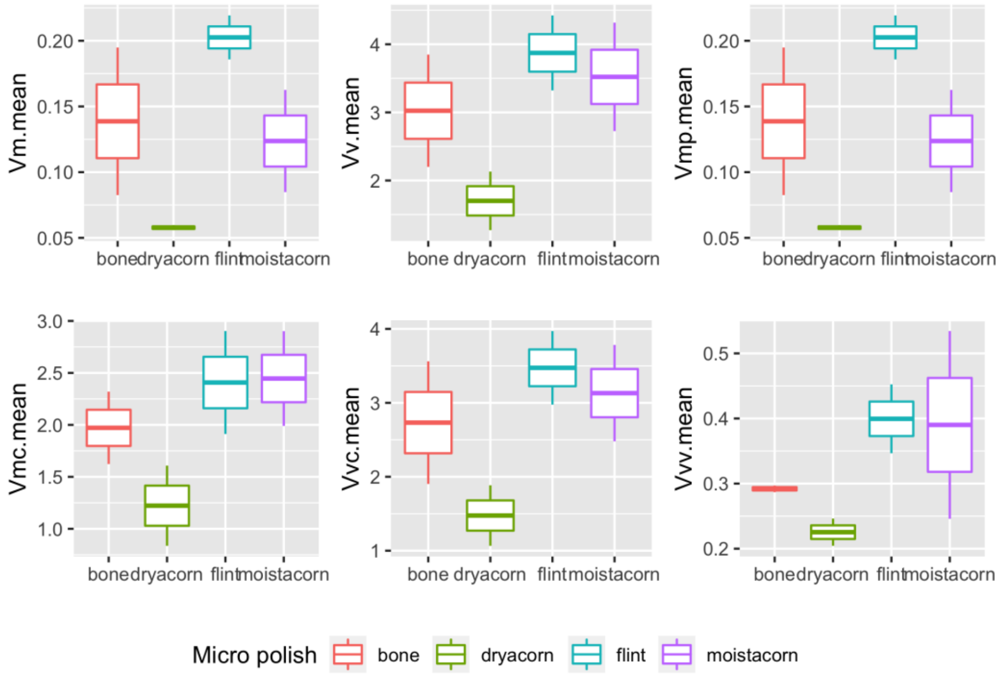


Figure 55: Box plots with texture surface analyses of experimental results (volume parameters).

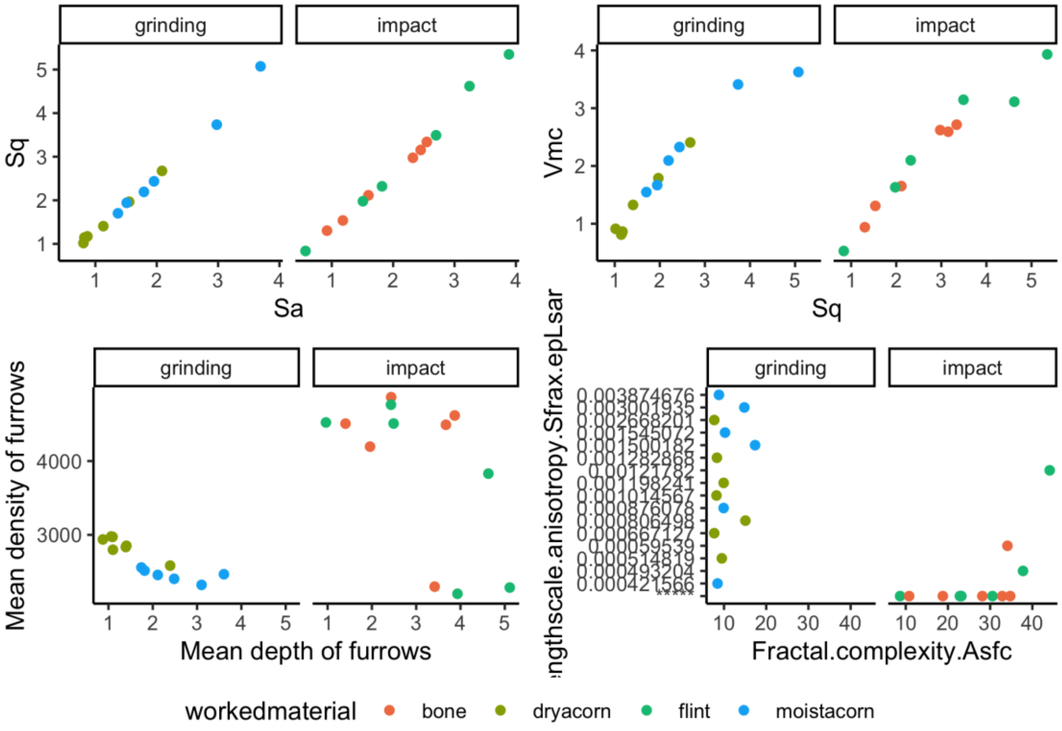


Figure 56: Scatterplot with some of the most significant parameter for micro surface quantitative analyses.

5.2. Archaeological results

5.2.1. Nesher Ramla Results

A total of 471 artifacts were analyzed, including pieces typologically categorized as pebbles, blocks, cobbles, and boulders. These artifacts consist mostly of limestone (97.5%) and a small proportion of flint (2.5%).

Table 4: General inventory of the Ground Stone Tools assemblage from Unit V of Nesher Ramla, organized by raw-material and support.

Raw material	Block	Boulder	Pebble	Total
Flint	1	0	5	6
Limestone	68	7	390	465
Total	69	7	395	471

The combination of analysis through the *naked eye* and through low and high magnifications allowed the identification of a large number of artifacts with possible evidence of anthropic alterations (n=185, c. 39% of the entire assemblage). This group consists mostly of pebbles, cobbles, and blocks, with a considerable metric (length and width) and weight variation. There is also a group of cobbles and pebbles that did not have any identifiable evidence of use, but since these are interpreted as been transported to the site by non-natural causes, they were classified as manuports (de la Torre & Mora, 2005; Leakey, 1966).

5.2.1.1. ***Technology and typology***

A total of 185 artifacts were identified with surface alterations that we visually interpret as use-wear traces. From the typological perspective, these artifacts are categorized as anvils, hammerstones, abraders, pestles, and choppers. Only hammerstones were identified on flint (i.e., flint pebbles), with all the other types exclusively made of limestone.

Table 5: Typological inventory of the Ground Stone Tools at Unit V of Nesher Ramla.

Raw material	Abrader	Anvil	Chopper	Hammerstone	Manuport	Natural	Other	Pestle	Total
Flint	0	0	0	1	4	0	1	0	6
Limestone	11	23	13	105	220	43	46	4	465
Total	11	23	13	106	224	43	47	4	471

Most of the artifacts are in the size range between 42 and 176mm of maximum length axis, and the mean weight is approximately 450g (fig 62 and 62). All types fall within the same range of metric values, with exceptions for some anvils and one chopper tool that present bigger dimensions. A considerable number of tools show some level of fragmentation, in some cases small-fragmented areas are associated with impacted surfaces. In most cases the tools do not reveal any kind of technological preparations prior to their use, except for the tools classified as choppers and in some cases as anvils, that reveal some level of preparation by flake removal (see fig.57 and 58).

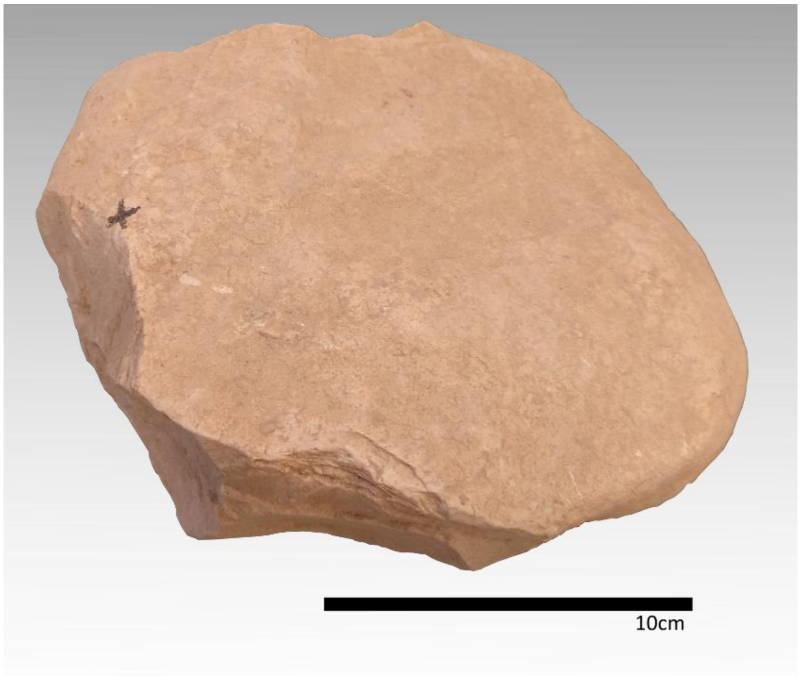


Figure 57: Anvil showing some flake scar, as a clear evidence of tool premeditated preparation.

In the case of the choppers, there is a trend of flake removal used to create and angle the tool, however with a low level of standardization. This type of tools appears in different sizes, and their angle are often quite irregular, in general the angles are approximately between 45 and 90 degrees.

Figure 58: Tools with flake removals that aimed to prepare a sharpened edge angle preparation (Photo: Eduardo Paixão).

Hammerstones, abraders, and pestles, do not show any evidence of preparation prior to their use. In this study, these three categories were divided according with a functional interpretation as a result of the multi-scale approach, and are not based on a significant difference in terms of morphometric or technological aspect.

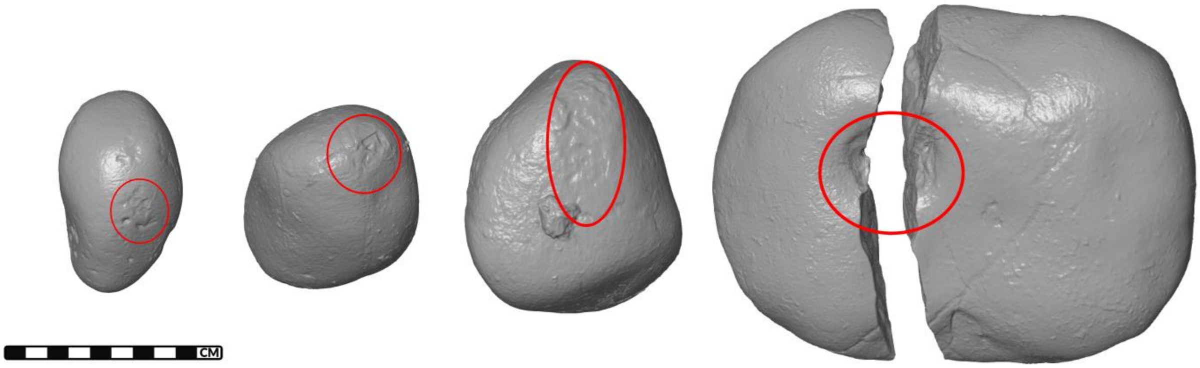


Figure 59: Nesher Ramla Hammerstones and anvil with red circle showing the impact marks (based on 3D models).

Figure 60: Hammerstones (Nesher Ramla).

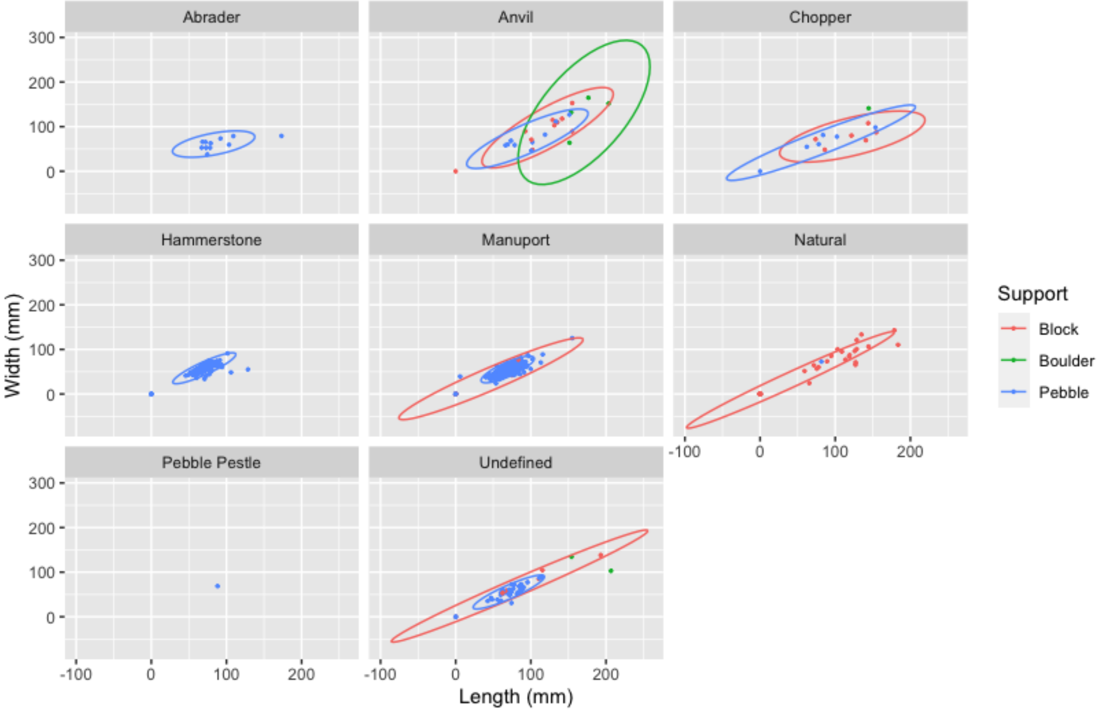


Figure 61: Scatterplot showing artifact dimensions organized by typology and support type (Nesher Ramla).

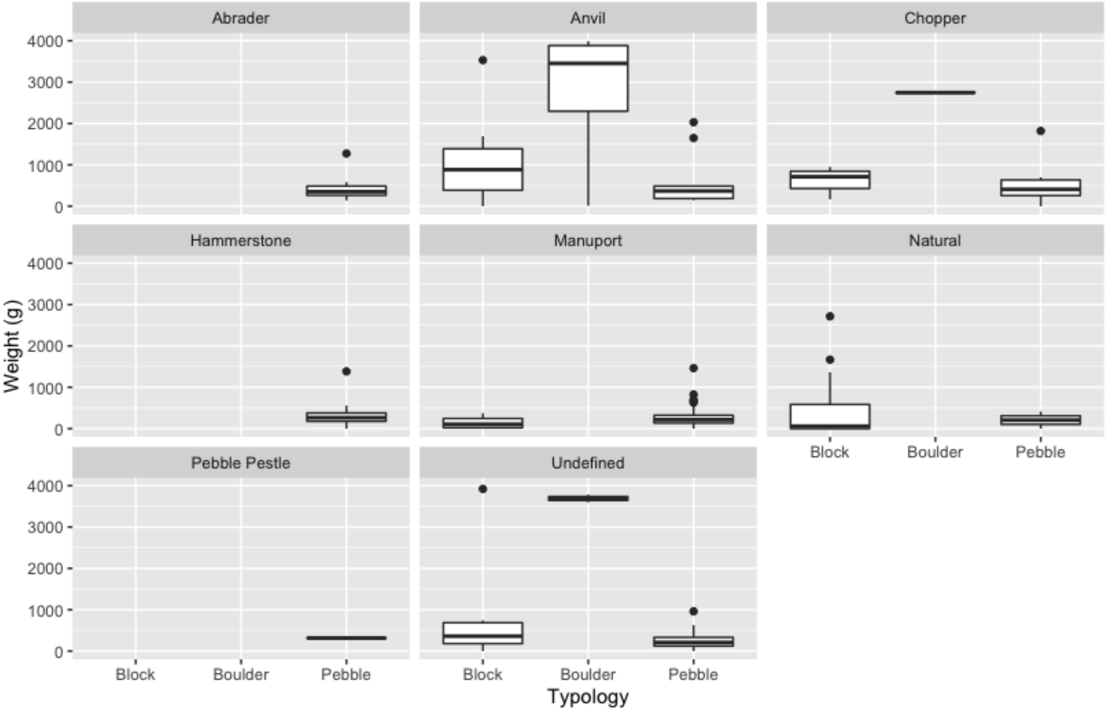


Figure 62: Boxplot showing artifact weight organized by typology and support type (Nesher Ramla).

5.2.1.2. ***3D analyses***

Using the 3D scans of the artifacts, it was possible to compute the slope of the surface in two different levels of observation. First by computing the entire surface of the tools, and second by focusing on the selected areas, that on visual examination show surface use-wear. The result of this approach highlights the influence that the scale of observation has on the analyses. The slope computation, when applied to the entire surface of the tools, was highly influenced by the natural morphology of the tools, which become an obstacle to the characterization and comparison between typologies. In this case, the results show a considerably higher frequency of areas with high levels of slope, where the signal presents with too much "noise" to allow detection of the smaller scale difference between active areas, as shown in the figure 58. Likely due to this "noise" all typologies reveal a similar pattern in the distribution of slope angles, where the angles bigger than 64º are always predominant. Nevertheless, it is interesting to verify a high level of similarities in terms of the supports surface topography.

In order to obtain higher resolution on the surface areas with damage, the slope was also computed in cut areas of the scan which correspond to the active area of the tools. In this case a group of hammerstones and anvils, which show the highest variability were selected and tested. By excluding the "noise" of the natural curvature of the tools, this results in a more equal distribution of slope values when compared with the analysis on the entire surface, and the comparison between types of tools becomes a possibility. Here it is possible to verify that despite the general similarities in the curve of values of the slope, the anvils show considerable higher percentage of areas with 0 to 9º when compared to the hammerstones (fig.64). This represents a quantitative characterization of the active areas that was not possible to achieve when applied to the entire surface of the slope.

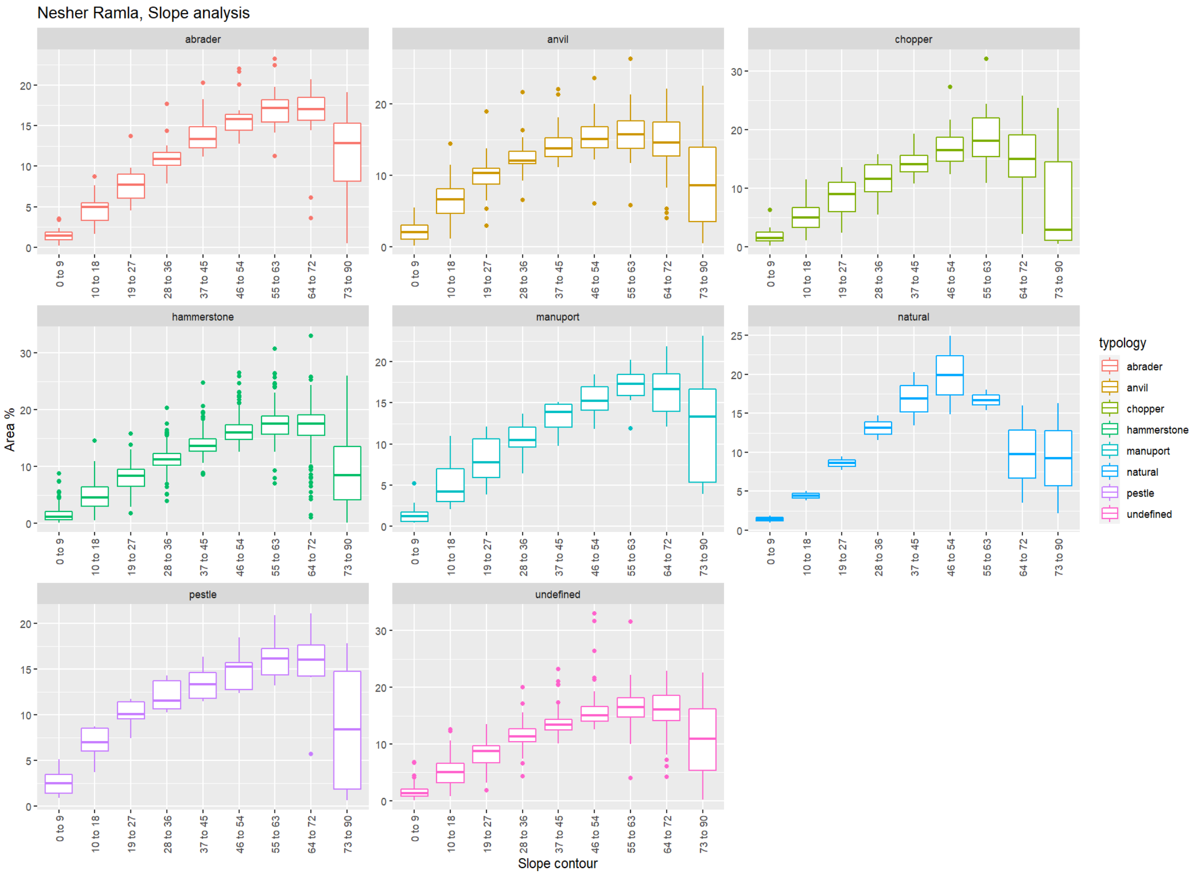


Figure 63: Box plots with slope contour values for the entire surface.

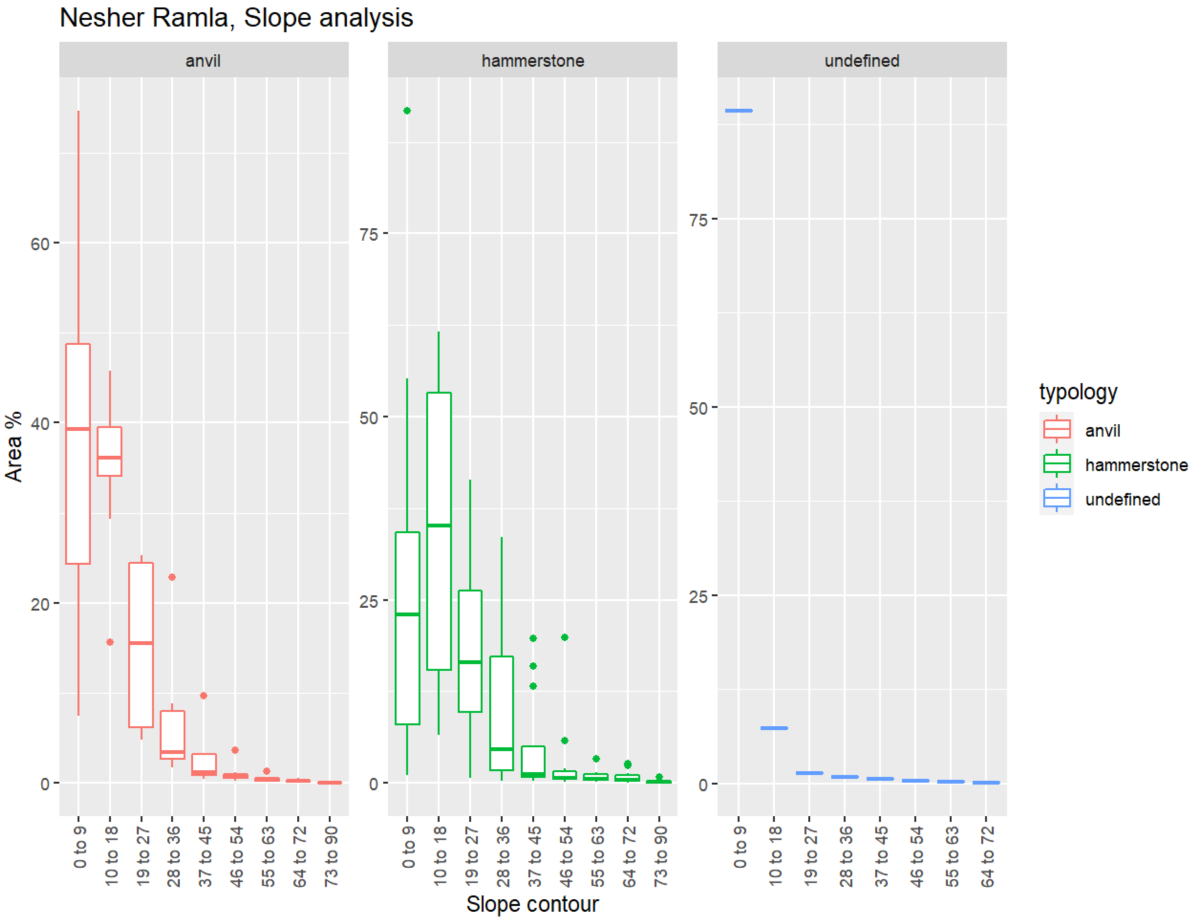


Figure 64: Box plots with slope contour values of the active area.

The analyses of the Terrain Ruggedness Index (TRI) were focused on the impact marks identified on the hammerstones, in order to test the variability within the most frequent tool type in the assemblage. The result of this computation reveals that this group of tools are homogenous in terms of their TRI values, where the predominant values are between 0 and 0.2. This result also indicates that in order to recognize different patterns within this type of tools, a higher scale of analyses should be applied (fig. 65).

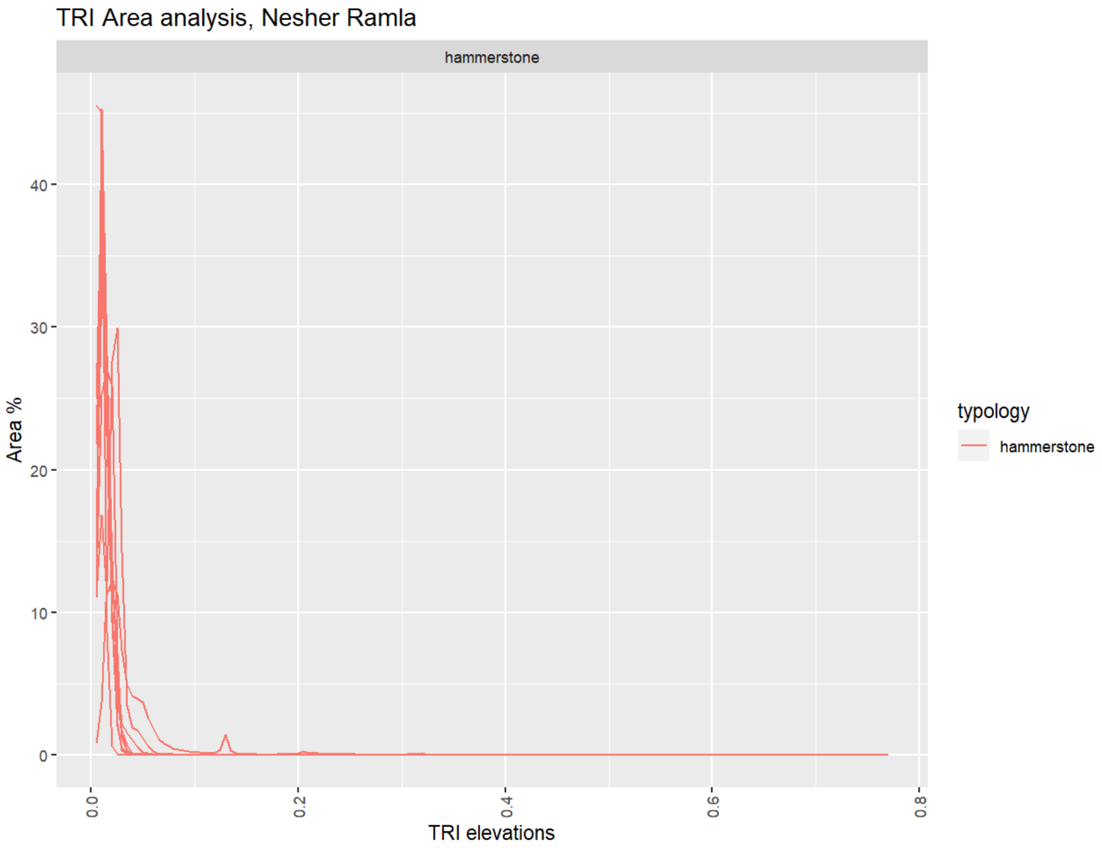


Figure 65: TRI values of the hammerstones active areas.

5.2.1.3. ***Use-wear analyses***

5.2.1.3.1. *Macro wear*

Preliminary macro-observations allow the identification of tools with impact marks (n=140), polished areas (n=24), striations (n=6), and some with a combination of different types of use-wear marks (n=15).

In this study, data shows that impact marks are present on most of the tool types, however, they are much more common on hammerstones (n=104), anvils (n=19), and choppers (n=1). In some cases, these three tool types exhibit combinations of impact marks and polish (here categorized as Mixed). Abraders are characterized by the exclusive presence of polish (n=8), occasionally associated with striations (n=2). The group of tools categorized as 'other' (i.e., non-diagnostic typological categorization), include tools with all types of wear, but the presence of polish is the commonest wear (n=16).

Table 6: Frequency of the different types of use-wear traces organized by tool type (Nesher Ramla).

Typology	Mixed	Impact marks	Polish	Striations	Total
Abrader	0	1	8	2	11
Anvil	2	19	0	1	22
Chopper	1	10	0	0	11
Hammerstone	4	104	0	0	108
Other	8	5	16	3	32
Pestle	0	1	0	0	1
Total	15	140	24	6	185

Following *naked eye* observations, the results of low magnification inspection also show that it is generally possible to distinguish between two main groups of anthropogenic impact marks, here called Type 1 and Type 2. Type 1, identified on 27 tools, is mainly characterized by clear concentrations of impacts although showing a low level of alteration of the tool surface. Type 2, identified on 82 tools, is characterized by impacts with considerable higher level of surface penetration in contrast with Type 1. Type 2 is also often present on tools where flake removals have been documented (i.e., choppers).

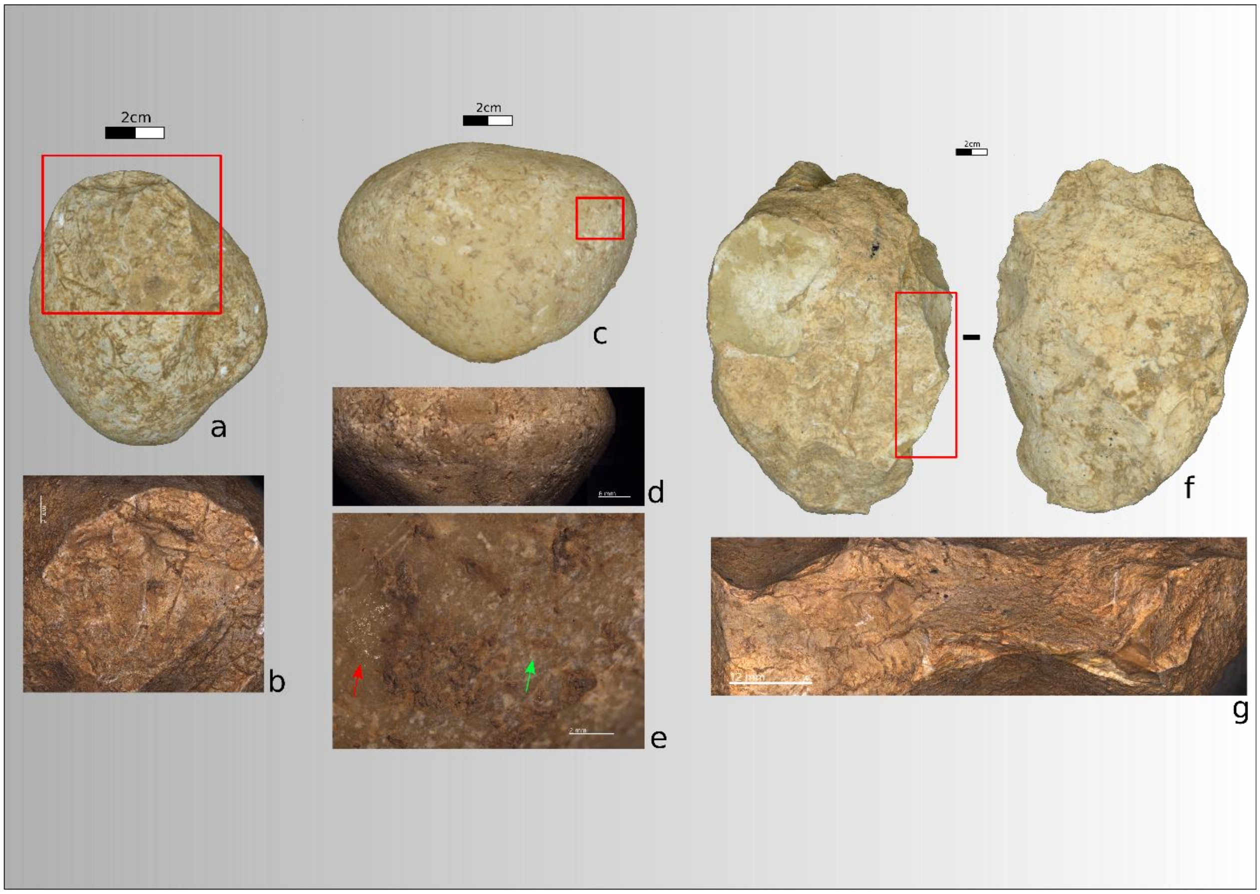


Figure 66: Examples of the different types of impact and polish wear traces: a) hammerstone with impact marks Type 2, b) fractured area associated with impact Type 2 c) general photo of hammerstone with impact marks Type1, d) fractured area associated with impact Type 1, e) polish (red arrow) in association with impact marks (green arrow), f) general photo of chopper tool, g) impact marks on chopper edge.

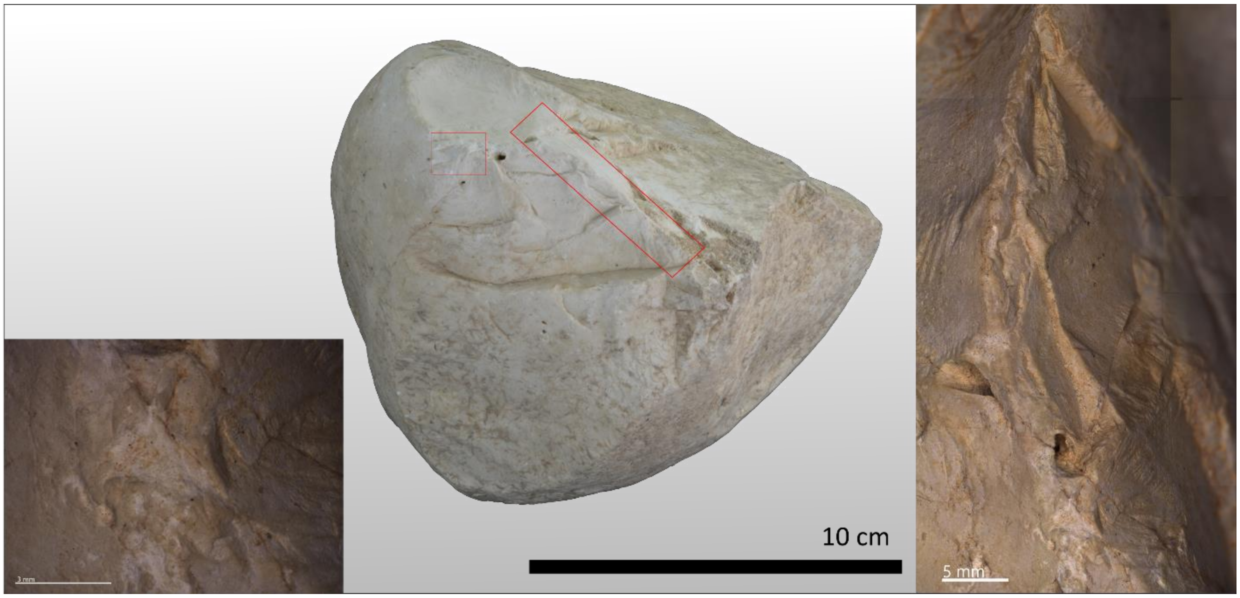


Figure 67: Tool with impact marks on the edge.

In most of the tool types where impact marks were identified they correspond to Type 2 (85.86%), except for in pestles, where Type 1 is dominant. Type 1 impacts (14.14%) are identified in all tool types. In real numbers, the difference between counts of Type 1 and Type 2 marks tends to be very small, except in the case of hammerstones. In this case, although the majority have macro-type 2 (n=82) there is also a considerable presence of type 1 (n=27).

Table 7: Macro use-wear traces organized by tool typology.

Typology	**Type 1**	**Type 2**	**Total**
Anvil	1	10	11
Chopper	2	4	6
Hammerstone	21	65	86
Pebble Pestle	2	1	3
Undefined	1	2	3
Total	27	82	109

Table 8: Criteria of classification for each macro use-wear traces type.

Impact marks type	Description		Interpretation
	Abrasive	***Fatigue***	
Macro 1	Low level of striations and scratching	Low level of surface crushing or fracturing	Bone breaking Semi-hard or soft materials
Macro 2	Identification of macro striations	High level of surface crushing or fracturing	Impact with hard mineral material
	Smoothed grain edges	Areas with deep depressions	knapping
		High level of macro mineral crushing	Abrasion and retouching

5.2.1.3.2. Micro wear

Microscopic analyses at high magnification allowed the identification and description of a total of 29 tools with clear evidence of micro polished areas (i.e., sheen). Generally, micro polish was identified on tools with a single active area, and in few examples on tools with two active areas. Concerning tool types, polish was identified on hammerstones, abraders and choppers. The different types of polish are organized into four main categories (described as A, B, C and D), established on their characteristics and functional interpretations. These categories are mainly based on the polish mesh, cross section of the polish, texture, reflectivity, contours, and presence of other features such as striations and abrasive tracks. The characteristics described for categorize the polish type A were experimentally reproduced during the experiments on flint knapping, and the characteristics of the polish type B were reproduced during the bone breaking experiment. In these two cases, the experiments corroborate the previous assumptions. The interpretations for the type C and D are not yet directly supported by experiments. In these cases, the suggested interpretation is based in the polish physical characteristics and distribution.

It is important to keep in mind that, in general, the frequency of micro traces is low, especially when compared with the occurrence of macro traces. Within the group of tools with micro use-wear traces, Types A (27.59%), B (34.48%) and D (31.03%) are represented in similar proportions, while type C (6.90%) appears to be less frequent. Type A was identified on abraders (n=4), and also rarely on hammerstones (n=1). On the other hand, type B was found in all types except for the pestle category. Type C occurred primarily on tools categorized as abraders and hammerstones. Type D was identified in most cases on tools categorized as *undefined*.

Table 9: Micro use-wear traces organized by tool typology.

TYPOLOGY	**A**	**B**	**C**	**D**	**TOTAL**
Abrader	4	1	1	0	6
Anvil	0	1	0	0	1
Chopper	0	1	0	0	1
Hammerstone	1	2	1	0	4
Pestle	0	0	0	1	1
Undefined	3	5	0	8	16
TOTAL	8	10	2	9	29

Figure 68: Abrader from Nesher Ramla (id: 4340).

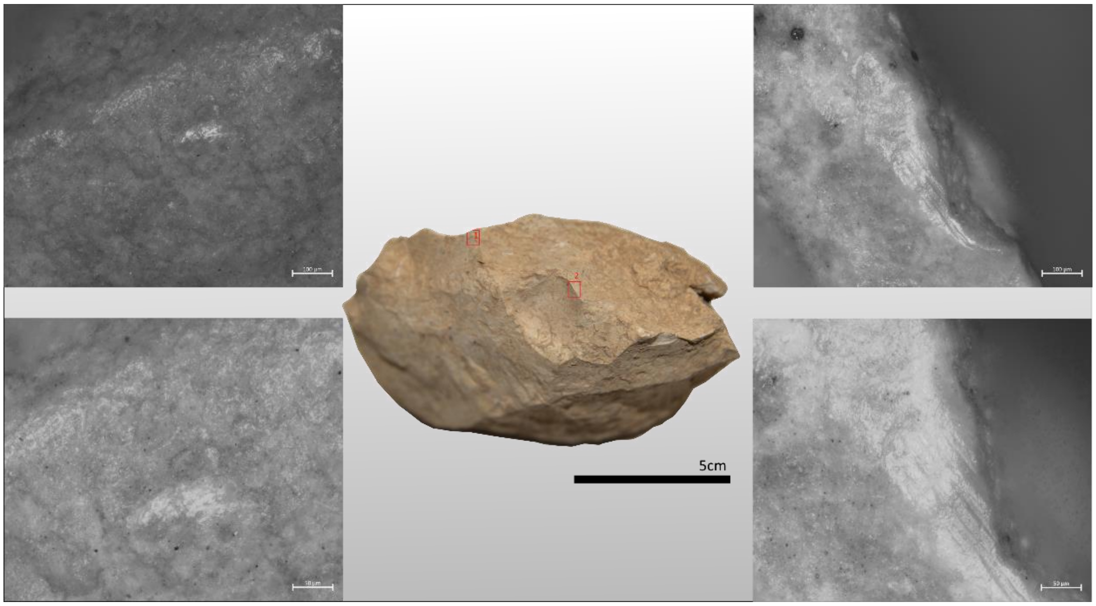


Figure 69: : Chopper tool from Nesher Ramla with polish formation (id:7263).

