

Set in Stone: Ground Stone Tools and Wild Plant
Processing in the Middle Holocene
Gobi Desert

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Abstract

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The Holocene Climate Optimum turned the Gobi Desert from a mainly grassland habitat into a mosaic landscape composed of dune-fields, wetlands and high elevation forests (Janz 2012, 2016; Janz et al. 2017). The populations that inhabited the region at the time adapted by adopting new settlement patterns and tools, which might have allowed them to better exploit a new wide range of resources (Janz 2012, 2016; Janz et al. 2017). This thesis investigates the emergence of ground stone tool technology in the Gobi Desert and its connection with wild plant use by foragers at the time. Twenty-one implements were studied through experimental, use-wear and residue analysis. The results reveal that the tools were used to process several categories of wild plants. By conducting this investigation in legacy collections, this study also proved that archaeological micro-botanical evidence can be recovered from such materials and that their contamination can be assessed through specific protocols.

Keywords:

Ground Stone Tools; Macro-lithics; Gobi Desert; Mongolia; Inner Mongolia; Northeast Asia; Middle Holocene; Neolithic; Wild Plant Use; Experimental Archaeology; Use-Wear; Residue Analysis; Holocene Climate Optimum; Technological Changes; Wetland Exploitation.

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Chapter 1

Introduction

This thesis investigates plant-use in the Gobi Desert during the Middle Holocene through use-wear analysis of ground stone tools (GST). The emergence of this technology at the time might reflect a distinct attitude towards plants and plant processing, associated with the environmental changes after the last glacial period. GSTs are often associated with a ‘Neolithic package’ that encompassed the domestication of plants and animals, adoption of agriculture and sedentism and emergence of food processing and storage technologies, such as GSTs and pottery (Childe 1957). However, the shift to agriculture and sedentism never happened in the Gobi Desert. Despite contact with Chinese agriculturalists societies, the inhabitants of the region sustained a forage-based lifestyle until the Late Holocene, when pastoralism appears to have been adopted (around 4500 BP, but still debated; see Janz et al. 2020). Due to the generally poor preservation of organic matters in prehistoric sites, little is known about the evolution of plant exploitation in the Gobi Desert and GST represent an unvaluable potential source of data in this respect. Therefore, this study aims to explore the connection between the adoption of GST technology and wild plant-use by foraging groups of the Middle Holocene in the east portion of the Gobi Desert.

The implements analyzed in this thesis are associated with the Oasis 2 period of the Gobi Desert chronology (8.5-5 k cal yr BP, Janz et al. 2021). At this time, new settlement patterns, technologies and environmental conditions emerged. The increased temperature and precipitation from the Holocene Climate Optimum (HCO) turned the dryland into a region with higher availability of water sources, which altered the range of plant species. These resources were exploited with a range of new technologies, such as GSTs, axes and adzes that were not as common in the region prior to that period. A change in settlement patterns is also noted during the Oasis 2. Land-use strategies were based on two types of sites: long-term residential sites close to dune-fields and wetlands and short-term, task specific sites spread through the desert (Janz 2012, 2016; Janz et al. 2021). Janz (2012, 2016) argues that this shift to dune-fields and wetland exploitation also results in the expansion of the diet breadth of the Gobi Desert inhabitants of the time, due to the wider availability of plants and animals.

Although the use of these new technologies suggests changes in plant use, more direct evidence is needed to understand that shift. Use-wear is often employed in conjunction with residue analysis in recently excavated artifacts; when combined, the complementary studies may provide a more comprehensive picture of plant processing (Lancelotti and Madella 2023:701). However, most of the GST assemblages collected in the Gobi Desert come from archaeological expeditions collected in the 1920s, that have been curated in museums ever since. These legacy collections have only been studied a few times, but have already yielded valuable information on the life of Gobi Desert inhabitants during the Holocene (Janz 2012; Janz et al. 2015, 2020; Dubreuil et al. 2021). The preservation of micro-botanical evidence on these implements, however, is still unknown.

By studying these museum collections, I aim to investigate these topics:

1. Can the GST of the Oasis 2 period in the Gobi Desert be associated exclusively with plant processing? Are there particular types of plants connected with these implements?
2. Do the tools reflect an intensification of plant exploitation and resources that are particular to specific environments, such as forests, forest-steppes, wetlands and/or dune-fields, that were widespread at the time?
3. What are the limitations of functional studies based on museum collections? Are they appropriate subjects for residue analysis?

My hypotheses are:

1. The GST were used to exploit wild plant resources, particularly species whose consumption is facilitated by processing.
2. Their widespread adoption in the Oasis 2 period is associated with the changes in resource availability and diversity in the region.
3. Museum-based collections can be useful sources of archaeological plant residues when recently excavated materials are not available, if clear protocols are followed to rule out contamination.

An experimental reference collection was developed to address these questions.

Sandstone tools were used in experiments of abrading, grinding and grinding/pounding. They were informed by archaeological and ethnographic data on ground stone tool use and with materials likely available in the Gobi Desert during the Middle Holocene. The experiments

include the abrasion of bone, wood, shell and ostrich eggshells and grinding and/or pounding of cereals, legumes, underground storage organs and minerals. The use-wear resulted from those activities was used as a reference for the traceological analysis on the archaeological sample. The distribution and damage of micro-botanical remains after the experiments informed the residue analysis.

1.1 Thesis organization

This document is composed of five chapters. The current chapter outlined my research questions and the organization of the thesis. Chapter 2 provides geographic and environmental context for the Gobi Desert and describes the chronology of its occupations from the post Last Glacial Maximum (LGM) until the early Bronze Age. This is followed by a definition of GST technologies and a discussion on how their association with Neolithization processes does not represent the entire range of use and contexts these tools are found, as some of them do not include agricultural or sedentary adaptations. The last part of Chapter 2 discusses Traditional Ecological Knowledge (TEK) in Mongolia and current wild plant use by Mongolian herders.

Chapter 3 outlines the materials and methods utilized in this research: the expedition campaigns and archaeological sites, the sample selection for the current study and the functional approaches employed. Chapter 4 presents the results of the experimental, use-wear and residue analysis. These are further discussed in Chapter 5, which also addresses other GST assemblages in Northeast Asia with available use-wear and residue data. In addition, Chapter 5 discusses particular species of plants that could have been present in the Gobi Desert at the time, and the known data regarding their processing. Then, my research

questions and hypothesis are addressed in lieu of the results of the analysis and existing literature regarding plant-use and environmental conditions in the East Gobi Desert. This final chapter concludes with a summary of the research conducted, its limitations, key findings and recommendations for future research on the topic.

Chapter 2

Gobi Desert Chronology and Traditional Use of Wild Plants in Mongolia

The Gobi Desert, located in the south of Mongolia and the north of China (between 37° and 47° N), is a vast dryland bounded by the Altai Mountains at northwest, the Tibetan Plateau in the southwest, Chinese plains in the southeast and Mongolian steppe in the northeast.

Topographically diverse, it is made of plateaus, mountain ranges, alluvial and aeolian dune-fields, dry lake basins and gravel plains (Janz et al. 2017); most of the Gobi Desert sits more than 1,000 m above sea level. Annual temperatures range from -21.6°C in the winter and 17.5°C in the summer; average annual precipitation is currently less than 200 mm. Its climate is affected by the Indian and East Asian Summer Monsoons (EASM), the Siberian-Mongolian High-Pressure System and the Westerlies. The EASM is a part of the Asian monsoon system, which also includes the Indian and Plateau monsoons (An et al. 2000). Its northern boundary currently reaches a peak of 40°N in the summer and is responsible for increased precipitation and temperatures during that season (An et al. 2000). The Westerlies dominate arid Central Asia (Chen et al. 2008); its core area extends from $36-54^{\circ}\text{N}$ and 50°E (Caspian Sea) to 90°E (Hexi Corridor) (Huang et al., 2015a). They are

strongest in the fall/winter, when the Siberian-Mongolian High-Pressure System dominates, and result in a cold and dry season. The EASM and the Westerlies affect the Gobi Desert differently depending on the location (Janz et al. 2017). As a result of that variety, three environmentally distinct sub-regions are present in the territory: Gobi-Altai, Alashan and East Gobi (Janz et al. 2017); their location is presented on Figure 2.1 and currently relevant environmental characteristics are outlined in Table 2.1.



Figure 2.1. Map of Gobi Desert subregions and geographic features mentioned in the text and in Table 2.1. Adapted from Janz et al. (2017).

Table 2.1
Gobi-Desert subregions and relevant environmental features. Sources: Janz et al. (2017), UNEP-WCMC (n.d.).

	Biome	Vegetation	Hydrology	Climate System
East Gobi	Desert-steppe	Shrubs <i>Caragana bungei</i> , <i>C. leucocephala</i> , <i>Salsola passerina</i> , <i>Artemisia zerophytica</i> , <i>Potaninia mongolica</i> , <i>Nitraria sibirica</i> Low grasses <i>Stipa gobica</i> , <i>S. glariosa</i> , <i>Cleistogenes soongorica</i>	Shara Murun River System	EASM (south) Westerlies (north)
Gobi-Altai	Desert and desert-steppe	Saxaul (<i>Haloxylon ammodendron</i>) forests; Grassland <i>Stipa glariosa</i> , <i>Stipa gobica</i> Herbs and shrubs <i>Caragana leucophloea</i> , <i>Cleistogenes squarrosa</i> , <i>Krachennikovia ceratoides</i> , <i>Allium polyrrhisum</i> Saline adapted plants <i>Anabasis brevifolia</i> , <i>Achnatherum splendens</i> , <i>Nitraria sibirica</i> , <i>Salsola passerina</i>	Semi-saline lakes: Böön Tsagaan Nuur, Adagin Tsagaan Nuur, Orok Nuur, Tsagaan Nuur	Westerlies
Alashan	Desert and semi-desert	Extensive dune-fields, dissected badlands, gravel plains; Drought adapted shrubs <i>Haloxylon ammodendron</i> , <i>Reaumuria soongorica</i> , <i>Artemisia salsoloides</i> , <i>A. ordosica</i> , <i>Zygophyllum xanthoxylum</i> , <i>Calligonum mongolicum</i>	Ruoshui–Hei He drainage system	Westerlies

2.1 Occupation of the Gobi Desert from the Late Epipaleolithic to the Early Bronze Age

The paleoenvironmental record of the Gobi Desert suggests that after the Last Glacial Maximum (LGM) and throughout the Holocene, the region was subjected to several climatic changes that influenced the distribution of fauna and flora and had consequences for human life. This is noted in changes in archaeological assemblages, settlement patterns and diet breadth (Janz 2012, 2016; Rosen et al. 2022). Janz (2012) associated chronometric,

paleoenvironmental data, variability in material culture, land-use and archaeological sites to establish a chronology of post-LGM occupations in the Gobi Desert from the Late Epipaleolithic to the Early Bronze Age (Janz 2012; Janz et al. 2021), which is described in the following sections.

2.1.1 Early Epipaleolithic (17-13.5 k cal yr BP)

This period is marked by the return of the EASM circulation post-LGM (ending after 18-17 k cal yr BP), with consequent increase in precipitation, stabilization of lake levels and expansion of desert oases (Lu 1999; Herzschuh and Liu 2007; Wünnemann et al. 2007; Bettinger et al. 2007; Janz 2012). Land-use patterns suggest high residential mobility between arid and humid environments, including across dune-fields, wetlands, plateaus and plains (Bettinger et al. 2007; Janz 2012:131). In China, research suggests that food plants likely came from herbaceous and grass species (Lu 1999). Technological assemblages associated with the Epipaleolithic in Mongolia are composed of flake and blade-based core technology, with a progressive increase in the importance of microblade technology throughout the period (Janz 2012:139).

2.1.2 Oasis 1 (13.5-8.5 k cal yr BP)

Oasis 1 is defined by significant environmental changes, with the interruption of the post-LGM trends seen during the early Epipaleolithic by the Younger Dryas event (13-11.6 kya in Central Asia and 12-10 kya on the Loess Plateau; Madsen et al. 1998; Herzschuh 2006) followed by a return to warm and humid conditions. Seasonality was enforced by the increased precipitation associated with the intensification of the Asian Monsoon systems

from 11.5-9.6 k cal yr BP (Herzschuh 2006). Throughout Northeast Asia, it resulted in a significant retreat of the boundaries of drylands (Starkel 1998; Feng et al. 2007), infilling of lake basins/river channels and stabilization of dune-fields (Owen et al. 1997; Hülle et al. 2009). Land-use strategies in southern Siberia and North China continue from the Epipaleolithic, now adapted to the new range of species available, as changes in environmental conditions led to shifts in vegetation and faunal composition (Janz 2012:143-144). The Gobi Desert sites of this period, however, reveal a tendency of occupation of high elevation environments, close to water sources, instead of the exploitation of dune-field sites as seen in arid Northern China - although Janz (2012:154) argues it could also be related to the challenges in identifying and dating aceramic sites.

A shift toward the exploitation of medium and smaller prey is expected for Mongolia (Janz 2012:154) based on the broader trend identified in Northeast Asia. In northern China, there is still evidence for large body prey consumption at this period, but medium and small body fauna is also incorporated in the diet (Gai and Wei, 1977; Chen and Wang, 1989; Lu, 1999). Macrobotanical and starch assemblages from the region at the time are mainly composed of fleshy fruits and nuts (acorns), followed by Triticeae grasses (Wang et al. 2016).

Oasis 1 lithic assemblages in Mongolia are defined by microblade core technology, with a variety of core types that tend to be smaller and less standardized than contemporaneous assemblages in Southern Siberia and Northern China (Janz 2012:151). Blade and flake cores are no longer used, and retouched microblade tools are common in the period; there are notable trends towards the exploitation of cryptocrystalline stones, such as jasper and chalcedony as they produced more reliable conchoidal fractures than coarser

grained stones (Janz 2012:155). Fiber-impressed pottery sherds and ostrich eggshell beads are also present in technological assemblages of Oasis 1 sites.

2.1.3 Oasis 2 (8.5-5 k cal yr BP)

The environment of the Oasis 2 period is marked by an increase in organic biomass, a result of the Holocene Climatic Optimum. The timing of peak humid conditions depended on the prevalence of circulation systems, varying between 9 and 4.5 k cal yr BP (Tarasov et al. 2000; Mischke et al. 2005; Jiang et al. 2006; Herzschuh 2006; Rudaya et al. 2008). Land use in the Gobi Desert at the time was organized around two types of sites: long-term habitation sites with hearths, located in dune-fields close to water sources such as streams and former lakes, and task-specific sites of variable locations (Janz 2012). Faunal remains from Oasis 2 sites reveal the use of small and large prey associated with dune-field, wetland and desert-steppe environments, such as birds, frogs and equids (Janz 2012:180; Janz et al. 2021).

In relation to previous periods, an intensified use of several technological elements is noted during the Oasis 2, such as net and textile impressed pottery, polished adzes and axes, bifaces and small points (assumed arrowheads). Large and manufactured GSTs are widespread, more common in the East Gobi than in western sites (Janz 2012:165). Lithic artifacts diagnostic of this period are unifacially retouched blade points and small bifacial flake points, found throughout the Gobi Desert and eastern Mongolia (Janz 2012:174). Shouldered unifacial points, a common type of artifact in the early Neolithic of southern Siberia, are also found in Gobi Desert sites (Janz 2012:171).

2.1.4 Oasis 3 (5-3 k cal yr BP)

The warm and humid conditions of the Middle Holocene reached an end in the Gobi Desert at the transition between the Oasis 2 and 3 periods. Increased aridity and expansion of steppe environments started around 6.3 k cal yr BP in the East Gobi (Herzschuh 2006), around 5.2 k cal yr BP in the Gobi-Altai (Starkel 1998; Tarasov et al. 2000) and around 4 k cal yr BP in the Alashan (Herzschuh et al. 2004; Mischke et al. 2005). Land-use patterns still revolve around dune-fields and wetlands and their associated fauna and flora species, but higher residential mobility is adopted than during Oasis 2 (Janz 2012:184).

Lithic assemblages are similar to the previous period, maintaining the same manufacturing techniques. Endscrapers are more common in Oasis 3 assemblages, as are microblades (retouched into perforators), chipped and polished adzes/axes (previously only semi-polished, now fully polished; Janz 2012:192-193). New lithic artifacts associated with this period are drills with wide bases made from micro-blades, large, curved knife blades and new types of bifacial points (now with stemmed and convex bases; Janz 2012:193). Pottery assemblages during this period are abundant and have a wide variety of finishes; the wares suggest formal kiln firing (Janz 2012:187). The large, manufactured GSTs common in the Oasis 2 period are replaced with smaller and informal implements (Janz 2012:199). Ostrich eggshell beads are more abundant in Oasis 3 assemblages.

2.1.5 Summation

The trajectory of the Gobi Desert inhabitants throughout the Holocene is marked by transformations in technology, settlement patterns, and diet that are often associated with changes in environmental conditions. Interpreting these developments within traditional

archaeological periodization schemes (i.e., Mesolithic, Neolithic), however, reflects that such narratives might not be suitable for discussing certain contexts. Unlike European or Western Asian contexts in which the Neolithic is characterized by the adoption of agriculture and sedentism, the Gobi Desert's Middle Holocene populations developed traditionally "Neolithic" technologies, such as ground stone tools and pottery, without evidence of food production or extensive sedentism (but see Zhao et al. 2021). Analyzing such developments through the traditional concept of the Neolithic may not fully capture their distinctive characteristic (Janz 2012). By using the Oasis periodization established by Janz (2012), however, it is possible to interpret the cultural developments in the Gobi Desert throughout the Holocene in a more contextual basis.

2.2 Ground stone tools and the problem of the Neolithic

According to Adams (2002:1), GSTs are artifacts 'primarily manufactured through mechanisms of abrasion, polish, or impaction, or are themselves used to grind, abrade, polish'. Specific activities in which they are employed are percussion, abrasion, polishing, grinding, chopping, pounding and pecking, among others (Adams et al. 2009; Dubreuil and Savage 2014). The category includes a wide variety of implements that were used individually (such as adzes and axes) or paired with other stone tools (such as grinding slabs/handstones – sometimes addressed as *manos* and *metates* or, in Chinese contexts, as mopans *and* mobangs – and mortars/pestles). They can also be used with non-stone tools, such as pottery or wood. GSTs are employed in the reduction of intermediate materials (vegetal, animal or mineral substances) and the manufacture of other tools, both ground and

flaked (Adams 2002:1). Assemblages can vary depending on location, time of occupation and type of settlement, and can inform on the tasks being undertaken at a site.

GSTs have been considered, alongside the emergence of food production and sedentism, as one of the defining criteria of the Neolithic period (Childe 1957). The term Neolithic (meaning ‘new stone’) was originally proposed by Lubbock (1865) to describe the emergence of polished stone axes in the archaeological record of Europe. The concept, however, was reformulated by Childe (1957) as a revolutionary process that occurred in Europe defined not only by the production and use of technology like polished tools and pottery, but also by plant domestication, agriculture, sedentism and the rise of hierarchical political organization, framed as “social complexity” (Uchiyama et al. 2014). Over time, different studies of hunter-gatherer societies (Price and Brown 1985; Zvelebil 1986) were used to question Childe’s formulations. They demonstrate that the sophisticated foraging strategies and technological developments employed by non-agricultural groups during the period were also elaborate and indicative of social complexity, despite a lack of food production and sedentism. Additionally, some scholars suggest that hunting and gathering was a deliberate choice, as this way of living was maintained in certain contexts even after contact between foraging and farming communities (Uchiyama et al. 2014).

Hence, the theoretical developments of the late twentieth century led to the questioning of Childe’s conceptualization of the Neolithic and the associated idea that it represented a ‘superior’ way of living. While the Middle Holocene appears to be marked by technological innovations worldwide, human groups followed distinct paths that did not always lead to sedentism and the adoption of agriculture; when they did, it was not necessarily final. Liu et al. (2016) argues that that is the case of the settlers of the Shihushan

sites (SHSI and SHSII), in south central Inner Mongolia. Shihushan I is dated to 6530–6440 k cal yr BP, and it is estimated to be later than SHSII based on ceramic typology. The authors associate it with a northward expansion of the Yangshao culture (that relied on milled-based agriculture); the groups that lived in the Shihushan sites, however, adopted a more diversified diet (Liu et al. 2016). According to use-wear and residue analysis of GSTs recovered from these localities, domesticated cereals were only a small part of the diet; after settling in Inner Mongolia, an adoption of local foraging strategies that involved hunting of large animals and cultivating/collecting diverse plants like underground storage organs replaced the previous agricultural diet (Liu et al. 2016).

The Neolithic of Northeast Asia is still often identified and investigated based on the agricultural and sedentary societies of the Central Plains and the Yellow River (Janz 2012:158). In the Gobi Desert, however, despite the likely contact of hunter-gatherers with agriculturalists groups from northern China (Janz 2012), the exploitation of wild fauna and flora prevailed over food production until the adoption of nomadic pastoralism in the Bronze Age (Janz 2012:157). Still, technologies that are typically associated with Neolithization, such as pottery and GSTs, are widespread in the Oasis 2 period. Studying those technologies can provide a more comprehensive understanding of wild plant-use by non-agricultural societies of the region. Use-wear analysis (which will be described in the following chapter) allows for the identification of patterns associated with materials processed and can be used to determine what a tool was used for.

In the Gobi Desert, GST assemblages have use-wear associated with the processing of plant materials, as noted by Dubreuil et al. (2021) and the results of this study, described in Chapter 4. As stated by Janz (2012), these tools are only adopted intensely in the region

during the Middle Holocene, or the Oasis 2 period. They are not indicative of agriculture or sedentism in the Gobi Desert, where groups maintained a foraging economy and high mobility. Given this context, one of the questions this thesis aims to explore is if GSTs can verify an intensification in plant exploitation by Oasis 2 foragers in the Gobi Desert, elucidating a distinct regional trajectory.

This question will be discussed based on Mongolian Traditional Ecological Knowledge (TEK), defined in the following section. Rosen et al. (2022) suggests that the TEK involving wetland zone's exploitation in the Gobi Desert started during the Oasis 2 period, when the strengthened EASM increased rainfall and stabilized water sources (Rosen et al. 2022). At the end of the Middle Holocene, when the EASM weakened and an aridification process intensified, the knowledge of seasonal linear valley drainages (which during the Oasis 2 would likely have been more stable) would favor Gobi Desert populations that oriented their mobility in relation to those water sources (Holguín, 2019; Holguín and Sternberg, 2018; Rosen et al., 2019, 2022). TEK studies among nomadic herders in Mongolia show that the seasonal availability of water still represents one of the main causes of migrations (Tugjamba et al. 2021). TEK is an important source of information regarding human adaptation to particular environments; therefore, the following section will present traditional knowledge regarding plant-use in Mongolia in the present.

2.3 Plant-use in Mongolia according to Traditional Ecological Knowledge

Traditional Ecological Knowledge (TEK) is built and transmitted for generations; more than knowledge per se, it is part of a culture's worldview – it shapes their behavior and beliefs

regarding the ecosystem they live in, allowing the identification of environmental components, their management and use (Berkes 1993). In Mongolia, TEK research often focuses on herding knowledge – investigations of pastoralist’s management of resources, its connection with climate change (Fernandez-Gimenez 1999, 2000; Fassnacht et al., 2011; Reid et al. 2015; Ahearn 2017, 2019) and the relationship between herders and their livestock (Fjin 2011). Animal products are central in the subsistence and economy of herders – meat and dairy are main components of the traditional diet of Mongolian nomadic pastoralists; today these diets are heavily supplemented by imported grains such as wheat flour and rice. However, according to Farquhar (2022), new archaeological research on early herders has highlighted the importance of combining strategies such as hunting, fishing, gathering and cultivating to pastoralists economies (Hermes et al. 2021; Ingold 1980; Kiryushin and Kiryushin 2005; Rosen 2008; Semibratov and Stepanova 2006).

The dietary use of wild plants by herders has been recorded through ethnobotanical investigations in Mongolia and Inner Mongolia (Yutanov 1954; Khasbagan and Sh 1990; Khasbaghan 1996; Khasbagan and Soyolt 1996; Khasbagan et al. 2000). Khasbagan et al. (2000) argues that they are valuable resources in terms of nutritional composition and health care. Table 2.2 outlines wild plant species consumed by herders in Mongolia based on the ethnobotanical data mentioned above. It includes 98 species that were consumed as grains, vegetables, seasonings, fruits and tea; some species are defined as food substitutes, consumed at times of shortage of grains (Zhang et al. 2011).

Table 2.2
Wild plant species consumed by herdsman in Mongolia and Inner Mongolia.

Plant species	Parts used	Consumed as	Source
<i>Acer truncatum</i>	Branches	Beverage	Khabasgan et al. 2000
<i>Agriophyllum squarrosum</i>	Seeds	Grain, flour	Yutanov 1954
<i>Allium altaicum</i>	Bulbs	Vegetable	Yutanov 1954
<i>Allium condensatum</i>	Young leaves, bulbs	Vegetable	Khabasgan et al. 2000
<i>Allium leucocephalum</i>	Young leaves	Vegetable	Yutanov 1954
<i>Allium lineare</i>	Young leaves	Vegetable, seasoning	Yutanov 1954
<i>Allium macrostemon</i>	Bulbs	Vegetable	Khabasgan et al. 2000
<i>Allium mongolicum</i>	Young leaves	Seasoning	Yutanov 1954
<i>Allium neriniflorum</i>	Bulbs	Vegetable	Khabasgan et al. 2000
<i>Allium polyrhizum</i>	Young leaves, inflorescens	Vegetable, seasoning	Khabasgan et al. 2000; Yutanov 1954
<i>Allium ramosum</i>	Young leaves, inflorescens, bulbs	Vegetable, seasoning	Khabasgan et al. 2000; Yutanov 1954
<i>Allium senescens</i>	Bulbs, lower stems, young leaves	Vegetable; stored for the winter (fermented, dried or ground)	Khabasgan et al. 2000; Yutanov 1954
<i>Allium victorialis</i>	Young leaves	Vegetable	Khabasgan et al. 2000; Yutanov 1954
<i>Amaranthus retroflexus</i>	Young leaves, seeds	Vegetable, grain	Khabasgan et al. 2000
<i>Apocynum venetum</i>	Young leaves	Beverage	Khabasgan et al. 2000
<i>Artemisia sieversiana</i>	Seeds	Grain	Khabasgan et al. 2000
<i>Atrophaxis manshuica</i>	Roots, stems and leaves together	Beverage	Khabasgan et al. 2000
<i>Bergenia crassifolia</i>	Possibly aboveground parts	Tea	Yutanov 1954
<i>Chenopodium album</i>	Young stems and leaves, together	Vegetable	Khabasgan et al. 2000
<i>Chenopodium acuminatum</i>	Young stems and leaves, together	Vegetable	Khabasgan et al. 2000
<i>Chenopodium mongolicum</i>	Seeds	Parched flour	Yutanov 1954
<i>Cirsium segetum</i>	Young leaves	Vegetable	Khabasgan et al. 2000
<i>Clematis hexapetala</i>	Stems and leaves together	Beverage	Khabasgan et al. 2000; Yutanov 1954
<i>Corispermum dilutum</i>	Seeds	Grain	Khabasgan et al. 2000
<i>Crataegus pinnatifida</i>	Mature fruits	Fruit	Khabasgan et al. 2000
<i>Crataegus sanguinea</i>	Mature fruits	Fruit	Khabasgan et al. 2000
<i>Cynanchum chinense</i>	Young fruits	Fruit	Khabasgan et al. 2000
<i>Cynanchum thesioides</i>	Young fruits	Fruit, vegetable	Khabasgan et al. 2000; Yutanov 1954
<i>Echinochloa caudata</i>	Seeds	Grain	Khabasgan et al. 2000
<i>Echinochloa crusgalli</i>	Seeds	Grain	Khabasgan et al. 2000
<i>Ephedra sinica</i>	Mature female cone	Fruit, refine sugar	Khabasgan et al. 2000
<i>Fragaria orientalis</i>	Fruits	Fruits	Yutanov 1954

Table 2.2
Continued.

