Food Practices in Transition:

Plant Processing and Recipes during the Transition from Foraging to Farming in the Levant.

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Abstract

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The onset of the Natufian sees the unfolding of a lasting dietary shift: the transition from foraging to farming. To understand this transition, we have to identify the exploited plants and explain why they were chosen. To that end, I used use-wear and residue analysis to isolate wear patterns distinctive of specific plants. I conducted a series of six grinding experiments on wheat, barley, fenugreek, lentils, roasted wheat, and rinsed/soaked fenugreek. I then examined the tools under multiple levels of magnification using established protocols and descriptive criteria. To ensure that my descriptive criteria are reproducible, a blind test was performed. The experimental data are then compared to previous studies and residue analysis on the tools used to process wheat and lentils was performed. My results have expanded the experimental database and support the idea that there are distinctions between cereals and legumes and differences between types of cereals and legumes.

Keywords: Groundstone tools, Use-wear Analysis, Starch Analysis, Blind Test, Cereals, Legumes, Natufians, Epi-Paleolithic, Foraging Theory, Origins of Agriculture.

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Chapter 1: Introduction

Research on the development of agro-pastoral communities in the Mediterranean Basin has given considerable importance to cereals and the making of bread or beer (Hayden et al. 2013). Yet, at a regional scale, the rise of farming communities in this region is associated with a diversity of dietary and food practices, manifest in differences between sites in terms of the specific and relative representation of plant and animal species (Fuller et al. 2011; Asouti and Fuller 2013; Caracuta et al. 2015; Munro et al. 2018; Dubreuil and Goring-Morris in press). In the Southern Levant, previous analyses of the tools used to process plants, such as grinding slabs and handstones, also support the hypothesis of a diversity of food practices during the transition from foraging to farming (Dubreuil 2004; Dubreuil 2002; Dubreuil and Goring-Morris in press). Two examples of use-wear analysis on a sample of groundstone tools hinting at the importance of legume processing are the Natufian site of Mallaha and the PPNB site of Kfar Hahoresh (Dubreuil 2002, 2004, 2009; Dubreuil and Goring-Morris in press). This thesis aims to explore this hypothesis further and better understand the evolution of food practices in the Epipaleolithic.

As organic material often fails to preserve in the archaeological record, groundstone tools are one of our windows into the past to learn about this dietary transition. These tools constitute one of the ways the people of the Southern Levant processed their food and, by doing so, they created a long-lasting physical record of their activities. If understood, these use-wear traces, i.e., the markings left behind on the surface of a tool after use, can allow us to decipher the materials they were used to process. Knowing what a diet is composed of is not enough; however, we need to understand the decision-making process. Foraging Theory will be used to rationalize the choices behind cereals and legumes covered in this thesis.

This research will expand the experimental database on cereal and legume processing and help develop the current interpretative framework for wheat, barley, fenugreek and lentils.

These materials are ground to identify the characteristic wear traces that set them apart from each other. Additionally, I performed a starch analysis on samples taken from the experimental grinding tools used for wheat and lentils to see if they could explore the residues associated with each material to further define and differentiate them. Lastly, the results from these analyses are compared to previously performed studies and are evaluated with a blind-test. This ensures two things: firstly, the trends observed have been replicated elsewhere and are not just once-off occurrences; secondly, what I observed in the reference collection are not misattributions and that the criteria used to define the wear traces is easy to understand and to use.

To understand the transition from foraging to farming, a series of questions are posited within this thesis. Can classes of materials, such as cereals or legumes, processed on groundstone tools be distinguished from one another by the wear traces they leave behind? Are there variations in wear patterns that can differentiate between materials within classes such as cereals or legumes? Can the distinctions found on the surface of the tool be supported by differences in the starches left? How can pre-treatment of materials affect wear development, and how can we be sure that our results are reproducible and not subjective?

Thesis Organization

This thesis is divided into six chapters which are briefly outlined here. Chapter 2 provides background information regarding the region of study and concepts surrounding the theoretical approach. This chapter also introduces groundstone tool technology, climatic changes and cultural evolution in the Levant. The Natufian culture, the exploited plant matter, and the shift from intensive agriculture to farming will be discussed. Regarding the theoretical approach, the main hypotheses suggested for the origins of agriculture are demographic pressure, the impact of climatic changes, entanglement, niche construction theory and the social hypothesis. Foraging Theory and the relationship between groundstone tools and resource intensification will also be discussed.

Chapter 3 outlines the methods I will be using to perform my analysis and starts with a brief outline of what tribology is and how it makes use-wear analysis possible. The methodology used in this research is then reviewed, explicitly focusing on the approach outlined by Adams and her colleagues (Adams et al. 2009) and the classification system created by Wright (1992). Details regarding the choice of materials for the experiments, their actions, and the equipment used to observe and record the data will be covered. Lastly, I outline how I structured the blind test and the residue analysis and 3D modelling.

Chapter 4 presents the results of my experiments. This includes what wear traces I found on each tool and how these tools compare to one another, and the results from the starch analysis and blind test.

Chapter 5 provides a recounting of various studies which have also performed use-wear analyses relating to cereals and legumes. After a brief presentation of these studies, I compare the wear found with mine, looking at where we had posted similar and differing results. I corroborate the differences between cereals and legumes with the results from the starch analysis. The different material's productivity rates are compared, looking at the amounts of "flour" produced with each in the five hours and how difficult or easy they are to grind. The effect that pre-treatments had on wear development will also be highlighted. Finally, a comparison between the results I found and what is reported in the blind test will be presented. Following this, I remark on the differences between both sets of observations.

Chapter 6 is the conclusion, and in this section, I will summarize all of my findings, acknowledge what limitations I had encountered during this study, and make suggestions for future research.

Chapter 2: Background and Theoretical Approach

Introduction

The primary question this thesis seeks to answer is how finely we can differentiate plant matter based on its associated wear patterns on groundstone tools (hereafter GST). This research is designed to answer specific questions relevant to understanding the evolution of plant exploitation during the Natufian. This topic is pursued because it has been found that the Late Natufian phase of occupation at ‘Ain Mallaha shows the development of handstones and grinding slabs (Dubreuil 2002; Dubreuil 2008). The majority of these tools can be related to the processing of ‘non-oily vegetal,’ a large class that encompasses cereals and legumes (Dubreuil 2004). Use-wear characteristics suggest furthermore that legume processing may have been an important activity at the site. This hypothesis, however, needs to be further explored by expanding our experimental database, which serves as a reference to interpret the use-wear patterns found on the archaeological tools (Dubreuil and Goring-Morris in press).

GSTs are “any tools made by combinations of flaking, pecking, pounding, grinding, drilling and incising” and have been a part of humanity's tool kit for as long as we have been using tools (Wright 1992). Use-wear analysis of grinding and pounding implements has shown that it is possible to find distinctions between different matter classes (e.g., mineral versus organic, oily versus dry, plant versus animal products, and cereals versus legumes). Several of these studies have also outlined differences in use-wear patterns between cereals and legumes (Bofill et al. 2020; Chondrou et al. 2018, 2021; Dubreuil 2004). This thesis seeks to push these boundaries further by attempting to differentiate not only between classes of materials (cereals vs. legumes) but additionally, substances within those groups (wheat vs. barley), as well as the same substance with pre-treatment applied (roasting and soaking). Finally, this thesis will re-examine and compare its results to previously completed studies with similar aims.

The specific goals of this research are tied to more critical theoretical questions about the changes in subsistence practices associated with the transition from foraging to farming. Issues surrounding what had prompted these changes in diets and what these changes are should be considered. This chapter particularly reviews the hypothesis that an increasing diet spectrum is a part of the process that leads to the development of farming communities. In examining this hypothesis, I will discuss Foraging Theory and the concept of resource intensification and provide some necessary background information. Hence, this chapter opens with a presentation of GST assemblages in the context of the Levant with a specific emphasis on the Late Epipaleolithic and successively presents the Natufian culture, Foraging Theory, the broad-spectrum revolution hypothesis and the concept of resource intensification. The reasoning behind ending with the Natufians is because they represent a turning point in dietary choices, initiating the transition from foraging to farming, and have been thought of as an 'introductory chapter' of the Neolithic and the process of Neolithization (Watkins 2013).

2.1 GST Technology, Climatic Changes and Cultural Evolution in the Levant

One of the oldest centers of domestication and the region in which the Natufians had lived in is the Fertile Crescent, understanding this region is essential while exploring the transition from foraging to farming. The Fertile Crescent is defined as the arc of hill country, composed of rich forest and woodland, extending across much of the Middle East, forming a crescent shape that gives the region its namesake (Munro 2004). The modern-day countries the Fertile Crescent spans across are Israel, Palestine, Jordan, Syria, Lebanon, Iraq, Turkey and Iran. The Fertile Crescent can be divided into the western, northern, and eastern wings (Figure 2.1). The west wing of the arc begins in Southern Israel and Jordan and extends north as hill country along the Jordan Rift Valley and westward towards the Mediterranean Littoral (Barker 2009; Munro 2004). The western wing of the Fertile Crescent makes up the Levant, the area in which many of the Natufian sites, such as 'Ain Mallaha, and Pre-Pottery Neolithic B (PPNB) sites, such as Kfar Hahoresh, are located. The northern extent of the Fertile Crescent consists of the Taurus Mountains along the southern border of the Anatolian Plateau, which moves eastward away from the Mediterranean. The eastern section of the Fertile Crescent is defined by the Zagros mountains, which run southeast from Eastern Turkey and Northwest Iran to the Persian Gulf and further into the straits of Hormuz (Barker 2009; Munro 2004). A map showing the extent of the Fertile Crescent can be seen in Figure 2.1.

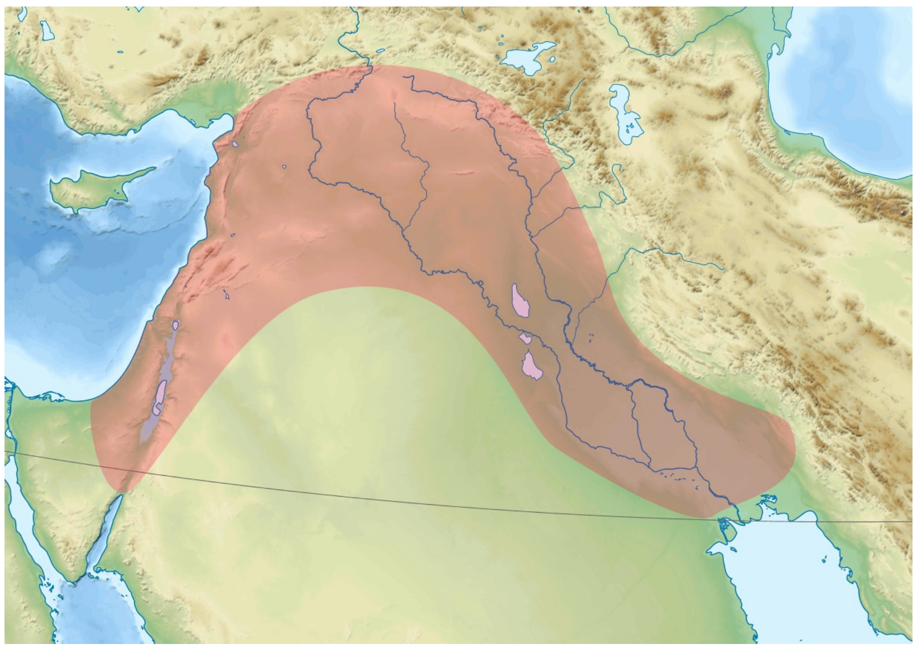


Figure 2.1: Map showing the extent of the Fertile Crescent
From Semhur https://commons.wikimedia.org/wiki/File:Fertile_Crescent.png

Today, the Natufian is generally divided into two or three different periods: the Early, Late, and Final Natufian. These divisions reflect changes in subsistence, settlement patterns, and technology (Belfer-Cohen and Hover 2005). While the beginning and end of the Natufian era are clearly defined, there is some debate regarding its subdivisions. For this thesis, I will be acknowledging the existence of the Final Natufian phase but will be merging it with the Late Natufian, resulting in a two-period schema. The Early Natufian begins at approximately ca. 15,000 cal. BP and ends at ca. 13,000 cal. BP. The Late Natufian/Final Natufian accordingly begins at approximately ca, 13,000 cal. BP and ends at ca. 11,500 cal. BP (Bar-Yosef and Belfer-Cohen 1989; Belfer-Cohen and Goring-Morris 2011; Goring-Moris and Belfer-Cohen 2011; Maher et al. 2011). A table displaying these periods (Table 2.1) is provided below.

Period	Beginning	End
Natufian (Total)	~15,000 cal. BP	11,500 cal. BP
Early Natufian	~15,000 cal. BP	13,000 cal. BP
Younger Dryas	~12,900 cal. BP	~11,600 cal. BP
Late/Final Natufian	13,000 cal. BP	11,500 cal. BP

Table 2.1: Chronology of the Natufian
From Bar-Yosef & Belfer-Cohen 1989, Belfer-Cohen & Goring-Morris 2011, Goring-Moris & Belfer-Cohen 2011 and Maher et al. 2011

To understand the context behind many cultural changes in the Levant, it is crucial to recognize how its climate has varied over time. The shifts in temperature and precipitation are critical for the study of subsistence and many theories regarding cultural and technological development. We will begin with a description of the current climate in this region and then move on to the large-scale historical shifts that have played a role in the region's development to show how the climate may encourage and discourage certain behaviour.

As it is found today, the upland regions of the Fertile Crescent, for the most part, receive more than 200 millimetres of rainfall a year, with the amount decreasing as you move down into the steppe and desert zones. At median elevations within the Levant, light oak woodland can be found (Barker 2009). The area most important for this thesis is the Southern Levant. There is a pronounced topographic variation there, with a strong gradient in temperature and precipitation along the north-south and east-west axes (Rivals et al. 2020; Makarewicz 2012). These gradients result in a substantial amount of phytological variations over small distances. As you move away from the Mediterranean and inwards toward the Red Sea, temperatures rise and precipitation drops (Makarewicz 2012).

During the last glacial maximum, between 25,000 and 18,000 BP (Maher et al. 2011; Holt and Formicola 2008), the climate in various parts of the world was highly variable and dry, and the fluctuations that occurred could last between under a decade to a millennium. This kind of patterning is not conducive to a subsistence pattern focused on plants as they are sensitive to temperature and precipitation extremes. However, during the end of the Pleistocene, a climatic shift ushered in the Bølling-Allerød phase, which had coincided with the retreat of continental glaciers (Richerson et al. 2001).

The Bølling-Allerød phase, which took place between about 14,600 and 12,900 BP, has been described as a warm and wet period that is characterized by a considerable increase of rainfall due to the end of the glacial period (Arranz-Otaegui et al. 2018; Bar-Yosef 2011; Maher et al. 2011). This weather pattern would have been optimal for plant growth. This sudden warm period has been related to the melting of the Antarctic ice sheets, an event dubbed the Meltwater Pulse IA (Maher et al. 2011). During this period in the Levant, it has been suggested by several scholars that naturally growing stands of wheat or barley would have been large enough to feed a whole family unit for the entirety of a year (Flannery 1973; Harlan 1989; Zohary 2004).

This phase of favourable temperature and precipitation was put to an end with the onset of the Younger Dryas, a climactic event that had significant effects all over the planet. The onset of the Younger Dryas in the Levant occurred approximately at 12,600/12,500 BP, possibly lasting for up to 1,000 years (Bar-Yosef 2011). Within this region, the Younger Dryas resulted in an increasingly arid environment due to colder conditions. This climatic shift harmed the production of C3 plants such as cereals (Bar-Yosef 1998, Richerson et al. 2001, Hartman 2012, Maher et al. 2011).

2.2 The Development of GST Technology in the Levant: An Overview

GSTs are, as mentioned in the introduction, any tool made or used by flaking, pecking, pounding, grinding, drilling, and incising (Wright 1992). This section will provide an overview of the development of GST technology throughout prehistory, with a particular focus on the Natufian period. Much of this brief retelling of tool history comes from DeBeaune's 2004 article *The Invention of Technology: Prehistory and Cognition.* While this article is dated and contains generalized information regarding GST development, it provides a condensed history of lithic development with a focus on the mechanics of use, which is especially useful when discussed in the context of a use-wear study. The information found within the article will be supplemented with other research articles. A figure showcasing a developmental tree of grinding tools can be seen in Figure 2.2.

The development of GSTs goes as far back as any tool can. The roots of GST technology can be extrapolated back to the common ancestors we share with chimpanzees, as chimpanzees have been found to use hammerstones to crack nuts (Boesch and Boesch-Achermann 2000; Visalberghi et al. 2015; Wynn et al. 2011). In some of the earliest hominin sites in Africa, such as Olduvai Gorge in Tanzania, "pitted anvils" with depressions ranging from 25 to 44 millimetres in diameter and 8 to 14 millimetres in depth have been formed into stone blocks. These "pitted anvils" also have at times been found with what can be interpreted as hammerstones in association with them (de Beaune 2004). Clear evidence that such tools may have been used for nut-cracking comes to us later from Gesher Benoet Ya'akov located in the Southern Levant. At this site, pitted stones belonging to the Acheulean period are found in association with several types of nuts; preserved by the damp environment (Goren-Inbar et al. 2002). The more advanced tools and techniques start from the simple implementation of pounding (Bril et al. 2015; de Beaune 2004).

The first significant change within the category of GSTs is the development of diffuse thrusting (pounding a material against a surface) and resting (grinding a material against a surface) percussion techniques. This is not a change brought about by developing a new tool; instead, this was brought about by using an old tool in a new way. With this change, individuals are no longer breaking apart a shell or other hard material but are now reducing material into a powder that is much softer than the original matter. Such a transition occurred during the Middle Paleolithic in Europe and the Middle Stone Age in Africa, which lasted from 300kya to 50kya (de Beaune 2004). While powder is possibly made before these specialized tools, these GSTs would have enabled the user to reduce matters into powders on a much larger scale.

During the Upper Paleolithic (50kya to 12kya), specific tools used specifically in diffuse resting percussion appeared. Before this, the means for both grinding and pounding would have been used interchangeably. From this point, there is a gradual development of new specialized tools such as the elongated pounder, milling stone, and smoothing stone, to name a few. The first netherstone to have been used alongside a handstone for grinding appeared during the beginning of the Upper Palaeolithic period, used by both Neanderthals and modern humans (de Beaune 2004). Tools made explicitly to process materials by grinding are not restricted to just Europe, as tools performing similar functions have been found in different parts of the world around the same time. Examples of early grinding tools can be found both at the Cuddie Springs site within Australia wherein a grinding stone was found dating between approximately 33,300 and 30,280 B.P. (Fullagar and Field 1997) and within Northern China at Xianchuan, whose examples date between 28,000 and 19,300 B.P (Elston et al. 2011).

From this point on, we will be keeping our focus on the Levant. While it is likely that stone tools would have been used to process materials by percussion as early as the Lower Paleolithic (Rosenberg 2013), they are quite scarce. An exception is the pitted anvils found at

Gesher Benot Yakov (Goren-Inbar et al. 2002). During the Upper Paleolithic, GSTs had continued to be fairly scarce. About 25 percent of 61 sites investigated contained very small assemblages, made up of small-sized portable handstones and grinding stones (Wright 1991). During the Kebaran period (22,000 and 14,500 B.P.), coinciding with the cold, dry condition of the last glacial period, grinding and pounding implements are equally as sparse. However, new tools are found: the deep vessel/mortars and elongated pestles (Wright 1991).

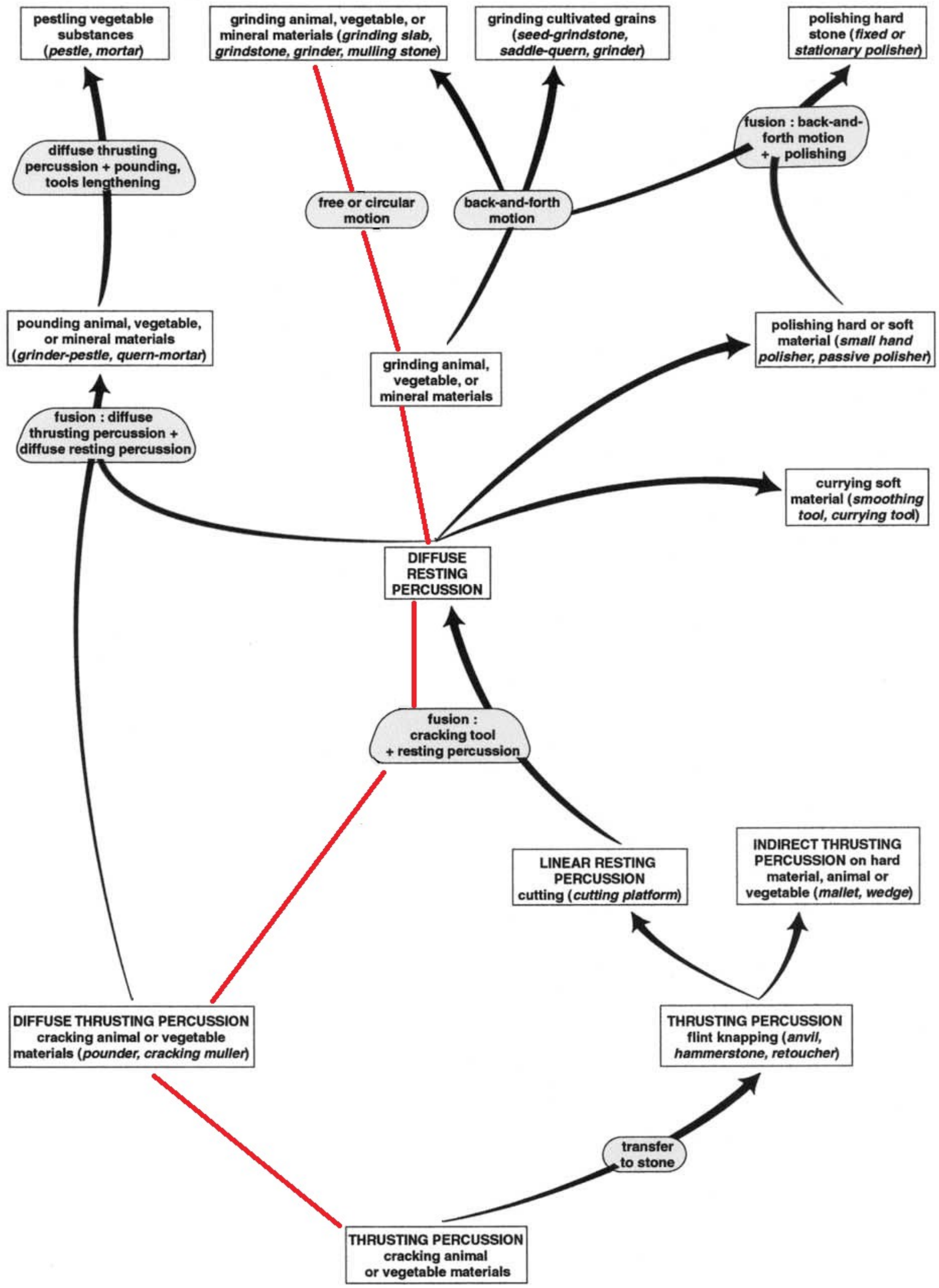


Figure 2.2: The Evolution of Percussion and the Associated Tools. Red lines show the developmental chain leading to grinding slabs. From de Beaune 2004 Figure 2.

2.3 The Natufian

In the early days of April in 1928, Dorothy Garrod and her team located a cave one kilometre south of the village of Shukba while surveying the Wadi en-Natuf in the Judean Hills. Inside the cave, they discovered the ‘Levantine Mesolithic’ cultural remains within a stratified deposit. During their initial two-month excavation, the archaeological deposits in the cave’s main chamber were emptied. According to Garrod, the stratification was quite complex and, as a result, difficult to interpret. The deposit contained several layers, the main ones being labelled A, B, and D, and layer B would prove to be of specific interest. Layer A contained materials dating to between the Early Bronze Age and recent times, while in layer D, Garrod and her team found materials that belonged to the end of the Mousterian period. Within Layer B, they uncovered a microlithic industry associated with several hearths, burnt animal bones, polished bone artifacts, and fragmentary remains of some human skeletons. Cultural remains uncovered in Layer B were then attributed to the ‘Levantine Mesolithic,’ later renamed the Natufian (Boyd 1999). A map showcasing the distribution of Natufian sites within the Levant can be seen in Figure 2.3.

Figure 2.3: Distribution of Natufian sites in the Levant, c. 14500-11500 BP. From Bar-Yosef, 2014 Figure 3.4.1 3.4.1

Following the Last Glacial Maximum and the return of a warm and wet climate, the Fertile Crescent became a much better-suited habitat for plant growth (Bar-Yosef 2011). By the end of this period of increased plant growth, there are well-established hunter-gatherer groups all over the Levant, some of which would go on to establish the Natufian hamlets (Bar-Yosef 2011). Roughly around 15,000 B.P., the Natufians emerged in their homeland of the central Levant in a woodland belt whose undergrowth consisted of grass with high frequencies of cereals (Bar-Yosef 1998). Other groups of Natufians could be found high up in the mountains of Lebanon, the steppic areas of Negev and Sinai, and the Syria-Arabian desert. However, these settlements are small due to these environments' low carrying capacity (Bar-Yosef 1998). During the Natufian period, the changes would have occurred differently and at disparate times within these varying ecological zones. It is hypothesized that within the region described as the core area, i.e. the central Levantine woodland ecological zone, the groups would have exploited typical forest plants such as acorns and nuts like the pistachio through pounding. This behaviour is in contrast to the peripheric steppic zones where grasses and cereals would have explicitly been exploited (Belfer-Cohen and Hover 2005; Goren-Inbar et al. 2002).

The Natufian settlements in Lebanon, Negev, Sinai, and the Syria-Arabian desert would have accommodated a few families or sub-clans and showed marked territorial ownership (Bar-Yosef 2011). These people were semi-sedentary and built camps that featured pit houses, buried their dead on-site, and, most importantly, consumed a large amount of plant food. The evidence for this consumption comes from sickle blades featuring a sheen that resulted from harvesting cereals and the presence of mortars and grinding stones that are hypothesized to have been used to process cereals (Bar-Yosef 2011; Maeda et al. 2016). Another critical aspect of the Early Natufian, which is related to both their semi-sedentary lifestyle and method of subsistence, is the building of storage pits. The earliest known example of a storage pit has been uncovered within the Near East at the Early Natufian site of Ain' Mallaha (Grosman et al. 2020). When studying the Natufian sites, it is vital to recognize the fact that due to poor preservation there is low visibility of plant remains. With this sparse botanical evidence, material culture such as stone tools has been used to validate regular cereal consumption and management claims among the Natufians (Asouti and Fuller 2012; Dubreuil 2004).

The Natufian lithic industry is characterized by the production of small, short, and wide bladelets and flakes and extensively used cores. A tool that is first seen in abundant numbers during the Natufian period is the sickle blade. According to experimental research and microscopic studies, these blades were used for harvesting cereals, albeit in small quantities (Maeda et al. 2016; Spivak 2008). It is possible these tools were developed in direct response to early experiments in cereal cultivation to maximize crop yield and minimize harvesting time (Bar-Yosef 1998). In a study performed by Kathrine Wright titled “The Origins and Development of Ground Stone Assemblages in Late Pleistocene Southwest Asia” (1991), she chronicled GST development during the Natufian period. Within this paper, an analysis of early Levantine groundstone assemblages spanning the Upper Paleolithic through the Neolithic is undertaken (Wright 1991). It is important to note here that much of the information within this section comes from Wright’s 1991 synthesis, and some of it might not hold up today as, despite the well-recognized importance of GSTs, comprehensive overviews are few and far between and are often lacking in details (Belfer-Cohen and Hovers 2005).

There are two broad categories of tools used to process the harvested plant materials, as defined by their shape. These categories of Natufian tools are those with a concave working surface, such as mortars and pestles, and those with a flat working surface, such as grinding slabs and handstones (Dubreuil 2004). The dominant type of raw material used to make the Natufian’s GSTs in most sites of the core area is cryptocrystalline basalt (Dubreuil 2004). This is likely due to the intrinsic qualities of basalt, those being that it has a rough surface and suffers minimal surface attrition. The minimal surface attrition is an attractive quality because it reduces the need to retouch the surface and prevents grits from mixing with the ground material (Ebeling and Rowan 2004).

Regarding the Early Natufians, 49 percent of the 35 sites investigated contained some GSTs (Wright 1991). Most of the assemblages occurred in well-watered regions, the largest of these assemblages being found in or around the Jordan Valley hilly woodlands, which made up the core area of the Natufian culture. Of these assemblages, the most dominant tool types are portable mortars and large pestles, several of which are incised and painted, suggesting they are trade wares. The reasons for the presence of a large number of pounding tools in Early Natufian assemblages could have been diverse and varied from site to site and may have had more to do with site size than with the specific resources exploited (Wright 1991). This reinforces the notion that some degree of differentiation between Natufian groups, based on their ecological setting, exists.

Considering the dental wear patterns of Epiplaeolithic skeletons and the fact that 49 percent of excavated sites contain some GSTs (Wright 1991), it is apparent that there is an increase in the reliance on ground food between the Kebaran and Natufian periods. In addition to this, the tool distribution is skewed, with most of them occurring in the well-watered regions (Wright 1991). While GSTs became more prominent within the region during the Natufian, they are not much different in their form from the sporadically used pre-Natufian counterparts. The Natufian tool assemblage could be described as a gradual development of pre-existing traditions, and early tool assemblages have been described as conservative, not varying much from previous tool-making traditions. This seems to indicate that the increase in their numbers is not due to a lifting of constraints that previously prevented the mass construction of tools (Belfer-Cohen and Hovers 2005). It is not until the Late Natufian that there would be changes in subsistence patterns, due in part to the onset of the Younger Dryas.

Within the Levant, the effects of the Younger Dryas would have restricted the distribution of annual grasses such as wheat and barley and would have reduced their productivity as well. The reasons for the reduced distribution are a decrease in temperature, precipitation and atmospheric CO_2 levels (Makarewicz 2012). However, this idea has been challenged recently, with evidence showing that while there is cooling during the Younger Dryas, it was not a dryer period. Yet, it is essential to underline that its impact on the availability of plant species remains the same (Hartman et al. 2016). Often it is assumed that the Younger Dryas had a severe effect on subsistence choices and is responsible for much of the developments during the Late Natufian (Makarewicz 2012). Following this reasoning, we would expect the tool assemblage to reflect such an impact on subsistence.

In Wright's 1991 publication, out of the 45 sites attributed to the Late Natufian, 49 percent contain GSTs. Additionally, the sites are more widely dispersed, moving into the more arid regions of the Levant. While the data Wright had access to suggests a similar amount of usage of GSTs between the Early and Late Natufian phases, other research has shown an increasing amount of use for grass and cereal processing. This increase is at the expense of food typically more associated with forest subsistence, when comparing the Late to Early Natufian periods (Belfer-Cohen and Hovers 2005; Dubreuil 2004). A use-wear analysis of grinding slabs and handstones assemblages of three different Natufian sites (Hayonim Cave, Hayonim Terrace and 'Ain Mallaha) spanning the Early to Late periods has shown that the Natufians are processing three different types of material. During the Late Natufian period at 'Ain Mallaha, 59 percent of the flat implements show use-wear associated with 'non-greasy plants' including legumes and cereal processing, and 5 percent show wear associated with mineral processing (Dubreuil 2004).

Coinciding with this apparent dietary shift in the Late Natufian, there is also a noticeable move away from some of the more sedentary practices found in the Early Natufian. The Late and Final Natufian sites of the Southern Levant, remarkably, produced poorer remains and increased consumption of low-ranked foods than their Early Natufian counterparts (Bar-Yosef 2011). This perspective, however, has been recently challenged by the discoveries from the site of Nahal Ein Gev II and Shubaka in Jordan, where a series of large structures has been found (Grosman et al.

2016; Richter et al. 2016). Additionally, a plastered installation, reminiscent of a storage pit, is also uncovered, which is significant as it goes against what was previously assumed about the Late Natufian, as aside from a few other examples, this era is largely devoid of these kinds of structures (Grosman et al. 2020).

2.4 Exploited Plant Materials

As mentioned previously, it was theorized that the Natufian diet had increased in regards to the number of grasses and cereals consumed. This trend had some variations due to the location of settlements. Before delving into the evidence of plant exploitation, it is important to address preservation bias. Due to the nature of organic materials, they often fail to preserve. They are absent in the archaeological record, influencing our ability to make definitive conclusions regarding plants' role in diets.

Arranz-Otaegui et al. (2018) report that while more than 400 Natufian sites have been excavated to this date, macro botanical remains have been retrieved only in a few of them. Even fewer sites have yielded a substantial number of remains, with less than 10,000 remains in total being uncovered. Although phytolith and starch sampling are being more widely implemented, our understanding of plant use during the Natufian remains incomplete. In addition to the lack of preservation, sampling bias is another pervasive problem (Arranz-Otaegui et al. 2018).

A list of Natufian botanical remains is provided by Power et al. (2014): almonds, lentils, peas, vetch, lupin, olives, grapes, barley, wheat, and various small-seeded grasses. In regards to the Early Natufian in particular, the archaeobotanical evidence we have, as of 2018, comes from three sites: Wadi Hammeh 27, el-Wad, and Hayonim Cave (Arranz-Otaegui et al. 2018). From Wadi Hammeh, 27 small-seeded grasses, wild plants, legumes, large and small-seeded, and wild barley are found. According to some researchers, it is likely that the inhabitants here would have incorporated pistachio and mallow into their diet. At the site of Hayonim Cave, lupin seeds are found and seem to be prominent, and additionally, wild barley seeds are found along with almond shells (Arranz-Otaegui et al. 2018). At the el-Wad site, legumes are dominant among the collected samples, followed by barley. In addition, amygdalus, hawthorn stones, and several kinds of weeds are also present. Phytoliths from the site had also shown a presence of wetland plants such as reeds (Arranz-Otaegui et al. 2018).

Regarding the Late Natufian period, it is from the site of Abu Hureyra I where we find the largest number of archaeobotanical remains (Arranz-Otaegui et al. 2018). From this site, around 31,000 non-woody plant remains are recovered, which represented 150 different food types. Interestingly in earlier studies the importance of wild food gathering was noted, as the seeds of clubrush, Euphrates grass-knot, wild wheat, wild rye, anabasis, hammada, and likely soft vegetative foods are hypothesized to have been used. However, no direct evidence of these has been found (Arranz-Otaegui et al. 2018). The site contained three different occupational phases, and between these, three changes in regards to the distribution of plants could be noted. During the second phase of occupation, which coincided with the Younger Dryas, there is a decrease in five plant groups: those which inhabited oak woodlands, such as the *Pistacia* genus, which includes the pistachio, large-seeded legumes, shrubby *Chenopodiaceae*, wheat, and barley. Corresponding with these decreases is an increase in the presence of the small-seeded legumes, grasses, and stony-seeded dryland gromwells (Arranz-Otaegui et al. 2018).