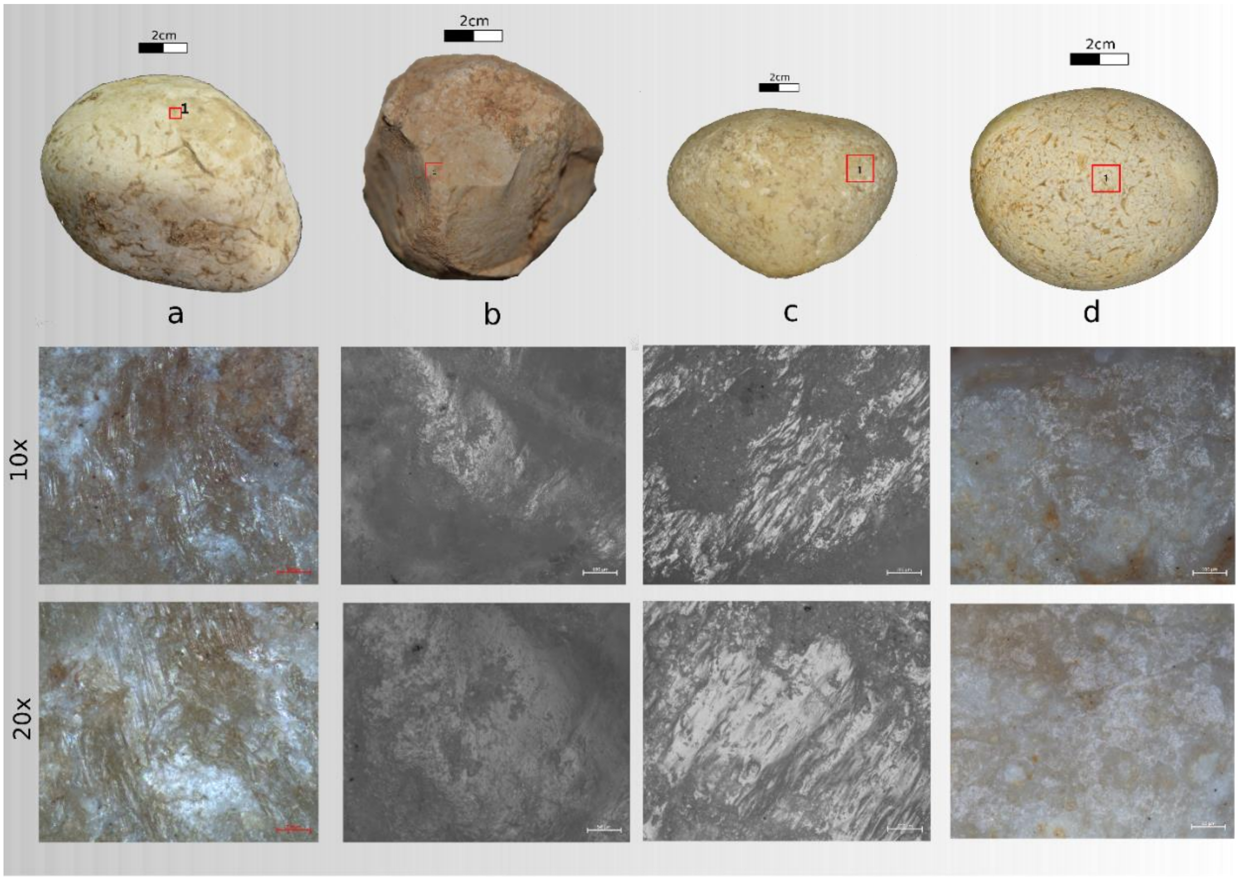


Figure 70: Examples of the different types of micro wear traces: a) polish Type A b) polish Type B c) polish Type C d) polish Type D, (all microscopic images with 10x and 20x objective, optical zoom).

Table 10: Criteria of classification for each micro use-wear traces type.

Polish types	Description	Interpretation
Type A	*Micro polish (i.e., sheen)* Generally, only on high microtopography Flat cross section Rough texture Sharp contours Frequent presence of abrasive tracks	Mineral contact material
Type B	Partially penetrating on low microtopography Domed cross section Fluid texture	Hard animal material (Bone and antler)
Type C	Deeply penetrating on low microtopography Domed cross section Smooth texture Diffuse contours	Oily contact material (e.g., acorn)
Type D	Random distribution on surface Polish spots with mix characteristics	Unclear Post-depositional processes

A sample of tools representing the variability of polish qualitatively identified were selected for confocal microscopy, to quantitatively characterize the type of polish formed by each type of activity and contact materials. In this analysis, ISO-25178 Height parameters for surface texture area analysis were explored. Although relying on a small sample size, the data clearly shows a distinctive signal between the two most common polish types present in the assemblage (A and B). In all the parameters analyzed, polish type B did not overlap with any other type of polish, with this true both for the volume parameters and for the area parameters. The types C and D did not overlap between them however their values of all volume and area parameters are also in the range of values of the polish type A. However, when mean depth of furrows was analyzed all four types showed a distinctive grouped signal (fig. 75).

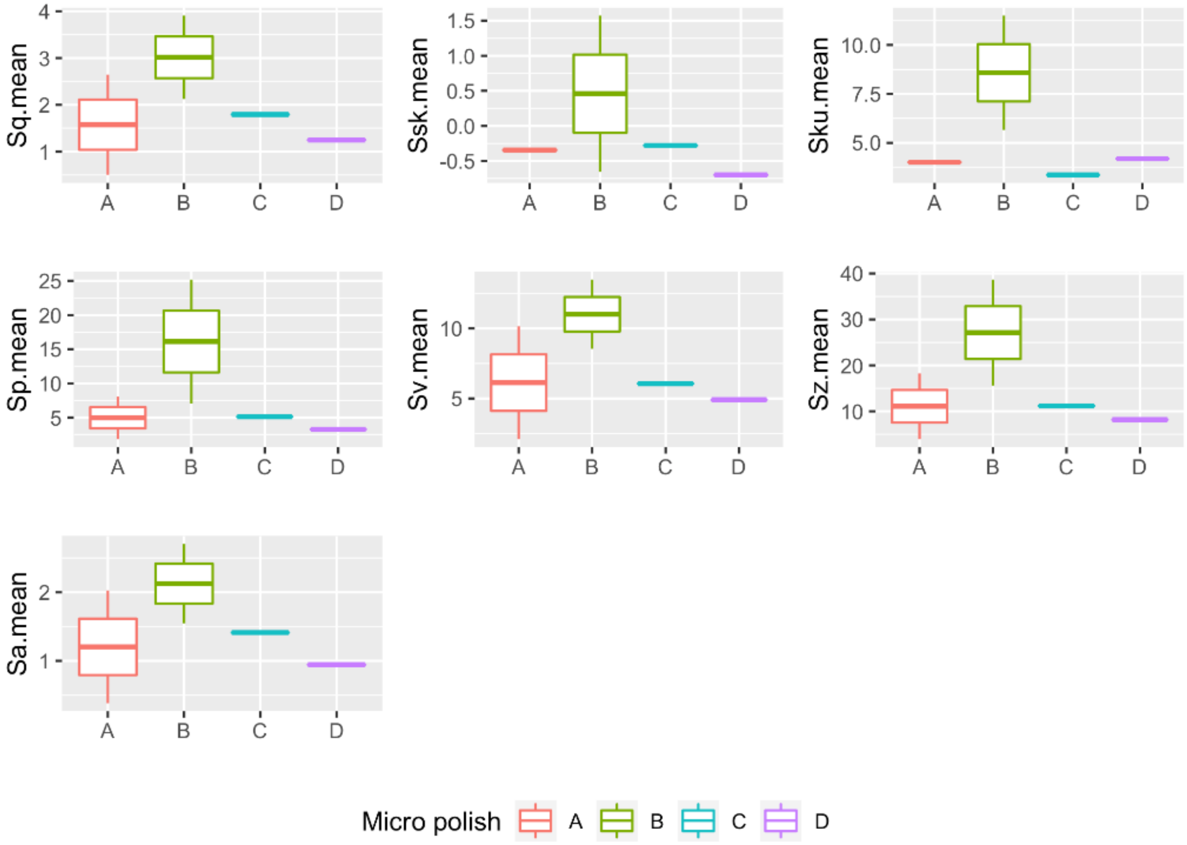


Figure 71: Box plots with texture surface analyses of the polish types identified at Nesher Ramla (area parameters).

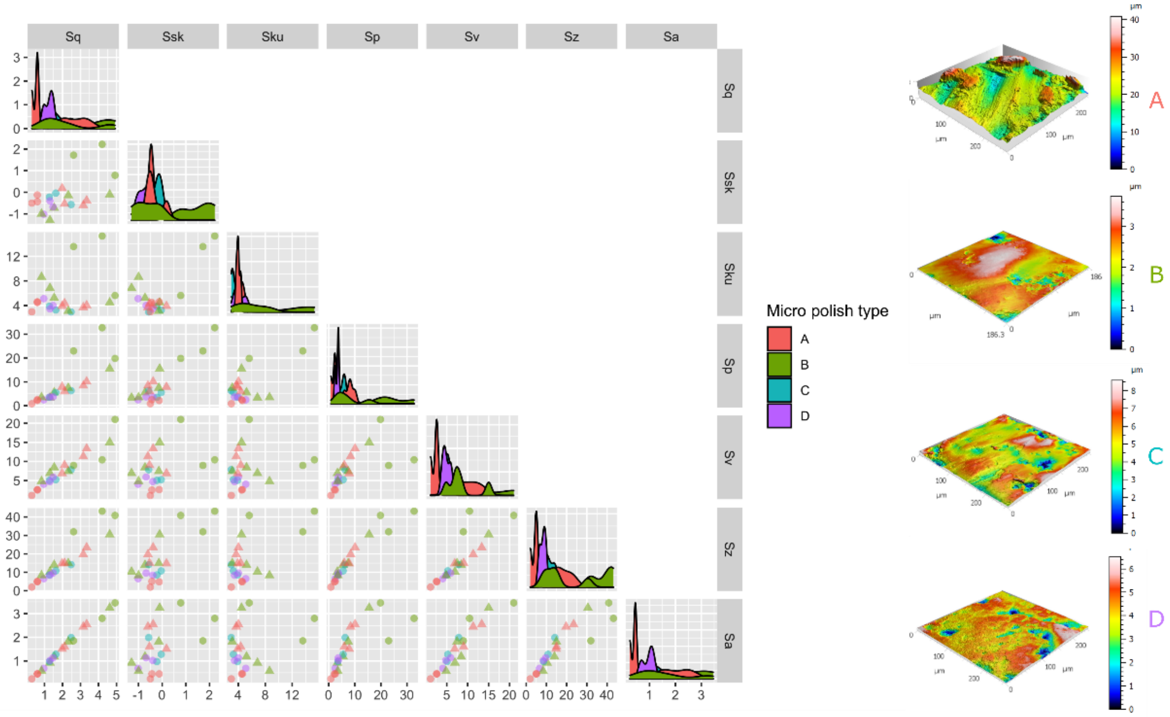


Figure 72: Confocal texture analysis of polish types (area parameters).

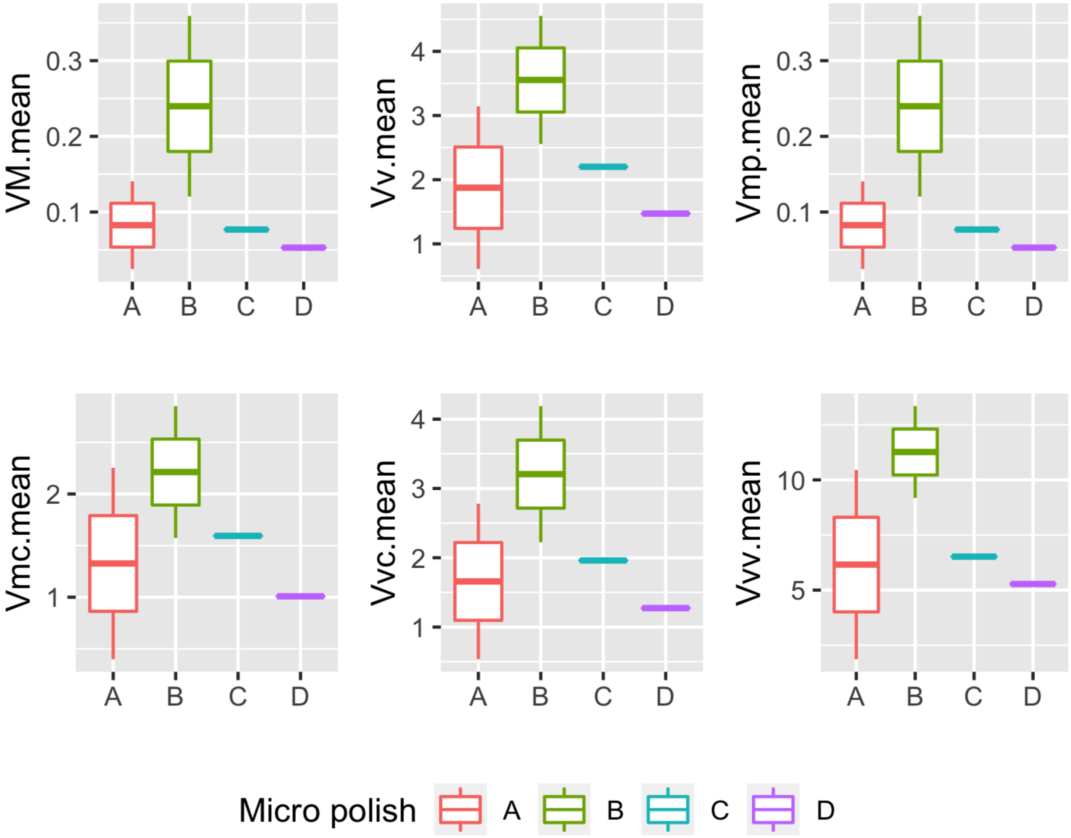


Figure 73: Box plots with texture surface analyses of the polish types identified at Nesher Ramla (volume parameters).

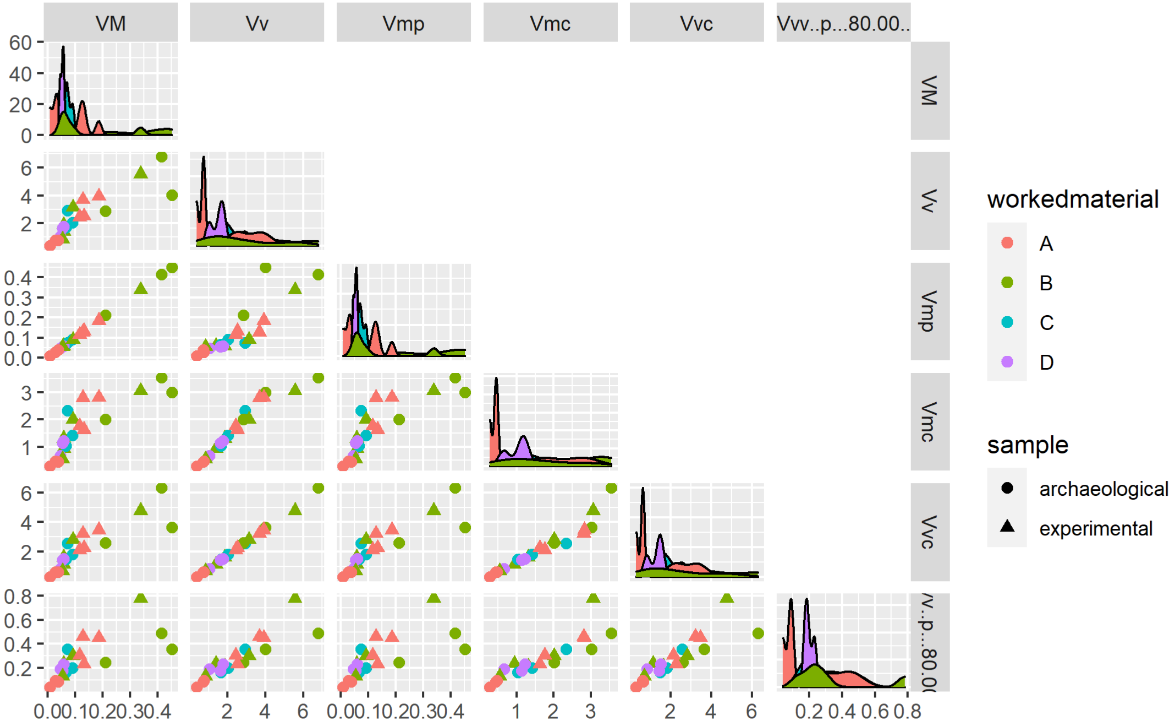


Figure 74: Confocal texture analysis of polish types (volume parameters).

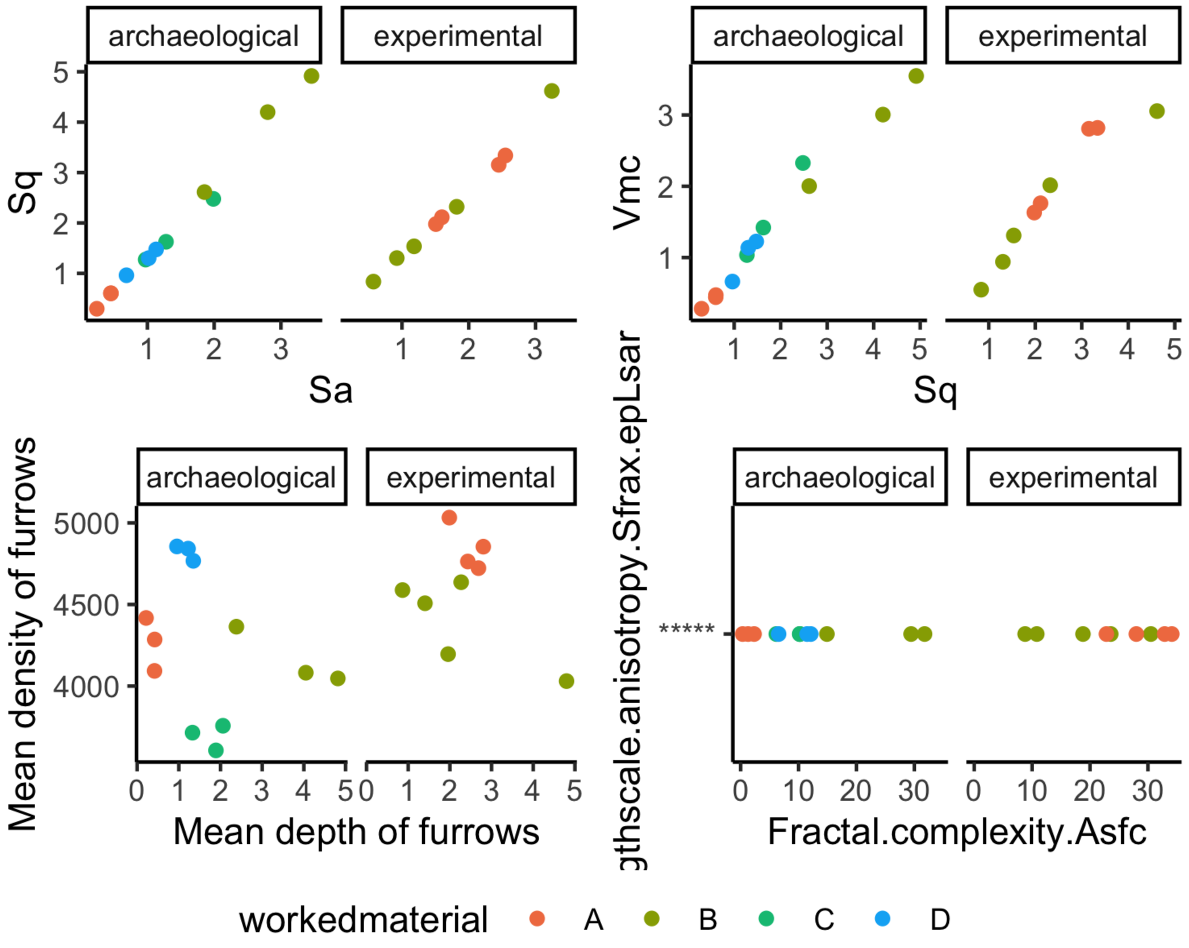


Figure 75: Scatterplot for micro polish quantitative analyses.

In sum, several tools reveal clear use-wear traces that result from impact activities. Hammerstones, anvils, and choppers, present a combination between impact marks, polish and striations. An overlap between impact marks and polish formations has only been identified on a small number of tools. For instance, such combination has been recognized on tools with impact marks type 1 (such as choppers) associated with type B polish. Another example is found on a few hammerstones with impact marks type 2 associated with type A polish.

On most of the tools, use-wear is located near the extremities, corresponding to A1, A2 and A3 positions according to the spatial grid (fig.76). Some tools also show use-wear concentration in their central areas (position A5), with those mainly interpreted as anvils. Generally, the marks are concentrated in a single location, however some hammerstones have marks on two extremities. When a tool exhibit more than one active area, the use-wear usually displays only impact marks.

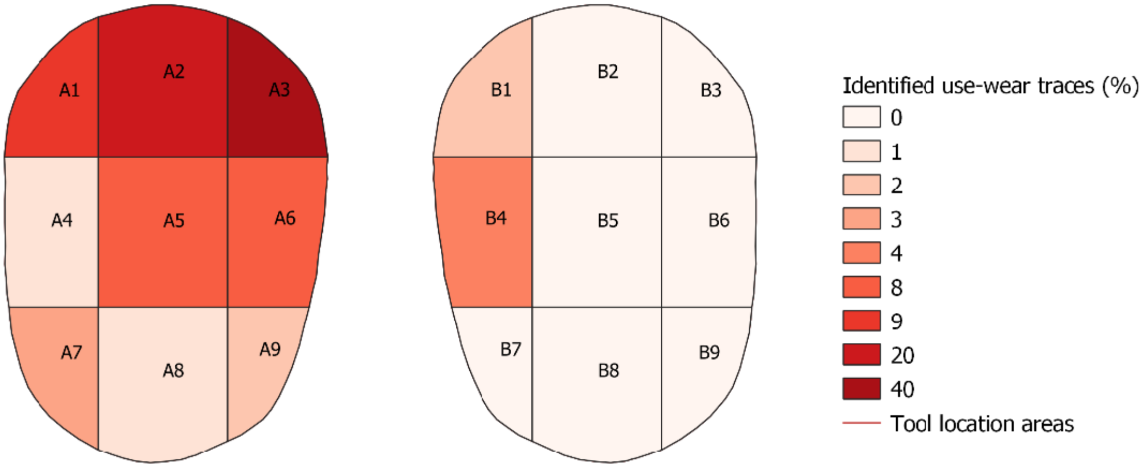


Figure 76: Schematic representation of the areas with use-wear traces in the hammerstones.

5.2.1.4. ***Nesher Ramla Ground Stone Tools interpretation***

In this study, based on the combination of various analytical scales, it was possible to suggest a functional-typological characterization for the Ground Stone Tools that includes the following tool types: hammerstones (n= 108), anvils (n= 22), pestles (n=1), abraders (n=11) and choppers (n= 10). Some artifacts identified here as tools do not show enough diagnostic traces allowing for an attribution to a specific tool-type and, therefore, were categorized as undefined (n = 33). Further experimentation and analysis are needed for these implements. For the rest of our sample, we observed different use-wear traces that can result from the contact with different types of materials, namely mineral, hard animal tissue (e.g., bone) and likely softer vegetal resources (e.g., acorn, pistachios). From the four types of micro wear identified in the archaeological materials, two (Type A and B) present characteristics that match with the reference collection generated by our experimental program, that allow us to argue for evidence of bone and mineral contact respectively. Type C was interpreted based on the micro wear physical properties, and still needs to be further explored, through expanding the experiments, namely by increasing the variety of contact materials included on the experimental program.

- *Mineral (Type A)*

Use-wear traces that are associated with activities resulting from the contact with hard materials, like minerals, are very frequent. We consider the possibilities for different tasks that involve contact with mineral materials. The combination of the analysis of archaeological material, together with the reference collection generated by experiments, allowed the associate of a large number of tools to flint knapping, mostly hammerstones, but also some tools with use-wear evidence that is possibly associated with retouching (i.e., retoucher; e.g., polish and striations in a small delimited area). The possibility of ochre processing as documented for other Middle Paleolithic contexts (Hodgskiss, 2020) is not excluded in this site, but needs to be further explored by combining more experiments with residue analyses. On this assemblage the wear associated with hard material, and mineral, have been identified on hammerstones and abraders.

- Hard animal material (bone and antler) (*Type B*)

Several tools present use-wear characteristics potentially associated with bone processing activities. We observed that some tools were primarily prepared with the creation of a rough edge, which was possibly used to break bones. These items identified as chopper tools, show areas of polish on the edge that is associated with bone. Some other tools, without preparation of an edge, also present use-wear traces associated with bone contact. Other scholars have also associated this type of tools with bone breaking (de la Torre et al., 2013; Goren-Inbar et al., 2015).

The polish characteristics (Type B) associated with bone contact correlates well with the data from the experimental program. Evidence for bone contact in this assemblage is present on anvils, hammerstones and choppers.

- *Other materials (Type C)*

Some tools classified as hammerstones and abraders show use-wear traces at high magnification that, although clearly anthropogenic in their nature, are considerably different from the use-wear formed by mineral or bone contact. In those cases, the polish present micro characteristics that can be associated with the processing of oily materials (e.g., acorn, pistachio) or hide (e.g., Dubreuil & Grosman, 2009). More experiments on limestone are needed to test these hypotheses.

- *Post-depositional processes (Type D)*

Some pebbles exhibit areas with polish that is characterized by undiagnostic features, and randomly distributed through the surface. For those pieces we do not correlate with any type of use and the possibility that these polished areas have been developed by post depositional factors should be highly considered.

5.2.2. Far’ah II results

The group of materials analyzed consists in a total of **30 lithic artifacts**, including pebbles and blocks**.** Some artifacts show several fragmented areas, some including small scars, while other artifacts are complete, with no evidence of fracturing or flaking. In terms of raw materials, the group of artifacts analyzed is mostly composed of limestone.

Table 11: General inventory of Far´ah Ground Stone Tools support.

Raw Material	Pebble	Block	Total
Flint	2	0	2
Limestone	17	9	26
Other	0	2	2
Total	19	11	30

5.2.2.1. *Technology and typology*

Typologically, it was possible to identify hammerstones, anvils, pestle, chopper tools, and two cores within the assemblage. The other tools were not possible to relate to some predefined typology at this time, and are classified as undefined, needing further analysis.

Table 12: Typological inventory of Far´ah Ground Stone Tools.

Row Material	**Anvil**	**Chopper**	**Core**	**Hammerstone**	**Manuport**	**Pestle**	**Undefined**	**Total**
Flint		1			1			2
Limestone	2	1	2	11	5	1	4	26
Other	1		1					2
Total	**3**	**2**	**3**	**11**	**6**	**1**	**4**	**30**

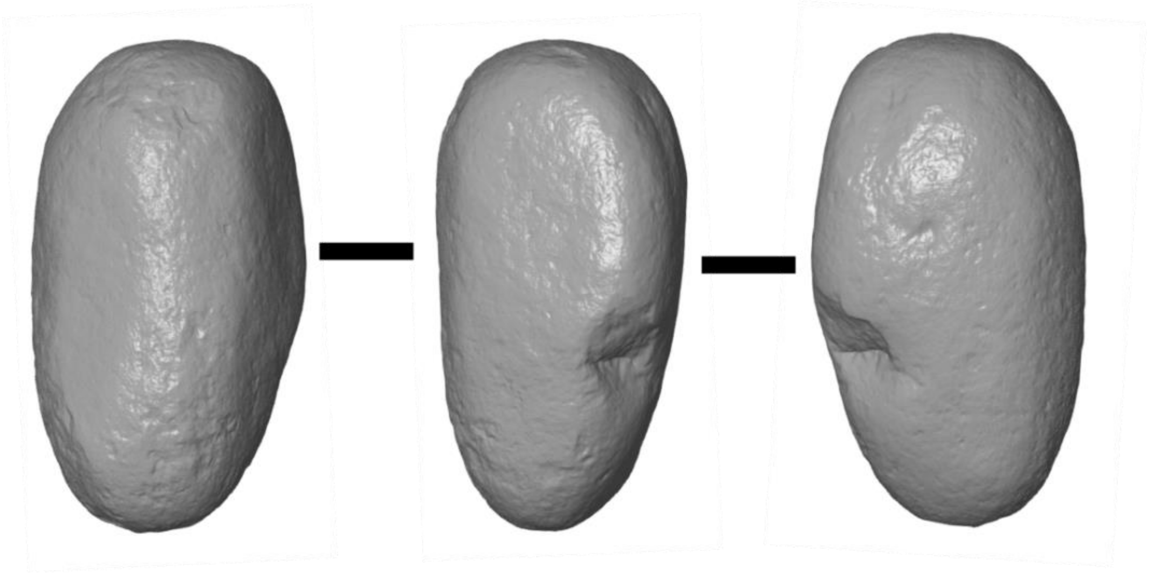


Figure 77: Pestle from Far´ah II (id:83).

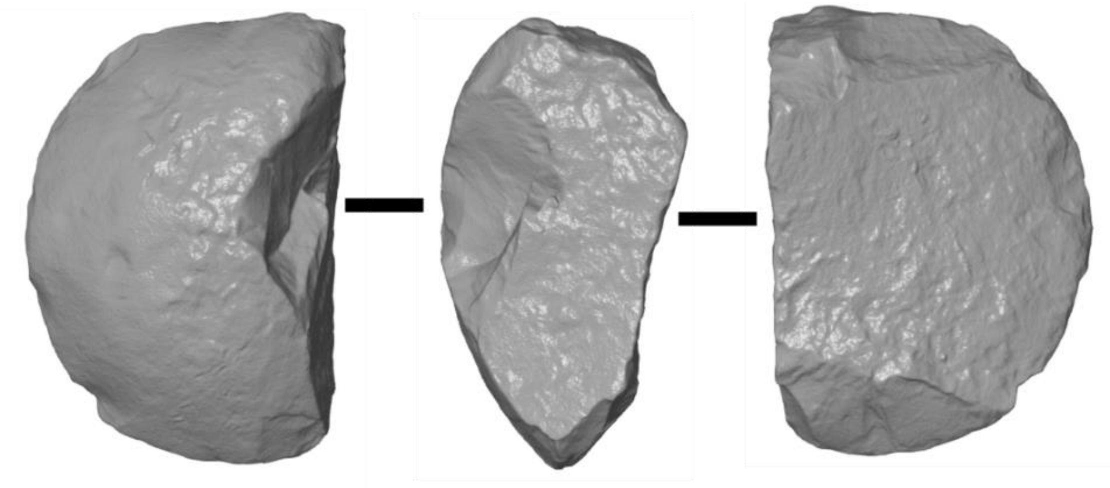


Figure 78: Broken anvil from Far´ah II (id:37).

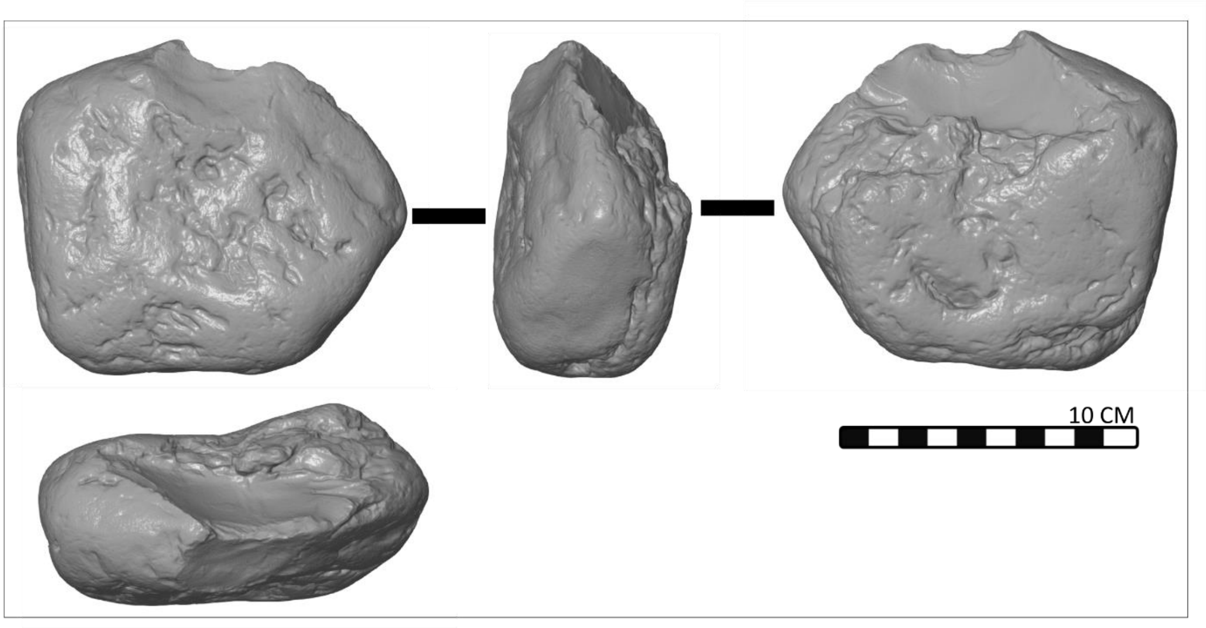


Figure 79: Chopper tool from Far´ah II (id: 85).

From the morphometric point of view, the materials show a range of lengths between 38 and 127 mm, widths between 33 and 90mm, thickness between 15 and 76 and the weights are between 44 and 974 g. (fig.80 and 81)

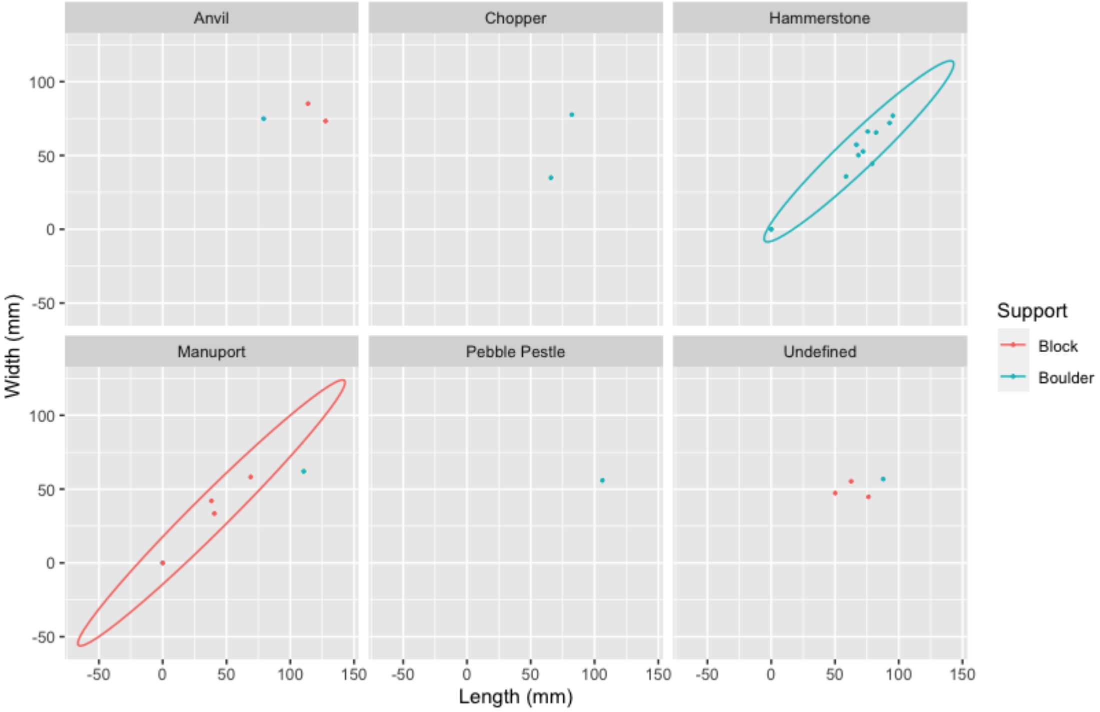


Figure 80: Scatterplot showing artifact dimensions organized by typology and support type (Far´ah II).

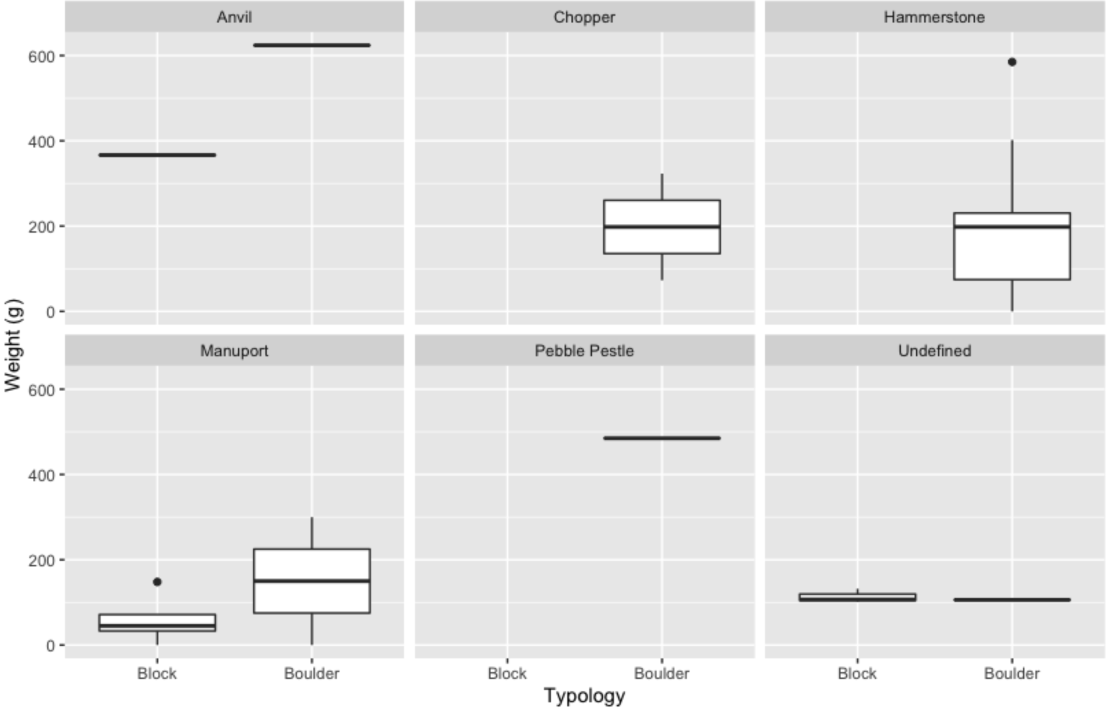


Figure 81: Boxplot showing artifact weight organized by typology and support type (Far´ah II).

5.2.2.2. ***3D analyses***

The analysis of the 3D scans from Far´ah II Ground Stone Tools reveals that the assemblage presents a high level of heterogeneity in terms of supports. The slope computation of the entire tools surface shows that despite the expected high percentages of areas with high angles, as a result of the natural curvature of the supports, in this case it is possible to verify that the distribution of values is not totally standardized along the assemblage, which reveals a considerable level of heterogeneity in terms of tools morphology. (fig.82)

In order to investigate if this heterogeneity is also reflected in terms of impact marks, the slope was also computed on cut areas restricted to the active areas, in order to exclude the "noise" caused by the natural curvature of the tools. In this case was possible to see that the distribution of values is different between types. These differences can be seen especially through the percentages of areas with lower angles (0º up to 9º), when comparing anvils and hammerstones, where the anvil reveals that their active areas are absent of totally flat spots in opposition to the hammerstones where the lower angle values occupy approximately 20% of the distribution. This can be seen as a reflection of different types of use that consequently will result in different damage patterns. (fig.84)

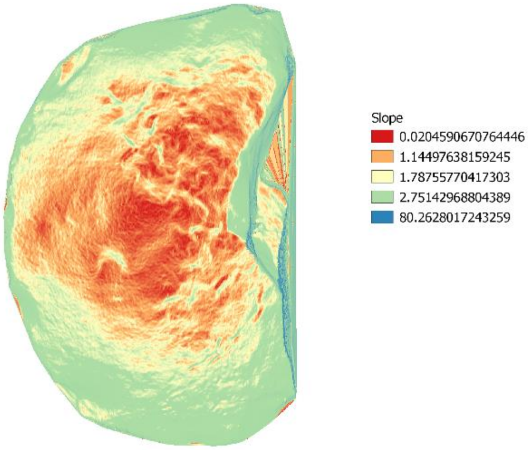


Figure 82: Example of slope projection.