Plant species	Parts used	Consumed as	Source
<i>Geranium pseudosibiricum</i>	Possibly aboveground parts	Tea	Yutanov 1954
<i>Glycine soja</i>	Seeds	Grain	Khabasgan et al. 2000
<i>Hemerocallis minor</i>	Flowers	Vegetable	Khabasgan et al. 2000
<i>Hibiscus trionum</i>	Young leaves	Vegetable	Khabasgan et al. 2000
<i>Kalidium gracile</i>	Seeds	Parched flour	Yutanov 1954
<i>Kochia scoparia</i>	Young stems and leaves, together	Vegetable	Khabasgan et al. 2000; Yutanov 1954
<i>Lespedeza davurica</i>	Leaves	Beverage	Khabasgan et al. 2000
<i>Leymus racemosus</i>	Seeds	Rice, parched flour	Yutanov 1954
<i>Lilium martagon</i>	Bulbs	Fresh or dried	Yutanov 1954
<i>Lilium pumilum</i>	Bulbs, flowers	Fruit, vegetable; eaten raw; boiled with milk; stored in cream or oil	Khabasgan et al. 2000; Yutanov 1954
<i>Malus baccata</i>	Mature fruits, leaves	Fruit, beverage	Khabasgan et al. 2000; Yutanov 1954
<i>Malva verticillata</i>	Young leaves	Vegetable	Khabasgan et al. 2000
<i>Morus mongolica</i>	Mature fruits	Fruit	Khabasgan et al. 2000
<i>Neopallasia pectinata</i>	Seeds	Grain	Khabasgan et al. 2000
<i>Nepeta annua</i>	Seeds	Seasoning	Yutanov 1954
<i>Nitraria sibirica</i>	Fruits	Fruits	Yutanov 1954
<i>Orobanchae coerulescens</i>	Aboveground parts	Vegetable, seasoning	Khabasgan et al. 2000
<i>Orostachys fimbriatus</i>	Leaves	Fruit	Khabasgan et al. 2000
<i>Ostryopsis davidiana</i>	Leaves, roots	Beverage	Yutanov 1954
<i>Paeonia anomala</i>	Roots, follicle	Flour, tea	Yutanov 1954
<i>Paeonia lactiflora</i>	Dry fruit peel, roots, follicle	Flour, tea	Khabasgan et al. 2000; Yutanov 1954
<i>Periploca sepium</i>	Young stems and leaves, together	Vegetable	Khabasgan et al. 2000
<i>Polygonatum macropodium</i>	Rhizomes	Fruit	Khabasgan et al. 2000
<i>Polygonatum odoratum</i>	Rhizomes	Fruit	Khabasgan et al. 2000
<i>Polygonatum sibiricum</i>	Rhizomes	Fruit	Khabasgan et al. 2000
<i>Polygonatum divaricatum</i>	Seeds, young stems	Grain, fruit	Khabasgan et al. 2000
<i>Polygonum lapathifolium</i>	Young leaves	Fruit	Khabasgan et al. 2000
<i>Polygonum viviparum</i>	Rhizomes	Cooked, flour, seasoning	Yutanov 1954
<i>Portulaca oleracea</i>	Young stems and leaves, together	Vegetable	Khabasgan et al. 2000
<i>Potentilla anserina</i>	Young leaves, roots	Vegetable	Khabasgan et al. 2000; Yutanov 1954
<i>Potentilla chinensis</i>	Aboveground parts	Beverage	Khabasgan et al. 2000
<i>Potentilla fruticosa</i>	Possibly aboveground parts	Tea	Yutanov 1954
<i>Prunus humilis</i>	Mature fruits, leaves	Fruit, beverage	Khabasgan et al. 2000

Table 2.2
Continued.

Plant species	Parts used	Consumed as	Source
<i>Prunus padus</i>	Mature fruits	Fruit	Khabasgan et al. 2000
<i>Prunus sibirica</i>	Young fruits, stems, seeds	Fruit, beverage, edible oil	Khabasgan et al. 2000
<i>Psammochloa villosa</i>	Seeds	Flour	Yutanov 1954
<i>Pugionium dolabratum</i>	Young plant	Salted	Yutanov 1954
<i>Pyrosia davidii</i>	Leaves	Beverage	Khabasgan et al. 2000
<i>Pyrus ussuriensis</i>	Mature fruits, leaves	Fruit, beverage	Khabasgan et al. 2000
<i>Quercus mongolica</i>	Nuts, leaves	Grain, beverage	Khabasgan et al. 2000
<i>Rhamus arguta</i>	Mature fruits	Fruit	Khabasgan et al. 2000
<i>Rheum nanum</i>	Roots	Flour	Yutanov 1954
<i>Ribes emodense</i>	Mature fruits	Fruit	Khabasgan et al. 2000
<i>Ribes pulchellum</i>	Mature fruits	Fruit	Khabasgan et al. 2000
<i>Rosa acicularis</i>	Possibly leaves	Tea	Yutanov 1954
<i>Rosa davurica</i>	Mature fruits, leaves, flowers	Fruit, beverage	Yutanov 1954
<i>Rubus saxatilis</i>	Mature fruits, leaves	Fruit, beverage	Khabasgan et al. 2000
<i>Salsola collina</i>	Young stems and leaves, together	Vegetable	Khabasgan et al. 2000
<i>Sanguisorba officinalis</i>	Leaves, roots, stems	Tea	Khabasgan et al. 2000; Yutanov 1954
<i>Saposhnikovia divaricata</i>	Seeds	Seasoning	Yutanov 1954
<i>Scutellaria baicalensis</i>	Stems, leaves and flower	Beverage	Khabasgan et al. 2000
<i>Setaria glauca</i>	Seeds	Grain	Khabasgan et al. 2000
<i>Setaria viridis</i>	Seeds	Grain	Khabasgan et al. 2000
<i>Sisymbrium heteromallum</i>	Seeds	Seasoning	Yutanov 1954
<i>Solanum nigrum</i>	Mature fruits	Fruit	Khabasgan et al. 2000
<i>Sonchus arvensis</i>	Young leaves	Vegetable	Khabasgan et al. 2000
<i>Spiraea pubescens</i>	Mature fruits, leaves	Beverage	Khabasgan et al. 2000
<i>Suaeda salsa</i>	Young stems and leaves, together	Vegetable	Khabasgan et al. 2000
<i>Taraxacum mongolicum</i>	Young leaves, inflorescens	Vegetable	Khabasgan et al. 2000
<i>Thladiantha dubia</i>	Young fruits	Fruit	Khabasgan et al. 2000
<i>Thymus serpyllum</i>	Aboveground parts	Seasoning	Khabasgan et al. 2000
<i>Ulmus pumila</i>	Young fruits	Vegetable	Khabasgan et al. 2000; Yutanov 1954
<i>Urtica cannabina</i>	Young leaves	Vegetable	Khabasgan et al. 2000
<i>Viburnum mongolicum</i>	Mature fruits, leaves, flowers	Fruit, beverage	Khabasgan et al. 2000
<i>Xanthoceras sorbifolia</i>	Branches, leaves	Beverage	Khabasgan et al. 2000

Another really important part of Mongolian TEK is Traditional Mongolian Medicine (TMM). There are around 600 plant species with medicinal properties in Mongolia, divided in 65 plant families such as Asteraceae, Fabaceae, Rosaceae, Liliaceae and Polygonaceae (Ligaa and Tsembe1 2015:120). TMM combines knowledge and practices of plants used for the treatment of diseases and conditions with Indo-Tibetan philosophies, introduced to Mongolia in the 16th century with the expansion of Buddhism (Ligaa and Tsembe1 2015). Although the Tibetan influence is strong, the adoption of its practices was contextual and connected to preexisting Mongolian techniques, resulting in the distinct TMM. Some of the Buddhist scriptures that influenced it are the *Rig-gnas* (which discusses not only medicine but technology, grammar, logic and religion) and the famous Indian *Ayurveda*, translated as *rGyud-bzhi* (*The Four Treatises*), by 15th century Indian author gYutog pa Yontan mgonpo. Pre-buddhist Mongolian practices are recorded in accounts of European travelers of the 13th century, such as Carpini and Rubruck (Khaidav et al. 1985), and in texts - such as the *gSang sMan sbyorba* (*Secret Recipes*) (Ligaa and Tsembe1 2015:117).

The union of Indo-Tibetan and Mongolian knowledge culminates in several manuscripts of TMM from the 18th, 19th and 20th centuries. Some examples of 18th century texts are: *Ngos 'Dzin Shel dkar Me long* (*Synonymous Cognition Mirror of Medicine*) and its companion text *Lhantabs kyi brda krol* (*Supplementary Lhantav*), written by Mongolian scholar Yeshe dPal sgor; *sNgo Sman shei byed* (*Inspection of Medicine*), written by physician Lo bsang Tsul Khrims; and *Ges btus snying nor* (*Selective First Essentials of Medicine*), compiled under Cho'phel. In the 1800s, the *mDzes mTsar mig rgyan* (*Book on Pharmacology*) was written in Tibetan by Jams dpal rdo rje; in the beginning of the 20th

century, the anthology *nGo mtsar dga'aston (Wonderful Collection of Medicine)* was assembled by Chos rgya mtso (Ligaa and Tsembe 2015:116).

These original manuscripts started being adapted to modern pharmaceutical terminology in the 1960s, in publications like *The Terminologies of Medicinal Plants Used in Mongolian Traditional Medicine* (Khaidav, 1965), *Terminology of Plant Names in Mongolian-Latin-Tibetan-Russian-Chinese Languages* (Mijiddorj, 1973), *Medicinal Plants in Mongolian Traditional Medicine* (Khaidav and Menshikov, 1978), *Medicinal Plants in Mongolian Medicine* (Khaidav et al., 1985), *Useful Plants of Mongolia* (Ligaa, 1987).

While TMM also includes the use of animal and mineral materials, plants are the primary ingredients in all aspects of treatments – which is why traditional sources record a wide range of information, such as species distribution, distinguishing characteristics, optimum time of collection, common names, medicinal properties, parts used and methods of preparation that preserve the medicinal compounds. Plants may be prepared according to a wide range of recipes that include turning them to powder, pill, paste, oil, or tincture (Ligaa and Tsembe 2015:118) A summary of the plant used as medicines in TMM available in the Gobi Desert is presented in Table 2.3.

Table 2.3

Plants used in Traditional Mongolian Medicine that grow in the Gobi Desert and their properties.

Scientific name	Found in	Parts used	Used for/properties	Prepared/used as	Sources
<i>Agriophyllum pungens</i>	Eastern Gobi, Gobi-Altai, Alashan Gobi	Seeds	Typhus, fever, urinary tract problems, kidney fever, bilious diseases (stomach and liver), rash, backache, cystitis, antioxidant	Not informed	Ligaa and Tsemel 2015; Birasuren et al. 2013;
<i>Artemisia annua</i>	Deserts, semi-deserts, mountain slopes, banks of waterbodies and dry riverbeds	All above-ground parts	Lung fever, stomatitis, gingivitis	Decoction; Infusion;	Ligaa and Tsemel 2015
<i>Vaccinium vitis-idaea</i>	Eastern Gobi	Leaves, fruits	Bilious diseases, fever, acute pains, liver pains, headaches, jaundice, arthritis, coughs	Infusion; Juice;	Ligaa and Tsemel 2015
<i>Cistanche deserticola</i>	Eastern Gobi, Alashan Gobi	Stem	Bilious diseases, digestion, enteric fever, backache, wounds	Not informed	Ligaa and Tsemel 2015
<i>Cynomorium songaricum</i>	Eastern Gobi, Gobi-Altai, Alashan Gobi	Stem	Bilious diseases, impotence, spermatorrhea, nervous disorders, constipation, dyspepsia, jaundice, hypertension	Infusion	Ligaa and Tsemel 2015
<i>Amygdalus mongolicus</i> , <i>Prunus mongolica</i>	Eastern Gobi, Gobi-Altai, Alashan Gobi	Seeds	Laxative, diuretic, skin-softening agent, sedative, anodyne, wounds	Oil; Burned seeds powder;	Ligaa and Tsemel 2015
<i>Caryopteris mongolica</i> <i>Bge.</i>	Eastern Gobi, Gobi-Altai, Alashan Gobi	Flowering branches	Gas relief, phlegmatic diseases, appetite increase, indigestion, pulmonary diseases, rheumatism, blood vessel constriction, diuretic, accelerates uterine contraction during childbirth, allergic and inflammatory skin diseases (itch relief)	Not informed	Ligaa and Tsemel 2015
<i>Peganum nigellastrum</i>	Eastern Gobi, Gobi-Altai, Alashan Gobi	Herb	Prophylactic purposes - purgative and bile-excretion actions	Not informed	Ligaa and Tsemel 2015
<i>Ephedra sinica</i>	Eastern Gobi; Gobi-Altai	Scions (plant shoots)	Fever, bleedings, blood vessel diseases, bronchial asthma, nettle rash, allergic diseases, kidney diseases byproducts (hematuria), rheumatism	Infusion	Ligaa and Tsemel 2015; Heinrich et al. 2013.
<i>Sophora alopecuroides</i>	Eastern Gobi; Gobi-Altai	Root and rhizome	Pulmonary disorders (cold, influenza and pneumonia)	Not informed	Ligaa and Tsemel 2015

Table 2.3
Continued.

Scientific name	Found in	Parts used	Used for/properties	Prepared/used as	Sources
<i>Rhodiola rosea</i>	Gobi-Altai	Rhizome	Lung regeneration, nervous system regulation, bleedings, fever and lung fever, cold, influenza and pneumonia	Infusion	Ligaa and Tsemel 2015
<i>Gentiana decumbens</i>	Gobi-Altai	Flowers and root	Digestion, chronic gastritis, hepatitis, cholangitis, stomach disorders, liver diseases, influenza/fever	Not informed	Ligaa and Tsemel 2015
<i>Peganum harmala</i>	Gobi-Altai	Flowers and leaves	Stimulant of the central nervous system, lower blood pressure, dilate peripheral blood vessels <i>Herb:</i> Prophylactic purposes (resistance enhancer), used in a hot bath to treat rheumatism and skin diseases or as a decoction to treat the inflammation of the mouth and throat; <i>Flowers and leaves</i> - Typhoid fever, respiratory tract problems, dizziness, malionant tumors, arthritis	Hot baths; decoction;	Ligaa and Tsemel 2015
<i>Glycyrrhiza uralensis</i>	Gobi-Altai, Alashan Gobi	Root and rhizome	Respiratory tract problems, chronic constipation, metabolic disorders, gastric ulcers, asthma	Dry and liquid preparations;	Ligaa and Tsemel 2015
<i>Polygonum aviculare</i>	Gobi-Altai;	Flowers and leaves	Infections on the urinary tract, metrorrhagia (uterine stypic remedy), kidney diseases, respiratory tract problems (cough, bronchial problems, asthma, and tuberculosis) <i>Flowers and leaves</i> - Irregular uterine bleeding	Infusion;	Ligaa and Tsemel 2015
<i>Thalictrum foetidum</i>	Gobi-Altai;	Herb and roots	Hypertension, stomach disorders, ulcers, wounds, anthrax, erysipelas, fever	Tincture	Ligaa and Tsemel 2015

TEK studies in Mongolia reveal that herders have a deep understanding of their environment and help in the management of the flora in arid regions. One example of that regards saxaul forests in Inner Mongolia. Saxaul (*Haloxylon ammodendron*) is a saline tolerant, drought-resistant tree species. Its endurance to harsh environments is responsible for its distribution in arid Central Asia, particularly North China, Mongolia and a part of Russia (Guo et al. 2005). A study in the Hatuhuduge Gacha village in the Alashan prefecture of Inner Mongolia revealed the importance of saxaul forests to Mongol communities, which were often settled near or inside them – as they indicate the presence of water (Tang and Gavin 2010:199). Some of the informants had knowledge of reproductive patterns of *H. ammodendron*, regarding its average seed production (3.5-4 kg/yr) and season of seed availability (mostly in September, as they need rainfall to produce seeds). Used primarily for firewood, different parts of saxaul were also used to build sheep shelters, wells and fodder. The informants revealed the importance of herding in saxaul forests. Animals like camels and sheep help the trees grow vertically when they browse, which helps main stems to become taller and thicker – which is fundamental in the maintenance and dispersion of new seeds, as tall mature trees functioned as shelter for seedlings (Tang and Gavin 2010:200). Without browsing, the trees have weaker main stems and too many side branches, making them easily breakable and more prone to uprooting by strong winds. Camels also influence the preservation of *H. ammodendron* forests by controlling its rat population.

In the early 1990s, protected areas of saxaul were established by government policies that attempted to prevent deforestation and desertification (Tang and Gavin 2010:195). A decade later, the saxaul population on the reserves, which were forbidden to human and livestock use, were more fragile than prior to the establishment of the protected areas (SEE

2005). With limited height, weak main stems and subjected to rat plague and high winds, mature specimens in the reserves had high mortality rates (SEE 2005); that was not observed in areas outside of the protected regions without restriction of use, which had healthier saxaul populations (SEE 2005; Tang and Gavin 2010:196). This example highlights the importance of traditional practices in indicating how to better handle the environment based on its needs, possibilities and limitations.

2.4 Conclusion

The mobile hunter gatherers of the Gobi Desert were extremely resilient, as noted in the adaptations of technology, settlement patterns and diet that varied throughout the Holocene, along environmental changes that affected resource reliability. One of the strategies used during the Oasis 2 period, when increase in precipitation and temperatures resulted in a peak in vegetative biomass, was the adoption of ground stone tool technology. This development is explored in this thesis through the hypothesis that it reflected a shift towards more intensive plant exploitation in the region at the time. Plants are extremely important to humans; in Mongolia, wild plants to this day are used as food, medicine, raw materials and pastures for herds.

The present thesis used Mongolian TEK regarding wild plant use amongst Mongolian herders to understand which plant species are targeted in the Gobi Desert for both dietary and medicinal purposes. As TEK's observations, practices, and beliefs are built over generations, they are a valuable resource to investigate cultural practices regarding plant use in the past. Using TEK to investigate Middle Holocene plant use in the Gobi

Desert might reflect resilient adaptations of ancient foragers and how they transformed or persisted throughout time. Beyond that, analyzing the developments of the Oasis 2 period in relation to particular trajectories of the Gobi Desert will help create alternative narratives to the “Neolithic” period that are more adequate to contexts that did not adopt agriculture or sedentism.

Chapter 3

Materials and methods

The current chapter will present the archaeological collection analyzed in this study, the instruments and methods applied. First, relevant background information regarding the archaeological implements will be provided. Then, the methods utilized in the analysis will be discussed: the use-wear analysis, experimental approach and residue analysis.

3.1 Archaeological collection formation and origin

The tools analyzed in this study come from surface and excavated finds collected in 1925 and 1928 during the Central Asiatic Expeditions that occurred in Mongolia and China from 1921 to 1930. They were organized by the American Museum of Natural History (AMNH) and led by Roy Chapman Andrews. All materials are associated with the Oasis 2 period and come from seven sites in the East Gobi (collected by Alonzo W. Pond in 1928) and the Gobi-Altai (collected by Nels C. Nelson in 1925) (see Figure 3.1). Table 3.1 includes a brief description of the material assemblage associated with each site and the implements that compose the sample studied in this thesis.

Table 3.1
Summarized site description based on Janz (2012), Janz et al. (2015), Pond (n.d., unpublished) and implements analyzed.

Region	Site	Dates	Assemblage	Implements	Typology	Raw material
	Jira Galuntu (site 18)	8.0-7.6 kya (estimated)	Unifacial points, pottery, microblade cores, cutting and non-cutting ground stone tools and flinted lithics (bifaces, hammerstones, scrapers, burins, flakes) (n=6,340).	73-2425	Rectangular handstone	Sandstone
	Baron Shabaka Well (site 19)	12,509 ± 59 (eggshell fragment) 12,450 ± 74 (eggshell fragment) 5609 ± 47 (net-impressed ceramic) 5954 ± 52 (plain ceramic) 5825 ± 85 (plain ceramic) 1445 ± 86 (roller-stamped ceramic) 3115 ± 47 (roller-stamped ceramic) 960 ± 80 (roller-stamped ceramic) (Janz et al. 2015)	Ground stone tools (cutting and non-cutting), flinted lithics, cores, endscrapers, pottery, mollusc and ostrich shell fragments, ostrich beads, a fragment of a stone ring and an iron vessel used for cooking (Janz 2012).	73-2079 73-2078 73-2082B 73-2082C 73-2083A 73-2083B 73-2083C 73-2085C 73-2085D 73-2085E 73-2088C 73-2088E 73-2088F	Grinding slab Grinding slab Rectangular handstone Rectangular handstone Rectangular handstone Oval handstone Oval handstone Elongated (without handle) Elongated (without handle) Elongated (without handle) Elongated (with handle) Elongated (without handle) Elongated (with handle)	Sandstone Sandstone Granite Sandstone Granite Sandstone Sandstone Sandstone Granite Sandstone Sandstone Sandstone
East Gobi	Baron Shabaka West (site 20)	not dated	Fragments of egg shells and projectile points, blades, flakes, cores and ground stone tools.	73-2242B 73-2243A 73-2243B	Grinding slab (fragmented) Elongated (with handle) Elongated (with handle)	Sandstone Sandstone Sandstone
	Irdin Manha (site 22)	not dated	Small amounts of flakes, worked lithics and ground stone tools.	73-2528	Elongated (without handle)	Sandstone
	Chilian Hotoga (site 35)	1866 ± 88 (plain ceramic) 17,120 ± 220 (plain ceramic) 5950 ± 390 (plain ceramic) 6728 ± 45 (net-impressed ceramic) 10,586 ± 56 (eggshell fragment) 10,103 ± 55 (eggshell fragment) (Janz et al. 2015)	Worked bones, pierced teeth, shells; hearths with burned stones, bone fragments, charcoal and ground stone tools; flinted lithics (uni and bifacial points and knives); adzes, cores, scrapers; ostrich and mollusks eggshells/fragments; bone awl, needles and faunal remains.	73-2746 73-2747	Elongated (without handle) Elongated (without handle)	Granite Sandstone
Gobi-Altai	Shabarakh-Usu	Multiple dates associated with Oasis 2 and 3 (see Janz et al. 2015)	Over 7000 artifacts, mostly flakes/microflithics. A grinding slab, pottery, polished bones and worked shells (pendant/perforated) were also found.	73-715	Grinding slab (fragmented)	Sandstone

3.2 Sample selection

The sample selection for the current study was informed by previous work on the collection conducted by Dr. Dubreuil (Dubreuil et al. 2021). The analysis contributed to the understanding of the Gobi collection in three main ways: by formulating a typological classification of the grinding and pounding systems that the implements were a part of; by identifying the signs of manufacture, use and post-depositional alterations on the tools; and finally, by identifying that their function related to plant processing. The classification determined by Dubreuil et al. (2021:130) includes abraders, one type of lower tool, 2 types of upper tools – one associated with grinding and the other, with grinding and pounding motions - and one semilunar implement that could not be defined in terms of kinematic (whether it is a lower or upper tool). The lower tool type is grinding slabs with signs of manufacture on the entirety of the stone, have elongated rectangular/oval morphology on plan, a flat/concave profile on the active surface and no borders (an open surface configuration) (Dubreuil et al. 2021:125). The upper tools are separated in two types, an elongated/pestle-like implement and a rectangular handstone/pounder, both types with evidence of manufacture. The first are implements with an elongated, rounded and faceted body. Some have knobs/handles and transversal profiles that are bi-convex, asymmetric or a combination of both. Some are elongated without knobs and have a plano-convex transversal profile (Dubreuil et al. 2021:127). The second type of upper tools, the rectangular handstones, have flat/convex profiles, rounded ends and are considerably thick (the average size in mm is 107.5 [l] x 76.5 [w] x 34.5 [t]) (Dubreuil et al. 2021:129). The semilunar implements have a half-moon morphology in plan and each face has a mostly flat, but slightly concave and convex, respectively, transversal profile.

Dubreuil et al. (2021) also recorded relevant data regarding the effects of post-depositional processes on the collection. After deposition, archaeological implements are subjected to processes that can compromise the morphological integrity of the tools and the use-wear preservation on them from the moment the implements are set in the archaeological record and while they are collected and stored. In the case of the Gobi collection, the most significant process that affected the tools relates to its deposition in the desert, where they are subjected to eolian abrasion and form rock varnish (Ugalde et al. 2015). Rock varnish (a darkening of the surface) and patina can chemically change the composition of the tool (Ugalde et al. 2015). Post-depositional wear may also include the deposition of compacted calcium carbonate (CaCO₃) mixed with dirt, breakages, grain rounding, striations and pitting (Asryan et al., 2014; Ugalde et al., 2015).

Another relevant finding outlined in Dubreuil et al. (2021) was the association of the GST with plant processing – of both dry and oily plants. Processing of nuts was discounted, and the authors suggest the likely processing of underground storage organs (USOs) or, potentially, the processing of dry meat. There was no wear related to grinding or pounding of mineral materials.

The current work aims to expand the typological classification and assess possible variability in the pre-established categories. The sample used for this analysis, therefore, included multiple implements of all typologies established above. The tools were selected based on photos taken by Dr. Janz in 2016 at the American Museum of Natural History and chosen primarily based on quality of preservation or minimal visible evidence of post-depositional alterations. Twenty-one implements were analyzed in this study, acquired through a one-year loan from the AMNH. Information about their origin, typology and raw

material was presented on Table 3.1. Before performing use-wear and residue analysis, a post-depositional wear assessment was conducted in search of the main traces of damage (presence of CaCO₃, extensive grain edge rounding and rock varnish). The tools with a good level of preservation and least affected by post-depositional wear were then used in the use-wear and residue analysis.

3.3 Use-wear analysis

Use-wear analysis is the functional study of the wear formed on a surface after use, based on comparative analysis. Wear can be defined as ‘a continuous damage process of surfaces, which are in contact with a relative movement’ (Shizhu and Ping 2012:263). Use-wear analysis is based on the observation that wear patterns vary according to the function of the tool in question (Dubreuil and Savage 2014) through unaided eyes and with microscopes of low and high magnifications. By investigating the use-wear, archaeologists can inform the activities conducted at a site, the materials transformed and how they were processed. All of this combined can give an insight into a group’s technological traditions, socioeconomic conditions and the resources that were utilized.

Although use-wear related observations have been noted for a long time (McGuire 1891), the systematization of the method was done in the 1950s by the researcher Sergei Semenov (Semenov 1964). While the method started being applied to flint materials, the pioneer work of Adams (1988, 1989, 1993, 2002) introduced the application of this method to GST analysis (Adams et al. 2009; Dubreuil and Savage 2014). The data used to base the analysis is acquired through experimental studies that can be done through different ways,

such as manually or mechanically and in an exploratory or systematic manner (meaning the range of control over variables when conducting an experiment). Experimental work with GSTs has been done for over 30 years (Dubreuil and Savage 2014), exploring a wide range of materials processed (vegetal, mineral, animal), nature (wet, dry, soft, hard), motions used (grinding, abrading, pounding) and raw materials explored (granites, sandstones, quartzites, basalt, and diabases of different granularities). Those works demonstrate that the variations in use-wear can be attributed to the combination of the elements outlined above.

Previous analysis on the ground stone tools from the Gobi Desert-Steppe focused on “distinguishing between grinding mineral versus non-mineral matters, greasy versus non-greasy and suggesting whether use-wear characteristics appear to indicate processing of plant or animal matters” (Dubreuil et al. 2021). The analysis in the present study maintained those goals while further aiming to distinguish between types of plants, when plant matter was judged to have been processed in the tools in question.

3.3.1 Equipment

Use-wear analysis is based on observations with the unaided eye and microscopes of low and high magnifications. When combined, the two techniques provide a full image of the implements and the characteristics of their surface and grains. A Nikon SMZ 1000 stereomicroscope with magnifications ranging from 8 to 80× in association with a fiber optic dual gooseneck illuminator was used in multiple angles to bring to evidence relevant features in the low-power analysis. A Nikon Eclipse LV-150 compound metallographic microscope with long distance objectives and equipped with DIC (with a magnification range of

50-500x) was used for high-power analysis. For the visual recording of the observations, a DSLR Canon EOS T2i camera was used. When the relevant wear traces were in different depths, acquiring only one image with everything on focus was not possible, so multiple pictures were taken at different depths and rendered into one image through focus stacking, using the software Helicon Focus 7.0 R. The images that result from that are useful to get a full picture of a specific section of the tool's surface, but the viewer should be advised that the surface ends up being portrayed as more leveled/flat than it is naturally. The macroscopic photos of the implements were taken with a Canon EOS 760D. One of the implements (cat. #73/2082C) had a distinct surface configuration that could not be successfully captured through photos, so a 3D model of the tool was made with the Scaniverse app to build a Digital Elevation Model (DEM) of the surface. The DEM model was made by Trent undergraduate student, Charles Cumberland, using QGIS.

3.3.2 Framework

Use-wear analysis starts with the observation of the tool without the aid of microscopes, to note any alterations to the topography of the use surface and visible macro use-wear. Then, through low power magnification, the microtopography will be assessed, through the formation or changes of the following elements: linear traces, sheen, leveling of the grains and the formation of plateaus, pits/grain extractions, fractures/cracks and grain edge rounding (Adams et al. 2009). The high-power analysis focuses on confirming the observations done at lower magnifications and describing the microtopography of the used surface. The micro traces described are: the relief of the topography, any individual grain modifications, linear traces and reflectivity. Micro-polish will also be described, as, when well developed, it is one

of the main use-wear elements related to the diagnostic of processed material and kinetics involved (Dubreuil et al. 2015). In both high and low power analysis, the elements are usually described through their distribution and density, their incidence (on the low, high topography or interstices) and orientation, when applicable, but there are variations in the criteria depending on each element.

Before conducting use-wear analysis, the implements were washed with demineralized water and sampled for the residue analysis. Then, the tools were investigated to assess the post-depositional wear based on the findings of Dubreuil et al. (2021). Table 3.2 presents the criteria utilized in the post-depositional wear assessment and Table 3.3, the ones utilized in the use-wear analysis of the archaeological and reference collections. They are modified from Adams et al. (2009) and Dubreuil et al. (2015). Grain edge rounding is the only criteria not utilized in the use-wear assessment of the archaeological implements, as it overlaps with grain edge rounding caused by the post-depositional wear. The sheen of the tools, observed with the naked eyes and both low and high magnification microscopes, was also used in the analysis.

Table 3.2
Criteria utilized in the post-depositional wear assessment.