A study at the Late Natufian site of Raqefet cave provides some additional evidence of plant exploitation during the Natufian. Phytoliths from this site were recovered from within carved deep bedrock features and were analyzed. These studies show that the features were used to process a wide range of plant materials. Phytolith analyses shows that there is no specialization for a particular kind of material, such as wheat or barley, which is often assumed, but rather a wide variety of grass seeds and tubers (Power et al. 2014). While not mentioned nearly as often as other flora, such as cereals, tubers are often recovered from sites in the Levant, specifically, sea-club rush (Wollstonecroft et al. 2008).

As mentioned previously, the Natufians were not the first groups within this region to exploit and process vegetal matters. Such evidence is found for instance at the Kebaran campsite of Ohalo-II, established on the shore of the sea of Galilee and occupied around 23,000 BP, predating the emergence of established farming communities in the region by 12,000 years. At this site, there is also evidence relating to the production of flour made from wild barley and oats, indicated by recovered organic residue (Piperno et al. 2004; Nadel et al. 2012; Dubreuil and Nadel 2015).

From these examples, we can see that these people's diet was not focused on a narrow range of plants but reflected a wider spectrum of flora. Additionally, the tools and plants incorporated into their subsistence economy would differ depending on where the Natufian camps are situated.

2.5 From Intensive Exploitation to Farming

The Pre-Pottery Neolithic A period (between 11,700/11,500 BP and 10,700/10,500 BP) marks another step in the development of farming (Makarewicz 2012). The Pre-Pottery Neolithic A communities are considered to be direct descendants of the Natufians. The people of the PPNA had a mixed economy, cultivating plants and hunting game and gathering wild plants (Bar-Yosef 2011). The warmer and wetter conditions after the Younger Dryas with forest expansion and higher biodiversity seem to have favoured the re-establishment of more sedentary settlements during the PPNA period (Yerkes et al. 2012). During this period of favourable conditions, the people of the PPNA returned to more permanent settlements and create new types of houses and tools that would begin the gradual development of agricultural practices (Yerkes et al. 2012).

During the PPNA in the Levant, there are signs of pre-domestication of barley and possibly emmer wheat and legumes (Asouti and Fuller 2012; Colledge et al. 2018). Pre-domestic cultivation refers to the deliberate growth of morphologically wild plants, which is a prerequisite stage that leads to morphological domestication (Wilcox 2014). This is based on information from the Gilgal I site, where large stores of wild oats and barley have been found (Asouti and Fuller 2012) and the site of Dhra, where barley, in the early stages of domestication, is found (Colledge et al. 2018). Further evidence for pre-domestication cultivation during this period has been found at Netiv Hagdud, where there have been large amounts of the weed *Veronica peregrina* found, which has been taken to be an indicator of cultivation and even possibly storage. At Netiv Hagdud, lentils are also found in large numbers. Further evidence of the domestication happening during the PPNA is found at Zahratadh-Dhra, where 29 percent of determined barley rachises are of the non-shattering type, which is an indicator of domestication (Asouti and Fuller 2012). In addition to these plants, the people of the PPNA were still reliant on wild game species such as gazelle and wild boar (Kujit and Goring-Morris 2002).

The PPNB period (9,500 - 7,500 BP; Simmons 2011) witnesses spectacular changes in areas such as ritual behaviour and trade, as well as the development of the mega-sites and, importantly, provided compelling evidence of plant and animal domestication (Simmons 2011). PPNB sites are found in various ecological niches and vary from each other in many ways; however, cultivated plants and domesticated animals represent an important part of their subsistence base (Steiner and Killebrew 2014). Hence, throughout the Natufian and PPNA periods, people became more and more reliant on cultivation. However, it is not until the PPNB that all of these developments culminate in a largely agricultural and sedentary lifeway based on domesticated animals and crops, supplemented with hunting and gathering.

The first clear signs of domesticated plants in the Old World come from Pre-Pottery Neolithic B farming villages. The plant that provides the confident signs of domestication is either emmer or einkorn wheat, which is primarily inferred from the presence of spikelet forks of these plants bearing rough disarticulation scars. The most numerous crop remains found within these early farming villages come from emmer wheat, einkorn wheat and barley (Zohary et al. 2012). The remains from these villages also show us that the people of the PPNB were not simply relying on one or two staple crops but were exploiting a combination of crops. This combination of emmer and einkorn wheat, barley, pulses and flaxes appear throughout the Fertile Crescent during this period. It has been claimed that they characterize the development of agriculture within the Fertile Crescent (Zohary et al. 2012).

2.6 Theoretical Approach

This section will now address the various theories suggested to explain the development of farming, the main ones being: demographic pressure, climatic hypothesis, entanglement, niche construction and the social hypothesis.

2.6.1 Demographic Pressure

While the aforementioned climate change undoubtedly played some role in the changes in diets and the transition from foraging to farming, some claim that increasing populations may have been a more casual factor in this process.

In 1968 Lewis Binford observed that there seemed to have been a large broadening of human diets within the middle and high latitudes of Europe at the end of the Paleolithic period (Binford 1968). This broadening of the diet, along with Binford's theory, would later be referred to as the Broad-Spectrum Revolution (hereafter BSR), which was first coined by Kent Flannery in 1969, who believed it preceded the domestication of plants and was as a pre-condition for it (Flannery 1969). In the BSR hypothesis, the expansion of diets described did not *ipso facto* lead to the transition from foraging to farming. The ultimate reason for this transition is suggested to be related to an imbalance between populations and the available resources. While the new dietary inclusions involved in this expansion differed between regions, some changes seem to be shared among different contexts, such as fish, birds, rabbits, and grass seeds (Janz 2016). In the BSR hypothesis, the expansion of the diet and ultimately the development of farming is a response to population pressure.

Another early theory of how population density may relate to the development of farming comes from Mark Cohen in his 1977 book “The Food Crisis in Prehistory.” Cohen’s definition of population pressure is integral for understanding how demographics may be related to an increased dietary breadth. Cohen defined population pressure as “… an imbalance between a population, its choice of foods and its work standards, which forces the population either to change its eating habits or to work harder.” (Cohen 1977: 50). It has been hypothesized that human populations grow continuously, which causes the equilibrium that people established with the carrying capacity of their environment to deteriorate. Previously it had been assumed that hunter-gatherers could not grow their populations beyond the environment’s carrying capacity. Issues with having a large number of dependents in a mobile society and high mortality rates are often put forward as constraining factors. However, many authors have argued against this idea, noting that the factors that limited these societies' population growth are not insurmountable but could be conceptualized as deliberate decisions interwoven into cultural practices such as intentional birth spacing and abortion (Cohen 1977). If we agree that hunter-gatherer groups can effectively control their population growth to maintain an equilibrium with the land’s carrying capacity in which context then would population growth occur and require new technology such as GSTs?

Cohen offers two models of population growth: a small scale and a large scale. I will be focusing on the small-scale in this chapter because it addresses why low-ranked foods are adopted. Taking the Kalahari bushmen as an example, Cohen posits that hunter-gatherers' population size is defined by the distance they are willing to walk to get food. The population size is rarely over 100 and typically much less than that. When the population gets much higher, the quality of the diet and the labour cost associated with food acquisition is threatened. Once the population expands beyond this threshold, the group is faced with either a lower quality diet or an increased workload. Cohen asserts that this would have been a constant struggle for most groups throughout history. Once this point has been reached, these groups would then be faced with several choices: they could limit their population, increase the radius in which they search for food, fission off into two groups, intensify their search within the same area or turn to foods which were previously ignored (Cohen 1977). It is that final choice that is related to the BSR.

According to Flannery, the BSR and the choice to turn to previously ignored foods led to agriculture because the targeted plants, such as barley and wheat, had qualities the first-choice foods lacked. These qualities are that they are mainly annuals, yield a high return, tolerate a wide range of habitats, and are easily modified and stored. Some plants may also quickly replace the original flora, which are introduced with a dense growth of storable food. Over time, these plants will be genetically altered, resulting in changes that will improve their productivity, ease of harvest and/or ease of preparation (Flannery 1973).

2.6.2 Climatic Hypothesis

For archaeologists who theorize that environmental change is the impetus behind the transition from foraging to farming, it is shifts in climatic conditions, from inhibitive to supportive and back to inhibitive again, that encourage and possibly require groups to adopt a strategy of intensive plant exploitation (Arranz-Otaegui et al. 2018; Bar-Yosef 2011; Holt and Formicola 2008; Maher et al. 2011). To clarify, what is meant by intensive exploitation is an increase in labour and/or capital inputs to a fixed area of land to increase or maintain production per unit of land (McClatchie 2014).

It has been hypothesized that it would have been possible to harvest wild wheat in stands comparable to a cultivated field within the Levant. During the rainy season, it has been claimed that for one hectare of land with a mixed stand of emmer wheat and barley, between 500 and 800 kilograms of grain could be produced (Flannery 1973; Harlan 1989). This translates to over 2 million calories, which is roughly the amount required to feed a family of three over a year (Flannery 1973). As mentioned earlier, the Younger Dryas would have ended such harvests (Bar-Yosef 2011). The shift in vegetal resources from plentiful to scarce first prompted groups to adopt them in a major way into their diet. Once the climate is no longer favourable, these groups are forced to develop intensification strategies. These intensification strategies, such as deliberate cultivation, selection of the most productive member of a species and the development of new tools to sow, reap and process plants, would develop into a full agricultural subsistence pattern.

2.6.3 Entanglement and Niche Construction Theory

The next school of thought relating to the transition from foraging to farming emphasizes the accumulation of knowledge, development of technology, and the environment's modification as driving forces, meaning that such lifestyle changes are conscious choices, and not made out of necessity. Grinding and pounding technologies are not created to respond to any specific external stimulus but relate to a “natural” progression of technology, allowing groups to shift their focus to different resources, such as cereals.

The entanglement theory proposed by Ian Hodder (2017) suggests that people form a dependency on the tools they make and that dependency generates the development of further technological advancements. For Hodder (2017), the neolithization process is put into motion due to a dialectical tension created by human-thing dependency. Hodder notes that while previous theories seem to regard the process of technological development to be relatively rapid, it should be viewed instead as a drawn-out, highly variable sequence of events. Hodder (2017) notes that since the Epipaleolithic, and possibly even earlier, there have been noticeable trends in the development of the body, including a reduction in stature, tooth size, and sexual dimorphism. From approximately 100,000 years ago to the end of the Pleistocene, human tooth size reduced at a rate of one percent every 2000 years, and after 10,000 BC, the rate of dental reduction doubled. It has also been noted that Upper Palaeolithic groups living before and after the Last Glacial Maximum differ significantly in craniofacial dimensions, stature, robusticity, and body proportions. While these trends are not seen worldwide, there is still a strong universal trend in the reduction of tooth size. These trends are especially relevant in the discussion of grinding and pounding technologies. It has been argued that the decrease in tooth size is due to the introduction and proliferation of pounding and grinding technologies. Hodder (2017) theorizes that this reduction is due to grinding and pounding technologies producing a much softer material and easier to chew. Grinding and pounding food is also reinforced since it improves the nutritional output.

According to this view, processing technologies are not adopted due to environmental changes promoting new inventions; rather, they flourished due to an interconnected series of human experimentation. Through natural human curiosity, new resources are discovered, which, when handled in a specific way, are easy to consume and especially nutritious. However, new tools led to the development of other technologies, such as the oven and storage containers, which further enhanced the reliance on a plant-based diet. However, this reduced human mobility as the implements used are either too large to move or took the form of immovable features. This reduced mobility created a limiting factor that pushed humans away from resources other than plants (Hodder 2017). For Hodder, there is no push of the environment or population density directing the development of these technologies. For Hodder, this development is due to a pull, the tools we made leading us down this path. Under this interpretation of internal development theory, our initial decision to experiment with wild cereals and other plant matters led us down this path. It is the role of direct human action, the way we interact with our environment, which links entanglement theory to niche construction theory.

Niche Construction Theory (NCT) is a branch of evolutionary biology that emphasizes the ability of organisms to modify their environment in a way that affects their own and other species' evolution. Some examples of NCT are animals building nests, webs, and burrows, plants modifying nutrient cycles, and bacteria fixing nutrients. NCT is first put forward within evolutionary biology by Richard Lewontin in the 1980s as a reaction against evolutionary theory that assumed that selective pressures were isolated from the organisms they were acting upon. A key component of NCT is the dependencies of co-evolution, an example of which is dam construction by beavers. As the beaver builds dams, they affect the probability of which genes for dam building will spread and affect nutrient cycling and decomposition dynamics. This influences both the water and minerals which flow downstream, which then, in turn, influences the plant composition and diversity downstream (Laland and O'Brien 2010).

As applied to archaeology and more specifically to the transition from foraging to farming, NCT provides a unique perspective as it focuses on the co-evolutionary interaction between humans and plants as a form of mutualism. Certain practices that contributed to this relationship are the selective collection of seeds, the transport and storage of seeds, the firing of grasslands, the felling of trees, tilling, and the creation of trash middens. All of these actions affect the plants, increasing their fitness, which increases the yields of the associated harvests. The increase in harvest size then promotes and encourages those cultural practices which promote plant growth (Laland and O'Brien 2010).

A benefit of NCT is that it can also explain why not all groups made the transition from foraging to farming. Under NCT, this is related to the fact that farming is expensive and intensive; hence farming will not be pursued if an easier alternative for food security is available (Laland and O'Brien 2010). This idea is eloquently summarised in Barlow (2002) "Engage in expensive Niche Construction only when you need to."

2.6.4 The Social Hypothesis

Other theories for the transition from foraging to farming involving more direct and intentional human agency can be labelled as the ‘social hypothesis,’ which claims changes in the social organization spurred on the shift towards agriculture. According to Bender (1978), for instance, while hunter-gatherer societies are largely self-sufficient and egalitarian, these societies still have people installed into some kind of authority position and have relationships and alliances with other groups. The strength of this leadership position is based on leaders' ability not to accumulate wealth for themselves but to redistribute wealth amongst their group and to develop alliances. Therefore, the power these individuals hold rests on their ability to produce, and naturally, to hold onto their power, they need to intensify their production. Additionally, if another individual in the group desires the leadership position, they will compete with the current leader and try to out-produce them (Bender 1978). It is through this power struggle, according to Bender, that we may find the reason for the development of intensification technologies.

Brian Hayden is one of the largest contributors to the social hypothesis of the transition from foraging to farming and the domestication of plants and animals. Hayden (2009) has developed what has been referred to as the feasting model of domestication, which holds that aggrandizers had used surpluses of food to transform egalitarian hunter-gatherer societies. These new societies, referred to as trans-egalitarian, had unequal economic systems and hierarchal leadership positions rooted in competitions, in which feasting is a major element. Feasting is enabled due to the development of food production, which allowed for reliable surpluses in certain ecological niches like cereal-rich environments. These technological developments included fishing technologies such as nets and fishhooks, seed gathering technologies and, most importantly for this discussion, processing technologies (Hayden 2009).

Feasting, according to Hayden, offers the host, when successful, not only benefits to their survival but also increases their chance to reproduce. The gains are achieved through the creation of both martial and marriage partners and the ability to survive food shortfalls. Due to the feasting system of status attainment, significant pressures are placed on increasing food production, especially foods that are thought to be luxurious (Hayden 2009). Two foods associated with feasts have received the most attention: bread and beer. It has been suggested that the desire to acquire these is the driving force behind the domestication of cereals in the Levant (Hayden et al. 2013; Liu et al. 2018). Evidence for the brewing of beer within the Levant by the Natufians comes to us from Raqafet Cave dating between 13,700 and 11,700 B.P., where large stone mortars are found to have been used to pound and cook food which included both wheat and barley-based beers (Liu et al. 2018).

2.7 Diet Choice and the Development of Farming through the Prism of Foraging Theory

Foraging theory is reviewed in this section. This broader theoretical approach related to food choices appears particularly relevant to exploring the processes that let past societies transition from foraging to farming. Foraging Theory provides well-grounded reasoning to explore food choices. It can be connected to the broad-spectrum revolution hypothesis discussed above, further explored here, as the BSR attempts to explain why groups had adopted low-ranked foods into their diets. Food ranking is an important concept we will be reviewing here. Finally, this section will address the concepts and methods of intensification as these are key to the BSR.

2.7.1 Definition and a Brief History of Research

Foraging Theory was originally proposed in 1966 by R. H. MacArthur and E. R. Pianka in their article, “On Optimal Use of a Patchy Environment”. The authors sought to determine which patches of resources a species would feed on and which items would form their diet if the species acted most economically. This is investigated to explore the perspective that natural selection would have reached an optimal usage of both time and energy. MacArthur and Pianka considered that an activity should be reinforced as long as the increased time spent per calorie exceeds the associated loss of energy. They also stated that the option should not be pursued if further enlargement results in a greater loss than gain. They claimed that we should find which components of a time or energy budget increase and which decrease as certain activities are enlarged. MacArthur and Pianka sought to create an equation to measure efficiency and to do so used two components to represent the time spent per item eaten. These two components are searching time and handling time. Searching time is the time it took to find the food item, and handling time is the time for the pursuit, capture, and consumption of the food item. This equation had allowed MacArthur and Pianka to measure the optimality of diet by measuring the energy expended in the pursuit for food by the energy gained by the capture of prey (MacArthur and Pianka 1966). MacArthur and Pianka had envisioned this model to be applied to predators in a wild environment and is concerned strictly with diet; however, over time, researchers in other fields, such as those concerned with human behaviour, would modify them to better suit their research objectives.

Stephen Shennan, an archaeologist, had taken the ideas outlined by MacArthur and Pianka and applied them holistically to human behaviour, as outlined in his book, "Genes, Memes and Human History" (2002). Shennan emphasizes the concept of optimization, which he claims to be the key principle behind Foraging Theory. Optimization assumes that individuals will relate to their environments in ways that will maximize their reproductive success (Shennan 2002). This differs from the foraging theory as outlined by MacArthur and Pianka, as rather than focusing solely on the search for food, the gain, and expenditure of energy, Shennan seeks to expand it to incorporate reproductive success more directly. To him, reproductive success does not imply that humans will seek to have as many offspring as possible. Rather, they will strive to have as many offspring that are reproductively successful themselves, which can often mean having fewer children (Shennan 2002).

The concept of optimization is most applicable to human beings in terms of their foraging habits. This is done by assuming that the foraging strategies that will be most effective in terms of fitness will be those that provide the maximum amount of energy for the smallest amount of effort. There are many ways in which this strategy can increase an individual's fitness, such as providing more time for social interactions and parenting (Shennan 2002). One model used to explore this behaviour further is the diet breadth model of Foraging Theory. According to the diet breadth model, the exploited resources are not necessarily those that are most widely available but those that provide the best return. The return for resources is broken up into two different components: 1) the time taken to find the prey and 2) the handling costs when it has been found and is measured against the calories gained. The search time for resources is influenced by the resource's density and, most importantly for this thesis, the technology involved. Likewise, handling times are also affected by the available technology (Shennan 2002; Hawkes and O'Connell 1992; Gremillion 2004).

2.7.2 The Ranking of Resources

Oftentimes, groups such as hunter-gatherers will rank resources in terms of their returns, and the highest return diet will only incorporate a small number of the highest return resources (Shennan 2002; Janz 2016; Hawkes and O'Connell 1992). Resources can be ranked by benefits gained from consumption relative to handling costs, like that outlined by MacArthur and Pianka (1966). As we have established earlier, theoretically, foraging groups will want to optimize the rate of return and, therefore, will theoretically stop searching once they encounter a high-ranked resource such as a deer or other similarly sized mammals. Groups will likely only utilize lower-ranked resources, such as cereals and legumes, when they fail to encounter higher-ranked resources. The type of food source is not the only variable in this equation, as there are two factors outside of technology that can alter the selection process. As the population of hunter-gatherers increases in density, those high-ranking food sources that are preferred are bound to be depleted over time as they are over-harvested, which will cause the group to focus on lower-ranked foods. In addition to this, as more kinds of resources are added to the diet, search time will decline and eventually reach a point where almost all of the foraging time is dedicated to resource handling rather than searching (Hawkes and O'Connell 1992). An advantage in increasing handling time and decreasing search time is that advances in food processing technologies can have clear-cut effects. Suppose we apply Foraging Theory to plant cultivation as an example. In that case, any advancements that influence the return rate of the plant, such as seed selection or processing technologies, will make a much larger difference in return rates.

As mentioned earlier, under the diet breadth model, the exploited resources are those that provide the best return. That return is determined by the time taken to find the food item and the handling costs. Plant matter has often been considered a low-rank food item. We must clarify what makes something low-ranked. Generally speaking, based on empirical studies of hunter-gatherer groups, low-ranked foods are either challenging to catch (such as hares) or difficult to process, like nuts and seeds (Winterhalder and Smith 2000). An assumption often made when it comes to prey ranking is that a larger animal will always be more valued than a smaller one; however, this has been found to not be the case universally and points us to the fact that prey ranking needs to be done on a case-by-case basis (Janz 2016).

What then about cereals and other plant materials? Without being able to study groups directly, we are forced to use either indirect physical evidence, the amount of an assemblage made up of plant material or an ethnographic analog. However, it is also possible to make conjectures based on the nutritional facts of a particular plant. To that end, information relating to certain cereals and legumes will be given within the methods section. Turning our gaze to North America, we can see through a combination of ethnographic, experimental, and nutritional studies that the small grains consumed within that region had offered low rates of return, as measured by energy per unit of time spent (Gremillion 2004). While the seeds used in North America and the Levant are different, they have an important similarity relevant for this thesis: both are difficult to process. The seeds need to be processed to remove the indigestible outer shells.

As this thesis focuses on grinding technologies, the most important aspect of Foraging Theory is how technological innovations can impact the return rates of food items and affect food ranking. As mentioned earlier, in places where the diet is broad, the handling time will make up most of the foraging effort. In such contexts, introducing a new technology that reduces the handling time will have pronounced effects. In some cases, it can be seen that foraging groups may attempt to eliminate search time, and that is when innovations will have their greatest effects. Hawkes and O'Connell (1992) go so far as to say that for such groups, technological developments which reduce search time will be the only way to achieve higher food acquisition rates. With these ideas now outlined, we will shift our attention to the specifics of the broad-spectrum revolution hypothesis.

2.8 Groundstone Tools, Intensification and Processing

In this section, I will outline the concept of resource intensification and the methods of intensification that often enable lower-ranked foods such as seeds and nuts (Gremillion 2004; Winterhalder and Smith 2000) to become a prominent part of people's diets.

Resource intensification involves increased extraction of food resources per unit of land and comes with a cost, either an increase in labour or investment in new technology (Buonasera 2015; Elston et al. 2011; Wright 2014). Two types of intensification occur, an increased amount of effort in collecting a particular resource, which is called specialization, or the broadening of the diet to include lower-ranked food resources, known as diversification (Elston et al. 2011). I focus here on intensification that includes a broadening of the diet.

As mentioned earlier, lower-ranked food can move up in the ranks according to changes in technology. While grinding tools, in some form, would have been present before the transition from foraging to farming in areas where wild seeds and nuts are available, it is not until those foods are relied on more heavily that an increased amount of effort went into producing a larger number of tools (Dubreuil and Nadel 2015). This investment into tool manufacture would have increased the return rates; otherwise, groups would not have made them such an important part of their subsistence toolkit. But how would groups using these resources have improved their tools to make these food sources more profitable?

Early on in the use of grinding tools, it is likely they would have been expedient, meaning that effort is not put into their construction, and any alterations to the surface would have been made through their use. However, the efficiency of a grinding tool can be improved through several different alterations (Adams 2013). Some of the techniques found to improve the use of a tool include: pecking to remove high points on the surface to maximize contact between the upper and lower grinding implements; pecking to create a rougher surface and a shallow depression to help keep the ground material on the surface and to increase the area of the grinding surface (Buonasera 2015). However, investment in tool manufacture is not the only method groups can use to increase the return rate of plants as preparing them by roasting and fermentation, also resulting in changing properties of the end product (Stahl 1989).

While we have touched on the fact that GSTs can improve the standing of low-ranked food products, we have yet to explain how they do so. There are four important functions milling/ grinding tools have. Firstly, grinding and pounding tools remove the indigestible parts, which is important as in the case of the Middle East, the nutrients located within the seeds are encased within fibrous indigestible husks, which need to be removed before being eaten (Wright 1994). Secondly, they reduce the particle sizes, which is important as it has been shown that this can increase the nutritional uptake, improving the cost-benefit ratio of the food (Wright 1994; Piperno et al. 2004; Dubreuil 2004; Wollstonecroft et al. 2008; Dubreuil and Goring-Morris in press). In addition, grinding plant matter into a “flour” like substance increases the “volume” of matter even though the weight stays the same. Thirdly, these tools can aid in detoxification. Many different plant materials, if ingested in large quantities unaltered, can have toxic effects. However, there are several ways to counter this, such as pre-treating the material, soaking or roasting, for example, or incising the grinding surface both longitudinally and transversely, which is said to facilitate the release of poisonous juices from plants (Wright 1994; Kraybill 1977). Finally, milling tools can also add or remove nutrients (Wright 1994; Dubreuil and Goring-Morris in press).

The question is, however, when does it pay off to invest more time making tools to intensify the production of plant-based foods rather than just devoting more time to processing with what you have? In her article “Modeling the Costs and Benefits of Manufacturing Expedient Milling Tools,” Tammy Buonasera (2015) outlines a model that predicts the minimum number of times a tool needs to be used to profit from the time spent manufacturing it. The model Bonasera uses in her article is a modification of Bettinger’s point estimate model (Bettinger et al. 2006), which itself is an adaptation of the optimality model, which compares rates of return with additional investments of time. The point-estimate model assumes that each category of technology has its own cost-benefit curve and plots the returns associated with each specific technology as discrete points rather than as a part of the same function. This model enables the comparison of different tools used to reach the same end, allowing us to compare the effectiveness of an unmodified versus an intentionally shaped grinding stone, for example. Buonasera used the modified point estimate model to compare gains in grinding efficiency with the cost of manufacturing an improved grinding surface. This study shows that the pre-shaping of seed-grinding tools can have a significant impact on productivity. A positive linear relationship is found between the rate of flour production and increasing the surface. Buonasera (2015) states that just a few hours of grinding would make it worthwhile to manufacture a grinding surface and that manufacturing a shallow basin in material like sandstone would be preferable to using an un-shaped one if more than 1.6 hours of grinding can be anticipated (Buonasera 2015).

What is important to note about Buonasera’s conclusion is the qualifier expected. While more expedient grinding stones were used before the transition from foraging to farming, the foods they were used to process were not meant to replace the higher-ranked foods but rather supplement them. It seems then that considering the low amount of time required to increase the efficiency of grinding surfaces, the biggest factor working against the adoption of a diet plant-based diet is the availability of food with a higher return rate.

The issues surrounding returns rates and productivity will be discussed further in the fifth chapter within section 5.7, where a comparison between the return rates of my experiments and two other studies is presented. Within this section the influence of tool size as well as pre-treatment and their abilities to enhance the productivity of tools is highlighted.

2.9 Chapter Summary

In this chapter, we have covered several changes in the Levant, including climate changes, changes in subsistence and changes in tools. Among these changes, there appears to be a trend of increasing the use of plant materials and specialized tools. Likewise, in this chapter, I have covered several theories which have sought to explain the relationship between these changes and the transition from foraging to farming. Some theories emphasize demographics, the relationship between population density and an area's carrying capacity. Others emphasize the availability of certain food resources and how groups sought to overcome a decline in productivity. Some theories emphasize how new technologies can influence the further development of tools and social structure, and others look at how organisms alter an environment that then, in turn, alters them. Finally, others look at how internal group dynamics can direct changes.

What all these theories have in common is that changes in subsistence are a key part of them; changes in the amount of plant material and changes in the handling of those materials. By utilizing Foraging Theory to understand and explain the decision-making process in regards to food, we can shed light on the key aspects behind these theories. Foraging Theory gives us a way to explain what food sources would have been more valued than others and how those food sources could be improved. However, as few macro botanical remains have been recovered, if we want direct evidence of what plants were exploited and how they were processed, we must turn to the tools used to do so. By studying these tools, we have the opportunity to learn what materials were processed and the mechanics behind that processing.

The focus will shift from a theoretical understanding of the transition from foraging to farming to studying the tools involved in the following chapters. In this perspective, the next chapter will focus on use-wear analysis and how it can help to unravel how GSTs were used.

Chapter 3: Methodology: Use-Wear Analysis, Residues & Experimental Approach

Introduction

Studies interested in exploring the specific functions of archaeological tools (i.e., what specific materials they were used to work and kinematics) employ use-wear and often residue analysis. This chapter will cover the foundation of use-wear and residue analysis and the experimental protocol used in this thesis. As such, the chapter will be broken into two parts: 1) in the first section, I will be covering mechanisms of wear and wear traces, Natufian tool designation and design, residue analysis and the importance of blind tests; 2) in the second section, I will be covering the building of my experimental collection, how the tools were analyzed, how the images of surfaces were captured, how the 3D models were created, residue analyses were performed and the structure of blind tests.

3.1 Tribology

All use-wear approaches find their basis within tribology, which is the science of interacting surfaces, investigating friction, wear and lubrication (Ciulli 2019; Jian-Yan 2018). Peter Jost first coined the term “tribology” in a report now commonly referred to as the “Jost Report” in 1966 (Ciulli 2019; Jost 1966). Still, various central concepts of tribological science, such as reducing friction by using lubricants, have been documented as far back as ancient Egypt, where artwork depicts the use of lubrication in the transportation of stone colossuses. (Ciulli 2019). Tribology is highly interdisciplinary and involves fields such as physics, mathematics, chemistry, material sciences and engineering and, as a result, connects both basic and applied sciences (Ciulli 2019). As this field covers the interactions between surfaces and is concerned with, for a large part, the wear that results from these interactions, it is no surprise that many archaeologists have utilized its concepts in their study of ancient tools.

Within a tribological context, wear has been defined as a continuous damage process of surfaces that are in contact with relative movement (Shizu and Ping 2012) and comprises four main types of wear formation (Adams et al. 2009). These four processes are abrasion, adhesion, fatigue and tribochemical wear (Adams 2013; Adams et al. 2009). Each of these processes has many different markers associated with them, which with proper identification allows the analyst to elucidate which actions were acting upon the surface studied. It is important to have a firm understanding of each of these categories when trying to understand use-wear formation. Here we will go into each category, describing how they form and their associated wear traces.

3.2 Mechanisms of Wear and Wear Traces

The wear mechanisms, along with their formation process, associated traces, and descriptive criteria, are outlined below in Table 3.1. Under that table, certain key definitions and concepts important to understanding use-wear analysis are briefly explained. Some of the terms are general in that they apply to multiple wear traces, and some of the terms are specific in that they apply to only one wear trace. A recap of the descriptive criteria of wear traces will be given later on in the chapter (Table 3.2). The information in Table 3.2 comes from the articles “Functional Analysis of Macro-Lithic Artifacts: A Focus on Working Surfaces” (Adams et al. 2009) and “Current Analytical Frameworks for Studies of Use–Wear on Ground Stone Tools” (Dubreuil et al. 2015).

Mechanism of Wear	Formation	Associated Wear Traces	Wear Trace Descriptive Criteria
Abrasive Wear	Movement of a harder or more durable surface across a softer, less durable one.	Linear Traces	Distribution, Density, Incidence, Disposition, Orientation, Width, Length, Longitudinal Morphology, and Transverse Morphology.
		Levelling	Distribution, Density, Incidence, Morphology, and Texture.
		Grain Edge Rounding	Distribution, Density and Incidence
Fatigue Wear	Pressure acting upon a surface, causing the highest elevations to crumble.	Fractures	Distribution, Density, Orientation, Depth, Shape in Plan, Shape in Cross-Section.
		Pitting	Distribution, Density, Orientation, Depth, Shape in Plan, Shape in Cross-Section.
Tribochemical Wear	Chemical reactions caused by the other wear mechanisms.	Polish/Sheen.	Distribution, Density, Incidence, and Reflectivity.
		Micro-polish	Localization, Distribution, Density, Microtopographic Context, Morphology in Cross-Section, Texture, Contours, Structure, Special Features, Vertical Extension, Opacity, and Brightness
Adhesive Wear	Surfaces coming into contact with one another, forming bonds and then moving apart.	Residue	Distribution, Density, Depth, and Reflectivity.

Table 3.1: Wear mechanisms, how they form, their associated traces and how those traces are defined. From Adams et al. 2009 and Dubreuil et al. 2015.

Distribution: Described as either loose, covered or concentrated and refers to the presence of a wear trace on the active surface; Figure 3.1 provides an example of each. When referring to the distribution of micro-polish, the only difference is that it is based on how it appeared at 50× magnification.

Density: Described as either separated, close or connected and refers to how close the different trace instances are to one another.

Incidence: Refers to the depth of wear trace and is described as either shallow or deep or as being on the surface's high topography or low topography, depending on the wear marker being described.

Orientation: Refers to trace's spatial relationship with the major axis of the surface and is described as either longitudinal, transversal or oblique.

Disposition: Refers to the spatial relationship between wear traces and is described as either random, concentric, parallel, oblique or perpendicular.

Morphology: This can be reported generally, in cross-section and plan view, depending on the specific trace being analyzed. The general morphology of wear is described as either described as flat, sinuous or rounded. The longitudinal morphology refers to whether the linear trace is continuous or intermittent, and the transverse morphology is described as either being U-shaped or V-shaped. When describing the morphology of micro-polish, it is reported as either being irregular, domed or flat.

Texture: Refers to the surface of a levelled area; described as either smooth or rough. When referring to the texture of micro-polish, it is described as being rough, smooth or fluid.

Depth: Described in terms such as fine or superficial and wide or deep.

Pit Shape in Plan View: Described as irregular, circular, triangular, starlike or comet-shaped.

Microtopographic Context: Refers to its position on the surface, both regarding whether it is found on the high or low topography and whether it is found on features like abraded, rounded or levelled areas.

Contours: Refers to the edges of a micro-polish patch; described as either sharp or diffuse.

Structure: Refers to variation within a “patch” of micro-polish. This is observed as levels over 50× and is described as either separated, close or connected.

Presence of Special Features: Refers to whether any striations, pits or other irregularities are found within the micro-polish.

Width: Refers to the size of a linear trace; if it is under 0.5mm wide, it is described as a striation, and if it is over 0.5mm, it is described as a scratch. This classification is done at low levels of magnification.