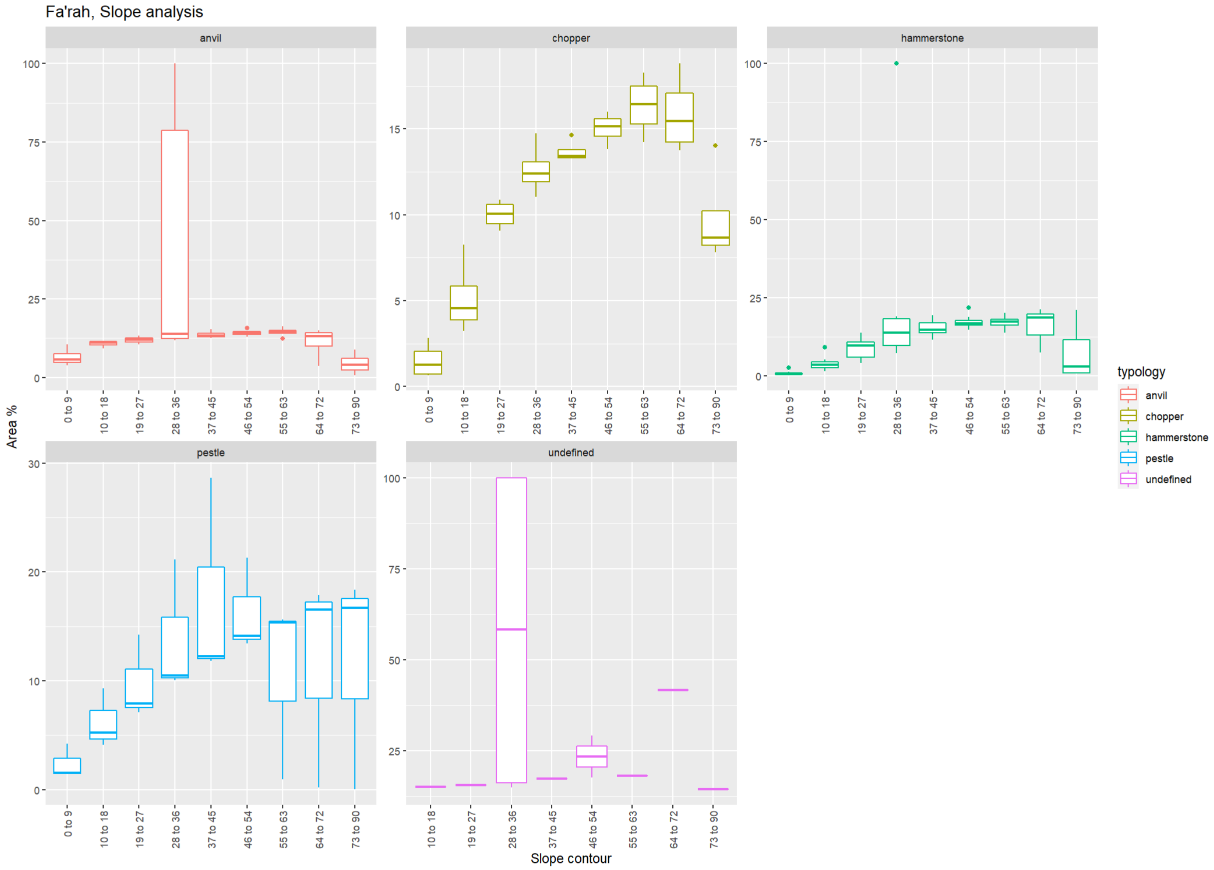


Figure 83: Box plots with slope contour values for the entire surface.

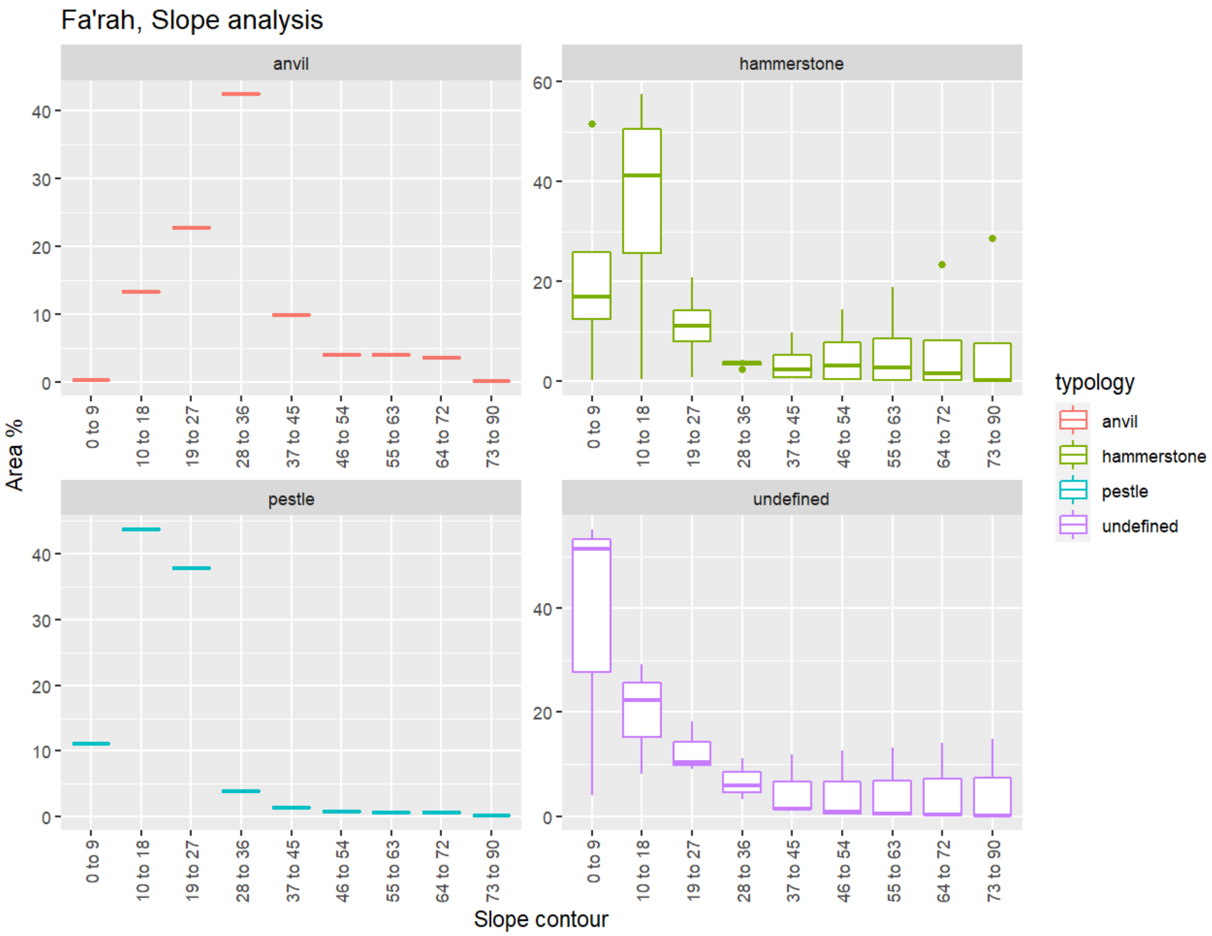


Figure 84: Box plots with slope contour values of the active area.

In terms of Terrain Ruggedness Index (TRI) it is possible to see a low level of variation on the active surfaces of the hammerstones. However, in all cases the values range is very small, with values between 0 and 0.1. This small range highlights the need to also adopt other scales of analyses, to detect any major differences within the group of impact marks associated with the hammerstones of Far´ah II (fig.85).

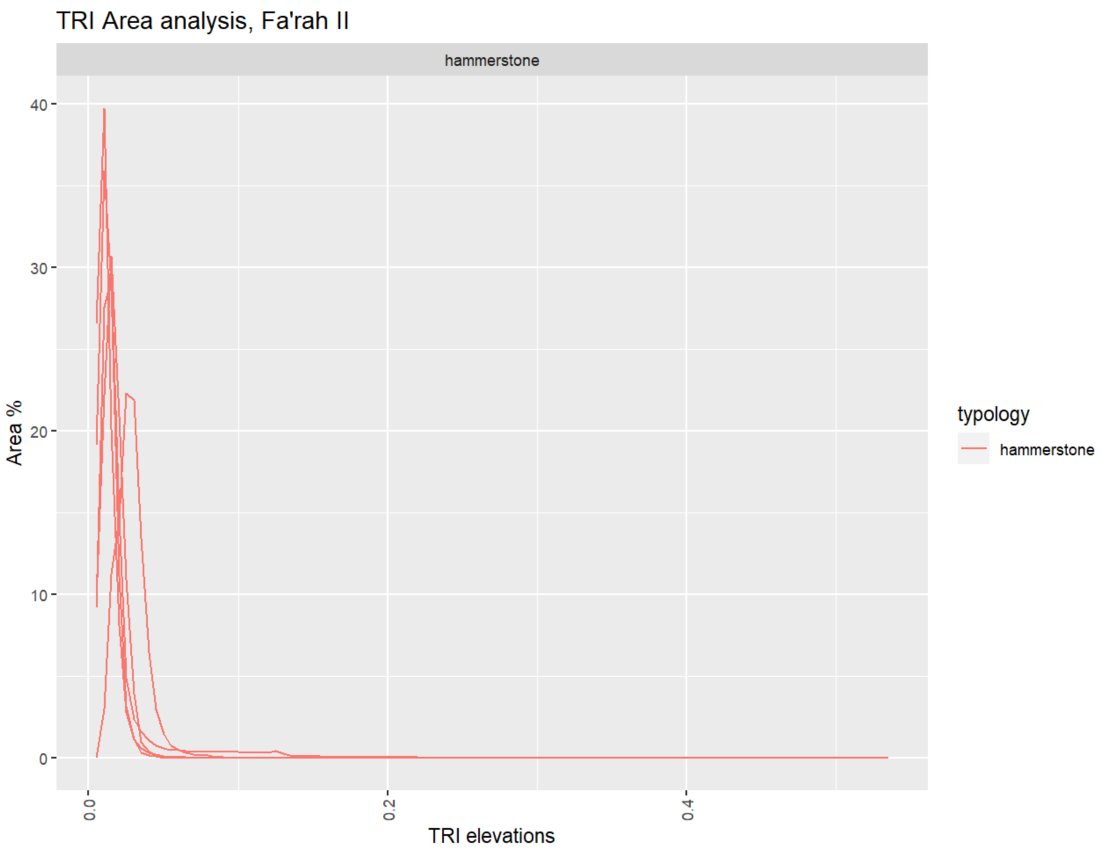


Figure 85: TRI values of the hammerstones active areas.

5.2.2.3. ***Use-wear analyses***

5.2.2.3.1. *Macro wear*

In 24 artifacts marks were identified, that are likely related with anthropic activities, specifically impact marks, striations, and polished areas, with in some cases a mixture of several types of traces present. In term of use-wear location, the marks are present in some cases in the tips of the tools, and in other cases in central areas. Some tools are classified as undefined (n=4) due to the lack of diagnostic traces, and the fragmented state. However, at the macro scale the surface reveals some abrasive features, which lead to the suggestion of the possibility of some fragments being part of a broken grinding stone.

Table 13: Frequency of the different types of use-wear traces organized by tool type (Far´ah II).

TYPOLOGY	Impacts	striations	Mix	Polish	Total
Anvil	3	0	0	0	3
Chopper	2	0	0	0	2
Core	2	1	0	0	3
Hammerstone	10	0	1	0	11
Pestle	0	0	1	0	1
Undefined	2	0	0	2	4
Total	19	1	2	2	24

Figure 86: Possible grinding stone fragment.

Figure 87: Tool with impact marks located in a central area (id:35).

Figure 88: Area with impact marks (id:72).

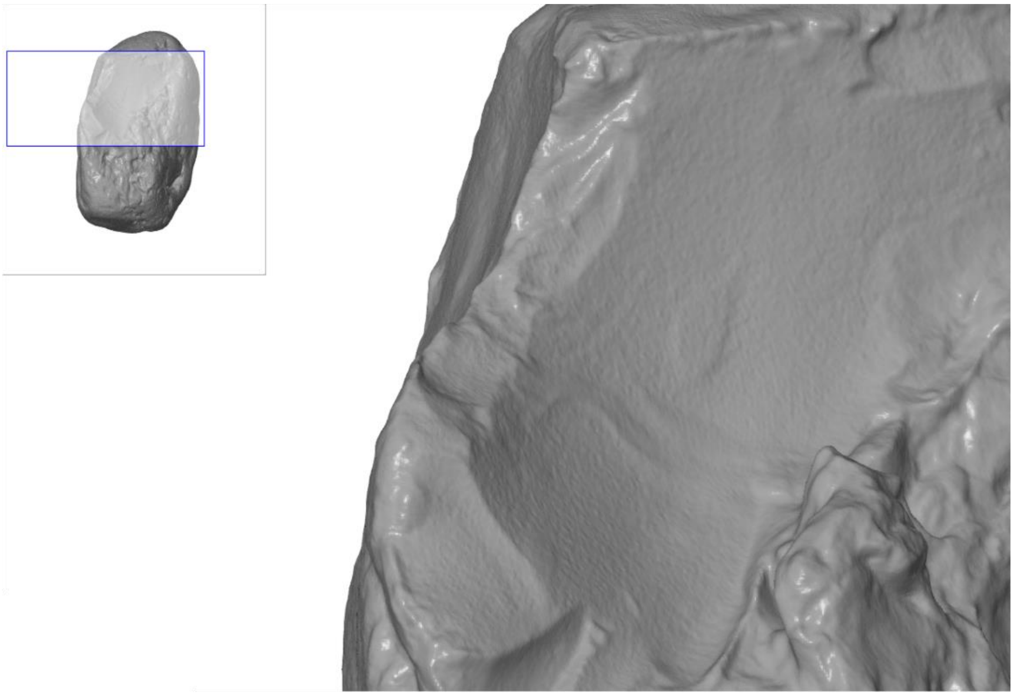


Figure 89: Impact marks on chopper edge (id: 85).

The preliminary analysis allowed the visual identification of residue remains on one of the tools (possible ochre), but this still needs to be tested for further conclusions. Although the preliminary analyses did not reveal clear evidence of residue preservation, the other artifacts were also sampled following the pipette extraction method, and the samples will be preserved for future analysis.

Figure 90: Pestle with red residue (id:83).

5.2.2.3.2. Micro wear

Although some tools have abraded surfaces present, the polish formations are poorly developed and absent of enough diagnostic use-wear traces for a clear association with a specific contact material. Even in the case of micro-polish presence, there were not enough diagnostic features to allow direct association with some specific activity. Some hammerstones have a clear presence of deep striations, in association with highly crushed surfaces, as commonly observed on experiments involving limestone on flint knapping. The tool classified as a pestle (id: 83), is the one that revealed most polish development. The polish is characterized by defuse contours, spread distribution, and domed cross section.

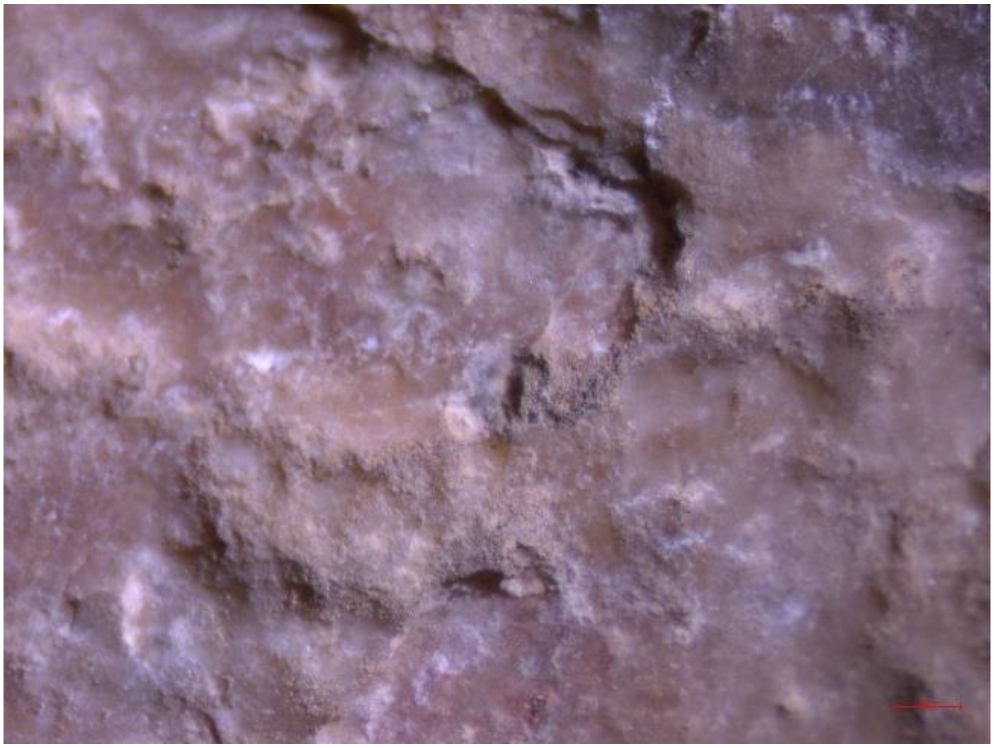


Figure 91: Abraded area on anvil fragment.

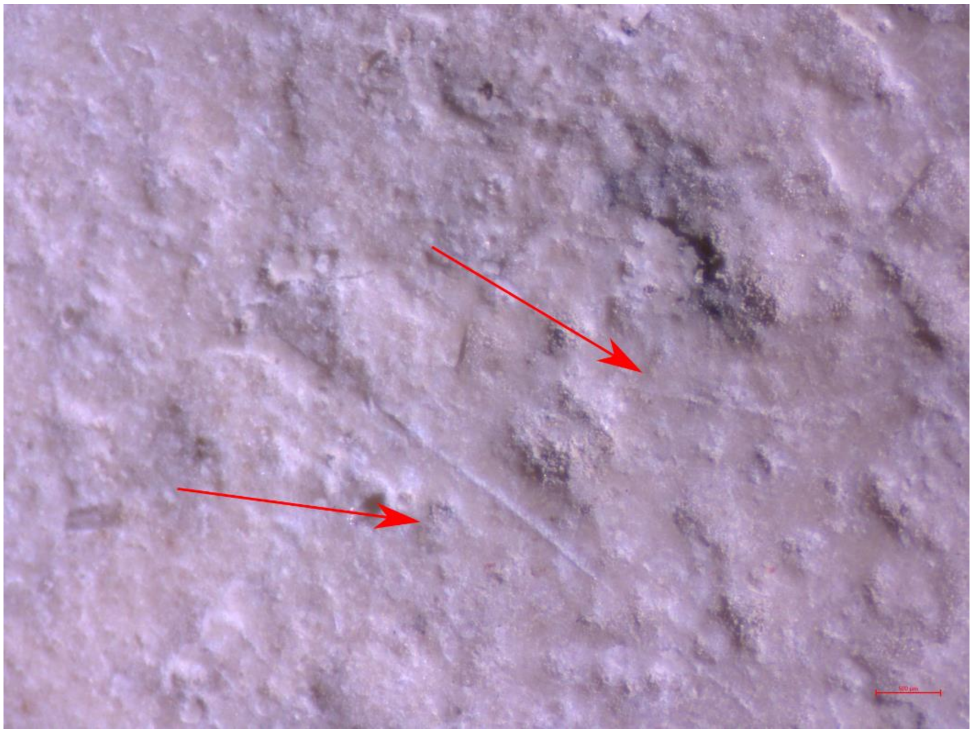


Figure 92: Example of polish area with striations on hammerstone, red arrow indicating striations, Stereomicroscope image 10x (id: 72).

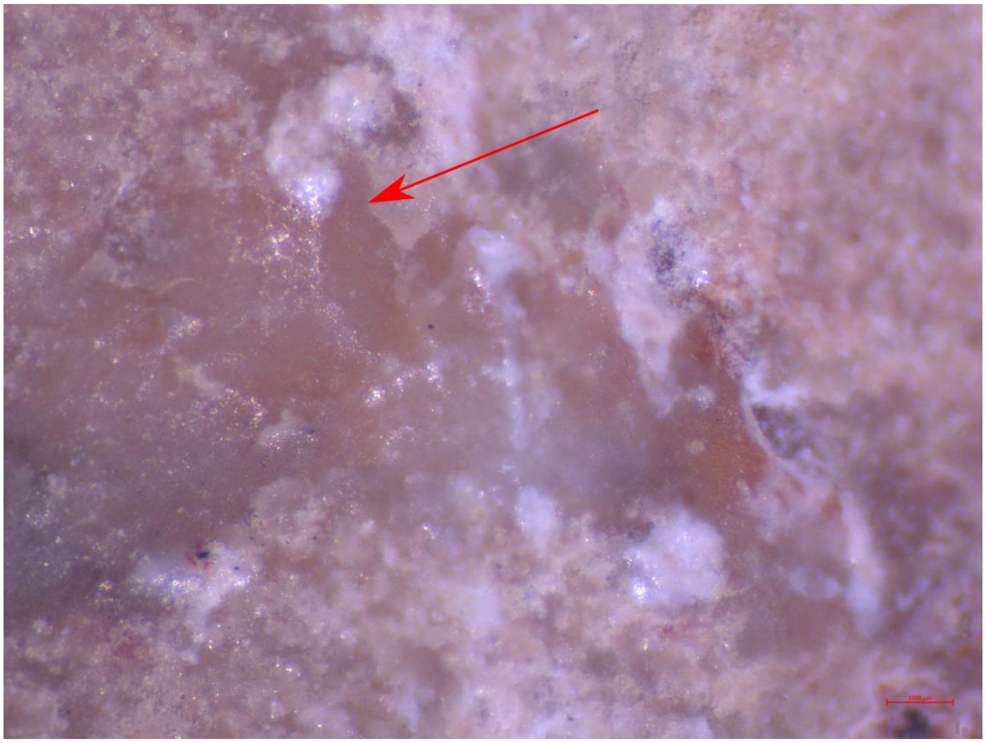


Figure 93: Polish formation on pestle, red arrow indicating polish Stereomicroscope image 10x (id:83).

5.2.2.4. ***Far’ah II Ground Stone Tools interpretation***

In a considerable number of the artifacts analyzed it was possible to identify impact marks with topographic characteristics associated with percussive activities on very hard materials, likely indicating activities such as lithic knapping. In this assemblage, those tools appear in the form of hammerstones and one anvil with deep impact marks and a high level of fragmentation.

The possibility of grinding activities should also be taken in consideration, due to the presence of a tool classified as a pestle, which reveals areas with evidence of crushing and abrasion on hard materials, in association with iron oxide residues. This opened the possibility for proposing an interpretative hypothesis, relating this evidence with activities involving processing ochre (e.g., pigments preparation). The possibility for grinding activities is also suggested by the presence of some lithic fragments with abraded surfaces. However, in this case the study is not conclusive due to the level of fragmentation and absence of diagnostic polish formation. Although it is outside the scope of this study, it is important to mention that limestone seems to be also explored for knapping. This phenomenon can be seen by the presence of multiple flakes and fragments that was successfully refitted in past studies.

In sum, it is reasonable to argue that limestone was an important resource explored by the groups that occupied Far´ah II during the Middle Paleolithic. This study indicates that limestone was used not only for percussive activities, but also very likely other types of motions, like abrasion or crushing.

5.2.3. Ein Qashish results

A total of eight artifacts were analyzed. This group consist mostly of limestone angular blocks recovered from layer 3b.

5.2.3.1. ***Technology and typology***

From the collection of eight artifacts analyzed, in three cases artifacts revealed surface alterations that were visually interpreted as use-wear traces. From the typological perspective, these artifacts are categorized as anvils, hammerstones and one chopper.

Table 14: Typological inventory of the Ground Stone Tools at Ein Qashish.

Raw material	Anvil	Chopper	Hammerstone	Manuport	Undefined	Total
Limestone	4	1	1	1	1	8
Total	4	1	1	1	1	8

Most of the artifacts fall in the size range of 112-306 mm of maximum length axis, and the mean weight is approx. 2 kg (fig.94 and 95). All types fall within the same range of metric values, with exceptions for some anvils and one chopper tool, which present larger dimensions. A considerable number of tools show some degree of fragmentation, with some cases of small-fragmented areas associated with the impact areas. Tool preparation by flake removal was clearly identified in two tools. In one anvil at least four surrounding flake removals were identified, indicating some reshaping/ preparation of the blocks. In a tool classified as a chopper two flake removals were identified, positioned in opposite directions and forming a rough acute angle.

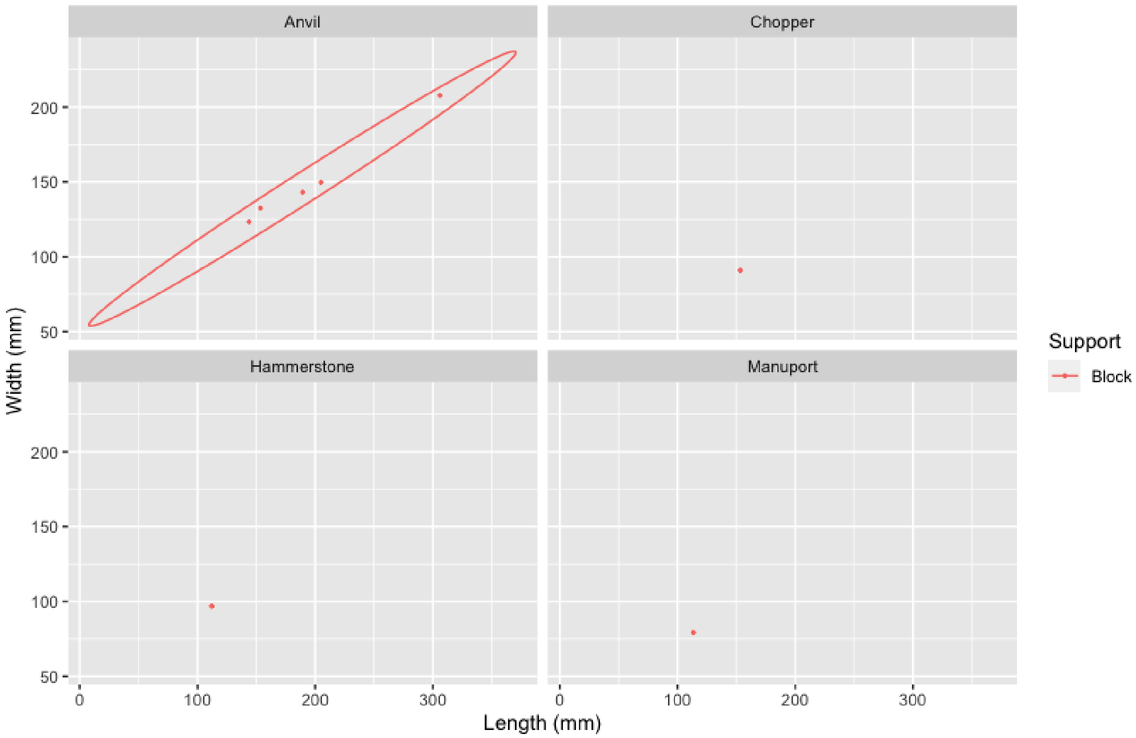


Figure 94: Scatterplot showing artifact dimensions organized by typology and support type (Ein Qashish).

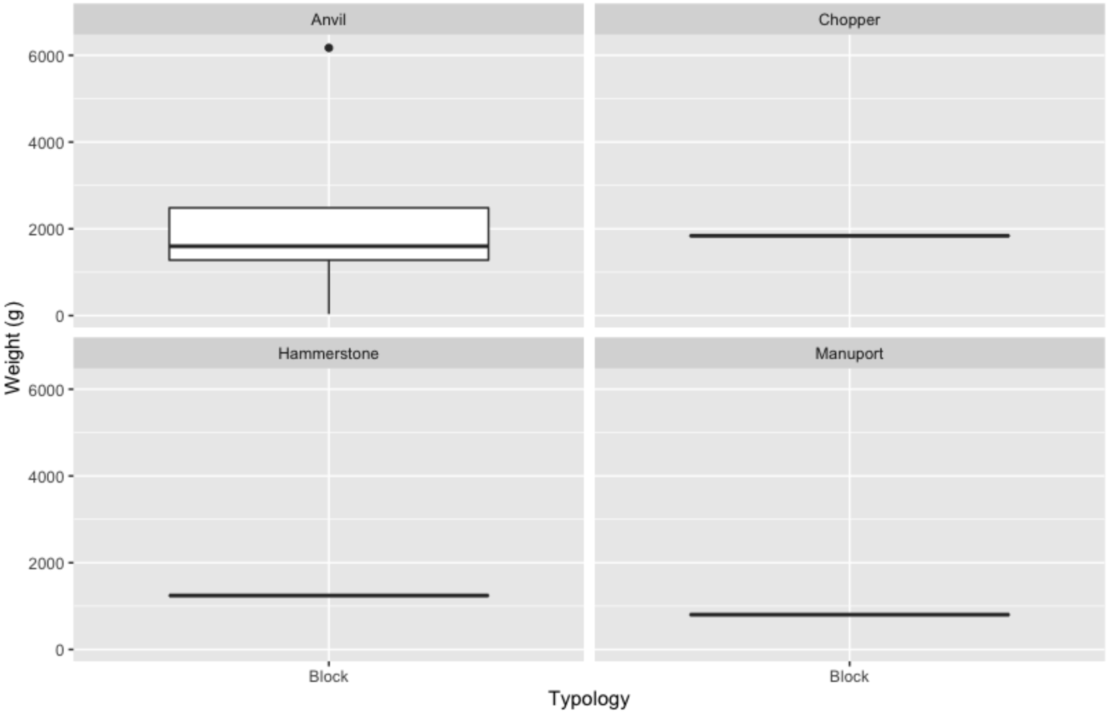


Figure 95: Boxplot showing artifact weight organized by typology and support type (Ein Qashish).

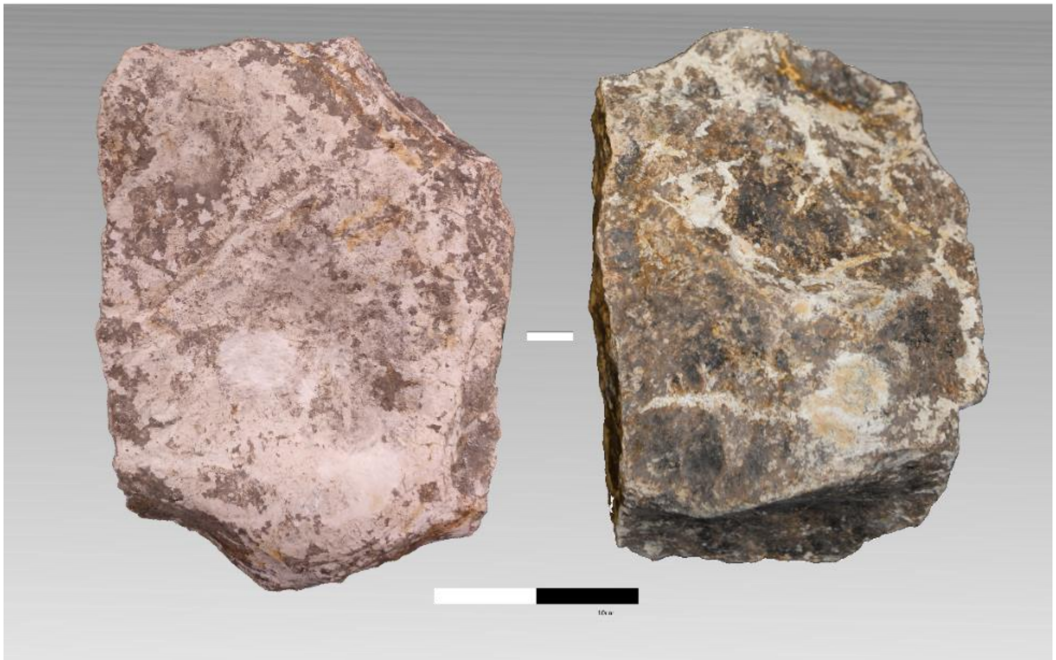


Figure 96: Anvil from Ein Qashish (id:2340).

Figure 97: Anvil from Ein Qashish (id: 1314).

5.2.3.2. *3D analyses*

Before further analysis it is important to highlight that the 3D analyses of the 3D scans from Ein Qashish Ground Stone Tools rely on a small number of artifacts, an aspect that is important to keep in mind before further conclusions. However, the presented characterization is an important step in quantifying the surface characteristics of the tools.

The analysis of the Slope considering the entire tools surface revealed the expected heterogeneity between type, since these are also related with considerably different types of support, as is reflected by the diverse distribution of values, as influenced by the support morphologies (fig.99). Focusing on the slope values distribution on cut surfaces that isolate the active areas it is possible to see a reduction on the differences between types. However, it is possible to see some variation especially in the angle values between 37º and 72º (fig.100).

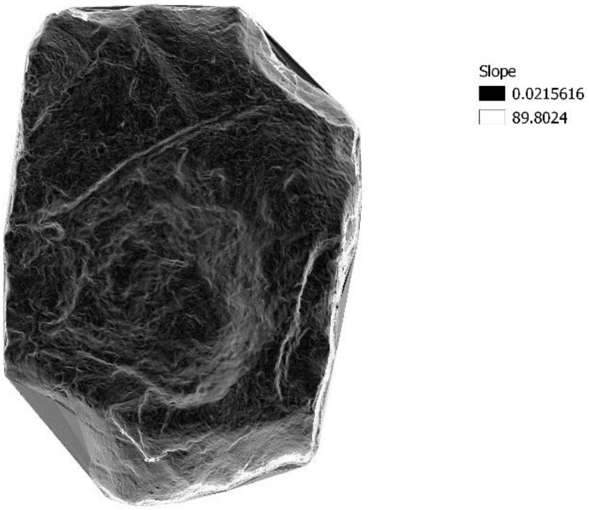


Figure 98: Example of slope projection showing active area (id:2340).

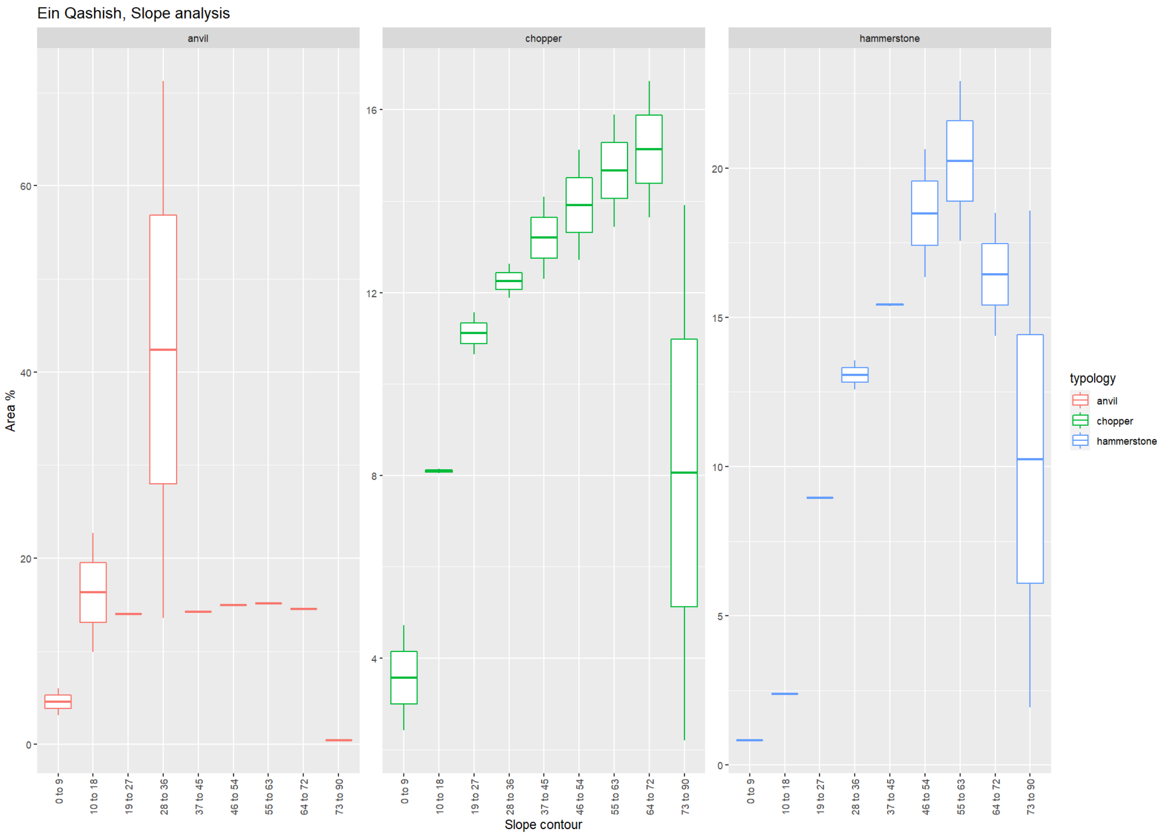


Figure 99: Box plots with slope contour values for the entire surface.

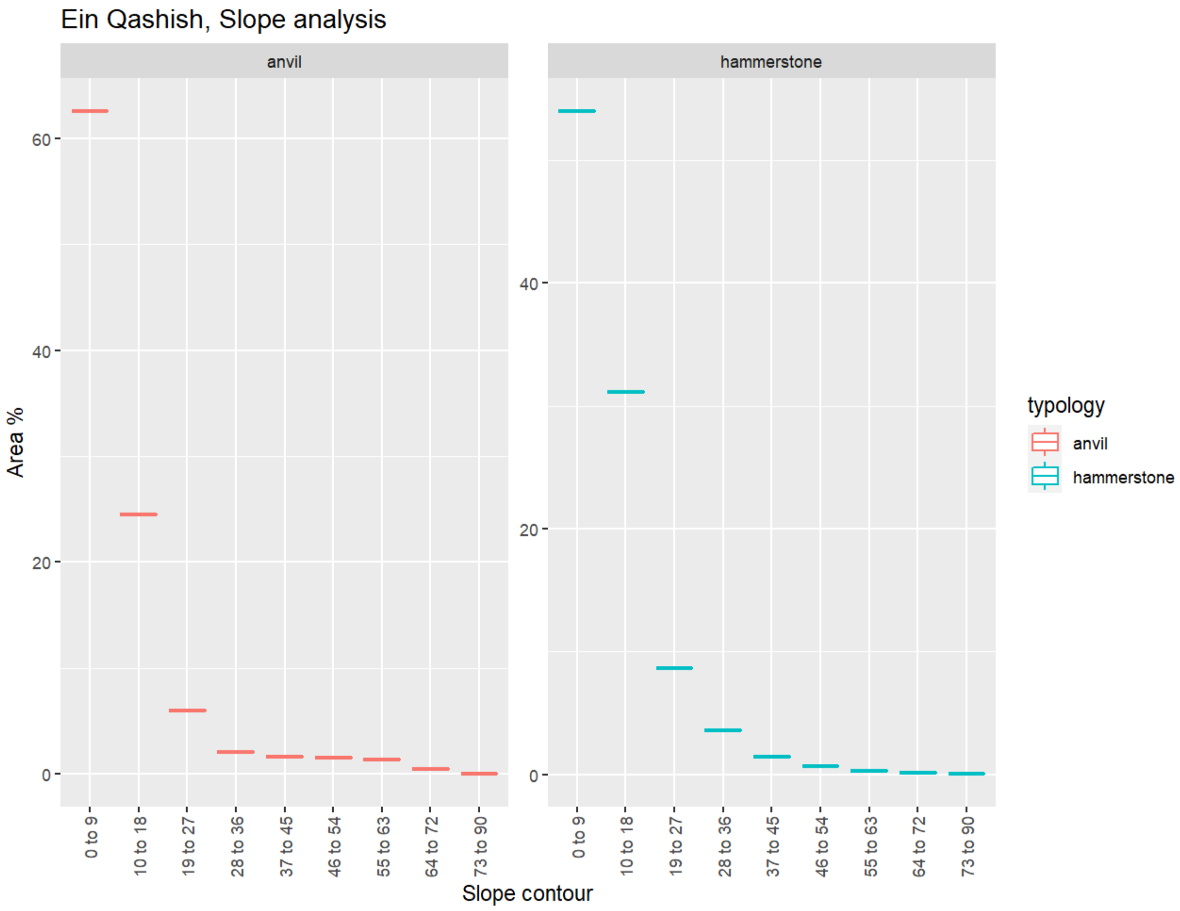


Figure 100: Box plots with slope contour values of the active area.

In terms of Terrain Ruggedness Index (TRI), the data originates from the impact marks on the hammerstone. Despite the fact this data relies on a single specimen, this data can later be compared with other tools and hammerstones from other sites. The TRI values sit between 0 and 0.1, which correspond to a low level of surface complexity at this scale of analyses (fig.101).