Presence of concretion (CaCO₃)	Presence/absence Incidence on the tool (<i>amount of surfaces it is present in</i>) Incidence on the surface (<i>more or less than 50% of the surface[s]</i>)
Grain edge rounding	Presence/absence Incidence (<i>high topography, low topography, interstices or all over the surface</i>) Intensity (<i>intense = grains are completely rounded and there are no angles noticeable; not intense = present but angles of the grains are still noticeable</i>)
Desert polish	Presence/absence Intensity (<i>intense = replaces use related polish; not intense = present but use related polish is still observed</i>)
Assessment of preservation	Highly affected (<i>extensive impact on the implement with the combination of multiple criteria</i>) Mildly affected (<i>less extensive impact on the implement; preserved use-wear is still identifiable</i>) Slightly affected (<i>no extensive impact on the implement</i>)

Table 3.3
Criteria utilized in the use-wear assessment, based on Adams et al. (2009) and Dubreuil et al. (2015).

Criteria	Categories used to describe it	Unaided analysis	Low power analysis	High power analysis
Topography of the active surface	Development (flat/sinuuous/uneven) Leveling (presence/absence) Texture (smooth/rough) Plateaux (presence/absence)	X	X	X
Linear traces: <i>striations or scratches that form through the contact of the active surface with another material</i>	Length (long/short) Orientation in relation to the major axis of the surface (longitudinal/transversal) Longitudinal morphology (continuous/intermittent) Disposition in relation to other linear traces (random/concentric/parallel/oblique/perpendicular) Depth (shallow/deep) Width morphology (thick or thin) Incidence (low topography/high topography/interstices)	X	X	X
Leveling: <i>loss of grain volume that results in the surface or grain being flat</i>	Texture (smooth/rough) Incidence (low topography/high topography/interstices)		X	X

Table 3.3
Continued.

Criteria	Categories used to describe it	Unaided analysis	Low power analysis	High power analysis
Fractures: <i>breakage of grains as a consequence of impact, usually generates sharp angles</i>	Distribution loose/covered/concentrated Incidence low topography/high topography/interstices		X	X
Frosting: <i>concentration of fractures that appear frosted, like frosted glass</i>	Incidence low topography/high topography/interstices		X	X
Grain edge rounding: <i>mechanical alteration that results in the gradual elimination of edges of the grains</i>	Occurrence presence/absence Incidence low topography/high topography/interstices		X	X
Pits: <i>places vacated due to grain extraction</i>	Distribution loose/covered/concentrated Density separated/close/connected Orientation longitudinal/transverse/oblique Depth shallow/deep Pit shape irregular/circular/triangular/starlike/comet shaped		X	X
Micropolish: <i>mechanical and/or chemical modification of the microtopography that reflects light differently than the natural rock</i>	Distribution loose/covered/concentrated Density separated/close/connected Incidence low topography/high topography/interstices Texture rough/fluid/smooth Reflectivity slightly/moderated/highly reflective Morphology flat/sinuuous/doomed Special features incidence striations/pits			X

3.4 Reference collection

As use-wear analysis is based on comparison, the development of a reference collection is necessary to successfully conduct the study. Wear formation is influenced by a number of characteristics, such as the nature of the raw material (in terms of coarseness, mineral composition, cohesion of the matrix), the shape of the tool, the motion in which it was used and the presence of intermediate substances (which can either facilitate or hinder wear formation) (Keeley 1980; Adams 1989, 1993, 2009). By developing experimental programs, it is possible to observe wear formation in a wide range of conditions. A reference collection will inform on the characteristics of the surfaces of raw materials before and after use. Additionally, it allows for the differentiation of manufactured and non-manufactured surfaces and the distinction between manufacturing wear and use-wear. The knowledge of the wear patterns developed in the association of specific materials and motions in a controlled setting, observed periodically, will serve as the comparative base for the functional analysis of the archaeological tools. Understanding how a type of plant, mineral or animal material was processed can give us an insight into resource uses, culinary and technological traditions and diet in the Gobi Desert during the HCO.

From 2019 to 2024, 14 experiments of grinding (n = 5), grinding and pounding (n = 3) and abrading (n = 6) were included in this collection (see Table 3.4). The active surfaces utilized in the experiments were manufactured, as Dubreuil et al. (2021:125-127) noted that the archaeological implements in the Gobi collection had signs of shaping and manufacture through pecking.

The experiments include a wide range of materials: plants (such as cereals, legumes, USOs and wood), animals and minerals that would likely be present in the Gobi-Desert based on paleoenvironmental data (Janz 2016; Janz et al. 2021; Rosen et al. 2022). Acquiring raw materials from Northeast Asia was not possible due to logistic reasons, therefore the stones used came from the south of the United States ($n = 7$) and Southern Ontario ($n = 7$). Multiple experimenters with comparable skill level recorded the perceived efficiency of the tools and how the product of the grinding behaved in each case. All of the grains processed were dehusked prior to grinding, and grinding continued until grains were reduced to a fine flour. The experiments provided a wide range of use-wear that was compared to the archaeological collection during the analysis. We prefaced plants over animal and mineral material based on the results of initial analysis (Dubreuil et al. 2021) and Janz's original hypothesis (2016) that ground stone tools are connected with an increased focus on plant processing and a higher incorporation of plants in the diet of the habitants of the Gobi Desert-Steppe during the Neolithic.

Table 3.4
Experiments conducted from 2019 to 2024.

Experiment	Upper implement	Lower implement	Total time (min)	Motion	Purpose
Poplar stick abrasion	N/A	5A	120	Back and forth	Cleaning, refining and polishing
Maple stick abrasion	N/A	5B	120	Back and forth	Cleaning, refining and polishing
Ostrich eggshells abrasion	N/A	5C	120	Back and forth	Beads
Bone (deer metapodial) abrasion	N/A	5D	120	Back and forth;	Awls
				Circular	
Bone abrasion	N/A	10C	145	Back and forth;	Awls
				Side to side;	
Shell abrasion	N/A	10A	240	Back and forth;	Beads
Barley grain grinding	4B3	4A2	600	Pounding;	Flour
				Back and forth;	
				Circular;	
Mung bean grinding	2B	2A	1380	Up and down;	Flour
				Back and forth;	
				Circular;	
Soybean grinding	12B	11A	525	Up and down;	Flour
				Back and forth;	
				Circular;	
Rhubarb root grinding	17A	18A	555	Up and down;	Flour
				Back and forth;	
				Circular;	
Dried lily bulb grinding/pounding	4B4	1A1	1125	Up and down;	Flour
				Back and forth;	
				Circular;	
Dry lean beef pounding/grinding	8	4A1	600	Up and down;	Flour
Dried clay grinding	13A	14A	430	Up and down;	Pottery production
				Back and forth;	
Granite fragments grinding/pounding	13C	14C	300	Up and down;	Temper for pottery production
				Back and forth;	

3.5 Residue analysis

Residue analysis has been successfully combined with use-wear when studying ground stone tools. The combined methodology can refine our understanding of the relationship between humans and the environment they lived in (Lancelotti and Madella 2023:701), past economic strategies, social organization and the origin of ‘complex’ behaviors (Dubreuil et al. 2015). They also allow the preservation of evidence of perishable technologies that might not be preserved in the archaeological record otherwise (Lancelotti and Madella 2023:701).

The micro-botanical research employed in this study is exploratory and focused on the preservation of starch grains. Starch granules are complex polymers produced in different parts (fruits, leaves, stems, roots, and seeds) of green plants (Perez et al. 2009). As they are a great source of energy: “starchy” plants are sought by humans for both food and non-food purposes (Zarrillo and Ramsey 2014:53). Ancient starch preservation in archaeological artifacts is well established (Barton and Matthews 2006:75), including from multiple GST in Northeast Asia, specifically from several archaeological sites in the Yellow River Region (Liu et al. 2010; 2011; 2013; 2014; 2016a, b; 2018) and in the eastern desert-steppe region of Mongolia (Schneider et al. 2016).

The main purpose of the micro-botanical investigation of the Gobi Desert collection, at this stage, is to assess the suitability of legacy collections for this type of research. Although residue studies in ethnographic or modern archaeological collections have had positive outcomes (Barton 2007; Liu et al. 2013), legacy collections are more controversial in that they are normally made of materials collected before modern theoretical paradigms and methods (Lyle 2017:6) and stored prior to the definition of current curation standards

conscious of the need to preserve use-related residues – the implements were often cleaned, which could affect the residue preservation (Louderback et al. 2015:536; MacFarland and Vokes 2016:161). In addition, detailed information on the curation of these collections is usually scarce. Therefore, micro-botanical preservation in legacy collections is distinct from modern collections and rather experimental in this context.

The extraction procedure for the residues was adapted from a protocol from the Ramsey Laboratory of Environmental Archaeology (RLEA - University of Toronto Mississauga) (Ramsey 2022). The equipment and protocol are outlined in Table 3.5. Distilled water was used to clean the surface where the samples were acquired. Nitrile gloves were used during the entire process.

Table 3.5
Equipment and protocol utilized in the residue extraction and mounting of slides.

Consumables

- 1 Disposable paper cups
- 2 Regular toothbrushes
- 3 15ml polypropylene test tubes
- 4 Disposable pasteur pipettes
- 5 Powder free nitrile gloves
- 6 Slides (3" x 1")
- 7 Cover slips (24mm x 24mm)
- 8 Delicate task wipes

Protocol

1. Clean artifact

Artifacts were rinsed with distilled water to remove adhering sediments.

2. Sample artifact

Exterior sample. A clean paper cup was lightly filled with distilled water. A regular toothbrush was then dipped in the cup and used to brush gently the sampled area. The toothbrush was dipped again to transfer the sampled water from the surface of the tool to the paper cup. The contents of the paper cup were transferred to a 15ml test tube.

New and clean toothbrushes and paper cups were used for each sample.

Interior sample. Same process as exterior sample, in the same area.

3. Starch Grain Recovery and Mounting

As the samples were collected months prior to their processing, natural decanting was enough to concentrate the residues at the bottom of the tube. A pipette was used to recover the residue suspension from the bottom of the extract. 2-3 drops were released onto a microscope slide.

When dye was used, an additional drop of the chosen dye was added to the slide. A coverslip was placed and its edges were secured with a drop of clear nail polish.

Samples were taken on all surfaces of the tools that were not intensely affected by post-depositional damages. 240 15 ml samples were collected from 20 of the implements analyzed in this study. Cats. #73/715 and #73/2242 had no surfaces unaffected by post-depositional processes and therefore were not utilized for the residue analysis.

Of the twenty-one implements, only the interior sample of the active surface of the tools with preserved use-wear (n = 14) was processed – meaning slides were mounted and analyzed. Three slides were processed per tool, with and without staining methods - one with no dye, one with Lugol (an iodine dye which stains starches into different colors according to their relative content of amylose and amylopectin) (Charles et al. 2009), and one with Orange G (an acidophilic dye that assists in the identification of animal-related residues (such as keratin and collagen) (Rots et al. 2016). When starches were identified, additional slides of the exterior sample of the same area and of the interior sample of a breakage area from the tool, when applicable, were processed to account for contamination, using the Lugol staining method.

Presence, relative abundance, morphology and alterations of starches were recorded as outlined in Table 3.6, following Dubreuil (2024, unpublished) descriptive system for residues observed in the Gobi Desert experimental collection (Appendix A).

Table 3.6
Criteria of description for starches observed under the polarized microscope.

<i>Presence/absence and relative abundance</i>	
Very high	Numerous on 1 field of view
High	More than five present in the whole slide with multiple starches in each field of view or in clusters
Moderate	More than 5 present on the whole slide
Low	Up to 5 present on the whole slide
<i>Size and morphology</i>	<i>Starch alterations</i>
Rounded, oval or polyhedral	Breakage
Bimodal distribution	Cracks (opening)
Small and circular	Deformation
	Loss of birefringence

3.6 Conclusion

This chapter outlined the materials and methods utilized in this study. Before performing the use-wear analysis on the archaeological collection, a post-depositional wear assessment was conducted to judge the level of damage on the active surface and its suitability for the study. The tools with good preservation were then sampled for residue analysis. The use-wear analysis was conducted on those tools with the instruments and criteria described above, and the results were compared to the reference collection in an attempt to determine the material processed in the archaeological implements. The results of the analysis of both reference and archaeological collections will be presented in the following chapter.

Chapter 4

Results of analysis

This chapter will present the results of the use-wear analysis of the reference and archaeological collections. The wear patterns observed on the reference collection will be presented first, in three sections describing respectively the wear related to: 1) the manufacture of the implements; 2) grinding and grinding/pounding activities; 3) abrading experiments. This will be followed by the presentation of the results of the post-depositional wear assessment of the archaeological tools and their use-wear analysis. Based on morphology, six types of tools were identified in the collection: two types of lower implements (open grinding slabs with flat and concave active surfaces) and four types of upper implements (handstones that are elongated with and without handles, rectangular and oval). Implements were then assigned to grinding sets, based on the configuration of the active surface; this section will provide suggestions regarding the possible pairing of the tools.

4.1 Use-wear description of the experimental collection

4.1.1 Wear related to manufacture

The tools in the reference collection were manufactured through pecking of the active surface. This made the surfaces of the upper and lower implements match, both flat and irregular, and resulted in better contact during grinding and grinding/pounding. When tools become less effective (if the surface is too leveled, for instance), pecking can be performed again to expand the use of the tool. The wear resulting from this action is described in Table 4.1 and is the same in all the pecked surfaces. To the naked eye, manufacturing turned the topography flat and irregular. The points of impact were depressed and frosted in relation to the rest of the surface. At low magnification, the microtopography was uneven and irregular, with micro-fractures and grain crushing covering the surface (Figure 4.1). Striations that indicated the angle in which pecking was performed were present, accompanied by localized micro-fractures (Figure 4.1).

Table 4.1.
Wear related to manufacture observed on the experimental tools.

Topography	Microtopography	Grain modification	Pits	Linear traces	Micro-polish
Flat	Uneven	Microfractures	Covered	Covered	Flat
Irregular	Irregular	Frosting	Close	Close	Rough
		Grain extraction	Deep	Shallow	Striated
		Crushing	Circular	Thin	Thin

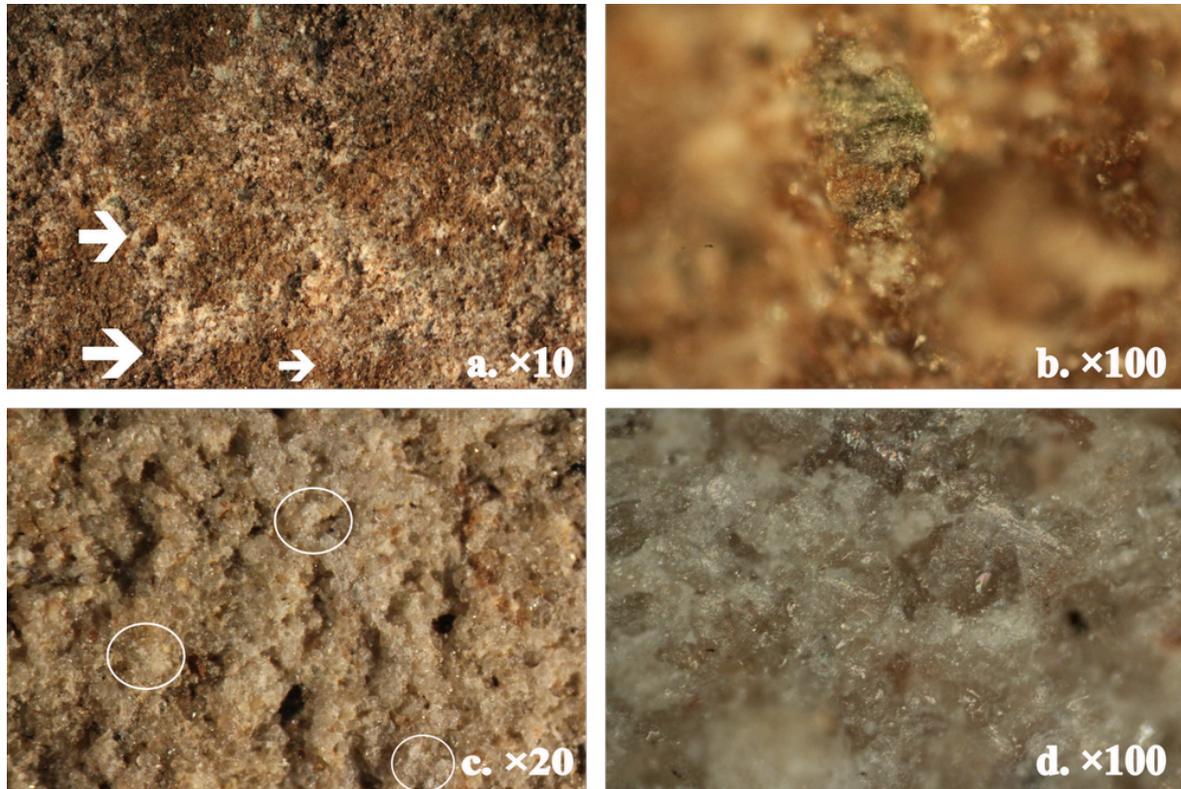


Figure 4.1. Use wear related to pecking in the experimental tools of the reference collection; a) frosting and linear traces in evidence at $\times 10$ magnification on tool 4A1; b) micropolish development at $\times 100$ magnification on tool 4A1; c) frosting highlighted at $\times 20$ magnification on tool 2A; d) striated micropolish at $\times 100$ magnification on tool 2A.

4.1.2 Wear formation on grinding and grinding/pounding implements

The materials processed include plants – cereals, such as barley (*Hordeum vulgare*); legumes, such as mungbean (*Vigna radiata*) and soybean (*Glycine max*); and underground storage organs, such as rhubarb roots (*Rheum palmatum*) and dried lily bulbs (*Lilium* sp.); meat (unseasoned and sundried lean beef) and minerals – clay and granite (as temper for pottery).

The wear patterns observed are summarized in Table 4.2 and detailed in the following sections.

Table 4.2
Description of use-wear identified in implements used for grinding and grinding/pounding.

Exp.	Tool	Topography	Micro-topography	Grain modification	Pits	Linear traces	Micro-polish
Cereal grinding (barley)	Lower (4A2)	Uneven Irregular	Sinuous Irregular Leveled	Fractures Micro-fractures Frosting	Concentrated (HT) Shallow/deep Irregular	Covered Close Long Random Thick Deep	Covered Connected Thin Sinuous Fluid Translucid
	Upper (4B3)	Sinuous Regular	Sinuous Regular Leveled	Grain edge rounding Micro-fractures	Covered Close Deep Circular	Loose Close Long Thin Shallow Perpendicular (HT)	Covered Connected Intermediate Sinuous Fluid Translucid/opaque Striated
Legume grinding (mung-beans)	Lower (2A)	Flat Irregular	Uneven Irregular	Fractures Micro-fractures Frosting	Covered Close Circular Intermediate depth	Concentrated (HT) Deep Long Perpendicular/ Random Thick/thin	Concentrated (HT) Rough Thin Translucid
	Upper (2B)	Flat Irregular	Uneven Irregular	Micro-fractures Grain edge rounding	Covered Close Deep Circular	Concentrated (HT) Deep Long Random Thick/thin	Concentrated (HT) Rough Thin Translucid
Legume grinding (soy-beans)	Lower (11A)	Sinuous Regular	Sinuous Regular	Grain edge rounding Micro-fractures Frosting (HT)	Absent	Concentrated (HT) Shallow Short Thin	Rough Flat Striated Thick
	Upper (12B)	Sinuous Regular	Sinuous Irregular	Grain edge rounding	Absent	Concentrated (HT) Long Parallel/ Perpendicular Intermittent	Domed Sinuous Thick

Table 4.2
Continued.

USO grinding (rhubarb roots)	Lower (18A)	Flat Irregular	Sinuus Irregular	Grain edge rounding Extractions	Absent	Concentrated (HT) Deep Long Random Thick	Concentrated (HT) Rough Thin Translucid Pitted
	Upper (17A)	Flat Irregular	Sinuus Regular	Fractures Grain edge rounding	Loose Shallow Irregular	Concentrated (HT) Shallow Short Random Thick	Covered Connected Fluid Sinuus Thick Striated Pitted
USO grinding/pounding (dried lily bulbs)	Lower (1A1)	Uneven Irregular	Sinuus Irregular	Fractures Micro-fractures	Covered Close Deep Circular	Covered Close Random Thick Shallow/ Deep	Domed Fluid Opaque/ Translucid Striated/ Pitted
	Upper (4B4)	Sinuus Regular	Regular (HT) Irregular (LT)	Fractures Frosting Grain edge rounding	Covered Close Deep Circular	Covered Close Perpendicular Short/long Thick Shallow/ Deep	Concentrated (HT) Fluid Dense Thick Striated Pitted Domed
Animal grinding/pounding (dried meat)	Lower (4A1)	Flat Irregular	Sinuus Irregular	Fractures Frosting Grain edge rounding	Absent	Loose Short Deep Random	Concentrated (HT) Domed Fluid Pitted Striated

Table 4.2
Continued.

Mineral grinding (clay)	Lower (14A)	Flat Irregular	Flat Irregular	Micro-fractures	Covered Close Deep Irregular	Covered Close Parallel Long	Absent
	Upper (13A)	Sinuuous Irregular	Sinuuous Irregular	Micro-fractures	Covered Close Deep/ Shallow Irregular/ Circular	Covered Close Deep Perpendicular	Concentrated (HT) Rough Thin Sinuous
Mineral grinding (granite fragments)	Lower (14C)	Sinuuous Regular	Flat/Uneven Irregular	Micro-fractures Frosting	Loose Intermediate depth Circular	Covered Close Perpendicular/ Random Long/Short	Absent
	Upper (13C)	Flat Irregular	Flat/Uneven Irregular	Micro-fractures Crushing	Covered Close Deep Irregular	Covered Close Perpendicular (diagonally) Long	Absent

4.1.2.1 Cereal grinding

The cereal grinding experiment, with barley seeds, was performed for approximately 11 hours. The goal of the experiment was to produce flour. The experimenter noted that the lower tool became less efficient (meaning more grinding was required to achieve the same amount of product) after three hours of grinding, as leveling increased.

Lower tool (4A2)

Although pecking with a pebble was attempted in the lower tool used for barley, the natural irregularity of the surface did not change, and pecking marks are only observable in the central region of the tool (Figure 4.2). After grinding for 11 hours, the surface became

sinuous and irregular, showing intense leveling (Figure 4.2). Fractures and micro-fractures were the most significant grain modification, concentrated in the high topography and resulting in frosting (Figure 4.2). Grain crushing and loose fragments are very common on the active surface and grain edge rounding is very slight. Pits are concentrated in the low topography, both shallow and deep, and linear traces in random orientations are common (Figure 4.2). The micro-polish is connected and covers the surface; it is relatively thick when compared to the rest of the experiments, sinuous, fluid and translucent (Figure 4.2).

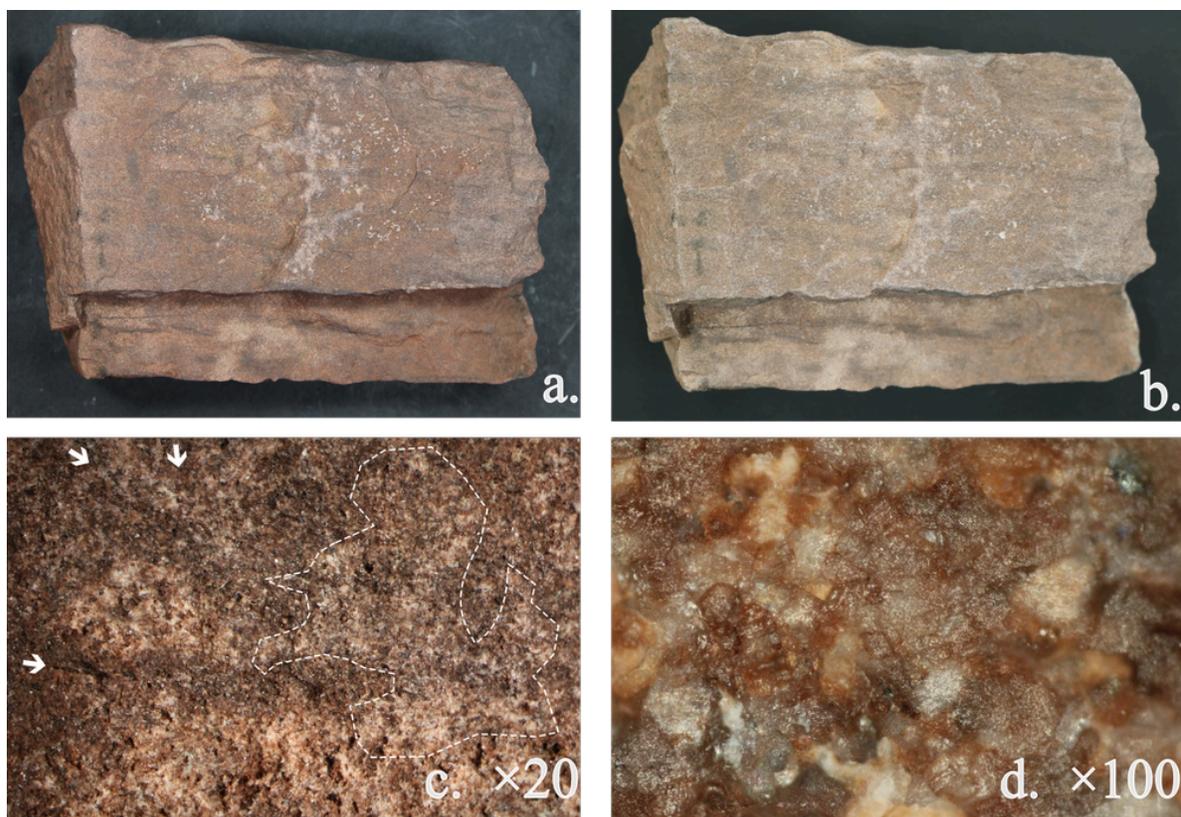


Figure 4.2. Use-wear on implement 4A1, lower tool used to grind cereal (barley seeds) for 11 hours; a) experimental surface after the pecking attempt, before grinding (the pecking wear is light-colored and concentrated in the middle of the tool); b) experimental surface after grinding for 11 hours; c) microtopography after grinding (linear traces are indicated by arrows and some of the frosted areas with microfractures by the dashed line); d) micro-polish development after 11 hours of grinding.

Upper tool (4B3)

After 11 hours of grinding, the topography of tool 4B3 is sinuous and smooth on the high topography, with perpendicular linear traces (Figure 4.3). Significant loss of grain volume and fractures are evident during most of the experiment, but only intense grain edge rounding and leveling are observable after 11 hours (Figure 4.3). Deep pits, which edges becoming progressively rounder and smoother, cover the surface (Figure 4.3). Initially, randomly oriented, thick and thin linear traces were observed; by the end of the experiment, they appear sparse, shallow, and perpendicular/randomly oriented, visible only on high topography (Figure 4.3). Micro-polish covers the tool, especially in high topography; it is connected, of intermediate development, doomed morphology, striated and opaque/translucent (Figure 4.3). The tool is only mildly reflective.

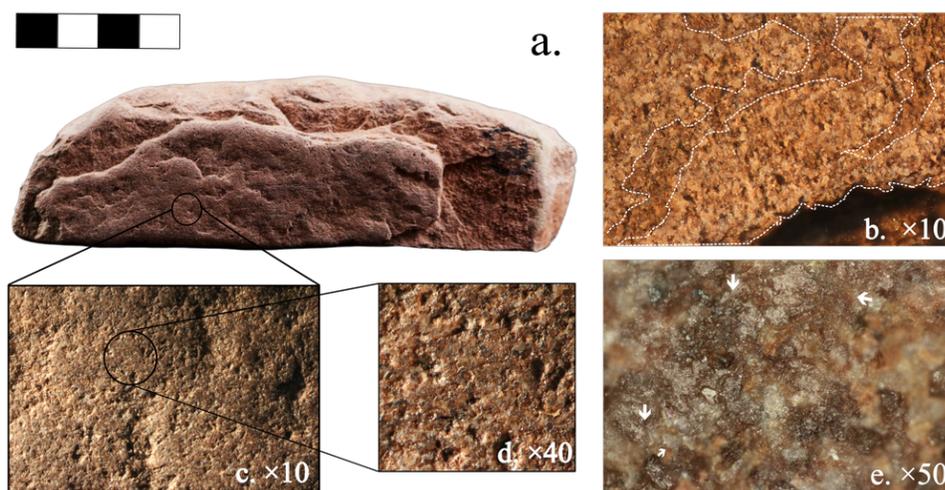


Figure 4.3. Use wear on tool 4B3, upper implement used to grind cereal (barley seeds) for 11 hours; a) photo of the implement after 11 hours of grinding, with the sinuous and smooth leveling evident; b) microtopography after 5 hours of grinding, frosted and fractured grains still obvious at $\times 10$ magnification; c) microtopography after 11 hours of grinding, with leveling and loss of grain volume and pits in evidence at $\times 10$ magnification; d) microtopography after 11 hours of grinding, with leveling and loss of grain volume and pits in evidence at $\times 40$ magnification; e) micro-polish development after 11 hours of grinding with arrows indicating the direction of the linear traces.

4.1.2.2 Legume grinding

Two legume grinding experiments were conducted, one with mungbeans and one with soybeans, with the goal of producing flour. The experimenter noted that on the mungbean experiment, performed for around 23 hours, the stones became less effective after 2 hours of grinding. Compact mungbean powder (present in all surfaces of both implements involved) when in contact with sweat from the hands of the experimenter, made a paste that stuck to the high topography and sides of the tool. Soybean grinding, done for five hours, lost efficiency faster than the mungbean experiment - before the first hour mark. After that, it became more difficult to achieve fine powder with grinding in the same amount of time, indicating a possible connection between surface irregularity (roughness) and the size of the resulting flour.