Length: Refers to the extension of a linear trace across the surface of the tool. The linear trace is either short if it fails to cross the entire working surface or long if it does. This classification is done at low levels of magnification.

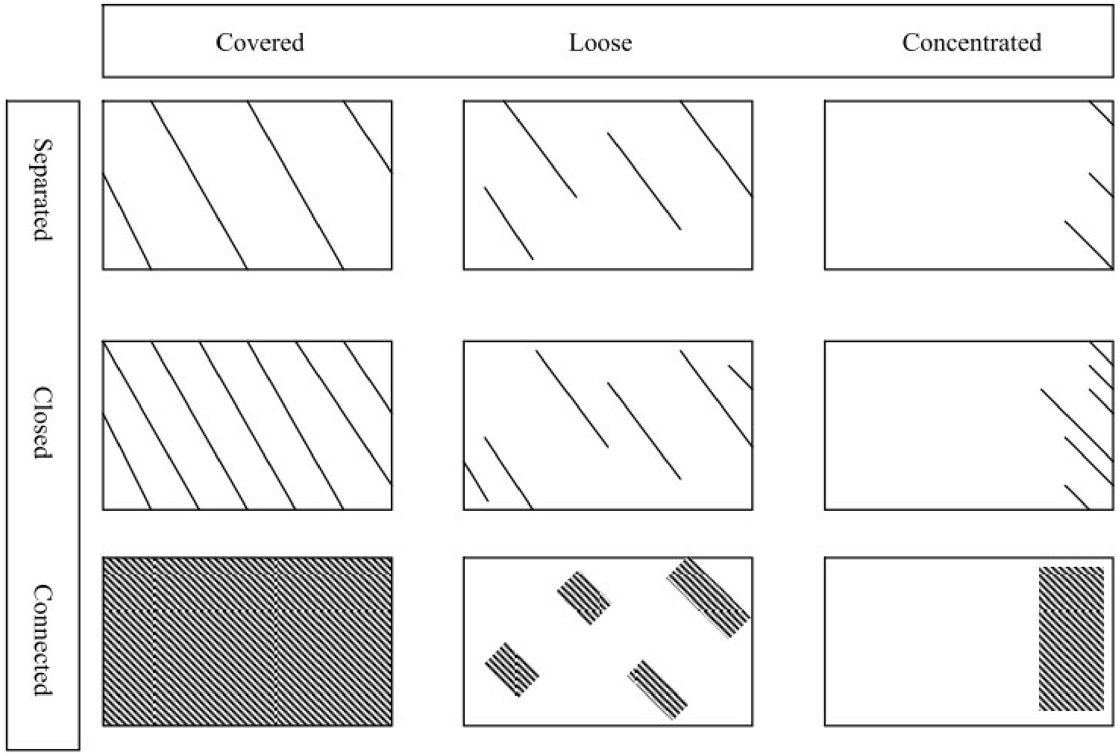


Figure 3.1: Representation of descriptive criteria for distribution and density of wear traces. From Adams et al. 2009, Fig. 6.5

3.3 Residue Analysis

The best functional hypotheses are those drawn from multiple lines of evidence, and as such, many studies on tool use employ multiple approaches. In conjunction with the characterization and explanation of the wear traces found on the surface, many studies include residue and phytolith analysis. While residue analysis has developed significantly since it entered the modern era with Thornton et al.'s 1970 paper *The Composition of Bog Butter*, not all artifact types have provided significant results. Stone artifacts have generally provided disappointing results when tested from organic residues, except when surface deposits are present (Evershed 2008). An important aspect of residue preservation is the porosity of the matrix of the raw materials. Many GSTs, especially those from the Levant, are made of basalt, which is often porous; and it has been suggested that artifacts such as grinding slabs, querns and storage containers might be good candidates for residue analysis (Evershed 2008). Within this section, we will cover two kinds of residue analysis: phytolith analysis and starch analysis.

The complementary nature of use-wear and residue analysis has been noted within many studies, with authors citing the ability of residue analysis to make up for the shortcomings of use-wear analysis and vice-versa. A good example of this is found within a study performed by Rots and Williamson (2004). In their article *Microwear and Residue Analysis in Perspective: The Contribution of Ethnoarchaeological Evidence,* they show that while use-wear analysis has been largely unable to determine the exact material processed with a tool, this is something residue analysis can do. Likewise, while residue analysis can largely determine the last material processed, it is unable to provide an insight into the life history of the tool, identify the active areas of the surface and the kinematics behind tool use, which use-wear analysis can do (Rots and Williamson 2004).

The most productive forms of residue analysis for GSTs are phytolith and starch analysis. Phytoliths are often present in contexts where other plant remains fail to survive, as they do not need to be charred or waterlogged to be preserved as they are minerals. Phytoliths are opaline silica deposits that form within and between the cells of some plants, making a "cast" of the space they occupy. They are formed when a plant absorbs silica in a soluble form through groundwater. It is assumed that they provide structural support and protection from herbivores; however, their role and variability are still poorly understood (Shillito 2013).

Since the 1970s, phytolith research has expanded greatly and has become an essential tool in studying past plant use (Zurro 2018). It isn't until the publication of the *International Code for Phytolith Nomenclature* in 2005 by Madella, Alexandre and Ball that a standardized method for phytolith classification is attempted (Shillito 2013). Despite this effort, however, there is still a lack of standardization in some areas, such as sampling, counting procedures and interpretation criteria. They have not received as much attention compared to aspects like creating reference collections and laboratory procedures (Zurro 2018). For this analysis, however, we will only be performing a starch analysis. The reason being for this is because when performing the residue analysis, the starches were much more abundant and easier to identify.

3.4 Starch Analysis

Starch analysis is incorporated into this study, specifically to track the distribution of starch on the tool's surface. Identifying starch to a specific plant species has become an increasingly important aspect of studies related to ancient subsistence patterns. As such, it will be important for us to understand the mechanics behind it. Starch grains are produced by green plants to store carbohydrates and can be found in many different plant tissues. The carbohydrates of specific interest to archaeology are the amyloplasts intended for long-term storage of carbohydrates and are most often found within seeds. Specific features have been noted as important for identifying starch to a specific plant in some starch grains. Some of these features include fissures, undulations on the surface, and the formations of facets. When viewed on a glass slide and placed within an appropriate mount, such as a water-glycerol mix, referencing a collection of previously identified starches makes it possible to relate the starch to a specific plant (Coster and Field 2015).

While starch analysis has proved to be a vital tool in exploring prehistoric plant use, there are three fundamental challenges in starch research that need to be kept in mind. These are the unexplained preservation at the millennial-scale of an easily decomposable molecule, the influence of laboratory contamination on false positives and the ambiguous taxonomic identification inherent to small polygenic assemblages. In addition to these problems, starch researchers do not have comprehensive, openly accessible, quantitative baselines to reconstruct the background which frames the archaeological excavation from which samples under analysis are retrieved (Mercader et al. 2007).

Starch contamination is a prevalent issue in residue analysis, leading to a lack of confidence in the determination of worked materials (Mercader et al. 2007). As the experiments carried out here involved multiple working surfaces on the same tool, this presents an opportunity to investigate cross-contamination of the various use surfaces. Investigating the proportion of starch present in different areas of the tool will allow us to assess the effects of cross-contamination. As the experiments all took place in a non-clean environment, we can examine the effects of environmental contamination. Some of the questions explored here are to what extent the starch of the matter processed is more or less prevalent on different surfaces and if the active surfaces have less mixed types than the intermediary section between the two surfaces.

Our analysis protocol encompasses a comparison of two samples taken from the center of the active surface used to grind wheat and the active surface used to grind lentils. This will allow us to measure the ratios of the different starches and see how much overlap and interference are present. While the grinding experiments and the storage of the tools did not take place in a "clean" lab, I do not suspect this will substantially influence the comparison. As I am working with tools with a known use and I seek to find out how these uses affected the opposing surface, any contamination from other sources should be easy to recognize. However, as this lab is a shared space, there is the possibility of contamination from experiments others who used the space were performing.

The materials used for this analysis were a pipette, de-ionized water, toothbrush, saucer, vials, glass slides and a mounting material (roughly 50 percent water and 50 percent glycerol). The steps taken to retrieve the residue samples during my analysis are as follows: the tools were used for an additional 30 minutes of grinding, and three testing locations were chosen: one on the center of each active surface and one on the boundary between the two sides. A pipette was then used to place de-ionized water on the selected areas of the tool, and each spot was scrubbed. After scrubbing for approximately two minutes, the pipette extracted some of the now dirty water from the surface and transferred it to a vial.

After the samples had settled, the heavy fraction of the solution was removed and mounted onto a slide. This was done by carefully removing as much water as possible with a pipette and then extracting the remaining heavy fraction. For both samples, roughly 0.125 ml was extracted. This isolated heavy fraction was then mixed with glycerol, about 0.125 ml. Once the solution was mixed, it was transferred to the slide, where a coverslip was placed and sealed.

Once the samples for the two surfaces were prepared, they had a one-square-cm section marked on the surface. This area was chosen by finding the slide section with the least issues as there were some complications during the mounting process. Following this, they were then examined under a polarized light microscope. The analysis of the surface and the identification of starches were conducted at 200× magnification. When necessary, starches were examined at 400× magnification if it was unclear whether they were starches.

For the starch analysis, I had performed a comparison between the starches observed on each slide; comparing the number, shape, size and the amount of extinction crosses visible. Starches were described as being circular, ovular, doughnut shaped, irregular, clustered or broken. This is a preliminary comparison and more should be done to reinforce and interpret the results, such as making better use of a reference collection and using more standardized terminology for shape recognition. While I had made and used a reference collection for the starches, I was observing I had used it more as a tool to help identify starches generally than to make specific determinations. I referenced the article “Starch – Composition, fine structure and architecture” (Tester et al. 2004) for a general overview of the properties of starch as well as separate studies dedicated to different materials (Okumus et al. 2016; Shevkani et al. 2016; Zhu 2017). Despite this however I still had difficulties determining particular starches.

3.5 Importance of Blind Tests

As use-wear analysis is based on experimental research, both replicating and corroborating results are necessary if we want to have confidence in our interpretations. As how we identify and describe wear traces is informed by our descriptive criteria, they must hold up to scrutiny. This is vital not only to ensure that they are used correctly but also to ensure that the descriptive criteria used are widely applicable and understood. Blind tests have proved to be a significant contributor to the methodological development of use-wear analysis since the earliest tests were conducted in the 1970s and 1980s on flaked tools. However, only two have been published on GSTs (Hamon and Plisson 2008; Hayes et al. 2016). We will cover one of these briefly as it served to inform the construction of my blind test.

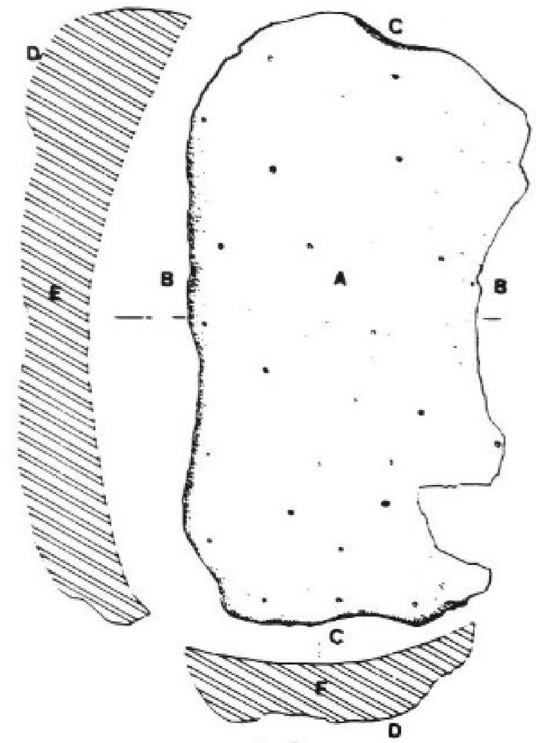
Hamon and Plisson (2008) emphasize that most archaeological reasoning is based on comparing past remains with contemporary models. The authors remark that the safer conclusions to make within archaeology are not dependent on cultural arbitrations but those that are based on physical remains. Conclusions that are largely based on physical materials and that are concerned with fundamental aspects of human behaviour, such as subsistence and tool use, are more straightforward and require fewer leaps of logic. For this reason, Plisson and Hamon claim that technological studies are so common within archaeology (Hamon and Plisson 2008). It is within this category that use-wear analysis falls. Because use-wear analysis depends so heavily on the analysts' ability to recognize and interpret wear patterns and make and use tools, blind-tests have played such an important role in its development. Having another analyst observe the tool and provide a second opinion on the wear, the tool type and active surfaces allows use-wear analysis to reinforce the replicability of the results.

Since the landmark 1977 blind test performed by Keeley and Newcomer demonstrated the limitations of use-wear analysis, many other similar tests have been performed (Hamon and Plisson 2008). However, the issue with the literature on blind testing is that these tests and the methodology they employed were focused not on GSTs but on tools with cutting edges. This lack of testing specific to GSTs is the issue Hamon and Plisson sought to remedy. While the blind test performed for this thesis varies significantly from Hamon and Plisson's, what I have designed is inspired by their study. Hamon and Plission tested the analysts' ability to determine the location, extent, intensity and aspect of use-wear and striations and the recognition of possible active zones, the type of tool, kinematics and the transformed matter. This compares to my protocol, where I opted to test the replicability of my descriptive protocol and use-wear descriptions by asking another use-wear analyst to use my framework to describe the experimental tools I produced. This analyst is not tasked with identifying the processed materials, only to describe the wear on each tool.

3.6 Natufian Groundstone Typology

While we have discussed GSTs in the previous chapter, it was done in a more generalized sense without an eye for the design and use of the implements. In terms of the Natufian tool industry, one of the most prolific writers on the subject is Katherine Wright. I have used her classification system created in 1992 to create the tools used in my experiments. Wright's classification system is outlined in "A Classification System for Ground Stone Tools from the Prehistoric Levant". It was created partly due to a lack of consistent terminology in GST analysis impeding studies (Wright 1992). While some elements have been superseded, it provides a well-articulated blueprint not only for how each tool variation had its surface shaped but also how the tool's designs changed over time.

As this thesis is concerned with grinding implements, I will be limiting the discussion in this section to grinding slabs and handstones. Wright's typology identified six different parts of a grinding stone, seen in Figure 3.2, which shows an edited version of Wright 1992 Figure 2.



(a) Grinding Slab :
A = Face (Use Surface)
B = Lateral Side
C = End
D = Dorsal Side (if unifacial)
= Face (if bifacial)
E = Longitudinal Section
F = Transverse Section

(c) Handstone :
A = Face (Use Surface)
B = Lateral Side
C = End
D = Dorsal Side (if unifacial)
= Face (if bifacial)
E = Longitudinal Section
F = Transverse Section

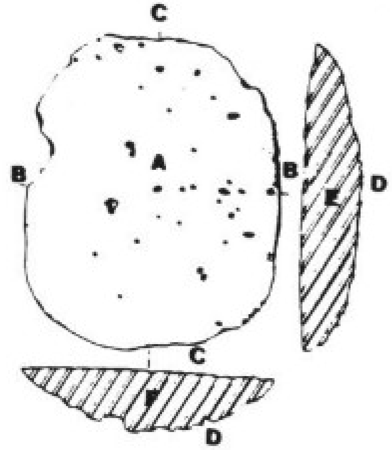


Figure 3.2: Labelled illustrations of a handstone and a grinding stone, showing the different aspects of each. From Wright 1992, Fig. 2

Wright describes a grinding slab and quern as a lower stationary stone in a pair of grinding tools. The difference between the slab and quern is that querns have an oval-shaped use surface, which is used in a rotary grinding motion, and slabs have a rectangular use surface, which is used with a linear grinding motion. Handstones, according to Wright, are the upper mobile stones in the pair of grinding tools and are made from either a flake, core or unmodified cobble. The used surface of these tools are broad and cover large areas of the tool, and, importantly, lack evidence of pounding (Wright 1992). In her typology, Wright identified 14 different grinding slabs/querns, made of six main types, each of them having two variations. For handstones, there are a total of 40 different types, which mostly fall into four different types with eight variations each.

The six main types of grinding stones Wright outlines in her typology are block, boulder, saddle-shaped, trough, basin and hollowed; each having a slab and quern variant, which is either unifacial, bifacial or multi-facial. Of these types outlined by Wright, I have chosen to base my tools off of the block grinding slab tool type. The block grinding slab is described by Wright as a largely unmodified tabular-stone boulder with a naturally stable base and a use surface that is unifacial, rectangular in plan, u-shaped in section, and closed, meaning it is surrounded in all sides. Finally, this tool type features no other modification other than the creation of the working surface.

However, it is important to note that the distinction between grinding slabs and querns is quite theoretical and is quite difficult to apply as issues such as fragmentation leave the tools incomplete and difficulties with identifying striations, which makes it difficult to determine the use of the tool. At sites such as ‘Ain Mallaha, though, there have been a high number of flat implements which function as a proxy for the block grinding slab (Dubreuil 2002; Dubreuil 2008).

There are 40 different types of handstones, which mostly fall into four different types with eight variations each. The handstones I have created to use in my experiments are unifacial ovates which, according to Wright, are handstones with an ovate shape in plan view and a singular use surface (Wright 1992).

3.7 Experimental Tool Manufacture

The tools used in this experiment are all made of a singular material: basalt. The choice of this material is due to the prevalence of basaltic rocks being used within the Southern Levant, as exemplified by sites such as ‘Ain Mallaha (Dubreuil 2004) and Wadi Hammeh 27 (Edwards 2013; Edwards and Webb 2013). Basalts register as a six on the Mohs hardness scale (Wright 1992) and, if vesicular, has a natural, durable roughness that limits the need for re-pecking after grinding. Additionally, the grits on these surfaces are not easily detached, which gives the tool a long use life (Wright 1992; Ebeling & Rowan 2004; Adams 2013).

The experimental tools were all manufactured through pecking on both sides of the basalt slab, resulting in two working surfaces per tool. I had done this to maximize the use of every piece of basalt available to me. The material used to manufacture these tools was a hard limestone hammerstone. The pecking of the surface was done at an angle to create a step, which enabled the second half of the worked surface to be easily altered. While the tools themselves all meet the criteria for a block grinding slab, one area where they differ slightly from those described by Wright is in the shape of their use surface, which is not strictly rectangular (Wright 1992). The reason for this is that the pieces of basalt I used to make the tools were uneven in shape, and I often had to make concessions for a useable working surface. Handstones were constructed in the same manner, built to match the surface of the grinding slabs. The difference was that only one side of the basalt was pecked as the contact with the hand would interfere with the wear development.

Both before the manufacture of the surfaces and after, I cleaned the tool to remove any loose debris resulting from the pecking and observed them under the microscope. This was done to familiarize me with the properties of the basalt but also to understand the wear associated with the manufacturing process. This understanding would allow me to differentiate what wear was formed before manufacture, due to manufacture, and what was use-related.

Tool	Side	Manufcature Method	Manufacture Time	Ground Substance	Pre-treatment	Kinematics	Grinding time
Netherstone 1	Side A	Pecking	Approx. 2 hours	Pot Barley	None	Flat strokes	5 Hours
	Side B	Pecking	Approx. 2 hours	Hard Wheat Kernels	None	Flat strokes	5 Hours
Netherstone 2	Side A	Pecking	Approx. 2 hours	Fenugreek	None	Flat strokes with intial downward thrust	5 Hours
	Side B	Pecking	Approx. 2 hours	Brown Lentils	None	Flat Strokes with intial downward thrust	5 Hours
Netherstone 3	Side A	Pecking	Approx. 2 hours	Fenugreek	Rinsing/Soaking	Flat Strokes	5 Hours
	Side B	Pecking	Approx. 2 hours	Hard Wheat Kernels	Roasting	Flat Strokes	5 Hours

Table 3.2: Manufacture and use of experimental tools

<u>3.8 Choices of Processed Materials</u>

Considerable importance has been given to cereals when researching the transition from foraging to farming, specifically the making of bread or beer (Hayden et al. 2013). However, the rise of farming communities in the Levant is associated with a diversity of dietary and food practices (Fuller et al. 2011; Asouti and Fuller 2013; Caracuta et al. 2015; Munro et al. 2018; Dubreuil and Goring-Morris in press). In the Southern Levant, previous analysis of the tools used to process plants also tend to support the hypothesis of a diversity of food practices during the transition from foraging to farming (Dubreuil 2004; Dubreuil 2002; Dubreuil and Goring-Morris in press). Ain' Mallaha is a major Natufian site dated to the end of the Epipaleolithic (Perrot et al. 1988; Valla 1984; Valla et al. 1999; Valla et al. 2001; Valla et al. 2004; Valla et al. 2007; Valla et al. 2010; Samuelian et al. 2006; Samuelian 2013) which has yielded a substantial sample of GSTs (Dubreuil 2002, 2004).

For this experiment, various cereals and legumes were chosen to be processed, which aim to represent part of the diversity of food practices during the transition from foraging to farming. The species chosen for the cereal category are wheat and barley, and those representing the legumes are fenugreek and lentils. These materials were chosen as they either have a geographical connection to the Levant, a cultural connection to the Natufians and their successors, have been used in previous use-wear studies (Dubreuil 2004), or represent an end product that has not received much attention. Since the diversity in food practices extends beyond material choice, the end goals for the food products need to be considered.

Within this section, I will provide details regarding the specific nature of each of the plants to showcase why studying them is important and provide relevant background information. Much of the information for this section comes from the website 'plants for a future', as it provided information regarding the productivity and growth of the plants and other relevant information such as any poisonous effects or medicinal benefits.

3.8.1 Fenugreek (*Trigonella foenum-graecum*)

Beginning with the legume family, the most important thing to note is that the seeds of this plant contain one percent saponins that, while poisonous, are poorly absorbed by the human body. This means that while it can be fatal if a large amount is eaten, it is not likely that these seeds would have caused any harm (Plants for a Future 2018 A). These poisons can be removed by leaching either the seed or the flour made from it in running water. There are some uses for the poisons found within. Hunter-gatherer groups have been found putting a large amount of them in bodies of water to either stupefy or outright kill the fish living within them (Plants for a Future 2018 A). Fenugreek has been found growing in field verges, uncultivated ground, dry grasslands and on hillsides. The seeds of fenugreek can be eaten cooked or raw and, when ground into a powder, is the principal ingredient in curries or chutneys and is also used in spice mixes and as a flavouring in bread. In terms of nutritional value, these seeds are reported as being a good source of elements such as iron, phosphorus and sulphur and, in addition to that, contain 23 percent protein, 10 percent carbohydrates, 8 percent fat and 10 percent fibre (Plants for a Future 2018 A). Within the Middle East, India and North Africa, fenugreek is also used as medicine. The seeds and leaves of this plant are anticholesterolemic, anti-inflammatory, antitumor and function as a laxative, to name just a few properties (Plants for a Future 2018 A; Ghasemi et al. 2015).

3.8.2 Lentils (*Lens culinaris*/*Trigonella)*

Lentils are an annual growing plant that is not frost tender and is self-fertile. This plant is suitable for sandy, loamy and clay soils, preferring them to be well-drained and can grow in nutritionally poor environments (Plants for a Future 2018 B). The seeds of the lentil plant can be eaten either raw or cooked and be extremely nutritious. They can be cooked on their own or added to soups or stews and, when dried, can be ground and made into a powder that can be added to cereal flours for making bread, enhancing their protein value. One of the more interesting things about this plant is that lentils are much more easily digested than other legumes. There are not many medicinal uses for this plant, but they can be used as a laxative and, when made into a paste, are useful as a cleansing application for ulcers (Plants for a Future 2018 B).

An additional reason for choosing fenugreek and lentils is that they represent both small and large-seeded legumes. It has been mentioned that the large-seeded ones are more prevalent in Natufian assemblages before the Younger Dryas, and after the Younger Dryas, small-seeded legumes became more prevalent. In their article, Arranz-Otaegui et al. identified the Lens species as a type of large-seeded legume and the *Trigonella* species as a type of small-seeded legume (Arranz-Otaegui et al. 2018).

3.8.3 Emmer Wheat (*Triticum turgidum)*

Emmer wheat is an annually growing cereal suitable for sandy, loamy and clay soils. While it can grow in nutritionally deficient environments and is not frost tender, it prefers its soil to be well-drained. The edible part of emmer is its seeds, and they are usually ground into flour and used as a cereal for making bread and similar foods (Plants for a Future 2018 C). In addition to bread making, wheat has also been used to brew drinks, such as beer (Hayden et al. 2013). Wheat has been identified as present in many of the Natufian sites within the Levant; examples being Raqefet Cave (Power et al. 2014), Ohalo II (Weiss et al. 2004), Abu Hureyra and Mureybit (Hayden et al. 2013), to name a few.

3.8.4 Barley (*Hordeum vulgare*)

Barley is an annual growing cereal suitable for all soil types and is not frost tender, can not grow in the shade, and prefers well-drained soil. It has been noted that barley can have some adverse effects on humans as exposure to barley flour can cause asthma, and it is also a possible trigger for coeliac disease. The edible part of the barley plant is the seed, and it can be either cooked as a whole grain or ground up into flour for bread or porridge. Barley can also have its seeds fermented into various foods such as sourdough or miso (Plants for a Future 2018 E). Malt can also be made from barley by sprouting the whole seed, roasting it, grinding it into flour, and finally boiling it in water. This water will then be very sweet and can be used for making a variety of drinks such as beer (Hayden et al. 2013; Liu et al. 2018; Plants for a Future 2018 E).

In addition to grinding these four materials, I also ground two of them after providing a form of pre-treatment. Pre-treatment is often done to plant materials before processing as either a way to improve the nutritional quality of the item or to ensure that it is safe for consumption (Kraybill 1977). The fenugreek and hard emmer wheat kernels were chosen for pre-processing alterations, representing the harder legume and cereal to grind. I decided to rinse and soak the fenugreek to prepare it in a manner used for tea (Ghasemi et al. 2015). To make a tea out of the fenugreek seeds, it is necessary to lightly crush them. However, when working the fenugreek dry, I observed that the hardness of the material processing had required much more downward force during grinding and an initial percussive impact as otherwise, the material would roll off the surface. By rinsing and soaking them, the seeds absorb the moisture and become softer as a result. This allows them to be crushed in a way where they remain in one piece rather than crumbling. For the hard wheat kernels, I decided to roast them as this is a common practice worldwide (Gremillion 2004), and additionally, this would create a nice contrast to the rinsed and soaked fenugreek seeds.

I decided to prepare the fenugreek as if it was to be used to make tea for two reasons. The first reason is that, as mentioned previously, fenugreek contains one percent saponins that can be removed through leaching, which softens the seed providing a less resistant grinding and providing a final form that seems more suitable for use in a tea. The second reason is that not much research in the realm of use-wear analysis has been performed regarding medicinal substances such as fenugreek tea, which has been noted to have a positive effect on breast-feeding mothers as its consumption seems to increase milk production (Ghasemi et al. 2015)

3.9 Experiment/Tool Action

All materials in this study were processed in the same manner, for the same amount of time and using the same motion, a lateral grinding motion done in a linear path, as Wright (Wright 1992) described. To control as many variables as possible that may influence wear development, all strokes performed will be flat strokes instead of rocking strokes. As defined by Adams, a rocking stroke is performed when the edges of a tool are lifted during a stroke, and a flat stroke is performed when all surfaces of the handstone are in constant contact with the grinding stone (Adams 2013). As rocking strokes add additional complexity to the formation of use-wear, I will be limiting the experiment solely to flat strokes. All tools had the same backing for these experiments, as all were placed on the same table, so there is no difference in “feedback” or working angle. To expedite the grinding portion of this experiment, I had enlisted the aid of some volunteers; however, due to lockdowns associated with COVID-19, their contribution to the grinding experiments was limited to just the first two hours of use for each tool.

All of the material in this study was ground for the same amount of time to ensure that the tools used have comparable states of wear and allow them to wear enough so that discernible characteristics can form. Since wear-traces on basalt GSTs are slow to develop, especially on the netherstone (Adams 2013), grinding intervals were fairly lengthy. Initially, for the first tool, I checked the surface 15 minutes after use, then 30 minutes after that, then 45 minutes later, and from that point on after each hour. This was done so that I could become more familiar with how wear develops. After each grinding session, the tool's surface was gently washed with a toothbrush and warm soapy water so that any debris that might be present would not interfere with the observations of the use-wear. An example of one of the hourly checks can be seen in Appendix B.

3.10 Recording Methods and Equipment

All tools used for this experiment have had photographs taken at multiple stages after each grinding session, so determinations of change due to use can be made. Photographs were taken before manufacture, after manufacture and after each hour of use. All photographs have their artifact number, level of magnification, and what feature is intended to be shown in the filename.

The equipment used for the observation and recording consists of two microscopes: a Nikon SMZ 1000 stereo microscope for magnification levels between 8× and 80× and a Nikon eclipse LV-150 compound microscope with long-distance objectives offering magnification from 50× to 500×. I used a Canon Rebel T2i EOS 550D with a Canon EFS 18-55mm lens to capture digital photographs of the tools and wear surfaces. The camera was used standalone and attached to the microscopes to take magnified photos of the tools.

I kept the processed material after each grinding session, and information relating to their products, such as processing time and the total weight, was also recorded. This information was kept as it will be used to measure the efficiency of each tool/material and could potentially be used for further analysis regarding how grinding can affect nutritional quality. Apart from cereals, we know little about the potential food values and functional properties of what was being exploited by early cultivators (Wollstonecroft et al. 2008). This could prove to be a fruitful avenue for future research.

3.11 Descriptive Criteria

I characterized the wear traces encountered on the surface as follows. I based my characterizations on the outline provided by Adams et al. (2009) and Dubreuil et al. (2015). I had deviated from this template when the descriptive categories were either unfitted or unnecessary. As I have already described the different wear categories and the features by which they are described in Table 3.1, only a chart showcasing how the results were tabulated showing the criteria are included below (Table 3.3). The data collection sheet I had used to perform my analysis can be seen in Appendix C and an example of a completed analysis can be seen in Appendix D.

Wear Type	Characteristic	Descriptions
Linear Trace	Distribution	Loose/Covered/Concentrated
	Density	Separated/Close/Connected
	Incidence	Shallow/Deep
	Disposition	Random/Concentric/Parallel/Oblique/ Perpendicular
	Orientation	Longitudinal/Transversal/Oblique
	Striation/Scratch	<0.5mm = striation >0.5mm = scratch
	Length	Short/Long
	Longitudinal Morphology	Intermittent/Continuous
	Transverse Morphology	U-Shaped/V-Shaped
Polish/Sheen	Distribution	Loose/Covered/Concentrated
	Density	Separated/Close/Connected
	Reflectivity	Slightly/Moderately/Highly
	Incidence	High/Low
Leveling	Distribution	Loose/Covered/Concentrated
	Density	Separated/Close/Connected
	Incidence	High/Low
	Morphology	Fine/Wide & Superficial/Deep
	Texture	Rough/Smooth
Pits/Grain Ext.	Distribution	Loose/Covered/Concentrated
	Density	Separated/Close/Connected
	Depth	Fine/Wide & Superficial/Deep
	Shape in Plan	Irregular/Circular/Triangular/Star like/Comet shaped
	Shape in Cross Section	U-Shaped/V-Shaped
Fracturing	Distribution	Loose/Covering/Concentrated
	Density	Loose/Close/Connected
	Depth	Fine/Wide & Superficial/Deep
Grain Edge	Present/Absent	Present/Absent

Rounding		
Micro-polish	Localization	Where on surface
	Distribution	Loose/Covering/Concentrated
	Density	Separated/Adjacent/Connected
	Microtopographic Context	High/Low & specific features
	Morphology in Cross-section	Irregular/Domed/Flat
	Texture	Rough/Fluid/Smooth
	Contours	Sharp/Diffuse
	Structure	Separated/Close/Connected
	Special Features	Striations/Pits etc.
	Vertical Extension	How deep
	Opacity	Transparent/Translucent/Opaque
	Brightness	Dull/Moderate/Bright

Table 3.3: Wear types, their characteristics and the description given to them.

3.12 3D Modelling

To better showcase the surface of the experimental collection of tools, I have opted to create a 3D model of each grinding surface. To do this, I used the program Agisoft (version 1.6.5). To create the 3D models, roughly 70 pictures per tool were taken. Each photo was taken from a slightly different position surrounding the tool and with a different set of pictures for three different elevations. The elevations were flush with the tool, slightly above and from an even higher, birds-eye view. These photos were all taken at the RAW quality and had the same amount and positioning of light. Once all the photographs were collected, they were then imported into Agisoft, where they were rendered into a model. These models are available as supplemental material.

While the 3D models made for this thesis were a preliminary effort, doing so has shown the possibilities they can provide. 3D models can be of use by allowing an analyst to make a permeant record of a tool at a specific point in time, which would be of use when seeking to understand the changes which occur to a tool over long periods of use. Likewise, they enable ease of access to the tool, allowing researchers to easily share their results with others. In the case of my thesis these 3D models had allowed me to examine the tools, specifically the shape of the active surface when I was unable to examine them in person.

3.13 Blind Testing

As mentioned previously, blind testing is vital for use-wear analysis because it can help establish the reproducibility and veracity of our results. As the aim of this thesis is to test previously used criteria and their findings, I would be remiss if I did not take the opportunity to include a formal test of the reproducibility of the descriptive criteria used in this study. The primary objective of this blind test will be to see if my characterization of the wear is reproducible. To test this, a second use-wear analyst, also a master’s student with a similar level of experience, used the same criteria to describe the wear occurring on the surfaces of the tools. The analyst used the identical criteria I had used to collect my data and a document that had explained each descriptive category. After the data was collected, I compared the results I gathered and made conclusions based on which areas we differed.

In addition to testing the reliability of descriptive criteria, the blind test will also be an opportunity to see whether raw material type influences the reproducibility of results. In this case, both the other use-wear analyst and I have the same amount of experience, but we have worked on different materials, our ability to recognize use-wear characteristics may differ. It might be possible that any differences between myself and the other two analysts may not be due to a failing of the descriptive framework but a lack of experience with the characteristics of the material. As the number of blind tests performed on GSTs is relatively low, the test results should prove to be of use, especially if multiple factors are examined within it.

It is important to note that this is not a traditional blind test in that it is not designed to test the ability to identify the worked substance. Instead, this blind test was designed to establish whether the descriptive criteria used to characterize wear are reproducible.

3.14 Chapter Summary

The onset of the Natufian represents a lasting dietary shift: the transition from foraging to farming. To understand this transition, we have to identify the plants being exploited and explain why they would have been chosen. To that end, use-wear analysis, residue analysis and blind tests are performed to isolate wear patterns distinctive to specific plants, which are then examined through the lens of Foraging Theory.