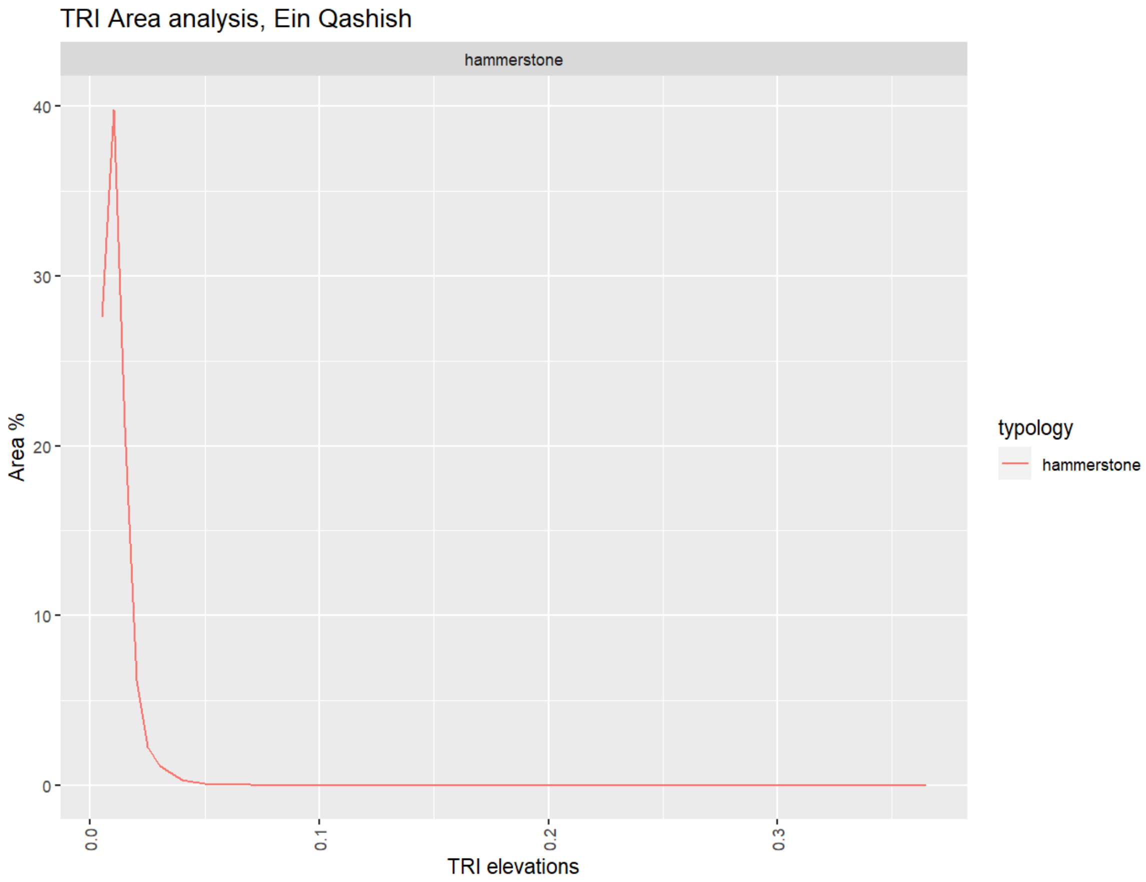


Figure 101: TRI values of the hammerstones active areas.

5.2.3.3. ***Use-wear analyses***

5.2.3.3.1. Macro wear

The active/used areas were identified by the presence of a concentration of traces such as impacts marks, which are in some cases associated with small flake removals and abrupt depressions on the surface. The anvils are characterized by a central active area, and in some cases, the surface shows clear depressions likely resulting from the performed activities, with these cases it is possible to visualize some impact marks. The hammerstone is marked by concentrations of impact marks in the extremities associated with small flake removal, with three active areas identified in this case, situated next to natural angular part of the tool (id: F6047). On the tool characterized as a chopper, some level of abrupt irregularities on the edge surface were identified. These are interpreted as impact marks, however in this case it is not possible to say with certainty that this damage was caused by human activities.

Table 15: Frequency of the different types of use-wear traces organized by tool type (Ein Qashish).

TYPOLOGY	Impacts	Mix	Total
Anvil	2	1	3
Chopper	1	0	1
Hammerstone	1	0	1
Total	4	1	5

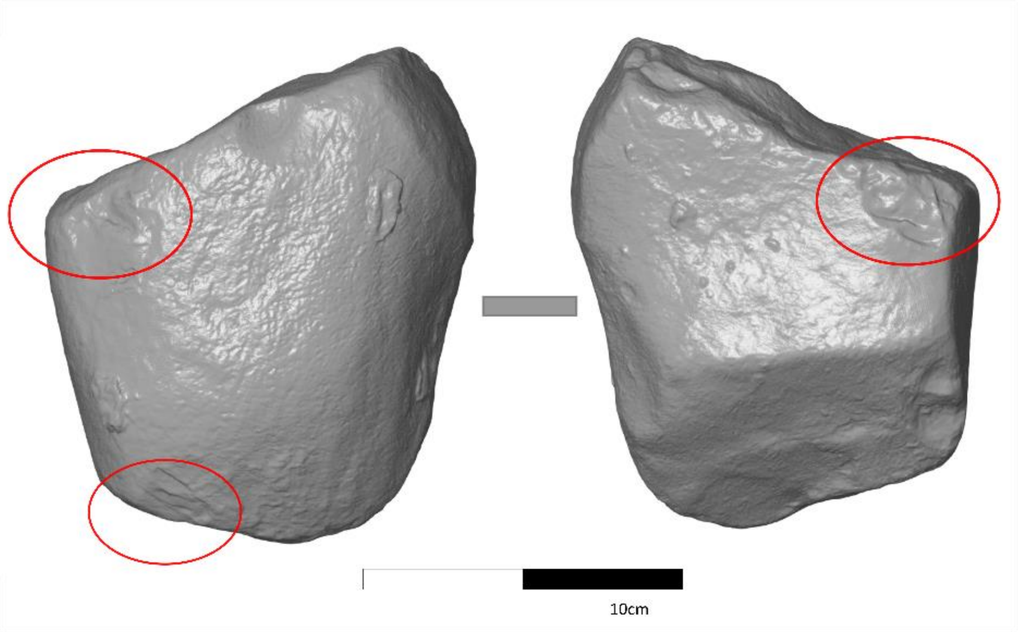


Figure 102: Hammerstone from Ein Qashish (id: F6047) red circles indicating area with impact marks.

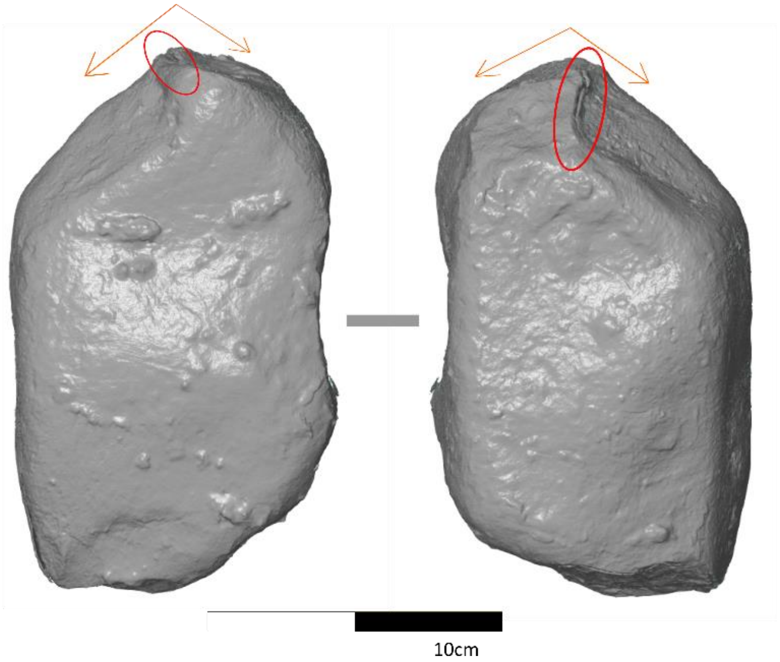


Figure 103: Chopper tools from Ein Qashish (id: S6106). Arrows indicating interpretations of anthropic flake removal and red circles indicating area with impact marks.

5.2.3.3.2. Micro wear

In these analyses it was not possible to identify clear micro polish formation. However, in one anvil (id: 2340) it was possible to identify some smoothed surfaces with some striations.

Figure 104: Striation on smoothed area on Anvil (id: 2340) form Ein Qashish. Dino lite image 63.9x.

5.2.3.4. *Ein Qashish Ground Stone Tools interpretation*

The group of artifacts analyzed have a considerable level of surface erosion, which represented a major obstacle for a clear functional interpretation. However, in some cases it was possible to collect evidence that allows the identification of active areas and suggestion of an interpretation for their type of use. From the group of seven tools analyzed, three allowed an interpretation with a higher level of confidence then the rest of the analyzed artifacts. The three mentioned artifacts consist of one anvil, one chopper, and one hammerstone. The hammerstone surface reveals a considerably better surface preservation than the other artefacts. In this case it was possible to clearly identify three concentrations of impact marks, with a high degree of surface crushing that could indicate the possible use of the hammerstone against a very hard material. This led to the interpretation of this tool having been used in lithic knapping.

The chopper tool showed evidence of a rough edge preparation, with it possible to verify some level of fatigue on the edge. This led to the interpretation of this tool being used in some percussive activity. In these cases, the level of surface damage is considerably lower than the observation made on the hammerstone, suggesting a plausible interpretation of this tool is use in bone breaking activity.

The third artifact mentioned is an anvil. This tool presents clear preparations/ reshaping by flake removals. In this artifact it was possible to identify one active area, that is characterized by a circular depression. This depression presents a very regular shape gradually getting deeper towards the center. This regularity of the active area was possible to identify due to the computation of the slope of the surface. Concerning the interpretation of this tool, it is considered to have been used for a percussive activity, with a high level of standardized location for the impacts. Some type of nut cracking is a plausible possibility to explain the surface alterations observed. However, due to the lack of other evidence, this interpretation should be seen as a possibility that still need to be further investigated.

In sum, it is possible to say that the assemble limestone assemblage of Ein Qashish represents clear evidence that percussive activities were part of the activities performed by the groups that occupied the site. It is also possible to say with a good level of confidence that different percussive activities occurred. This explains the different types of limestone exploitation, which in some cases required previous preparation of the tool, while in other cases the tools were used in their natural condition. These tools were used not only for technological need (e.g., knapping), but also reveal evidence of their importance in the diet, since they very likely were used to manipulate food resources.

6. Discussion

6.1. Ground Stone Tools multi-scale analyses, challenges and potential

As highlighted multiple times throughout this work, Ground Stone Tools are an important key to explore many aspects related to the daily routines of past human populations. Through the study of this type of artifacts, it is possible to characterize aspects related to diet, technology, and symbolic behavior. During this research three distinct Ground Stone Tools assemblages from three different archaeological sites were analyzed. In all case studies, it was possible to present a significant contribution to the technological characterization of the past groups that occupied these sites during the Middle Paleolithic.

In order to efficiently explore the high potential of Ground Stone Tools, it was fundamental to take into consideration two major complementary approaches: a) a detailed analysis that interrelates different scales of observation, combined with the implementation of qualitative and quantitative methods of data acquisition, and b) the linking of the archaeological observations with data from experimental reference collections.

For the analyses of the archeological materials, it is important to start from the general characterization, including the technology and morphometry, and gradually progress to the characterization of the micro use-wear. It is fundamental that the different scales of observation work in a complementary way to contribute to the complete picture of the materials. In order to include quantitative data in the characterization of the tools at the macro scale, this project explored the use of 3D models of the tools to provide a detailed characterization of their surfaces, in terms of the distribution of the slope angles and also their surface complexity by computing the Terrain Roughness Index (TRI). By applying these computations to the entire surface of the tools, it was possible to characterize the different typologies at a macro scale and have a general overview on the complexity of the assemblages, however, due to the heterogeneity and variation of the natural morphologies of the tools, this approach becomes very challenging in characterizing smaller scale variations, particularly different types of anthropogenic damage. To overcome the "noise" of the natural morphologies of the tools, a small area, restricted to the active areas of the tools, was sampled to run these same computations, and by doing this, it was possible characterize and quantify with higher precision the active areas of different typologies.

The 3D models, and the resulting digital elevation models of the surfaces, are valuable tools to quantify the macro alterations of the tool surfaces, however they are not suitable for characterizing the tools use-wear as a single method, since there are limitations in the characterization of the micro alterations, such as polish formation. This reinforces the importance of combining different scales of surface analysis, where the combination of 3D scanning and microscopic imaging become a powerful analytical combination to understand archeological tools.

In the study of Paleolithic Ground Stone Tools, one of the first challenges is the need to distinguish which alterations on the materials surfaces are caused by human use and which result from natural post-depositional processes. In many cases this sorting is difficult and is based on qualitative criteria that are in turn based on singular experiments or empirical observations. Such procedures have been criticized due to high level of subjectivity and lack of solid experimental background.

Therefore, use-wear analysis has been developing methods during the last decades to help in this crucial task. The location of the use-wear on the tools surface is very important, showing patterns for the concentration and distribution of use-wear traces in opposition to the natural wear (e.g., post-depositional), that had been assumed to appear in arbitrary locations on the tool's surface. Beside the location, it is also crucial to explore the combination of macro and micro diagnostic features of use-wear, that can be related to and diagnostic of the contact with some type of material, and/or different types of actions. Based on the archaeological evidence from the case studies explored in this project, an experimental program to test percussive and grinding motions was developed, including different contact materials. Since high levels of bone fragmentation and flint debitage are documented in considerable frequencies at all archaeological case studies, the percussive experiments included two different worked materials, flint and bone, (Centi & Zaidner, 2020; Gershtein et al., 2020; Gilead & Grigson, 1984; Goder-Goldberger et al., 2020; Malinsky-Buller et al., 2014a; Prévost & Zaidner, 2020; Zaidner et al., 2014).

Due to the complexity of polish types identified in the Nesher Ground Stone Tools assemblage, a set of experiments dedicated to grinding activities on vegetal matter were developed, where acorns were used in both a dry and moist state in order to explore different conditions. During the analysis of the archaeological materials tools with a specific polish (type C) were identified, with characteristics that seem to have been developed by contact with some product with oily features and some plasticity, which promoted the development of a micro-polish which is very penetrative on the low micro topography. Therefore, based on the type of polish identified in previous experiments involving this material, acorns were selected for this experiment. In this sense, these were selected as proxy to explore this hypothesis and understand how this type of products develop use-wear on limestone.

All the experimental results were analyzed in a multi-scale approach that helped to explore with a high level of detail the different features that characterize the various types of use-wear traces that are found to be diagnostic of a given type of use. Based on the research questions driven from the variability observed in the archaeological record, the experimental program followed a mechanical design based on two major goals: 1), differentiating Ground Stone Tools from unused items, and 2) in the case of Ground Stone Tools, understanding their main functions.

Experiments were designed with standardized and reproducible settings (in terms of action), with results showing that the use-wear formed on limestone samples used to strike flint is characterized by deeper alterations at a macro scale level, when compared with use-wear on samples used on impact bone experiments, on which no significant damage was identified. In terms of macro scale perspective, our results show that flint produces much deeper alterations in terms of surface topography, even when used less intensively.

By analyzing at the micro level, it was possible to understand that while all the explored materials can produce polished areas, the characteristics of the different micro surface features show polish patterns which are considerable different. The bone impact experiments tend to develop polished areas that are more penetrating in the lower micro topography, with domed cross sections, fluid texture and more defuse contours. The flint contact experiments tend to produce polished areas more restricted to the high micro topography, with flat cross sections, rough texture, and sharp contours. The formation of deep abrasive tracks is also very frequent.

During the qualitative analysis at micro scale, we identify overlap in some of the features of the polish formed by the contact with flint and dry acorn, namely in terms of the cross sections, polish contours, and patterns of striations. However, when combining and comparing macro and micro traces, it was possible to clearly distinguish the use-wear formed by those two activities, since the flint contact produces high level of macro surface alterations (e.g., fatigue, mineral crushing, and some level of shipping, flaking), while the acorn produces almost no macro surface changes. The application of confocal analyses to the micro polish also supports the distinction between these two types of polish, where it was possible to verify that there is no overlap in most of the parameters used for micro surface analysis. This practical case highlights once again the importance of combining different scales of analyses and explore the quantitative tools available to complement the qualitative analyses.

Nevertheless, the experiments reveal that the contact material can be differentiated in terms of use-wear, even when preforming the same type of motions. Being aware of the limitations of the reference collection, since only a few products were tested, it is important to keep in mind that these results should be used as a baseline to help use-wear analysts in the identification of a type of contact material and not a specific material in terms of species, type of bone, or specific rock. In this sense, the experiments on flint should support the identification of traces produced by the contact a very hard mineral. In the same way, our results of the dry acorn experiment should help the identification of traces generated by contact with a hard seed, because at this stage we do not know if contact with another seed with similar physical properties would produce similar results.

These experimental results should be seen as a contribution for the field of use wear analyses that together with other reference collections developed by other researchers should contribute to equipping use-wear archaeologists with methodological “tools” of great importance for functional interpretations of the materials handled by past humans.

6.2. New data about Paleolithic Ground Stone Tools in the Levant

Moving through the different scales of analyses it was possible to extract different sets of complementary data, that when combined allowed a comprehensive characterization of the studied assemblages. In terms of morphometry and typology, the three analyzed assemblages reveal clear difference between them. Although, when doing such a comparison it is important to keep in mind the very first and notorious element of distinction, which is the size of the assemblages in terms of tools frequencies. Concerning this aspect, Nesher Ramla presents a number of artifacts that is by far the largest one included in this study. Although Far´ah II is a comparatively small assemblage by comparison with Nesher Ramla, the assemblage of Far´ah II Ground Stone Tools is in fact not a small assemblage within the Middle Paleolithic context in general. Still in terms of frequencies, it is important to remember that the assemblage of Ein Qashish is very small by comparison with the previous mentioned sites. With these differences in mind, it is possible to start comparing the data itself resulting from the different analytical approaches.

The first significant element of similarity between the case studies, is the presence of limestone as the predominant raw material within the Ground Stone Tools assemblages. However, there is some variation in terms of the type of limestone, where Nesher Ramla and Far´ah II reveal a harder type of limestone and Ein Qashish limestone tends to be softer, as shown by the level of surface erosion present on most of the analyzed tools. This can be a possible explanation for the higher level of general surface erosion observed on the Ein Qashish tools when compared with the other sites. However, within each assemblage, the limestone tends to be generally homogenous.

In terms of tool supports it is possible to see a clear difference in terms of morphometric patterns, where Nesher Ramla presents a considerably more homogeneous pattern by comparison with the other two sites, where the assemblages are much more heterogeneous in terms of sizes and shapes of the tools. These general differences are supported by the data that results from the 3D analyses. However, when moving to a finer scale of observation using microscopy, it is possible to verify that the assemblage of Nesher Ramla is very complex in terms of the different types of wear associated with anthropogenic actions. All of the assemblages present a very high percentage of tools with evidence of having been used, where in the case of Ein Qashish and Far´ah II the percentages are higher than 80%. However, in the case of Nesher Ramla, this number drops to 53% due to the higher number of identified manuports (n=224). Nesher Ramla presents the larger diversity of both impact marks and development of micro polish, where different types of micro wear were associated with different activities and contact materials   Specifically, in terms of the micro scale it is possible to see that Nesher Ramla presents multiple tools with the development of micro-polish, while micro polish is rare in the case of Far´ah II and absent in the case of Ein Qashish. The higher diversity identified in Nesher Ramla in terms of use-wear is also reflected in a higher diversity of typologies, although the distribution of use-wear traces across typologies is not equal, such as in the case of Hammerstones, where it is possible to identify a larger diversity of impact marks and types of polish. However, here again the differences in terms of frequencies should be considered before jumping to further explanations of this scenario. Another important aspect to consider when comparing the micro polish presence between sites, is the level of preservation of the tools, with this consideration especially important in the case of Ein Qashish, where the tools present a considerably higher level of surface erosion compared with the other assemblages. In other words, it is possible to say that if there are use-wear marks on the tool, those marks can be interpreted and linked to past human actions, but when a tool presents a surface absent of marks, in many cases it is not possible to be sure that this represents an absence of past use: absence of *use-wear* is not evidence of *lack of use*. Other possibilities should also be taken in consideration in the debate, such as the possibility of the erosion of marks due to natural elements, or a limitation in the current methods of observation.

This study provides a solid combination of data that brought to light two levels of new data. First it clearly identified a large number of tools with solid evidence of being used by past humans, and secondly characterized at different scales these tools, allowing the identification of different types of use. The development of a dedicated experimental program supports an important part of the use wear characterization, helping to test the interpretations of mineral contact and bone contact. Due to the experimental result, it is now possible to present those interpretations with solid support. The experimental program also included the grinding of acorn seeds in order to learn about the use-wear formation associated with this type of product on limestone. This set of experiments represents the first trial to find an explanation for one type of polish identified at Nesher Ramla, which is clearly different from the ones associated with bone and flint. However, the experimental results in this case are not conclusive. This highlights the importance of further continuation of experiments in testing more products and increasing the experimental sample size.

The site of Nesher Ramla presented an exceptionally high amount of Ground Stone Tools, which deviates from that registered for most Middle Paleolithic contexts. From these Ground Stone Tools different types of traces were documented. In the Middle Paleolithic of the Levant and beyond, these tool types normally appear in low frequencies and almost exclusively in open-air sites. This raises the question of the relationship between Ground Stone Tools technology, site function and settlement pattern. To explore this question, it is fundamental to understand the activities in which the Ground Stone Tools were involved.

The multi-scale approach applied here allows the characterization of surface alterations at different scales. This approach stands on the principle that for a complete understanding of the tools, different levels of magnification must be included in a complementary workflow (Marreiros et al., 2020). The analysis of the tool’s entire surface was crucial to identifying the artifacts which presented a high potential for micro use-wear preservation. Nevertheless, it should be taken in consideration that some activities can leave traces which are not detectable at all scales of observation. Some activities produce different types of polished areas which only observable at a microscopic scale (the so-called high-power approach).

This study reveals that pebbles and cobbles of different sizes were used as tools, without any preparation, performing the activities directly on their cortical face. However, the preparation of an irregular "edge" with low level of symmetry was also observed on some tool types (i.e. chopper-like tools), which was evidently intended to perform some tasks that, according to the use-wear interpretation are related to percussive activities on bone.

The identification of macro and micro traces allowed a detailed characterization of the assemblage. Nevertheless, it is important to emphasize that macro traces were identified much more often than micro traces in all the analyzed assemblages. The overlap between macro traces (e.g., impacts) and micro traces (e.g., polish) rarely occurs in this assemblage. Most of the tools where micro polish was identified do not show conspicuous macro alteration. This characteristic is especially interesting as it can be indicative of individual tool use variability not only in terms of materials processed but also in terms of types of actions/motions.

From use-wear studies, macro and micro wear traces are known to vary according to both kinematics and worked material (Adams, 2014). Macro traces are influenced not only by contact material, but also by the way the tool is used (e.g., percussion vs grinding or cutting vs scrapping). On the other hand, beside the kinematics and tool's raw material, micro wear traces are largely affected by the contact material (e.g., flint vs bone).

Hammerstones and anvils are the most common type of artifact that was identified and characterized in the assemblages analyzed during this study. The anvils tend to be smaller at Far´ah II, in opposition to Ein Qashish where the biggest one was documented. Nesher Ramla presents a considerable variation in terms of metrics for this artefactual category. However, it is important to keep in mind, the large difference in terms of frequency of this type of artifacts, when compared Nesher Ramla with Far´ah II and Ein Qashish, which represents an obstacle to presenting comparative conclusions based on metrical patterns.

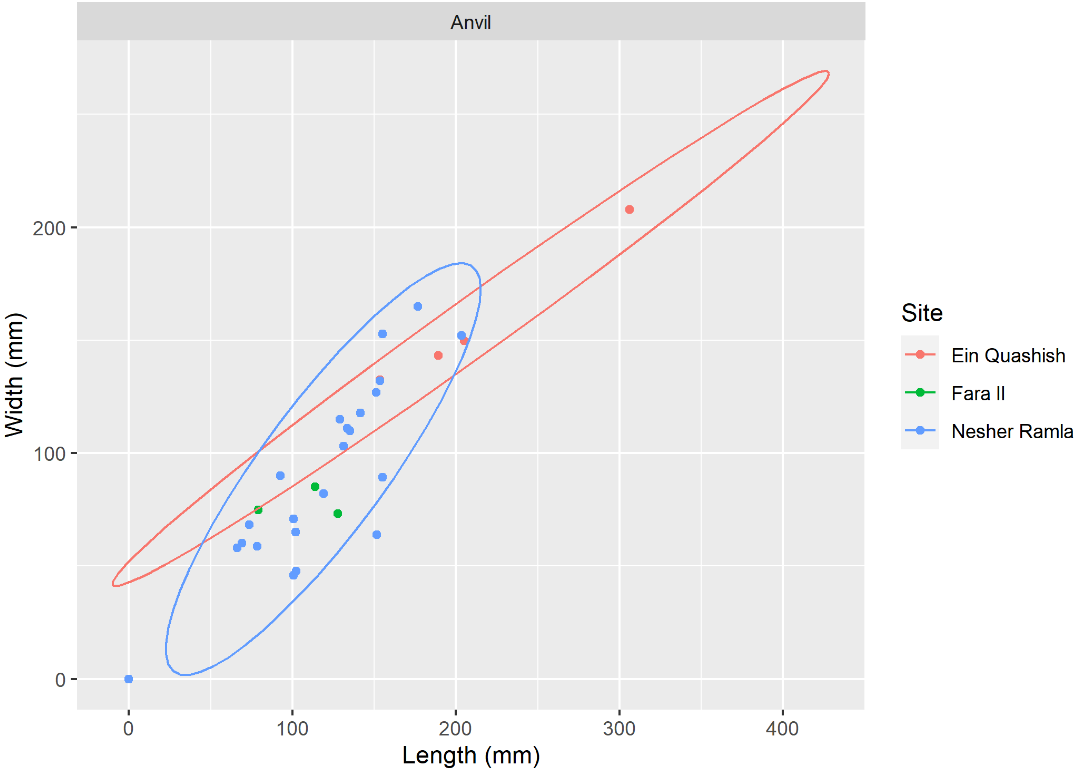


Figure 105: Scatterplot showing the anvils metric distribution per site.

In terms of hammerstones, the metric variation is not considerably different between the tools recovered at Nesher Ramla and Far´ah II. In Ein Qashish the single hammerstone analyzed is bigger than the majority of the tools of this category from the other two sites, but once again since it is a single occurrence, so does not allow further comparisons.

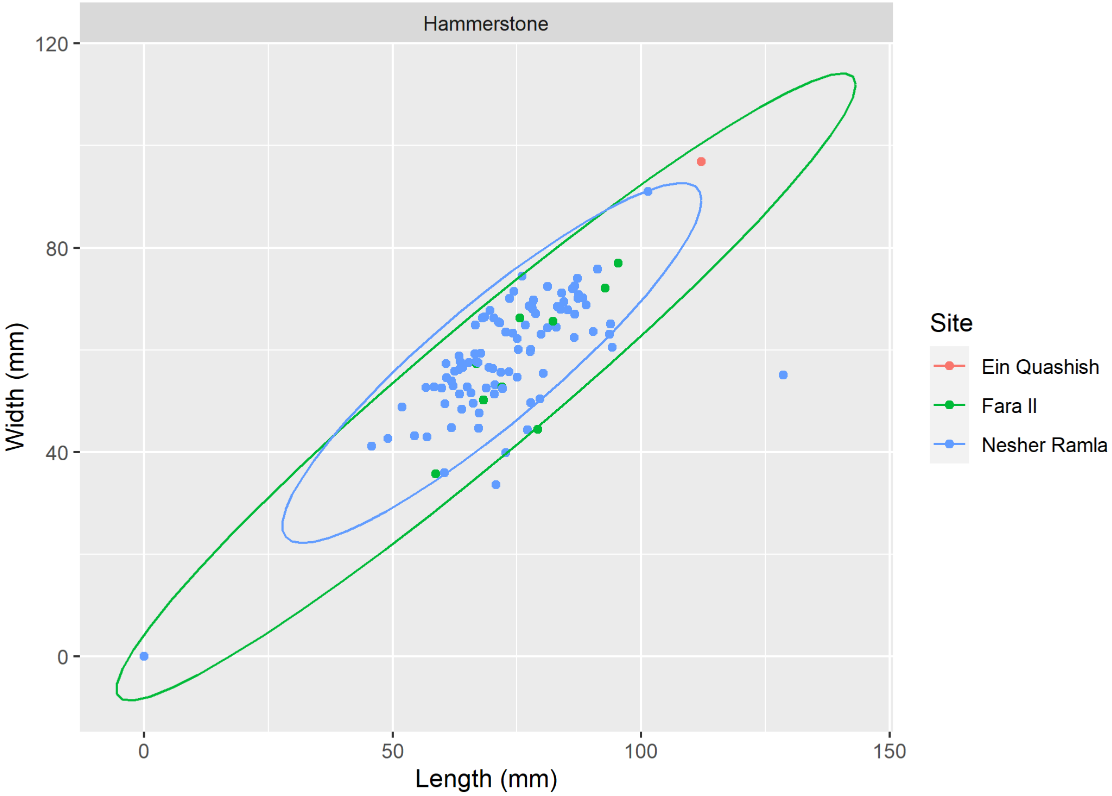


Figure 106: Scatterplot showing the hammerstones metric distribution per site.

6.3. Processing of organic materials and their implication on subsistence

The microscopic analysis at low and high magnification shows that at Nesher Ramla many stone materials were used for different types of actions, mainly for activities involving impact and abrasion motions. Use-wear traces identified on hammerstones and choppers reveal actions involving bone contact, which may represent bone breaking. Bone breaking for marrow extraction can be explained by its nutritional importance, since marrow possesses a high level of calories, fat, protein and vitamins, namely B12, E and A (Hassan et al., 2012). Different types of tools were identified with use-wear related to bone processing. This observation corroborates the archeozoological analyses of the other units at the site (Gershtein et al., 2020). Tool morphological variability at Nesher Ramla may indicate two different types of activities involving bone processing, or alternatively the processing of different types of bone (e.g., anatomical parts or species). Some tasks required the preparation of an edge, i.e., choppers that show polish associated with bone contact. Such polish is also present on unprepared tools such as hammerstones.

Other activities such as plant, wild grain, or fruit processing, should not be totally excluded, as suggested by the presence of use-wear traces categorized as type C. This type of wear is observed on tools showing no impact marks or a limited number of impact marks. However, it shows characteristics such as micro-polish and striations, indicating contact with a soft and flexible material, which allows the polish to develop in the lowest micro-topography. Some characteristics of polish, such the deep penetration into low microtopography, raise the hypothesis that some wear was produced by the contact with oily products (e.g., pistachio, acorn, nuts). Although more experiments should be done in the future in order to test in more detail this hypothesis, it is worth mentioning that evidence for the exploitation of this kind of product has been recovered in sites dated to the Lower Paleolithic, such as Gesher Benot Ya‘aqov (Goren-Inbar et al., 2015), as well as from Middle Paleolithic contexts (Akazawa, 1974; Lev et al., 2005; Madella et al., 2002; Rosen, 2003). The preparation of those type of oily products for consumption using Ground Stone Tools has been demonstrated by multiple ethnographic studies around the world (Driver, 1961; Hudson, 1976; Robitaille, 2016).

The hypothesis of plant, wild grain, nut, or fruit processing should be further explored in the future by increasing the range of experiments with different materials and movements. It is important to keep in mind that independently of how detailed, extensive, and controlled experiments are, they will never cover all the possibilities of past activities. However, they are one of our best tools to get closer to the understanding of past tool use. In this sense investing in experiments is always crucial in use-wear research.

In the site of Ein Qashish, the possibility for nut cracking activities is strongly suggested by a large passive tool with a circular depression. However due to the absence of micro polish preservation, it is difficult to prove this hypothesis. The assemblage of Ein Qashish also points to the possibility that bone marrow exploitation had been part of the routines at the site, where large stones probably were used for breaking large mammal bones.

In Far´ah II the possibility for bone breaking is not excluded, however evidence for the exploitation of other organic materials were not detected during this study.

Concerning specifically the bone breaking activities, this study suggests that different tool types were used for that task, including hammerstones, anvils and choppers. The hammerstones consist of the use of tools with no preparation, while the choppers are tools with a rough angle with some degree of damage on the edge.

This study associates these chopper tools for bone contact activities, mostly due to the fact that at Nesher Ramla choppers were identified where there was some micro polish formation associated with bone contact, together with macro damage related with impact motions but with topographic characteristics far from the ones observed during the experiments with mineral materials. This category of tools, although often in low percentages when compared with hammerstones, were present in all the case studies included in this project. This phenomenon suggests that these tools could represent a solution for a common need among the Middle Paleolithic communities, which can be related with some specificity of the bone breaking process.

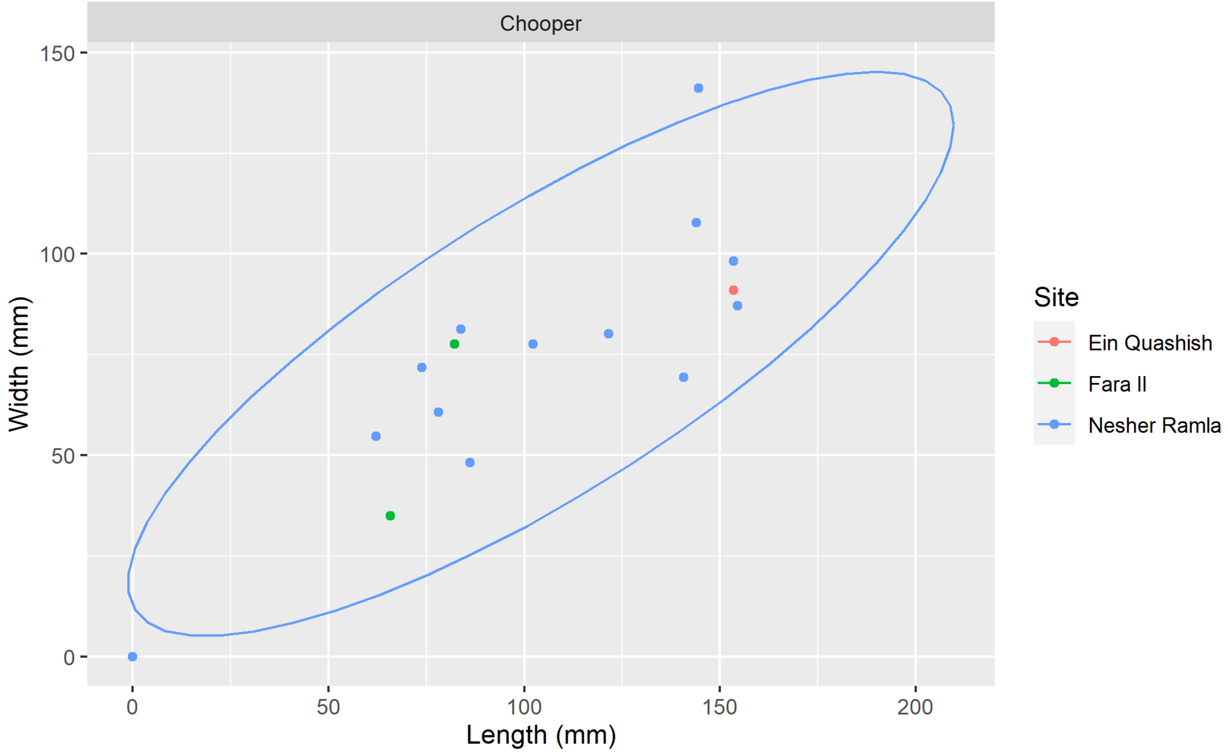


Figure 107: Scatterplot showing the choppers metric distribution per site.

6.4. Processing of inorganic materials (just technology or something else?)

In all the studied sites materials were identified with traces associated with mineral contact activities. At Nesher Ramla many hammerstones are associated with knapping activities, with some tools used probably for retouching activities. Other mineral contact activities such as ochre processing are not excluded. This specific question is worth addressing in further studies, which could combine the use-wear presented in this study with residue analyses. Despite the fact that ochre processing can be related to non-functional and symbolic behavior, it can also be related to technological aspects such as hide treatment (Dubreuil & Grosman, 2009). The importance of ochre processing among current hunter-gatherer groups has been demonstrated by ethnographic research (Hayes, 2015), and should be further explored for Middle Paleolithic Ground Stone Tools.

In Far´ah II the possibility for ochre manipulation/processing is suggested by the presence of a tool with impacts marks and crushing evidence in association with iron oxides concentration. The natural presence of this oxides should be considered as a possible scenario, which could complicate interpretation. However, this element in correlation with macro and micro traces allows the claim that ochre processing should be considered a very likely possibility. Relating the possibility of ochre processing with some type of symbolic behavior is a totally different level of interpretation, and in this case, there is not enough evidence that clearly points in that direction.

6.5. Implications for future research

Throughout this manuscript, the importance for multi-scale analyses that combines qualitative and quantitative data has been highlighted. This project stands as an example of the importance of taking these different approaches and combining them.

The development of experiments is crucial in use-wear studies, and the research on Ground Stone Tools is no exception to that rule. Concerning the experiments, once again different approaches should be complementarily adopted, in this case, namely manual and mechanized experiments. While the manual experiments are important to recreate activities and understand the main aspects of the activities, the mechanized experiments represent a possibility for establishing a high level of reproducibility and control of the variables involved in a certain action. In this research the main focus was the functional study of limestone materials. Different actions and contact materials were explored, presented with objective data, which was both crucial for the presented interpretations and can also support other researchers working in this topic.

This project brought some interpretations for the presence of limestone artifacts in the studied contexts, but also raised several questions that can represent important lines of research for future investigation on this topic. One example is the presence of bone contact evidence in tools that are considerably different, namely tools without any prior preparation and tools with flake removal prior to their use. Breaking bones is the main suggestion to explain the presence of both categories but explaining the reason behind this techno-typological difference deserves to be further explored. This could be achieved by developing further experimental programs that includes limestone tools with edges, and include other activities related with bone processing in the experimental program.

The methods explored here can and should be improved upon in the future, but they represent a solid foundation that contributes for future studies on Ground Stone Tools, especially from Middle Paleolithic contexts. It is important that more raw materials and activities are explored in the future, to enlarge the reference collection which is always the foundation for a strong functional analysis.

7. Conclusion

This study explored three ground stone tool assemblages from three different Middle Paleolithic sites in the Levant. By the application of a detailed multi-scale approach and by the combination of qualitative and quantitative analyses, supported by a dedicated experimental program, this project successfully characterized the archeological materials, contributing new understanding on several aspects of past hominin technology in the Levant. The new data presented in this thesis, brings new data to answer the main research questions, but also contributes to highlight new important questions that should be explored in the future.

The assemblage of Ground Stone Tools from Nesher Ramla is unique due to several factors. First, this assemblage represents the largest Ground Stone Tools assemblage from a Middle Paleolithic context retrieved in the Levant at the time this thesis was written. This unique assemblage contains a large number of tools that reflect several activities related to different worked materials. In Unit V, many Ground Stone Tools present areas with clear evidence of anthropic alterations, mainly in the form of impact marks, polish and striations. The various scales of analyses used in this study have revealed clear differences between different types of impact marks, both in terms of distribution and pit depth. Those differences can be related to different types of percussive/impact activities performed at the site, involving different contact materials, such as flint knapping and bone breaking.

At the micro scale, it was possible to identify four different patterns of micro polish characteristics, including traces associated with mineral and organic contact materials. Traces of flint knapping and bone breaking are predominant, and are directly supported by the experimental data presented in this thesis. Other groups of use-wear present in the assemblage exhibit characteristics that, based on existing reference collections, could be associated with the processing of perishable organic materials such as acorn, pistachio, or other products with similar characteristics. However, for a more precise interpretation of those types of polish, more experimental data should be developed in the future.

The functional variability observed among the Ground Stone Tools at Nesher Ramla indicates that pebbles and cobbles used as tools were more important in the Levantine Middle Paleolithic technological system than previously thought. The reason for such high frequencies of Ground

Stone Tools in Nesher Ramla compared with other Middle Paleolithic sites is still open to debate. Nevertheless, the singularity of Nesher Ramla due to the characteristics of the site location and geomorphology has been suggested as a major factor for the unique patterns in human settlement and resource exploitation in the local landscape. These aspects are also reflected in the high frequency and variability of the Ground Stone Tools technology at the site.

In the Far´ah II assemblage, limestone was also an important resource explored during the Middle Paleolithic. This study indicates that limestone was used mainly for percussive activities, but also very likely for other types of motions, namely abrasion and crushing. The possibility for ochre processing, although not totally proven, is highly suggested by this study. This presents new information, which needs to be furthered investigated, and likely contributes to the debate about the possibility of symbolic behavior as a characteristic of Middle Paleolithic communities.

The site of Ein Qashish represents the smaller Ground Stone Tools assemblage in terms of frequencies analyzed during this study but is not by any chance less scientifically interesting and relevant. This assemblage presents tools associated with knapping and bone breaking, and also presents a tool with evidence of some type of nut cracking. This is a particularly rare find in Levantine Middle Paleolithic contexts, and no other similar tools were found in the other assemblages explored in this work. This tool also presents clear evidence of tool preparations by flake removal, an aspect that shows that limestone was not simply used in its natural shape but instead, was prepared in order to be suitable for a specific need.

Together with new data from archaeological materials, this study provides an experimental reference collection, focused on use wear formed on limestone. This reference collection represents a solid contribution for functional studies by showing the main characteristics of the traces caused by different products and actions on this raw material. This represents an important step for understanding the function of Ground Stone Tools in the Levant.

Isolating and controlling variables during experiments is crucial in identifying the responsible elements for the formation of use-wear traces. This study presented a detailed documentation of the main differences of the use-wear features on limestone, comparing percussive activities on flint and fresh bone, and grinding motions on vegetal materials with different degrees of hardness, where dry and moist acorns were included.