Mungbean grinding, lower tool (2A)

Grinding (for 23 hours) has leveled the surface of tool 2A, but the microtopography is still irregular and uneven (Figure 4.4). Fractures, microfractures and frosting are common in the non-leveled areas of the tool (Figure 4.4), while linear traces are observed in the high topography (they are deep, long and perpendicular/randomly oriented) (Figure 4.4). Some edge rounding is associated with grain microfractures (Figure 4.4). Small pits of intermediate depth and density are noted all over the surface (Figure 4.4). Micro-polish is weakly developed, translucent and rough (Figure 4.4).

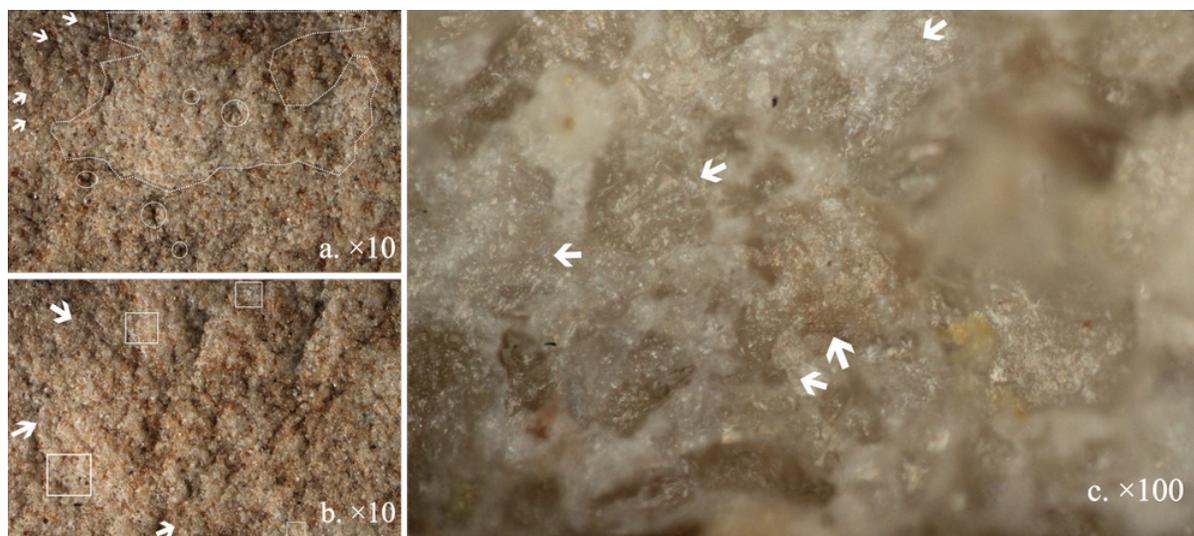


Figure 4.4. Use wear on tool 2A, lower implement used to grind legumes (mungbeans) for 23 hours; a and b) microtopography at $\times 10$ magnification (arrows indicate the direction of linear traces, dashes lines the frosted area and the circles outline the pits); c) striated micro-polish at $\times 100$ magnification (arrows indicate the direction of micro-striations).

Mungbean grinding, upper tool (2B)

Grinding turned the sinuous and regular topography of tool 2B (Figure 4.5) into flat but irregular with some leveling (Figure 4.5). The center of the tool is slightly more irregular than the rest since it is where grinding was more intense (Figure 4.5). There is an abundance of microfractures that are rounded and frosted. Pits, caused by grain extractions, and linear traces are common all over the tool (Figure 4.5). The micro-polish does not show great changes after 8 hours of experiment (Figure 4.5), and after 23 hours of grinding it is still mildly reflective, thin and rough (Figure 4.5).

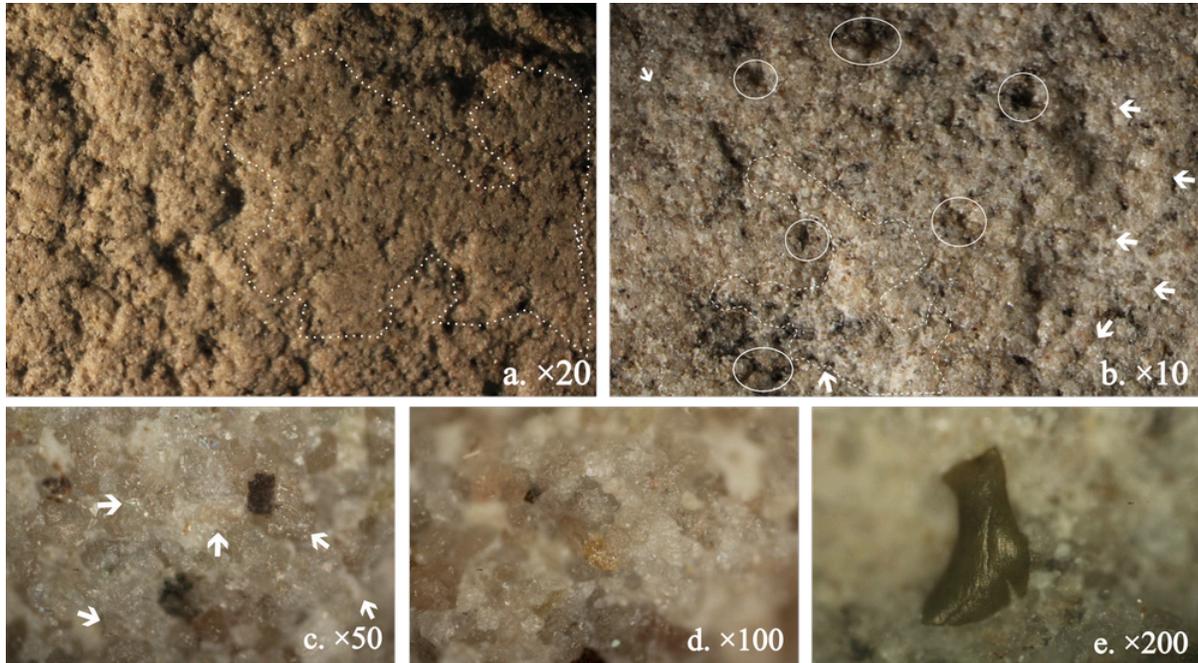


Figure 4.5. Tool 2B, upper implement used to grind legumes (mungbeans) for 23 hours; a) after two hours, the microtopography is leveled and regular, as indicated by the dotted line; b) after 23 hours, the surface is irregular, with frosting, pits and linear traces indicated by dashed lines, circles and arrows, respectively; c) striated micro-polish at $\times 50$ magnification; d) striated micro-polish at $\times 100$ magnification; e) striated micro-polish at $\times 200$ magnifications.

Soybean grinding, lower tool (11A)

The topography of tool 11A starts sinuous and becomes progressively flattened and smooth through the 5 hours of grinding (Figure 4.6). Most grains are rounded, but microfractures and frosting cover areas of high topography (Figure 4.6). Linear traces are associated with those areas, becoming denser throughout the experiment (Figure 4.6). Micro-polish is rough, flat and striated/pitted (Figure 4.6).

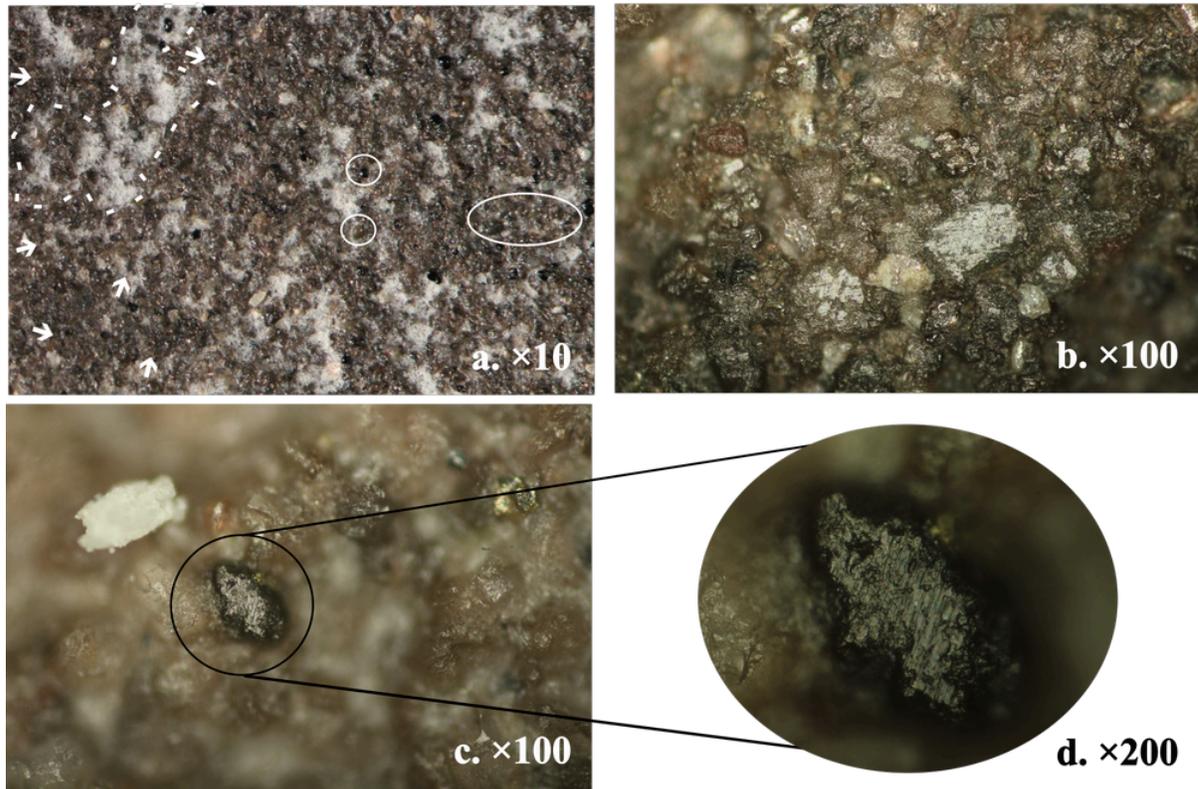


Figure 4.6. Use-wear on tool 11A, lower implement used to grind legumes (soybeans) for five hours; a) microtopography with linear traces indicated by arrows, frosting outlined by a dashed line and grain edge rounding circled; b and c) striated micro-polish at $\times 100$ magnification; d) striated micro-polish at $\times 200$ magnifications.

Soybean grinding, upper tool (12B)

Both topography and microtopography are sinuous and grinding (5 hours) seems to increase the height difference between high and low topography. Leveling is extensive and irregular, with grain edge rounding and linear traces (Figure 4.7). There is a material buildup similar to tool 17A (Figure 4.7). On the low topography, fractures, frosting and pits remain from before grinding. Micro-polish is well developed and present all over the surface (Figure 4.7).

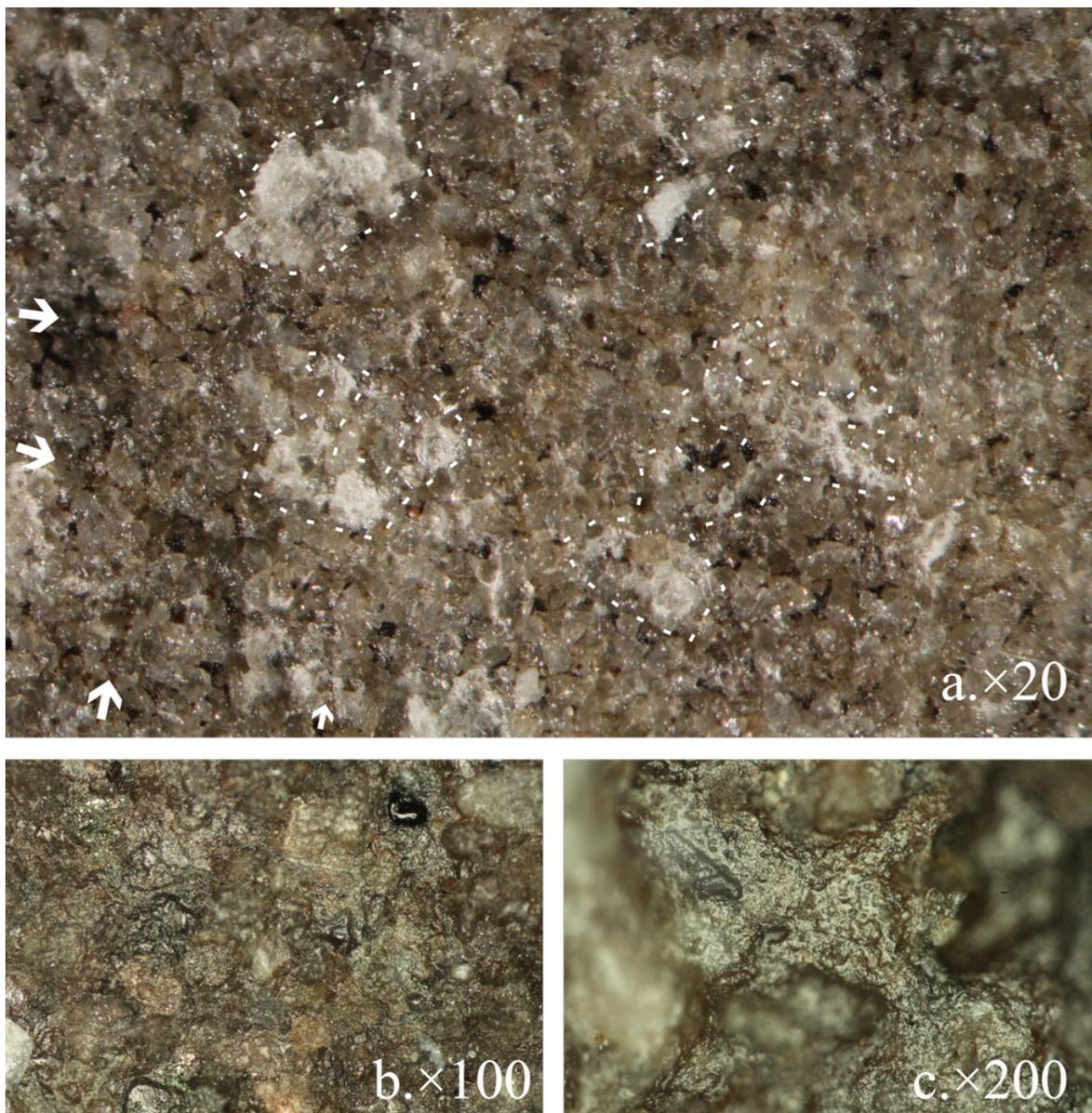


Figure 4.7. Use-wear on tool 12B, upper implement used to grind legume (soybeans) for five hours; a) microtopography at $\times 20$ magnification with frosting outlined by dashed lines and linear traces indicated by arrows; b) domed and sinuous micro-polish at $\times 100$ magnification; c) domed and sinuous micro-polish at $\times 200$ magnification.

4.1.2.3 Underground storage organ grinding/pounding

Two USO grinding experiments were conducted, with dried rhubarb roots and lily bulbs, to produce flour. Rhubarb roots were ground for around five hours; the experimenters noted that

after two hours, the stones became less effective. Powder (from processing) was present on all surfaces of both stones, and its yellow tone stained the light raw material. To process dried lily bulbs, pounding was necessary, in addition to grinding. They were processed for around 20 hours. A light coat of the powder that resulted from the experiment was noted in the active surface of the tool in all stages of observation (5, 10 and 20 hours), but it was not present in the unused surfaces of the stone.

Rhubarb root grinding, lower tool (18A)

Tool 18A is leveled at the high topography after 5 hours of grinding, yet overall its surface remained irregular (Figure 4.8). In the margins of the surface, where manufacture traces are less frequent and grinding was less intense, the natural topography is more regular and smoother. The grains show slight loss in volume at around 90 minutes of grinding and after 5 hours of work, a buildup of yellow oily material forms a film on the surface of the tool, filling the interstices. Edge rounding is also present (Figure 4.8). The low topography, however, is still not leveled and shows remnants of the frosted pecking marks that are not seen on the rest of the tool anymore (Figure 4.8). Striations are concentrated in the high topography, with multiple orientations and a non-linear morphology (Figure 4.8).

Micro-polish formation is slow and even after 5 hours of experiment it is not well developed (Figure 4.8).

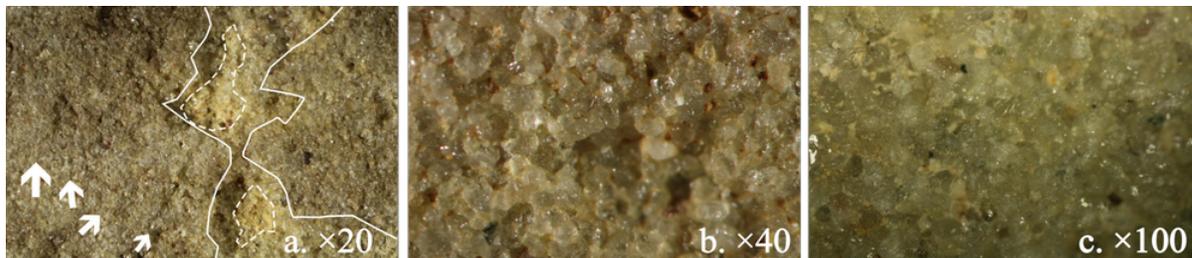


Figure 4.8. Use-wear on Tool 18A, lower tool used to grind USO (rhubarb roots) for five hours; a) microtopography at $\times 20$ magnification with leveled areas (outlined), linear traces (indicated by arrows) and the irregular low topography with pecking marks (evidenced by a dashed line); b) grain modification at $\times 40$ magnification, grains are fractured and have a lot of volume, and the film of material buildup is present; c) rough micro-polish at $\times 100$ magnification.

Rhubarb root grinding, upper tool (17A)

Both macro and microtopography are sinuous, smooth and leveled on the high topography (Figure 4.9). The surface is very reflective, due to material build up all over the tool (Figure 4.9). Grinding resulted in a lot of fractures and grain edge rounding (Figure 4.9), and the grains in the low topography have more volume than the ones in the high topography (Figure 4.9). Pits start appearing as sparse, deep, and with an irregular shape - due to connected grain removals. As the surface becomes increasingly leveled, grain removals are limited to individual grains and therefore are shallower and more difficult to notice. Linear traces are shallow, thick and randomly oriented (Figure 4.9). Micro-polish is fluid, sinuous and thick all over the tool (Figure 4.9).

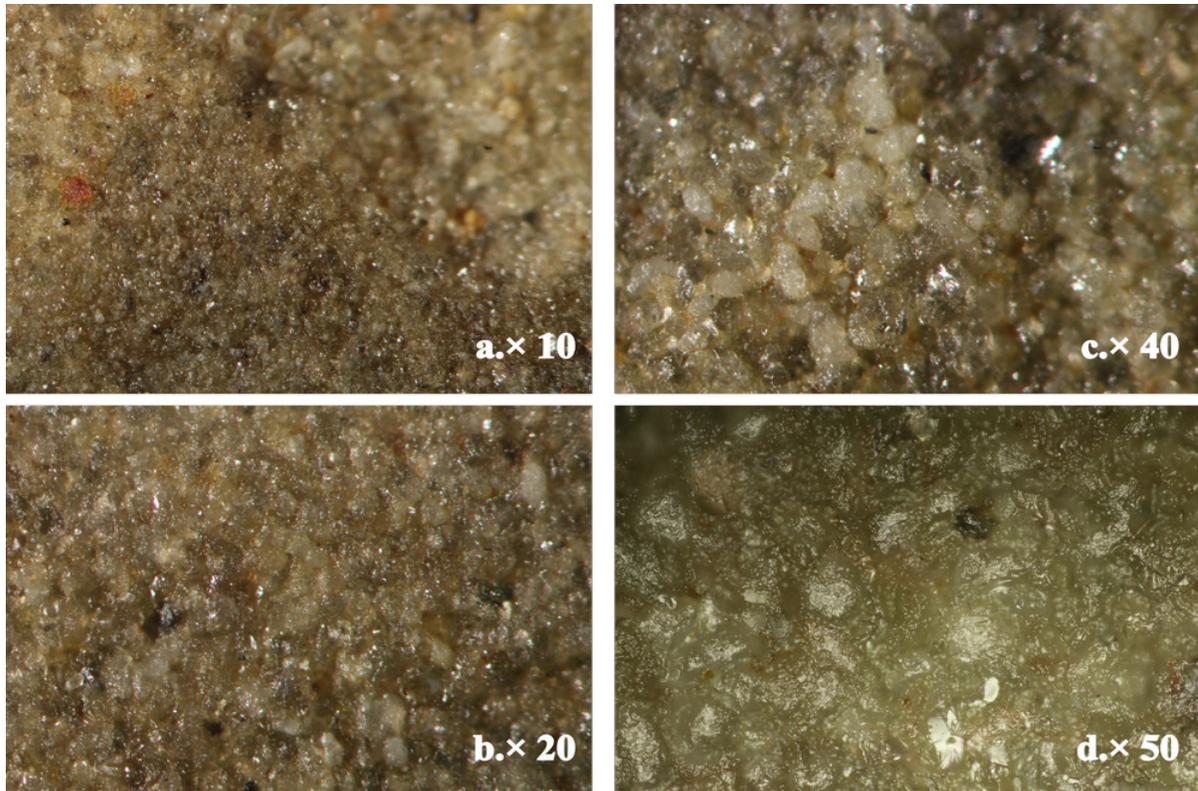


Figure 4.9. Use-wear on Tool 17A, used to grind USO (rhubarb roots) for five hours; a) microtopography at $\times 10$ magnification with leveled areas in evidence; b) material buildup at $\times 20$ magnification; c) material buildup at $\times 40$ magnification; d) thick fluid and sinuous micro-polish at $\times 50$ magnification.

Dried lily bulb grinding/pounding, lower tool (1A1)

After grinding/pounding for 20 hours, the topography of tool 1A1 is uneven, while the microtopography is sinuous and rough (Figure 4.10). Grains are micro-fractured and slightly rounded. Frosting is concentrated in the low topography. Linear traces are thick and random, both superficial and deep, interrupted by the changes in the microrelief (Figure 4.10). Pits are abundant all over the surface. Micro-polish occurs in small patches; it is domed, opaque/translucent and striated/pitted (Figure 4.10).

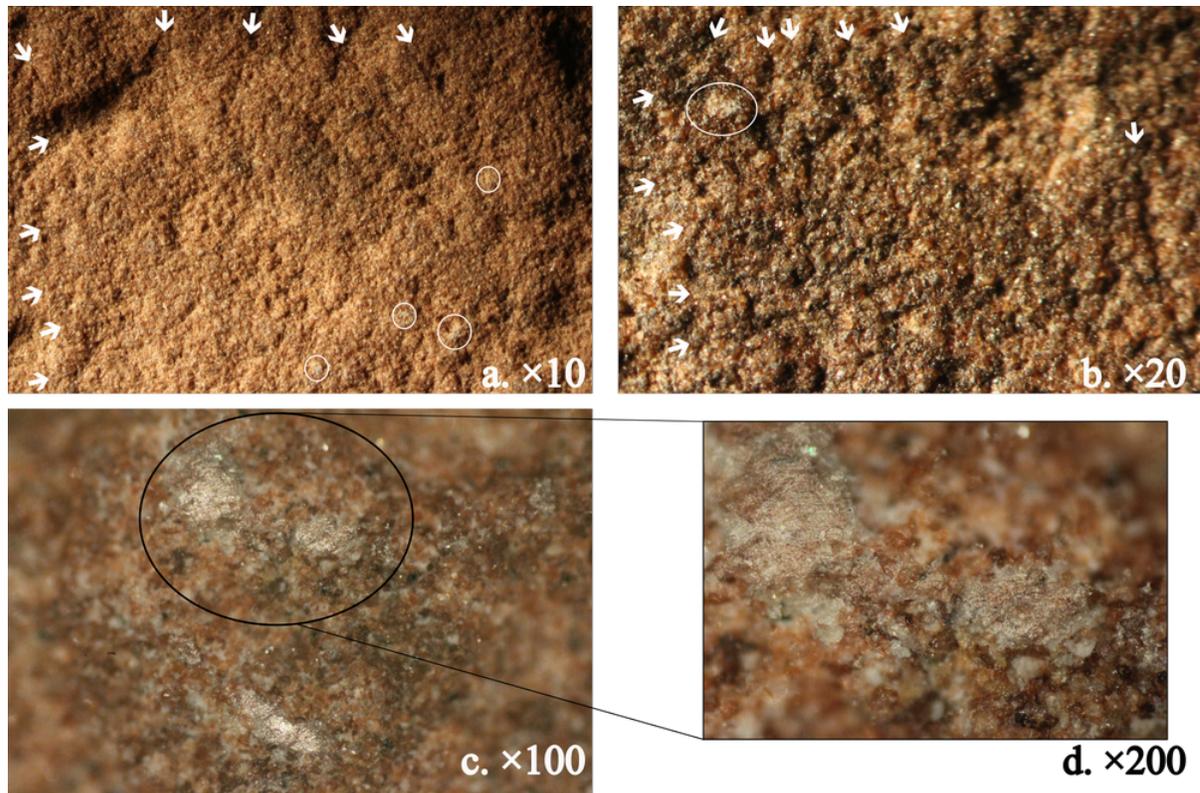


Figure 4.10. Use-wear on tool 1A1, lower implement used to grind/pound USO (dried lily bulbs) for 20 hours; a) microtopography at $\times 10$ magnification, with linear traces indicated by arrows and microfractures/frosting outlined by circles; b) microtopography at $\times 20$ magnification; c) striated micro-polish at $\times 100$ magnification; d) striated micro-polish at $\times 200$ magnification.

Dried lily bulb grinding/pounding, upper tool (4B4)

The unaided observation of the topography of tool 4B4 showed increasing smoothing of the surface as grinding progressed, with an expansion of the leveled areas (Figure 4.11). Several grains are fractured and frosted; the loss of volume made it difficult to identify their outline (Figure 4.11). Pits and linear traces are present all over the surface (Figure 4.11).

Micro-polish is concentrated in the leveled high topography, domed and sinuous, thick, striated, pitted; on the low topography, it is rough, sinuous and thin (Figure 4.11).

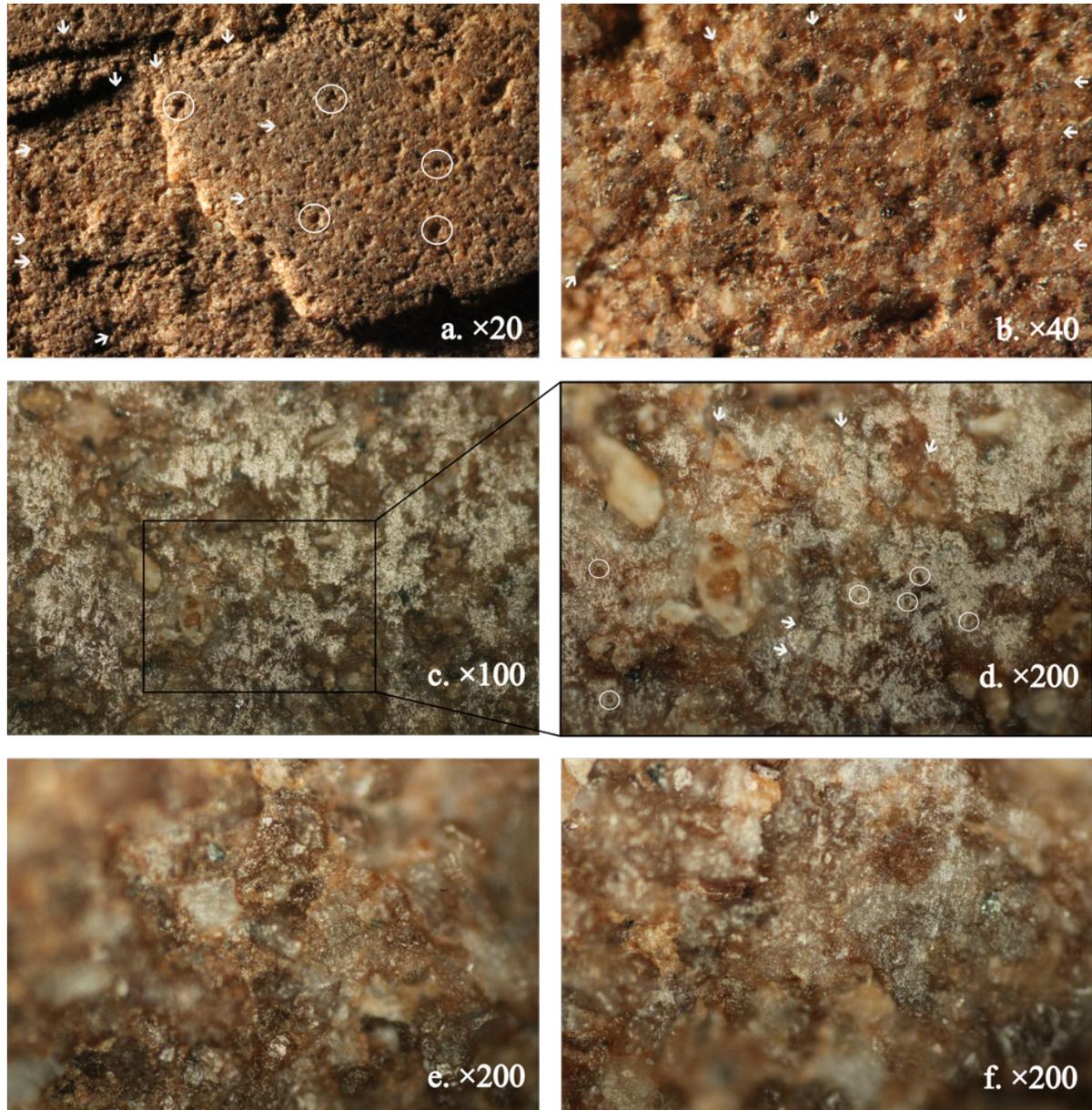


Figure 4.11 Use-wear on tool 4B4, upper implement used to grind/pound USO (dried lily bulbs) for 20 hours; a) microtopography at $\times 20$ magnifications with linear traces indicated by arrows and pits outlined by circles; b) leveling and linear traces (arrows) at $\times 40$ magnification; c) striated and pitted micro-polish on the high topography at $\times 100$ magnification; d) striated and pitted micro-polish on the high topography at $\times 200$ magnification; e and f) rough micro-polish on the low topography at $\times 200$ magnification.