The experimental collection is comprised of six surfaces all made from basalt and used to process four different materials; hard wheat kernels, pot barley, fenugreek and brown lentils. In addition to these materials, hard wheat kernels were roasted, and fenugreek was rinsed and soaked. Notes were taken during the grinding processes documenting the ease or difficulty involved in rendering the material to its desired end state. At the end of the five hours of grinding, what was the ground was collected and weighed. Hourly checks were performed on each tool's surface, and a penultimate examination of the surface was performed at the five-hour mark. Following this examination, three residue samples were taken from each tool to perform both starch analysis and phytolith analysis of multiple tool sections. Lastly, a 3D model was constructed of each tool to aid in the visualization of each surface

Within the next chapter, I will be covering the results from the study I have performed. The results will be shown primarily through a chart to enable quick comparisons between the tools. I will be including numerous photos of differing magnifications to show the changes due to use. Specific aspects of the different linear traces will be covered in more or less depth, depending on how promising they are in differentiating the various materials processed.

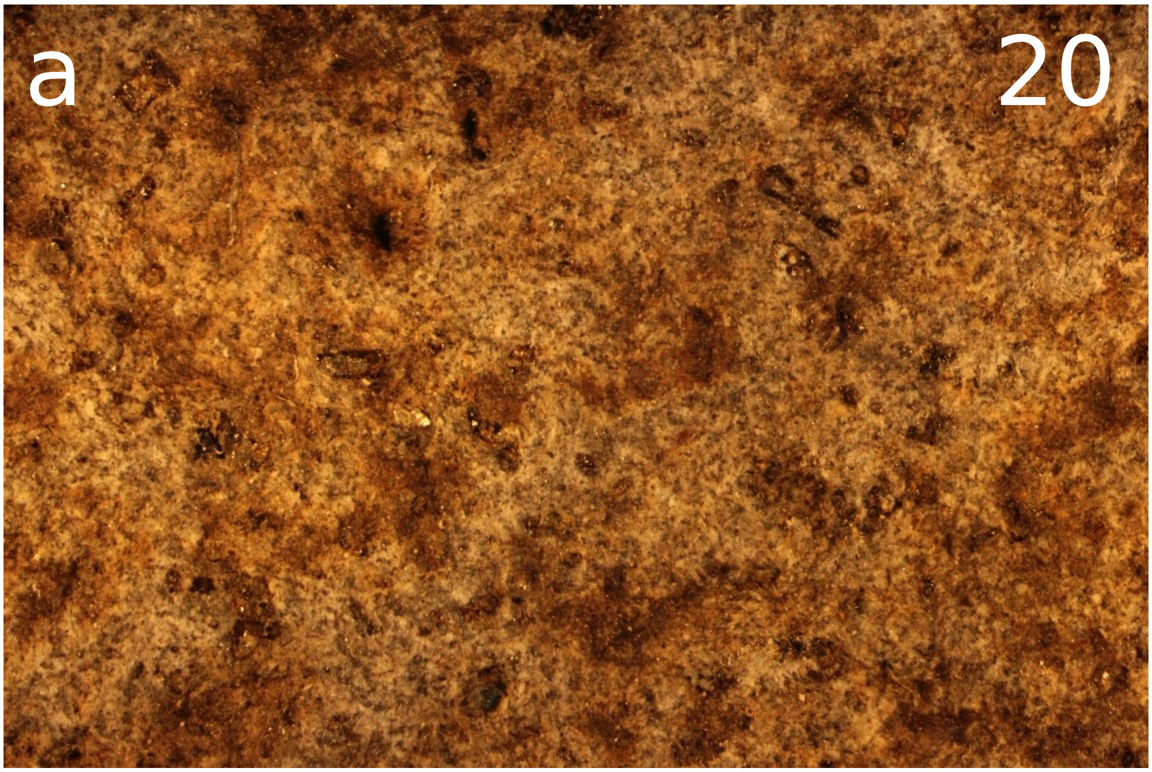
Chapter 4: Experimental Findings

Introduction

Within this chapter, the results from the experiments I have performed are laid out as follows; 1) a petrographic description of the material used to make the tools; 2) the results from all the low-power magnification (8× to 80×) observations by wear category; 3) the high magnification analysis (50× to 500×). After the description of each wear category, at least one photo will be included; in addition, more pictures of each surface will be provided within the appendix. A table synthesizing all of the results is presented at the end of the chapter. The results of the starch analysis and the blind test will be discussed afterwards.

4.1 Petrographic Description

All surfaces used in the experiments are made from the same igneous material, basalt, and the qualities did not differ between tools. As the material is consistent between each tool, I used a single petrographic description for all of them. The fabric/structure is isotropic, and the texture is fine with uniform grain size (aphanitic) held together by a matrix. The stone is slightly porous, as vesicles are present, but they are not prevalent. Regarding the mineral composition, the groundmass is primarily made up of feldspar, and there are phenocrysts present, making it porphyritic. Those phenocrysts are black when whole and orangish/yellow when worn, indicating that they are olivine. Some of these characteristics can be seen in Figure 4.1, which shows a comparison between a pre-manufacture and post-manufacture surface.



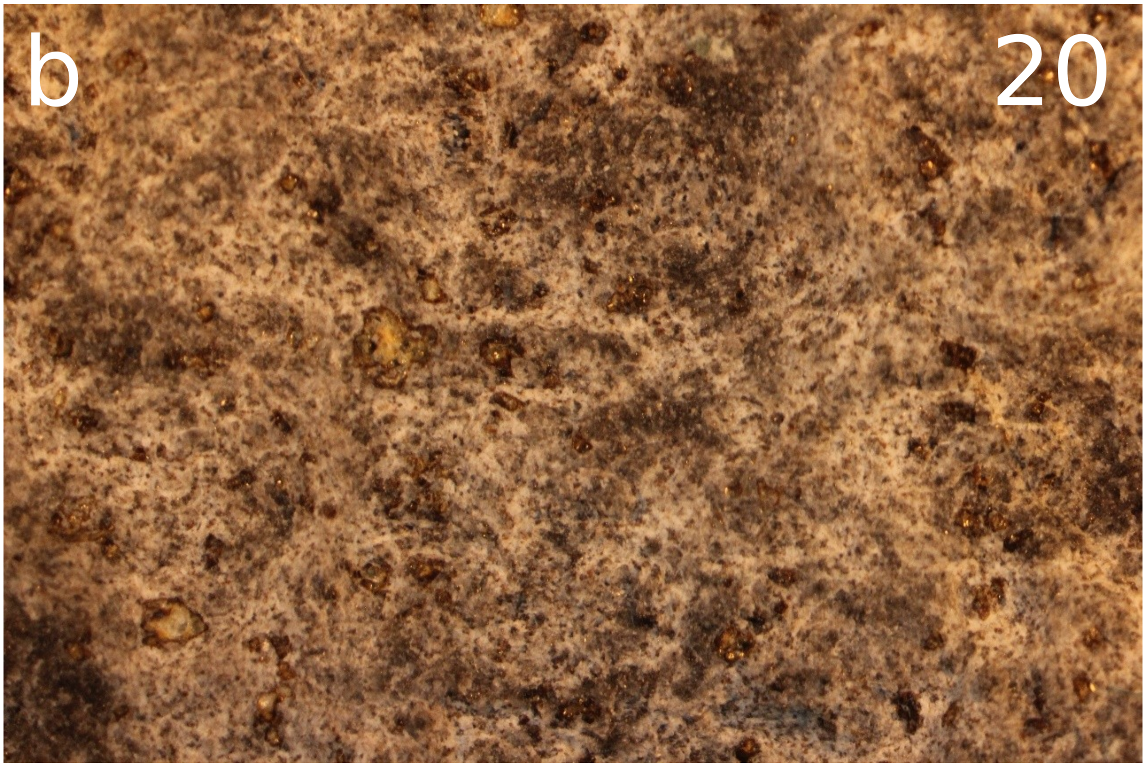


Figure 4.1: Photos of the pre-manufacture surface (a) and the post-manufacture surface (b) of the surface used to grind pot barley.

4.2 Experiments

As previously discussed, the working surfaces in this experiment were used to process: pot barley (*Hordeum vulgare L.*), wheat kernels (*Triticum asetivum*), fenugreek (*Trigonella foenum-graecum*), and brown lentils (*Lens culinaris)*. Each of these substances is ground for a total of five hours. Observations were taken in one-hour intervals, and grinding is performed until the substance reached the consistency of flour. An additional two working surfaces were used to process roasted wheat kernels and rinsed/soaked fenugreek, each also for five hours. It is important to note that the grinding surfaces used in these experiments are quite small, which likely impacted how much is ground during the experiments. Figures 4.2-7 present photos of the tools with a scale.

Figure 4.2: The post-experiment surface of the tool used to grind pot barley
(Netherstone 1 Side A)

Figure 4.3: The post-experiment surface of the tool used to grind hard wheat kernels (Netherstone 1 Side B)

Figure 4.4: The post-experiment surface of the tool used to grind fenugreek
(Netherstone 2 Side A)

Figure 4.5: The post-experiment surface of the tool used to grind lentils
(Netherstone 2 Side B)

Figure 4.6: The post-experiment surface of the tool used to grind rinsed/soaked fenugreek (Netherstone 3 Side A)

Figure 4.7: The post-experiment surface of the tool used to grind roasted hard wheat kernels (Netherstone 3 Side B)

After the five hours mark, the total amount of product produced, in grams, was measured. The results of which can be seen in Table 4.1. Pot barley had provided a total of 350 grams of barley flour. As the experiments progressed, more barley flour is processed within each one-hour session, culminating at 80 grams for the final hour. Hard wheat kernels provided a total of 235 grams of flour. Generally, 40 grams of wheat flour were processed within each session, except for the second hour in which 75 grams were ground. The difference in the amounts of wheat is likely due to two factors; the use of volunteers and the increasing comfortability with the tools. Fenugreek produced 210 grams of flour in five hours of grinding and is the most rigid material to work with. Generally, 40 grams of fenugreek were processed per hour, the only exception being the second grinding session in which 50 grams were produced. Brown lentils produced a total of 270 grams of flour in five hours. The number of lentils processed during the hour-long sessions varied, most sessions being either 40 grams or 60 grams. An exception to this is the fifth session in which 70 grams were ground.

For the roasted wheat kernels, the end product is once again flour; however, for the rinsed/soaked fenugreek, the end product is a crushed/flattened seed. After the five hours mark, a total of 330 grams of the rinsed/soaked fenugreek is processed. The first two grinding sessions had 60 grams processed during each, while the last three grinding sessions had 70 grams. After five hours, 557 grams of flour is produced from the roasted hard wheat kernels. This experiment seemed to have the most efficient grinding, with the least amount of seeds ground being 100 grams and the highest amount being 130 grams. An example of the difference between the post-manufacture and post-experiment surfaces is shown in Figure 4.8.

Material	First Hour	Second Hour	Third Hour	Fourth Hour	Fifth Hour	Total
Wheat	40 g	75 g	40 g	40 g	40 g	235 g
Barley	100 g	40 g	60 g	70	80 g	350 g
Lentils	40 g	60 g	40 g	60 g	70 g	270 g
Fenugreek	40 g	50 g	40 g	40 g	40 g	210 g
Roasted Wheat	100 g	130 g	116 g	100 g	111 g	557 g
Soaked Fenugreek	60 g	60 g	70 g	70 g	70 g	330 g

Table 4.1: Amount of product (grams) produced in each grinding session. For wheat, barley, lentils, fenugreek and roasted wheat the desired outcome was flour while for the soaked fenugreek the desired product was a "pulp".

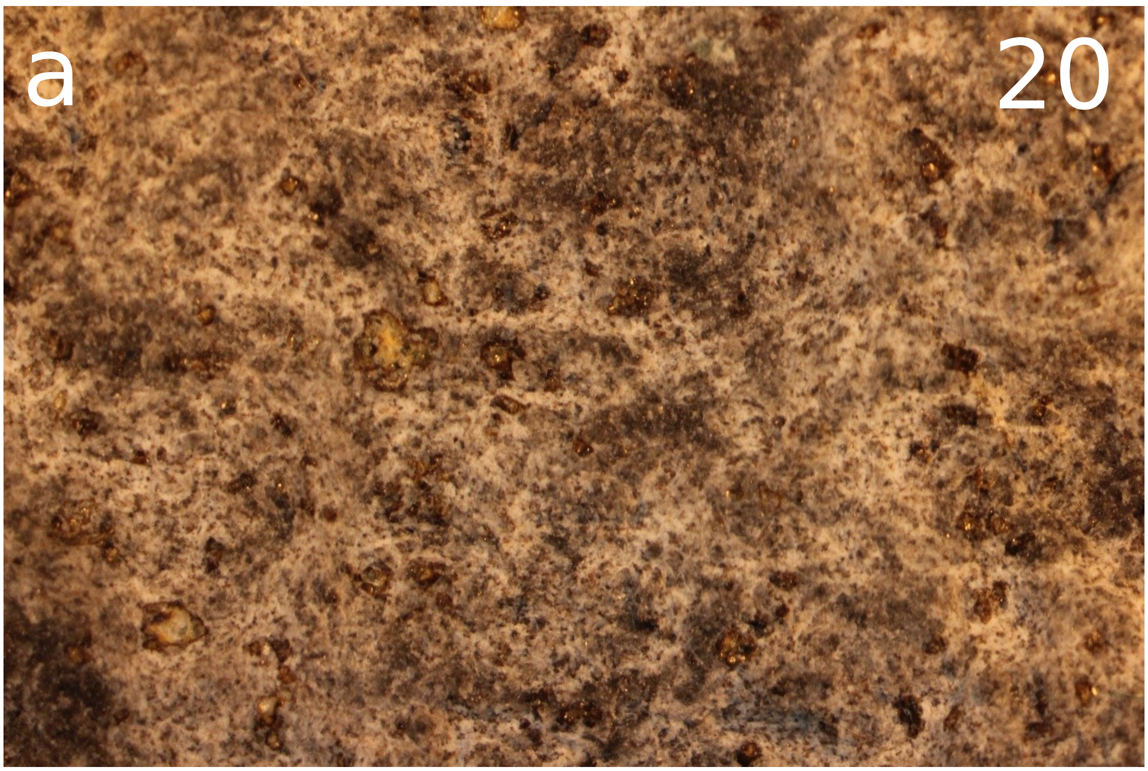


Figure 4.8: Photos of the (a) post-manufacture surface and the (b) post-experiment surface for the tool used to grind pot barley.

4.3 Wear Development

Before describing the wear related to the experiments, it would be beneficial to outline the wear incurred on the surfaces due to the manufacturing process. The wear associated with the manufacturing processes is shared between all of the surfaces. An extensive degree of shallow pitting covered what was to be the active surfaces of these tools, as well as a white discolouration. The pitting on these surfaces is a result of the manufacturing process, which involved pecking the surface. The white discolouration is due to the hammerstone, a piece of hardened limestone, which produced dust when striking the surface.

Across all of the experiments, several trends common to all the tools are present, and we will cover these after discussing the characteristics specific to particular experiments. These common points could be due to the tool's raw material, the manufacturing process, or how they were used, which was the same for each experiment. The results are briefly outlined in a table (Table 4.1) before discussing use-wear variation between the experimental tools.

First, I will describe the tools used to grind cereals. No linear traces are observed on the surface used to process pot barley when using low magnification levels. The polish has a covering distribution, connected density, a moderate reflectivity and extended to both the high and low topography. The levelling on this tool has a covering distribution, close density, a high incidence, a sinuous morphology and rough texture. While no pitting related to use is found, grain extraction is observed; having a loose distribution, close density, superficial depth, circular shape and a u-shaped cross-section. Fracturing on this surface has a covering distribution, close density and a moderate depth. Grain edge rounding is present on this tool. The micro-polish is found on the center of the active surface, has a covering distribution and an adjacent density within this area. The orientation of the micro-polish is parallel to the active surface and could be found on the topographic highs of the surface. The micropolish has an irregular cross-section, a rough texture, diffuse contours and a connected structure. The micro-polish is observed on levelled areas where it ranged between translucent and opaque with a moderate brightness.

On the surface used to grind hard wheat kernels, linear traces are not present when using low magnification levels. The polish on the surface has a loose distribution, close density, a slight reflectivity and a high incidence. Levelling on this surface has a loose distribution, close density, high incidence, a sinuous morphology and a rough texture. No use-related pitting is observed on this surface, although grain extraction has a loose distribution, separated density, superficial depth, irregular shape and a u-shaped cross-section. Fracturing on this surface is characterized by a covering distribution, connected density and a moderate depth. Grain edge rounding is seen on this tool. The micro-polish is located at the center of the active surface and has a spare distribution and adjacent density within that area. The micro-polish is orientated parallel to the major axis and developed on the topographic highs. This micro-polish has an irregular morphology, a rough texture, diffuse contours, and a connected structure. The micropolish also features striations and is primarily found on the levelled areas of the surface. Lastly, the micro-polish ranges between being translucent and opaque and has a dim brightness.

Next, we will cover the results from the tools used to grind legumes. On the surface used to process fenugreek, the striations are not visible under low levels of magnification. The polish on this surface has a covering distribution, connected density, slight reflectivity and is found on both the high and low topography. Levelling on this surface has a covering distribution, connected density, high incidence and a flat morphology. Use-related pitting is not seen on this tool; however, instances of grain extraction are. The grain extraction on this surface has a covering distribution, close density, superficial depth, circular shape and is u-shaped in cross-section. Fracturing on this tool has a concentrated distribution, close density and minor depth. Grain edge rounding is largely absent on this surface. The micro-polish on this tool is found on the center of the active surface. Within that area, it has a covering distribution and an adjacent density. This micro-polish has an orientation parallel to the major axis of the tool and is found on both the high and low topography. It also can be described as having an irregular morphology with a fluid texture, diffuse contours and a connected structure. In addition, striations are observed with the micro-polish, and it is found on levelled areas and extends partway into the interstices. This micro-polish varies between translucent and opaque and has a moderate brightness.

On the tool used to grind lentils, striations are not present at low levels of magnification. The polish on this surface has a covering distribution with a connected density, slight reflectivity and extends from the high topography to the low. The levelling on the surface has a covering distribution, connected density, a high incidence and a rough texture. Use-related pitting is not observed on this surface; however, grain extraction is, and it has a concentrated distribution, close density, superficial depth, irregular shape and a u-shaped profile. Fracturing on this surface has a concentrated distribution, close density, and minor depth. Grain edge rounding is absent on this surface. The micro-polish on this surface is located at the center of the active surface and has a covering distribution with an adjacent density. As with the previous surfaces, the orientation is parallel to the major axis of the tool and found both on the high topography and into the interstices. The micro-polish presents an irregular morphology, rough texture, diffuse contours, connected structure, is found only on areas where levelling has occurred, ranges from translucent to opaque and has a dim brightness.

Finally, we will cover the surfaces used to grind the pre-treated materials. On the tool used for grinding rinsed/soaked fenugreek, no linear traces could be found at low magnification levels. The polish has a covering distribution, close density, moderate reflectivity and is found on both the high and low topography. The levelling on this surface has a covering distribution and close density; it is present on both the high and low topography and shows a sinuous morphology and a smooth texture. Pitting on this surface is attributed to the manufacturing process. The grain extraction is described as having a covering distribution, close density, superficial depth, a mixture of irregular and circular shapes and in all instances has u-shaped profiles. Fracturing on this tool can be described as having a loose distribution, separated density and minor depth. Grain edge rounding is present on this surface. Lastly, the micro-polish observed is found across the whole working surface, with a covering distribution and an adjacent density. The orientation of the micro-polish is parallel to the major axis of the tool and is found on both the topographic highs and within the interstices. This micropolish has an irregular morphology, fluid texture with sharp contours and an adjacent structure. The micro-polishing is primarily found in areas with levelling and ranges between translucent and opaque with a dim brightness.

Lastly, we will cover the tool used to grind the roasted hard wheat kernels. On this surface, linear traces are present and described as having a loose distribution, separated density, shallow incidence, parallel disposition and longitudinal orientation. The linear traces are described as being striations, short, continuous and V-shaped. The polish has a covering distribution, close density, slight reflectivity and is found on both the high and low topography. The levelling has a covering distribution and close density while being found on the high topography with a sinuous morphology and rough texture. No use-related pitting is present; however, there is grain extraction observed. The grain extraction has a loose distribution, separated density, superficial depth, circular shape and a u-shaped cross-section. Fracturing on this surface is characterized as having a covering distribution, close density and minor depth. Grain edge rounding is present on this surface. The micro-polish on this tool is found across the whole surface and has a covering distribution with an adjacent density. The orientation of the micro-polish is parallel to the major axis, is found on the high topography, has an irregular morphology, fluid texture and diffuse contours. The structure is connected, and the micro-polish is found on the areas where levelling has occurred, ranges from translucent to opaque and has a dim reflectivity.

The wear traces found on each tool can be found in Table 4.1 on page 76. The use-wear results are broken up by tool, allowing for an easy comparison of the wear traces associated with each task. Areas that show promise for differentiation are highlighted in the table as well.

4.4 Commonalities

Commonalities are found among the tools in their linear traces, pitting, fractures, levelling, topography, and micro-polish. Regarding the linear traces, there is overlap between all of them in their orientation and length, as all the linear traces follow the axis of the tool and are short in length. Regarding the pitting, as the working surface was created through pecking, most pitting can be attributed to the manufacturing process. Any use-related pitting is determined by referencing post-manufacture observations (an example of the pitting found on the surfaces can be seen in Figure 4.9). Fracturing between the surfaces is the same regarding the depths at which it can be found, most likely due to the manufacturing process.

Additionally, the topography of these surfaces showed a universal trend for the development of levelled homogenous plateaus. The differences between the tools are not in whether these plateaus have formed or not but in how fast they are developing. Finally, the commonalities between all of the tool's micropolish are their morphology in cross-section, the presence of micro-polish on levelled areas and their opacity, which ranges from translucent to opaque.

Wear Type	Characteristic	Netherstone 1; Side A Pot Barley	Netherstone 1; Side B Hard Wheat Kernels	Netherstone 2; Side A Fenugreek	Netherstone 2; Side B Lentils	Netherstone 3; Side A Rinsed/Soaked Fenugreek	Netherstone 3; Side B Roasted Wheat Kernels
Linear Trace	Distribution	Not Observed	Not Observed	Not Observed	Not Observed	Not Observed	Loose
	Density	Not Observed	Not Observed	Not Observed	Not Observed	Not Observed	Seperated
	Incidence	Not Observed	Not Observed	Not Observed	Not Observed	Not Observed	Shallow
	Disposition	Not Observed	Not Observed	Not Observed	Not Observed	Not Observed	Parallel
	Orientation	Not Observed	Not Observed	Not Observed	Not Observed	Not Observed	Longitudinal
	Stiration/Scratch	Not Observed	Not Observed	Not Observed	Not Observed	Not Observed	Strations
	Length	Not Observed	Not Observed	Not Observed	Not Observed	Not Observed	Short
	Longitiudnal Morphology	Not Observed	Not Observed	Not Observed	Not Observed	Not Observed	Continuous
	Transverse Morphology	Not Observed	Not Observed	Not Observed	Not Observed	Not Observed	V-Shaped
Polish/Sheen	Distribution	Covered	Loose	Covered	Covered	Covered	Covered
	Density	Connected	Seperated	Connected	Connected	Close	Close
	Reflectivity	Moderate	Slight	Slight	Slight	Moderate	Slight
	Incidence	High/Low	High	High/Low	High/Low	High/Low	High/Low
Leveling	Distribution	Covering	Loose	Covering	Loose	Covering	Covering
	Density	Close	Close	Close	Seperated	Close	Close
	Incidence	High	High	High	High	High/Low	High
	Morphology	Sinuous	Sinuous	Flat	Sinuous	Sinuous	Sinuous
	Texture	Rough	Rough	Smooth	Rough	Smooth	Rough
Pits/Grain Ext.	Distribution	Loose	Loose	Covering	Concentrated	Covering	Loose
	Density	Close	Seperated	Close	Close	Close	Seperated
	Depth	Superficial	Superficial	Superficial	Superficial	Superficial	Superficial
	Shape in Plan	Circular	Irregular	Circular	Irregular	Irregular/Circular	Circular
	Shape in Cross Section	U-Shaped	U-Shpaed	U-Shpaed	U-Shaped	U-Shaped	U-Shaped
Fracturing	Distriubution	Covering	Covering	Concentrated	Concentrated	Loose	Covering
	Density	Close	Connected	Close	Connected	Seperated	Close
	Depth	Moderate	Moderate	Minor	Minor	Minor	Minor
Grain Edge Rounding	Present/Absent	Present	Present	Absent	Absent	Present	Present
Micropolish	Localization	Center of Active	Center of Active	Center of Active	Center of Active	Whole Surface	Whole Surface
	Distribution	Covering	Sparse	Covering	Covering	Covering	Covering
	Density	Adjacent	Adjacent	Adjacent	Adjacent	Adjacent	Adjacent
	Orientation	Parallel to Major Axis	Parallel to Major Axis	Parallel to Major Axis	Parallel to Major Axis	Parallel to Major Axis	Parallel to Major Axis
	Microtopographic Context	Topographic Highs	Topographic Highs	Highs/Interstices	Highs/Interstcies	Highs/Interstices	High
	Morphology in Crosssection	Irregular	Irregular	Irregular	Irregular	Irregular	Irregular
	Texture	Rough	Rough	Fluid	Rough	Fluid	Fluid
	Contours	Diffuse	Diffuse	Diffuse	Diffuse	Sharp	Diffuse
	Structure	Connected	Connected	Connected	Connected	Adjacent	Connected
	Special Features	On Leveled Areas	Striations/Leveled	Striation/Leveled	On Leveled Areas	On Leveled Areas	On levled Areas
	Vertical Extension	Only on Highs	Only on Highs	Part way into interstices	Can be found in pitting	Part way into interstices	Only on Highs
	Opacity	Translucent/Opaque	Translucent/Opaque	Translucent/Opaque	Translucent/Opaque	Translucent/Opaque	Translucent/Opaque
	Brightness	Moderate	Dim	Moderate	Dim	Dim	Dim

Table 4.2: Results from the final observation of the netherstones. Structured variations observed on tools are highlighted; Green for cereals, blue for legumes and yellow for pre-treated.

Figure 4.9: Example of the pitting shared amongst all the surfaces, as seen on the tool used to grind fenugreek.

Specific Findings

Within this section, I will outline how either a specific material, such as fenugreek, or a class of material, such as cereals, shows results that distinguished that wear from the rest. The information provided within this section will be presented again in a synthesized method with other studies showing the significant trends within the interpretation chapter. Images will be provided along with a chart that will highlight the trends observed. Trends will be covered by the wear category, beginning with linear traces.

4.5 Linear Traces

While many of the surfaces have linear traces on them, which could be seen within their micro-polish at high levels of magnification, the only surface on which linear traces could be found at low levels of magnification is the one used to grind roasted hard wheat kernels. An example of the linear trace found on this tool can be seen in Figure 4.10.

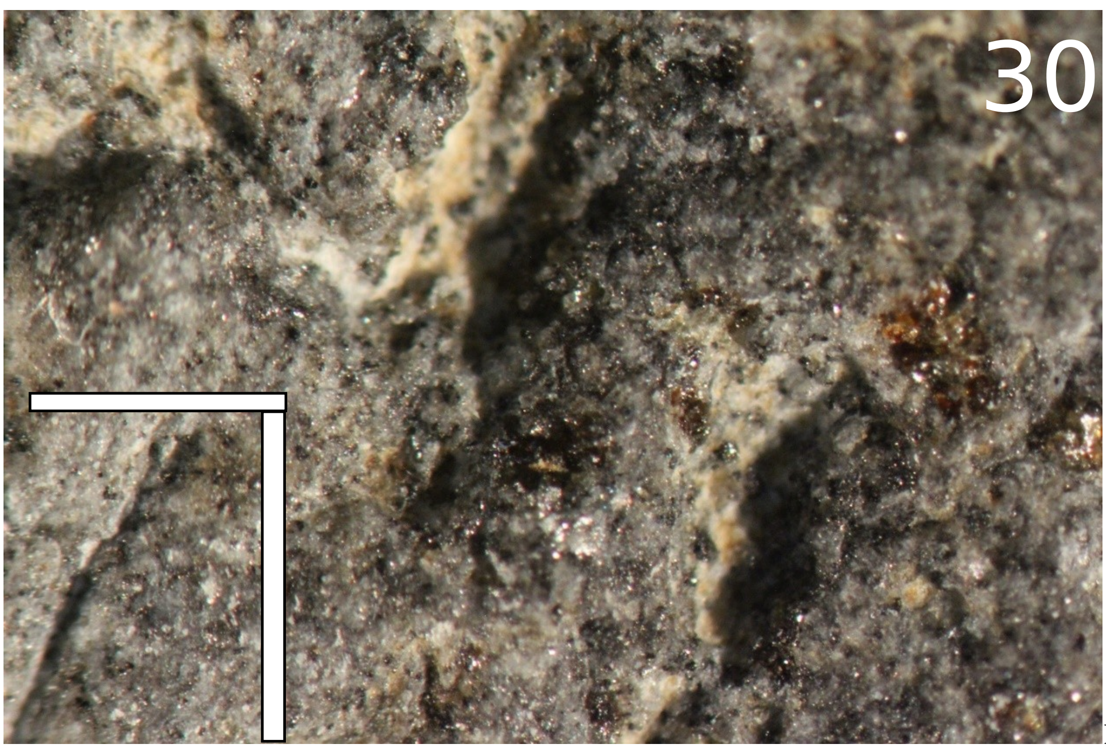


Figure 4.10: Example of a striation on the tools used to grind roasted hard wheat kernels.

4.6 Polish/Sheen

Sheen corresponds here to a darkening of the surface on which reflective patches, polish could be found. The distribution and density of the polish/sheen showed some pattering in the sample as well as its incidence. Incidence refers to the position of the polish on the surface and whether it can be found on the high topography and/or the low topography. On the surfaces used to process the un-treated legumes (netherstone 2, sides A and B), the polish/sheen has its greatest's distribution and density, while on the surface used to process the hard wheat kernels (netherstone one side B), there is the least amount of polish/sheen buildup. In addition, the tool used to process hard wheat kernels is also the only surface on which sheen could only be found on the high topography of the surface. A comparison between the sheen found on the surfaces used to grind lentils and hard wheat kernels can be seen in Figure 4.11.

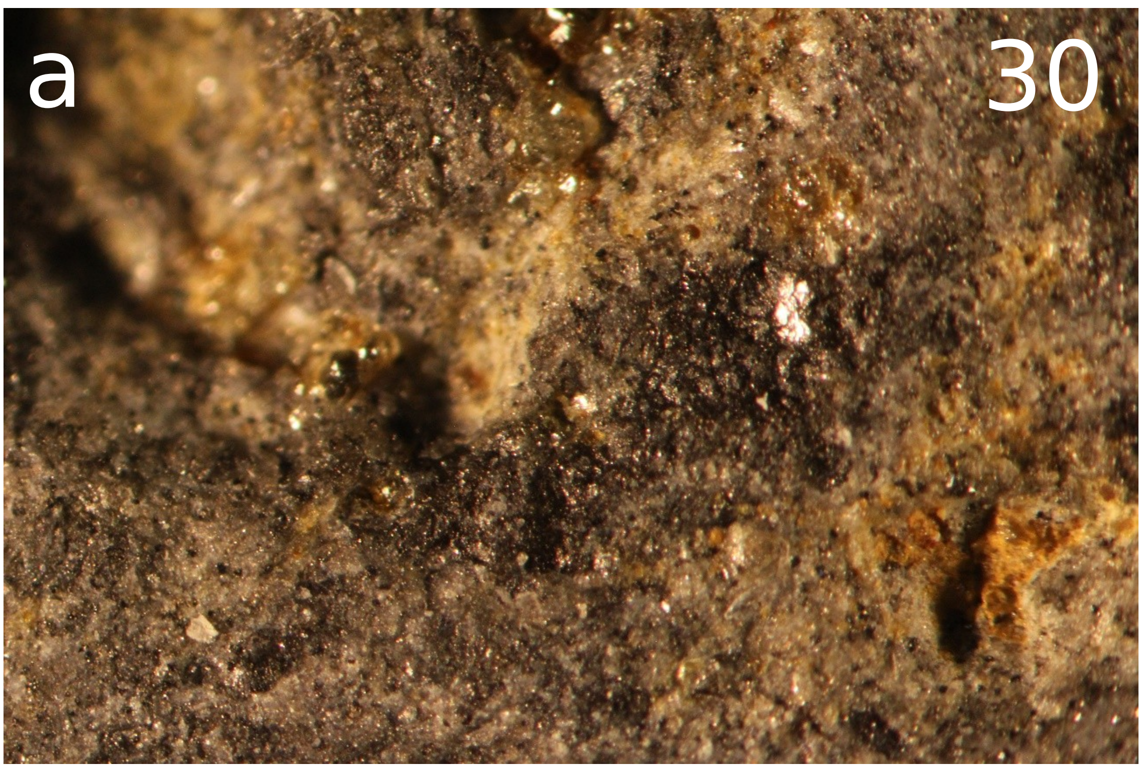


Figure 4.11: Sheen buildup on the surfaces used to grind lentils (a) and hard wheat kernels (b). Polish is much darker with the lentils and extended into the interstices.

4.7 Leveling

Two trends can be found when comparing the active surfaces in regards to the levelling found. On the netherstones used to grind legumes, the highest degree of surface levelling is found. Likewise, on these surfaces, the levelling also has a smooth texture. In addition to this, the netherstone used to grind the soaked fenugreek also featured a smooth texture to its levelling. The levelling on this surface is also found to extend into the low topography. A comparison between multiple surfaces levelling can be seen in Figure 4.12.


a
8


b
8

Figure 4.12: Leveling associated with pot barley (a), fenugreek (b) and rinsed/soaked fenugreek (c). Levelling is most pervasive with fenugreek and is the least so with pot barley, where it had a "wavy" appearance.

4.8 Fracturing

Regarding grain fragmentation, two trends can be observed when examining the distribution and depth of the fracturing on the surfaces. Concerning the distribution, while the cereals, including the pre-treated hard wheat kernels, all shared a covering distribution, the lentils show a concentrated distribution and the rinsed/soaked fenugreek a loose concentration. Secondly, the depth of fracturing differs between classes of materials. While the legumes and pre-treated materials have a minor depth of fracturing, on the surfaces used to process the unaltered cereals, there is moderate depth to the fracturing. A comparison between the fracturing of the cereals and the legumes can be seen in Figure 4.13.