By using a multi-scale approach and by combining quantitative and qualitative data, this project demonstrated that wear on limestone Ground Stone Tools connected with different motions and contact materials can result in diagnostic traces both at a macro and micro level.

This study can be seen as an important step towards the development of an extensive use-wear reference collection for the study of Ground Stone Tools in the Levant and elsewhere. Since the data presented here includes only Ground Stone Tools made of limestone, it is important to mention that in the future other raw materials should be explored, since the use wear resulting from the same activities in different raw materials may be significantly different. It is always important to keep in mind the importance of conducting experiments with raw materials as similar as possible to the ones found at the archaeological sites.

The experimental data included in this thesis did not only support the analysis of the sites explored in this work, but also provides a valuable dataset that can be consulted in the future, by use-wear analysts dealing with limestone Ground Stone Tools in very different geographical contexts.

Together with this new data, this project highlights the importance of conducting detailed analysis of Ground Stone Tools in order to provide a solid foundation for exploring new hypothesis, and to better understand the impact of this technology on Middle Paleolithic populations in the Levant.

In this study it was possible to infer about many aspects that represent a solid contribution to the study of the Middle Paleolithic in the Levant. Progressing through the different scales of analyses it was possible to understand that the three presented case studies presented very different assemblages, with the aspects of these described in the text. Nesher Ramla presents the largest variability of uses, where the intensive exploitation of animal bones, the processing of mineral products, and very likely the processing of vegetal products highlights the importance of Ground Stone Tools for the daily life routines of the middle Paleolithic populations. The larger variability of Nesher Ramla assemblage when compared with the other case studies, has a correlation with a considerable larger number of tools, where this clear difference between assemblages can be explained by several possibilities. It can be the result of a larger population group at the site which consequently led to a need for more tools, and/or by better access to a large variability of resources. Another hypothesis for this discrepancy is the likely difference in terms of site type or function, which can potentially be related to the previous ideas. Here, although Nesher Ramla can be considered an open-air site like the other case studies, in fact it is a totally different type of open air-site because it is formed in a topographic concavity originated by a sinkhole. This element contributes to a natural protection of the elements together with the possible easy access to water. This means that in theory it represents a much better location for the groups to install themselves, and develop a large range of daily tasks.

Despite the differences between the analyzed assemblages, all of them show that Ground Stone Tools during the MP in the Levant are a complex phenomenon, that is associated with a large variability of solutions for the exploitation of biotic and abiotic elements present in the environment. All the assemblages have the common ground of highlighting that Ground Stone Tools were an important tool set within this period of Humankind. These tools, mostly made of limestone, an abundant resource in the region, reveal an extraordinary capability by these populations to solve multiple challenges with the available resources. This is reflected on multiple evidence strands, showing that this type of tools was frequently adopted as a solution to multiple technological needs, such as those related with knapping, but also with the exploitation of dietary resources, as shown by the evidence for bone working and possibly other organic material. As a final message this study claims that Ground Stone Tools was a fundamental technological element for the Middle Paleolithic population, and it is very likely that we are just in the beginning of understanding much of the information hidden on the surfaces of these tools. With the exponential growth of detailed lithic studies, which include the analyses of tools without knapping, it is almost a certainty that new information about the Middle Paleolithic communities that used them also appear at an exponential rate in the scientific debate.

8. References

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9. Appendix

9.1. Tutorials and workflows

9.1.1. Application of GIS analysis for macro traces

The analysis workflow of the macro surface data processed with GIS tools is adapted from Benito-Calvo et al., 2015; 2018; Caricola et al., 2018; Zupancich et al., 2019. In our study we used Qgis 3.14.1 “Pi” through the following steps:

1. **Import surface xyz** point coordinates (.csv, .txt, .ascii). Using ***UTM coordinate projection***

2. Digital Elevation Model (***DEM***)
    a. Create DEM raster, Z coordinate as elevation value (using: **TIN Interpolation** tool)
        i. Interpolation attribute: Z
    b. Fill No Data cell (using ***Fill nodata Gdal***)
3. Digital Surface Models (***DSM***) or Terrain analysis computation (***TAC***)
    a. Hillshade inspection (**Hillshade Gdal**)
        i. Z factor: 1.0
        ii. Scale: 1.0
    b. Fatigue and Macro surface depressions
        i. Create Slope raster using **Slope Gdal** (from the genetared fill nodata DEM)
            1. Ratio of vertical units to horizontal: 1.0
            2. Create **Contour polygons** (Gdal)
                a. Interval between contour lines: 10.0
                b. Offset: 0
            3. **Polygon properties** using SAGA (number of parts, number of points, area and perimeter per polygon)
        ii. Create **TRI** raster (from DEM)
            1. Create **Contour polygons** (Gdal)
                a. Interval between contour lines: 0,05
                b. Offset: 0

    2. **Polygon properties** using SAGA (number of parts, number of points, area and perimeter per polygon)

c. **Export Contour polygons data** from each DEM as a .csv and combine them to a single dataset.

9.1.2. Confocal Surface texture analysis workflow

The analysis workflow of the surface data acquired with the confocal microscope is adapted from the template defined by (Calandra et al. 2019a, Calandra et al. 2019b, Pedergana et al. 2020). This follows several steps which are included in a ConfoMap ST (v 8.1.9369) templates, a derivative of MountainsMap Imaging Topography (Digital Surf, Besançon, France). Two templates were used:

a) **Template - Mirroring surfaces (impressions)**, this template was used to mirror the surfaces in x and z that have been acquired with the LSM 800 based on molds instead of the original artefact surface.
b) **Template - Processing analysis**, this template to process all surfaces acquired with the LSM with the 50x/0.75 and 50x/0.95 objectives.

Workflows

Template - Mirroring surfaces (impressions)

1. Loading the original topography surface;
2. Mirrored surface (in X and Z);
3. Export mirrored surface

Template - Processing analysis

1. Loading the original topography surface;
2. Levelling (Least squares method by subtraction);
3. Form removal (polynomial of degree 3);
4. Thresholding the surface between 0.1 and 99.9% material ratio to remove the aberrant positive and negative spikes;
5. Outliers removal (maximum slope of 80º);
6. Applying Microroughness removed (S-filter, 2.5 µm);
7. Filling-in the non-measured points (NMP), necessary for the computation of some parameters;
8. Calculating ISO 25178-2 parameters (International Organisation for Standardisation, 2012), Furrow analysis, Texture direction, Texture isotropy, and SSFA.

ConfoMap templates for each surface in MNT and PDF formats (including all original and processed surfaces, as well as all results) will be freely available on Zenodo.

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9.2. Tables

Table 16: General metric inventory.

Site	Id	Raw Material	Support	Preservation	Length (Mm)	Width (Mm)	Thickness (Mm)	Weight (G)	Use-wear Macro	Use-wear Location	Use-wear Type	Active Areas	Typology
Nesher Ramla	112	Limestone	Pebble	Small scar	71.61	65.28	47.92	364	Yes	Tip	Impacts	2	Hammerstone
Nesher Ramla	8350	Flint	Pebble	Complete	45.8	41.15	29.89	91	Yes	Central	Impacts	1	Hammerstone
Nesher Ramla	52	Limestone	Pebble	Small scar	66.34	58.14	26.57	186	No				Anvil
Nesher Ramla	4340	Limestone	Pebble	Complete	90.32	63.61	55.06	448	Yes	Tip	Mix	2	Hammerstone
Nesher Ramla	8743-1	Limestone	Pebble	Complete	75.04	62.18	46.89	345	Yes	Tip	Impacts		Hammerstone
Nesher Ramla	8743-3	Limestone	Pebble	Complete	74.37	71.42	53.35	425	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	631	Limestone	Pebble	Small scar	67.73	59.3	42.58	243	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8519	Limestone	Pebble	Complete	63.58	57.72	48.1	265	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8501	Limestone	Pebble	Complete	74.17	63.3	56.36	366	Yes	Central	Impacts	1	Hammerstone
Nesher Ramla	5083	Limestone	Pebble	Broken	0	0	0	0	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8743-4	Limestone	Pebble	Complete	94.15	60.53	40.1	310	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8743-6	Limestone	Pebble	Complete	0	0	0	0	Yes	Central	Impacts	1	Hammerstone
Nesher Ramla	x2	Limestone	Pebble	Small scar	91.2	75.8	64.88	558	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	x3	Limestone	Pebble	Complete	0	0	0	0	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8141-2	Limestone	Pebble	Small scar	51.85	48.81	33.6		Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8255	Limestone	Pebble	Complete	63.33	58.82	39.49	201	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	5033-1	Limestone	Pebble	Broken	67.33	44.68	36.37	180	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8246	Limestone	Pebble	Broken	70.54	53.11	43.42	241	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	6780-1	Limestone	Pebble	Small scar	81.13	72.37	49.19	393	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	6780-3	Limestone	Pebble	Broken	78.48	58.72	27.53	146	Yes	Central	Impacts	1	Anvil
Nesher Ramla	8646-1	Limestone	Block	Broken	0	0	0	0	Yes	Central	Impacts	1	Anvil

Nesher Ramla	7689-1	Limestone	Pebble	Complete	83.99	71.09	66.14	530	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8361	Limestone	Pebble	Complete	76.72	64.9	43.73	287	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	5520	Limestone	Pebble	Broken	0	0	0	0	Yes	Tip	Impacts	1	Chopper
Nesher Ramla	1822	Limestone	Pebble	Complete	69.59	67.73	46.01	0	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla		Limestone	Pebble	Broken	0	0	0	0	No				Hammerstone
Nesher Ramla	8267	Limestone	Pebble	Complete	61.84	53.91	48.68	217	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	5722	Limestone	Pebble	Broken	77.12	44.37	50.02	275	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	1626	Limestone	Pebble	Complete	79.85	63.06	48.65	321	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla		Limestone	Pebble	Broken	0	0	0	0	Yes	Tip	Impacts	2	Hammerstone
Nesher Ramla	6079	Limestone	Pebble	Complete	128.63	55.07	63.48	389	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	7630	Limestone	Pebble	Complete	83.19	68.49	49.16	377	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	7630-1	Limestone	Pebble	Small scar	70.49	51.31	43.96	212	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	5925	Limestone	Pebble	Small scar	70.1	56.4	44.46	286	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	738	Limestone	Pebble	Small scar	0	0	0	0	Yes	Tip	Impacts	2	Hammerstone
Nesher Ramla	4292	Limestone	Pebble	Complete	0	0	0	0	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	90	Limestone	Pebble	Complete	73.38	55.71	45.93	278	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	7260	Limestone	Pebble	Small scar	62.51	55.8	39.04	164	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8001	Limestone	Pebble	Complete	62.11	52.92	49.26	209	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	234	Limestone	Pebble	Complete	63.5	51.39	31.68	147	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	1181	Limestone	Pebble	Small scar	65.33	57.51	47.42	217	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	56	Limestone	Pebble	Small scar	59.86	52.51	46.36	270	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	1808	Limestone	Pebble	Complete	70.35	66.24	40.82	263	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	1145	Limestone	Pebble	Complete	86.69	72.55	53.65	492	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	7062-1	Limestone	Pebble	Complete	71.21	65.53	43.88	305	Yes	Central	Impacts	1	Hammerstone
Nesher Ramla	1830	Limestone	Pebble	Complete	77.46	68.55	50.7	355	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	19	Limestone	Pebble	Complete	71.79	55.61	50.66	290	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	4783-1	Limestone	Pebble	Complete	77.66	59.63	56.28	404	Yes	Tip	Impacts	2	Hammerstone

Nesher Ramla	5526	Limestone	Pebble	Small scar	77.81	60.08	46.29	302	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	1072	Limestone	Pebble	Complete	83.81	67.96	44.26	385	Yes	Tip	Impacts	3	Hammerstone
Nesher Ramla	4522	Limestone	Pebble	Complete	48.99	42.63	37.44	116	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	5118	Limestone	Block	Broken	154.49	87.13	44.61	715	No				Chopper
Nesher Ramla	1939	Limestone	Boulder	Broken	144.51	141.18	84.47	2745	No				Chopper
Nesher Ramla	1593	Limestone	Pebble	Complete	87.4	70.86	49.93	479	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	6034	Limestone	Pebble	Complete	93.64	63.09	47.11	413	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	6109	Limestone	Pebble	Complete	68.8	52.54	37.52	212	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	4309-1	Limestone	Pebble	Complete	0	0	0	0	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	351	Limestone	Pebble	Small scar	87.19	74.03	54.88	465	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	4391	Limestone	Pebble	Small scar	0	0	0	0	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	4263	Limestone	Pebble	Complete	0	0	0	0	Yes	Central	Impacts	1	Hammerstone
Nesher Ramla	6355	Limestone	Pebble	Broken	70.79	33.63	57.2	184	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8273	Limestone	Pebble	Complete	58.31	52.71	42.83	197	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	346	Limestone	Pebble	Complete	68.52	66.43	51.02	292	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	296	Limestone	Block	Broken	121.64	80.1	50.24	710	Yes	Tip	Impacts	1	Chopper
Nesher Ramla	1667	Limestone	Pebble	Small scar	60.5	49.47	35.05	154	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8064	Limestone	Pebble	Broken	69.12	60.1	31.05	177	Yes	Central	Impacts	1	Anvil
Nesher Ramla	8064-1	Limestone	Pebble	Complete	78.14	68.03	36.45	264	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	4736-3	Limestone	Pebble	Small scar	60.71	57.33	45.35	205	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	6955	Limestone	Pebble	Complete	66.55	59.26	36.68	215	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	5100	Limestone	Pebble	Complete	56.94	42.91	36.07	115	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	1719	Limestone	Pebble	Complete	82.92	64.4	53.1	449	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	5701-3	Limestone	Pebble	Complete	61.81	44.76	39.73	168	Yes	Tip	Mix	1	Hammerstone
Nesher Ramla	5911	Limestone	Pebble	Broken	78.06	60.75	53.56	448	Yes	Tip	Impacts	1	Chopper
Nesher Ramla	5904-1	Limestone	Pebble	Small scar	77.96	68.74	56.04	408	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	345	Limestone	Pebble	Broken	86.68	67.03	45.58	454	Yes	Tip	Impacts	1	Hammerstone

Nesher Ramla	261	Limestone	Pebble	Complete	87.32	70.02	60.34	470	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	5701	Limestone	Block	Broken	86.13	48.24	36.16	168	Yes	Tip	Impacts	1	Chopper
Nesher Ramla	235	Limestone	Pebble	Complete	72.8	63.49	45.88	375	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	1663	Limestone	Pebble	Complete	75.05	54.66	42.88	247	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	7968	Limestone	Pebble	Broken	63.86	48.33	40.28	168	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	6888	Limestone	Pebble	Complete	65.78	51.53	39.04	205	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	362	Limestone	Block	Broken	155.03	89.32	74.13	1693	Yes	Central	Impacts	1	Anvil
Nesher Ramla	7006	Limestone	Pebble	Broken	81.14	64.32	53.21	386	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	6292	Limestone	Pebble	Complete	78.83	67.08	56.16	433	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8714	Limestone	Pebble	Small scar	88.24	70.19	47.24	377	Yes	Tip	Impacts	2	Hammerstone
Nesher Ramla	132	Limestone	Pebble	Broken	72.75	39.86	35.34	121	Yes	Tip	Impacts	1	Hammerstone
Nesher Ramla	8675	Limestone	Block	Broken	135.23	109.92	52.68	1109	Yes	Central	Impacts	1	Anvil
Far´ahII	5	Flint	Pebble	Small scar	65.84	34.94	23.3	73	Yes	Tip	Impacts	1	Chopper
Far´ahII		Limestone	Pebble	Small scar	92.81	72.03	67.19	585	Yes	Tip	Impacts	2	Hammerstone
Far´ahII	21	Limestone	Pebble	Complete	72.05	52.68	38.39	198	Yes	Tip	Impacts	1	Hammerstone
Far´ahII	72	Limestone	Pebble	Complete	79.25	44.4	15.88	87	Yes	Tip	Mix	3	Hammerstone
Far´ahII	16	Other	Block	Broken	113.93	85.14	28.35	368	Yes	Central	Impacts	1	Anvil
Far´ahII	23	Limestone	Pebble	Complete	58.67	35.75	21.42	62	Yes	Tip	Impacts	2	Hammerstone
Far´ahII	4	Limestone	Block	Broken	127.69	73.32	33.35	365	Yes	Central	Impacts	1	Anvil
Far´ahII	35	Limestone	Pebble	Broken	82.25	65.56	31.47	220	Yes	Central	Impacts	1	Hammerstone
Far´ahII	85	Limestone	Pebble	Broken	0	0	0	0	Yes	Central	Impacts	1	Hammerstone
Far´ahII	40	Limestone	Pebble	Broken	82.23	77.66	48.23	323	Yes	Tip	Impacts	1	Chopper
Far´ahII	42	Limestone	Pebble	Broken	95.38	76.93	52.78	402	Yes	Both	Impacts	3	Hammerstone
Far´ahII	37	Limestone	Pebble	Broken	68.29	50.2	31.39	134	Yes	Central	Impacts	1	Hammerstone
Far´ahII	85	Limestone	Pebble	Broken	79.15	74.94	57.42	624	Yes	Central	Impacts	1	Anvil
Far´ahII		Limestone	Pebble	Broken	0	0	0	0	Yes	Tip	Impacts	2	Hammerstone
Far´ahII	84	Limestone	Pebble	Small scar	66.81	57.27	37.34	220	Yes	Both	Impacts	3	Hammerstone

Nesher Ramla	5570-1	Limestone	Pebble	Broken	86.49	62.37	62.65	541	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	8150	Limestone	Pebble	Broken	60.81	54.56	35.09	172	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	5506	Limestone	Pebble	Broken	101.97	65.01	29.3	363	Yes	Central	Mix	1		Anvil
Nesher Ramla	8716-2	Limestone	Block	Broken	128.97	114.92	49.3	1031	Yes	Central	Impacts	1		Anvil
Nesher Ramla	1674	Limestone	Pebble	Complete	93.88	65.05	39.74	297	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	141	Limestone	Pebble	Complete	73.52	70.02	57.53	341	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	6079	Limestone	Pebble	Broken	73.54	68.25	59.14	454	Yes	Central	Impacts	2		Anvil
Nesher Ramla	145	Limestone	Pebble	Broken	133.52	111.1	70.66	1648	Yes	Central	Impacts	2		Anvil
Nesher Ramla	108	Limestone	Block	Broken	131.29	102.97	35.2	621	Yes	Central	Impacts	1		Anvil
Nesher Ramla	12	Limestone	Pebble	Complete	88.98	68.77	43.75	410	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	115	Limestone	Block	Broken	143.9	107.72	42.74	887	Yes	Tip	Impacts	1		Chopper
Nesher Ramla	1173	Limestone	Pebble	Complete	78.39	69.74	37.98	320	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	232	Limestone	Pebble	Complete	67.18	57.51	39.54	219	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	999	Limestone	Pebble	Complete	86.26	72.02	58.31	486	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	146	Limestone	Pebble	Small scar	62.21	54.78	50.23	222	Yes	Tip	Impacts	1		Chopper
Nesher Ramla	149	Limestone	Block	Broken	100.8	70.81	59.39	737	Yes	Central	Impacts	1		Anvil
Nesher Ramla	7711-5	Limestone	Pebble	Complete	84.47	69.44	50.76	418	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	7711-1	Limestone	Pebble	Broken	0	0	0	0	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	8711	Limestone	Pebble	Complete	54.42	43.14	21.87	63	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	8096-1	Limestone	Pebble	Broken	60.42	35.97	25.06	85	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	8082	Limestone	Pebble	Complete	72.16	52.38	41.27	211	Yes	Tip	Impacts	1		Hammerstone
Ein Qashish	S1314	Limestone	Block	Broken	306.03	207.79	67.81	6172	Yes		Impacts		2	Anvil
Ein Qashish	M49	Limestone	Block	Broken	153.52	132.48	40.46	1280	No					Anvil
Ein Qashish	2340	Limestone	Block	Broken	204.88	149.69	73.37	35.08	Yes	Central	Mix	1		Anvil
Ein Qashish	S6106	Limestone	Block	Broken	153.42	90.96	71.8	1840	Yes	Tip	Impacts	1		Chopper
Ein Qashish	F6047	Limestone	Block	Broken	112.16	96.9	80.31	1244	Yes	Tip	Impacts	4		Hammerstone
Ein Qashish	S1875	Limestone	Block	Broken	189.37	143.1	77.54	2484	Yes	Central	Impacts		1	Anvil

Nesher Ramla	924	Limestone	Pebble	Complete	68.07	66.21	38.04	244	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	307	Limestone	Pebble	Complete	0	0	0	0	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	8	Limestone	Block	Broken	140.72	69.42	55.16	951	Yes	Tip	Impacts	1		Chopper
Nesher Ramla	1	Limestone	Pebble	Complete	63.33	56.15	47.73	220	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	8741	Limestone	Block	Broken	141.5	117.81	58.8	1481	Yes	Tip	Impacts	1		Anvil
Nesher Ramla	8741-7	Limestone	Block	Broken	73.84	71.82	48.99	335	Yes	Tip	Impacts	2		Chopper
Nesher Ramla	6898	Limestone	Pebble	Complete	80.33	55.4	54.06	394	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	8067	Limestone	Pebble	Complete	66.61	64.84	49.18	302	Yes	Tip	Impacts		1	Hammerstone
Nesher Ramla	8741	Limestone	Pebble	Small scar	66.17	49.54	45.04	256	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	8743-2	Limestone	Pebble	Complete	64.14	56.51	46.12	217	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	8743-4	Limestone	Block	Broken	102.2	47.83	52.39	293	Yes	Central	Impacts	1		Anvil
Nesher Ramla	8743	Limestone	Pebble	Complete	69.42	56.56	48.89	296	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	1751	Limestone	Pebble	Broken	83.79	81.34	45.32	365	Yes	Tip	Impacts	1		Chopper
Nesher Ramla	8114	Limestone	Pebble	Complete	77.81	49.7	47.63	234	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	8741-4	Limestone	Pebble	Small scar	66.77	57.7	46.75	220	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	8741-2	Limestone	Pebble	Broken	102.24	77.57	74.28	696	Yes	Tip	Impacts	1		Chopper
Nesher Ramla	1086	Limestone	Pebble	Complete	56.74	52.62	30.32	111	Yes	Both	Impacts	1		Hammerstone
Nesher Ramla	8038-1	Limestone	Pebble	Broken	100.67	45.89	64.56	486	Yes	Central	Impacts	1		Anvil
Nesher Ramla	8039-1	Limestone	Pebble	Complete	76.02	74.38	54.71	449	Yes	Tip	Impacts	1		Hammerstone
Nesher Ramla	8038	Limestone	Pebble	Complete	65.05	52.76	36.84	193	Yes	Tip	Impacts	2		Hammerstone
Nesher Ramla	8741-7	Limestone	Pebble	Complete	101.42	91.04	93	1384	Yes	Tip	Impacts	1		Hammerstone
Far´ahII	180	Limestone	Pebble	Broken	75.66	66.19	44.15	241	Yes	Central	Impacts		1	Hammerstone
Nesher Ramla	8289/1	Limestone	Pebble	Broken	75.32	60.12	43.52	303	Yes	Tip	Impacts		1	Hammerstone
Nesher Ramla	1635	Limestone	Pebble	Complete	79.63	50.4	38.12	229	Yes	Tip	Impacts		1	Hammerstone
Nesher Ramla	8536	Limestone	Pebble	Broken	67.42	47.58	38.78	169	Yes	Tip	Impacts		1	Hammerstone
Nesher Ramla	5115	Limestone	Pebble	Broken	153.55	98.21	81.56	1819	Yes	Tip	Impacts		1	Chopper
Nesher Ramla	76	Limestone	Boulder	Broken	176.57	164.8	65.32	3988	Yes	Central	Mix		2	Anvil

Nesher Ramla	7098	Limestone	Boulder	Broken	203.48	152.03	75.61	3848	Yes	Central	Impacts	1	Anvil
Nesher Ramla	1534	Limestone	Block	Broken	155.06	152.89	93.99	3532	Yes	Central	Impacts	1	Anvil
Nesher Ramla	4152	Limestone	Boulder	Complete	153.6	132.06	103.82	3058	Yes	Central	Impacts	1	Anvil
Nesher Ramla	5071	Limestone	Block	Broken	92.64	89.91	35.87	308	Yes	Central	striations	1	Anvil
Nesher Ramla	5551	Limestone	Boulder	Broken	151.45	63.91	71.02	11.71	Yes	Central	Impacts	1	Anvil
Nesher Ramla	5935	Limestone	Pebble	Broken	118.9	82	30.26	367	Yes	Central	Impacts	1	Anvil
Nesher Ramla	4277	Limestone	Pebble	Complete	151.24	126.93	73.73	2031	Yes	Central	Impacts	1	Anvil
Nesher Ramla	4260	Limestone	Pebble	Broken	85.28	67.82	59.11	420	Yes	Central	Impacts	2	Hammerstone

Table 17: Functional inventory (simplified).

Site	Id	Raw material	Cortex	Patina	Burned	Wear1marks type	Wear1 Location	Wear1 striation	Wear1 Polish Mesh	Wear1 Marks Direction	Wear1 Worked Material Hardness	Wear1 Worked Material Type	Wear 2	Tool Movement	Typology	Macro Type	Micro Type
		Flint	25%	light-patination	No	Polish	A1		Na	NA	NA	NA	yes	NA	Anvil		
Far´ah II	41	Limestone	25%	none	No	Striation	A5	Parallel			Hard	NA	no	NA	Undefined	2	
Far´ah II	83	Limestone	100%	none	No	Impact	A1	Parallel			Hard	Mineral	yes	grinding	Pestle	2	
Far´ah II		Limestone	100%	light-patination	No	Impact	A1	Parallel			Hard	Mineral	yes	grinding	Hammerstone	2	
Far´ah II	16	Limestone	50%	none	No	Impact	A6	Parallel			Hard	Mineral	no	NA	Undefined	2	
Far´ah II	42	Limestone	50%	light-patination	No	Impact	A5	Parallel			Hard	Mineral	yes	NA	Hammerstone	2	
Far´ah II	37	Limestone	50%	light-patination	No	Impact	A5	Parallel			Hard	Mineral	no	knaping	Hammerstone	2	
Far´ah II	35	Limestone	50%	light-patination	No	Impact	A5	Parallel			Hard	Mineral	no	NA	Undefined	2	
Far´ah II	16	Other	0%	none	No	Polish&Striation	A5	NA	Na	NA	NA	Unrecognized	no	grinding	Undefined		
Far´ah II	20	Other	0%	none	Yes	Polish&Striation	A5	NA	Na	NA	NA	Unrecognized	no	grinding	Undefined		
Far´ah II	72	Limestone	100%	none	No	Polish&Striation	A1	NA	Na	NA	NA	Unrecognized	yes	NA	Undefined		
Far´ah II	87	Other	25%	none	No	Polish&Striation	A2	NA	Na	NA	NA	Unrecognized	no	NA	Chopper		
Far´ah II	180	Limestone	50%	none	No	Impact	A5	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2	
Far´ah II	101	Limestone	100%	none	No	Impact	A1	NA	Na	NA	Semi-hard	NA	no	NA	Undefined	1	
Far´ah II	7	Limestone	50%	none	No	Impact	A3	NA	Na	NA	NA	NA	no	NA	Anvil		
Far´ah II	8	Limestone	50%	none	No	Polish	A3	NA	Na	NA	NA	NA	no	NA	Anvil		

Nesher Ramla	8273	Limestone	100%	none	No	Impact	A2				Semi-hard	NA	no	breaking	Hammerstone	1	
Nesher Ramla	1593	Limestone	100%	none	No	Impact	A9				Hard	NA	no	breaking	Hammerstone	2	
Nesher Ramla	5904	Limestone	100%	none	No	Polish	A2		Open	NA	NA	NA	no	NA	Undefined		D
Nesher Ramla	1830	Limestone	100%	none	No	Impact	A2		Open	NA	Semi-hard	NA	no	breaking	Hammerstone	1	
Nesher Ramla	6780-3	Limestone	50%	none	No	Polish	A5		Open	NA	NA	NA	no	NA	Undefined		D
Nesher Ramla	1086	Limestone	100%	none	No	Impact	A2		Open	NA	Semi-hard	NA	no	NA	Hammerstone	1	
Nesher Ramla	8517-1	Limestone	100%	none	No	Polish&Striation	A5	Parallel	Open	NA	NA	NA	no	NA	Abrader		A
Nesher Ramla	6034	Limestone	100%	none	No	Impact	A3	Parallel	Open	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	112	Limestone	75%	none	No	Impact	A3	Parallel	Open	NA	Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	8743-1	Limestone	100%	none	No	Impact	A3	Parallel	Open	NA	Hard	NA	yes	breaking	Hammerstone	2	
Nesher Ramla	6759	Limestone	100%	none	No	Polish&Striation	A2	Parallel	Open	Parallel	NA	NA	no	polishing	Abrader		C
Nesher Ramla	5033-1	Limestone	75%	none	No	Impact	A3	Parallel	Open	Parallel	Hard	NA	yes	breaking	Hammerstone	2	
Nesher Ramla	8718	Flint	100%	none	No	Polish	A2		Open	NA	NA	NA	no	NA	Undefined		D
Nesher Ramla	1231	Limestone	50%	none	No	Impact	A1		Open	NA	Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	234	Limestone	100%	none	No	Impact	A1		Open	NA	Semi-hard	NA	no	NA	Hammerstone	1	
Nesher Ramla	1512	Limestone	100%	none	No	Polish	A3		Na	NA	NA	NA	no	NA	Undefined		D
Nesher Ramla	8067	Limestone	100%	none	No	Impact	A2		Na	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	x2	Limestone	75%	none	No	Impact	A1		Na	NA	Hard	NA	yes	breaking	Hammerstone	2	
Nesher Ramla	7630	Limestone	100%	none	No	Impact	A2		Na	NA	Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	7062-1	Limestone	100%	none	No	Impact	A5		Na	NA	Semi-hard	Hard animal material	no	breaking	Hammerstone	1	

Nesher Ramla	8743	Limestone	100%	none	No	Impact	A2			Hard	NA	yes	breaking	Hammerstone	2	
Nesher Ramla	631	Limestone	100%	none	No	Impact	A2			Hard	NA	no	breaking	Hammerstone	2	
Nesher Ramla	8141	Limestone	100%	none	No	Impact	A2			Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	8501	Limestone	100%	none	No	Impact	A5			Hard	NA	no	breaking	Hammerstone	2	
Nesher Ramla	6780-1	Limestone	100%	none	No	Impact	A2			Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	8350	Limestone	100%	none	No	Impact	A5			Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	8719	Limestone	100%	none	No	Impact	A3			Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	783	Limestone	100%	none	Yes	Impact	A1			Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	1145	Limestone	100%	none	No	Impact	A1			Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	8647	Limestone	75%	none	Yes	Impact	A2			NA	NA	no	NA	Hammerstone		
Nesher Ramla	5506-1	Limestone	50%	none	No	Polish	A5	Na	NA	NA	NA	no	NA	Undefined		D
Nesher Ramla	8743-4	Limestone	100%	none	No	Impact	A5	Na	NA	NA	NA	no	knaping	Hammerstone		
Nesher Ramla	6079	Limestone	100%	none	No	Impact	A1	Na	NA	NA	NA	no	knaping	Hammerstone		
Nesher Ramla	367	Limestone	100%	none	No	Impact	A3	Na	NA	Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	7630-1	Limestone	75%	none	No	Impact	A3	Na	NA	Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	4340	Limestone	100%	none	No	Impact	A1	Na	NA	Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	5722	Limestone	75%	none	Yes	Impact	A1	Na	NA	Hard	NA	yes	NA	Hammerstone	2	
Nesher Ramla	8743-6	Limestone	100%	none	No	Impact	A5	Na	NA	Hard	NA	yes	knaping	Hammerstone	2	
Nesher Ramla	1626	Limestone	100%	none	No	Impact	A3			NA	NA	no	NA	Hammerstone		
Nesher Ramla	8661	Limestone	100%	none	No	Impact	A5			NA	NA	no	NA	Hammerstone		

Nesher Ramla	4522	Limestone	100%	none	No	Impact	A3				Semi-hard	NA	no	NA	Hammerstone	1	
Nesher Ramla	8141-2	Limestone	75%	none	No	Impact	A4				NA	NA	no	NA	Hammerstone		
Nesher Ramla	381	Limestone	100%	none	No	Polish	A3		Open	NA	NA	NA	no	NA	Undefined		B
Nesher Ramla	300	Limestone	100%	none	No	Impact	A5		Open	NA	NA	Mineral	no	crushing	Pestle		
Nesher Ramla	8064	Limestone	75%	none	No	Impact	A5				NA	NA	no	breaking	Anvil		
Nesher Ramla	6355	Limestone	50%	none	No	Impact	A2				NA	NA	no	knaping	Hammerstone		
Nesher Ramla	1808	Limestone	100%	none	No	Impact	A2				Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	7689-1	Limestone	100%	none	No	Impact	A3				Hard	NA	no	breaking	Hammerstone	2	
Nesher Ramla	8509	Limestone	50%	none	No	Impact	A1				Hard	NA	no	breaking	Anvil	2	
Nesher Ramla	5100	Limestone	100%	none	No	Impact	A3				Semi-hard	NA	yes	NA	Hammerstone	1	C
Nesher Ramla	8646	Limestone	75%	none	No	Impact	A8				Hard	NA	no	breaking	Anvil	2	
Nesher Ramla	5526	Limestone	100%	none	No	Impact	A2				Hard	NA	no	breaking	Hammerstone	2	
Nesher Ramla	793	Limestone	100%	none	No	Impact	A5				Hard	Hard animal material	no	breaking	Anvil	2	
Nesher Ramla	8133	Limestone	100%	none	No	Impact	A3				Hard	NA	no	breaking	Hammerstone	2	
Nesher Ramla	8001	Limestone	100%	none	No	Impact	A5				Hard	NA	no	breaking	Hammerstone	2	
Nesher Ramla	8267	Limestone	100%	none	No	Impact	A3				Hard	NA	no	breaking	Hammerstone	2	
Nesher Ramla	5701	Limestone	75%	none	No	Impact	A5				Hard	NA	no	breaking	Chopper	2	
Nesher Ramla	8519	Limestone	100%	none	No	Impact	A2				Semi-hard	NA	no	breaking	Hammerstone	1	
Nesher Ramla	7260-1	Limestone	100%	none	No	Striation	A7	Parallel			Semi-hard	NA	no	NA	Undefined	1	
Nesher Ramla	8246	Limestone	75%	none	No	Impact	A2	Parallel			Semi-hard	NA	no	NA	Hammerstone	1	

Nesher Ramla	4736-3	Limestone	75%	none	No	Impact	A2	Parallel			Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	8711	Limestone	50%	none	No	Impact	A2	Parallel			Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	6780-1	Limestone	100%	none	No	Impact	A2	Parallel			Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	56	Limestone	100%	none	No	Impact	A1	Parallel			Semi-hard	NA	no	knaping	Hammerstone	1	
Nesher Ramla	8716-2	Limestone	75%	none	No	Impact	A5	Parallel			Hard	Mineral	yes	crushing	Anvil	2	
Nesher Ramla	1822	Limestone	100%	none	No	Impact	A3	Parallel			Hard	NA	yes	NA	Hammerstone	2	
Nesher Ramla	8743-2	Limestone	100%	none	No	Impact	A2	Parallel			Semi-hard	NA	no	knaping	Hammerstone	1	
Nesher Ramla	4873-1	Limestone	100%	none	No	Polish	A5	Parallel	Na	NA	Semi-hard	Mineral	no	crushing	Pestle	1	D
Nesher Ramla	6109	Limestone	100%	none	No	Impact	A3	Parallel	Na	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	95	Limestone	75%	none	No	Impact	A2	Parallel	Na	NA	Hard	NA	no	crushing	Pestle	2	
Nesher Ramla	90	Limestone	100%	none	No	Impact	A6	Parallel	Na	NA	Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	8361	Limestone	100%	none	No	Impact	A2	Parallel	Na	NA	Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	5946	Limestone	100%	none	No	Polish	A3	Parallel	Na	NA	NA	NA	no	NA	Undefined		D
Nesher Ramla	6404	Limestone	100%	none	No	Polish	A5	Parallel	Na	NA	NA	NA	no	NA	Abrader		A
Nesher Ramla	1502	Limestone	100%	none	No	Striation	A4	NA	Na	NA	Semi-hard	Mineral	yes	crushing	Pestle	1	
Nesher Ramla	6292	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Hard	NA	no	breaking	Hammerstone	2	
Nesher Ramla	349	Limestone	100%	none	No	Polish	A1	NA	Na	NA	NA	NA	no	NA	Abrader		A
Nesher Ramla	5911	Limestone	75%	none	No	Impact	A3	NA	Na	NA	NA	NA	no	NA	Chopper		
Nesher Ramla	5925	Limestone	75%	none	No	Impact	A1	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	6888	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Semi-hard	NA	no	NA	Hammerstone	1	

Nesher Ramla	6955	Limestone	100%	none	No	Impact	A2	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2
Nesher Ramla	232	Limestone	100%	none	No	Impact	A2	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2
Nesher Ramla	1173	Limestone	100%	none	No	Impact	A2	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2
Nesher Ramla	8038	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2
Nesher Ramla	8038-1	Limestone	50%	none	No	Impact	A5	NA	Na	NA	Hard	NA	no	breaking	Anvil	2
Nesher Ramla	5520	Limestone	75%	none	No	Impact	A2	NA	Na	NA	Hard	NA	no	breaking	Chopper	2
Nesher Ramla	7260	Limestone	75%	none	No	Impact	A2	NA	Na	NA	Hard	NA	no	knaping	Hammerstone	2
Nesher Ramla	8039-1	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Hard	NA	no	knaping	Hammerstone	2
Nesher Ramla	7968	Limestone	75%	none	No	Impact	A2	NA	Na	NA	Hard	NA	no	knaping	Hammerstone	2
Nesher Ramla	1667	Limestone	75%	none	No	Impact	A1	NA	Na	NA	Hard	NA	no	breaking	Hammerstone	2
Nesher Ramla	1674	Limestone	100%	none	No	Impact	A2	NA	Na	NA	Hard	NA	no	breaking	Hammerstone	2
Nesher Ramla	362	Limestone	75%	none	No	Impact	A4	NA	Na	NA	Hard	NA	yes	breaking	Anvil	2
Nesher Ramla	146	Limestone	75%	none	No	Impact	A2	NA	Na	NA	Hard	NA	no	breaking	Chopper	2
Nesher Ramla	8150	Limestone	50%	none	Yes	Impact	A2	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2
Nesher Ramla	8255	Limestone	100%	none	No	Impact	A2	NA	Na	NA	Semi-hard	NA	no	NA	Hammerstone	1
Nesher Ramla	5701-3	Limestone	100%	none	No	Impact	A2	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2
Nesher Ramla	7931	Limestone	100%	none	No	Polish	A6	NA	Na	NA	NA	NA	no	NA	Undefined	B
Nesher Ramla	12	Limestone	100%	none	No	Impact	A6	NA	Na	NA	Semi-hard	NA	no	NA	Hammerstone	1
Nesher Ramla	8096-1	Limestone	50%	none	No	Impact	A3	NA	Na	NA	NA	NA	no	NA	Undefined	
Nesher Ramla	1584	Limestone	25%	none	No	Impact	A2	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2

Nesher Ramla	924	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Semi-hard	NA	no	NA	Hammerstone	1	
Nesher Ramla	5506	Limestone	25%	none	No	Striation	A4	NA			NA	NA	no	NA	Undefined		
Nesher Ramla	8485	Limestone	100%	none	No	Striation	A1	Parallel			NA	NA	no	NA	Abrader		
Nesher Ramla	8501-2	Limestone	75%	none	No	Impact	A3	Parallel			NA	NA	no	NA	Undefined		
Nesher Ramla	145	Limestone	75%	none	No	Impact	A4	Parallel			NA	NA	yes	NA	Anvil		
Nesher Ramla	8646-1	Limestone	100%	none	No	Polish&Striation	A2	NA	Open	NA	NA	NA	no	NA	Undefined		A
Nesher Ramla	141	Flint	100%	none	No	Impact	A2	NA	Open	NA	Semi-hard	NA	no	NA	Hammerstone	1	
Nesher Ramla	345	Limestone	75%	none	No	Impact	A3	NA	Open	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	157	Limestone	100%	none	No	Polish	A5	NA	Na	NA	NA	NA	no	NA	Undefined		A
Nesher Ramla	346	Limestone	100%	none	No	Impact	A3	NA	Na	NA	NA	NA	no	NA	Hammerstone		
Nesher Ramla	8743-3	Limestone	100%	none	No	Polish&Striation	A2	NA	Na	NA	NA	NA	no	NA	Abrader		B
Nesher Ramla	8743-2	Limestone	100%	none	No	Impact	A1	NA	Na	NA	Semi-hard	NA	no	NA	Hammerstone	1	
Nesher Ramla	8519	Limestone	75%	none	No	Impact	A1	NA	Na	NA	NA	NA	no	NA	Hammerstone		
Nesher Ramla	1072	Limestone	75%	none	No	Polish	A6	NA	Na	NA	NA	NA	yes	NA	Undefined		D
Nesher Ramla	8723	Limestone	100%	none	No	Impact	A3	NA	Na	NA	NA	NA	yes	NA	Hammerstone		A
Nesher Ramla	19	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Semi-hard	NA	no	NA	Hammerstone	1	
Nesher Ramla	1719	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Hard	NA	yes	NA	Undefined	2	
Nesher Ramla	5570-1	Limestone	75%	none	No	Impact	A1	NA	Na	NA	Hard	NA	yes	NA	Hammerstone	2	B
Nesher Ramla	8741-3	Limestone	100%	none	No	Polish	A6	NA	Na	NA	NA	NA	no	NA	Undefined		B
Nesher Ramla	8741-2	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Semi-hard	NA	no	NA	Hammerstone	1	