4.1.2.4 Meat grinding/pounding

Dried meat was ground/pounded for around 10 hours, with the goal of producing flour. A granite pebble was used as an upper tool and was not included in the analysis. The center of both upper and lower tools became stained in a yellow tone, due to the powder of the meat.

Lower tool (4A1)

After grinding/pounding for 10 hours, the surface of tool 4A1 is sinuous and irregular, with leveling at the high topography (Figure 4.12). It still shows signs of pecking from manufacture in the form of frosting in the center of the tool (Figure 4.12). The microtopography is irregular, microfractures are abundant but grains are rounded (Figure 4.12). Pitting was abundant after pecking but the material buildup leftover from grinding fills the pits and interstices, even after washing the tool with detergent and a toothbrush (Figure 4.12). Micro-polish is domed and fluid at the leveled high topography, pitted and striated, but not so intense in lower areas of the surface (Figure 4.12).

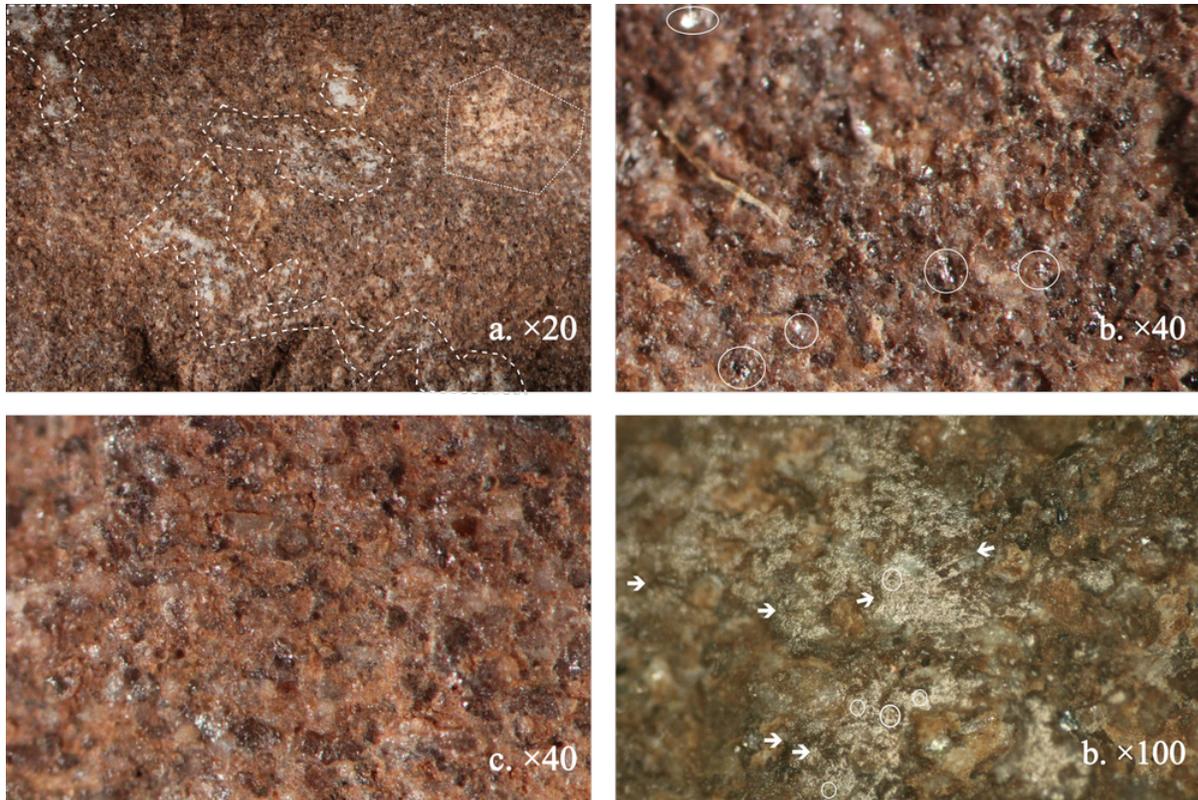


Figure 4.12. Use-wear on tool 4A1, lower implement used to grind/pound dried meat for 10 hours; a) microtopography at $\times 20$ magnification with frosting outlined by a dashed line; b) microfractures indicated by a circle at $\times 40$ magnification; c) material filling the interstices at $\times 40$ magnification; d) pitted and striated micro-polish at $\times 100$ magnification.

4.1.2.5 Mineral grinding

Two experiments of mineral grinding were performed. One experiment was with dried natural clay, and the other with granite fragments (similar to those used to make temper for the sand-tempered ceramics found in Gobi Desert assemblages). Both were performed for five hours; none resulted in leveling of the surface, so the efficiency remained constant.

Clay grinding, lower tool (14A)

The topography of tool 14A is flat, irregular and leveled, with linear traces noted at naked eyes (Figure 4.13). After 45 minutes of grinding, irregular plateaus are noted, but they are absent in posterior observations, replaced by connected leveling at the high topography at 5 hours of processing. Microfractures are common and there is intense loss of grain volume. (Figure 4.13). Pits are observed all over the surface. Micro-polish is absent, but the surface is very reflective due to the abundant microfractures (Figure 4.13).

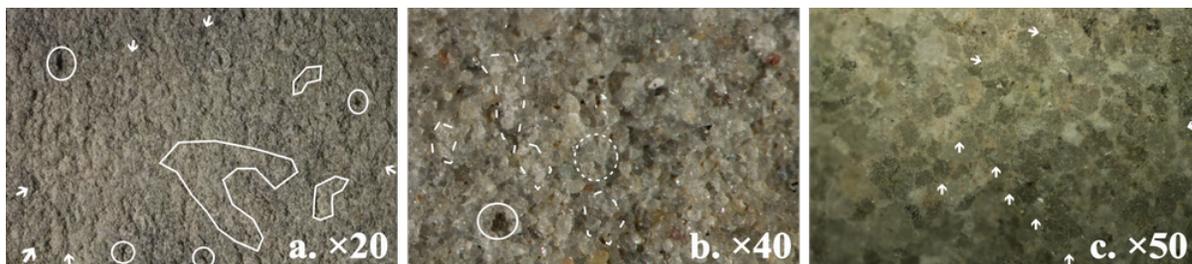


Figure 4.13. Use-wear on tool 14A, lower implement used to grind dried clay for 5 hours; a) microtopography at $\times 20$ magnifications with linear traces indicated by arrows, pitted circled and frosted areas outlined; b) pits indicated by a circle, microfractures by dashed lines at $\times 40$ magnification; c) micro-striations at $\times 50$ magnification.

Clay grinding, upper tool (13A)

The microtopography of tool 13A is irregular and sinuous, and there is significant leveling at the high topography (Figure 4.14). Grains are fractured and rounded (Figure 4.14). Pits and linear traces are abundant (Figure 4.14). Frosting is present in the interstices and low topography (Figure 4.14). Micro-polish is rough and sinuous, concentrated in the high topography, but only noted at higher magnifications (200x) (Figure 4.14).

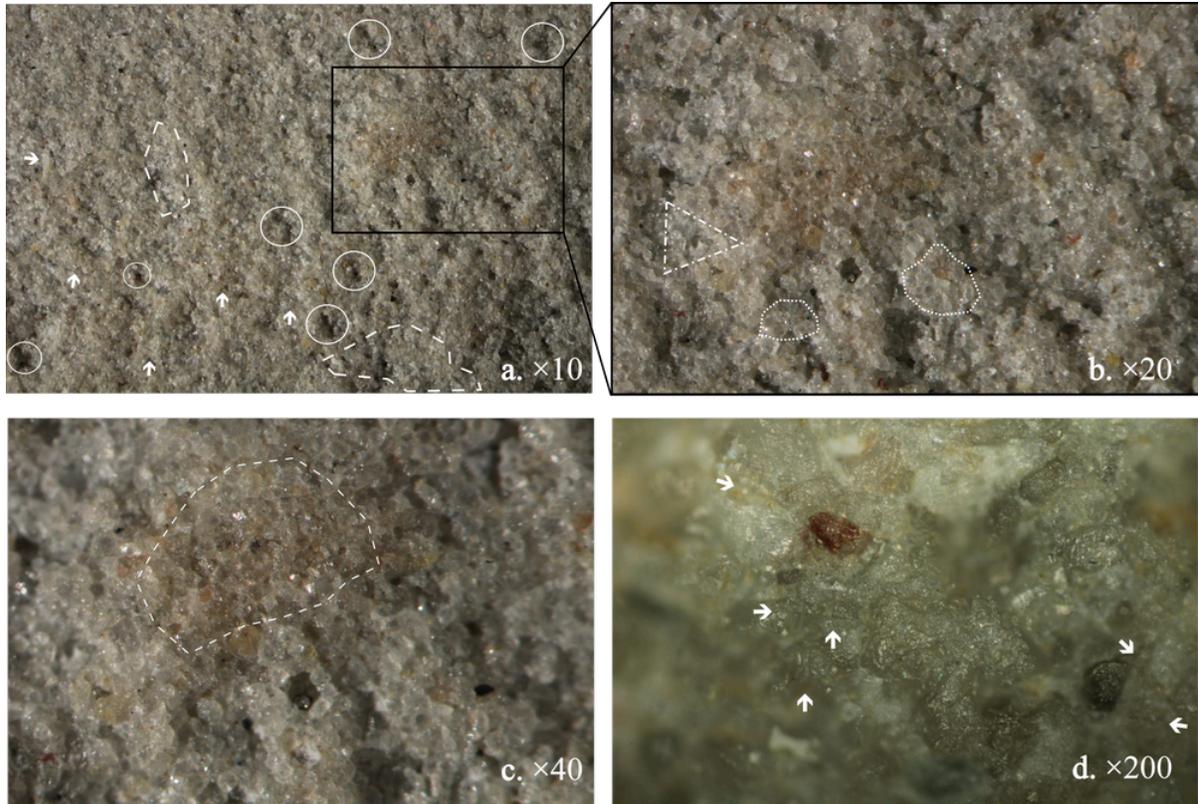


Figure 4.14. Use-wear on tool 13A, upper implement used to grind dried clay for 5 hours; a) microtopography at $\times 10$ magnifications with linear traces indicated by arrows, pitted circled and frosted areas outlined by dashes; b) grain edge rounding outlined by dotted lines and microfractures outlined in a triangular shape at $\times 20$ magnification; c) leveling $\times 40$ magnification; d) micro-polish and striations at $\times 200$ magnification.

Granite grinding, lower tool (14C)

Surface C of tool 14 had naturally higher ends than the body of the tool, and so grinding occurred mainly in the flat mid portion of the lower tool, with the upper implement (13C) held at a 45-degree angle. The topography of tool 14C is flat and irregular with linear traces visible to the naked eye. Both implements involved in this experience show a circular depression in the center of the tool (Figure 4.15), less pronounced on the lower implement compared to the upper tool. The microtopography is uneven in the areas outside this depression (Figure 4.15), but flat inside it, both irregular (Figure 4.15). Grains are fractured

and frosting is abundant (Figure 4.15). Linear traces are visible during the low power analysis. They are abundant, long and perpendicular. Short and randomly oriented traces are observed in individual grains and low topography at a higher scale (Figure 4.15). Pits of intermediate depth and sparse are present (Figure 4.15) and there is no micro-polish formation.

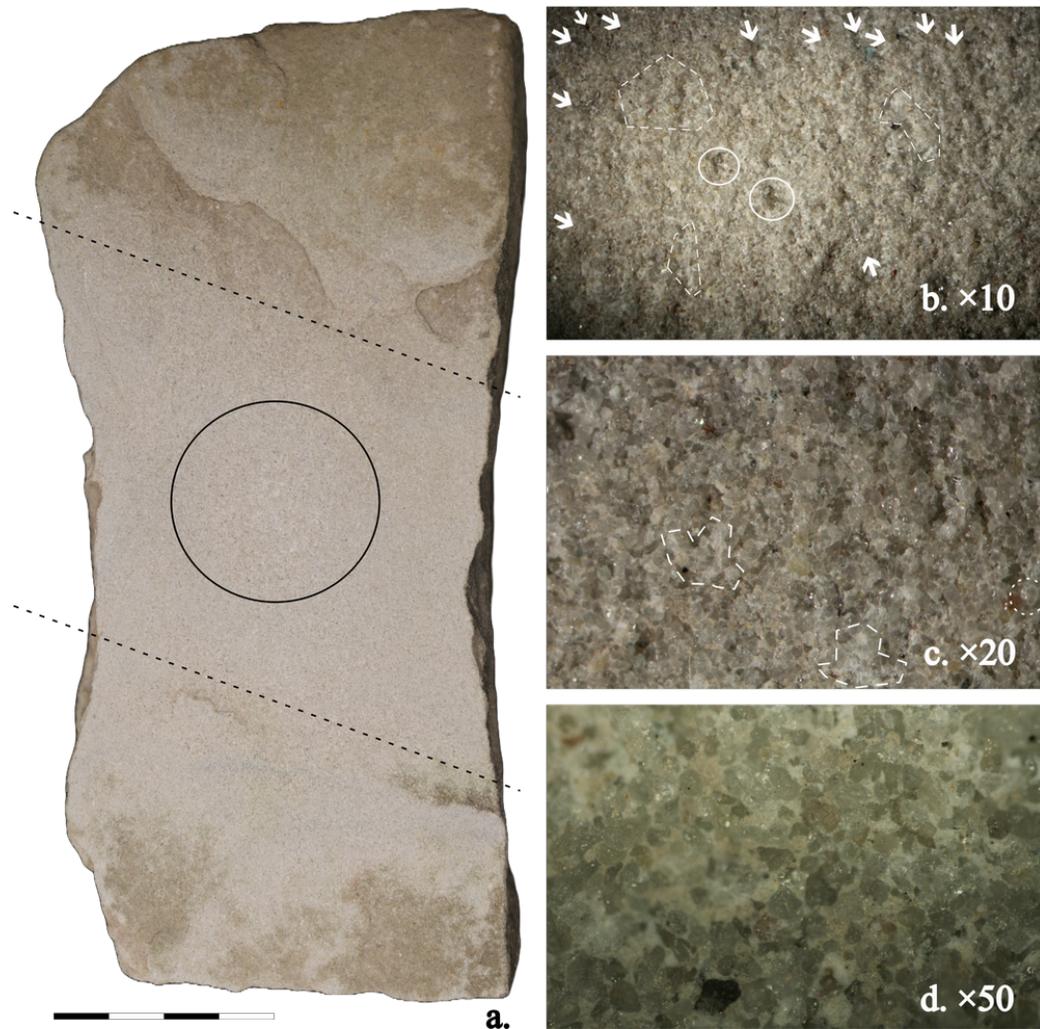


Figure 4.15. Use-wear on tool 14C, lower implement used to grind granite fragments for 5 hours; a) photo of the active surface with the depression at the center outlined in a circle and flat area where grinding was concentrated limited by a dashed line; b) microtopography at $\times 10$ magnification with pits indicated by circles, linear traces by arrows and frosting by dashed lines; c) frosting and grain edge rounding (dotted line) at $\times 20$ magnification; d) lack of micro-polish at $\times 200$ magnification.

Granite grinding, upper tool (13C)

The topography of tool 13C is flat and irregular, with a central depression as previously mentioned (Figure 4.16). The microtopography is uneven and irregular (Figure 4.16); grains have a lot of volume, are angular and micro-fractured (Figure 4.16). There is very little plateau development on the high topography, these are produced through grain crushing (Figure 4.16). Sparse frosting is observed in the interstices and high topography (Figure 4.16). Pits are irregular and deep, and linear traces are perpendicular to each other, displayed in a diagonal manner that corresponds to the way the tool was used (Figure 4.16). Micro-polish is absent, but parallel micro-striations that extend beyond individual grains are present (Figure 4.16).

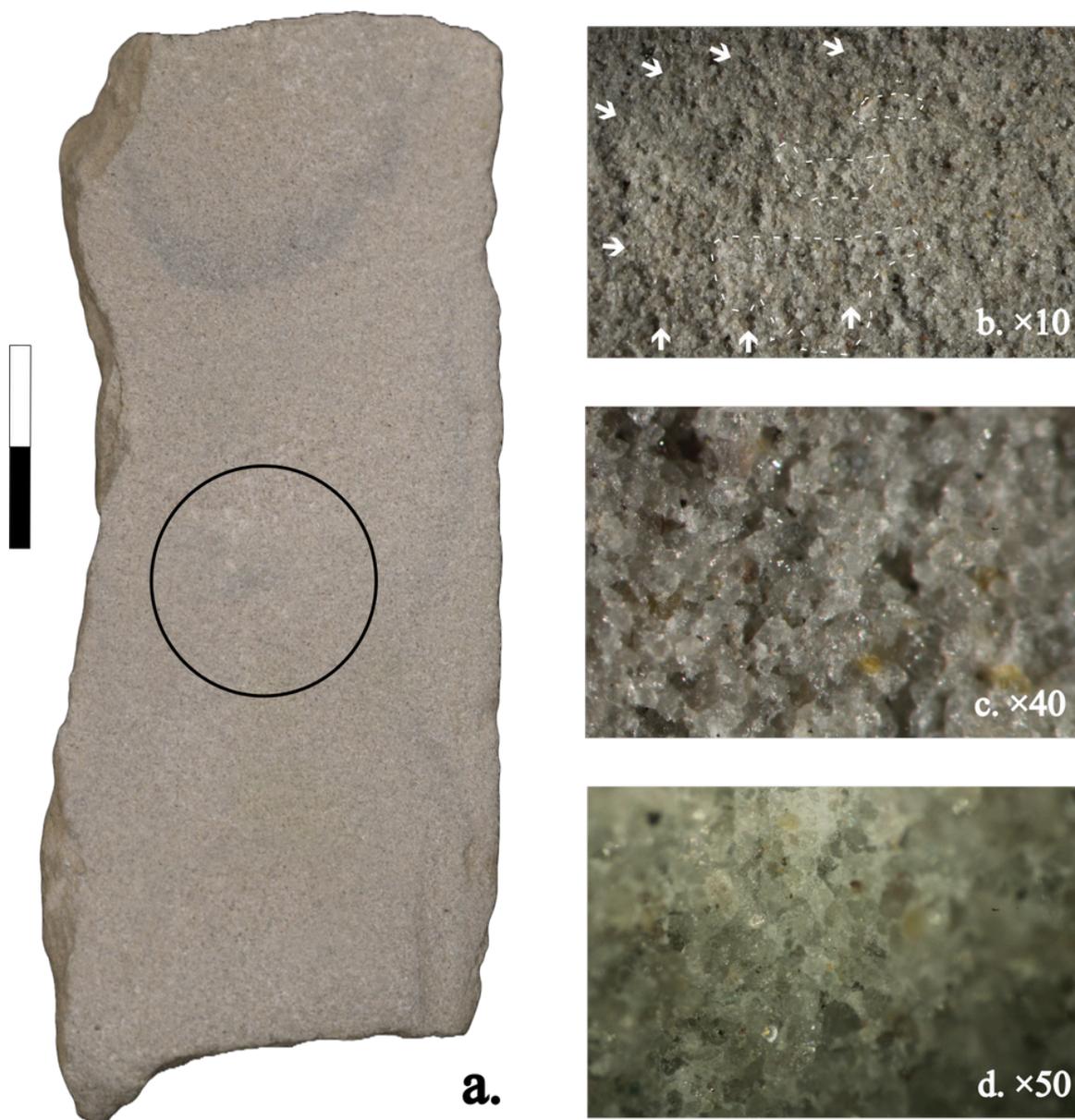


Figure 4.16. Use-wear on tool 13C, upper implement used to grind granite fragments for 5 hours; a) photo of the active surface with the depression at the center outlined in a circle; b) microtopography at $\times 10$ magnification with linear traces by arrows and frosting/microfractures by dashed lines; c) frosting and microfractures at $\times 40$ magnification; d) lack of micro-polish at $\times 50$ magnification.

4.1.3 Wear description on abrading implements

Five different abrading experiments were conducted in two separate tools. On tool 5, ostrich eggshells (OES), soft wood (Maple), hard wood (Poplar) and bone (deer metapodial) were abraded for two hours, and on tool 10A shell was abraded for the same time. All abrasions resulted in similar changes to the microtopography at low magnifications (see Table 4.3).

Table 4.3.
Use-wear related to abrasion observed on Slab 5.

Topography	Micro-topography	Grain Modification	Pits	Linear traces	Micro-polish
Flat	Uneven	Micro-	Covered	Covered	OES: rough, flat, thin,
Irregular	Irregular	fractures	Close	Close	pitted/striated
		Frosting	Deep	Random	Bone: rough, sinuous, thin
			Irregular	Deep	Shell: rough, sinuous, thin, striated

The microtopography after the abrasions became uneven and microfractures are more abundant. Grains still have a lot of volume and are very angular; frosting is common, but abrading erased frosted areas that resulted from pecking. Linear traces cover the surface, are random (parallel in the case of shell abrasion), both shallow and deep. Pits are dense, deep and irregular. Bone abrasion leveled the microtopography more in relation to OES, but the surface was still uneven and irregular (Figure 4.17). No distinction was observed between the soft and hard woods. Micro-polish did not develop in the wood abrasions; OES abrasion generated pitted and striated micro-polish in fractured grains (Figure 4.17), bone abrasion resulted in smoother and sinuous polish that accompanies the microrelief of the fragmented

grain (Figure 4.17) and shell abrasion resulted in micro-polish that is sinuous and striated, concentrated in leveled grains of high topography (Figure 4.18).

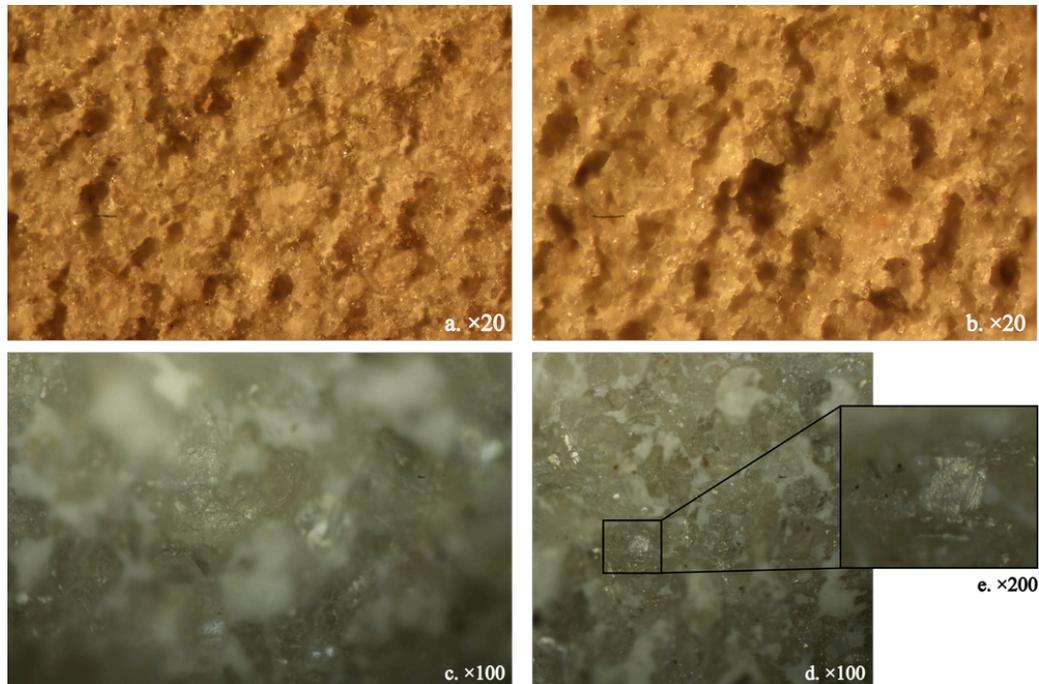


Figure 4.17. Use-wear on tool 5 after abrading for 2 hours; a) microtopography at $\times 20$ magnification after grinding bone; b) microtopography at $\times 20$ magnification after grinding OES; c) micro-polish after abrading bone at $\times 100$ magnification; d) micro-polish after abrading OES at $\times 100$ magnification; e) micro-polish after abrading OES at $\times 200$ magnification.

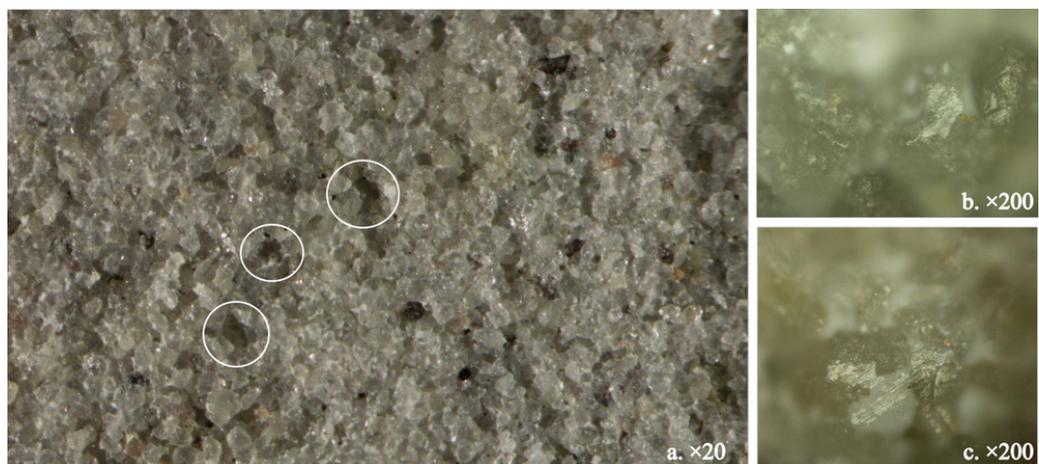


Figure 4.18. Use-wear on tool 10A after abrading shell for 2 hours; a) microtopography at $\times 20$ magnification with pits indicated by circles; b, c) striated micro-polish at $\times 200$ magnification.

4.1.4 Definition of diagnostic use-wear criteria used in the analysis of the archaeological collection

The use-wear related to plant and meat grinding/pounding is distinct from that associated with mineral grinding and the abrading experiments. While the former often results in grain edge rounding and leveling of the surface (as the materials are softer and moister), the mineral grinding and abrasions produced mainly microfractures and deep striations, irregular surfaces and weakly developed or non-existent micro-polish.

Between the different plants, materials with a higher level of moisture/grease - like soybeans and rhubarb roots – resulted in strongly developed polish that formed a thick coat across the topography of the entire active surface. Materials with a lower level of moisture, like mungbeans, resulted in weakly developed polish apparent mainly in the high topography.

Dried materials (lily bulbs and meat) resulted in very reflective and striated polish. The distinction between them is still possible, however, as meat is a greasy material. It leaves a buildup of leftover material after grinding/pounding which fills the low topography and interstices. This buildup was not noted in the stones that processed lily bulbs (likely due to the higher grease content on meat in relation to lily bulbs). In addition, other criteria observed at low magnification (such as topography configuration, pitting and linear traces) on the lower tools that processed dried meat and lily bulbs were distinct enough (see Table 4.2) and also facilitated their distinction.

Cereal grinding produced a leveled surface that was also noted on other experiments (such as dried lily bulbs grinding/pounding), but the micro-polish associated with it is more translucent than other experiments. It shows common points with mungbean grinding, but with a thicker development.

The results demonstrated that a distinction between grinding of plants (cereals, legumes and USOs), animals and mineral materials is possible when combining low and high-power use-wear analysis. Micro-polish was the most straightforward criteria when analyzing the reference collection (as its development is distinct from material to material), but when analyzing the archaeological tools, its combination with low magnification observations is crucial to establish a more accurate reference for comparison and diagnostic of materials processed. Regarding the abrading experiments, the only diagnostic feature identified was the presence of striated micro-polish after OES and shell abrasions. The experiments with bone and wood did not yield any discernible wear pattern that allowed their distinction.