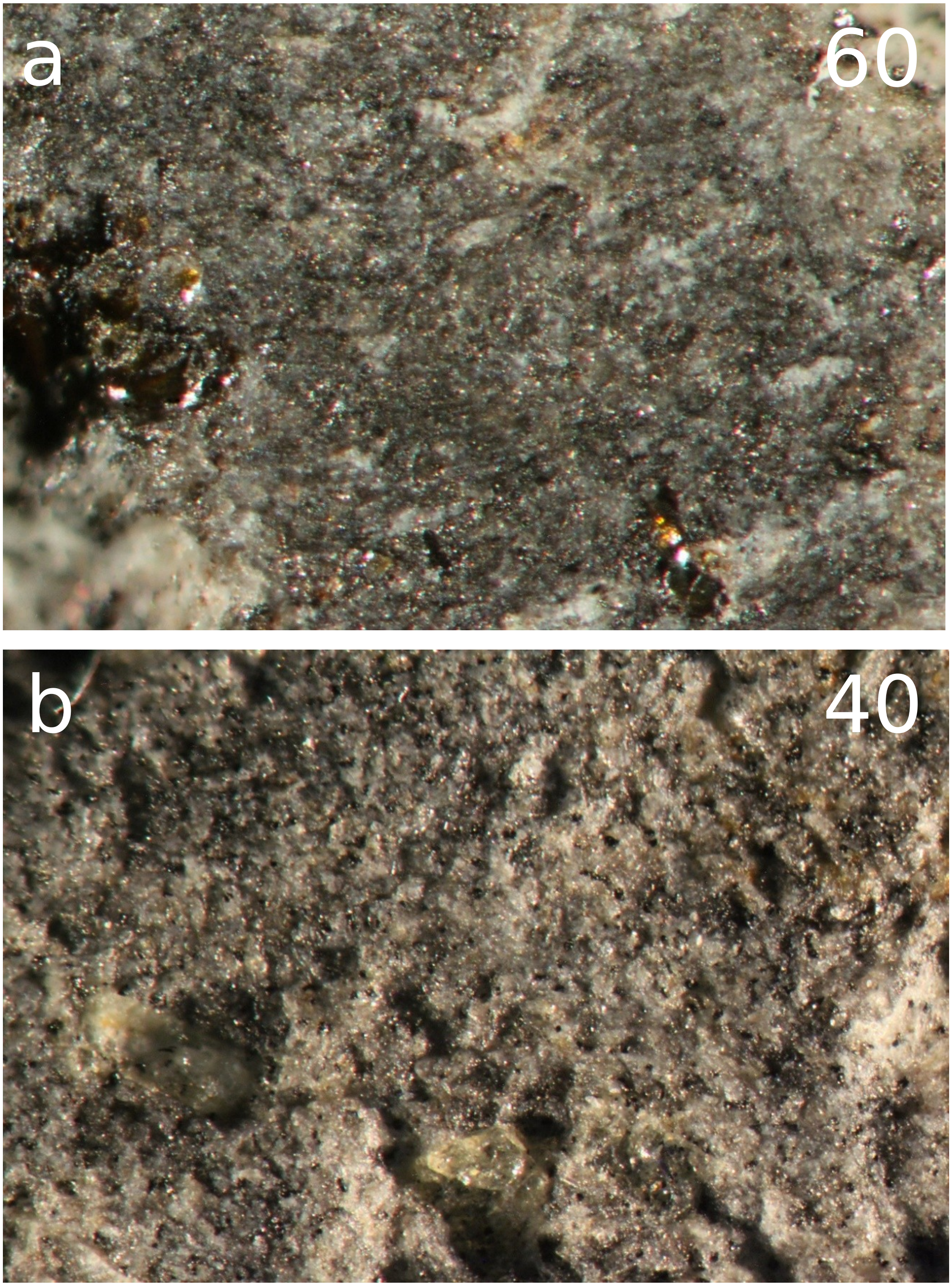
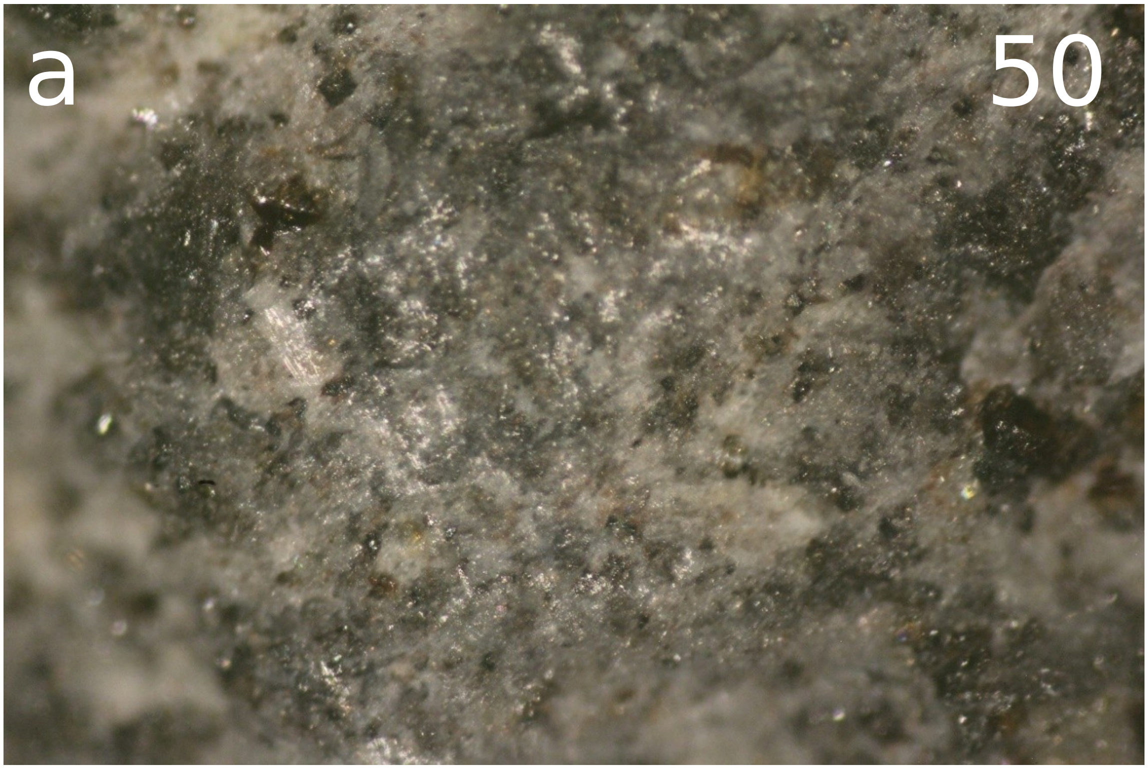


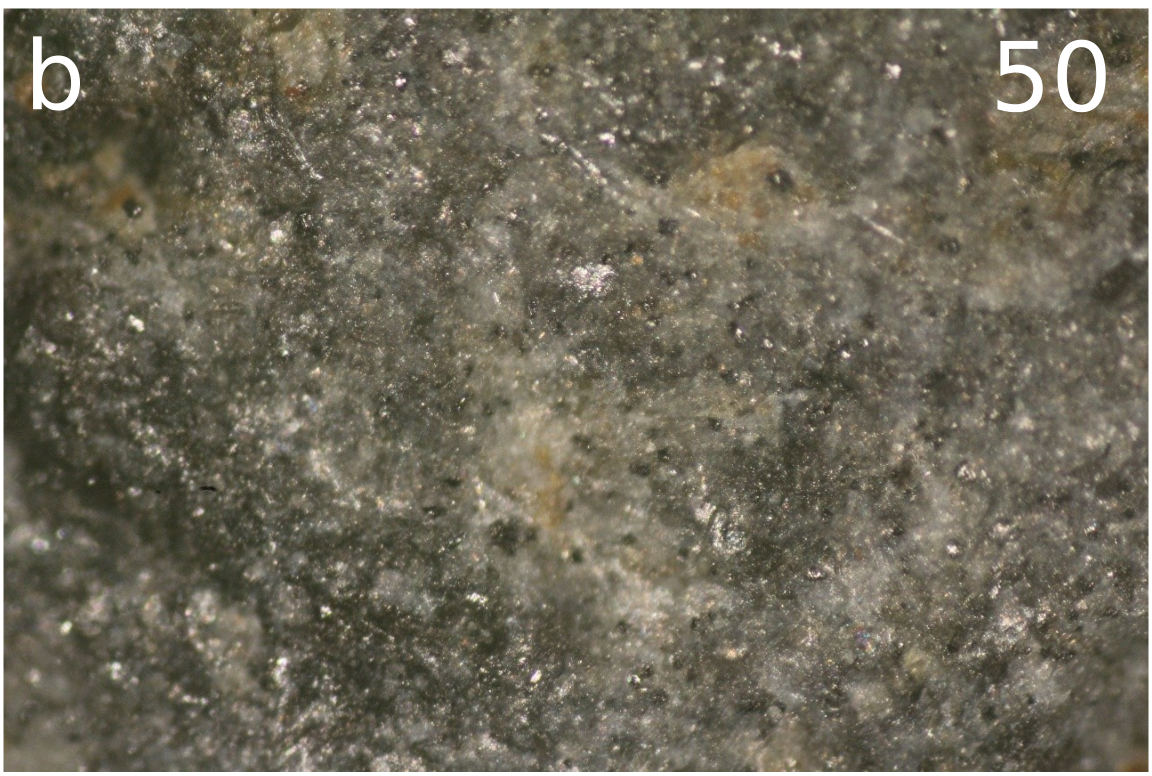
Figure 4.13: Example of fracturing found on the surface used to grind pot barley (a) and the one used to grind lentils (b); fracturing is seen in the white “scaring” on the surface.

4.9 Micro-polish

The micro-polish observed on the netherstones appears to be less developed when compared to the other wear traces. While variations could be found between the tools, these are less stark than those observed at lower magnification levels. Since these tools' micro-polish is not quite developed enough to make confident distinctions between the surfaces, the micro-polish on the handstones is also examined. As the handstones were used to grind multiple materials, one for the cereals and one for the legumes, they have encountered a total of 15 hours of use. After providing the information regarding the differentiating characteristics of the netherstones, the handstone results will then be reported.

Tools used to process the pre-treated materials (rinsed/soaked fenugreek and roasted hard wheat kernels) have micro-polish, which extend over their entire active surface, compared to the other tools that have their micro-polish confined to the center of their active surfaces. When looking within the areas in which micro-polish is present on the surfaces, however, the micro-polish distribution, density, and structure are all very similar between the surfaces. The other difference between the surface's micro-polish is that the pot barley and fenugreek tools are moderately bright. Additionally, the fenugreek and pre-treated materials have a fluid texture and that the rinsed/soaked fenugreek has sharp contours for its micro-polish. A comparison of three surfaces micro-polish can be seen in Figure 4.14.


a
50


b
50

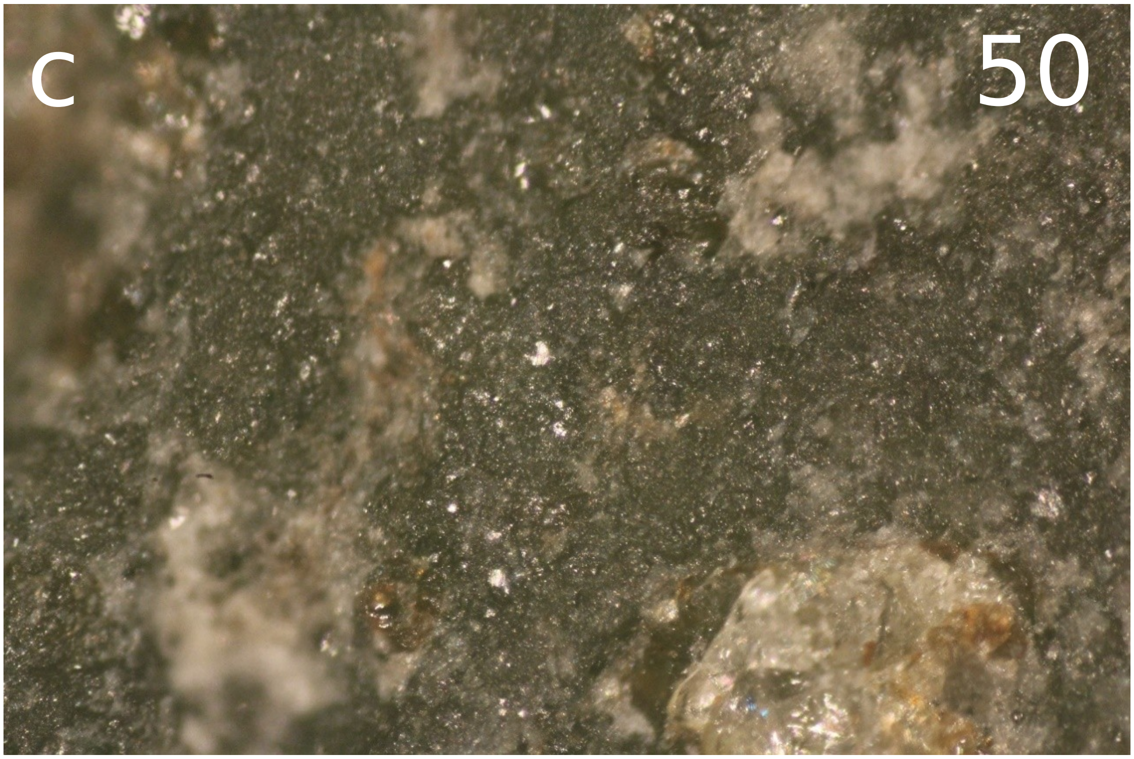


Figure 4.14: Examples of the distribution and density of micro-polish associated with hard wheat kernels (a), lentils (b) and rinsed/soaked fenugreek (c). The prevalence of the reflective patches defines distribution and density.

4.10 Handstones

As the micro-polish on the netherstones lacked any defining characteristics for specific materials or material classes, I decided to include an observation of the micro-polish found on the handstones in my analysis. While the netherstones only had 5 hours of use, the netherstones used for each material class (cereals or legumes) had a total of 15 hours of use. The examination of these tools allows exploring more long-term development of micro-polish belonging to both cereals and legumes and micro-polish development relating to multi-function surfaces. In addition to the information regarding the micro-polish, some brief observations regarding other aspects of the surface will also be relayed. The results from this observation are presented in Table 4.3.

On the handstone used to grind the cereals, the micro-polish characteristics are not substantially different from those observed on the corresponding netherstone; however, it is much more developed. The micro-polish is located across the entirety of the active surface with a concentrated distribution and connected density. Micro-polish is observed both on the high topography of the surface and the lower areas, extending partway into the interstices yet not at the bottom of the pitting. In cross-section, the micro-polish has a flat morphology, with a smooth texture, sharp contours, connected structure, and visible striations. The opacity ranged between translucent and opaque, and overall, the micro-polish is relatively bright. An example of the micro-polish observed on this tool can be seen in Figure 4.15.

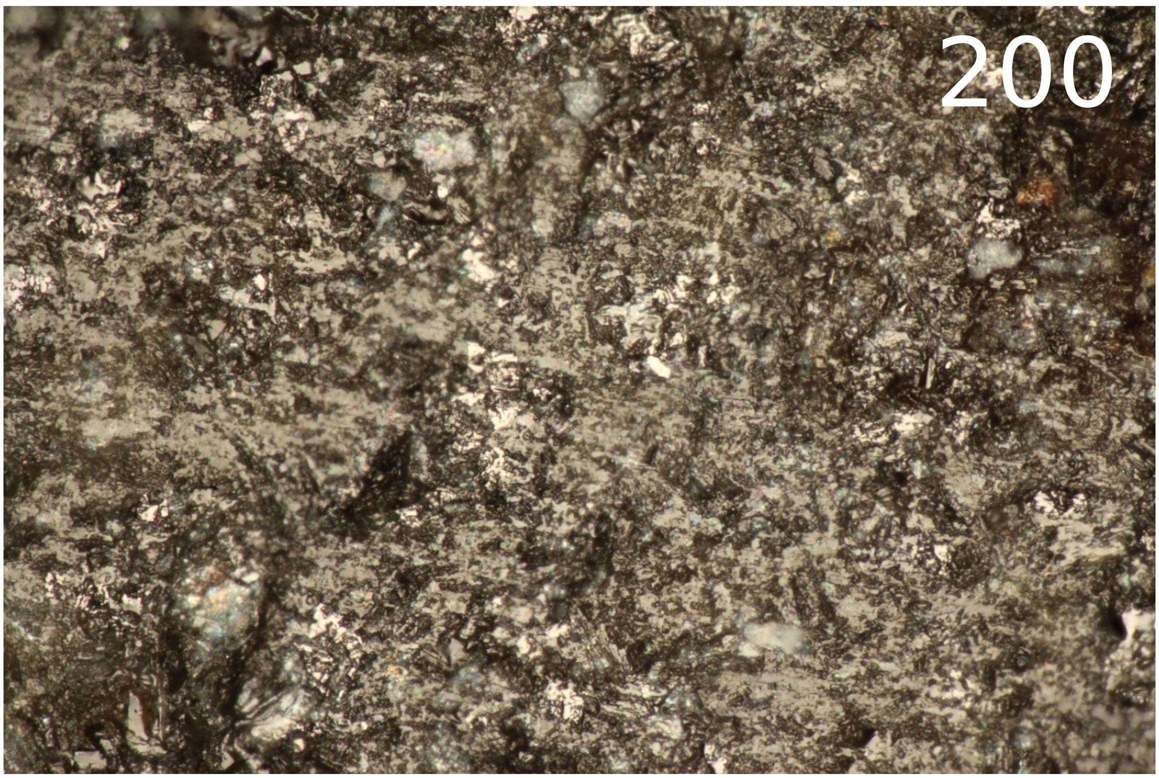


Figure 4.15: An example of the micro-polish on the handstone used to grind the cereals; taken at 200× magnification.

For the handstone used to process the legumes, micro-polish is developed across the entirety of the active surface and displays a covering distribution and a close density. The micro-polish can be found on both the high and low topography, extending partway into the interstices. In cross-section, the micro-polish has an irregular morphology with a fluid texture, diffuse contours, connected structure, and some striations are visible within the micro-polish. The opacity ranges from translucent to opaque, and the brightness level is dim. An example of the micro-polish observed on this tool can be seen in Figure 4.16.

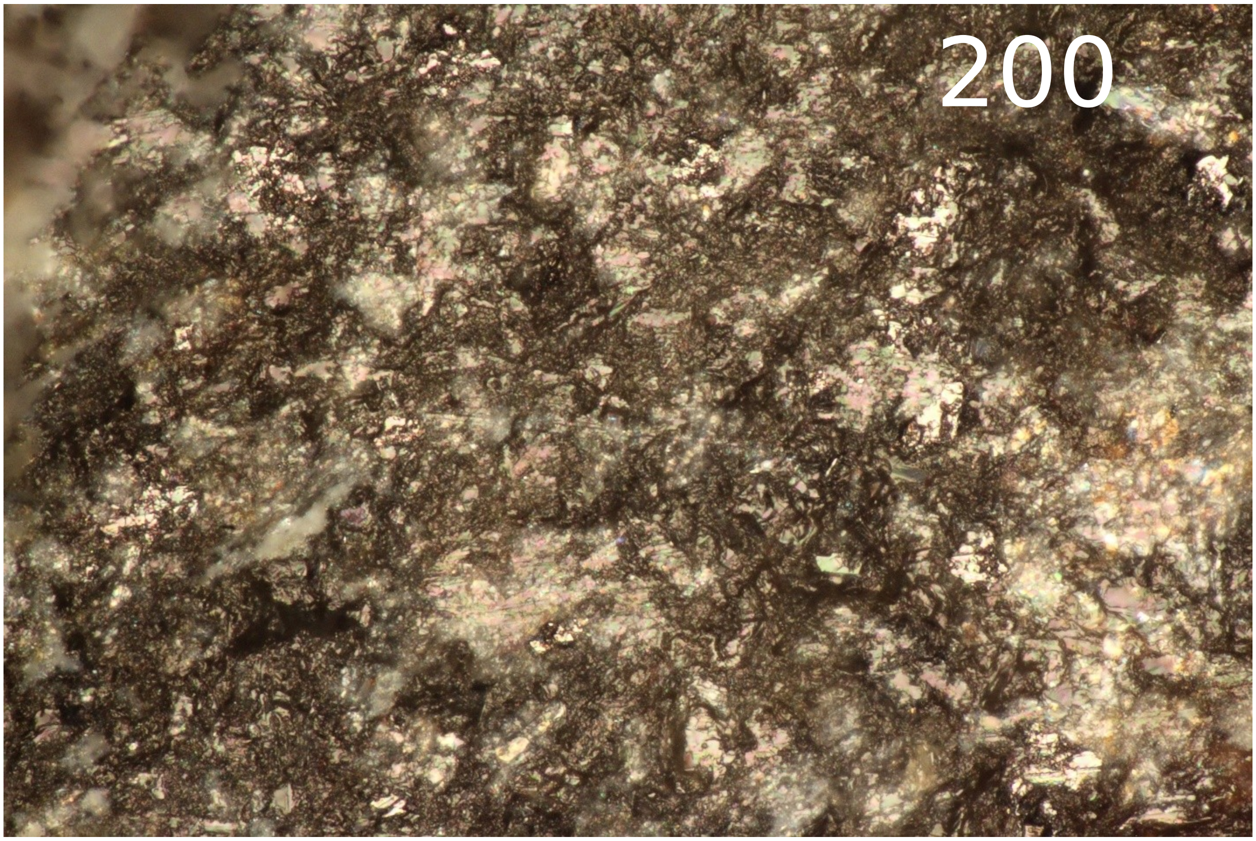


Figure 4.16: An example of the micro-polish from the handstone used to process the legumes; taken at 200× magnification.

Cereal Handstone			Legume Handstone		
Micro-polish	Localization	Entire Surface	Micro-polish	Localization	Entire Surface
	Distribution	Concentrated		Distribution	Covering
	Density	Connected		Density	Close
	Microtopographic Context	High and Low		Microtopographic Context	High and Low
	Morphology	Flat		Morphology	Irregular
	Texture	Smooth		Texture	Fluid
	Contours	Sharp		Contours	Diffuse
	Structure	Connected		Structure	Connected
	Special Features	Striations		Special Features	Striations
	Vertical Extension	Partway into Interstices		Vertical Extension	Partway into Interstices
	Opacity	Translucent/ Opaque		Opacity	Translucent/ Opaque
	Brightness	Bright		Brightness	Dim

Table 4.3: Results from the analysis of the micro-polish on the handstones. The total number of hours of use for these tools is 15.

4.11 Starch Analysis Results

On the netherstone used to grind wheat, across a 1cm wide sample of the prepared slide, a total of 388 starches are recognized. As mentioned in the methods section, starches are described according to their shape, size and whether an extinction cross is present. On this tool, of the total 388 starches, 188 are circular (48.5 percent), 84 are ovals (21.7 percent), 64 are doughnut-shaped (16.5 percent), one cluster is present (0.3 percent), 21 are broken (5.4 percent), and 30 are irregularly shaped (7.7 percent). The average size of the starches found is 395.98, and of the 388 observed, 22 have extinction crosses visible.

On the netherstone used to process lentils, once again with a 1cm wide sample, a total of 31 starches are identified. Of these 31 starches; 5 can be classified as circles (16.1 percent), 11 as ovals (35.5 percent), one presents a doughnut-shaped (3.2 percent), five correspond to clusters (16.1 percent), three are irregular (9.7 percent), and six are broken (19.4 percent). The average size of the starches is 517.1; of the 31 observed, only one had a visible extinction cross. Overall, there are much more starches present on the slide associated with wheat than with lentils. Likewise, the circles seem to have a stronger association with wheat and the clusters with lentils.

4.12 Blind-Test Results

The results from the blind-test are presented below (Table 4.7, 4.8 and 4.9), with the differences between my results and the blind-test highlighted. Close differences will be highlighted in yellow, and more significant differences will be highlighted in red. Here I will briefly outline the results and provide a ratio of how well the results overlap with one another. The blind-test is graded out of a score of 39. This is because there is a total of 39 characteristics described in the use-wear analysis. The tables (Table 4.4, 4.5, and 4.6) below provide the number of characteristics that overlapped, had minor or major differences. The blind tester was given the descriptive criteria I had used so differences are not due to discrepancies in terminology. The results highlighted in green are the tool with the highest degree of similarity and the tool highlighted in red the most dissimilar. A more detailed exploration of the blind test results will be provided within the interpretation chapter. The complete and unaltered blind test results can be seen in Appendix E.

For the tool used to process pot barley, out of 39 descriptive criteria, 16 overlapped (41 percent), while 14 are of minor difference (35.9 percent) and 9 are major differences (23.1 percent). For the hard wheat kernel surface, the results are very much the same; out of 39 descriptive criteria, 16 overlapped (41 percent), while 14 are of minor difference (35.9 percent) and 9 are major differences (23.1 percent). The results are presented in Table 4.4.

	Pot Barley	Hard Wheat Kernels
Overlap (/39 and percent)	16/39; 41%	16/39; 41%
Minor Difference (/39 and percent)	14/39; 35.9%	14/39; 35.9%
Major Difference (/39 and percent)	9/39; 23%	9/39; 23%

Table 4.4: Results of the blind test for the surfaces used to grind cereals.

On the surface used to grind fenugreek, of the 39 descriptive criteria, 17 overlapped between the blind test and my results (43.6 percent), while 9 have minor differences (23.1 percent) and 13 have major differences (44.8 percent). The tool used to process lentils provided results that are the most different from what I encountered. Out of the 39 descriptive criteria, 15 overlapped (38.5 percent) while 11 are minor differences (28.2 percent), and 13 are major differences (44.8 percent). The results are shown in Table 4.5.

	Fenugreek	Lentils
Overlap (/39 and percent)	17/39; 43.6%	15/39; 38.5%
Minor Difference (/39 and percent)	9/39; 23.1%	11/39; 28.2%
Major Difference (/39 and percent)	13/29; 44.8%	13/29; 44.8%

Table 4.5: Results of the blind test for the surfaces used to grind legumes.

The results of the blind test for the surface used to process the rinsed/soaked fenugreek are as follows: out of the 39 criteriums, 26 overlapped (66.7 percent), 12 have minor differences (30.8 percent), and there is only one major difference (2.6 percent). This is the surface that best matches my results. For the tool used to grind the roasted hard wheat kernels, 17 descriptive criteria overlapped (43.6 percent), 11 have minor differences (28.2 percent), and 11 have major differences (28.2 percent). The results are shown in Table 4.6.

	Rinsed/Soaked Fenugreek	Roasted Hard Wheat
Overlap (/39 and percent)	26/39; 66.7%	17/39; 43.6%
Minor Difference (/39 and percent)	12/39; 30.8%	11/39; 28.2%
Major Difference (/39 and percent)	1/39; 2.6%	11/39; 28.2%

Table 4.6: Results of the blind test for the surfaces used to grind pre-treated materials.

Wear Type	Characteristic	Barley	Barley - Blind Test	Wheat	Wheat - Blind Test
Linear Trace	Distribution	Not Observed	Loose	Not Observed	Loose
	Density	Not Observed	Connected	Not Observed	Separated
	Incidence	Not Observed	Shallow	Not Observed	Shallow
	Disposition	Not Observed	Parallel	Not Observed	Parallel
	Orientation	Not Observed	Longitudinal	Not Observed	Longitudinal
	Striation/Scratch	Not Observed	Striation	Not Observed	Striation
	Length	Not Observed	Short	Not Observed	Short
	Longitudinal Morphology	Not Observed	Intermittent	Not Observed	Intermittent
	Transverse Morphology	Not Observed	U-Shaped	Not Observed	U-shaped
Polish/Sheen	Distribution	Covered	Concentrated	Loose	Covering
	Density	Connected	Connected	Separated	Separated
	Reflectivity	Moderate	Slight	Slight	High
	Incidence	High/Low	High topography (leveled)	High	High topography
Levelling	Distribution	Covering	Loose	Loose	Connected
	Density	Close	Connected	Close	Connected
	Incidence	High	High topography	High	High topography
	Morphology	Sinuous	Flat	Sinuous	Uneven (sinuous)
	Texture	Rough	Smooth	Rough	Rough
Pits/Grain Ext.	Distribution	Loose	Covering	Loose	Covering
	Density	Close	Closed	Separated	Closed
	Depth	Superficial	Most wide/deep	Superficial	Most wide/deep
	Shape in Plan	Circular	Irregular, Some Circular	Irregular	irregular
	Shape in Cross Section	U-Shaped	U-shaped	U-Shaped	U-shaped
Fracturing	Distribution	Covering	Appears in pits	Covering	Loose
	Density	Close	Loose	Connected	Loose
	Depth	Moderate	Superficial	Moderate	Deep/Wide
Grain Edge Roundi	Present/Absent	Present	Present	Present	Present
Micropolish	Localization	Center of Active	On leveled areas	Center of Active	On Leveled Areas
	Distribution	Covering	Concentrated	Sparse	Sparse
	Density	Adjacent	Connected	Adjacent	Connected
	Microtopographic Context	Topographic Highs	Leveled areas	Topographic Highs	High topography
	Morphology in Crosssectio	Irregular	Sinuous	Irregular	Sinuous
	Texture	Rough	Rough/Fluid	Rough	Fluid
	Contours	Diffuse	Diffuse	Diffuse	Diffuse
	Structure	Connected	Connected	Connected	Connected
	Special Features	On Leveled Areas	Linear Traces	Striations/Leveled	None
	Vertical Extension	Only on Highs	Shallow	Only on Highs	Extends into pits
	Opacity	Translucent/Opaque	Opaque	Translucent/Opaque	Opaque
	Brightness	Moderate	Medium (Moderate)	Dim	Moderate

Table 4.7: Comparison between the results I have gathered and those of the blind test for the cereals. Major differences with the blind test are highlighted in red and minor differences are highlighted in yellow.

Wear Type	Characteristic	Fenugreek	Fenugreek - Blind Test	Lentils	Lentils - Blind Test
Linear Trace	Distribution	Not Observed	Loose	Not Observed	Loose
	Density	Not Observed	Connected	Not Observed	Separated
	Incidence	Not Observed	Shallow	Not Observed	Shallow
	Disposition	Not Observed	Parallel	Not Observed	Parallel
	Orientation	Not Observed	Longitudinal	Not Observed	Longitudinal
	Striation/Scratch	Not Observed	Striation	Not Observed	Striation
	Length	Not Observed	Short	Not Observed	Short
	Longitudinal Morphology	Not Observed	Intermittent	Not Observed	Intermittent
	Transverse Morphology	Not Observed	U-shaped	Not Observed	U-Shaped
Polish/Sheen	Distribution	Covered	Concentrated	Covered	Covered
	Density	Connected	Connected	Connected	Connected
	Reflectivity	Slight	High	Slight	Moderate
	Incidence	High/Low	High Topography	High/Low	Lower Topography
Levelling	Distribution	Covering	Loose	Loose	Covering
	Density	Close	Connected	Separated	Connected
	Incidence	High	High Topography	High	High topography
	Morphology	Flat	Flat/Rounded	Sinuous	Flat/rounded
	Texture	Smooth	Smooth	Rough	Smooth
Pits/Grain Ext.	Distribution	Covering	Covering	Concentrated	Covered
	Density	Close	Closed	Close	Closed
	Depth	Superficial	Wide and deep	Superficial	Wide and Deep
	Shape in Plan	Circular	Irregular	Irregular	Irregular
	Shape in Cross Section	U-Shaped	U-Shaped	U-Shaped	U-Shaped
Fracturing	Distribution	Concentrated	Not Observed	Concentrated	Not Observed
	Density	Close	Not Observed	Connected	Not Observed
	Depth	Minor	Not Observed	Minor	Not Observed
Grain Edge Rounding	Present/Absent	Absent	Present	Absent	Present
Micropolish	Localization	Center of Active	On leveled areas	Center of Active	Covers use area
	Distribution	Covering	Covering	Covering	Covering
	Density	Adjacent	Connected	Adjacent	Connected
	Microtopographic Contex	Highs/Interstices	High Topography	Highs/Interstices	High and low topography
	Morphology in Crosssecti	Irregular	Sinuous	Irregular	Sinuous
	Texture	Fluid	Fluid	Rough	Fluid
	Contours	Diffuse	Diffuse	Diffuse	Diffuse
	Structure	Connected	Connected	Connected	Connected
	Special Features	Striation/Leveled	Striations	On Leveled Areas	
	Vertical Extension	Part way into interstices	Only on highs	Can be found in pitting	Deep
	Opacity	Translucent/Opaque	Opaque	Translucent/Opaque	Opaque
	Brightness	Moderate	High	Dim	Moderate

Table 4.8: Comparison between the results I have gathered and those of the blind test for the legumes. Major differences with the blind test are highlighted in red and minor differences are highlighted in yellow.

Wear Type	Characteristic	Rinsed/Soaked Fenugreek	Rinsed/Soaked Fenugreek - Blind Test	Roasted Wheat Kernels	Roasted Hard Wheat - Blind Test
Linear Trace	Distribution	Not Observed	Not Observed	Loose	Not Observed
	Density	Not Observed	Not Observed	Separated	Not Observed
	Incidence	Not Observed	Not Observed	Shallow	Not Observed
	Disposition	Not Observed	Not Observed	Parallel	Not Observed
	Orientation	Not Observed	Not Observed	Longitudinal	Not Observed
	Striation/Scratch	Not Observed	Not Observed	Striations	Not Observed
	Length	Not Observed	Not Observed	Short	Not Observed
	Longitudinal Morphology	Not Observed	Not Observed	Continuous	Not Observed
	Transverse Morphology	Not Observed	Not Observed	V-Shaped	Not Observed
Polish/Sheen	Distribution	Covered	Loose	Covered	Loose
	Density	Close	Covering	Close	Separated
	Reflectivity	Moderate	Slight	Slight	High
	Incidence	High/Low	Extends into low topography	High/Low	High/low
Levelling	Distribution	Covering	Covered	Covering	Covered
	Density	Close	Connected	Close	Connected
	Incidence	High/Low	High topography	High	High topography
	Morphology	Sinuous	Sinuous	Sinuous	Rounded/Sinuous
	Texture	Smooth	Rough	Rough	Rough
Pits/Grain Ext.	Distribution	Covering	Covering	Loose	Covering
	Density	Close	Closed	Separated	Closed
	Depth	Superficial	Wide and Deep	Superficial	Wide/Deep & Shallow
	Shape in Plan	Irregular/Circular	Irregular	Circular	Irregular/Rounded
	Shape in Cross Section	U-Shaped	U-Shaped	U-Shaped	U-shaped
Fracturing	Distribution	Loose	Loose	Covering	Loose
	Density	Separated	Concentrated	Close	Concentrated
	Depth	Minor	Shallow	Minor	Shallow
Grain Edge Rounding	Present/Absent	Present	Present	Present	Absent
Micropolish	Localization	Whole Surface	On leveled areas	Whole Surface	Leveled areas
	Distribution	Covering	Sparse	Covering	Sparse
	Density	Adjacent	Connected	Adjacent	Separated
	Microtopographic Context	Highs/Interstices	High and low	High	Highs and lows
	Morphology in Crosssectio	Irregular	Sinuous	Irregular	Sinuous
	Texture	Fluid	Fluid	Fluid	Fluid
	Contours	Sharp	Diffuse	Diffuse	Diffuse
	Structure	Adjacent	Connected	Connected	Connected
	Special Features	On Leveled Areas	Linear traces	On levelled Areas	Linear traces
	Vertical Extension	Part way into interstices	Shallow	Only on Highs	Shallow
	Opacity	Translucent/Opaque	Opaque	Translucent/Opaque	Opaque
	Brightness	Dim	Moderate	Dim	Moderate

Table 4.9: Comparison between the results I have gathered and those of the blind test for the pre-treated materials. Major differences with the blind test are highlighted in red and minor differences are highlighted in yellow.