Nesher Ramla	235	Limestone	100%	none	No	Impact	A4	NA	Na	NA	Semi-hard	NA	yes	NA	Hammerstone	1	
Nesher Ramla	5904-1	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	261	Limestone	100%	none	No	Impact	A1	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	149	Limestone	75%	none	No	Impact	A4	NA	Na	NA	Hard	NA	no	NA	Anvil	2	
Nesher Ramla	8	Limestone	50%	none	No	Impact	A1	NA	Na	NA	Hard	NA	no	NA	Chopper	2	
Nesher Ramla	8202	Limestone	100%	none	No	Polish	A4	NA	Na	NA	NA	NA	no	NA	Undefined		D
Nesher Ramla	8082	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	108	Limestone	75%	none	No	Polish	A5	NA	Na	NA	NA	NA	no	NA	Anvil		B
Nesher Ramla	999	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	7006	Limestone	75%	none	No	Impact	A3	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	1663	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	8114	Limestone	100%	heavy-patination	No	Impact	A3	NA	Na	NA	Hard	NA	yes	knaping	Hammerstone	2	
Nesher Ramla	8546	Limestone	100%	none	No	Polish	A5	NA	Na	NA	NA	NA	no	NA	Abrader		A
Nesher Ramla	8743-4	Limestone	75%	none	No	Impact	A5	NA	Na	NA	NA	NA	no	breaking	Hammerstone		
Nesher Ramla	4783-1	Limestone	100%	none	No	Impact	A2	NA	Na	NA	Hard	NA	yes	knaping	Hammerstone	2	
Nesher Ramla	8741-2	Limestone	50%	none	No	Impact	A3	NA	Na	NA	Semi-hard	NA	no	NA	Chopper	1	
Nesher Ramla	6079	Limestone	75%	none	No	Impact	A4	NA	Na	NA	Hard	NA	no	NA	Anvil	2	
Nesher Ramla	4340-1	Limestone	100%	none	No	Polish	A5	NA	Na	NA	NA	NA	no	NA	Undefined		B
Nesher Ramla	8741-7	Limestone	75%	none	No	Impact	A3	NA	Na	NA	NA	NA	no	breaking	Chopper		
Nesher Ramla	8741-4	Limestone	100%	none	No	Impact	A6	NA	Na	NA	NA	NA	no	NA	Hammerstone		

Nesher Ramla	8064-1	Limestone	100%	none	No	Impact	A1	NA	Na	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	8741-5	Limestone	100%	none	No	Impact	A1	NA	Na	NA	NA	NA	no	NA	Hammerstone		
Nesher Ramla	8675	Limestone	75%	none	No	Impact	A5	NA	Na	NA	Semi-hard	NA	yes	crushing	Anvil	1	
Nesher Ramla	6109	Limestone	75%	none	No	Impact	A3	NA	Na	NA	Semi-hard	NA	no	knaping	Hammerstone	1	
Nesher Ramla	1181	Limestone	100%	none	No	Impact	A3	NA	Na	NA	Hard	NA	yes	NA	Hammerstone	2	
Nesher Ramla	1159	Limestone	75%	none	No	Impact	A3	NA	Na	NA	NA	NA	no	breaking	Undefined		
Nesher Ramla	1160	Limestone	100%	none	No	Polish	A9		Na	NA	NA	NA	yes	breaking	Hammerstone		B
Nesher Ramla	4389	Limestone	100%	none	No	Polish	A6		Na	NA	NA	NA	yes	NA	Undefined		B
Nesher Ramla	8502	Limestone	100%	none	No	Striation	A5	Parallel	Na	NA	NA	NA	no	NA	Undefined		
Nesher Ramla	8743	Limestone	100%	none	No	Impact	A3				Hard	NA	yes	NA	Undefined	2	
Nesher Ramla	8030	Limestone	100%	none	No	Polish	A5		Na	NA	NA	NA	no	NA	Undefined		A
Nesher Ramla	8741-111	Limestone	75%	none	No	Impact	A2		Na	NA	Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	6898	Limestone	100%	none	No	Impact	A3				Hard	NA	no	knaping	Hammerstone	2	
Nesher Ramla	8498	Limestone	100%	none	No	Impact	A6				NA	NA	no	NA	Hammerstone		
Nesher Ramla	7711-5	Limestone	100%	none	No	Impact	A2				Hard	NA	no	NA	Hammerstone	2	
Nesher Ramla	296	Limestone	25%	none	No	Impact	A6				Semi-hard	NA	no	breaking	Chopper	1	B
Nesher Ramla	115	Limestone	50%	none	No	Impact	A3				Semi-hard	NA	no	breaking	Chopper	1	
Nesher Ramla	4736-1	Limestone	50%	none	No	Impact	A5				NA	NA	no	NA	Anvil		
Nesher Ramla	8741	Limestone	50%	none	No	Impact	A4				NA	NA	yes	breaking	Anvil		
Nesher Ramla	1839	Limestone	75%	none	No	Impact	A4				NA	NA	yes	breaking	Anvil		

Ein Qashish	2340	Limestone	0%	none	No	striation	A5	NA	NA	NA	no	NA	Anvil	
Ein Qashish	6106	Limestone	75%	none	No	Impact	A2	NA	NA	NA	no	breaking	Chopper	
Ein Qashish	1573	Limestone	50%	none	No	Impact	A5	NA	NA	NA	no	breaking	Undefined	
Ein Qashish	6047	Limestone	75%	none	No	Impact	A3	NA	Hard	NA	yes	breaking	Hammerstone	2
Ein Qashish	1314	Limestone	0%	none	No	Impact	A5	NA	NA	NA	yes	breaking	Anvil	
Ein Qashish	M49	Limestone	0%	none	No	Impact	A5	NA	NA	NA	no	NA	Anvil	
Ein Qashish	1875	Limestone	0%	none	No	Impact	A5	NA	NA	NA	no	NA	Anvil	
Nesher Ramla	4277	Limestone	100%	none	No	Impact	A5		NA	NA	yes	breaking	Anvil	
Nesher Ramla	1534	Limestone	100%	none	No	Impact	A5		Hard	NA	yes	NA	Anvil	2
Nesher Ramla	4152x2	Limestone	100%	none	No	Impact	A5		Hard	NA	no	NA	Anvil	2

Table 18: Experimental analysis.

Id	Worked Material	Polish	Distribution	Mesh	Micro Topographic Context	Morphology Cross Section	Texture	Contours	Opacity	Brightness	Special Features	Striations	Observations
3-7	Fresh Bone	Yes	covering	closed	penetrating on low	sinuous	fluid	diffuse	trans/opaque	high	striations	grouped-with directions	
anvil-flint	Fresh Bone	Yes	sparse	connected	only on high	flat	fluid	sharp	opaque	medium	abrasive track	groped-parallel-deep	cracks in the polish
anvil-bone	Flint	Yes	covering	closed	penetrating on low	domed	fluid	diffuse	trans/opaque	low	none		loosing reflectivity at 200x
3-3	Flint	Yes	sparse	connected	only on high	flat	rough	sharp	trans/opaque	medium	abrasive track	grouped-parallel	
3-8	Fresh Bone	Yes	covering	closed	penetrating on low	sinuous	fluid	diffuse	trans/opaque	medium	none		
2-11	Fresh Bone	Yes	sparse	closed	penetrating on low	sinuous	fluid	sharp	trans/opaque	medium	none		
3-11	Fresh Bone	Yes	sparse	separated	penetrating on low	sinuous	fluid	diffuse	trans/opaque	medium	none		
3-1	Fresh Bone	Yes	sparse	separated	penetrating on low	sinuous	fluid	diffuse	trans/opaque	medium	none		groped-direction
3-9	Fresh Bone	Yes	covering	separated	only on high	sinuous	fluid	diffuse	trans/opaque	medium	none		
3-5	Fresh Bone	No											no polish-some damage
2-6	Fresh Bone	Yes	covering	closed	penetrating on low	sinuous	fluid	diffuse	trans/opaque	medium	none		grouped polish
3-4	Fresh Bone	No											
3-10	Fresh Bone	No											
3-6	Fresh Bone	Yes	covering	separated	penetrating on low	sinuous	fluid	diffuse	trans/opaque	medium	none		
4-1	Flint	Yes	sparse	connected	only on high	flat	rough	sharp	trans/opaque	medium	abrasive track		flaked-polish on the edge
2-12	Flint	Yes	sparse	separated	only on high	flat	rough	sharp	trans/opaque	medium	none		just small dots of polish

2-1	Flint	Yes	sparse	connected	only on high	flat	rough	sharp	trans/opaque	medium	abrasive track		
2-2	Flint	Yes	sparse	connected	only on high	flat	rough	sharp	trans/opaque	medium	abrasive track		
2-9	Flint	Yes	sparse	connected	only on high	flat	rough	sharp	trans/opaque	medium	abrasive track		
3-12	Flint	Yes	sparse	connected	only on high	flat	rough	sharp	trans/opaque	medium	striations	grouped-parallel	big flat polished area
2-10	Flint	No											brake at 7 impact
2-7	Flint	No											
2-5	Flint	Yes	sparse	connected	only on high	flat	rough	sharp	trans/opaque	medium	abrasive track	grouped parallel	
6-5	Humid Acorn	Yes	sparse	separated	penetrating on low	domed	rough	diffuse	trans/opaque	low	none	no	poorly develop
6-2	Dry Acorn	Yes	concentrated	connected	only on high	flat	smooth	diffuse	trans/opaque	medium	striations	mainly parallel, and some oblique	well develop
6-1	Dry Acorn	Yes	covering	connected	only on high	sinuous	smooth	diffuse	trans/opaque	medium	striations		very develop
6-6	Dry Acorn	Yes	covering	connected	only on high	sinuous	rough	diffuse	trans/opaque	medium	striations	different directions	well develop
6-7	Humid Acorn	Yes	sparse	separated	penetrating on low	sinuous	smooth	diffuse	trans/opaque	medium	none		poorly develop
6-3	Humid Acorn	Yes	sparse	separated	penetrating on low	sinuous	smooth	diffuse	trans/opaque	medium	none		poorly develop
6-10	Humid Acorn	Yes	sparse	separated	penetrating on low	sinuous	fluid	diffuse	trans/opaque	medium	none		isolated small spots
6-12	Dry Acorn	Yes	covering	separated	penetrating on low	sinuous	fluid	diffuse	trans/opaque	medium	striations		well develop

9.3. Figures

9.3.1. Experiments

Percussive experiments

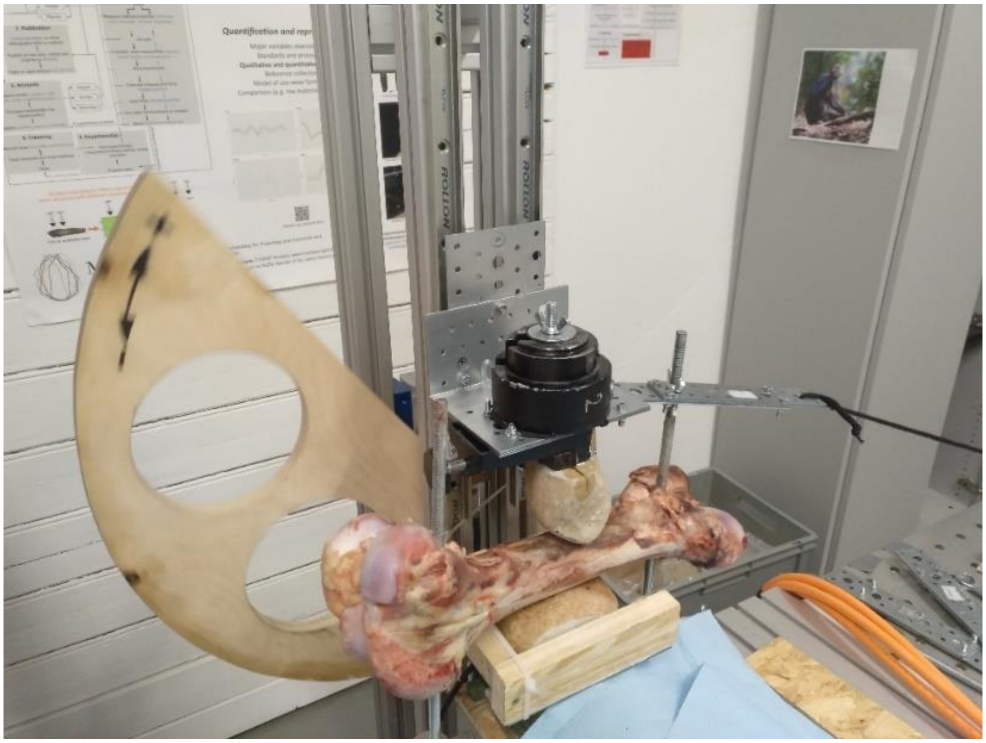

Figure 108: Bone breaking experiment (Photo: Eduardo Paixão).

Figure 109: Flint knapping experiment (Photo: Eduardo Paixão).

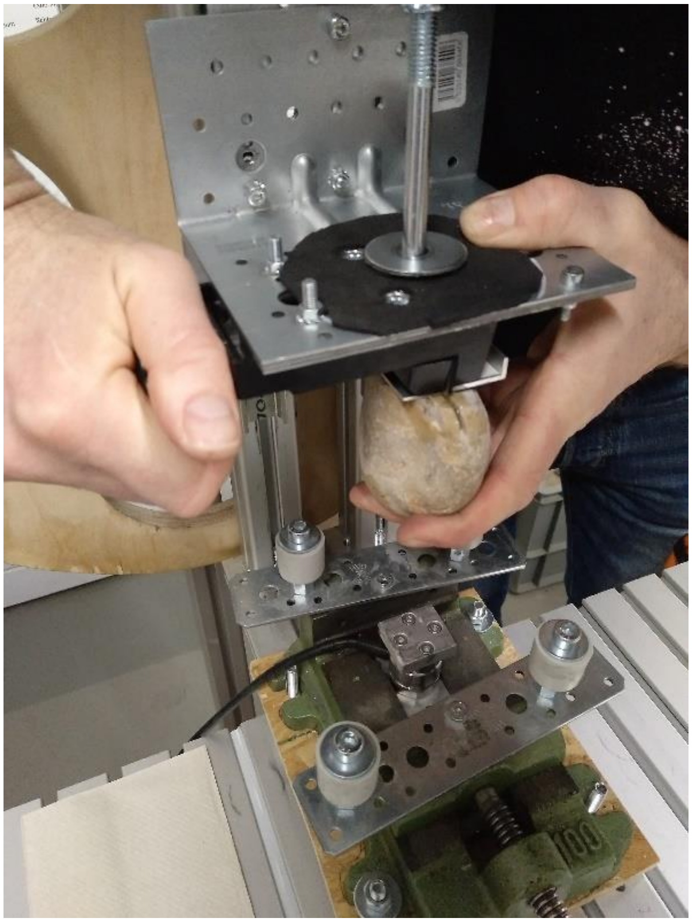

Figure 110: Fixing sample on the sample holder device (Photo: Eduardo Paixão).

Figure 111: Cleaning samples in ultrasonic bath after the experiments (Photo: Eduardo Paixão).

Flint Knapping (macro)

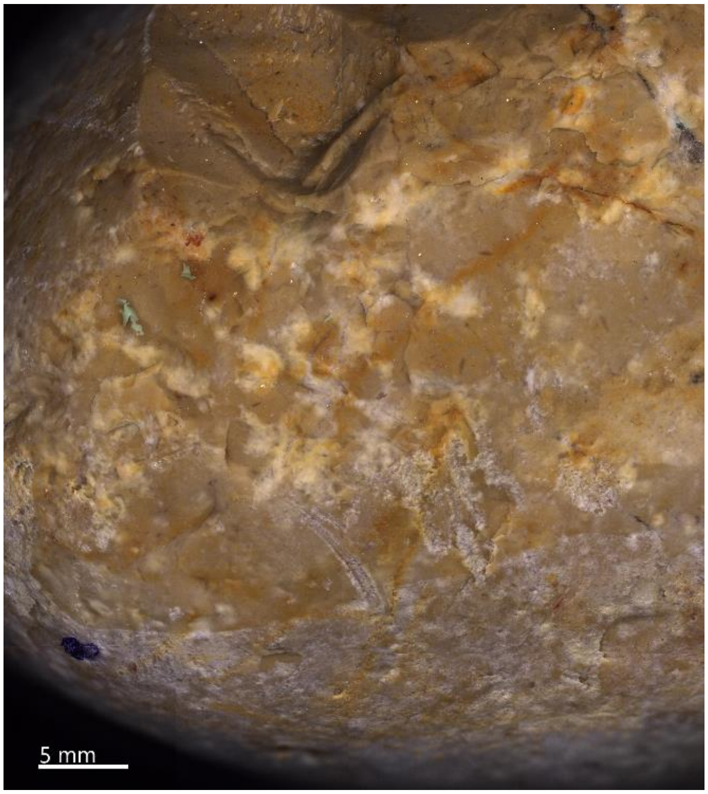

Figure 112: Smart zoom microscope image (34x): Sample 2-5 (50 impacts on flint).

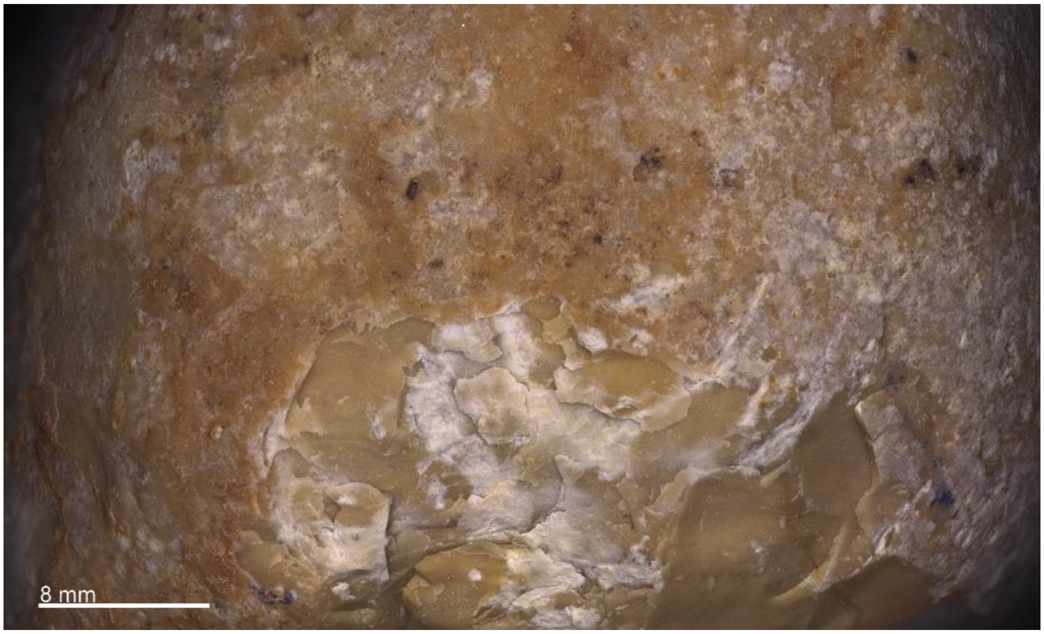

Figure 113: Smart zoom microscope image (34x): Sample 3-12 (50 impacts on flint).

Figure 114: Smart zoom microscope image (34x): Sample 3-3 (50 impacts on flint).

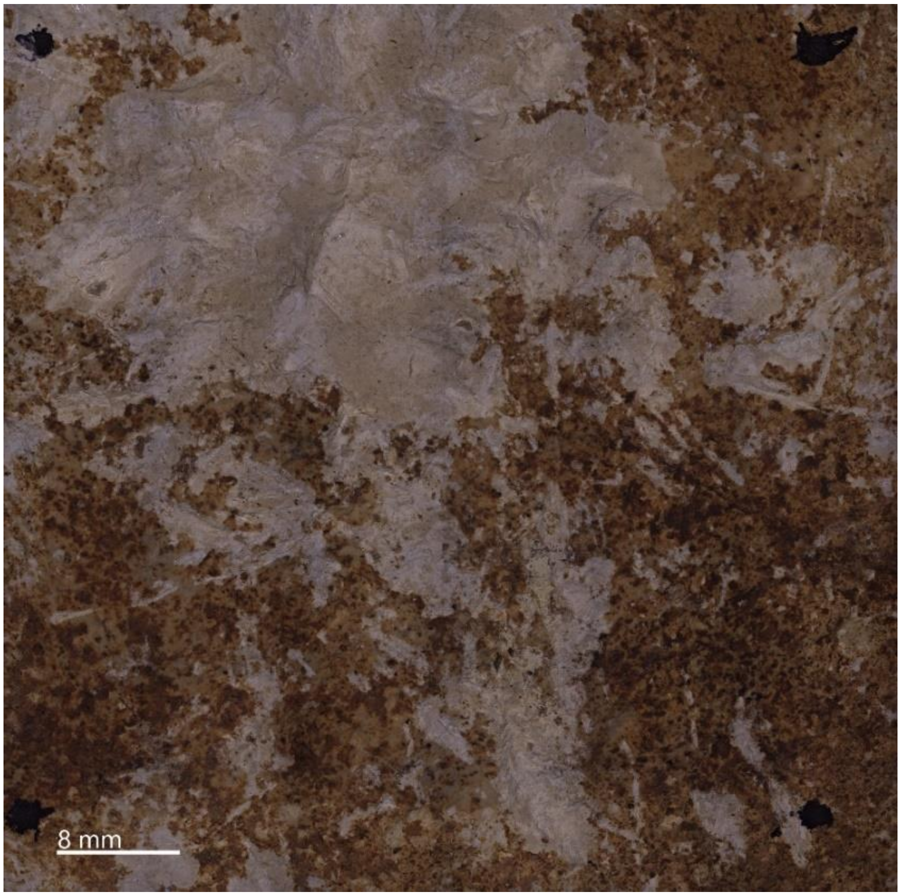

Figure 115: Smart zoom microscope image (34x): Anvil for flint (after 100 impacts).

Bone breaking (macro)

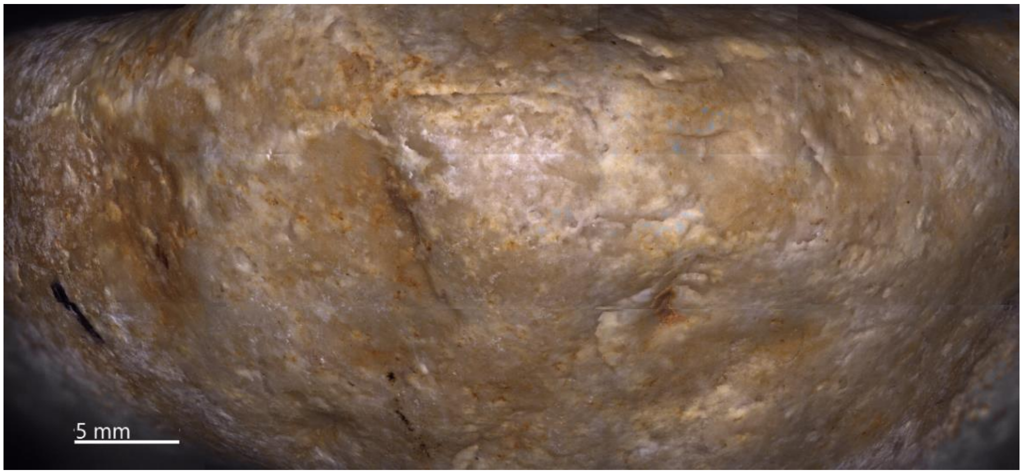

Figure 116: Smart zoom microscope image (34x): Sample 2-11 (50 impacts on bone).

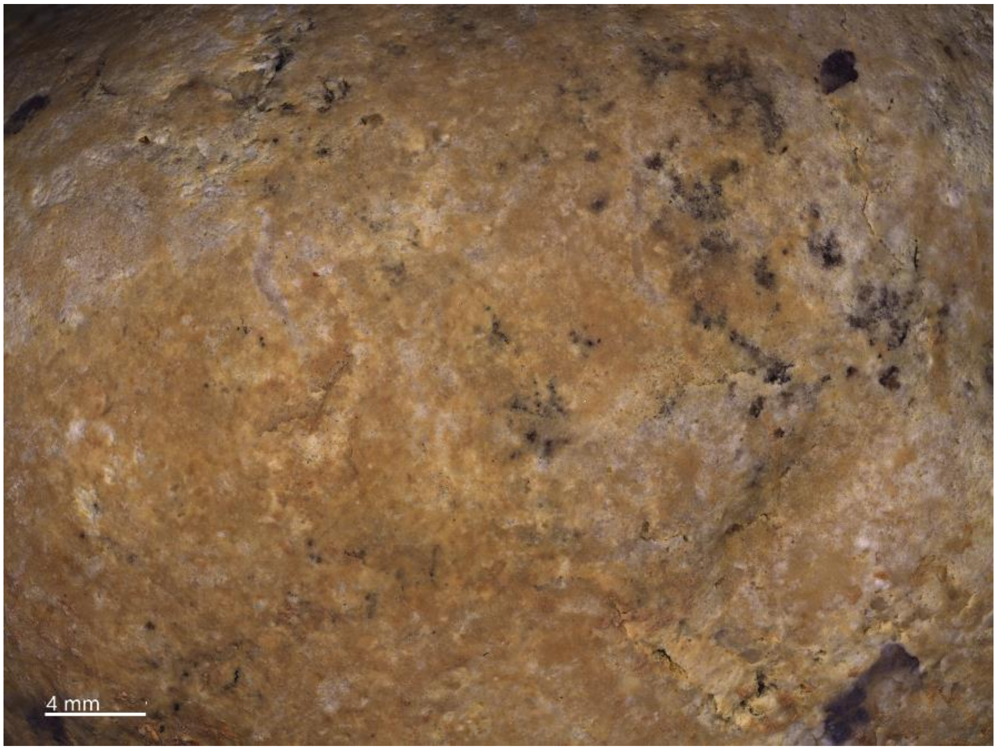

Figure 117: Smart zoom microscope image (34x): Sample 3-8 (50 impacts on bone).

Figure 118: Smart zoom microscope image (34x): Sample 3-6 (500 impacts on bone).

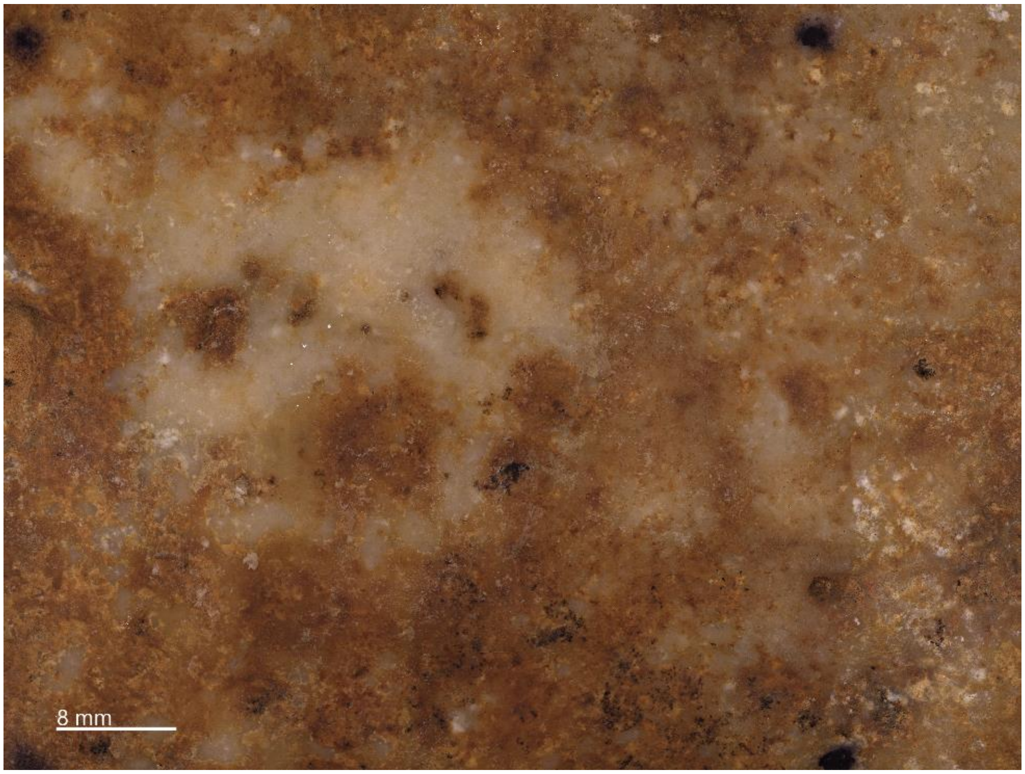

Figure 119: Smart zoom microscope image (34x): Anvil for bone (after 885 impacts).

Grinding experiments

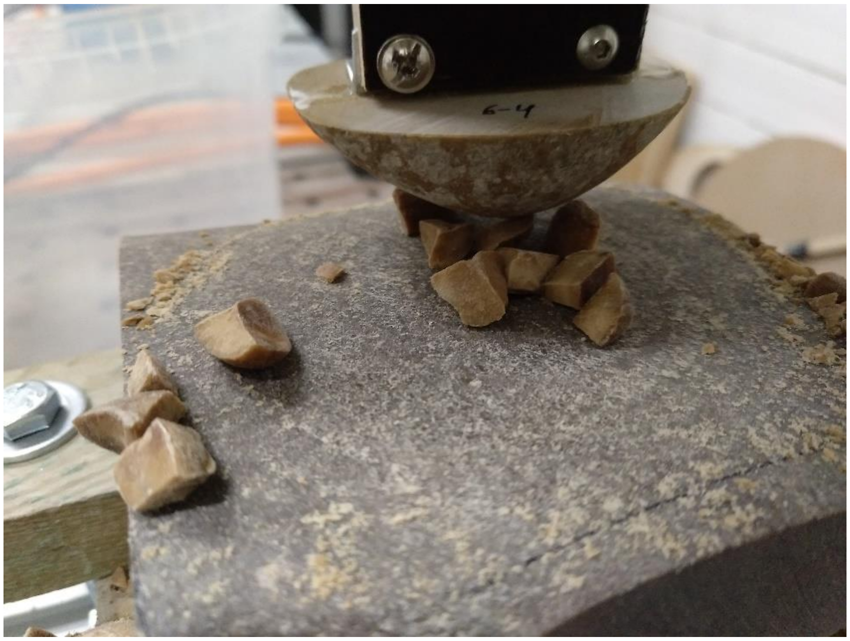

Figure 120: Grinding dry acorn.

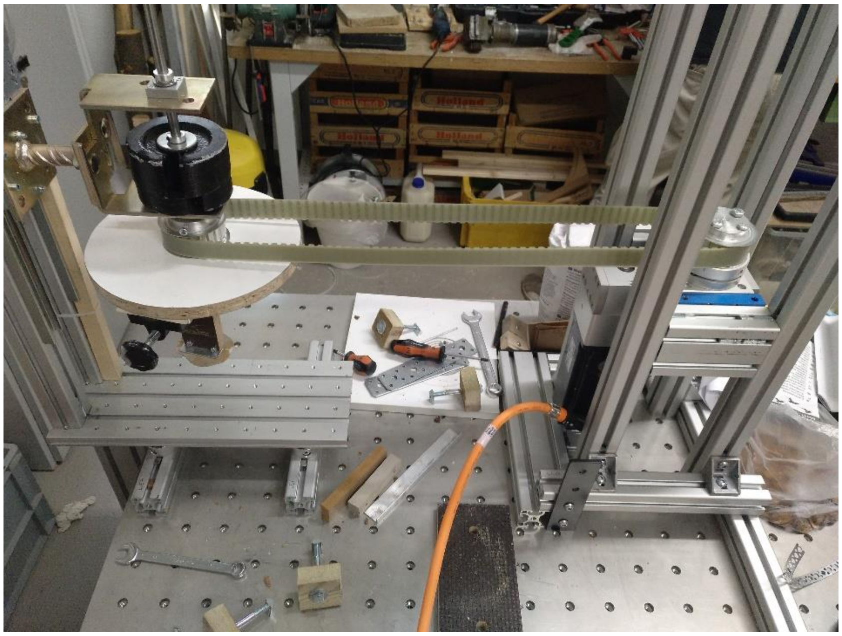

Figure 121: Mechanized system for grinding experiments.

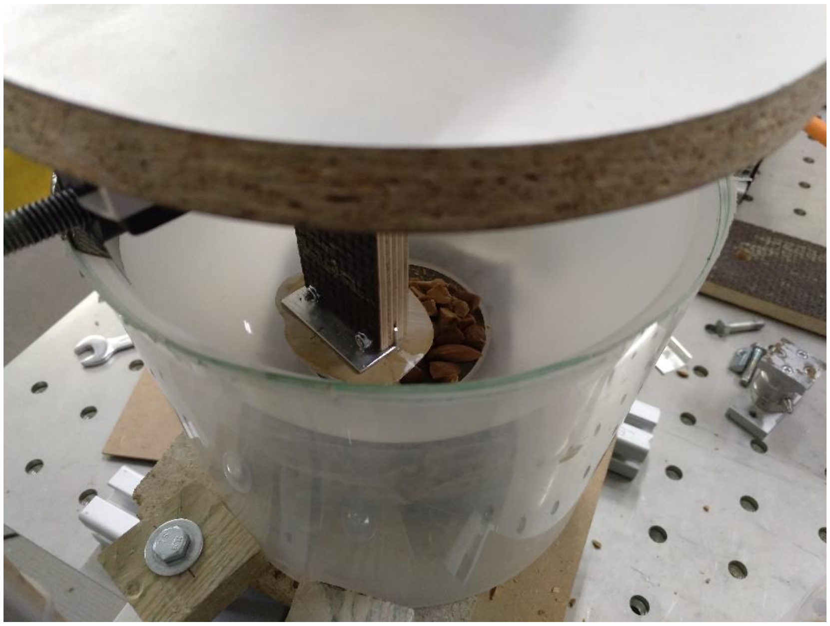

Figure 122: Bucket system for grinding experiments.

Figure 123: Acorn seeds used for experiments.

Grinding Dry Acorn (macro)

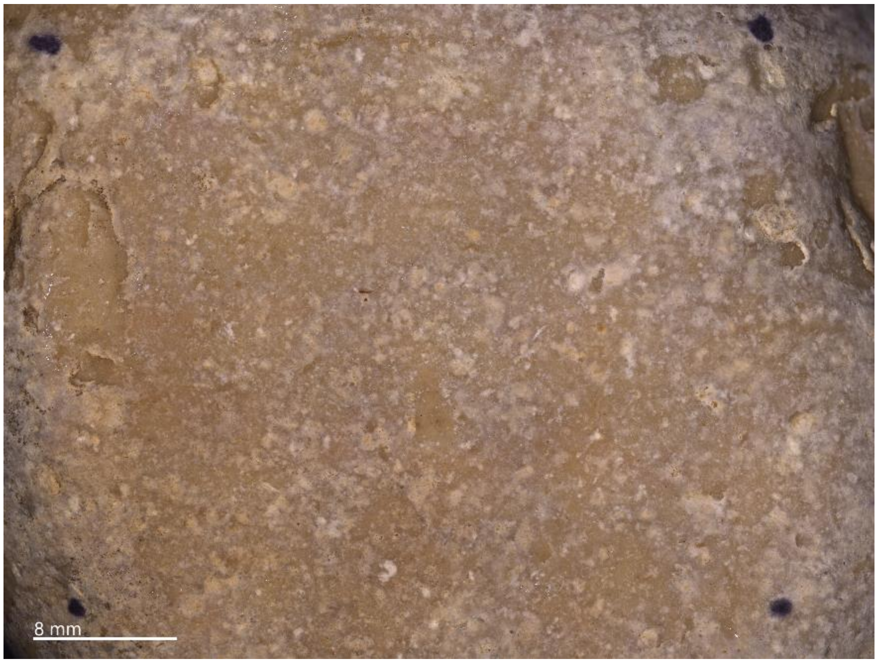

Figure 124: Smart zoom microscope image (34x): Sample 6-1 (1000 rotations).

Figure 125: Smart zoom microscope image (34x): Sample 6-2 (1000 rotations).

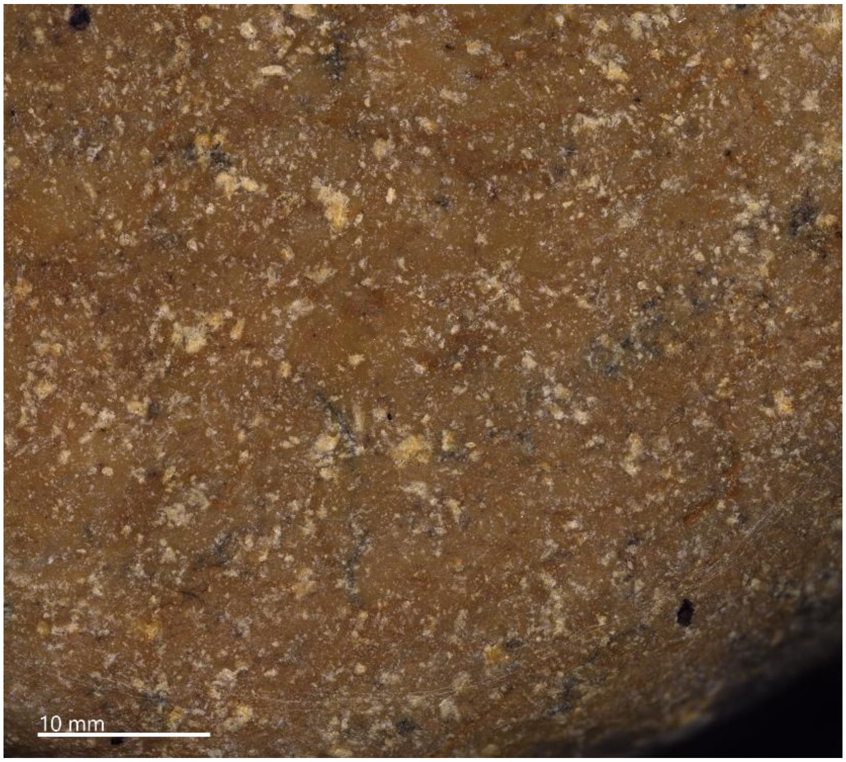

Figure 126: Smart zoom microscope image (34x): Sample 6-12 (3000 rotations).

Grinding Moist Acorn (macro)

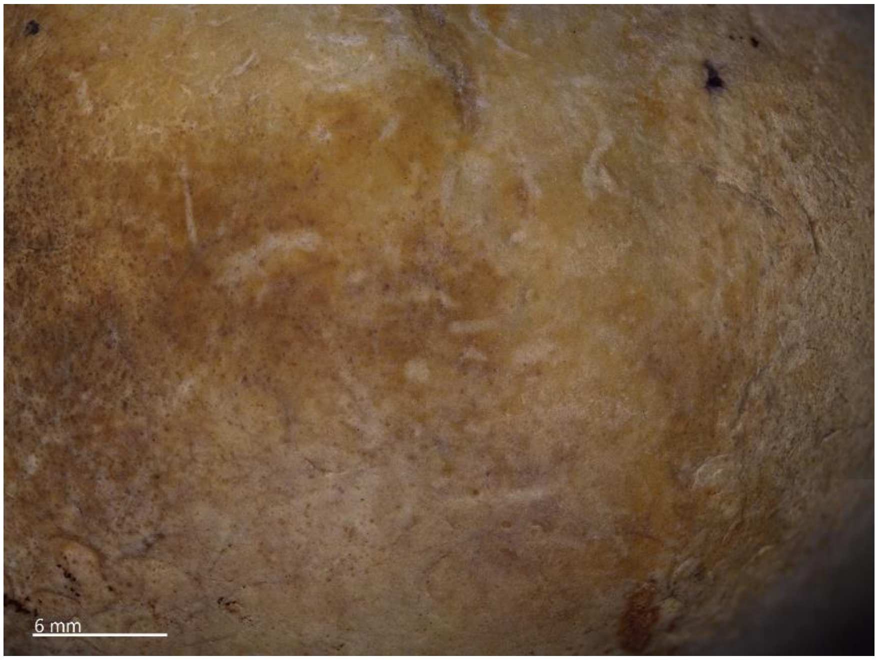

Figure 127: Smart zoom microscope image (34x): Sample 6-5 (1000 rotations).

Figure 128: Smart zoom microscope image (34x): Sample 6-7(1000 rotations).