4.2 Use-wear analysis of the archaeological collection

The analysis of the archaeological collection started with a post-depositional wear (PDW) assessment of all the implements (see Table 4.4). The damages related to PDW were different in each tool, and the artifacts were grouped into having high ($n = 6$), moderate ($n = 15$) and low ($n = 1$) impact. High impact meant no use-wear was preserved, moderate meant some preservation of use-wear and low impact meant good preservation of use-wear. In most cases, despite significant (high/moderate impact) PDW, the identification of active surfaces and general use of the tool (as part of a grinding system or as an abrader) was possible.

Table 4.4
Post-depositional wear distribution on the collection and assessment of impact.

Cat. #73/	Type	Fragmented/ Complete	Presence of concretion (CaCO ₃)	Grain edge rounding	Desert polish	Impact
2242	Grinding slab	Fragmented	Present in more than 50% of all surfaces	Could not be assessed due to abundance of CaCO ₃	Could not be assessed due to abundance of CaCO ₃	High
715	Grinding slab	Fragmented	Present in more than 50% of all surfaces	Intense and all over the tool	Present and intense	High
2079	Grinding slab	Fragmented	Present in more than 50% of all surfaces	Intense and all over the tool	Present but not intense	Moderate
2078	Grinding slab	Fragmented	Present in less than 50% of all surfaces	Intense and all over the tool	Present but not intense	Moderate
2243A	Elongated handstone with handle	Fragmented	Present in more than 50% of all surfaces	Intense and all over the tool	Present but not intense	High
2243B	Elongated handstone with handle	Fragmented	Present in more than 50% of all surfaces	Intense and all over the tool	Present and intense	High
2088C	Elongated handstone with handle	Fragmented	Present in less than 50% of all surfaces	Intense, but in unused surfaces	Present but not intense in the active surface	Moderate
2088F	Elongated handstone with handle	Fragmented	Present in less than 50% of all surfaces	Not intense but all over the tool	Present but not intense	Moderate
2085E	Elongated handstone without handle	Complete	Present in more than 50% of all surfaces	Intense on the high topography, not intense in the low topography and interstices	Present and intense	High
2528	Elongated handstone without handle	Complete	Present in less than 50% of all surfaces	Not intense but all over the tool	Present but not intense	Moderate
2746	Elongated handstone without handle	Complete	Present in more than 50% of all surfaces	Intense and all over the tool	<i>could not assess</i>	Moderate
2747	Elongated handstone without handle	Complete	Present in more than 50% of all surfaces	Intense on the high topography, not intense in the low topography and interstices	Present but not intense	Moderate
2085C	Elongated handstone without handle	Complete	Present in more than 50% of one surface	Intense and all over the tool	Present and intense	Moderate
2085D	Elongated handstone without handle	Complete	Present in more than 50% of all surfaces	Intense and all over the tool	Present and intense	Moderate
2088E	Elongated handstone without handle	Fragmented	Present in more than 50% of all surfaces	Intense and all over the tool	Present but not intense	Moderate
2083B	Oval handstone	Fragmented	Present in less than 50% of all surfaces	Not intense but all over the tool	Present but not intense in the active surface	Moderate
2083C	Oval handstone	Fragmented	Present in more than 50% of all surfaces	Intense, but in unused surfaces	Present but not intense	Moderate
2425	Rectangular handstone	Complete	Present in more than 50% of all surfaces	Intense and all over the tool	Absent in the active surface	High
2082B	Rectangular handstone	Complete	Present in less than 50% of all surfaces	Intense, but in unused surfaces	Present but not intense	Moderate
2082C	Rectangular handstone	Complete	Present in more than 50% of one surface	Intense on the high topography, not intense in the low topography and interstices	Present but not intense	Moderate
2083A	Rectangular handstone	Fragmented	Present in less than 50% of all surfaces	Intense and all over the tool	Present but not intense	Low

All tools in the sample were included in this study, grouped into types based on their morphology (two types of lower tools and four types of upper implements). Use-wear analysis, however, was only performed on sandstone implements with sufficiently preserved wear-related traces (thirteen out of the twenty-one implements in the sample). The sandstone tools were chosen as they represented most of the sample (see Table 3.1), reflected all types, and the similar raw material allowed comparison between each other (as well as the reference collection). Two grinding sets were identified, based on the configuration of the surface of upper and lower tools. The following sections will describe the implements according to morphological categories (types) and the variability within them, as well as the use-wear identified in the tools. Then, the tools will be combined according to their designation within a grinding set and suggestions of motion and use will be outlined.

4.2.1 Lower tools

Two types of lower tool were identified in the archaeological sample, both grinding slabs with an open surface configuration. Type 1 slabs have a concave longitudinal profile ($n = 3$) and Type 2 slabs have a flat profile ($n = 1$). All of them have signs of manufacture and are made of coarse or medium-grained sandstone. They have an elongated rectangular shape with a concave outline on the longer sides and convex on the short ones. The ends are wider and slightly thicker than the body, making the transversal section of the active surfaces concave (see Figure 4.19).



Figure 4.19. Lower implements in the archaeological collection; a-c) Type 1 grinding slabs; a) Cat. #73/2079; b) Cat. #73/2078; c) Cat. #73/2242 with a longitudinal profile; d) Type 2 slab, Cat. #73/715.

Only Type 1 slabs had preserved use-wear (cat. #73/2078 and cat. #73/2079), which was consistent with plant processing - specifically with the grinding of USOs (see Table 4.5). Both tools have significant loss of grain volume resulting in leveling and long linear traces parallel to the length of the implement, as well as shorter striations that follow the width of the slabs (see Figure 4.20). On cat. #73/2078, the micro-polish occurs in patches concentrated in the high topography that are adjacent to each other and parallel to the length of the tool. It is flat, smooth and striated but not very reflective, resembling the processing of dry lily bulbs in our reference collection (see Figure 4.21). Cat. #73/2079 has highly reflective, flat and sinuous micro-polish associated with micro-striations and pitting that did

not match our experiments, but resembles the processing of dry snakegourd roots (*Trichosanthes kirilowii*) seen in Liu et al. (2014). Snakegourd (or any species of the genus *Trichosanthes*) is not currently present in the Gobi Desert, however, wear patterns are not species-specific and rather suggest the connection to a similar type of plant.

Table 4.5
Use-wear on Type 1 grinding slabs.

Cat. #73/	Topography	Micro-topography	Grain modification	Pits	Linear traces	Micro-polish
2078	Sinuuous Regular	Sinuuous Irregular	Loss of volume	Concentrated (LT) Circular Shallow	Long/short Longitudinal/ transversal Deep/shallow Thin/thin	Flat Smooth Patches Striated
2079	Flat Regular	Flat Regular	Loss of volume	Covered Close Circular/ Comet-shape d Shallow	Multi-directional Short/long Intermittent	Concentrated (HT) Flat Sinuous Pitted Striated

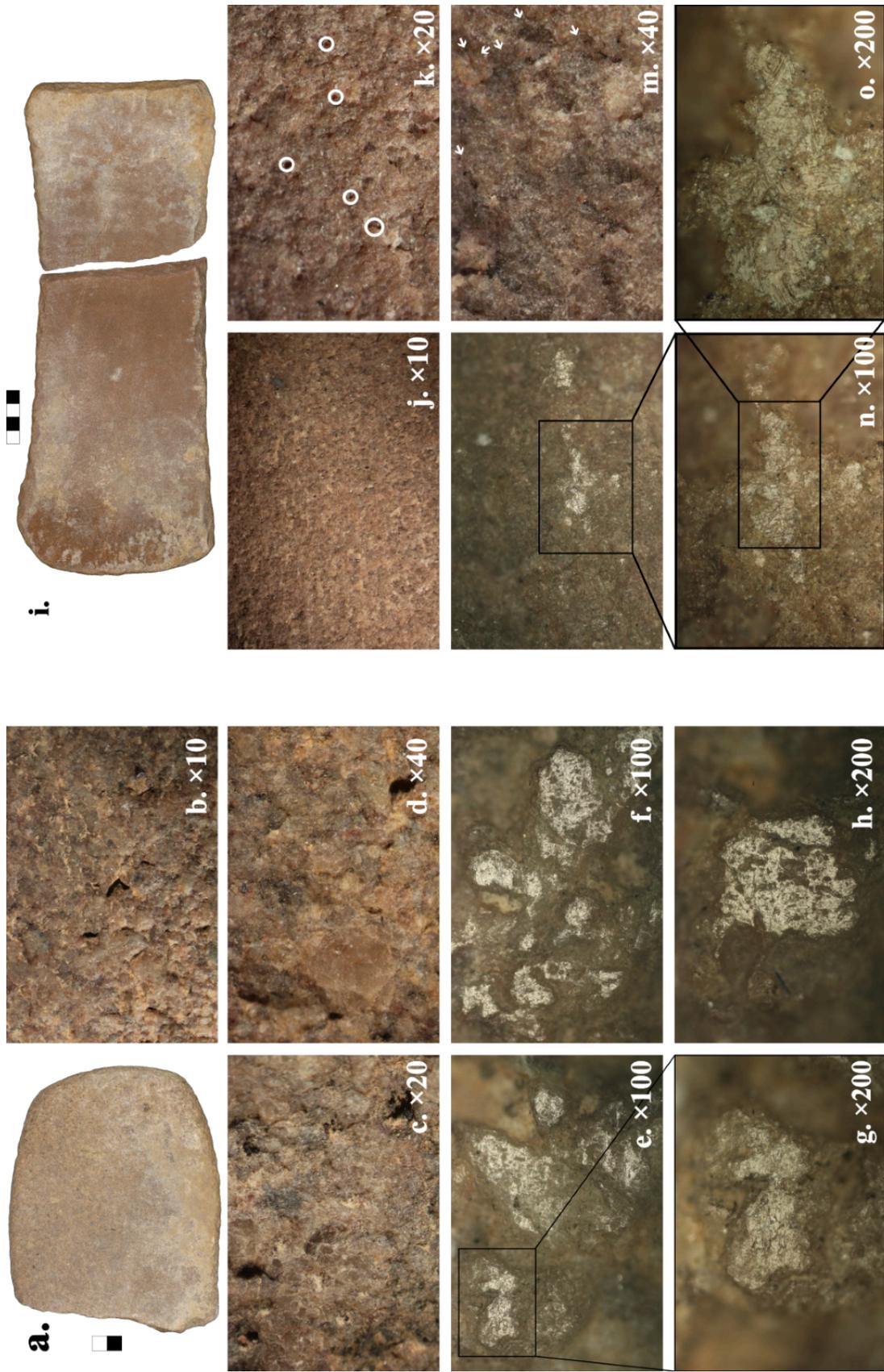


Figure 4.20. Use-wear on the lower implements; a-h) Cat. #73/2079; b-d) leveling and pitting on the microtopography at $\times 10$, $\times 20$ and $\times 40$ magnifications; e-h) striated and pitted micropolish at $\times 100$ and $\times 200$ magnifications; i-o) Cat. #73/2078; j, k, m) leveling, pitting and linear traces at $\times 10$ (j), $\times 20$ (k) and $\times 40$ (m) magnifications; l, n, o) striated micropolish at $\times 50$, $\times 100$ and $\times 200$ magnifications.

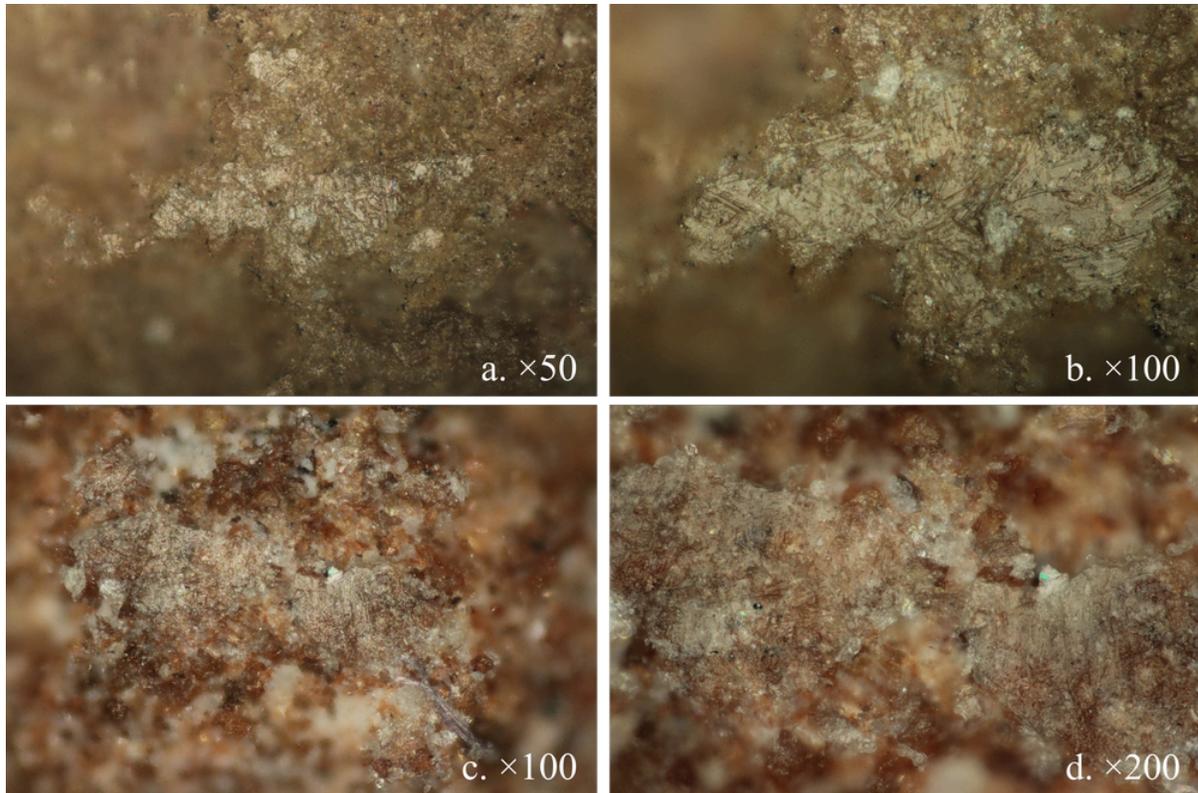


Figure 4.21. Comparison of micro-polish between cat. #73/2078 and tool 1A1, lower tool used for processing dried lily bulbs; a, b) Cat. #73/2078 at $\times 50$ (a) and $\times 100$ magnifications; c, d) 1A1 at $\times 100$ (c) and $\times 200$ (d) magnifications.

4.2.2 Upper tools

Four types of upper tools used mainly for grinding were identified in the archaeological sample. Type 1 are elongated implements with thicker ends (handles) ($n = 4$), Type 2 are elongated implements with no handle ($n = 7$), Type 3 are rectangular handstones ($n = 4$) and Type 4 are oval handstones ($n = 2$). All of them have signs of manufacture to particular shapes, or “strategic design” (Adams 2002:99).

4.2.2.1 Type 1 – Elongated handstones with handles

Type 1 implements have an elongated body and wider, spherical ends. The transversal profile of these tools is variable (see Figure 4.22), but all have more than one active surface and are made of coarse sandstone. There is no use-wear on the larger ends of the tools, which suggests that they are a comfort feature (an element that makes the tool more comfortable to hold and use [Adams 2002:19]) and are therefore interpreted as a handle. The morphology and use-wear distribution of Type 1 tools suggests that they are paired with Type 1 grinding slabs of width smaller than the length of the body of the upper tool (as there is a concentration of use-wear associated with stone-to-stone contact in the gauge, area which connects the handle to the body of the upper tool) and are rocked in a back and forth motion. The motion is indicated by the bi-convex shape of the transversal profile of the body of Type 1 tools in conjunction with the concave configuration of the active surface of Type 1 grinding slabs (see Figure 4.32).

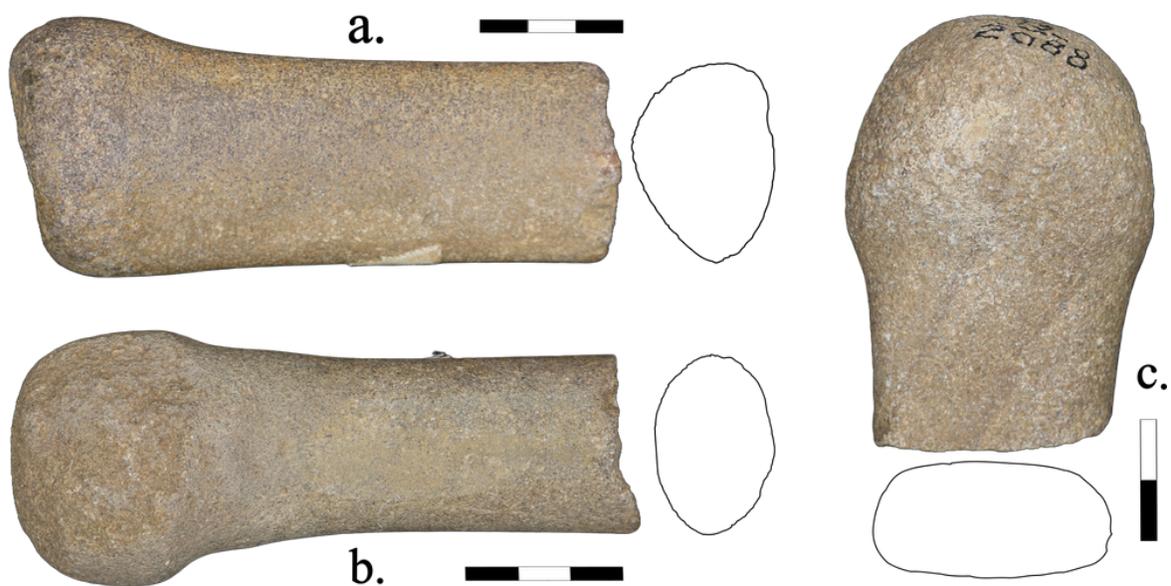


Figure 4.22. Analyzed Type 1 upper implements in the archaeological collection and the transversal section of the bodies; a) Cat. #73/2243A; b) Cat. #73/2243B; c) Cat. #73/2088F.

The use-wear on two of the preserved Type 1 (see Table 4.6) tools (Cat. #73/2088F and #73/2243B, see Figure 4.23) is also consistent with the processing of USOs. All implements have irregular micro-topographies, grains that have been micro-fractured, abundant pits and linear traces parallel to the width of the tool (that are indicative of the direction of use) as well as short and transversal/random striations (see Figure 4.23). The micro-polish covers the active surface but it is more intense in the high topography - it is sinuous, fluid and striated. Cat. #73/2243B matches our experiments of processing dry lily bulbs (see Figure 4.25), but Cat. #73/2088F has pitted micro-polish that did not have an equivalent in our reference collection - it is, however, very similar to Liu et al. (2014) processing of dry yam (*Dioscorea opposita*) and snakegourd roots (*Trichosanthes kirilowii*). Cat. #73/2243B seems to have been used in modern periods, as it has two flat facets that seem to have been cut with a mechanical tool and have no match in our reference collection. The facets are sinuous, grooved and leveled, with less pitting as the area with plant processing use-wear.

The use-wear identified on Cat. #73/2243A (see Figure 4.24) is consistent with cereal processing. The microtopography is leveled in higher areas but grains still have volume and are often frosted and micro-fractured. Deep pits and linear traces that are random, deep, intermittent and short cover the surface. The micro-polish is fluid, sinuous and pitted (see Figure 4.25), and it matches the micro-polish identified in tool 4B3 of our reference collection, used for grinding barley (see Figure 4.25).

Table 4.6
Use-wear on Type 1 handstones.

Cat. #73/	Topography	Micro-topog raphy	Grain modification	Pits	Linear traces	Micro-polish
2243A	Flat Irregular	Uneven Irregular	Micro- fractures Frosting	Covered Close/ connected Deep Circular	Covered Separated/ close Thin Perpendicular/ random Intermittent	Concentrated (HT) Sinuous Rough Striated
2088F / 2243B	Flat/sinuuous Regular	Sinuuous/ uneven Irregular	Grain edge rounding Micro- fractures Frosting	Covered Close/ connected Deep Circular/ irregular	Covered Close Long/short Parallel/ perpendicular Transversely oriented Deep/shallow	Covered Connected Flat Fluid Highly reflective Pitted Striated
2243B (facet)	Sinuuous Regular	Sinuuous Regular Leveled	Micro- fractures Frosting	Separated Connected Deep Irregular	Covered Close Random Shallow Thin	Covered Connected Sinuous Fluid Highly reflective



Figure 4.23. Use-wear on Type 1 implements associated with USO grinding; a-h) Cat. #73/2088F; b-d) leveling, pitting and frosting on the microtopography at $\times 10$, $\times 20$ and $\times 40$ magnifications; e-h) striated and pitted micropolish at $\times 50$ and $\times 100$ magnifications; i-m) Cat. #73/2243B; j, k) leveling and pitting at $\times 20$ and $\times 40$ magnifications; l, m) striated and pitted micropolish at $\times 100$ and $\times 200$ magnifications.

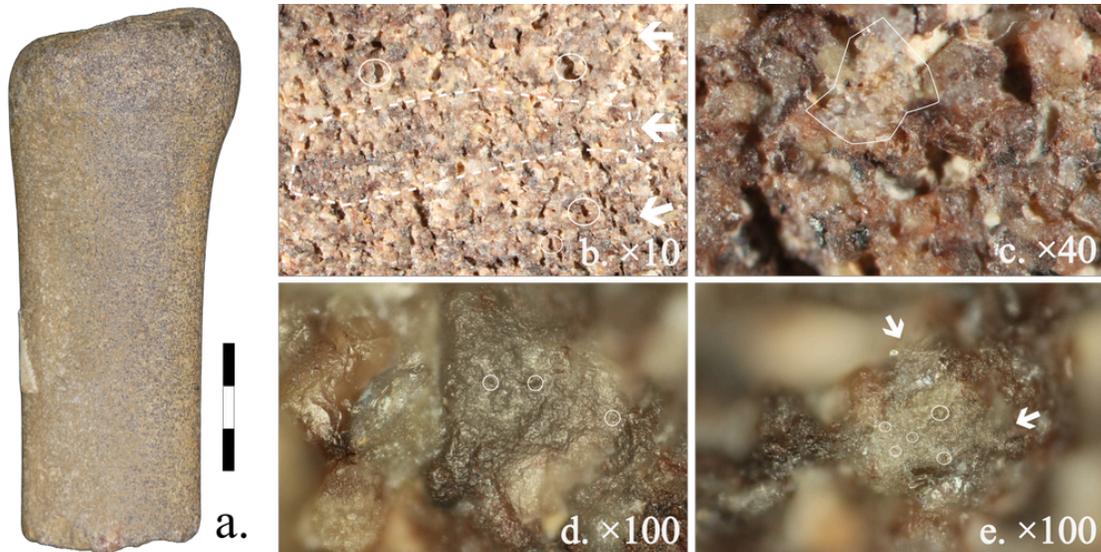


Figure 4.24. Use-wear identified on Cat. #73/2243A; a) Cat. #73/2243A; b) microtopography with leveling outlined by dashes, pits circled and arrows indicating the direction of linear traces at $\times 20$ magnification; c) micro-fractures at $\times 40$ magnification; d, e) striated and pitted micro-polish at $\times 100$ magnification.

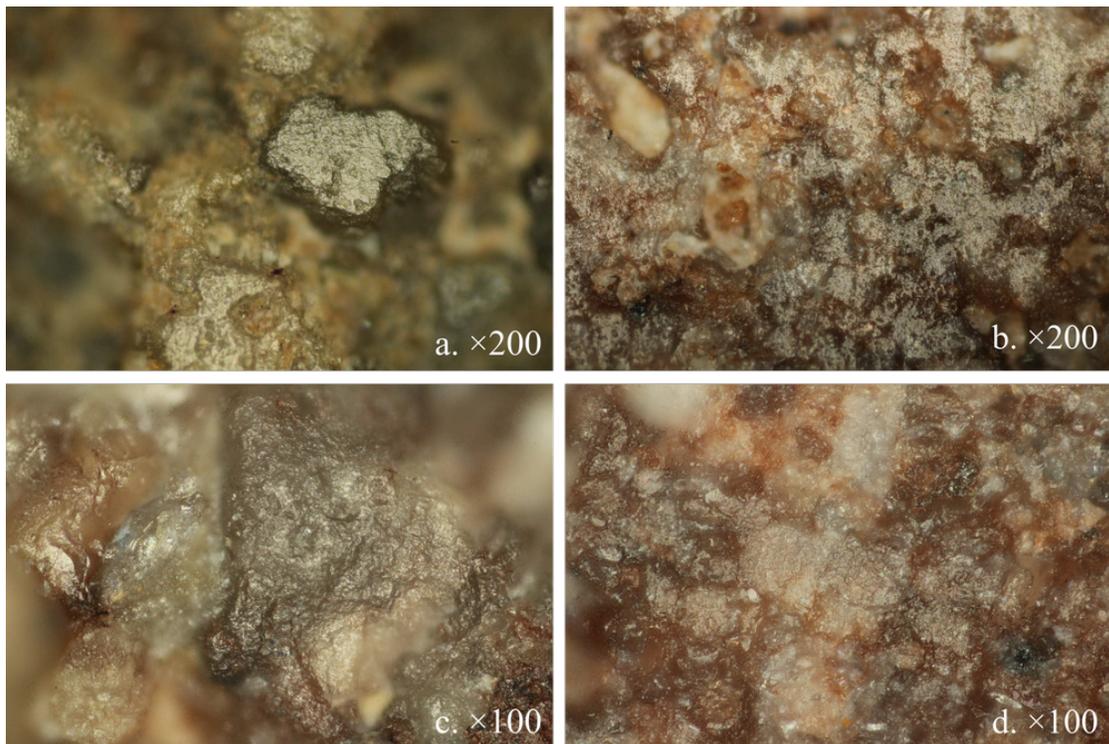


Figure 4.25. Comparison of micro-polish between Type 1 tools and the reference collection; a) Cat. #73/2243B at $\times 200$ magnification; b) Tool 4B4 (processed dry lily bulbs) at $\times 200$ magnification; c) Cat. #73/2243A at $\times 100$ magnification; d) Tool 4B3 (processed barley seeds) at $\times 100$ magnification.

4.2.2.2 Type 2 – Elongated handstones without handles

Type 2 implements are also elongated but have no handles; there are seven artifacts of this category in this sample. Three of them are made out of coarse or medium-grained sandstone. Although the transversal profile of Type 2 tools is variable (see Figure 4.26), the transversal section of their active surfaces is mostly convex, suggesting a back-and-forth movement against a slightly concave lower stone (see Figure 4.26).

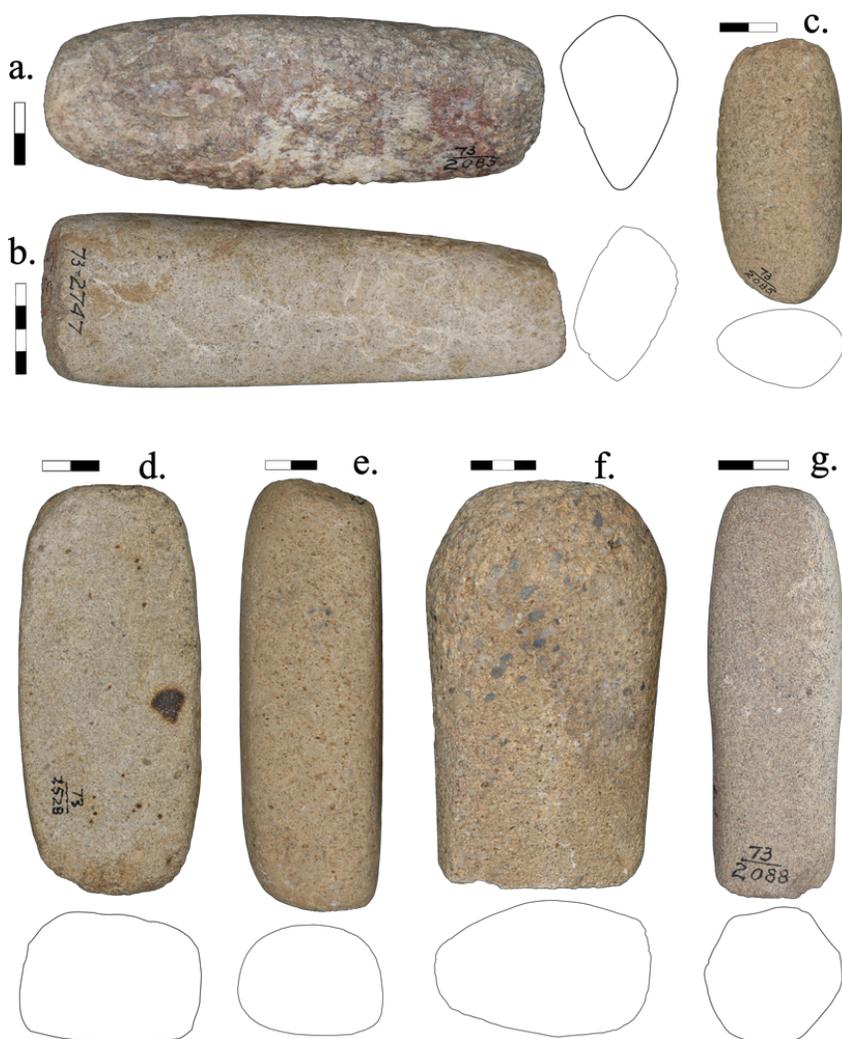


Figure 4.26. Type 2 implements in the sample and their transversal profiles; a) Cat. #73/2085D; b) Cat. #73/2747; c) Cat. #73/2085E; d) Cat. #73/2528; e) Cat. #73/2085C; f) Cat. #73/2088E; g) Cat. #73/2088D.