4.13 Chapter Summary

The experimental data set shows that while there are many similarities between the use-wear found on the various working surfaces, some key differences can also be found. These differences will be more fully explored in the interpretation chapter, but a few trends are outlined here. Differences can be found between the different classes of ground materials; those classes are cereals (netherstone 1), legumes (netherstone 2) and pre-treated materials (netherstone 3). The largest structured source of variation between the surfaces seems to be the linear traces. The surfaces used to process cereals feature a close density with shallow incidences. In contrast, the tools used for legumes have a separated density with a moderate incidence and the surface used for the altered materials has a close density. Additionally, in the case of the cereals, the linear traces are described as scratches, whereas for the other two categories, they can be classified as striations. Another seemingly structured source of variation can be found with the micro-polishing, where the pre-treated materials have the most extensive micro-polish, followed by the legumes and finally by the cereals.

	Barley and Wheat	Fenugreek and Lentils	Pre-Treated
Overlap (/39 and %)	30/40; 75%	30/40; 75%	20/40; 50%
Minor Difference (/39 and %)	9/40; 22.5%	9/40; 22.5%	10/40; 25%
Major Difference (/39 and %)	1/40; 2.5%	1/40; 2.5%	10/40; 25%

Table 4.10: A table that shows the degree of overlap in wear traces within the classes of material (cereal, legume and pre-treated).

In the above table (Table 4.7), the results of experiments are presented in a way that shows the degree of similarity within a material class. In the table, we can see that the wear on the tools used to process the cereals and legumes have identical rates of overlap in their respective classes. This is in contrast to the pre-treated materials, which have a relatively low amount of overlap between the two surfaces. While it is encouraging to see the high degree of overlap between surfaces used to grind cereals and, on the surfaces, used to grind legumes, what is more important is whether those areas where there is overlap in cereals there is also overlap with different characteristics in the other classes. This issue will be discussed further and answered in the following chapter.

The differences in observations found during the blind test show that it is possible to accurately identify and describe wear traces on a tool surface, even for an analyst with little familiarity with the tool type and raw material. Generally speaking, the results are similar, with most differences being a difference of degree; an example being that while during the blind test, the analyst found the polish on the tool used to process pot barley to have a concentrated distribution with a slight reflectivity I found it to have a covered distribution with a moderate reflectivity. These discrepancies seem to be more a matter of degree than kind, and much of the difference could be attributed to either a lack of familiarity with the surface, a differing understating of the criteria or differences in lighting, which can have a distinct effect on the visibility of linear traces, especially when they are shallow. All of the differences found both within my findings and when compared to the blind-test, will be covered in greater detail within the interpretation chapter, where they will be further contrasted with previously performed use-wear studies. The questions raised regarding the replicability of linear traces will be answered in the interpretation chapter.

Chapter 5: Previous Studies and Interpretations

Introduction

This chapter will consist of two sections; the first section reviews previous studies, emphasizing their descriptive criteria and the system they used to characterize use-wear. The experimental protocols will also be presented to see how they conducted their experiments, what materials they used, and their manufacturing process. At the end of this section, I will highlight previous studies' interpretations of their results and see whether they match what I found. Within the second section of this chapter, I will be detailing the interpretation of my results along with the blind-test and compare these to and the results of previous studies. Whether the results of the previous research reinforce the findings of others or conflict with one another, valuable conclusions will be drawn.

5.1 Previous Studies

The first use-wear study I will highlight in this section is the study performed by Dubreuil, published in 2004, titled “Long-term Trends in Natufian Subsistence”. Within this study, Dubreuil explores the relationship between the types of material processed and the resulting use-wear pattern. The types of material used to manufacture the tools for this study is cryptocrystalline basalt, and the material ground for this study is ochre, domesticated wheat, wild barley, acorns, nuts, mustard seeds, fenugreek fava beans, dried meat and dried fish, along with using abraders for bone, wood and hide processing. As my study consisted of grinding wheat, barley, fenugreek and brown lentils, the relevant observations and interpretation from this study are those surrounding the domesticated wheat, wild barley and fenugreek. The tools used for grinding in Dubreuil’s study were used for a total of 5 hours each, which gives the same level of use that the tools in my study have.

In Dubreuil's study, she described wear traces in regards to the formation of plateaus, the striations present, grain modification and the presence of reflective zones. As the article studied both cereals and legumes, we will begin by covering the results from grinding each different material. Regarding wheat, it is found that the topography had seen the development of plateaus on the macroscopic level, which started as rounded but became flatter as the experiment progressed. Using a stereomicroscope, I found that on the plateaus, there is fracturing, extensive levelling of summits, grain edge rounding and the formation of homogenous zones, as well as some traces of pecking. The surface of this tool is slightly reflective, and a group of short striations could be found within the homogenous zones. For the tool used to grind barley, on the macroscopic level, the results are much the same as on the previous. When examining the surface under a stereomicroscope, it is found that there is evidence of chipping on the levelled plateaus, an extensive amount of levelling, grain edge rounding, the formation of homogenous zones, and some evidence of pitting. The surface of this tool is highly reflective, and once again, short striations can be found in the levelled-off areas (Dubreuil 2004).

For the tool used to grind fenugreek, there is extensive development of plateaus. When using a stereomicroscope, it is found that the levelled-off plateaus, which are significant, are interrupted by small hollows and that the use-wear is mainly developing through grain micro fracturing. No striations are found on this tool, and both a gloss and a dark colouration can be found on the surface. On the macroscopic level, rounded levelled off areas that are seemingly becoming flatter are observed for the fava beans. Using a stereomicroscope, it is observed that the levelled-off areas are interrupted by small pits, and the formation of those areas is being developed primarily through pitting. As with the fenugreek, there is the formation of a gloss and a dark metallic coloration on the surface, and no striations are present (Dubreuil 2004).

The second use-wear study selected here is "Grinding Cereals and Pulses in the Neolithic Site of Kleitos: an Experimental Investigation of Microconglomerate Grinding Equipment, Final

Products and Use Wear” written by Chondrou et al. in 2018. This paper conducted a series of grinding experiments to process einkorn wheat and grass pea using small-sized grinding tools that replicate the Neolithic implements recovered at the Kleitos site. Two sets of grinding implements were manufactured. Each set is composed of a quern with an open, flat active surface and an elongated shape and a curvilinear handstone, with a flat, open surface and length exceeding the quern's width. Four water-rolled microconglomerate stones were selected due to their raw material and morphometric traits. The active surfaces of the implements have the same size, and the handstones have the same weight. Pecking was applied on the active surfaces of the four tools with a hard pebble-stone to obtain the required surface roughness. The grinding process was divided into ten-minute sessions. The total amount of grain processed, the number of back-and-forth movements, and the number of pauses for the grinder to relocate the grain onto the grinding surface were counted. The grinding stones were operated in the typical reciprocal movement for a total of 1 hour and 20 minutes (Chondrou et al. 2018).

The tool used to grind grass peas, when observing it macroscopically, kept its irregular surface with the addition of sporadic plateaus of mild levelling. The surface is dull, having minimum reflectivity. On the microtopography, there is an intense roughness and fracturing present on the high topography. On the low topography, there is limited grain edge rounding present (Chondrou et al. 2018). For the tool used to grind einkorn wheat, the levelling is said to have been more intense than the previous surface, and there is also a sheen that formed in small patches. The microtopography of the surface also displays signs of fracturing, albeit with asperities with a smoother relief. There are signs of intense levelling on the protruding grains of the surface and some mild alteration being found in the interstices but none on the lowest points of the surface (Chondrou et al. 2018).

The third use-wear study I will be comparing my results to is from a journal article titled “Functional Analysis of Stone Grinding and Polishing Tools from the Earliest Neolithic of North-

Western Europe" by Caroline Hamon in 2008. In this study, an experimental collection of 92 tools were used to grind cereals, pound temper, colourants and various plants, shape mineral, vegetal and animal objects by polishing and softening skin. The tools in this experimental collection are made of sandstone, and this experiment is done for two reasons; the first reason being to gain an understanding of cereal processing techniques and the second reason being to understand how and which stone tools were involved in the processing of a wide range of substances and the manufacture of specific objects. Of the 92 tools in the experimental collection, 19 were used to grind wheat, hulled barley and spelt; six were used to pound legumes, hazelnuts and plants; 10 were used for crushing clay and colourant and burnt flint, bone and grog. 51 surfaces were used to work dry or wet bone, antler, shell, limestone and schist, and finally, six were used to de-flesh and soften dry and wet hide (Hamon 2008).

In Hamon's study, it is noted how quickly use-wear forms is influenced by the type of sandstone used; well-cemented sandstone became smoother much quicker than the poorly cemented sandstone. Additionally, it is remarked that due to the concentration of silica within the glumes of cereals and how it influences wear development, it is possible to distinguish grinding naked cereals from grinding to de-husk. However, the distinction is only visible after at least 180 minutes of use. The results of their experiments grinding de-husked wheat shows the surface to have levelled grains with contiguous edges, with a transparent residue that covered the entire surface (Hamon 2008).

Fourthly, a use-wear study titled "Sandstone Grinding/Pounding tools: Use-Trace Reference Libraries and Australian Archaeological Applications" by Hayes et al. in 2018 is relevant to this thesis. Twenty-eight grinding stones were used in 19 controlled experiments to assess sandstone tools' variables, particularly sandstone hardness and how it can affect wear formation. Ten stones were used individually, and the rest were partnered as dedicated upper and lower pairs to process an intermediate material. Stones were used individually or as paired grinding stones to replicate a range of known Aboriginal grinding activities. Processing actions included grinding, pounding and abrading and processing times ranged from 10 minutes to 4 hours (Hayes et al. 2018). The results I will be covering are those related to seed grinding and wheat grinding, as they are the closets to my experiments.

For the experiments on seed grinding, the authors report that surface levelling ranges from minimum to high, grain rounding varies from moderate to high, macro striae are present and common, the polish's morphology is described as reticular with a brightness that ranges from moderate to bright, a coverage which ranges from localized to extensive, a development which ranges from weak to well-developed and finally fine striae are common and have multiple orientations, and grain fractures are present. On the surface used to grind wheat, there is a high degree of levelling and grain rounding; macro striae are present and have multiple orientations. The micro-polish on the tools has a reticulated morphology and formed in striations; the brightness varies from dull to moderately bright and has a coverage that ranges from localized to moderate with a moderate development. Fine striae are present with multiple orientations, and grain fracturing is also present (Hayes et al. 2018).

The fifth use-wear study included in my comparative approach is titled "Processing Plants For Food: Experimental Grinding Within the ERC Project PLANTCULT", written by Bofill et al. in 2020. This study focuses on tools operated by back-and-forth reciprocal motion and circular motion and manufactured from different raw materials (sandstone, andesite and granite), morphologies and sizes. The experimental protocol included the manufacture of three querns and handstones made of the three raw materials (sandstone, andesite and granite) and five extra pairs of tools of the same types and size. The experimental grinding tools fall into two major size categories, small (grinding slabs < 30 cm long) and big (> 30 cm) implements; only small size granite tools were replicated. Three different categories were created based on the three basic tool-types of archaeological grinding implements that they came across: grinding slabs with handstones of the "overhanging" type used in a back-and-forth reciprocal motion, grinding slabs with a small handstone used in a back-and-forth reciprocal motion and grinding slabs with a small handstone used in a circular and free motion (Bofill et al. 2020). The tools used to grind einkorn, hulled einkorn and barley, as well as legumes, were all used for a total of five hours. Once again, this gives the tools in this study the same amount of use as the ones in my experiment.

I will be discussing their observations on the grinding of de-husked einkorn wheat, hulled einkorn wheat and barley, and legumes. On the tool used to grind the de-husked einkorn, the distribution of the use-wear is largely contained to the center of the active surface, where the traces of manufacture (pecking) have largely been overwritten. Some grain levelling is found on the lower topography of the surface. The levelled-off plateaus on two of the tools have flat and sinuous morphologies, and on the third, they are more rounded. Grain removal and grain edge rounding are observed on the high topographies of the surfaces, the polish is found within the center of the active surface and striations are observed on the larger inclusions (Bofill et al. 2020).

For the tool used to grind the hulled einkorn and barley, the traces of manufacture (pecking) are still observed after grinding, and the only instances of (rough) levelling are seen on the center of the active surface where the most amount of contact with the handstone would have been. The morphology of the surface is described as being composed of sinuous platforms with angular-edged grains. The use-wear traces reported on this surface are a low degree of grain edge rounding, low development of polish on individual grain summits and the presence of micro fracturing, preserved from the manufacture of the tools. No linear traces are observed on the surface (Bofill et al. 2020).

The plateaus visible on the surface are made through the levelling and rounding off of grain’s summits on the tool used to grind legumes. The distribution of these plateaus is loose across the whole surface, except in the center of the tool, where they have a dense concentration. The surface morphology is described as having a sinuous texture and a rounded shape, with an almost unaltered low topography; generally, most edges are angular, and only a few instances of grain levelling can be found within the center of the active surface. Microfractures and grain extraction leftover from the manufacture can be found, and some general grain rounding can be observed and some striations on the larger crystals. No polish is observed on this surface (Bofill et al. 2020).

Now that the studies have been introduced and their observations have been laid out, I can compare their results to my own. The comparison between the different studies will be broken up into sections; the first outlines the similarities and differences in cereal wear traces, the second outlines the similarities and differences between legumes, and finally, the third section will outline the similarities and differences between cereals and legumes.

5.2 Similarities and Differences in Experimental Use-Wear Related to Grinding Cereals

Largely, the outlined studies reported their findings, first by outlining the general topography of the surface, identifying the wear traces visible on the micro-topography, the presence and character of polish and lastly, the presence of linear traces. To compare my results easily to these studies, I had to re-organize my observations to align with this format. A table showcasing the observations of all these studies can be seen in Table 5.1.

Looking at the results of the surfaces used to grind wheat in these studies, what patterns can be seen? Regarding the topography of the surface, it is reported in three studies (Chondrou et al. 2018, Hamon 2008 and Hayes et al. 2018) that a high degree of surface levelling has occurred, which resulted in levelled plateaus forming while in two other studies (Bofill et al. 2020 and Dubreuil 2004) there is minor surface levelling which has resulted in the formation of sinuous plateaus, which conforms to what I have observed as well. It is important to note that it is mentioned that in one of the studies (Dubreuil 2004) that while they have observed rounded plateaus, they are becoming increasingly levelled and flat. The grain modification on the homogenous zones of these tools shows that all of the surfaces used to grind cereals have shown grain levelling, grain edge rounding, fracturing and grain extraction. Of the studies surveyed, all have described seeing levelling on individual grains, with three of them (Chondrou et al. 2018, Dubreuil 2004, and Hayes et al. 2018) reporting a high degree of it.

Regarding the presence of polish on these surfaces, all of the studies have reported seeing it, describing it to be on the high topography and either having a dull or slight reflectivity. The only outlier to this is Hayes et al.'s study (2018), where it is described as ranging from dull to highly reflective. This might not be indicative of the worked material; however, as in this study, the tool is made of sandstone. Lastly, three studies reported linear traces (Bofill et al. 2020, Dubreuil 2004 and Hayes et al. 2018), each describing them slightly differently. In Dubreuil 2004, short striations are found on the levelled plateaus, while in Hayes et al. 2018, they have seen both macro and micro striations, and in Bofill et al. (2020), striations are seen on large inclusions. With the wear trends belonging to the wheat surfaces outlined, we will now move on to the tools used for barley.

The topography of the surfaces used to grind barley has varied more between studies than wheat. In one case (Dubreuil 2004), the topography is primarily the same as that encountered on the tool used for wheat, while the other surfaces showed a less levelled and worn-down topography. In the case of Bofill et al.'s (2020) experiment, only a single rough instance of levelling is present, as well as a surface which still shows the wear traces associated with manufacture. This is much different from my results, where I observed the formation of plateaus with a higher degree of levelling. This result is interesting as this would suggest a short use-time for the tool, but our tools have been used for the same duration: five hours. As the results from Dubreuil's study (2004) have reported findings similar to my own, I would hypothesize that this difference would likely be due to the tool being used to grind both wheat and barley. Perhaps a higher degree of material was placed on the tool, and there was a reduced amount of contact between the handstone and netherstone, or a difference in grinding technique could have resulted in this difference.

On these surfaces, levelling, fracturing, grain edge rounding and grain removal are all documented. In the studies performed by Dubreuil (2004) and Hayes et al. (2018), a high degree of grain edge rounding is reported, and in both of those studies, as well as my own, a high degree of levelling is also documented. When examining the polish on these tools, all studies have reported its presence on the surface and have reported its brightness to either be highly reflective/ bright (Dubreuil 2004), ranging between moderate to bright (Hayes et al. 2018) or just simply moderate in the case of my study. Lastly, in two studies relating to barley (Dubreuil 2004 and Hayes et al. 2018), striations are observed on well-developed areas of the tool's surface.

When comparing the results from the tool used for grinding wheat and those used for grinding barley, one thing that becomes immediately apparent is the issues around topography. As wheat and barley are largely similar in their physical attributes (hardness, dryness, size), variations in how the material will affect the topography development are likely to be quite limited. Looking at the results in the studies surveyed and my experiments, this seems to be the case. It seems to require significant differences between two materials' hardness or moisture content for a clear difference in the tools' topography to manifest. Without a substantial difference in the materials' nature, the morphology of the topography seems to be defined by the amount of time the tool has been used for.

Regarding the ability to differentiate these two materials, what then can we look towards? It appears that grain modification shows the most promise. Polish has developed on all of these tools, with wheat and barley resulting in different polish. Their polish varied in brightness, with barley providing a brighter reflectivity. However, due to the subjective element of this attribute, it is not a reliable differentiator. In a similar fashion to polish, linear traces have also formed an association with both materials, albeit less reliably. When differentiating the aspects of micro-topography between these two materials, it is not dependent on finding a feature exclusive to the material but rather identifying what forces are dominant in the modification of the micro-topography. According to the studies I have surveyed for the surfaces used to grind wheat, it appears as though there is more levelling and fracturing present on the surfaces that ground barley. However, these differences do not seem to be clear cut; as in my study, I observed more levelling on the surface associated with barley. With this data, there are only slight differences between the two surfaces due to the degree of development of one or two aspects of the wear.

Material/Study	Wheat - Dubreuil 2004	Barley - Dubreuil 2004	Wheat - Chondrou et al. 2018	Wheat - Hamon 2008	Wheat - Hayes et al. 2018	Barley - Hayes et al. 2018	Wheat - Bofill et al. 2020	Barley - Bofill et al. 2020	Wheat - Personal Experiment	Barley - Personal Experiment
Topography	Rounded Plateaus - Becoming Increasingly levelled.	Rounded Plateaus - Becoming Increasingly levelled.	Levelled	Levelled	Levelled	Minimum to high surface levelling	Sinuous/Rounded edged levelled Pllateaus	Traces of manufacture (pecking) still present, one instance of rough levelling.	Sinuous Plateaus	Levelled plateaus with rounded edges
Micro-topogrpahy	Fracturing, extensive levelling of grains, grain edge rounding, formation of homogenous zones, some pitting.	Extensive amount of levelling, fracturing, grain edge rounding, formation of homogenous zones, some evidence of pitting.	Fracturing, intense levelling on grains	Levelling on grains	High degree of levelling, grain edge rounding, fracturing	Moderate to high grain edge rounding, fracturing present.	Grain levelling, grain removal and grain edge rounding	Low degree of grain edge rounding, fracturing (leftover from manufacture)	Slight levelling and slight grain extraction present. Grain fracturing and edge rounding also present.	Grain removal, levelling, edge rounding and fracturing all present.
Polish/Reflectivity	Polish present, slightly reflective.	Polish present, highly reflective	Small patches of sheen	Transparent residue covered entire surface	Micro-polish present, reticulated morphology and forming in striations. Dull to bright.	Present, coverage varies from localized to extensive reticular morphology with a brightness ranging from moderate to bright.	Present on high topography	Present, low devlopment on summits of individual grains	Present on high topographies with a slight reflectivity.	Present on high and low topography with a moderate reflectivity.
Linear Traces	Short striations found in homogenous zones.	Short striations can be found in levelled areas	Not Observed	Not Observed	Macro and micro striations	Fine striations were common, having multiple orientations	Striations present on larger inclusions	Not Observed	Not Observed	Not Observed

Table 5.1: Results from a sample of studies investigating use-wear associated with grinding cereals; results are broken down by the topography, micro-topography, presence and character of polish and the presence and character of linear traces.

5.3 Similarities and Differences in Experimental Use-Wear Related to Grinding Legumes

It is important to note that in contrast to the cereals, there is much less data related to use-wear experiments focusing on legumes, specifically fenugreek and lentils, leaving this section with less information to work with. A table highlighting the simplified results from these studies can be seen in Table 5.2. We will start the comparison with fenugreek.

In Dubreuil's 2004 study, the fenugreek results highlight that there is a development of extensive levelled plateaus, and on the microtopography, there is extensive fracturing along with the formation of gloss with a dark colouration. No linear traces are observed. Comparing this to my study, the results seem quite similar. Re-iterating what is covered in the results, I reported the observation of extensive levelled plateaus and fracturing alongside grain levelling and grain extraction. I also reported the presence of polish on both the high and low topography, which has a slight reflectivity. This polish coincides with a darkening of the surface. No linear traces are observed on this tool as well. The results from Dubreuil's 2004 study and my experiments seem to line up well. Next, we will move on to the experiments on lentil processing and see what trends exist.

Bofill et al.'s 2020 experiments, a combination of grinding lentils and bitter vetch, report the formation of loosely distributed plateaus with a sinuous morphology. This differs from what I have observed on the tool I used to grind lentils which saw the formation of extensively levelled plateaus. On the microtopography of Bofill et al.'s tool, few instances of grain levelling and grain edge rounding are observed. Fracturing and grain extraction is more common on this surface. On the tool I used to grind lentils, similar results are seen. A high degree of grain extraction, grain levelling and fracturing is recoded for this tool, which mirrors Bofill et al.'s results except for grain levelling, which on Bofill et al.'s tool only a few instances are seen. A stark departure between Bofill et al.'s result and mine is regarding the formation of polish. On Bofill et al.'s tool, no signs of polish are observed, whereas, on my own, I have seen it form on both the high and low topography with a slight reflectivity. Another departure between our two studies is that while I did not observe any linear traces on the surface, Bofill et al. have on the larger crystalline inclusions.

Comparing the results from the studies on fenugreek and lentils, what, if any, wear traces can differentiate the two? Similar to what was mentioned when comparing the cereals, I don't believe the topography of these tools is a reliable way to set them apart, as it is most likely influenced more by use-time than anything else. However, it might be helpful when comparing classes of material. Once again, it appears that the grain modifications will provide the best, most reliable way of differentiating these materials. For both materials, fracturing played a prominent role in plateau formation, but in the case of fenugreek, it is much more pervasive in both Dubreuil's 2004 study and my experiments. Likewise, for the lentils, while levelling is also observed on the tools used to process fenugreek, it is much more pervasive on these surfaces. It is important to note that while my study has found a high degree of levelling in association with lentils, Bofill et al.'s study only observed a few instances of grain levelling; the differences might be because they ground a mixture of lentils as well as bitter vetch (Bofill et al. 2020).

Material/Study	Fenugreek - Dubreuil 2004	Lentils* - Bofill et al. 2020	Fenugreek - Personal Experiment	Lentils - Personal Experiment
Topography	Extensive development of levelled plateaus.	Loose distribution of plateaus with a sinuous texture and a rounded shape.	Extensive levelled plateaus.	Extensive levelled plateaus.
Micro-Topography	Extensive fracturing.	Few instances of grain levelling and grain edge rounding. Fracturing and grain extraction are present.	High degrees of fracturing and grain extraction are present. Levelling present.	High degree of levelling present as well as grain extraction. Fracturing present
Polish/ Reflectivity	Gloss and dark colouration are present.	Not Observed	Present on both high and low topography, slight reflectivity.	Present on both the high and low topography has a slight reflectivity.
Linear Traces	Not Observed	Present on larger crystals.	Not Observed	Not Observed

Table 5.2: Compilation of the studies analyzing use wear related to legumes. *Bofill et al. 2020 results from grinding both lentils and bitter vetch.

5.4 Similarities and Differences Between Use-Wear Related to Cereals and Legumes

Differentiating cereals and legumes begins with looking towards the surfaces of the tools' overall topography to help make distinctions. While for both cereals and legumes, there is a pronounced levelling of the topography and the formation of plateaus, the speed of this process and the edges of these plateaus have differed. On the surfaces used to grind cereals, the topography, while having some degree of levelling, is much more rounded, having a sinuous shape along with a rougher texture. In the study performed by Dubreuil (2004), Bofill et al. (2020) and the barley experiment done by Hayes et al. (2018), instances of a moderate amount of levelling with rounded/sinuous plateaus are reported, which matches the data I gathered for both my wheat and barley experiments. These topographies contrast with those used to grind the legumes as on the study performed by Dubreuil in regards to fenugreek and lentils (2004) and my own on both fenugreek and lentils the development of extensive levelled plateaus are observed. This differs from the results found by Bofill et al., however, who had described a loose distribution of plateaus with a sinuous texture and rounded shape. This difference could be due to the different materials the tools were made from; as in Dubreuil's (2004) study and my experiments, basalt is used; in Bofill et al.'s (2020), it is not.

Regarding grain modifications, the most significant difference between cereals and legumes seems to be that in the case of cereals, much more grain edge rounding is present, often missing outright for legumes. In the studies overviewed, grain edge rounding is reported for all cereal grinding, the only exception being the study performed by Chondrou et al. (2018). In the case of Chondrou et al.'s study, this is likely due to the tool only being used for 1 hour and 20 minutes. For the grain modifications on the surfaces used to grind legumes, the dominant and distinguishing feature is the amount of fracturing. While fracturing is present in the surfaces used to grind the cereals, it is far less prevalent than on the surfaces used to grind either legume or fenugreek, which are found to have an extensive amount of fracturing, in my experiment as well as in Dubreuil 2004. While fracturing is not the most proliferated wear trace on the tool I used for lentils, it still did have an extensive presence on the tool.

While grain edge rounding and fracturing seem to be the best differentiating factors between cereals and legumes, there is another, less pronounced, differentiating factor; the amount of grain levelling. On the surfaces used to grind cereals, levelling is much more common than those used to grind the legumes. In all of the studies surveyed, except one, grain levelling is found on the micro-topography. In the study performed by Dubreuil (2004) on both the tools used for wheat and barley, extensive levelling of grains is observed, mirroring the findings of Hayes et al. (2018), who reported extensive levelling in association with wheat. While I have not seen an extensive amount of levelling associated with barely, I have seen it with the surface used with wheat. While the surface used to process fenugreek shows more levelling, pot barley has a similar amount to it and more than is found on the surface used to grind lentils.

5.5 Influence of Pre-Treatment

Aside from the amount of time a tool is used, some of the most significant influences on wear formation are the worked materials' hardness, size and moisture content. It would then stand to reason that if the same material is ground but with one of these aspects altered somehow, different wear patterns should be observed. To explore this, I will now cover the results from the pre-treated ground materials and how they have varied from the unaltered counterparts (presented in tables 5.3 and 5.4). We will start by comparing the un-altered and pre-treated hard wheat kernels.

Comparing the unaltered and roasted hard wheat kernels, the most notable difference is the appearance of linear traces on the surface, missing on the unaltered variant. The appearance of linear traces could be due to the ease of rendering the hard wheat kernels into flour. When grinding the roasted hard wheat kernels, almost no pressure is required to render them into flour, which has resulted in the majority of the material becoming an increasingly fine flour. In contrast, the hard kernels were slowly being reduced in size. This smaller particle size of the work material resulted in an increased amount of contact between the upper and lower tools and is likely the cause for the appearance of striations. Protruding grains on the handstone were able to make contact and gouge the surface of the netherstone. This increased amount of contact between the surfaces is likely the reason for the increased levelling on the surface.

Wear Type	Netherstone 1; Side B Hard Wheat Kernels	Netherstone 3; Side B Roasted Wheat Kernels
Linear Trace	Not Observed Not Observed Not Observed Not Observed Not Observed Not Observed Not Observed Not Observed Not Observed	Loose Separated Shallow Parallel Longitudinal Striations Short Continuous V-Shaped
Polish/Sheen	Loose Separated Slight High	Covered Close Slight High/Low
Levelling	Loose Close High Sinuous Rough	Covering Close High Sinuous Rough
Pits/Grain Ext.	Loose Separated Superficial Irregular U-Shaped	Loose Separated Superficial Circular U-Shaped
Fracturing	Covering Connected Moderate	Covering Close Minor
Grain Edge Rounding	Present	Present
Micro-polish	Center of Active Sparse Adjacent Parallel to Major Axis Topographic Highs Irregular Rough Diffuse Connected Striations/Leveled Only on Highs Translucent/Opaque Dim	Whole Surface Covering Adjacent Parallel to Major Axis Topographic Highs Irregular Fluid Diffuse Connected On levelled Areas Only on Highs Translucent/Opaque Dim

Table 5.3: Comparison of the unaltered and pre-treated hard wheat kernels. Differences are highlighted in red.

The other area in which the use-wear patterns of these surfaces differed is in their polish and micro-polish. The polish has a more developed distribution and density on the roasted hard wheat kernels, going from loose and separated to covered and close. Likewise, the micro-polish associated with the roasted hard wheat kernels went from a sparse covering within the centre of the active surface and a rough texture to the entire active surface with a covering distribution with a fluid texture. Once again, aside from the change in texture, I believe these changes are due to an increased amount of contact. However, this time it is not an increased amount of contact between the two tools but an increased amount of contact between the netherstone surface and the material. With the unaltered hard wheat kernels, only a few could be placed on the netherstone and worked at a time, whereas with the roasted variant, as the kernels broke down quite rapidly, more material is in contact with the surface. While this might explain the increased coverage of the polish and micro-polish, it does not explain the change in texture. I believe this difference might be due to the increased softness of the roasted variant over the unaltered kernels.

The two surfaces used to process fenugreek differ in the development of levelling, fracturing, grain edge rounding, and the micro-polish's nature. The rinsed/soaked fenugreek shows levelling similar to the unaltered except in two characteristics; the incidence and texture. The levelling for the altered is found on both the high and low topography, with a sinuous rather than flat texture. I believe this difference to be due to the increased malleability and reduced hardness of the rinsed/soaked fenugreek. When grinding the fenugreek, I found it to be the most rigid material out of all of the experiments, and a high degree of force is required to render it to flour. This contrasts with the rinsed/soaked fenugreek, which deformed into a pulp when worked and required little force to do so. When the rinsed/soaked fenugreek is ground, it moulded to the tool's surface and would have rubbed against the netherstone. This material would have been much gentler on the surface. This is also likely the reason for the reduced amount of fracturing and the presence of grain edge rounding on the surface.

The differences in the polish and micro-polish between the two surfaces are likely due to the reduced hardness of the material. The unaltered fenugreek has a more contained presence on the tool, only appearing within the center of the active surface, in contrast to the altered variant, whose micro-polish is observable across the entire active surface. This is because when grinding the un-treated fenugreek, only a few kernels at a time could be ground due to their hard nature. Adding too many would result in the fenugreek spilling off of the surface, so only a few kernels, which required a significant amount of downward pressure, could be worked at a time. For the rinsed/soaked fenugreek, more could be placed and processed on the surface at once. For the difference in the contours of micro-polish, the change might be because the rinsed/soaked fenugreek did not move around much on the surface when being worked, so individual patches of micro-polish might have had a longer time to develop.

Wear Type	Netherstone 2; Side A Fenugreek	Netherstone 3; Side A Rinsed/Soaked Fenugreek
Linear Trace	Not Observed	Not Observed
	Not Observed	Not Observed
	Not Observed	Not Observed
	Not Observed	Not Observed
	Not Observed	Not Observed
	Not Observed	Not Observed
	Not Observed	Not Observed
	Not Observed	Not Observed
	Not Observed	Not Observed
Polish/Sheen	Covered	Covered
	Connected	Close
	Slight	Moderate
	High/Low	High/Low
Levelling	Covering	Covering
	Close	Close
	High	High/Low
	Flat	Sinuous
	Smooth	Smooth
Pits/Grain Ext.	Covering	Covering
	Close	Close
	Superficial	Superficial
	Circular	Irregular/Circular
	U-Shaped	U-Shaped
Fracturing	Concentrated	Loose
	Close	Separated
	Minor	Minor
Grain Edge Rounding	Absent	Present
Micro-polish	Center of Active	Whole Surface
	Covering	Covering
	Adjacent	Adjacent
	Parallel to Major Axis	Parallel to Major Axis
	Highs/Interstices	Highs/Interstices
	Irregular	Irregular
	Fluid	Fluid
	Diffuse	Sharp
	Connected	Adjacent
	Striation/Leveled	On Leveled Areas
	Partway into interstices	Partway into interstices
	Translucent/Opaque	Translucent/Opaque
	Moderate	Dim

Table 5.4: Comparison of the unaltered and pre-treated fenugreek. Differences are highlighted in red.

5.6 Insights from Starch Analysis of Experimental Tools

As mentioned in the previous chapters, use-wear studies are greatly aided by the inclusion of multiple analysis streams. In that vein, I will now discuss the starch analysis results I have reported within the results chapter, outlining whether or not they can aid this differentiation process. While the results of this residue analysis are admittedly quite limited, I believe it can still provide some insight regarding the broad strokes of contrasting nature of cereal and legume starches. As a reminder, in the present study, a sample of residue is taken from the tools used to process pot barley and lentils, which were then mounted onto a slide and observed under a transmitted light microscope. The number of starches observed a well as their shape, and relative size is recorded. The results from this study can be seen in Table 5.5.