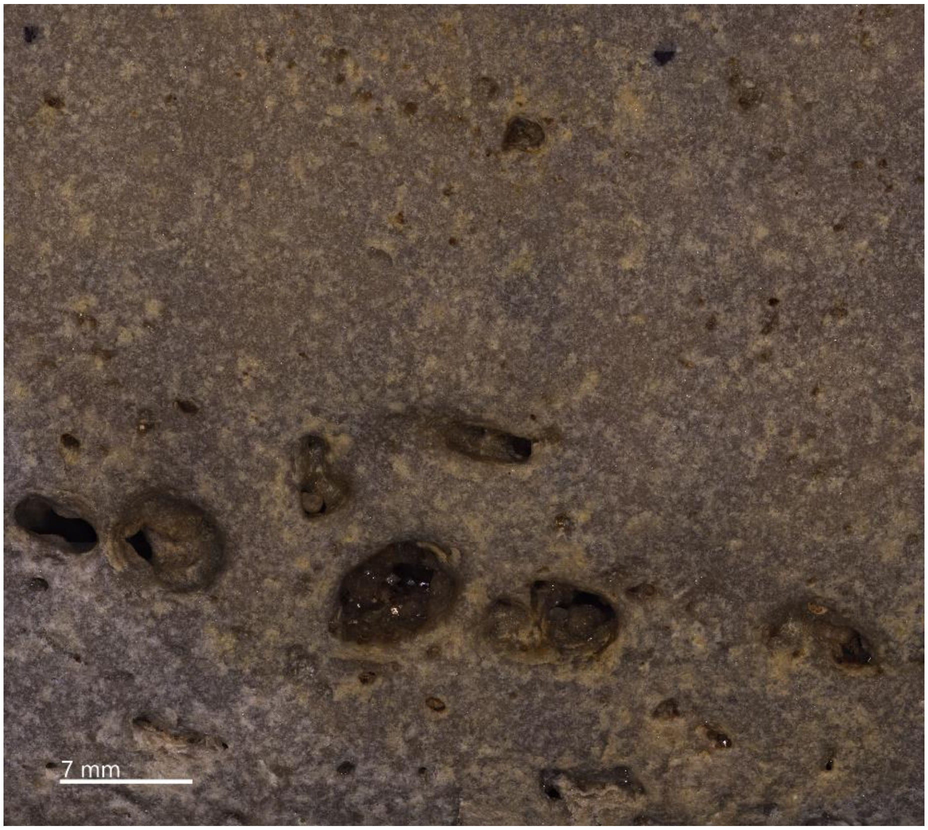

Figure 129: Smart zoom microscope image (34x): Sample 6-10 (3000 rotations).

Flint knapping (micro)

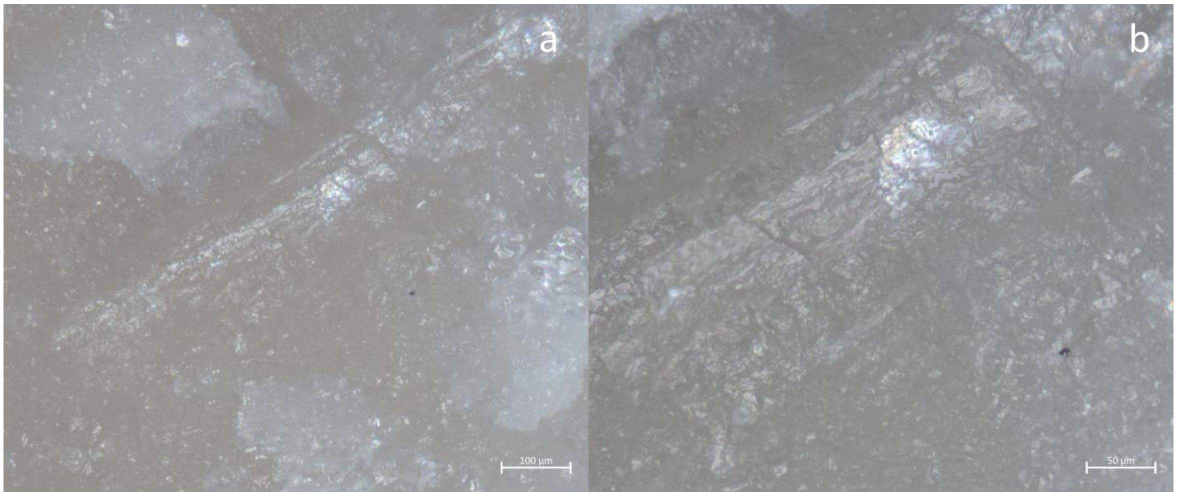

Figure 130: Metallographic microscope image of a polish formed by experiment with flint: a) 10x image of a polish, b) 20x image of a polish area (Sample: 2-9).

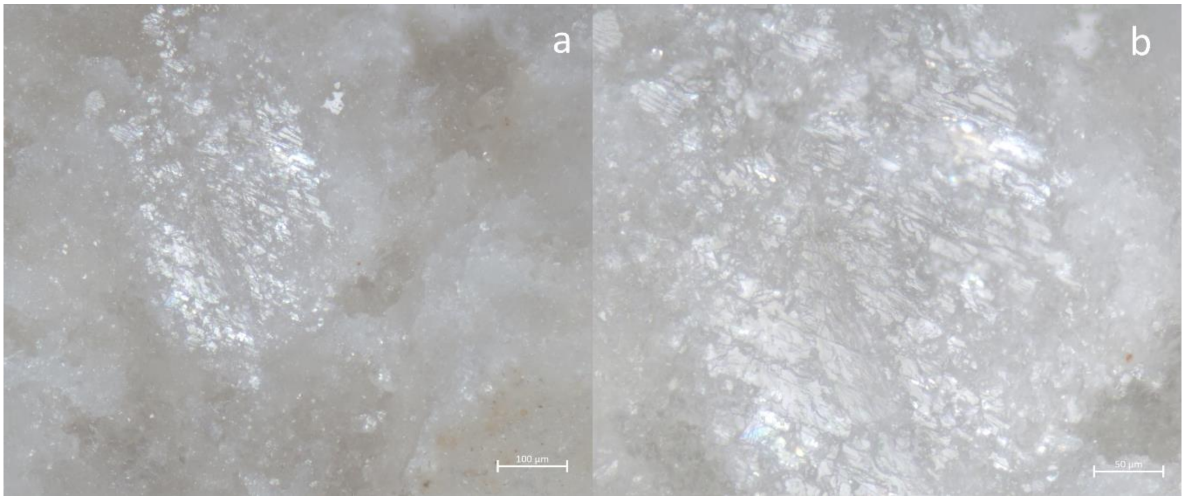

Figure 131: Metallographic microscope image of a polish formed by experiment with flint: a) 10x image of a polish, b) 20x image of a polish area (Sample: 2-2).

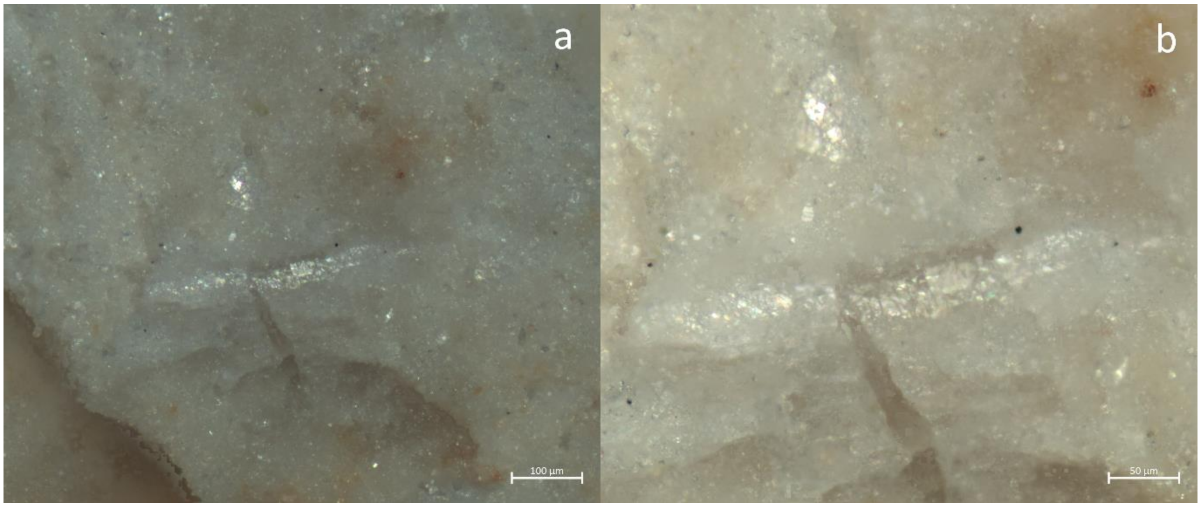

Figure 132: Metallographic microscope image of a polish formed by experiment with flint: a) 10x image of a polish, b) 20x image of a polish area (Sample: 2-1).

Bone Breaking (micro)

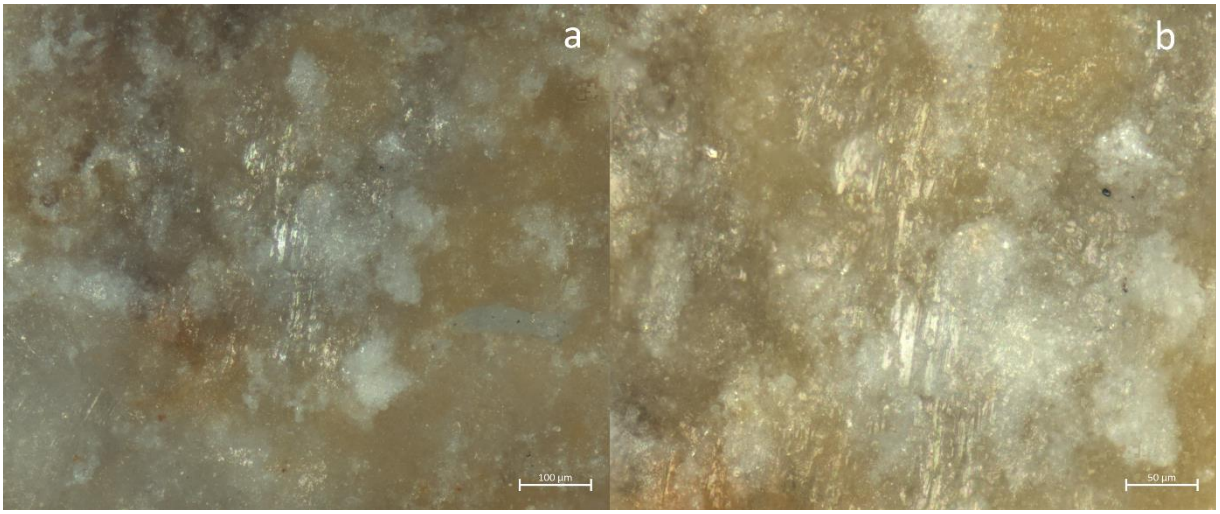

Figure 133: Metallographic microscope image of a polish formed by experiment with bone: a) 10x image of a polish, b) 20x image of a polish area (Sample: 3-1).

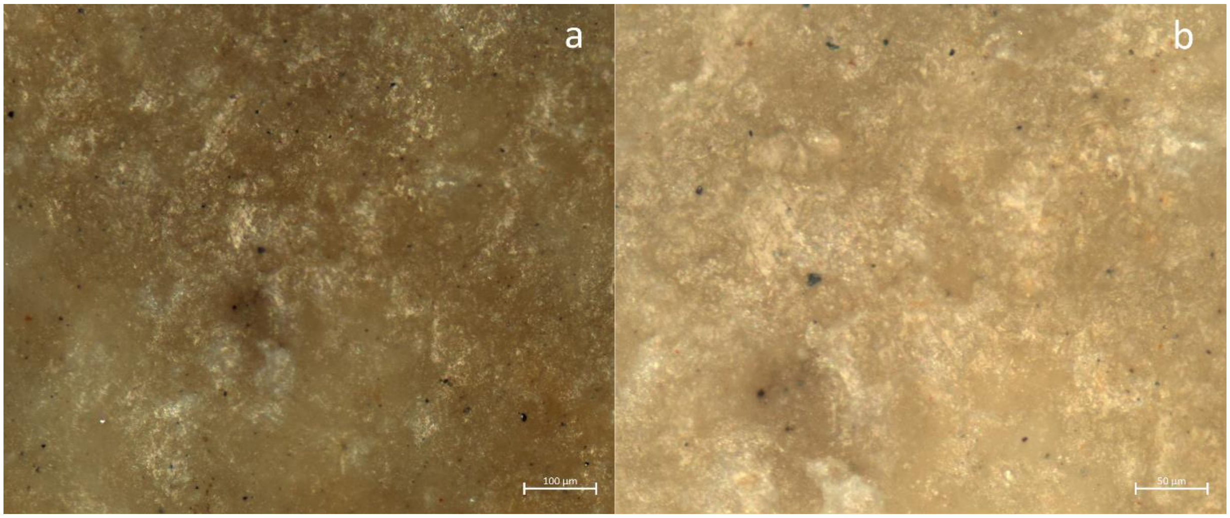

Figure 134: Metallographic microscope image of a polish formed by experiment with bone: a) 10x image of a polish, b) 20x image of a polish area (Sample: 3-8).

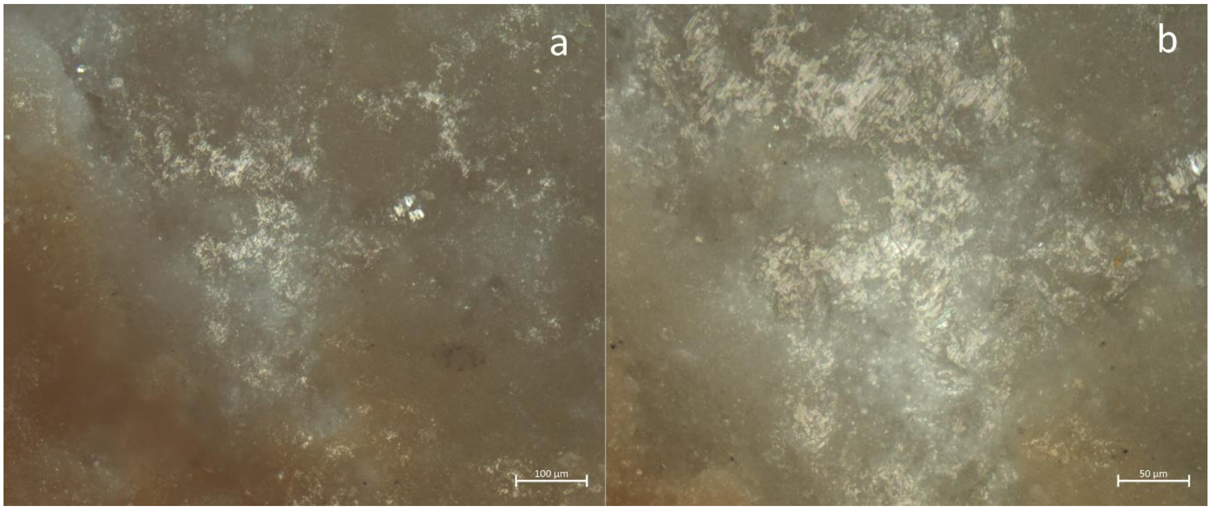

Figure 135: Metallographic microscope image of a polish formed by experiment with bone: a) 10x image of a polish, b) 20x image of a polish area (Sample: 3-9).

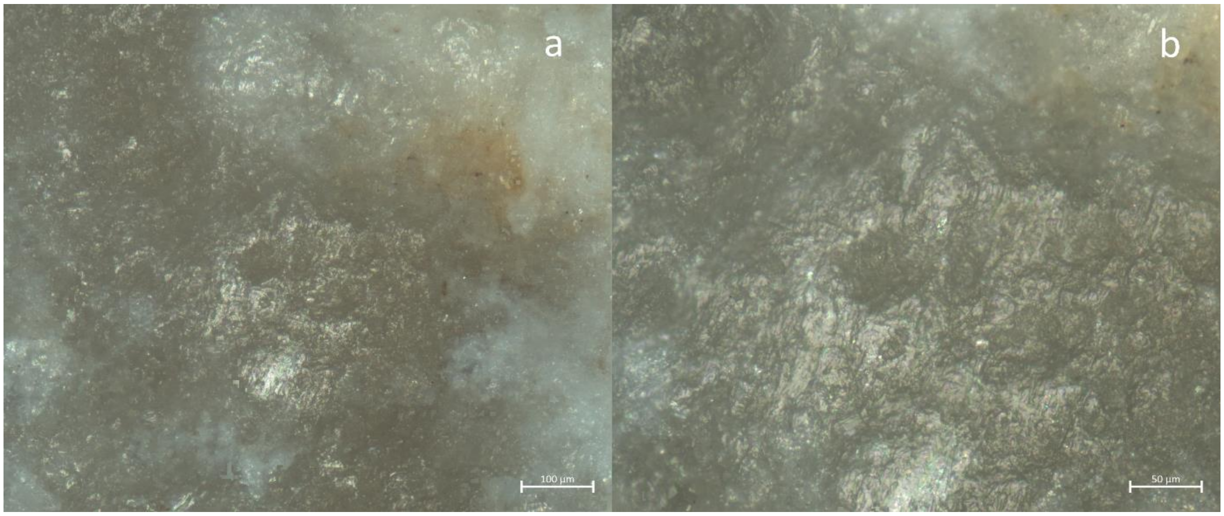

Figure 136: Metallographic microscope image of a polish formed by experiment with bone: a) 10x image of a polish, b) 20x image of a polish area (Sample: 3-11).

Dry acorn (micro)

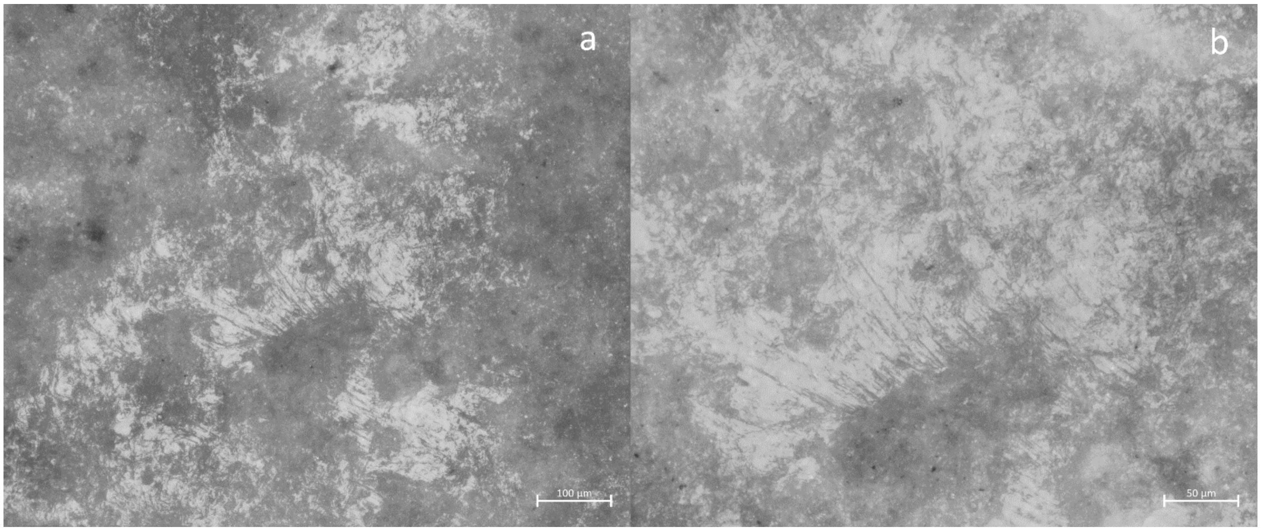

Figure 137: Metallographic microscope image of a polish formed by experiment with dry acorn: a) 10x image of a polish, b) 20x image of a polish area (Sample: 6-1).

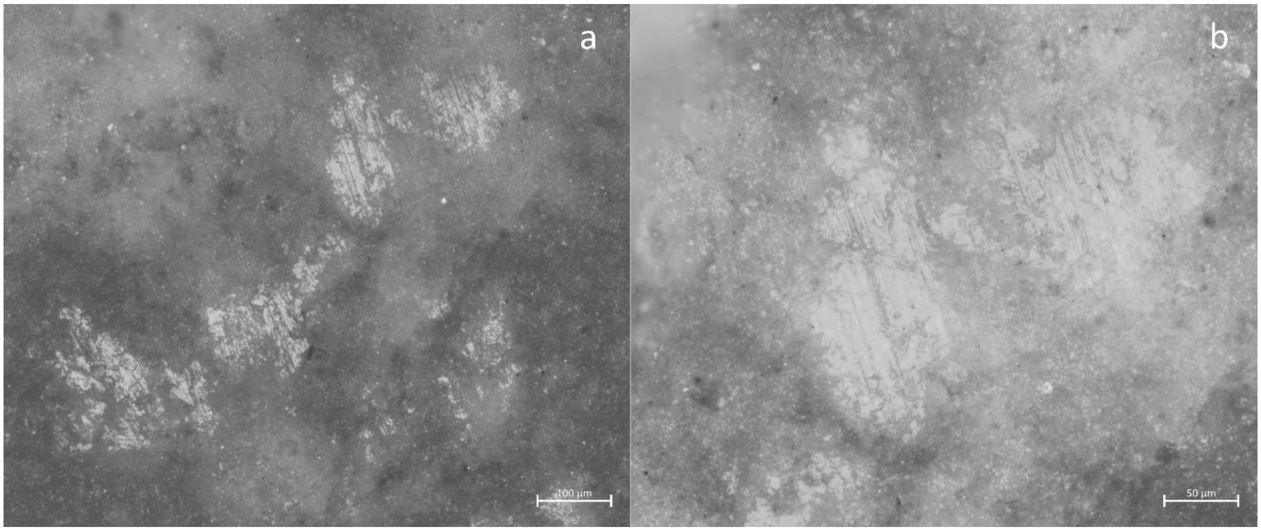

Figure 138: Metallographic microscope image of a polish formed by experiment with dry acorn: a) 10x image of a polish, b) 20x image of a polish area (Sample: 6-2).

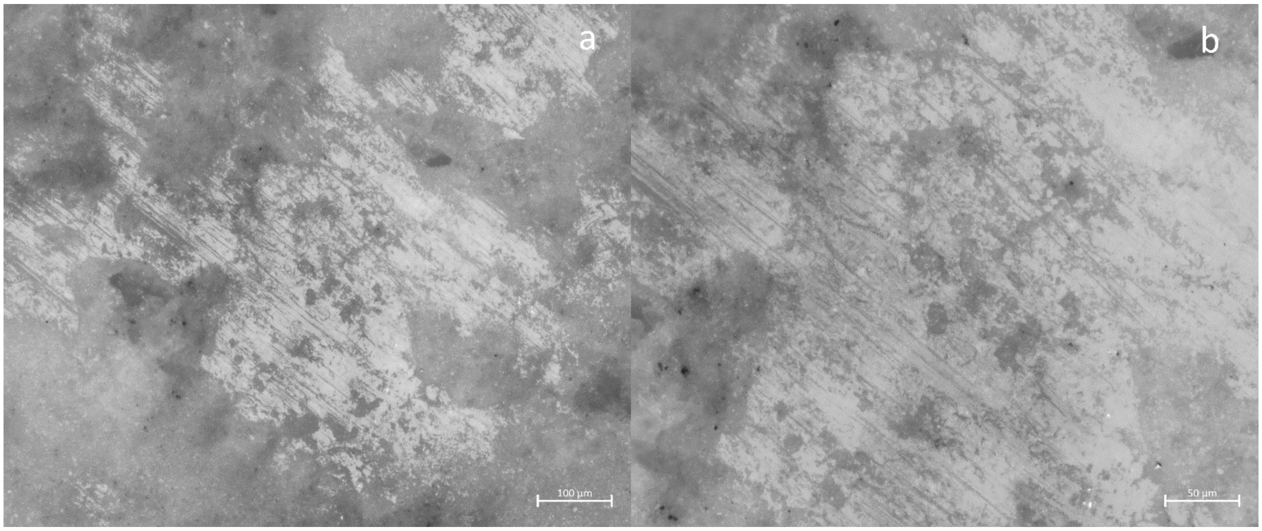

Figure 139: Metallographic microscope image of a polish formed by experiment with dry acorn: a) 10x image of a polish, b) 20x image of a polish area (Sample: 6-6).

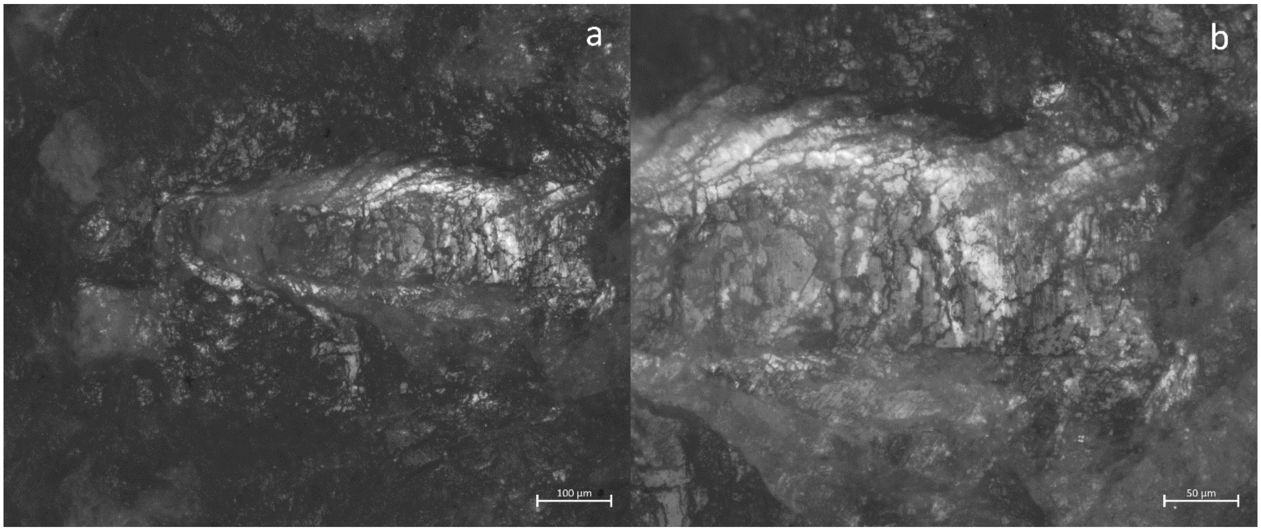

Figure 140: Metallographic microscope image of a polish formed by experiment with dry acorn: a) 10x image of a polish, b) 20x image of a polish area (Sample: 6-12).

Moist acorn (micro)

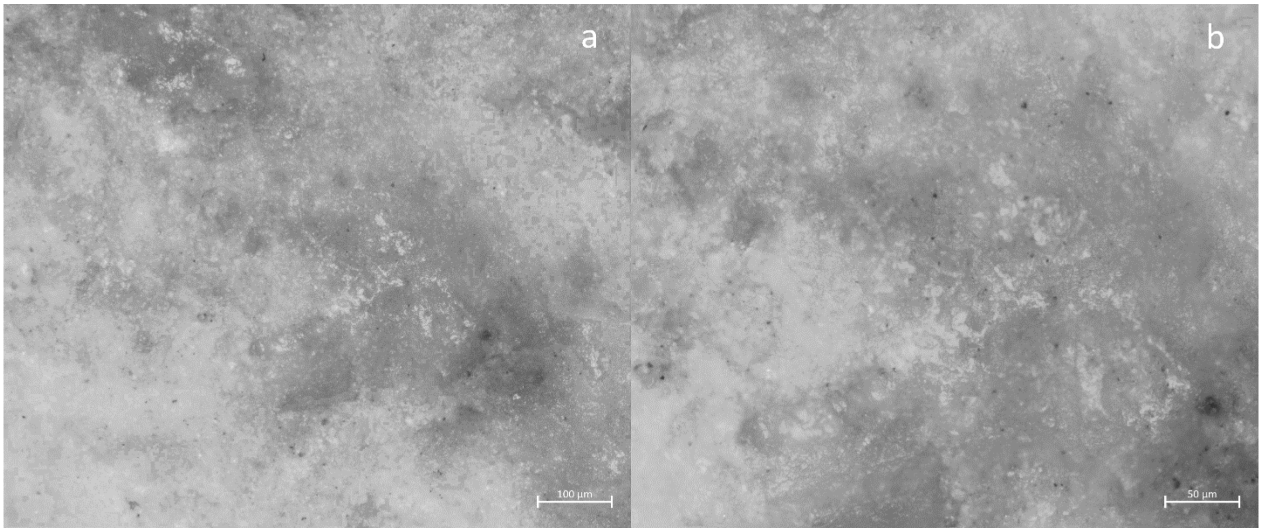

Figure 141: Metallographic microscope image of a polish formed by experiment with moist acorn: a) 10x image of a polish, b) 20x image of a polish area (Sample: 6-3).

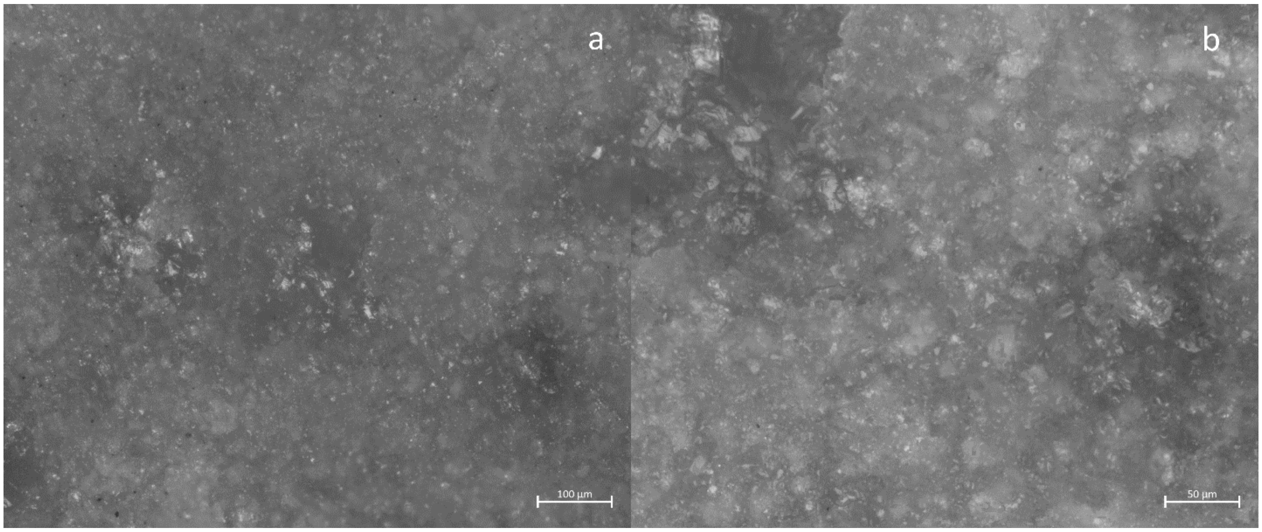

Figure 142: Metallographic microscope image of a polish formed by experiment with moist acorn: a) 10x image of a polish, b) 20x image of a polish area (Sample: 6-5).

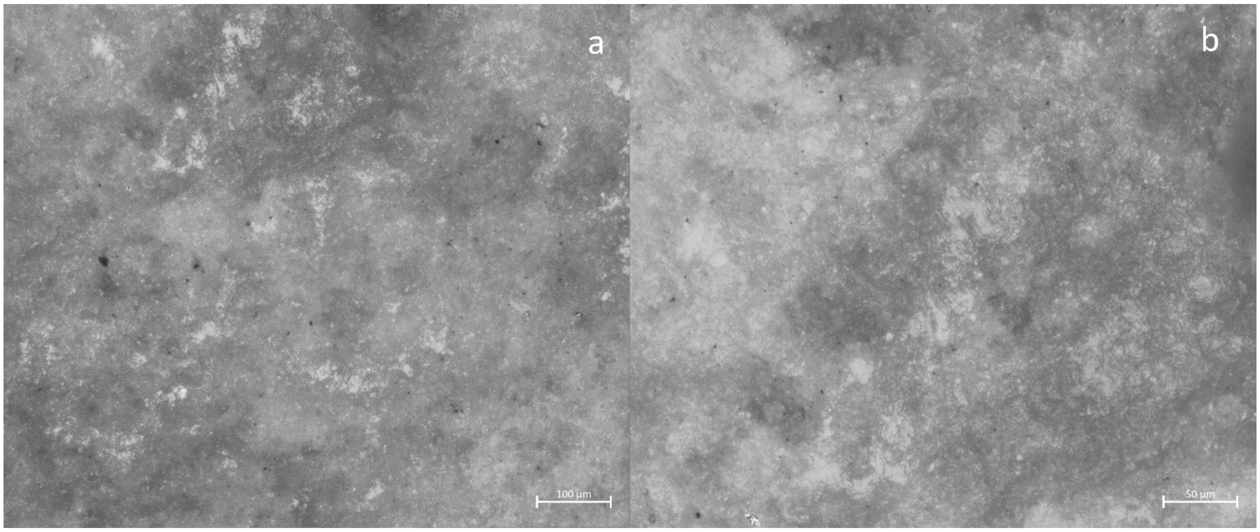

Figure 143: Metallographic microscope image of a polish formed by experiment with moist acorn: a) 10x image of a polish, b) 20x image of a polish area (Sample: 6-7).

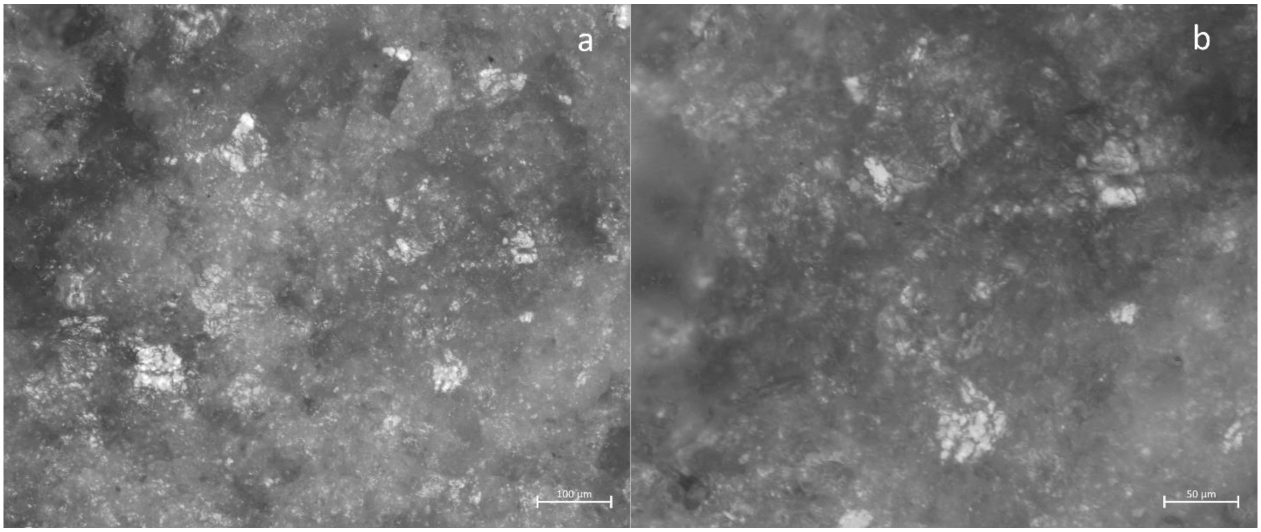

Figure 144: Metallographic microscope image of a polish formed by experiment with moist acorn: a) 10x image of a polish, b) 20x image of a polish area (Sample: 6-10).

9.3.2. Archaeological materials

Nesher Ramla

Figure 145: Hammerstone from Nesher Ramla (id: 8743).

Figure 146: Hammerstone from Nesher Ramla (id: 8719).

Figure 147: Anvil from Nesher Ramla (id: 6079 and 145).

Figure 148: Chopper tool from Nesher Ramla (id: 377).

Figure 149: Chopper from Nesher Ramla (id: 296).

Figure 150: Undefined tool from Nesher Ramla with polish formation (id: 157).

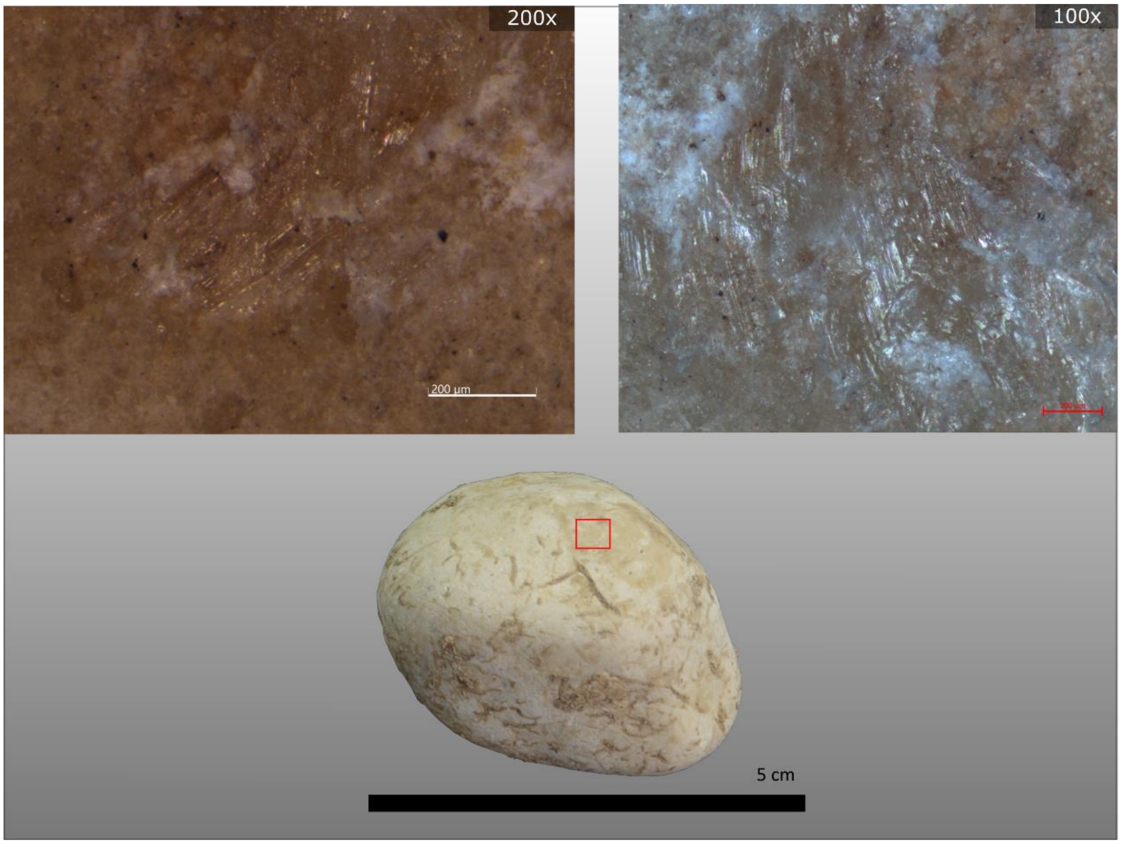

Figure 151: Undefined tool with polish formation (id: 8646-1).

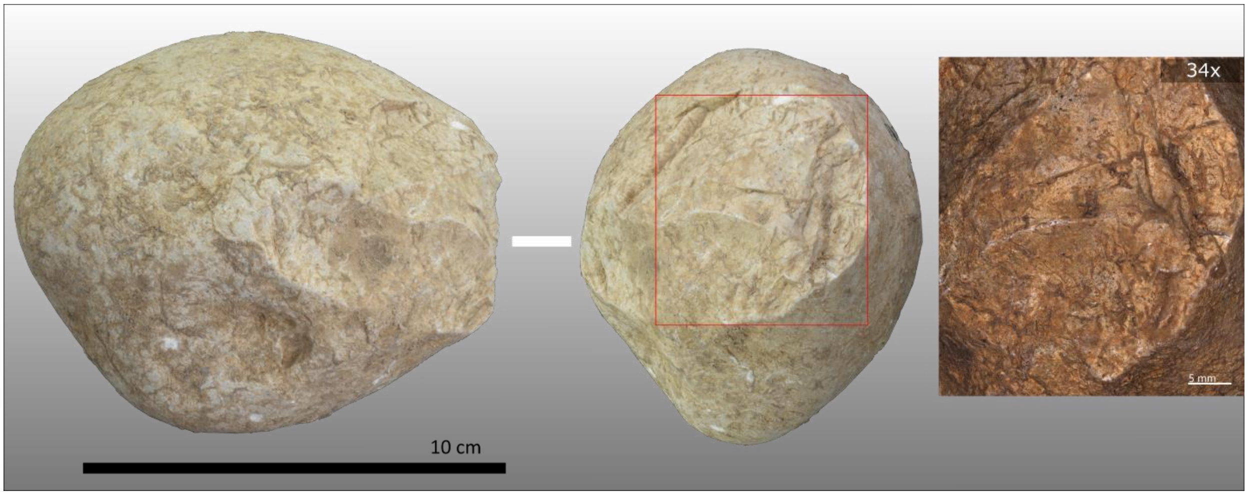

Figure 152: Hammerstone from Nesher Ramla (id: x2).