Five out of the seven Type 2 tools were sufficiently preserved for use-wear analysis. The use-wear on cat. #73/2528 and #73/2747 (although the last did not have preserved micro-polish) is the same as Type 1 implements, consistent with the processing of USOs (see Figure 4.27), but cat. #73/2085C, #73/2085D and #73/2088E resemble the processing of legumes (see Figure 4.28, Table 4.7). Those artifacts have a high topography that is leveled and regular and an irregular low topography. Pits cover the surface and are deep; the linear traces are random/multidirectional, shallow and concentrated in the high topography. The micro-polish is thick, sinuous and fluid, pitted and striated.

Table 4.7
Use-wear on Type 2 handstones.

Cat. #73/	Topography	Micro-topography	Grain modification	Pits	Linear traces	Micro-polish
2528/	Flat	Flat	Grain edge	Covered	Covered	Flat
2747	Regular	Irregular	rounding Micro-fractures	Close Deep/ intermediate Circular/ irregular Transversal	Close Transversal/ perpendicular Deep/shallow Thick/thin	Sinuuous Striated Pitted
2085C	Flat	Flat	Grain edge	Covered	Concentrated	Fluid
2085D	Regular	Irregular	rounding	Separated	(HT)	Sinuuous
2088E			Micro-fractures Frosting	Circular Transversal Deep	Random Shallow	Striated Pitted

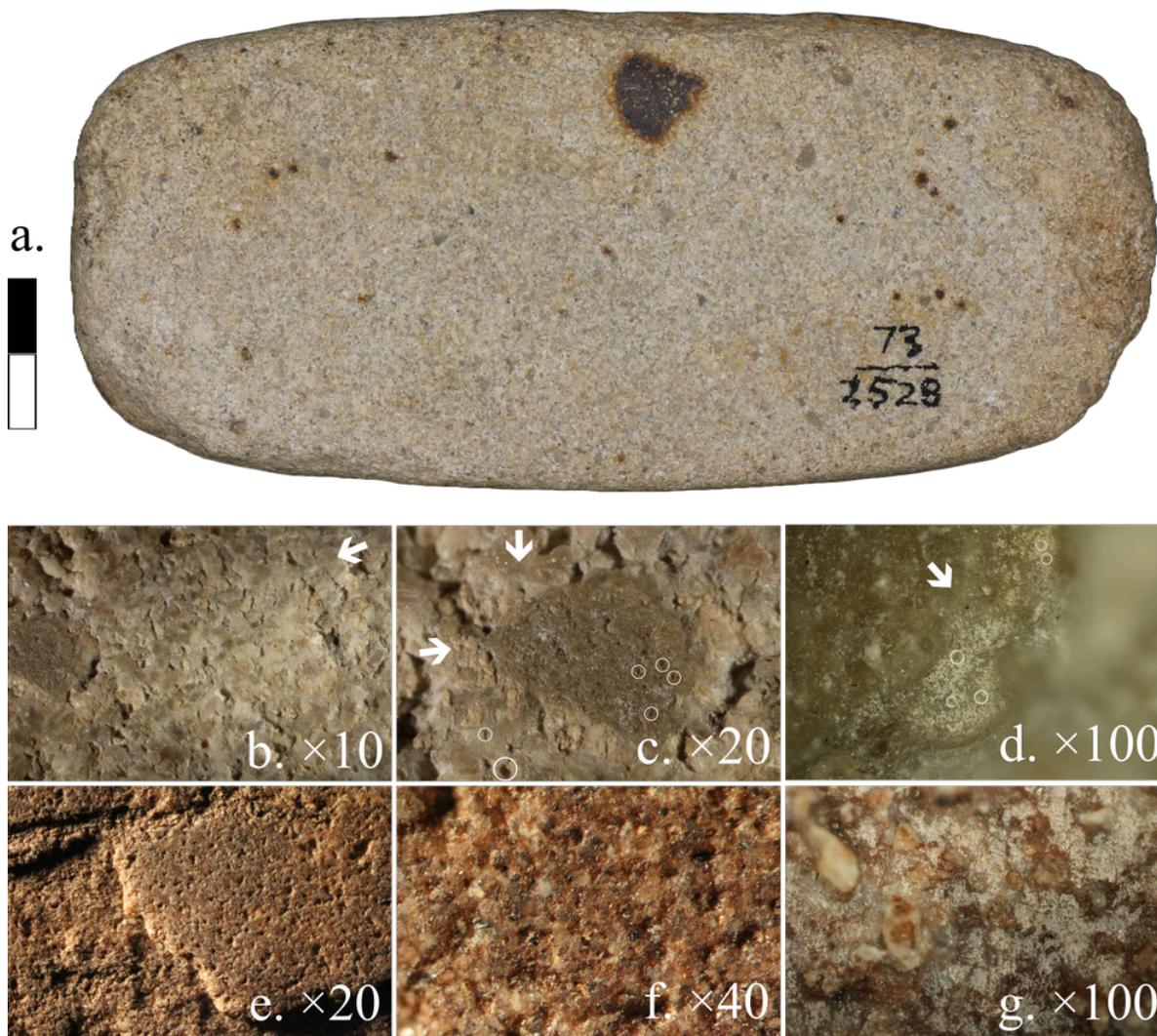


Figure 4.27. Use-wear on Cat. #73/2528 and on tool 4B4, that processed dry lily bulbs; a) Cat. #73/2528; b) microtopography at $\times 10$ magnification, general direction of linear traces is indicated by an arrow; c) microtopography at $\times 20$ magnification, linear traces and pits indicated; d) micro-polish at $\times 100$ magnification, micro-striations and pitting indicated; e-g) use-wear on tool 4B4, previously discussed.

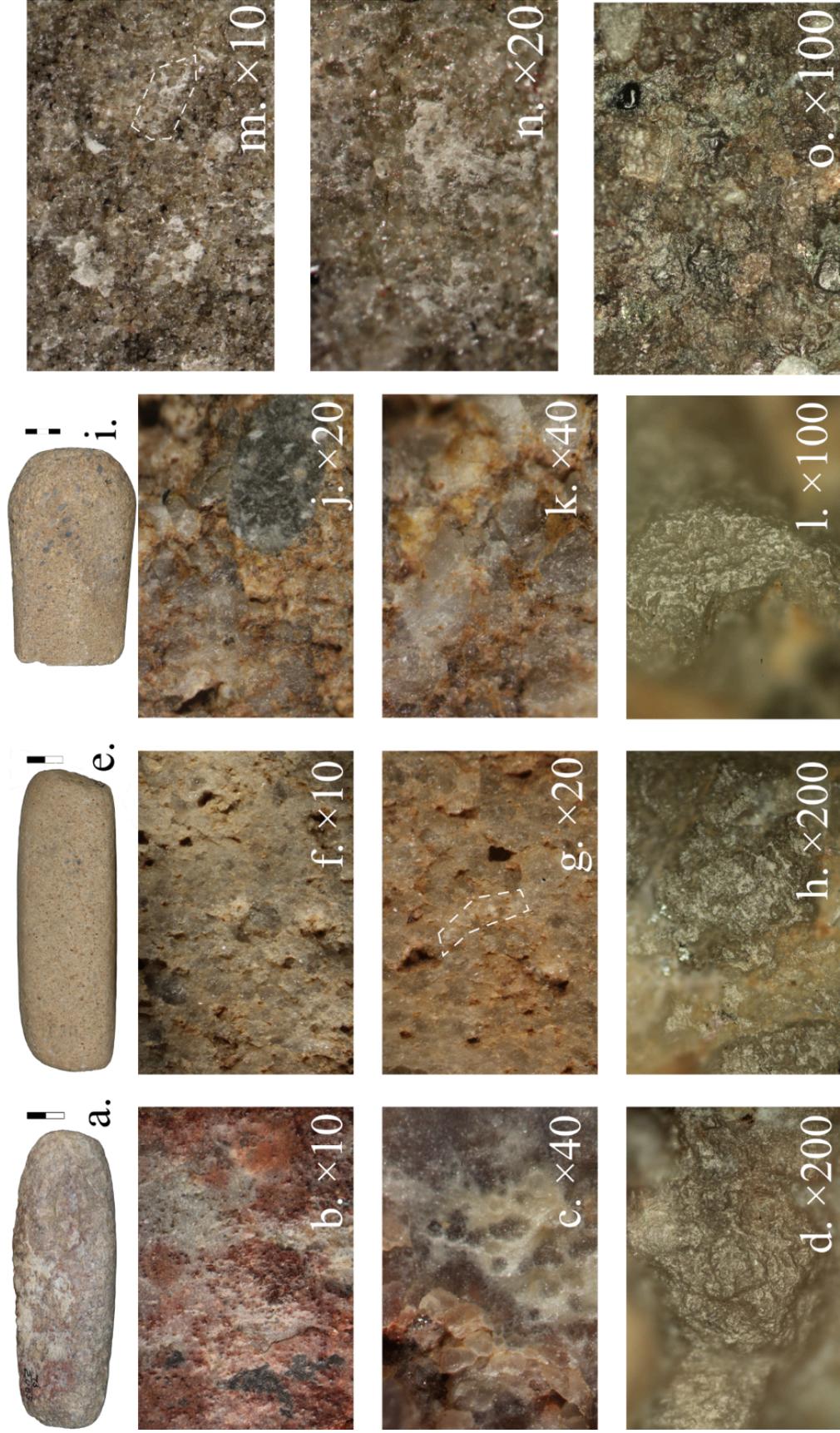


Figure 4.28. Use-wear on Type 2 tools associated with legume processing; a-d) Cat. #73/2085D; b) microtopography at $\times 10$ magnification; c) grain edge rounding and material buildup at $\times 40$ magnification; d) fluid and sinuous micropolish at $\times 200$ magnification; e-h) Cat. #73/2085C; f, g) microtopography at $\times 10$ and $\times 20$ magnifications, with leveling outlined; h) micropolish formation at $\times 200$ magnification; i-l) Cat. #73/2088E; j, k) leveled and frosted microtopography at $\times 20$ and $\times 40$ magnifications; l) micropolish at $\times 100$ magnification; m-o) use-wear identified on tool 12B, used to process legume (soybean).

4.2.2.3 Type 3 – Rectangular handstones

Type 3 tools have a rectangular-like shape and a rectangular transversal profile. Most have convex active surfaces, and the ones analyzed by Dubreuil et al. (2021) showed signs of use in both grinding (on the faces and longer sides) and pounding (in the shorter sides). From the sample analyzed in this study, two have a hyperbolic configuration with a concavity in the middle of the tool and two diagonally opposed ends higher than the rest of the surface (see Figure 4.29). Two of the implements are made of granite and two out of medium and coarse-grained sandstone, out of which one had sufficiently preserved use-wear.

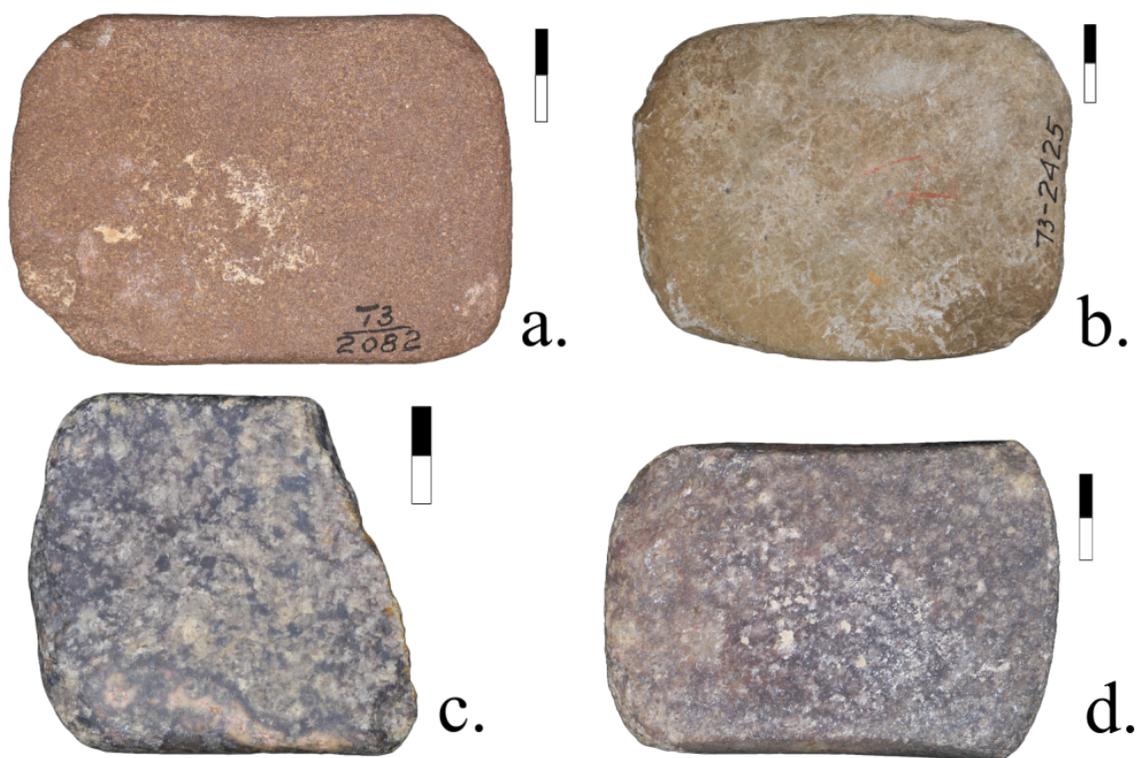


Figure 4.29. Type 3 implements; a) Cat. #73/2082C; b) Cat. #73/2435; c) Cat. #73/2083A; d) Cat. #73/2082B.

The preserved implement, Cat. #73/2082C, has use-wear similar to USO processing (see Table 4.8). It has a sinuous and regular topography and microtopography, and the higher

areas are leveled. Frosting and microfractures are present in the low topography and deep pits and linear traces that are random, deep, intermittent and short cover the surface. The micro-polish is concentrated in individual grains on the high topography; it is flat, fluid and pitted (see Figure 4.30). The center of this active surface and one of the longer sides of the tool were posteriorly used for pounding (see Figure 4.30). Both areas are topographically lower than the rest of the surface; their microtopography is uneven and irregular with crushed, frosted and micro-fractured grains. Deep pits and long perpendicular linear traces cover the surface (but deep/short striations are also noted). There is no micro-polish in those areas, just a high reflectivity due to the abundance of microfractures.

The active surface of cat. #73/2082C has a hyperbolic configuration that could not be illustrated in photos. Figure 4.30 includes a very saturated digital elevation model to show such configuration. The darker areas, in black and red, are topographically higher than lighter areas, in light red, orange and yellow. The color gradient does not intend to represent the exact topographic variability (in terms of measured altitude differences), but to show which areas are topographically higher and lower.

Table 4.8
Use-wear on Type 3 handstones.

Cat. #73/	Topography	Microtopography	Grain modifications	Pits	Linear traces	Micro-polish
2082C	Sinuuous	Sinuuous	Micro-	Covered	Covered	Fluid
	Regular	Regular	fractures	Close	Close	Sinuuous
		Leveled (HT)	Frosting	Deep	Random	Pitted
					Deep	
					Short	

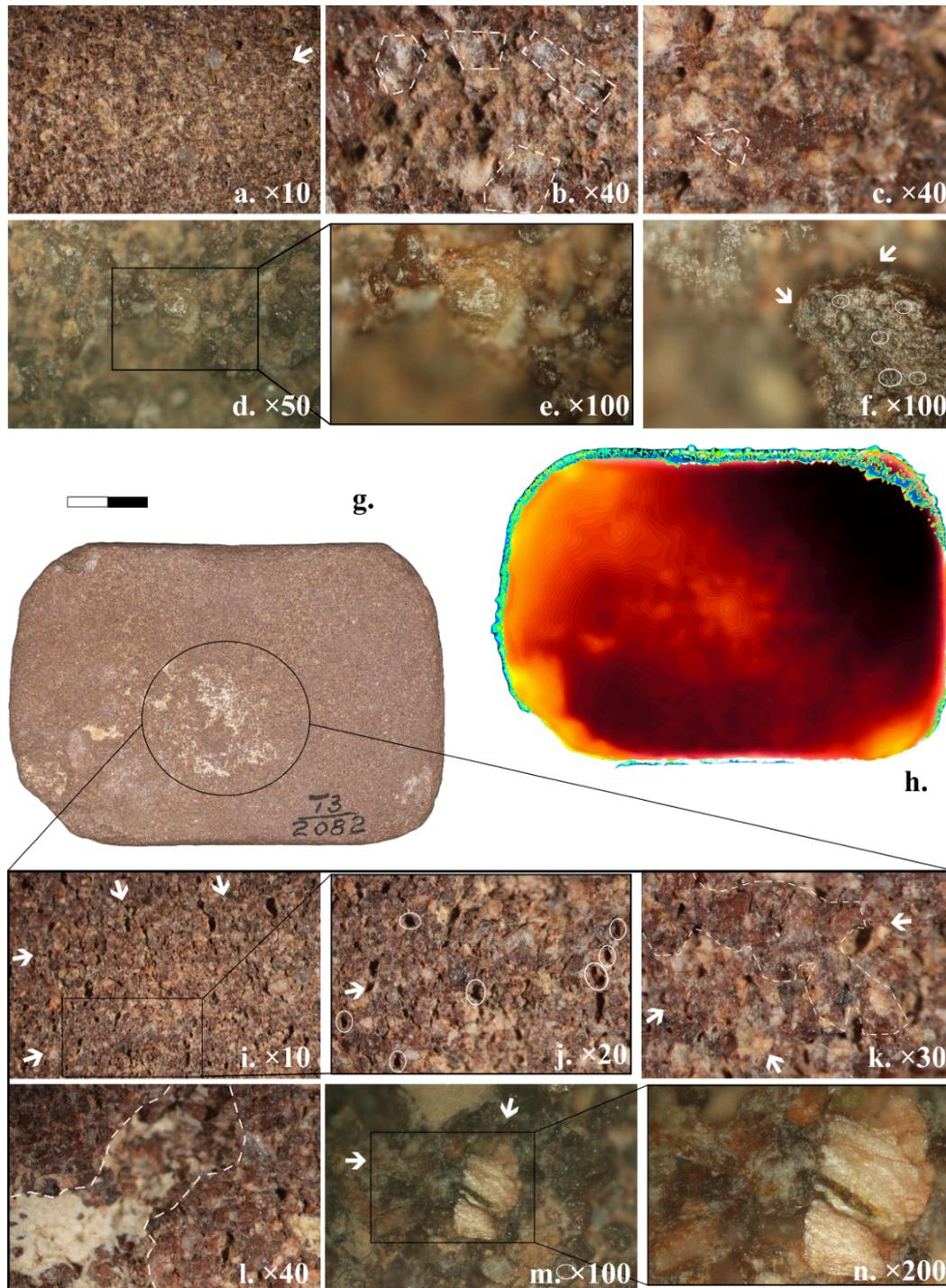


Figure 4.30. Use-wear on cat. #73/2082C; a-c; microtopography at low magnifications (×10-×40) with direction of linear traces indicated by an arrow and micro-fractures/frosting outlined; d-f) pitted and striated micro-polish at high magnifications (×50-×100); g) Cat. #73/2082C; h) Digital Elevation Map of the active surface of the tool, in which the darker sections represent higher topographic areas and lighter sections, lower areas; i-l) microtopography on the center depression of the tool, with pits, linear traces and leveling in evidence at low magnifications (×10-×40); m-n) lack of polish at high magnification (×100).

4.2.2.4 Type 4 – Oval handstone

Type 4 tools have an oval shape and a rectangular/rhombus transversal profile (see Figure 4.31). They have flat active surfaces and are made of medium and coarse-grained sandstone. Two tools of this type were included in our sample, and both had sufficiently preserved use-wear consistent with processing USOs (see Table 4.9), as described for Type 1, 2 and 3 tools (see Figure 4.32).



Figure 4.31. Type 4 implements and their transversal section; a) Cat. #73/2083B; b) Cat. #73/2083C.

Table 4.9
Use-wear on Type 4 handstones.

Cat. #73/	Topography	Micro-topography	Grain modifications	Pits	Linear traces	Micro-polish
2083B	Flat	Flat	Grain edge rounding	Covered	Covered	Flat/sinuuous
2083C	Irregular	Irregular	Micro-fractures	Connected Irregular Transversal Deep	Close Transversal/ perpendicular Long/short Deep/shallow Thick/thin	Fluid Thick Striated Pitted

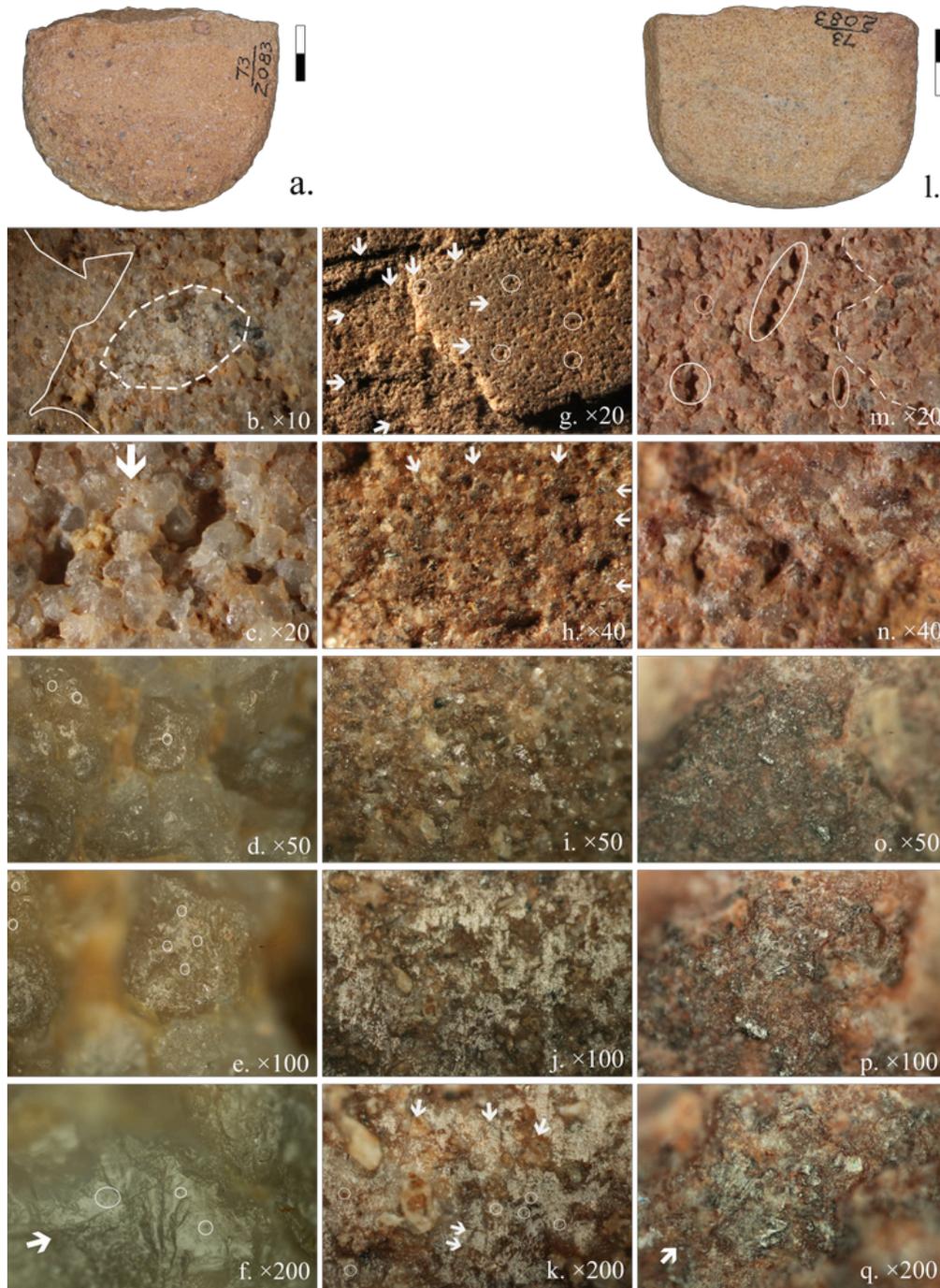


Figure 4.32. Use-wear on cat. #73/2083B and cat. #73/2083C compared to tool 4B4, used to process dry lily bulbs; a-f) Cat. #73/2083B; b) micro-fractures and frosting (outlined by dashes) and leveling (indicated by a line) at $\times 10$ magnification; c) grain edge rounding and linear traces at $\times 20$ magnification; d-f) striated and pitted micro-polish at $\times 50$ - $\times 200$ magnifications; g-k) use-wear on tool 4B4, as described before; l-q) Cat. #73/2083C; m) pitting and leveling at $\times 20$ magnification; n) frosting oriented with linear traces at $\times 40$ magnification; o-q) striated and pitted micro-polish at $\times 50$ - $\times 200$ magnifications.

4.2.3 Grinding sets

Based on the configuration of the active surface(s) of the archaeological tools, two grinding sets are proposed. The first is made of Type 1 grinding slabs (such as cat. #73/2078 and #73/2079) and Type 1 and 2 handstones. Despite the elongated configuration of these handstones, no use-wear was identified on their ends, which suggests the implements were not used as a pounder. Therefore, the enlarged knobs found on Type 1 tools were defined as handles, after Dubreuil et al. (2021). Although all Type 1 tools were fragmented on the body, the ruling assumption is that they had another handle on the opposite end of the longitudinal axis, which would allow for its use with two hands, in a rocked back and forth motion. The profile of the body of the tools is not circular, but oval or triangular with convex surfaces, suggesting that the tools were not used in a complete rotation (see Figure 4.33).

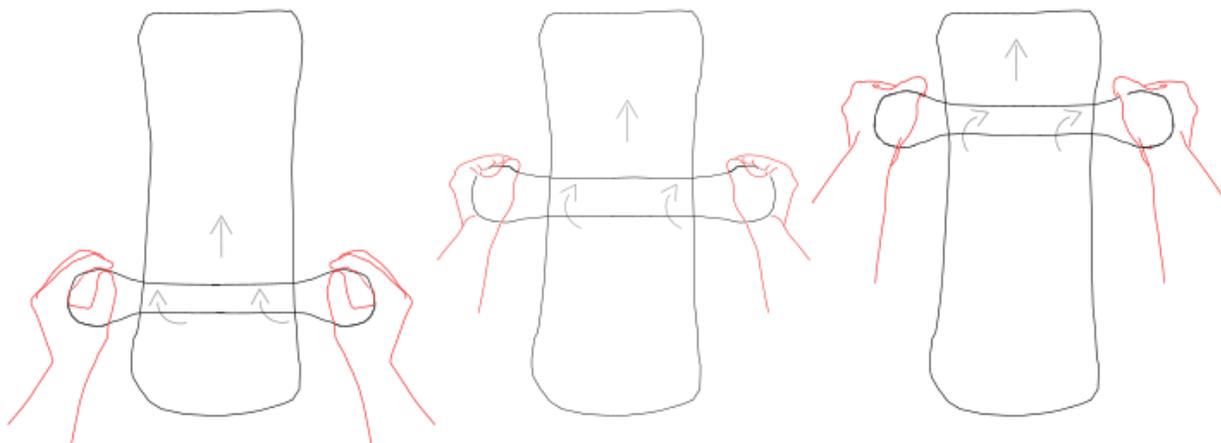


Figure 4.33. Proposed grinding set with Type 1 handstones and grinding slabs with a concave active surface (based on cat. #73/2242A and cat. #73/2078). Suggested motion use: the handstone had likely another handle at the end of the body in which the second hand was placed to move the stone. The partial rotation of the handstone, indicated by arrows, results in the convex configuration of the active surface.

The body gesture used with Type 2 tools was likely distinct from the one employed with Type 1 as there is no area destined specifically for holding, however, the similar convex configuration of the transversal profile of their active surfaces suggests its use with Type 1 grinding slabs – that have a concave active surface. They could likely be manipulated with either one or two hands.

The second grinding set proposed is made of the Type 2 grinding slab (cat. #73/715) and Type 4 handstones (see Figure 4.34). Despite fragmentation, the width and thickness of the oval handstones makes them distinct from Type 2 handstones (elongated without a handle), as Type 4 tools are wider and thinner. These handstones were likely used on Type 2 slabs with one hand in a flat motion – based on the use-wear of the handstones, in a reciprocal back and forth movement (see Figure 4.34).