When performing the starch analysis, one thing became apparent right from the beginning; there were vastly more starches present on the wheat slide than on the lentil slide. In total, there were 389 starches within the section of the wheat slide I observed and only 31 for the lentils. With a difference this vast, it seems that some aspect of the mounting or residue collection procedure potentially influenced the results; however, all steps taken were the same for both slides. At this point, the discrepancy remains challenging to explain. Taking this problem into account, I decided to compare the different shapes encountered by the percentage of the sample they had made up. For the starches encountered on the wheat slide, the largest group is the circle starches, comprising 48.6 percent of the starches observed on the slide. For the lentils, the largest group is the ovals, which comprised 35.5 percent of the starches encountered. The least encountered starch types on each slide are the clusters on the wheat slide, with only one being encountered, and the doughnut type on the lentil slide. In addition to these differences, it also seems the starches on the lentil slide are larger, a large part of which is due to the higher number of starch clusters.

Wheat	Shape	Extinction -Cross	Size	Lentils	Shape	Extinction -Cross	Size
	Circle = 188 (48.45%)	Yes = 22	Avg = 395.98		Circle = 5 (16.13%)	Yes = 1	Avg = 517.11
	Oval = 84 (21.65%)	No = 367			Oval = 11 (35.48%)	No = 30	
	Doughnut = 64(16.49%)				Doughnut = 1 (3.23%)		
	Irregular = 30 (7.73%)				Irregular = 3 (9.68%)		
	Cluster = 1 (0.26%)				Cluster = 5 (16.13%)		
	Broken = 21 (5.41%)				Broken = 6 (19.35%)		

Table 5.5: The results from the starch analysis; the shape of starches, the presence of extinction crosses and average size are reported.

5.7 Differences in Productivity

If we aim to understand the transition from foraging to farming, we need to consider the thought process which led to the material being ground. In pursuit of this, I will be examining the materials ground during the experiments in terms of their output in total time spent processing them. As outlined in the background chapter, Foraging Theory examines choices in subsistence by their measured inputs and outputs. Evaluating the productivity of grinding will enable us to better understand past dietary choices. All of the materials ground in the experiments will be discussed here concerning their output and the ease or difficulty of the grinding. The only material not covered will be the ground rinsed/soaked fenugreek as its intended product is vastly different from the others and not apt for comparison.

Starting with the pot barley, which did not require a significant amount of pressure to grind, a total of 350 grams of flour was produced over five hours. As with nearly all of the materials, the amount ground per hour increased as I became more familiar with the material and acquired a “feel” for it. The hard wheat kernels were much more difficult to grind, requiring more force to render them into flour. In total, 235 grams of flour were produced. For the fenugreek, which was the hardest material to grind, 210 grams of flour was produced over the five hours. The lentils, which required some force to grind, mainly due to the outer shell, produced 270 grams of flour. Lastly, the roasted hard wheat kernels, which were by far the easiest product to grind, produced a total of 557 grams of flour.

To compare the efficiency of the tools, we will rank the cereals and legumes by the weight of flour they produced, the order is; 1) roasted hard wheat kernel, 2) pot barley, 3) brown lentils, 4) hard wheat kernels, and 5) fenugreek. Simply looking at just the amount produced does not give the whole story, as the ease of grinding is also essential. This aspect largely mirrors the amount produced. However, given that the hard wheat kernels needed to be roasted before grinding, this negatively affects their ranking as this represents an additional investment. Additionally, roasting the hard wheat kernels runs the risk of burning them and would also impact the taste. If I chose a single material to be the most attractive from an input/output perspective, I would say the pot barley provided the best output in terms of grams without requiring any additional investment aside from the grinding.

Comparing the results on productivity it is important to make note of the size of the tools. Naturally a larger active surface will enable a greater quantity of material to be processed, which can skew a comparison. It is important to note that in Bofill et al. 2020, two sets of tools were used, those classified as large tools (>30cm) and those classified as small tools (<30cm); the tools compared here belong to the small category. Comparing what I found for wheat and barley to what Bofill et al. (2020) found produces some interesting results. While I had 350 grams of flour produced after 5 hours for barley and 235 grams for the hard wheat kernels in Bofill et al.'s study, 1,050 grams of flour is produced from the barley, and 975 grams of flour is produced from the wheat, both of which were created over a total of 5 hours. Two things are notable in this comparison; firstly, in Bofill et al.'s experiments, more than double the amount of flour is produced in the same amount of time and secondly, the total amount of what is produced in those

5 hours is closer between the wheat and barley compared to my results. As the tools in both of these studies are considered small, these results most likely show that, above all else, it is the person behind the tool use who is most responsible for the output of a tool. These results can be seen in Table 5.6.

Material	Total (5Hrs)
Wheat	235 grams
Barley	350 grams
Wheat (Bofill et al.)	1,050 grams
Barley (Bofill et al.)	975 grams

Table 5.6: Comparison between the amount of flour produced in my experiments and Bofill et al.'s experiments.

Looking towards another study on grinding productivity, similar results can be found. In "The Origins of Grinding Grains and Breadmaking" by Hayden et al. (2017) they report the results from a number of different studies and ethnographic data. Of these covered studies one is highlighted which included grinding experiments on both wet and dry wheat grains. For the dry wheat kernels, it took 2.5 hours to grind one kilogram of flour. For the wet grain however it had only taken 1.7 hours to grind one kilogram into a paste like substance. Comparing the amount of flour produced from dry wheat kernels between out two studies shows significant differences. While the study Hayden et al. had referenced produced one kilogram in 2.5 hours I was only able to produce 235 grams in five hours, roughly a quarter of what they produced in double the amount of time. Interesting results can also be found when comparing the increased productivity between dry and wet variants of the same material. In my study I had found that there was an increase of productivity when grinding the soaked fenugreek compared the dry, an increase from 210 grams of flour to 330 grams of pulp. This matches the study Hayden et al. had cited in their recounting, which was an increase from 1 kilogram in 2.5 hours to 1 kilogram in 1.5 hours. While the way in which we sought to measure the productivity differed, the rise in productivity associated with pre-treatment remains apparent. These results can be seen in Table 5.7.

Material	Initial Product	Post Treatment	Increase
Fenugreek	210 grams (5hrs)	330 grams (5hrs)	120 grams
Wheat	1,000 grams (2.5 hrs)	1,000 grams (1.7hrs)	0.8 hrs

Table 5.7: Comparison between my results on the effects of soaking and those reported in Hayes et al.’s article.

5.8 3D Models

The 3D models created of each of the grinding surfaces were created and used for various reasons. Firstly, the models enabled me to review the tools' morphology when away from the lab in a much more thorough and interactive way than a photograph. Secondly, these models create a permeant record of the tool after 5 hours of use. This is important because if the tools encounter further use, are destroyed or are misplaced, a record of the wear-traces developed will remain, which can still be compared to other tools. Lastly, these models also present an opportunity for others to better understand the tool's morphology by manipulating the model in a three-dimensional space, giving them a better idea of how the tool may have been held and used. An example of the 3D models created can be seen in Figure 5.1, and links to view each model is provided in Appendix A. While these models represent a preliminary effort and more could have been done with them, creating them had given me insight into how they could be used in further research.

Figure 5.1: An example of one of the 3D Models.

5.9 Blind-Test Differences

The wear traces I have found on the surface did not come from a single round of observations. The tools were examined multiple times, and my findings were constantly being re-examined as I became more familiar with the tool's surface. It is important to clarify that the ability of a use-wear analysis to identify wear traces accurately depends on their familiarity with both the raw material they are looking at and with the actions the tool is used for. Without prior experience with a specific material, a use-wear analyst might mistake a natural feature for a sign of use. An example is the natural asperities of some types of basalt being mistaken for pitting.

While assessing the results of the blind-test, I will separate the major and minor differences found between my observations and those of the other analyst. Major differences correspond to a large degree of disagreement, such as recognizing or failing to recognize the presence of a wear trace or a significant disagreement on the nature of wear trace. Minor differences correspond to a slight disagreement over the nature of wear trace. For instance, if I identified the levelling on a surface as having a covering distribution and the other analyst described it as having a connected distribution. In this section, a focus is placed on the major differences as those are the areas that may pose significant problems for use-wear interpretation. These results, in comparison to my own, can be seen back in Tables 4.7, 4.8 and 4.9.

The most striking difference between my results and the other analyst is the identification of linear traces for almost all of the tools, aside from the ones used to grind the rinsed/soaked fenugreek. I believe this is related to the other analyst's lack of experience with basalt and grinding tools. During the manufacturing process, a large amount of pecking develops on the surfaces of the tools. While the grinding overwrites much of the manufacturing wear, some of the pitting associated with it remained after the 5 hours. This worn-down pitting on the low topography of the surface can be mistaken as scratches developed in the low topography. I think this is likely the reason for the miss-attribution for scratches on the surface, especially since the amount of experience the other analyst and I have is the same.

The second area of major disagreement surrounds the fracturing present on the tools used to grind fenugreek and lentils. The blind-test reports that there are no traces of fracturing on these tools, while I had reported it as being plentiful on these surfaces. Initially, I also had great difficulty identifying fracturing on these surfaces and opted to use the fracturing of phenocrysts as a proxy for grain fracturing. It was not until I had gone back to the surfaces a good deal of time after my initial observations and with some extra guidance that I was able to identify the fracturing. The issue here is that grain fracturing can be a subtle feature to identify, especially on basalt, which has a darker surface and finer grain structure. While fracturing is reported on the other surfaces, which sets these two apart is how the fracturing is present. On the surfaces used to grind legumes, the fracturing is much more plentiful and much smaller than on the others. I think it is likely that the reason none is reported for these surfaces is that the fracturing has appeared differently from what was expected or observed on the other surfaces and was overlooked.

The last two areas in which the blind-test and I differed is in the grain edge rounding for the fenugreek, lentils and the roasted hard-wheat kernels, as well as the distribution of the micro-polish for the pre-treated materials. In the blind-test, grain edge rounding is identified for the un-altered legumes, while it is not identified for the roasted hard wheat kernels. This is also an area where I struggled early on. In my initial observations, I miss attributed the rounding off of small isolated levelled areas as grain edge rounding. It was, again, not until I went back and re-evaluated the surfaces and with further guidance that I was able to recognize the actual grain edge rounding on these surfaces. It is possible that a similar mistake was made during the blind test. The last major discrepancies are the distribution of micro-polish on the surfaces used for the pre-treated materials, which I describe as having a covering distribution, but a sparse distribution is mentioned in the blind-test. It is possible here that these differences are related to the formation of two kinds of micro-polish, a dull transparent micro-polish and an opaque and highly reflective micro-polish. Potentially the duller and transparent micro-polish is missed, and only the brighter opaque micro-polish is observed, leading to the conclusion that less micro-polish is present.

5.10 Chapter Summary

This chapter has shown that the data collected in this research can be used to differentiate between cereals and legumes use-wear patterns and that comparable trends have been highlighted in previous studies. The data also supports the idea that with a keen eye and familiarity with both the raw material of the tool and the ground matter, it is possible to differentiate cereals from one another and legumes from one another. Lastly, this chapter has also shown the effects pre-treatment could have on how wear-traces develop.

For wheat and barley, it is found that the amount of levelling present on the surfaces used to grind wheat is higher than the levelling found in association with barley. There is a higher degree of fracturing present for the surfaces used to grind barley than on those used in association with wheat. Likewise, for the legumes, it is found that while both materials have high degrees of fracturing on their levelled plateau, it is much more prevalent on surfaces used with fenugreek.

For the lentils, then the differentiating factor is the degree to which levelling is present, as it is more commonly found than on the surfaces used with fenugreek.

Comparing cereals to legumes, the differentiating wear is levelling and grain edge rounding on the cereals and fracturing on the legumes. Additionally, the topography of the overall surface is also found to be distinctive between the two classes. On the surfaces used to grind cereals, the topography, while having some degree of levelling, is much more rounded, having a sinuous shape along with a rougher texture. These topographies are in contrast with those used to grind the legumes where extensive levelled plateaus are observed. Grain edge rounding is present, often being missing outright for legumes. While fracturing is present on the surfaces used to grind the cereals, it is far less prevalent than on the surfaces used to grind either legume. Another less pronounced differentiating factor is the amount of grain levelling. On the surfaces used to grind cereals, levelling is much more common than those used to grind the legumes.

The starch analysis also supports these findings. The analysis shows that the dominant types of starches and the least common vary significantly between wheat and lentils. For the starches encountered on the wheat slide, the largest group is the circle starches, comprising 48.5 percent of the starches observed on the slide. For the lentils, this category is the ovals, which comprised 35.5 percent of the starches encountered. The least encountered starch types on each slide are the clusters on the wheat slide, with only one being found and the doughnut type on the lentil slide.

Through this research, the influence of pre-treatment is highlighted, which shows that one of the most significant ways pre-treatment affects wear development is by altering the materials so that they are easier to process, which creates wear that has a slightly altered appearance. For instance, an increasing the amount of polish and micro-polish is present, and the use also produced a more rounded sinuous topography and grain edge rounding. Lastly, the results of the blind test are examined and rationalized with insights from my learning process in use-wear analysis. What is found is the importance of understanding the context in which wear develops, knowing both the raw material being used for the tool and the materials being worked.

Examining the productivity of the tools by measuring the amount of flour produced, we can put the results of our experiments into a broader perspective. The materials ground can be ranked from most productive to least as follows: 1) roasted hard wheat kernels, 2) pot barley, 3) brown lentils, 4) hard wheat kernels, and 5) fenugreek. As a reminder, the rinsed/soaked fenugreek is not included as the desired end product is quite different and could not be preserved. The influence of roasting on the hard wheat kernels renders the seeds into a state where they can be processed quickly and with little effort, making them significantly more appealing than the un-treated variant. However, it is important to note that the effect the roasting process may have on their nutritional quality is not analyzed here. When looking at the materials from this perspective, we can see that while the two most productive materials are cereals, this is only the case after the hard wheat kernels were roasted. Excluding the pre-treated materials, the pot barley and brown lentils are the most productive, both a cereal and a legume. This shows us that there is no inherent difference in the ease of grinding or flour output between these materials. An investigation into the caloric and nutritional differences between these materials, especially after pre-treatment, would be required to explore the nutritional qualities of the by-products further.

Taken together, this comparative analysis has shown that it is possible to differentiate between cereals and legumes based on their wear traces. I am unsure whether or not differentiation can be made between the materials within these classes. While some differences between them could be seen, the differences do not seem to be significant. As pre-treatment can alter the traces associated with each material, residue analysis can provide data that can be used to help identify what is processed. Likewise, it is important to cross-reference the results from a use-wear study to those of another and to perform a blind-test on the experimental collection you have made to ensure that your results are not misinterpreted.

Chapter 6: Conclusion

GSTs have been a part of humanities' toolkit for as long as we have been using tools and are employed to process food since early prehistory, possibly even by a common ancestor we share with chimpanzees (Mercader et al. 2007; de Beaune 2004). In the Southern Levant, clear evidence that GSTs have been used for food processing, specifically in nut-cracking, comes from the site of Gesher Benet Ya'akov, where pitted stones belonging to the Acheulean period have been found in association with several types of nuts (Goren-Inbar 2002). The findings at Gesher Benet Ya'akov represent one of the earliest pieces of evidence for plant processing with GSTs; it is only fitting that this is also in the Southern Levant that the Natufians, extensively using GSTs, would set on a course for the development of agricultural practices.

The Natufians, who emerged from their homeland in the Central Levant roughly around 15,000 B.P. (Bar-Yosef 1998), represent a turning point in food choices, initiating the transition from foraging to farming. The Natufian is often thought of as an 'introductory chapter' to the Neolithic and the process of Neolithization (Watkins 2013). The changes which happened during the Natufian period would have occurred differently, and at disparate times within the varying ecological zones they inhabited. (Belfer- Cohen and Hover 2005; Goren-Inbar et al. 2002). Within the peripheric zones of Natufian occupation and other areas of occupation, the exploitation of grasses and cereals coincides with the presence of sickle blades. According to experimental research and microscopic studies, sickle blades have been confirmed to have been used for harvesting cereals, albeit in small quantities (Maeda et al. 2016; Spivak 2008). It is quite possible that these tools were developed in direct response to early experiments in cereal cultivation to maximize crop yield and minimize harvesting time (Bar-Yosef 1998).

There are two broad categories regarding the tools used to process the harvested plant materials, as defined by their shape. These categories of Natufian tools are those with a concave working surface (i.e. mortars and pestles) and those with a ‘flat’ working surface (Dubreuil 2004). It is the second type, those with a flat working surface, that comprises grinding slabs and handstones, this thesis is concerned with. While the 35 Early Natufian sites excavated show that 49 percent contained some GSTs and most of the assemblages occurred in well-watered regions (Wright 1991), it would not indicate a population largely dependent on grinding grasses and cereals for subsistence. Those changes began in the Late Natufian (Belfer-Cohen and Hovers 2005; Dubreuil 2004), and it has been hypothesized that this could be due to the Younger Dryas (Hartman et al. 2016; Makarewicz 2012). Within the Levant, the effects of the Younger Dryas would have restricted the distribution of annual grasses such as wheat and barley and would have reduced their productivity as well. The reasons for the reduced distribution of these grains have been theorized to be due to the decrease in temperature (Hartman et al. 2016; Makarewicz 2012).

During the Late Natufian, the sites are more widely dispersed, moving into the more arid regions of the Levant. While the data Wright (1991) had access to suggests a similar amount of usage of GSTs between the Early and Late Natufian phases, some research has shown an increasing amount of use for grass and cereal processing (Belfer-Cohen and Hovers 2005, Dubreuil 2004). While more than 400 Natufian sites have been excavated, macro botanical remains have been retrieved only in a few of them. Even fewer sites have yielded a substantial number of remains, with less than 10,000 remains in total being uncovered (Arranz-Otaegui et al. 2018). A list of Natufian botanical remains is provided by Power et al. (2014): almonds, lentils, peas, vetch, lupine, olives, grapes, barley, wheat, and various small-seeded grasses. However, the question remains which of these materials has the most significant economic importance.

Research on the development of agro-pastoral communities in the Mediterranean Basin has given considerable importance to cereals and the making of bread or beer. However, within the Southern Levant, the rise of farming communities in this region is associated with a diversity of dietary and food practices, manifest in differences between sites in terms of the specific and relative representation of plant and animal species (Fuller et al. 2011; Asouti and Fuller 2013; Caracuta et al. 2015; Munro et al. 2018; Dubreuil and Goring-Morris in press). Previous analysis of the tools used to process plants, such as grinding slabs and handstones, within the region also supports the hypothesis of a diversity of food practices during the transition from foraging to farming (Dubreuil 2004; Dubreuil 2002; Dubreuil and Goring-Morris in press). In particular, use-wear analysis of a sample of groundstone tools hinted at the importance of legume processing in some sites, more particularly at the Natufian site of Mallaha and the PPNB site of Kfar Hahoresh (Dubreuil 2002, 2004, 2009; Dubreuil and Goring-Morris in press). This research aims to explore this hypothesis further and better understand the evolution of food practices in the Epipaleolithic.

To fulfill the goal of understanding the evolution of practices, this thesis has created an experimental collection of basalt GSTs, manufactured through pecking and used to process a variety of different cereals and legumes. The species chosen for the cereal category are wheat and barley, and those representing the legumes are fenugreek and lentils. These materials were chosen as they have a geographical connection to the Levant, a cultural connection to the Natufians and their successors. They also have been used in previous use-wear studies (Bofill et al. 2020, Dubreuil 2004). In addition to grinding these four materials, I also ground two of them after providing a form of pre-treatment. The fenugreek and hard emmer wheat kernels are chosen for pre-processing alterations in part as they represent the harder legume and cereal to grind. I decided to rinse and soak the fenugreek to prepare it in a manner used for tea (Ghasemi et al. 2015). For the hard wheat kernels, I decided to roast them as this is a common practice worldwide (Gremillion 2004), and additionally, this would create a nice contrast to the rinsed and soaked fenugreek seeds. All materials in this study were processed in the same manner, for the same amount of time and using the same motion, reciprocal strokes where pressure is greatest under the grinder's palm on the away stroke; less pressure is applied under the fingers on the return stroke. (Adams 2013). All materials were used for five hours.

The results of my experiments were then compared to those of other studies. A blind-test was also performed. Our analysis and cross-examination through blind-test indicate that the differentiating wear at low magnification corresponded to ‘grain levelling and edge rounding’ characterizing the cereals and ‘grain fracturing’ for the legumes. Hence, grain edge rounding is present for cereals but often missing outright for legumes. On the other hand, fracturing is observed on the surfaces used to grind cereals, yet it is far less prevalent than on the surfaces used to grind either of the legumes. Similarly, on the surfaces used to grind cereals, levelling is much more common than on the surfaces used to grind legumes. Additionally, the topography of the overall surface is also distinctive between the two classes. On the surfaces used to grind cereals, the topography, while having some degree of levelling, have much more rounded plateaus (i.e., levelled part of the high topography), with a sinuous and a rougher texture. These topographies contrast with those used to grind the legumes where extensive levelled plateaus are observed.

Starch analysis, through the comparison of starches found in samples taken from the tools used to process wheat and lentils, shows that the dominant types of starches and the least common vary significantly between the two surfaces. When comparing these surfaces, the number of starches belonging to each category (circle, oval, doughnut, irregular, cluster and broken) was counted as well as the number of starches which displayed and extinction cross as well as their sizes. For the starches encountered on the wheat slide, the largest group is the circle shape, comprising 48.5 percent of the starches observed. The oval shape dominates the lentils, representing 35.5 percent of the starches encountered. The least encountered starch types on each slide are the clusters on the wheat slide, with only one being encountered and the doughnut type on the lentil slide.

The influence of pre-treatment is highlighted here. It is shown that one of the most significant ways pre-treatments affect wear developments is by altering the materials so that they are easier to process, which in turn creates wear that has a slightly altered appearance. This is done by increasing the amount of polish and micro-polish present and leading to a more rounded sinuous topography and grain edge rounding. Lastly, the results of the blind test are examined and rationalized with insights from my learning process around the use-wear analysis. What is found is the importance of understanding the context in which wear is found, knowing both the raw material being used for the tool and the materials being worked.

When discussing the efficiency of tool use and how attractive a particular resource might have been, I framed the discussion in terms of how many grams of flour is produced within five hours of grinding. What I found is that roasting has a drastic impact on the amount of flour produced, increasing the weight produced in five hours from 235 grams to 557 grams. Additionally, aside from the roasted hard wheat kernels, I found that when we compare cereals to legumes in terms of their ease of grinding and output, they are not too dissimilar. The most productive materials without pre-treatment are pot barley and lentils, producing 350 grams and 270 grams, respectively. Likewise, hard wheat kernels and the un-treated fenugreek have produced similar amounts of flour. Overall, there is no inherent difference in productivity between cereals and legumes. If there is any sort of advantage cereals have over legumes or vice versa, I do not believe it would relate to their grinding productivity but rather to their nutritional content; something which could not be covered in this thesis. This opinion is reinforced by Bofill et al.'s (2020) study. If we want to use Foraging Theory to understand diet choices better, we will need to look further than just the amount of flour produced.

This thesis has not only expanded the experimental database by providing new experimentation, but, has also shown us that the previous differentiation made between cereal and legume grinding holds true, and it is possible to make differentiations between both material classes and specific materials based on the wear traces they leave behind. While these differences may not always be stark and obvious, by paying attention to the variations of wear traces, we can find dominant wear mechanisms and ratios of wear on the micro-topography that can be diagnostic. However, to do so requires the creation of experimental collections and a large number of studies to draw results from. In addition, we need to consider the effect pre-treatment may have and double-check and corroborate results via blind-tests to ensure a high level of accuracy. By doing so, we will be able to use this data on archaeological tools to assess what materials they were used to process and answer questions regarding dietary choices.

Much of Chapter 2 was dedicated to discussing information on the transition from foraging to farming and different theories trying to explain why this had occurred. These topics, while not directly related to use-wear analysis, are important parts of the discussion as they are the motivators behind many use-wear studies, this one included. Simply being able to identify what material a tool was used to process is not the penultimate end of use-wear analysis. Experimental collections are made and studied so that questions surrounding their use can be answered. In the case of this thesis, while the focus was mostly on the creation, interpretation and validity of use wear traces, questions surrounding the specifics of subsistence patterns during the transition from foraging to farming are the intended application of these results. This thesis had shown that is in fact possible to differentiate cereal from legumes as well as altered materials from their un altered variants. The hope for this research is that these findings will then be applied to archaeological collections to aid in the analysis of GST used to process food items from during the transition from foraging to farming to fill in the gaps of our knowledge surrounding what material were being consumed. By understanding what was being consumed it an help provide evidence from which previous theories on the transition from foraging to farming and foraging theories can be checked and new theories can draw from.

The data presented in this thesis regarding wear-development on GSTs will hopefully be used in further studies as the implementation of use-wear analysis on GSTs requires a large pool of information to draw from. To contribute to this pool of knowledge, the 3D models I have used in this thesis are made available via links found within Appendix A. During the writing process, when I finished with my experiments and was no longer able to access the tools directly, I would frequently refer back to and study the photographs taken of the surfaces. Using the photographs, the 3D models, and the descriptions I have made of the surfaces, I have created a permanent record of the characteristics of the tools after five hours of use which is both easily accessible and understandable. I hope that this research will be helpful for others who intend to study tool use through use-wear analysis. The use of 3D models can benefit use wear analysis in a number of ways. 3D models can provide contextual information that photographs are unable to, such as the shape of the active surface as well as the shape of the tool its self. This information is conveyed better through a 3D model as the viewer is able to rotate the camera freely, enabling a better understanding of the tool's morphology. Additionally, 3D models help facilitate the sharing of materials. It would be impossible for every analyst reading a paper on use-wear analysis to physically hold and see the tools in question but with 3D models it helps bridge that gap by providing an easily accessible, and manipulated, model.

6.1 Limitations and Avenues for Further Research

Several aspects of this thesis could be expanded upon in future studies. These include comparing the results found to archaeological tools, experimenting with and examining multi-use tools, performing a starch analysis for every material and performing a more comprehensive range of use-wear experiments. While the data found within this study and the conclusions drawn from it stand on their own, performing more experiments could have given extra weight to the results and made them more widely applicable.

Opportunities for further research can be found primarily in further expanding the experimental collection of GSTs and applying results from a reference collection directly to archaeological tools. These opportunities would result in not only more information regarding wear patterns in association with specific material to be made available but would also show whether the trends found on experimental collections can be applied directly to archaeological tools. Additionally, experiments regarding multi-use surfaces and how exactly the tools' raw material can affect wear development would also be excellent avenues of research. Lastly, further experiments regarding the nutrition of the products created through grinding, especially after pre-treatment, would be invaluable information regarding the attractiveness of materials.

In further research, I would recommend developing of phytolith and starch analysis as well as more extensive mapping of the 3D model’s surfaces, for both before and after use. The preliminary effort I had incorporated in this work had shown me the potential they hold for functional studies and for investigating taphonomy of micro-botanical remains (contamination and changes through processing). Integrating phytolith and starch analysis would add to the robustness of any arguments or hypotheses made as well as allow for an additional avenue of differentiation. Likewise, using software to map the surfaces of the experimental tools both before and after use would aid in the preservation of data and its accessibility and in generating quantitative information about how the surface wears and deforms over time.

Bibliography

Adams, Jenny
2013 *Ground Stone Analysis. A Technological Approach*, The University of Utah Press, Salt Lake City.

Adams, Jenny, Selina Delgado-Raack, Laure Dubreuil, Caroline Hamon, Hughes Plisson and Roberto Risch
2009 *Functional Analysis of Macro-Lithic Artifacts*. Non-flint Raw Material Use in Prehistory: Old Prejudices and New Directions Vol. 11. Archaeopress, Oxford.

Asouti, Eleni and Dorian Fuller
2013 A Contextual Approach to the Emergence of Agriculture in Southwest Asia. *Current Anthropology* 54: 299–345.

Asouti, Eleni and Dorian Fuller
2012 From Foraging to farming in the Southern Levant: The development of Epipalaeolithic and Pre-Pottery Neolithic plant management strategies. *Vegetation History and Archaeobotany* 21 (2): 141-162.

Arranz-Otaegui, Amai, Lara Gonzalez Carretero, Joe Roe and Richter Tobias
2018 "Founder Crops" V. Wild Plants: Assessing the Plant-Based Diet of the Last Hunter-Gatherers in Southwest Asia. *Quaternary Science Reviews* 186: 263-283.

Barker, Graeme
2009 *The Agricultural Revolution in Prehistory: Why did Foragers become Farmers?* Oxford & New York: Oxford University Press

Barlow, K. Renee
2002 Predicting Maize Agriculture Among the Fremont: An Economic Comparison of Farming and Foraging in the American Southwest. *American Antiquity* 67: 65–88.

Bar-Yosef, Ofer
1998 On the Nature of Transitions: The Middle to Upper Paleolithic and the Neolithic Revolution. *Cambridge Archaeological Journal* 8 (2): 141-163.
2011 Climatic Fluctuations and Early Farming in West and East Asia. *Current Anthropology* 52 (4): 175-193.
2014 The Origins of Sedentism and Agriculture in Western Asia. Chapter. In *The Cambridge World Prehistory*, edited by Colin Renfrew and Paul Bahn. Pages: 1408–1438. Cambridge: Cambridge University Press

Bar-Yosef, Ofer and Anna Belfer-Cohen
1989 The Origins of Sedentism and Farming Communities in the Levant. *Journal of World Prehistory* 3 (4): 447-498.

Belfer-Cohen, Anna and Nigel Goring-Morris
2011 Becoming Farmers: The Inside Story. *Current Anthropology* 52(54): 209-220.

Belfer-Cohen, Anna and Erella Hovers
2005 The Ground Stone Assemblages of the Natufian and Neolithic Societies in the Levant – A Brief Review. *Journal of the Israel Prehistoric Society* 35: 299-308.

Bender, Barbara
1978 Gatherer-Hunter to Farmer: A Social Perspective. *World Archaeology* 10 (2): 204-222.

Bettinger, Robert L., Bruce Winterhalder and Richard McElreath
2006 A Simple Model of Technological Intensification. *Journal of Archaeological Science* 28: 747-761.

Binford, Lewis
1968 Post-Pleistocene Adaptations. In *New Perspectives in Archaeology*, edited by Lewis Binford, pages 313-341. Aldine Publishing Company Chicago.

Boesch, Christophe and Hedwige Boesch-Achermann
2000 The Chimpanzees of the Taı Forest: Behavioural Ecology and Evolution (Oxford Univ Press, Oxford)

Bofill, Maria; Danai Chondrou, Antoni Palomo, Hara Procopiou and Maria Soultana Valamotti
2020 Processing Plants for Food: Experimental Grinding within the ERC-Project PLANTCULT. *Journal of Lithic Studies* 7 (3): 1-26.

Boyd, Brian
1999 Twisting the Kaleidoscope: Dorothy Garrod and the Natufian Culture in *Dorothy Garrod and the Progress of the Paleolithic* edited by William Davies and Ruth Charles, pages 209. Oxford, Oxbow Books.

Bril, Blandine, Ross Parry and Gilles Dietrich
2015 How Similair are Nut-Cracking and Stone-Flaking? A Functional Approach to Percussive Technology. *Philosophical Transactions of the Royal Society B: Biological Sciences* 370: 1-13.

Buonasera, Tammy
2015 Modeling the Costs and Benefits of Manufacturing Expedient Milling Tools. *Journal of Archaeological Science* 57: 335-344.

Caracuta, Valentina, Omry Barzilai, Hamudi Khalaidy, Ianir Milevski, Yitzhak Paz, Jacob Vardi, Lior Regev and Elisabetta Boaretto
2015 The Onset of Faba Bean Farming in the Southern Levant. *Scientific Reports* 5(1): 14370.

Chondrou, Danai; Maria Soultana Valamoti, Haris Procopiou and L. Papadopoulou
2018 Grinding Cereals and Pulses in the Neolithic Site of Kleitos: an Experimental Investigation of Microconglomerate Grinding Equipment, Final Products and Use Wear. *Journal of Geek Archaeology 3:* 23-45.

Chondrou, Danai; Maria Bofill, Haris Procopiou, Roberto Vargiolu, Hassan Zahouani and Maria Soultana Valamoti
2021 How do you like your Cereal? A Qualitative and Quantitative Use-Wear Analysis on Archaeological Grinding Tools from Prehistoric Greek Sites. *Wear 476:* 1-11

Ciulli, Enrico

2019 Tribology and Industry: From the Origins to 4.0. *Frontiers in Mechanical Engineering* 5: 1-12.

Cohen, M. N.

1977 The Food Crisis in Prehistory: Overpopulation and the Origins of Agriculture. New Haven, CT: Yale University Press.

Colledge, Sue; James Conolly, Bill Finlayson and Ian Kuijt

2018 New Insights on Plant Domestication, Production Intensification, and Food Storage: The Archaeobotanical Evidence from PPNA Dhra *Levant* 50 (1):14–31.

Coster, Adelle and Judith Field

2015 What Starch Grain is That? - A Geometric Morphometric Approach to Determining Plant Species Origin. *Journal of Archaeological Science* 58: 9–25.

De Beaune, Sophie

2004 The Invention of Technology. *Current Anthropology* 45 (2): 139-162.

Dubreuil, Laure

2002 etude fonctionnelle des outils de broyage natoufiens : nouvelles perspectives sur l'émergence de l'agriculture au proche-orient. Thèse de doctorat, Thèse de l'Université de Bordeaux 1.

2004 Long-term Trends in Natufian Subsistence: A Use-Wear Analysis of Ground Stone Tools. *Journal of Archaeological Science* 31 (11): 1613-1629.

2008 Mortar versus Grinding-Slabs Function in the Context of the Neolithization Process in the Near East. In *"Prehistoric Technology" 40 Years Later: Functional Analysis and the Russian Legacy*, edited by L. Longo and N. Skakun, pp. 169–177. Verona: Museo Civico di Verona, & Universita degli Studi di Verona, BAR International Series 1783.

2009 Functional Analysis of Grinding Tools from the Natufian Site of Mallaha: Towards an Understanding of Assemblage Evolution in the Levant. Arkeotek: on line publication.

Dubreuil, Laure and Nigel Goring-Morris

in press Exploring Food Practices among the First Agro-Pastoral Communities of the Southern Levant: The Ground Stone Tool Perspective. *Food History*.

Dubreuil, Laure and Dani Nadel

2015 The Development of Plant Processing in the Levant: Insights from Use-Wear Analysis of Epipaleolithic Ground Stone Tools. *Philosophical Transactions of the Royal Society B: Biological Sciences* 370(1682): 1-11.