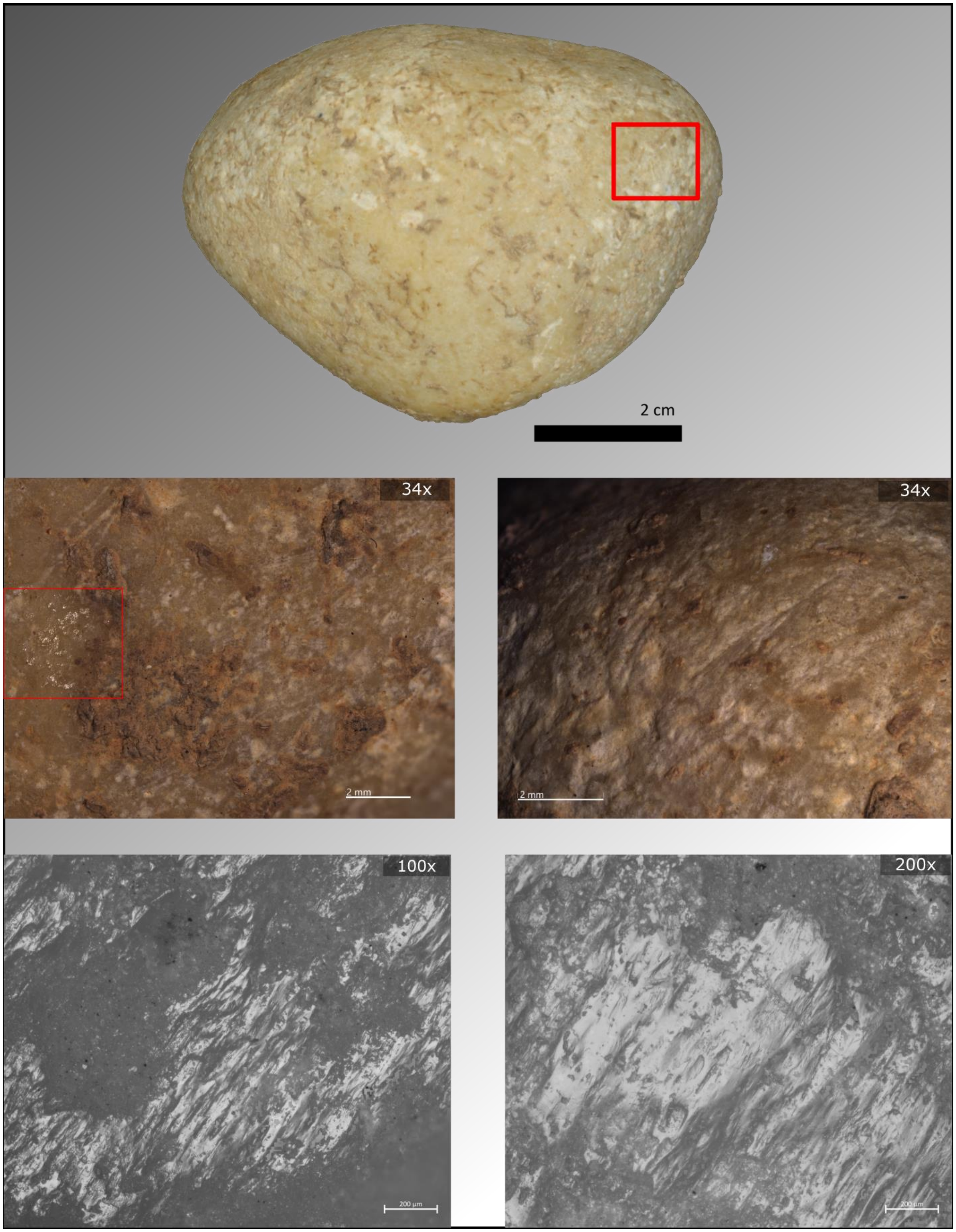

Figure 153: Hammerstone from Nesher Ramla with polish formation (id:5100).

Figure 154: Abrader tool from tool from Nesher Ramla (id:4389).

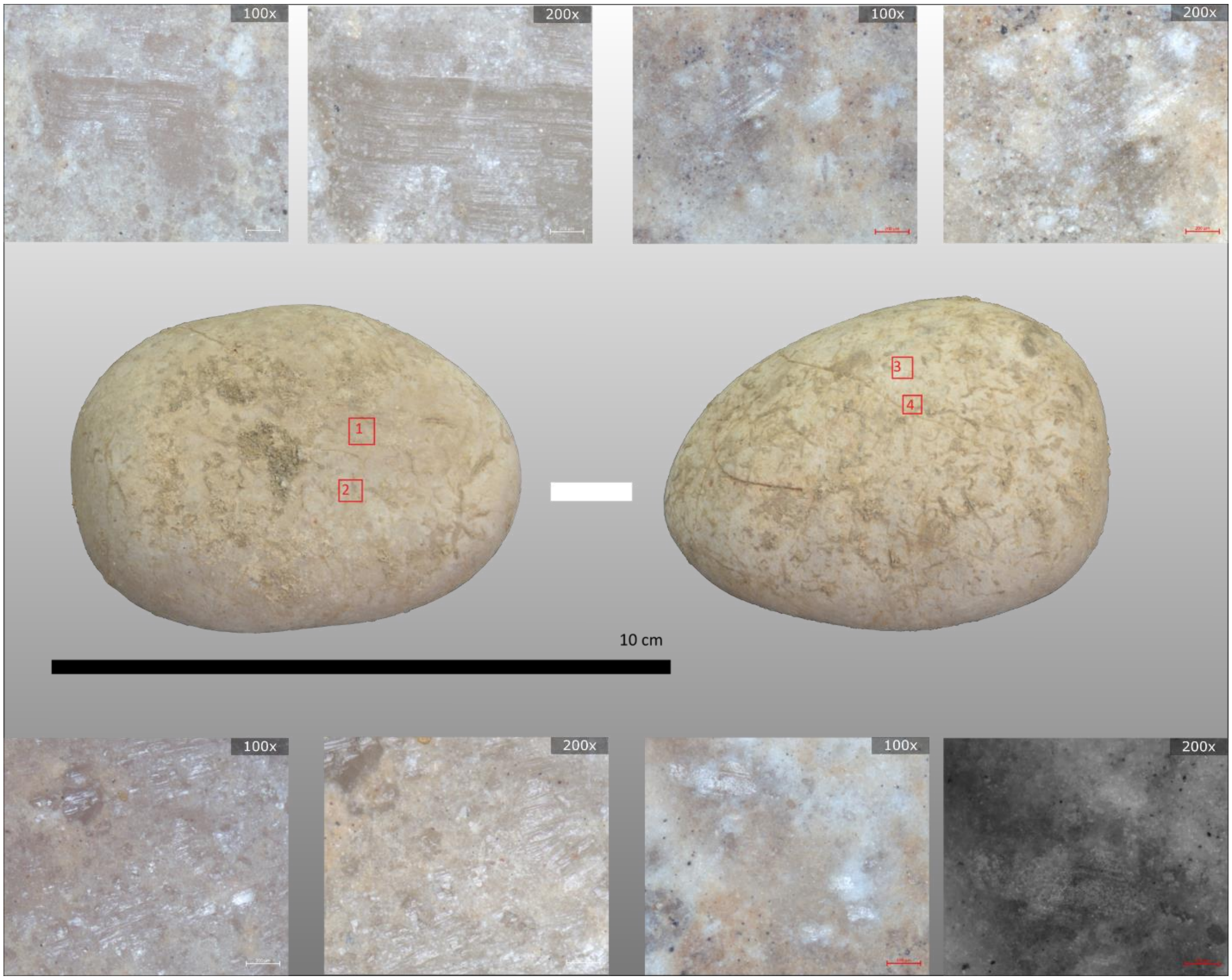

Figure 155: Abrader tool from tool from Nesher Ramla (id: 6759).

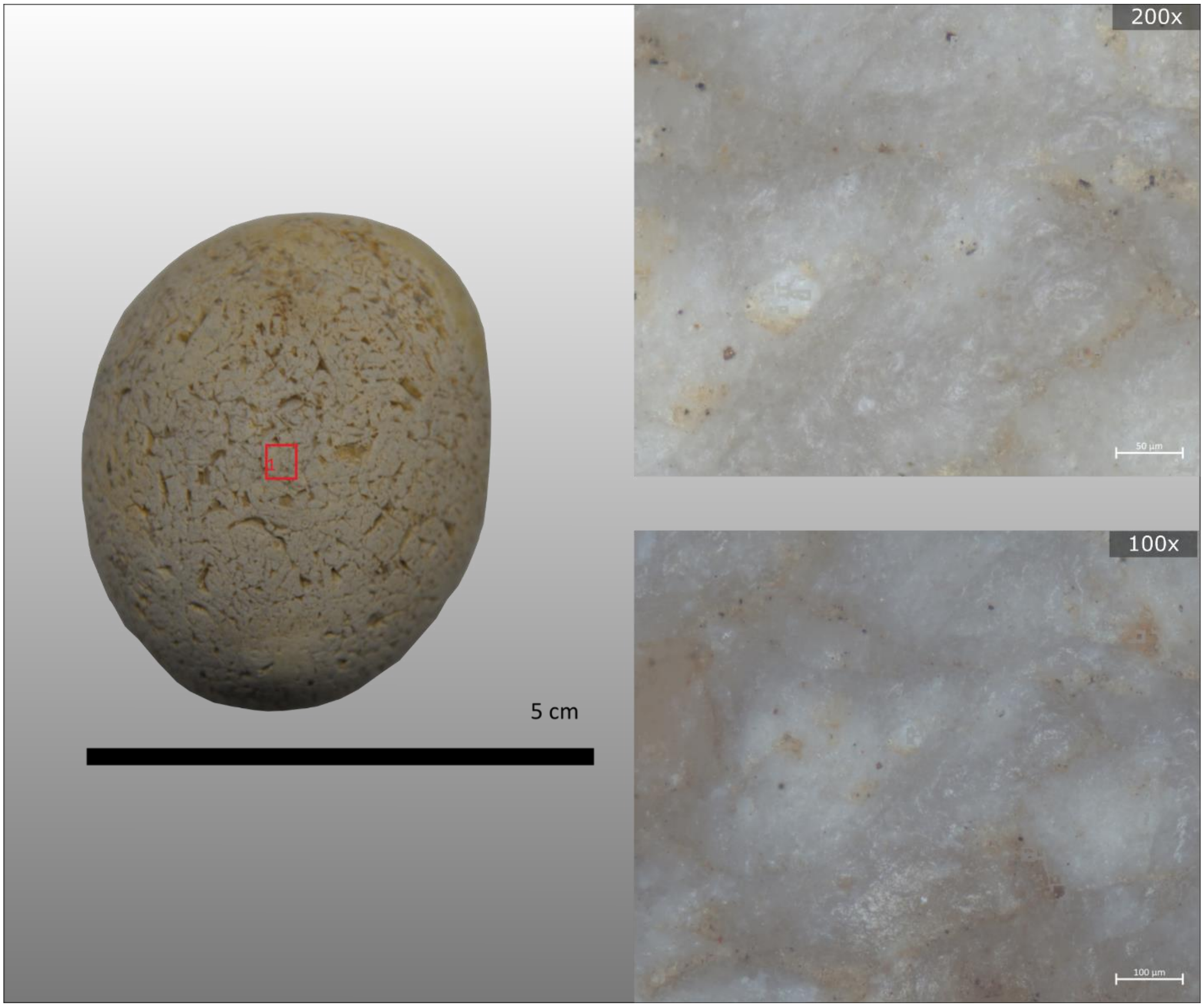

Figure 156: Undefined tool from Nesher Ramla (id: 8718).

Figure 157 Hammerstone from Far´ah II (id: 72).

Figure 158: Refitting from Far´ah II (possibly fragmented hammerstone).

Figure 159: Hammerstone from Far´ah II (id: 180).

Figure 160: Anvil fragment (id:38).

Figure 161: Undefined tool with deep striations (id: 41).

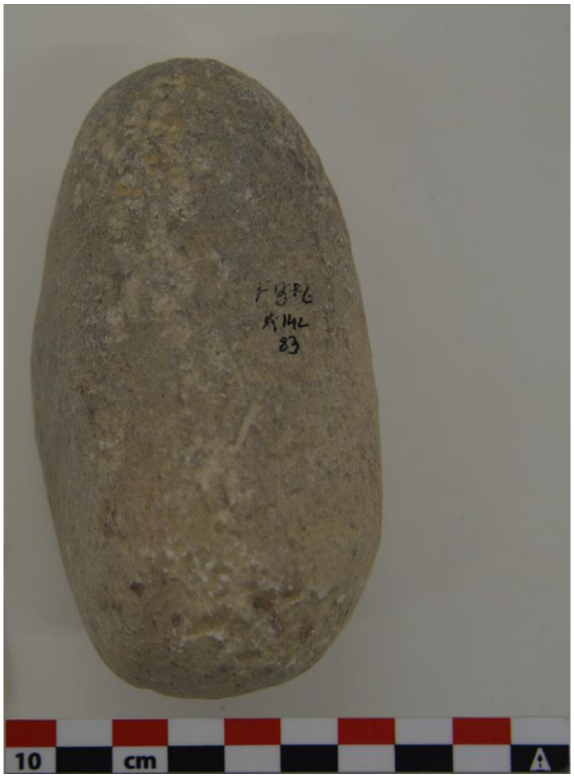

Figure 162: Pestle tool from Far´ah II (id: 83).

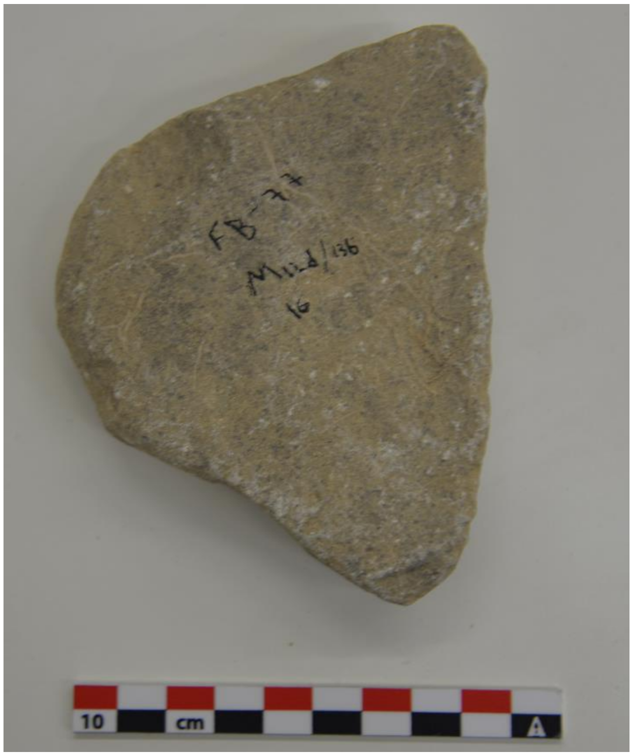

Figure 163: Possible grinding stone fragment from Far´ah II (id:16).

Figure 164: Possible grinding stone fragment (id: 26).

Ein Qashish

Figure 165: Anvil from Ein Qashish (id: 6210).

Figure 166: Chopper tool from Ein Qashish (id: 6106).

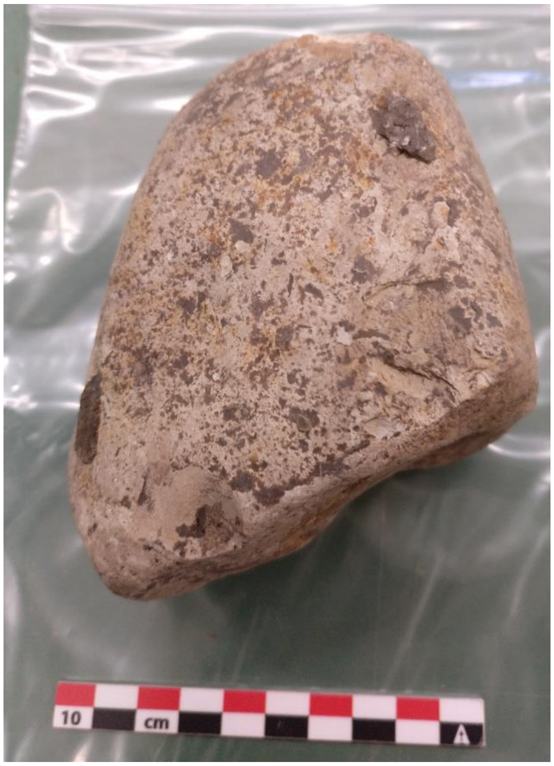

Figure 167: Hammerstone from Ein Qashish (id: 6047).

Figure 168: Undefined tool from Ein Qashish (id: 1573).

9.3.3. Use-Wear location (schematic representation)

Nesher Ramla

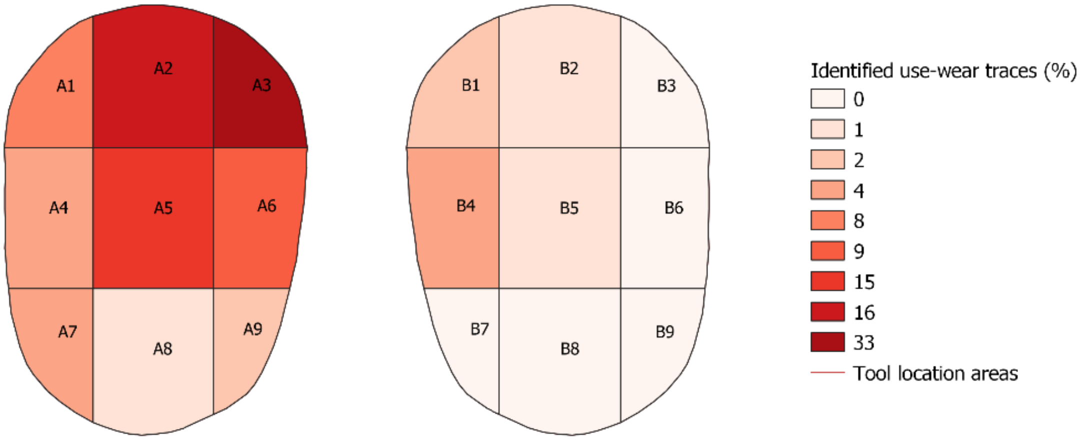

Figure 169: Use-wear location on all tool types.

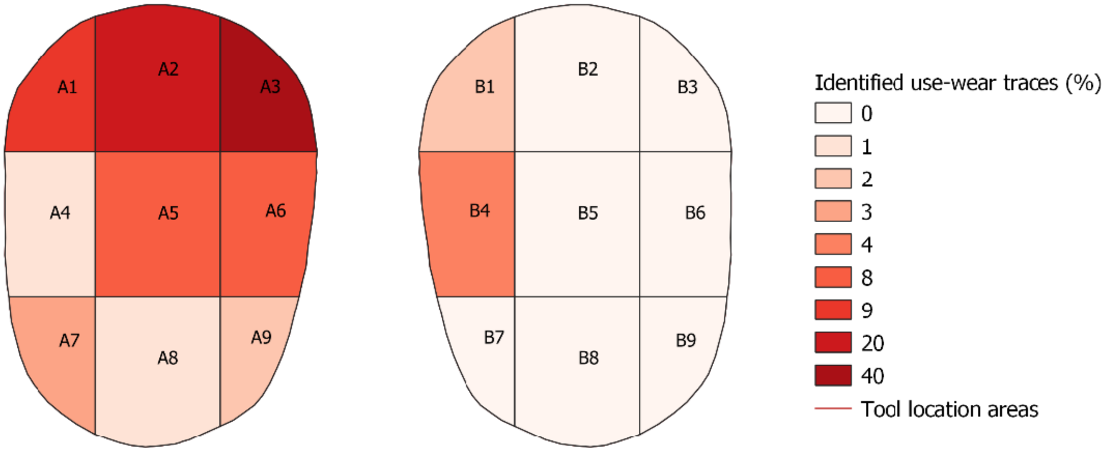

Figure 170: Use-wear location on Hammerstones.

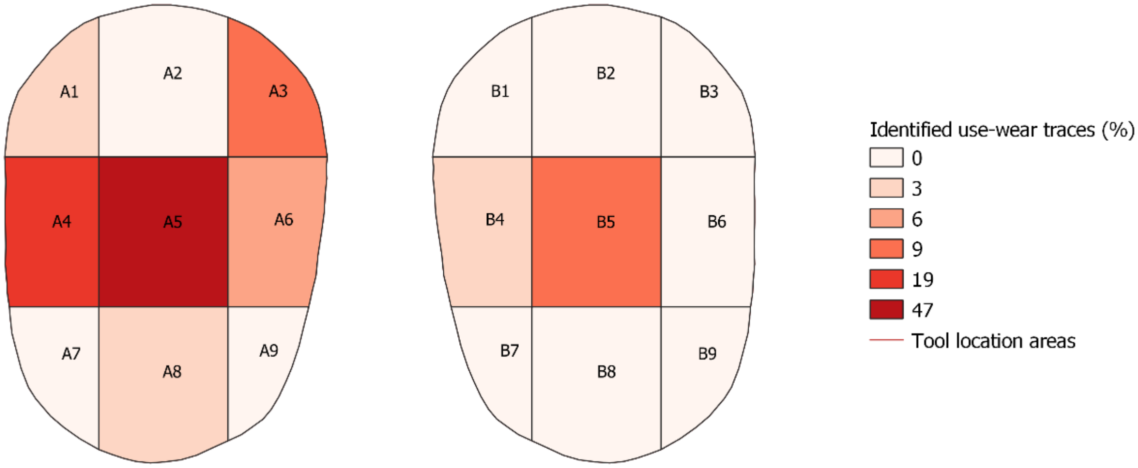

Figure 171: Use-wear location on Anvils.

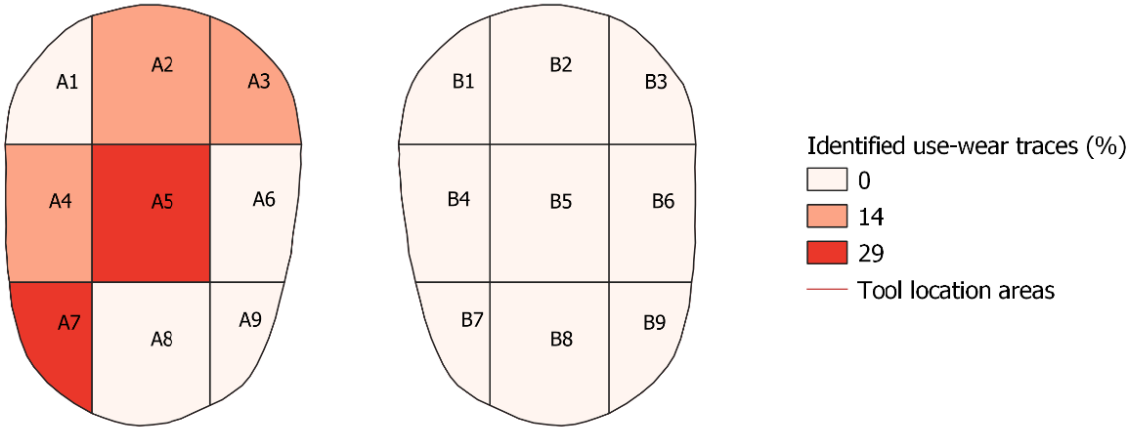

Figure 172: Use-wear location on Pestles.

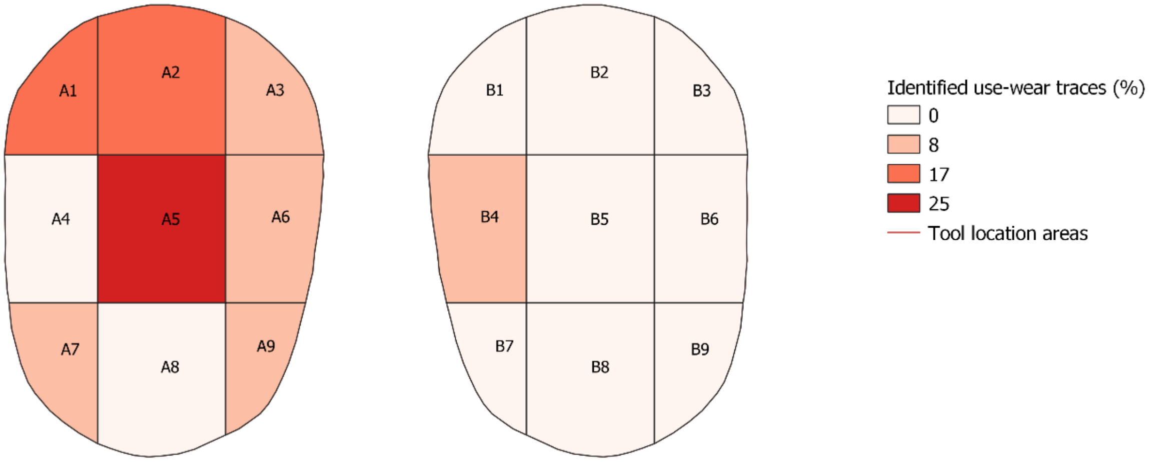

Figure 173: Use-Wear location on Abraders.

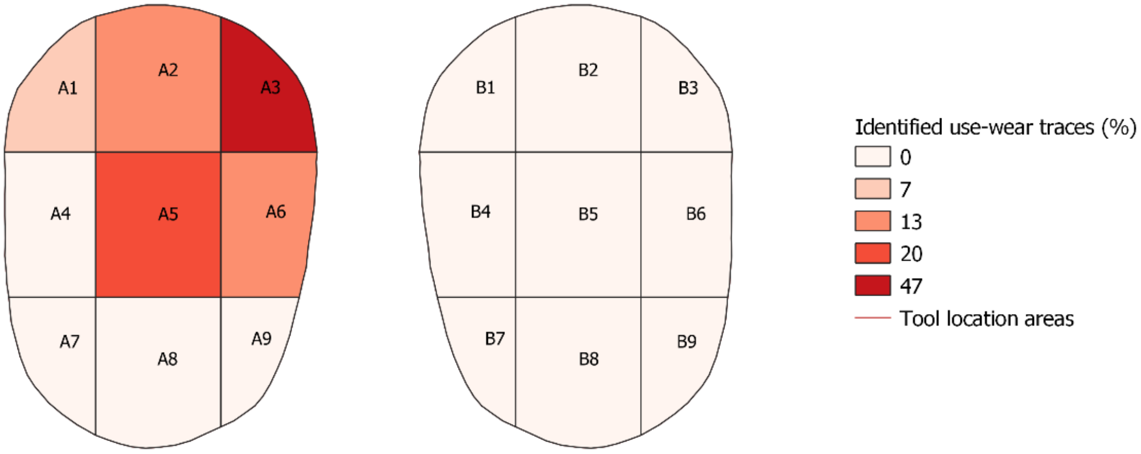

Figure 174: Use-wear location on Choppers.

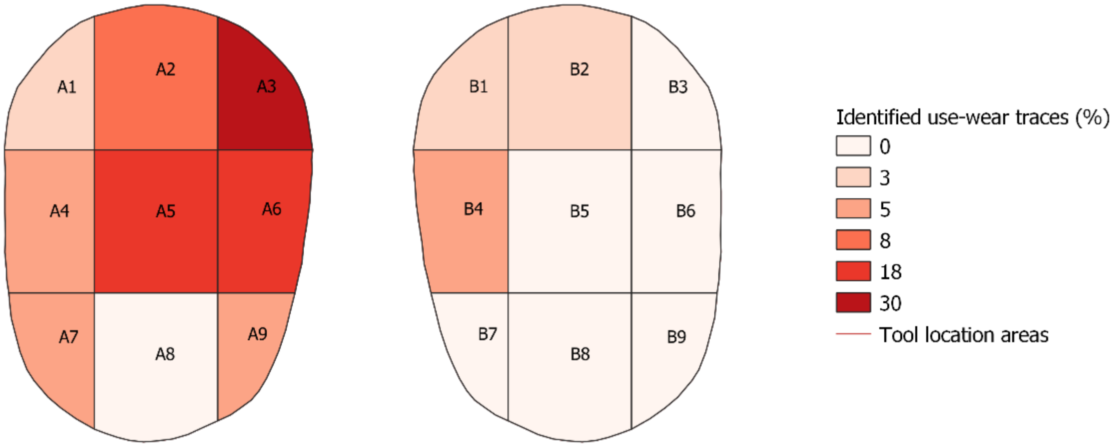

Figure 175: Use-wear location on undefined types.

Far´ah II

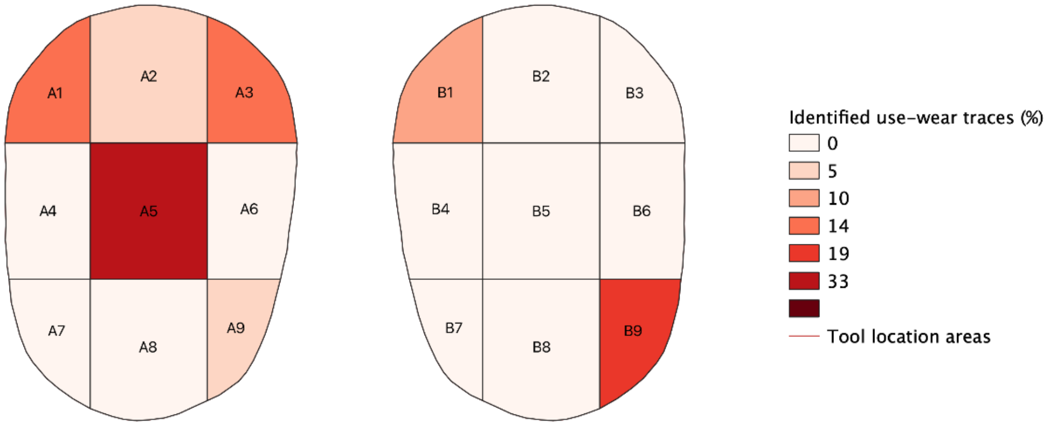

Figure 176: Use-wear location on Hammerstones.

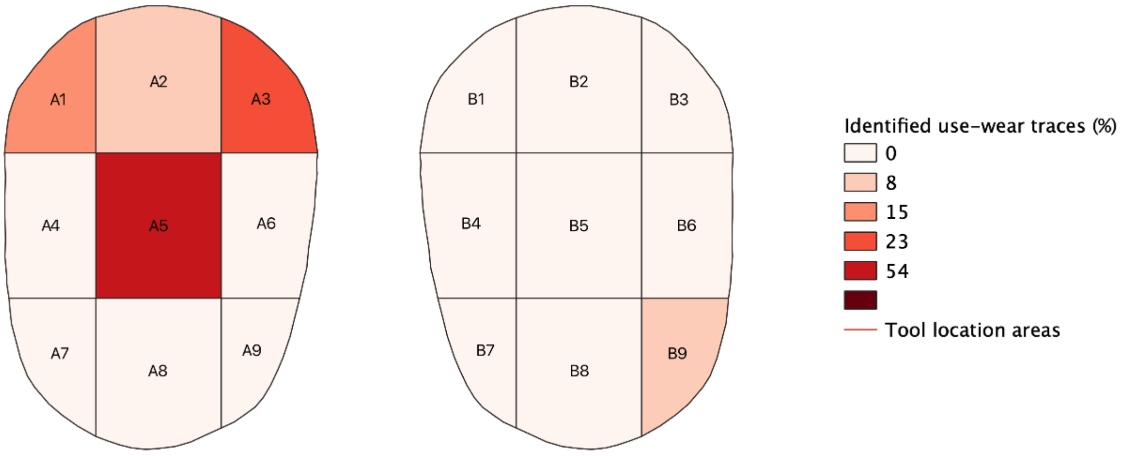

Figure 177: Use-wear location on Anvils.

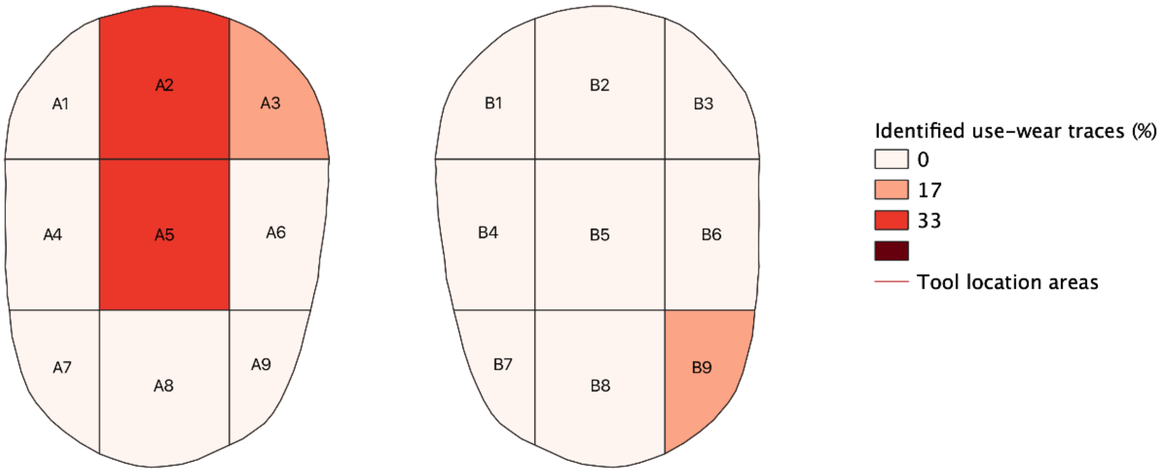

Figure 178: Use-wear location on Choppers.

Ein Qashish

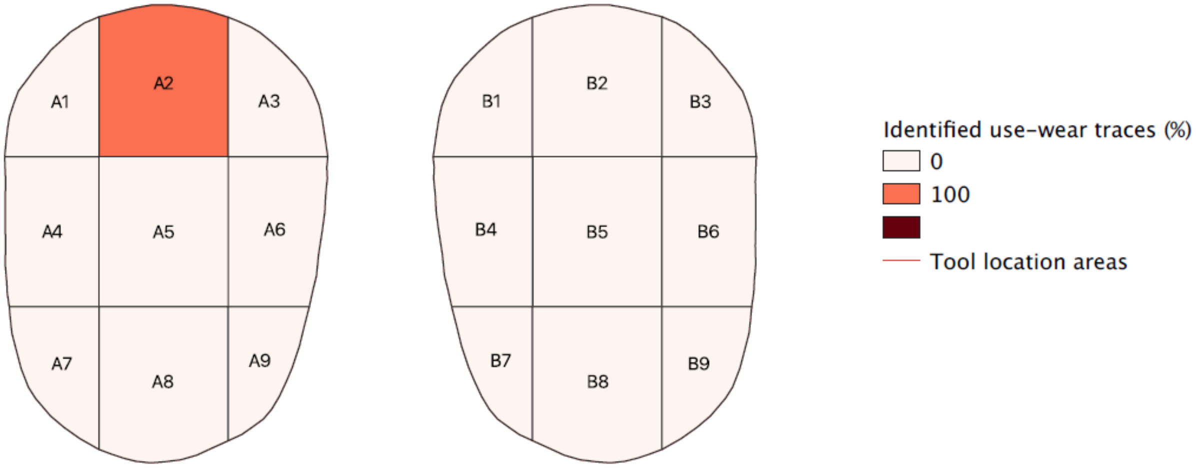

Figure 179: Use-wear location on Choppers.

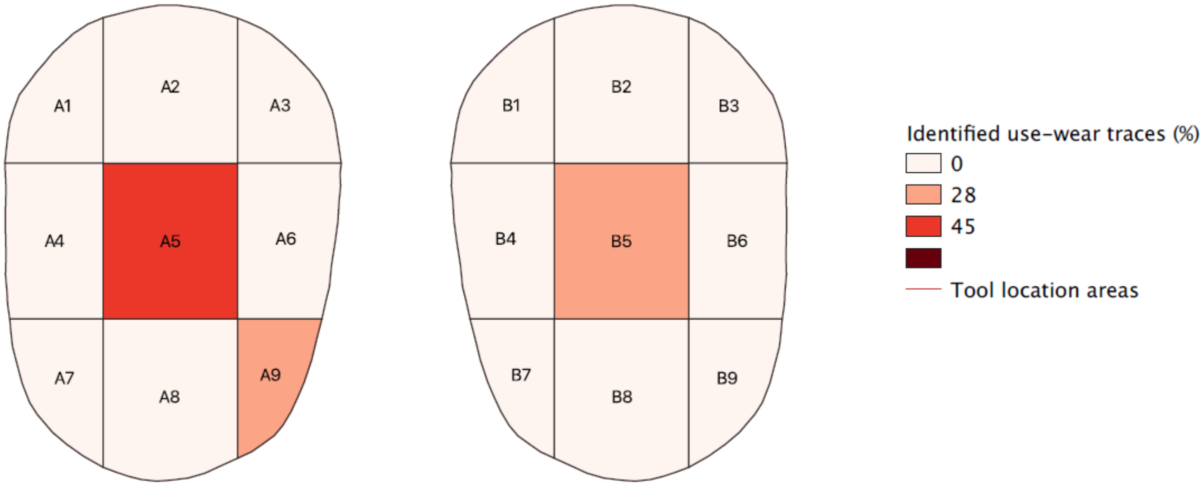

Figure 180: Use-wear location on Anvils.

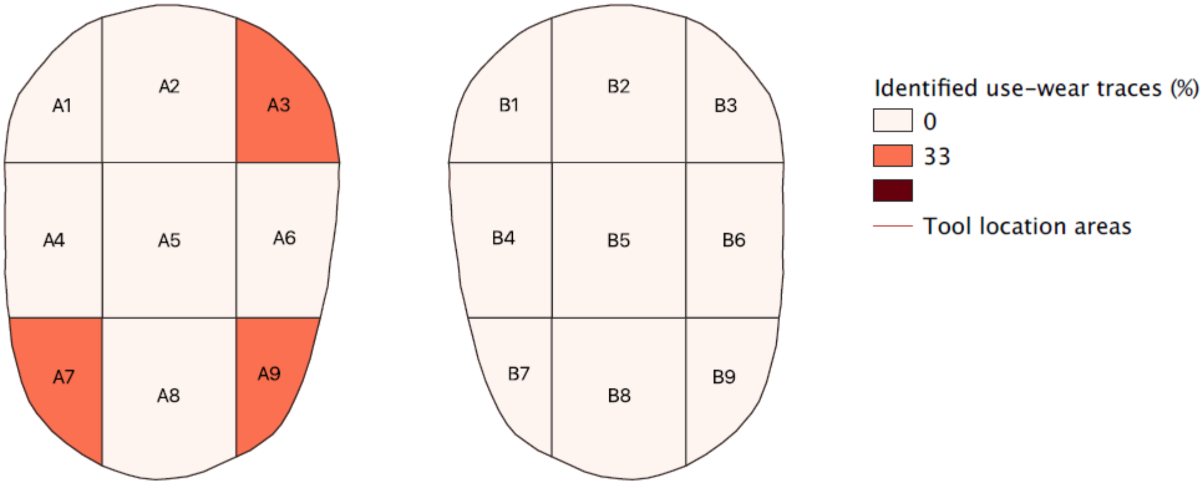

Figure 181: Use-wear location on Hammerstones.

9.4. Equipment and acquisition settings

Imaging technique	*Equipment*	*Objective*	Other objective or light seetings
Photography	Nikon DSLR D160	Nikon AF-S VR Micro-Nikkor 105 mm f/2.8G IF-ED	
Imaging equipment	*Equipment*	*FOV*	*Resolution*
3D scanner	HP Pro S3 David SLS-3	Up to 120 mm	up to 0.06 mm
Imaging equipment	*Equipment*	*Objective*	
3D digital microscope	ZEISS Smartzoom 5	PlanApo 1.6×/0.1	
Imaging equipment	*Equipment*	*Objective*	
Stereomicroscope	ZEISS Stemi 305	0,75x FWD 128mm	
Imaging equipment	*Equipment*	*Objective*	
Upright microscope	ZEISS Axio Scope.A1 MAT	EC Epiplan 5x/0,13	
		EC Epiplan 10x/0,25	
		EC Epiplan 20x/0,4	
Imaging equipment	*Equipment*	*Objective*	
Transmitted light microscope	ZEISS Axio Lab.A1 Pol	N Achroplan Pol 50x/0,80/ WD=0,41 mm	
Imaging equipment	*Equipment*	*Objective*	Others
Laser Confocal microscope	LSM 800 MAT mounted onto an Axio Imager.Z2 Vario	50×/NA=0.75/WD=0.22mm	
		Illumination	Source: Laser
			Wavelength: 405 nm
			Intensity: 4%
		Settings	Scanning direction:
			Scanning speed: 8 (max)
			Bit depth: 16 bits
			Master Gain: 240-300 V
			Pinhole diameter: 54 µm (= 1 AU lateral optical resolution)

		Size and resolution	Zoom: 0.5x
			Field of View: 255.56 * 255.56 μm
			Frame size: 3000 * 3000 pixels
			X/Y pixel size: 0.0852 μm
			Step size: 0.25 μm
			Data quality: No noise cut
AU = Airy Unit, NA = numerical aperture, WD = working distance			

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