Dubreuil, Laure, Daniel Savage, Selina Delgado-Raack, Hugues Plisson, Birgitta Stephenson and Ignacio de la Torre

2015 Current Analytical Frameworks for Studies of Use–Wear on Ground Stone Tools. In *Use-Wear and Residue Analysis in Archaeology*, edited by João Manuel Marreiros, Juan F. Gibaja Bao, and Nuno Ferreira Bicho, pp. 105–58. Cham: Springer International Publishing.

Ebeling, Jennie and Yorke Rowan

2004 The Archaeology of the Daily Grind: Groundstone Tools and Food Production in the Southern Levant. *Near Eastern Archaeology* 67(2): 108-117.

Edwards, Phillip
2013 Limestone Artefacts. In *Wadi Hammeh 27, an Early Natufian Settlement at Pella in Jordan*, edited by P. Edwards, 234–44. Leiden, Boston: Brill.

Edwards, Phillip and John Webb
2013 The Basaltic Artefacts and Their Origins. In *Wadi Hammeh 27, an Early Natufian Settlement at Pella in Jordan*, edited by P. Edwards, 205–33. Leiden, Boston: Brill.

Elston, Robert, Dong Guanghui and Zhang Dongju
2011 Late Pleistocene Intensification Technologies in Northern China. *Quaternary International* 242: 401-415.

Evershed, Richard
2008 Organic Residue Analysis in Archaeology: The Archaeological Biomarker Revolution. *Archaeometry* 50 (6): 895-924.

Flannery, Kent
1969 *Origins and Ecological Effects of Early Domestication in Iran & the Near East*. In The Domestication and Exploitation of Plants and Animals. Edited by Peter Ucko and G.W. Dimbleby, pages 73-100. Aldine. Chicago.
1973 The Origins of Agriculture. *Annual Review of Anthropology* 2: 271-310

Fullagar, Richard and Judith Field
1997 Pleistocene Seed-Grinding Implements from the Australian Arid Zone. *Antiquity* 71(272): 300-307.

Fuller, Dorian, George Willcox and Robin Allaby
2011 Cultivation and Domestication Had Multiple Origins: Arguments against the Core Area Hypothesis for the Origins of Agriculture in the Near East. *World Archaeology* 43(4): 628–652.

Ghasemi, Vida, Masoomeh Kheirkhah, and Mohsen Vahedi
2015 The Effect of Herbal Tea Cointaing Fenugreek Seed on the Signs of Breast Milk Sufficiency in Iranian Girl Infants. *Iran Red Crescent Medical Journal* 17 (8): 1-6.

Gremillion, Kristen
2004 Seed Processing and the Origins of Food Production in Eastern North America. *American Antiquity, 69*(2): 215-233.

Grosman, Leore, Timna Raz and David Friesem
2020 Tomorrow's Mundane is Today's Extraordinary: A Case Study of a Plastered Installation During Neolithization. *Humanities and Social Sciences Communications* 7: 1-13.

Grosman-Yaroslavski, Iris, Danny Rosenberg, Reuven Yeshurun, Daniel Kaufman and Mina Weinstein-Evron
2016 The Function of Early Natufian Grooved Basalt Artefacts from El-Wad Terrace, Mount Caramel: Prelimanry Results of Use-Wear Analysis. *Journal of Lithic Studies* 3(3): 221-242.

Goren-Inbar, Naama, Gonen Sharon, Yoel Melamed and Mordechai Kislev
2002 Nuts, Nut Cracking and Pitted Stones at Gesher Benot Ya'aqov, Israel. *PNAS* 99(4): 2455-2460

Goring-Morris, Nigel and Anna Belfer-Cohen
2011 Neolithization Process in the Levant. *Current Anthropology* 52(54): 195-208.

Hamon, Caroline
2008 Functional Analysis of Stone Grinding and Polishing Tools from the Earliest Neolithic of North-Western Europe. *Journal of Archaeological Science* 35(6): 1502-1520.

Hamon, Caroline and Hugues Plisson
2008 Which Analytical Framework for the Functional Analysis of Grinding Stones? The Blind Test Contribution. In "*Prehistoric Technology" 40 years later: Functional Studies and the Russian Legacy*. Edited by Laura Longo and Natalia Skakun, pages 29-38. Archaeopress, Oxford.

Harlan, Jack
1989 Wild-Grass Seed Harvesting in the Sahara and Sub-Saharan of Africa. In *Foraging and Farming: The Formation of Plant Exploitation*. Edited by D.R. Harris and G.C. Hillman, pages 79-95. Unwin Hyman ltd. London.

Hartman, Gideon
2012 Impacts of Environmental Deterioration on the Carbon Isotope Values of Modern Vegetation and Gazelles in the Southern Levant: Predicting the Severity of the Younger Dryas. *Palaeogeography, Palaeoclimatology, Palaeoecology* 321-322: 55-64

Hartman, Gideon, Ofer Bar-Yosef, Alex Brittingham, Leore Grosman and Natalie Munro
2016 Hunted Gazelles Evidence Cooling, but not Drying, During the Younger Dryas in the Southern Levant. PNAS 113(15): 3997–4002.

Hawkes, Kristen and James O'Connell
1992 On Optimal Foraging Models and Subsistence Transitions. *Current Anthropology* 33 (1): 63-66.

Hayden, Brian
2009 The Proof is in the Pudding: Feasting and the Origins of Domestication. *Current Anthropology* 50 (5): 597-601.

Hayden, Brian, Neil Canuel and Jennifer Shanse
2013 What was Brewing in the Natufian? An Archaeological Assessment of Brewing Technology in the Epipaleolithic. *Journal of Archaeological Method and Theory* 20 (1): 102-150.

Hayden, Brian, Laurie Nixon-Darcus and Logan Ansell
2017 "Our Daily Bread? The Origins of Grinding Grains and Breadmaking" In *Exploring the Materiality of Food "Stuffs": Transformations, Symbolic Consumption and Embodiments.* Edited by Louise Steel and Katharina Zinn, pages 57-78. Routledge, New York.

Hayes, Elspeth, Dries Cnuts; Christian Lepers and Veerle Rots
2016 Learning from Blind Tests: Determining the Function of Experimental Grinding Stones Through Use-Wear and Residue Analysis. *Journal of Archaeological Science: Reports* 11 (2017): 245-260.

Hayes, Elspeth, Colin Pardoe and Richard Fullagar
2018 Sandstone Grinding/Pounding Tools: Use-Trace Reference Libraries and Australian Archaeological Applications. *Journal of Archeological Science: Reports* 20: 97-114.

Hodder, Ian
2017 Things and the Slow Neolithic: the Middle Eastern Transformation. *Journal of Archaeological Method and Theory* 25: 155-177.

Holt, Brigitte and Vincenzo Formicola
2008 Hunters of the Ice Age: the biology of Upper Paleolithic people. *American Journal Of Physical Anthropology Supplement*, 47,70–99.

Janz, Lisa
2016 Fragmented Landscapes and Economies of Abundance: The Broad-Spectrum Revolution in Arid East Asia. *Current Anthropology* 57 (5): 537-564.

Jing-Yan, Lu
2008 Tribology. In *Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures*. Edited by Selin H. Springer, Dordrecht.

Jost, H. Peter
1966 Lubrication (Tribology) Education and Research. A Report on the Present Position and Industry's Needs. In *Her Majesty's Stationary Office,* Department of Education and Science.

Kraybill, Nancy
1977 Pre-agricultural Tools for the Preparation of Foods in the Old World., in *Origins of Agriculture*, edited by Charles A. Reed. Mouton, The Hague, pp. 485-521.

Kujit, Ian and Nigel Goring-Morris
2002 Foraging, Farming, and Social Complexity in the Pre-Pottery Neolithic of the Southern Levant: A Review and Synthesis. *Journal of World Prehistory* 16 (4): 361-440.

Laland, Kevin and Michael O'Brien
2010 Niche Construction Theory and Archaeology. *Journal of Archaeological Method and Theory* 17(4): 303-322.

Liu, Li, Jiajing Wang, Danny Rosenberg, Hao Zhao, Gyorgy Lengyel and Dani Nadel
2018 Fermented Beverage and Food Storage in 13,000 Year-old Stone Mortars at Raqefet Cave, Israel: Investigating Natufian Ritual Feasting. *Journal of Archaeological Science: Reports* 21: 783-793.

MacArthur, Robert and Eric Pianka
1966 On Optimal Use of a Patchy Environment. *The American Naturalist* 100 (916), 603-609.

Maeda, Osamu, Lelilani Lucas, Fabio Silva, Ken-Ichi Tanno and Dorian Fuller
2016 Narrowing the Harvest: Increasing Sickle Investment and the Rise of Domesticated Cereal Agriculture in the Fertile Crescent. *Quaternary Science Reviews* 145: 226–237.

Maher, Lisa, E.B Banning and Michael Chazan
2011 Oasis or Mirage? Assessing the Role of Abrupt Climate Change in the Prehistory of the Southern Levant. *Cambridge Archaeological Journal* 21(1): 1-29.

Makarewicz, Cheryl
2012 The Younger Dryas and Hunter-Gatherer Transitions to Food Production in the Near East Hunter-Gatherer Behavior. In *Hunter-Gatherer Behavior: Human Response During the Younger Dryas*, edited by Metin I. Erin. pp. 195-230. Taylor and Francis, Walnut Creek.

McClatchie Meriel
2014 Archaeobotany of Agricultural Intensification. *In Encyclopedia of Global Archaeology* edited by Smith C. Springer, New York, NY

Mercader, Julio; Huw Barton, Jason Gillespie, Jack Harris, Steven Kuhn, Robert Tyler and Christophe Boesch
2007 4,300-Year-Old Chimpanzee Sites and the Origins of Percussive Stone Technology. *PNAS* 104 (9): 3043-3048.

Munro, Natalie
2004 Zooarchaeological Measures of Hunting Pressure and Occupation Intensity in the Natufian: Implications for Agricultural Origins. *Current Anthropology* 45.

Munro, Natalie, Guy Bar-Oz, Jacqueline Meier, Lidar Sapir-Hen, Mary Stiner and Reuven Yeshurun
2018 The Emergence of Animal Management in the Southern Levant. *Scientific Reports* 8(1): 9279.

Nadel Dani; Dolores Piperno, Irene Holst, Ainit Snir and Ehud Weiss
2012 New Evidence for the Processing of Wild Cereal Grains at Ohalo II, a 23 000-year-old Campsite on the Shore of the Sea of Galilee, Israel. *Antiquity* 86, 990–1003.

Perrot, Jean; Daniel Ladiray, and Odile Soliveres-Massei
1988 les hommes de mallaha (eynan) israël. Paris: Association Paléorient.

Piperno, Dolores; Ehud Weiss, Irene Holst and Dani Nadel
2004 Processing of Wild Cereal Grains in the Upper Palaeolithic Revealed by Starch Grain Analysis. *Nature* 430, 670–673.

Plants for a Future
2018 A Trigonella foenum-graecum-L. Electronic document, https://pfaf.org/user/Plant.aspx?LatinName=Trigonella+foenum-graecum, accessed April 14th 2020.
2018 B Lens-Medik. Electronic document, https://pfaf.org/user/Plant.aspx?LatinName=Lens, accessed April 14th 2020.
2018 C Triticum turgidum dioccon-(Schrank.) Thell. Electronic document, https://pfaf.org/user/Plant.aspx?LatinName=Triticum+turgidum+dicoccon, accessed April 14th 2020.

2018 E Hordeum vulgare - L. Electronic document, https://pfaf.org/user/Plant.aspx?LatinName=Hordeum+vulgare, accessed April 14th 2020.

Power, Robert, Arlene Rosen and Dani Nadel
2014 The Economic and Ritual Utilization of Plants at the Raqefet Cave Natufian Site: The Evidence from Phytoliths. *Journal of Anthropological Archaeology* 33: 49-65.

Richerson, Peter, Robert Boyd and Robert Bettinger
2001 Was Agriculture Impossible During the Pleistocene but Mandatory During the Holocene? A Climatic Change Hypothesis. *American Antiquity* 66:387–412.

Richter, Tobias, Elisabetta Arranz-Otaegui, Emmy Boaretto, Emmy Bocaege, Erin Estrup, Cesar Martinez-Gallardo, Georger Pantos et al.
2016 Shubayqa 6: A new Late Natufian and Pre-Pottery Neolithic A Settlement in North-East Jordan. *Antiquity, 90:* 354-359.

Rivals, Florent, Rika Rabinovich, Hamoudi Khalaidy, Francois Valla and Anne Bridault
2020 Seasonality of the Natufian Occupation at Enyan/Ain Mallaha (Israel): An Approach Combining Dental Ageing, Mesowear and Microwear. *Archaeological and Anthropological Sciences* 12 (232): 1-15.

Rosenberg, Danny
2013 Not "Just Another Brick in the Wall"? The Symbolism of Groundstone Tools in Natufian and Early Neolithic Levantine Constructions. *Cambridge Archaeological Journal* 23(2).

Rots, Veerle, and Bonny Williamson
2004 Microwear and Residue Analyses in Perspective: The Contribution of Ethnoarchaeological Evidence. *Journal of Archaeological Science* 31: 1287–99.

Samuelian, Nicolas
2013 A Study of Two Natufian Residential Complexes: Structures 200 and 203 at Eynan (Ain Mallha), Israel. In *Natufian Foragers in the Levant*, edited by O. Bar-Yosef and F. Valla, pp. 172–184. Ann Arbor: International Monograph in Prehistory.

Samuelian, Nicolas, Hamoudi Khalaily, and Francois Valla
2006 Final Natufian Architecture at 'Eynan (Ain Mallaha): Approaching the Diversity behind Uniformity. In *Domesticating Space. Construction, Community, and Cosmology in the Late Prehistoric Near East. Studies in Early Near Eastern*, edited by E.B Banning and M. Chazan, pp. 35–41. Berlin: ex oriente.

Shennan, Stephen
2002 *Genes, Memes and Human History: Darwinian Archaeology and Cultural Evolution.* Thames and Hudson. London.

Shevkani, Khetan; Narpinder Singh, Ritika Bajaj and Amritpal Kaur
2016 Wheat Starch Production, Structure, Functionality and Applications – A Review. *International Journal of Food Science and Technology* 52(1): 38-58.

Shillito, Lisa-Marie
2013 Grains of Truth or Transparent Blindfolds? A Review of Current Debates in Archaeological Phytolith Analysis. *Vegetation History and Archaeobotany* 22(1): 71-82.

Spivak, P
2008 Limestone and Basalt Assemblage from the Epipaleolithic Site of Ohalo II, a 23,000 Years Old Fisher-Hunter-Gatherers' Camp. *Unpublished MA thesis, Archaeology Department, University of Haifa, Haifa*.

Shizhu, Wen and Huang Ping
2012 *Principles of Tribology*. Hoboken: Wiley.

Simmons, Alan
2011 *The Neolithic Revolution in the Near East: Transforming the Human Landscape*. University of Arizona Press: Tucson

Stahl, Ann Brower
1989 Plant-Food Processing: Implication for Dietary Quality. In *Foraging and Farming: The Formation of Plant Exploitation*. Edited by D.R. Harris and G.C. Hillman, pages 171-186.

Steiner, Margreet and Ann Killebrew
2014 *The Oxford Handbook of The Archaeology of the Levant 8,000-332 BCE.* Oxford: Oxford University Press.

Tester, Richard; John Karkalas and Xin Qi
2004 Starch—Composition, Fine Structure and Architecture. *Journal of Cereal Science* 39 (2):151-165.

Thornton, M.; E. Morgan and F. Celoria
1970 The Composition of Bog Butter. *Science and Archaeology* 2(3): 20-25.

Valla, Francois
1984 les industries de silex de mallaha (eynan) et du natoufien dans le levant. Paris: Association Paléorient, Mémoires et travaux du Centre de Recherche Français de Jérusalem, Vol. 3.

Valla, Francois, Hamoudi Khalaily, Helene Valladas, Nadine Tisnerat-Laborde, Nicolas Samuelian, Fanny Bocquentin, Rivka Rabinovich, et al.
2004 les fouilles de mallaha en 2000 et 2001: 3eme rapport préliminaire. *Journal of the Israel Prehistoric Society* 34: 49–244.

Valla, Francois, Fanny Bocquentin, Hugues Plisson, Hamoudi Khalaily, Christophe Delage, Rivka Rabinovich, Nicolas Samuelian et al.
1999 le natoufien final et les nouvelles fouilles à mallaha (eynan), Israel 1996 - 1997. *Journal of the Israel Prehistoric Society* 28: 105–176.
2001 le natoufien final de mallaha (eynan), Deuxième Rapport Préliminaire : Les Fouilles de 1998-1999. *Journal of the Israel Prehistoric Society* 31: 9–151.

Valla, Francois, Hamoudi Khalaily, Nicolas Samuelian, and Fanny Bocquentin
2010 What Happened in the Final Natufian? *Journal of the Israel Prehistoric Society* 40: 131–148.

Valla, Francois, Hamoudi Khalaily, Helene Valladas, Evelyene Kaltnecker, Fanny Bocquentin, Cabellos Teresa, Daniella Bar-Yosef et al.
2007 les fouilles de aïn-mallaha (eynan) de 2003 à 2005: Quatrième Rapport Préliminaire. *Journal of the Israel Prehistoric Society* 37: 135–383.

Visalberghi, Elisabetta; Giulia Sirianni, Dorothy Fragaszy and Christophe Boesch
2015 Percussive tool use by Taı Western chimpanzees and Fazenda Boa Vista bearded capuchin monkeys: a comparison. *Philosophical Transactions. Biological Sciences* 370.

Watkins, Trevor
2013 The Neolithic in Transition — How to Complete a Paradigm Shift. *Levant*, 45(2):149-158

Weiss, Ehud; Wilma Wetterstorm, Dani Nadel and Ofer Bar-Yosef
2004 The Broad Spectrum Revisited: Evidence from Plant Remains. *PNAS* 101(26):9551-9555

Willcox, George
2014 Near East (Including Anatolia): Origins and Development of Agriculture. In Encyclopedia of Global Archaeology edited by Smith, C. Springer, New York, NY

Winterhalder, Bruce and Eric Alden Smith
2000 Analyzing Adaptive Strategies: Human Behavioral Ecology at Twenty-five. *Evolutionary Anthropology* 9(2): 51-72.

Wollstonecroft, Michele, Peter Ellis, Gordon Hillman and Dorian Fuller
2008 Advances in Plant Food Processing in the Near Eastern Epipaleolithic and Implications for Improved Edibility and Nutrient Bioaccessibility: an Experimental Assessment of *Bolboschoenus maritimus* (L.) Palla (sea club-rush). *Vegetation History and Archaeology* 17.

Wright, Katherine
1991 The Origins and Development of Ground Stone Assemblages in Late Pleistocene Southwest Asia. *Paléorient* 17 (1): 19-45
1992 A Classification System for Ground Stone Tools from the Prehistoric Levant. *Paléorient* 18 (2): 53-81.
1994 Ground-Stone Tools and Hunter-Gatherer Subsistence in Southwest Asia: Implications for the Transition to Farming. *American Antiquity, 59*(2), 238-263.
2014 Domestication and Inequality? Households, Corporate Groups and Food Processing Tools at Neolithic Catalhoyuk. *Journal of Anthropological Archaeology* 33: 1-33.

Wynn, Thomas, R. Adrianna Hernandez-Aguilar, Linda Marchant and William McGrew
2011 'An Ape's View of the Oldowan' Revisited. *Evolutionary. Anthropology. Issues News Review* 20: 181–197.

Yerkes, Richard, Hamoudi Khalaily and Ran Barkai
2012 Form and Function of Early Neolithic Bifacial Stone Tools reflects Changes in Land Use Practices During the Neolithization Process in the Levant. *PLOS ONE* 7(8): e42442.

Zhu, Fan
2017 Barley Starch: Composition, Structure, Properties, and Modifications. *Comprehensive*

Reviews in Food Science and Food Safety 16(4): 558-579.
Zurro, Debora
2018 One, Two, Three Phytoliths: Assessing the Minimum Phytolith Sum for Archaeological Studies. *Archaeological and Anthropological Sciences* 10 (7): 1673-1691.

Zohary, Daniel
2004 Unconscious Selection and the Evolution of Domesticated Plants. In *Economic Botany* 58 pp. 5-10.

Zohary, Daniel, Maria Hopf and Ehud Weiss
2012 *Domestication of Plants in the Old World* 4th edition. Oxford University Press: Oxford.

Appendix A: 3D Models

Link to Google Dropbox for Netherstone 1 Side A (Pot Barley):

https://drive.google.com/file/d/1NpR4imIOZk30DrsgnSr8P40PyW7uSQMv/view?usp=sharing

Link to Google Dropbox for Netherstone 1 Side B (Hard Wheat Kernels)

https://drive.google.com/file/d/1GoG5lCkLUy8HHRFjST3cis3pkVSZ0Frz/view?usp=sharing

Link to Google Dropbox for Netherstone 2 Side A (Fenugreek)

https://drive.google.com/file/d/1ZKXl1Nu_A_nf6lpIftQeJQMvEK0dpxkW/view?usp=sharing

Link to Google Dropbox for Netherstone 2 Side B (Lentils)

https://drive.google.com/file/d/1RUB_7J6o6b1ZuKKEqrQsXx87Be8fbWc8/view?usp=sharing

Link to Google Dropbox for Netherstone 3 Side A (Rinsed/Soaked Fenugreek)

https://drive.google.com/file/d/1plLgFdRj_jYR34srEkYPVX3-iEeRAjbB/view?usp=sharing

Link to Google Dropbox for Netherstone 3 Side B (Roasted Hard Wheat Kernels)

https://drive.google.com/file/d/1CgWfK3S24_hwYCRdc05SqApfBr_xHb8P/view?usp=sharing

Appendix B: Example of Hourly Examination

Netherstone 2, Side A: Fenugreek
July 31/20

3 Hour Observations

Low-Power Magnification

Further levelling of the surface. The surface is not uniform in elevation but lacks any extremities of large variation among heights. The greatest variation is between the largely levelled surface and the pitting/asperities. The levelled surface is a dark colour and has a reflective quality – polish? Pitting is white in colour and for most, outside of their outer rims, lack the reflective quality of the rest of the surface. Pitting is fairly mild; pits are not very large (wide) and are shallow. Faint striations seem to be forming on the surface, not immediately visible as they are difficult to see. These striations have a reflective quality to them, are short, shallow, thin and run lengthways across the active surface – follow the direction of the stroke.

Handstone: Further levelling of the surface, highest elevations are largely the same height and have polish formation on them. Pitting is still present and the pits are roughly the same size in diameter but vary in their depth. Deeper pitting is white in colour while the shallower pitting and the lower elevations are beige in colour and the higher elevations are dark grey/black. Polish formation, while largely concentrated on the highest elevations also extends slightly into the lower elevations. Polish takes the form of flecks, no large concentrations.

High Power Magnification

As the grinding surface for this netherstone is on the side of the tool it is difficult to get a good image. Micropolish seems to be present over much of the observed surface and the areas where it is present seems to cover the surface entirely regardless of elevation. While the micropolish covers the surface fairly well it appears to be translucent as in sections where the surface is lighter in colour, you can make out what is underneath. Example at 20x0.40X magnification.

Handstone: Micropolish is present on most areas of the surface, varying in thickness. Some areas are thick and opaque but most examples observed seem translucent.

Appendix C: Data Collection Sheet

Petrographic Description of the Rock (Functional Analysis of Macrolithic Artefacts: A Focus on Working Surfaces)

1. General Classification
    - Igneous/Sedimentary/Metamorphic
2. Fabric/Structure
    - Isotropic (random grain orientation)
    - Planar (grain particles organized along parallel surface)
    - Linear (elongated grains oriented in a single direction)
    - Plano-linear (combination of a planar and linear fabric)
3. Texture
    - Granularity (refers to grain size and homogeneity; uniform or irregular)
    - Cohesion (how the grains and minerals are bound together; recrystallization or matrix/cement)
    - Porosity (empty spaces between mineral components)
4. Mineral Composition

Low Power Magnification – (Functional Analysis of Macrolithic Artefacts: A Focus on Working Surfaces)

*Make sure to indicate how the tool is positioned prior to descriptions!

1. Linear Traces
    - Distribution (loose, covered or concentrated)
    - Density (separated, close or connected)
    - Incidence (shallow or deep)
    - Disposition (random, concentric, parallel, oblique or perpendicular)
    - Orientation (longitudinal. transversal or oblique)
    - <0.5mm = striation, >0.5mm = scratch
    - Length (long extend across the working surface, short extend only part way)
    - Longitudinal morphology (continuous or intermittent striations)
    - Transverse morphology (U-shaped or V-shaped linear trace in profile)
2. Polish/Sheen
    - Distribution (loose, covered or concentrated)

- Density (separated, closed or connected)
- Reflectivity (slightly, moderately or highly reflective)
- Incidence (only on topographic highs or also in interstices)

3. Leveling
    - Distribution (loose, covered or concentrated)
    - Density (separated, close or connected)
    - Incidence (on high or low topography)
    - Morphology (flat, sinuous or rounded)
    - Texture (rough or smooth)

4. Pits/Grain Extraction
    - Distribution (loose, covered or concentrated)
    - Density (separated, close or connected)
    - Depth (relative desc. Such as fine/wide and superficial/deep)
    - Shape in plan (irregular, circular, triangular, star like or comet shaped)
    - Shape in cross-section (U-shaped or V-shaped)
5. Fractures
    - Distribution (loose, covering or concentrated)
    - Density (loose scattering, closed or dense pattern or a connected pattern)
    - Depth (fine/wide, superficial/deep)
6. Grain Edge Rounding
    - Described as present or absent

<u>High-Power Magnification </u>(Current Analytical Frameworks for Studies of Use-Wear on GST)

*Make sure to indicate how the tool is positioned prior to descriptions!

1. Micropolishing
    - Localization (Where on the surface)
    - Distribution (sparse, covering and concentrated) Bright/reflective patches
    - Density (separated, adjacent and connected)
    - Microtopographic context (position on the high/low topography, specific features such as abraded, rounded and leveled areas)
    - Morphology in cross section (irregular, domed or flat)
    - Texture (rough, fluid or smooth)
    - Contours (edges sharp or diffuse)
    - Structure (variation in distribution; separated, closed or connected) – Density within a “patch”, done at higher levels of magnification.
    - Presence of special features (striations, pits etc.)
    - Vertical extension (how deep does it extend)
    - Opacity (transparent, translucent or opaque)
    - Brightness

Appendix D: Example of Data Collection

Netherstone 2, Side A: Fenugreek

Petrographic Description

1. General Classification:
   Igneous, basalt
2. Fabric/Structure:
   Isotropic, has a random grain orientation
3. Texture:
   Fine and uniform grains size making it aphanitic
   Grains and minerals held together by a matrix
   Slightly porous, vesicles present but not prevalent
4. Mineral Composition:
   Groundmass primarily made up of feldspar.
   Porphyritic, phenocrysts present. Black when whole, orange/brown when worn, indicating olivine.

Low-Power Magnification

*Orientation matches photo at macroscopic level, direction of use was left to right across the active surface. Active surface propped up using wooden block to allow for proper examination.

1. Linear Traces
   The linear traces on this surface have a loose distribution and a separated density as there are only a few clear examples of them on the surface and they are spaced out from one another by quite a bit. Very few! The incidence of the observed linear traces range from shallow to a more moderate depth, as they seem to be influenced by the asperities they formed on top of. Their disposition is parallel as they are all moving in the same direction to one another, which is longitudinally across the active surface. Width of the linear marks ranges from a striation (<0.5mm), to a scratch (>0.5mm), once again seemingly deepened ton where on the surface they formed (influenced by asperities on surface). The length of the observed linear traces all fell into the short category, all failed to successfully cross the entire

surface. Linear traces were found to be both continuous and intermittent. Without the aid of a constructed profile view I would say that these traces are U-shaped in profile.

2. Polish/Sheen
   This polish on this tool's surface has a covered distribution with a connected density. This development of polish is present on nearly every part of the active surface, only being broken up by the natural asperities of the stone. The reflectivity of this polish is fairly slight, while it does catch the light it is not especially bright. Polish takes the form of a darkening of the surface, almost black or dark grey in colour. The polish observed is found both on the topographic highs and within the interstices.

3. Leveling
   The leveling found on this surface has a covered distribution as it is found consistently and frequently on the working surface; the density of the leveling is connected as it covers nearly the entire surface, the only breaks being due to the natural asperities found on the surface. Leveling observed is found on the high topographies, worth noting that the active surface is not completely flat, slight curvature to active surface. Despite this, leveling is found not only at the highest points of the active surface but also where the surface slopes downward. Leveled areas feature a flat morphology and have a smooth texture.
4. Pits, Grain Extraction
   Pitting has a covering distribution and a close density. Pits frequently encountered on the surface and are found in close proximity with one other, although with some space in between them. Most pits found on the surface are superficial in depth, those that are not are actually natural asperities not pits made through use. The pits encountered have either a circular or an irregular shape in plan view, similar to the previous two surfaces. Without the aid of a profile reconstruction I would determine that these pits have a U-shaped cross section.
5. Fractures
   As with the previous two surfaces the basalt is too fine grained for fracturing of the groundmass to be observed. On the visible phenocrysts however where it is possible to see, fracturing does seem to be present, but perhaps is best not to be taken as representative of the use-wear for the surface as a whole. Phenocrysts not as prevalent on this surface, seem to be clearer than previous stone.
6. Grain edge rounding
   Present but not as developed compared to the cereals, especially on the right edge of the working surface.

High-power Magnification

1. Micropolishing

The micropolish on this surface is primarily localized within the center of the active surface, the area of the tool which experienced the most wear and has the greatest degree of leveling and polish buildup. The distribution of the micropolish within this area could be characterized as covering and has a density I would describe as adjacent. This because while the micropolish seen frequently on the surface there is some space between instances. The structure of this micropolish, its density within a higher magnification view point, is connected. The orientation of this micropolish is seemingly parallel, moving along the working surface. The microtopographic context of the micropolish is that it seems to exist primarily on the highest elevations and leveled areas of the surface but can also bee seen to an extent somewhat into the interstices. Is not found within the bottom of pits and asperities however. The contours of this micropolish are diffuse, at lower levels clearly defined patches are visible but the stronger the magnification gets the less apparent these distinctions are. Overall, the texture of the observed micropolish is rough and also seemingly has a irregular structure as it seems conform to the shape of the surface underneath it. At lower levels of magnification (5x) the micropolish can be seen to create the appearance of a striation. The micropolish observed is fairly opaque, the surface beneath is not discernable and has a mild brightness.

Appendix E: Blind Test Results

Wear Type	Characteristic	Tool 1; Side A (Barley)	Tool 1; Side B (Wheat)	Tool 2; Side A (Fenugreek)	Netherstone 2; Side B (Lentils)	Netherstone 3; Side A (Rinsed/Soaked Fenugreek)	Netherstone 3; Side B (Roasted Hard Wheat)
Linear Trace	Distribution	Loose	Loose	Loose	Loose	Not Observed	Not Observed
	Density	Connected	Seperated	Connected	Seperated	Not Observed	Not Observed
	Incidence	Shallow	Shallow	Shallow	Shallow	Not Observed	Not Observed
	Disposition	Parallel	Parallel	Parallel	Parallel	Not Observed	Not Observed
	Orientation	Longitudianl	Longitudianl	Longitudinal	Longitudianl	Not Observed	Not Observed
	Striation/Scratch	Striation	Striation	Striation	Striation	Not Observed	Not Observed
	Length	Short	Short	Short	Short	Not Observed	Not Observed
	Longitiudnal Morphology	Intermittent	Intermittent	Intermittent	Intermittent	Not Observed	Not Observed
	Transverse Morphology	U-Shaped	U-shaped	U-shaped	U-Shaped	Not Observed	Not Observed
Polish/Sheen	Distribution	Concentrated	Covering	Concentrated	Covered	Loose	Loose
	Density	Connected	Seperated	Connected	Connected	Covering	Seperated
	Reflectivity	Slight	High	High	Moderate	Slight	High
	Incidence	High topography (leveled)	High topography	High Topography	Lower Topography	Extends into low topography	High/low
Leveling	Distribution	Loose	Connected	Loose	Covering	Covered	Covered
	Density	Connected	Connected	Connected	Connected	Connected	Connected
	Incidence	High topography	High topography	High Topography	High topography	High topography	High topography
	Morphology	Flat	Uneven (sinuous)	Flat/Rounded	Flat/rounded	Sinuous	Rounded/Sinuous
	Texture	Smooth	Rough	Smooth	Smooth	Rough	Rough
Pits/Grain Ext.	Distribution	Covering	Covering	Covering	Covered	Covering	Covering
	Density	Closed	Closed	Closed	Closed	Closed	Closed
	Depth	Most wide/deep	Most wide/deep	Wide and deep	Wide and Deep	Wide and Deep	Wide/Deep & Shallow
	Shape in Plan	Irregular, Some Circular	irregular	Irregular	Irregular	Irregular	Irregular/Rounded
	Shape in Cross Section	U-shaped	U-shaped	U-Shaped	U-Shaped	U-Shaped	U-shaped
Fracturing	Distriubution	Appears in pits	Loose	Not Observed	Not Observed	Loose	Loose
	Density	Loose	Loose	Not Observed	Not Observed	Concentrated	Concentrated
	Depth	Superficial	Deep/Wide	Not Observed	Not Observed	Shallow	Shallow
Grain Edge Rounding	Present/Absent	Present	Present	Present	Present	Present	Absent
Micropolish	Localization	On leveled areas	On Leveled Areas	On leveled areas	Covers use area	On leveled areas	Leveled areas
	Distribution	Concentrated	Sparse	Covering	Covering	Sparse	Sparse
	Density	Connected	Connected	Connected	Connected	Connected	Seperated
	Microtopographic Context	Leveled areas	High topography	High Topography	High and low topography	High and low	Highs and lows
	Morphology in Crosssection	Sinuos	Sinuous	Sinuous	Sinuous	Sinuous	Sinuous
	Texture	Rough/Fluid	Fluid	Fluid	Fluid	Fluid	Fluid
	Contours	Diffuse	Diffuse	Diffuse	Diffuse	Diffuse	Diffuse
	Structure	Connected	Connected	Connected	Connected	Connected	Connected
	Special Features	Linear Traces	None	Striations		Linear traces	Linear traces
	Vertical Extension	Shallow	Extends into pits	Only on highs	Deep	Shallow	Shallow
	Opacity	Opaque	Opaque	Opaque	Opaque	Opaque	Opaque
	Brightness	Medium (Moderate)	Moderate	High	Moderate	Moderate	Moderate