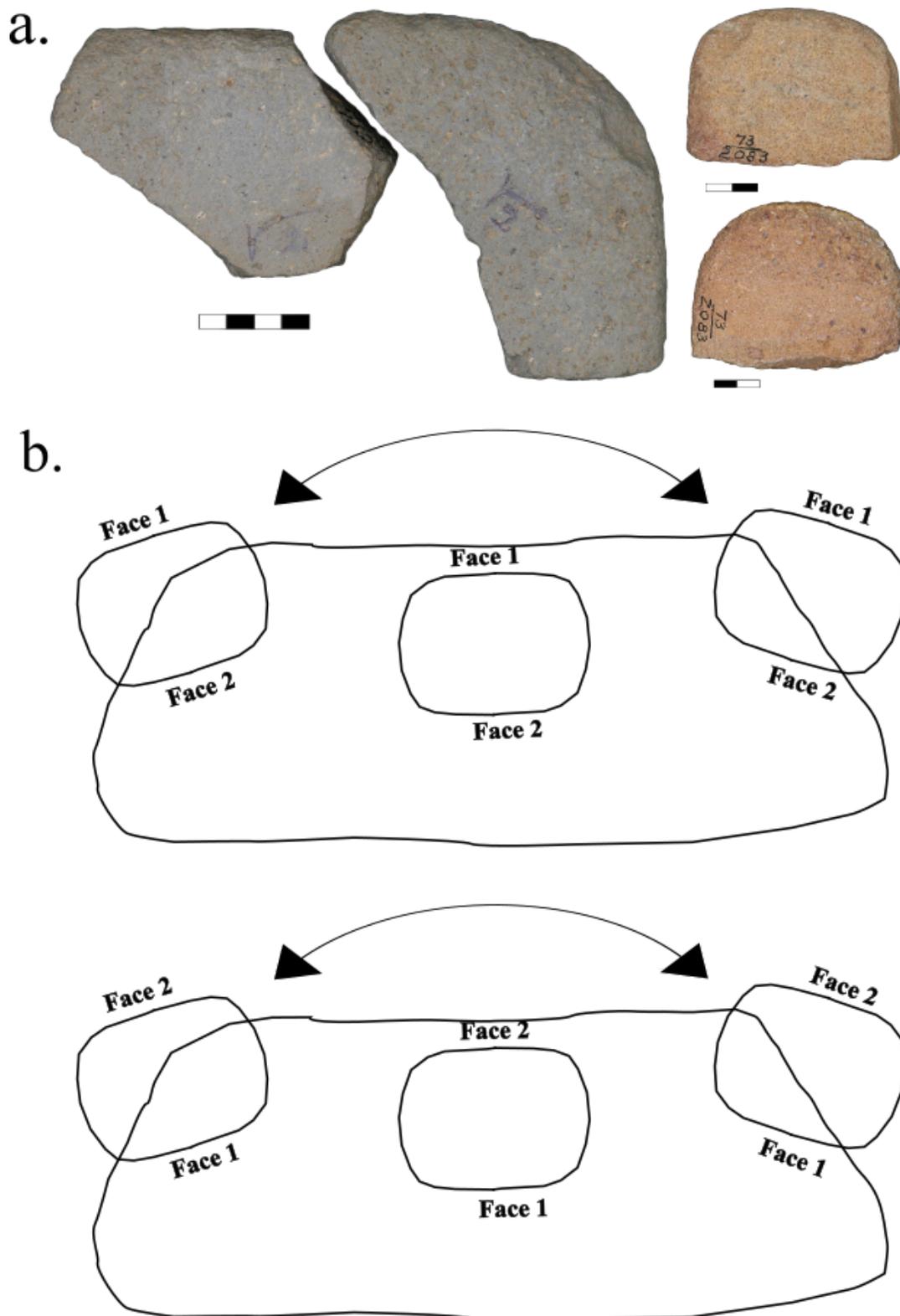


Figure 4.34. Proposed grinding set with Type 4 handstones and grinding slabs with a flat active surface (based on cat. #73/715). A) Tools that compose this grinding set; B) Suggested motion of use, a reciprocal back and forth movement.

4.3 Residue analysis results

The thirteen sandstone implements that were subjected to use-wear analysis were also used in the exploratory residue analysis. Seven out of the thirteen yielded starches (see Table 4.10). Three tools had micro-botanical remains only in the interior sample of the active surface and four, on the breakage and/or exterior sample of the active surface; 32 starches were recovered in total. Although the identification of the residues was not performed (with the exception of one starch found on Cat. #73/2079, identified by Dr. Monica Ramsay as belonging to the Fabaceae family; see Figure 4.35), it was noted that most starches (25 out of 32) had morphological alterations (such as damage or loss of birefringence; see Figure 4.36), which are common consequences of food processing (Henry et al. 2009; Wang et al. 2017; Ma et al. 2019). Further information about the starches found in the archaeological collection is available in Appendix B.

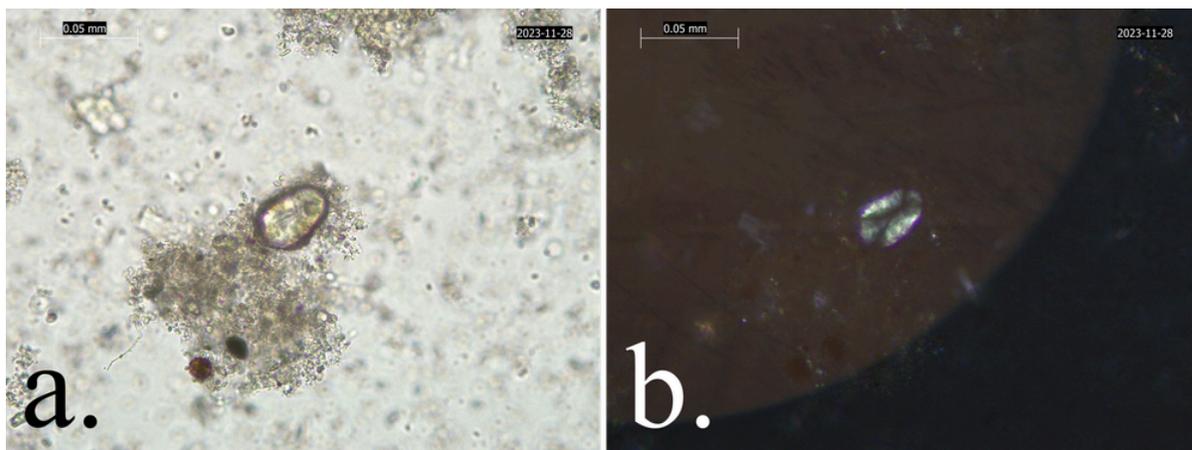


Figure 4.35. Starch grain collected from the interior sample of the active surface of Cat. #73/2079, identified by Dr. Monica Ramsey as belonging to the Fabaceae family without (a) and with (b) polarized light.

Table 4.10
Starches identified in the tools sampled from the archaeological collection

Cat. #73	Surface	Sample	Staining method	Starch count	Morphology	Damage
2078	Active surface	Interior	N/A	Low (n = 3)	Polyhedral Oval	All
2079	Active surface	Interior	N/A	Low (n = 1)	Rounded	No damage
	Breakage	Interior	Lugol	Low (n = 3)	Oval and elongated 2 oval and elongated 1 small and rounded	All
2088F	Active surface	Interior	Lugol	Low (n = 2)	Oval	Loss of birefringence
2747	Active surface 1	Interior	One slide without dye, one with Lugol	Moderate (n = 5)	Polyhedral 1 oval and elongated 1 rounded 3 ?	4 damaged, rounded is complete
	Active surface 2	Interior	Lugol	Low (n = 2)	Oval and elongated Small and rounded	Oval and elongated is damaged, circular is not
2088E	Active surface	Interior	N/A	Low (n = 2)	Polyhedral ?	All
	Breakage	Exterior	Lugol	Low (n = 1)	?	All
		Interior	Lugol	Moderate (n = 5)	4 ?	4 damaged, rounded is complete
2083B	Active surface	Interior	One slide with Lugol, one with Orange G	Low (n = 3)	1 small and rounded 2 ?	All
	Breakage	Interior	Lugol	Low (n = 1)	1 rounded ?	All
2083C	Active surface	Interior	Lugol, Orange G and nc	Low (n = 3)	Rounded	All
		Exterior	Lugol	Low (n = 1)	Oval and elongated ?	All

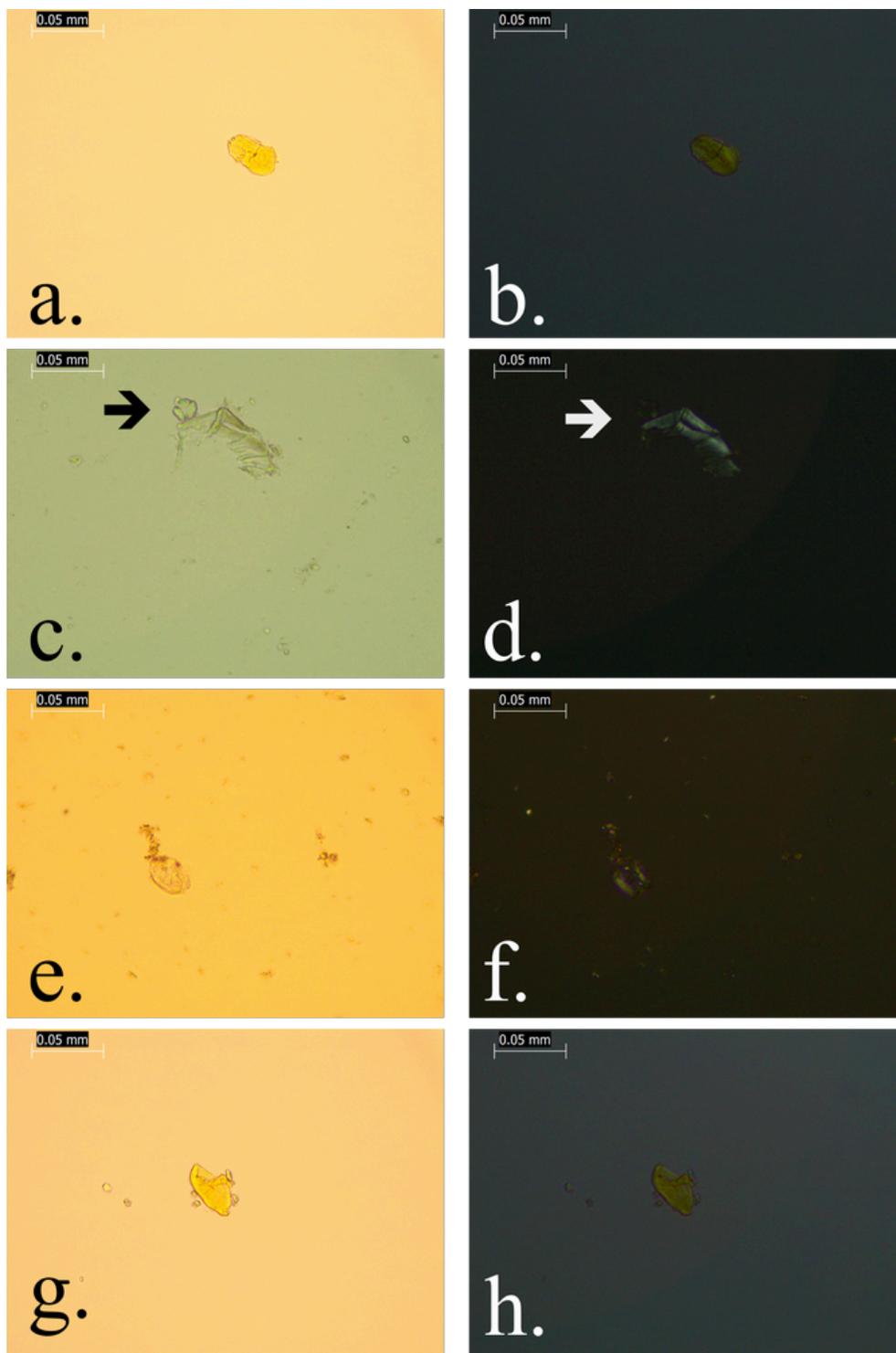


Figure 4.36. Damaged starch grains collected from the interior sample of the active surfaces of multiple implements without (a, c, e, g) and with (b, d, f, h) polarized light; a, b) Cat. #73/2079; c, d) Cat. #73/2088E; e, f) Cat. #73/2747 (active surface 1); g, h) Cat. #73/2747 (active surface 2).

Although the starch count was not intense, the results indicate that it is possible to assess contamination in the collection. In this study, that was done by processing samples of the breakage surfaces of tools that yielded starches in their active surfaces, based on the idea that use-related residues should not be present in the breakage samples. When starches were found in those samples, the tool was not considered suitable for the residue analysis. While more recent excavated materials tend to yield a higher amount of starch (see Liu et al. 2011, 2014, 2016), residue analysis could contribute to research in contexts where acquiring such materials is not possible. When associated with use-wear analysis, which is less likely to be affected by handling in museums, these methods can provide a more comprehensive understanding of the function of the tools. It is important, however, to remember that the Gobi Desert GST collection, although curated by the AMNH, has not been used in museum exhibits (which would increase their handling and, likely, the potential for the contamination of the residues). When working with museum collections that have been moved or handled more often (as is the case of artifacts used in exhibits), these results might not be appropriate. Despite the low amount of residues collected from the tools, these results suggest that micro-botanical research can be viable with legacy collections, when following protocols that account for possible contamination of the evidence.

4.4 Conclusion

Although different levels of preservation were attested in the artifacts of the archaeological collection, the identification of active surfaces was possible for all tools. Five morphological categories described as types - were identified in the sample, one of lower implements and

four of upper implements. The types were assessed to two grinding sets, based on the configuration of the active surface of the tools. The first grinding set is composed of Type 1 grinding slabs used with elongated upper tools, such as Types 1, 2 and some Type 3 implements (see Table 4.11). The second set is made of Type 2 grinding slabs and Type 4 handstones. The hyperbolic configuration of Type 3 tools analyzed here needs further assessment before being associated with a grinding set.

Table 4.11
Summary of results.

Cat. #73/	Type	Grinding set	Associated use-wear	Presence of starches
715	Type 2 Grinding slab	2	N/A	
2078	Type 1 Grinding slab	1	USO	X
2079	Type 1 Grinding slab	1	USO	X
2242	Type 1 Grinding slab	1	N/A	
2243A	Type 1 Handstone	1	Cereal	
2243B	Type 1 Handstone	1	USO	
2088C	Type 1 Handstone	1	N/A	
2088F	Type 2 Handstone	1	USO	X
2088E	Type 2 Handstone	1	Legumes	X
2528	Type 2 Handstone	1	USO	
2746	Type 2 Handstone	1	N/A	
2747	Type 2 Handstone	1	USO	X
2085C	Type 2 Handstone	1	Legumes	
2085D	Type 2 Handstone	1	Legumes	
2085E	Type 2 Handstone	1	N/A	

Table 4.11
Continued.

2425	Type 3 Handstone	N/A	N/A	
2082C	Type 3 Handstone	N/A	USO	
2082B	Type 3 Handstone	1	N/A	
2083A	Type 3 Handstone	1	N/A	
2083B	Type 4 Handstone	2	USO	X
2083C	Type 4 Handstone	2	USO	X

All implements have use-wear associated with plant processing. Type 1 grinding slabs (cat. #73/2078 and cat. #73/2079) were associated with the grinding of USOs, as were some Type 1 and 3 upper implements; use-wear associated with legume and cereal processing was also identified in the upper tools (see Table 4.11). The distinction of material processed was made by combining and comparing low and high-power observations between the reference collection and the archaeological tools. When the use-wear varied and could not match what was seen in the reference collection (as in cats. #73/2079 and #73/2088F), the use of other sources (Liu et al. 2014) provided helpful comparative data that was used to make suggestions regarding the material processed.

Regarding the residue analysis, the goal of this study was to assess the suitability of the Gobi Desert GST assemblage for such research. The sandstone implements with preserved use-wear were used for the residue assessment. Seven of the implements made of sandstone with preserved use-wear yielded starch grains. Regarding the level of contamination, three tools had starches on the breakage surface, but all the starch counts were low or moderate (up to five starches in one slide). All tools that yielded starches (see Table 4.10) had them on their active surface as well, and they often had damage that could be

consistent with plant processing – however, further research is necessary to confirm this hypothesis.

The following chapter will discuss the results of the analysis in relation to GST assemblages in Northern China that are also associated with the exploitation of wild resources. Then, likely species of plants to have been processed with the implements will be discussed, based on the environmental description of the Gobi Desert around the Oasis 2 period outlined on Chapter 2 and paleoenvironmental data from sites in the Northeastern Gobi Desert.

Chapter 5

Discussion and Conclusion

The goal of my research was to explore whether the adoption of ground stone tool technology in the Gobi Desert during the Oasis 2 period (8.5-5 k cal yr BP, Janz et al. 2021) was related to plant processing. At the time, changes in technology and settlement patterns suggest that Gobi Desert populations were intensifying the use of wetland resources as a response to the increased biodiversity of the HCO (Janz 2012, 2016; Janz et al 2017; Evoy 2019; Rosen et al. 2022). Analysis conducted by Dubreuil et al. (2021) suggested that the use-wear identified in the GST assemblage was related to the processing of different plant materials, both dry/hard and wet/soft. The present study furthered this hypothesis by identifying use-wear related to three different plant groups: legumes, cereals, and underground storage organs (USOs) - roots, tubers and rhizomes.

This chapter will synthesize results from the analysis of the archaeological collection, discuss how the implements connect to ground stone tool assemblages from nearby regions in Northeast Asia and present the species of plants that were likely consumed at the time

(based on vegetation surveys, phytolith data and ethnobotanical information). This discussion aims to outline the implications of the results of the present analysis to the understanding of plant use in the Oasis 2 period in the Gobi Desert.

5.1 Summary of use-wear results

The implements analyzed in this study were chosen because they represent the most common implements observed in the GST collections of Oasis 2 sites. The assemblage is composed of grinding implements made in two different raw materials (granite and sandstones of varying granularities), manufactured into five different morphologies.

The lower implements are grinding slabs with an open surface configuration (meaning they have no borders on the tools) and either concave (Type 1) or flat (Type 2) profiles; the upper implements are handstones of varied morphologies that were divided in four types: elongated with handles (Type 1), elongated without handles (Type 2), rectangular (Type 3) and oval (Type 4). Types 1 and 2 handstones would have been used with two hands, while Types 3 and 4 would have been used with one hand. Two distinct grinding sets were identified, based on the configuration of the active surfaces and the morphology of the tools. Grinding set 1 was composed of Type 1 grinding slabs and the two-hand tools (Types 1 and 2). In Type 1 handstones, the area which connects the handle to the body of the tool has a concentration of stone-to-stone wear that further supports this idea. The configuration of the surfaces indicates that the upper tools were used in a rocked back-and-forth motion which created the concavity in the lower implement and the convexity in the upper one (see Figure 4.33). Grinding set 2 is composed of Type 2 grinding slabs and Type 4 handstones, used in a straight back-and-forth motion. The Type 3 upper tools analyzed in this study show signs of

grinding in an unidentified movement, as the configuration of their surface resembles a hyperbolic paraboloid (see Figure 4.30), and therefore were not attributed to any grinding set.

The results of the functional analysis on the implements with sufficient use-wear preservation made of sandstone suggest that the tools were used to process different types of plants, supporting the initial hypothesis. Wear associated with the processing of USOs was present on most of the implements, but wear related to legume and cereal processing was also identified. There is no evidence to suggest that the variability in morphology was tied to a particular material. The Gobi Desert GST collection had both similarities and distinctions to other assemblages from Northeast Asia, and they will be presented in sequence.

5.2 Ground Stone Tool assemblages in Northeast Asia

This section will describe GST assemblages from Northeast Asia from sites that are associated with wild plant processing or date prior to the introduction of agriculture. They come from distinct regions – the Loess Plateau, Daihai Lake and West Liao River – but paleoenvironmental reconstructions from the Holocene show similar pollen assemblages. Common species found are *Artemisia* sp., *Pinus* sp. and *Quercus* sp. The sites mentioned throughout this chapter are illustrated in Figure 5.1.

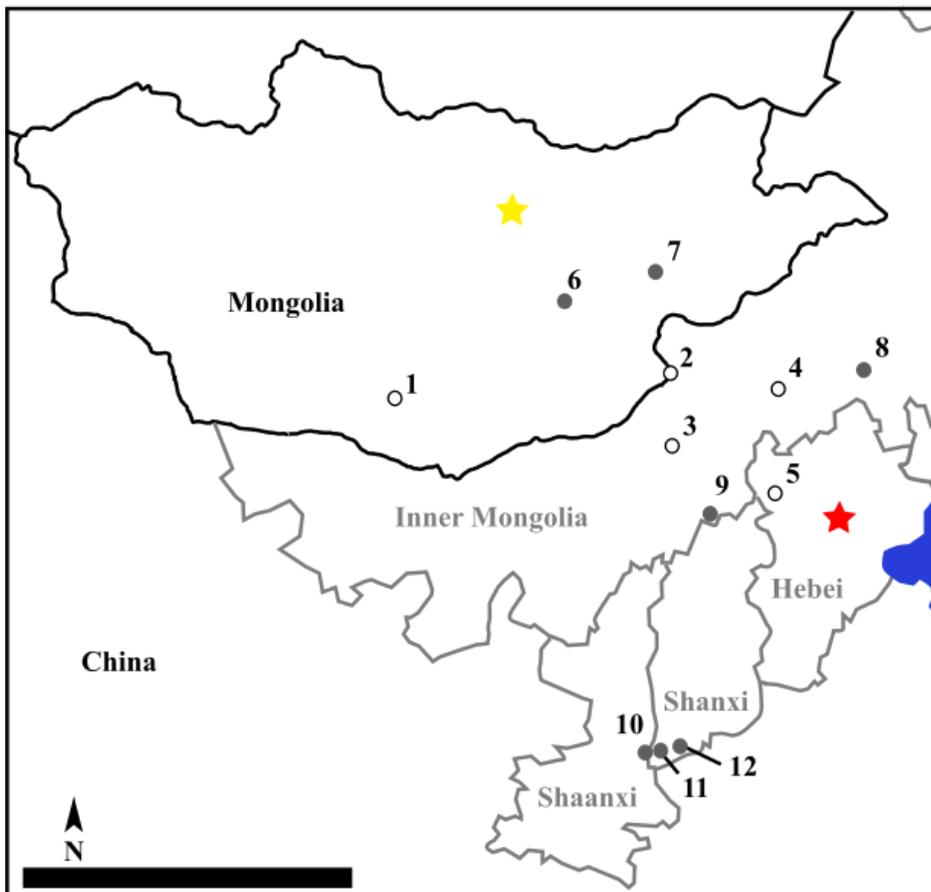


Figure 5.1. Location of the sites mentioned in this chapter. 1. Shabarakh Usu; 2. Irdin Manha; 3. Baron Shabaka localities; 4. Chilian Hotoga Well; 5. Jira Galantu; 6. Ikh Nart Nature Reserve; 7. Zaara Uul; 8. Baiyinchanghan; 9. Shihushan I and II; 10. Shizitan; 11. Longwangchan; 12. Xiachuan.

5.2.1 Loess Plateau

GSTs are found in Northern China since the Upper Paleolithic (Liu et al. 2018), appearing first in sites along the Yellow River such as Xiachuan, (23.9-16.4 k BP) (Wang et al., 1978), Longwangchan (20-15 k BP) (Institute of Archaeology and Shaanxi Institute of Archaeology, 2007; Zhang et al. 2011), and Shizitan (Shizitan Archaeology Team 2010; 2013; Liu et al. 2011a, 2013, 2018) (see Figure 5.1). Such implements became more geographically widespread in the Early/Middle Holocene, found in Inner Mongolian sites

such as Shihushan I and II (SHSI dated to 6.5-6.4 cal. BP) (Liu et al. 2014) and Baiyinchanghan (with occupations that date from 8.2-5 k BP) (Liu et al. 2016; Tao et al. 2011). According to Liu et al. (2016:247), the technology becomes less abundant with the emergence of the Yangshao culture in the Yellow River (7 k BP), but it is still used in other areas.

The Upper Paleolithic sites (Xiachuan, Longwangchan and Shizitan) are found in the southeastern portion of the Chinese Loess Plateau (CLP). The CLP is formed by eolian sediments transported from nearby deserts (such as the Gobi, Mu Us, Hobq, Badain Jaran, Ulan Buh and Tengger) that underwent chemical weathering and carbonation after deposition (Sun et al. 2002; Li et al. 2020; Jiang et al. 2013). With a current arid/semi-arid climate, paleoenvironmental reconstructions in the region reveal that the southeastern portion of the CLP, represented by Jixian and Xiangfen and associated with the sites Xiachuan, Longwangchan and Shizitan, had dry-steppe vegetation during the LGM and a meadow steppe in the early Middle Holocene (Jiang et al. 2013). At that time, herbaceous pollen is mainly associated with *Artemisia* sp.; arboreal pollen comes mostly from *Pinus* sp., but *Quercus* sp. and *Forsythia* sp. are also found. Ferns and algae characteristic of meadows (such as *Selaginella sinensis* and *Zygnema*) are present in the assemblage. Shrubs are not intense in the region, particularly when compared to the northwestern CLP (Jiang et al. 2013).

Overall, the grinding sets of the Upper Paleolithic sites are composed of a grinding slab of open surface configuration with a rectangular/sub-rectangular shape (*mopan*) and an elongated handstone (*mobang*, which resembles Type 2 implements from the Gobi Desert assemblages) (see Figure 5.2). Functional analysis of implements at Locality 9 (13.8-8.5 k

cal BP) of the Shizitan site cluster (Liu et al. 2011), all made of sandstone, suggests that the tools were used for multiple purposes, such as abrading hard materials, processing nuts and wood, grinding/pounding hematite and grinding seeds and dry tubers. Starches of grasses (of *Triticeae*, *Paniceae* and *Panicoideae* families), acorns (*Quercus* sp.), tubers (*Dioscorea* sp., *Trichosanthes kirilowii*, *Lilium* sp.) and beans (*Vigna* sp.) were identified on the implements as well.

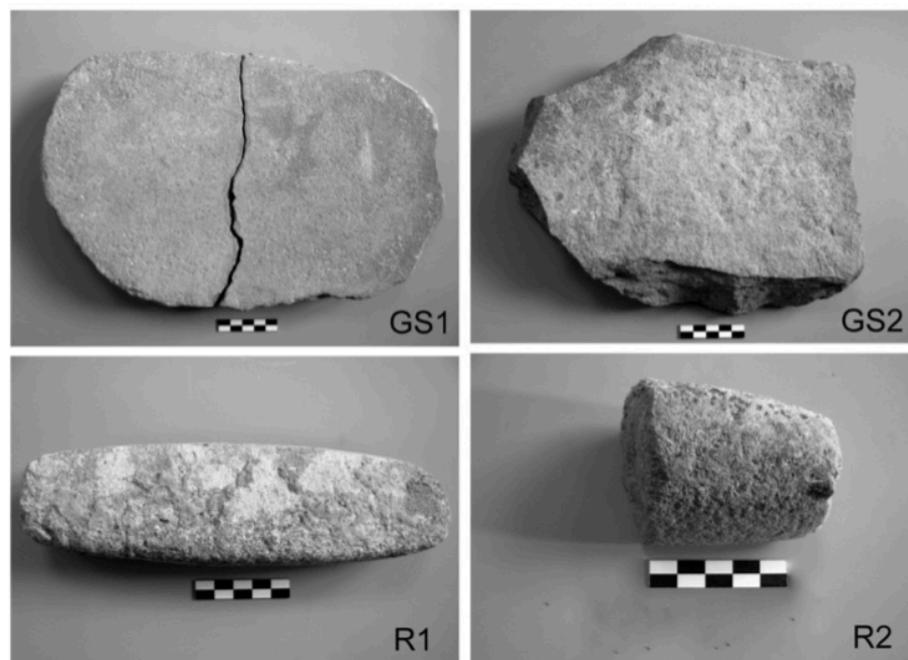


Figure 5.2. Grinding stones from Shizitan Locality 9. Source: Liu et al. (2011).

5.2.2 Daihai Lake

The Shihushan sites are located in the Daihai lake region, which has a MAT of 5.1 °C and a MAP of 423 mm (Xiao et al. 2004). Paleoenvironmental reconstructions of the Daihai lake are based on pollen assemblages recovered from sediment cores (Xiao et al. 2004). Dry and mild conditions ruled from 10.2-7.9 k cal yr BP but got progressively warmer and more humid. At the time, the vegetation was based on arid herbs and shrubs, with *Artemisia* sp.

pollen making from 61.1-75.5% of the assemblage (Xiao et al. 2004). Ephedra and Chenopodiaceae pollen were also high. Arboreal pollen was low, and made up only 20% of the assemblage; the main species were *Pinus* sp., but *Quercus*, *Betula* and *Ulmus* were also present, in lower quantities. From 7.9-4.4 k cal yr BP, warm and humid conditions peaked and the region was covered in mixed coniferous and broad-leafed forests – AP was responsible for almost 70% of the assemblage (Xiao et al. 2004). Herbaceous plants in the assemblage are associated with the *Artemisia* sp. The composition of the species varied in time according to shifts in temperature and precipitation; during colder stages within this period the main species was *Pinus*, but *Picea*, *Abies* and *Betula* trees are a small part of the pollen assemblage; *Quercus* and *Ostryopsis* trees are present in the warmer stages of this period (Xiao et al. 2004). From 4.4-2.9 k cal yr BP, a return to dry and cold conditions is noted and AP is only responsible for 7.4% of the assemblage. *Artemisia* sp., associated with the expansion of grasslands, increased along with Chenopodiaceae shrubs. After 2.9 k cal yr BP, herbs and shrubs' pollen peak, indicating a steppe environment made of *Artemisia* sp., Chenopodiaceae and Gramineae (Xiao et al. 2004).

In the Shihushan localities, *mopans* and *mobangs* with several small depressions across the active surfaces of the tools are found, in addition to regular grinding slabs and handstones and unidentified GSTs (see Figure 5.3). The regular handstones (see R1 and R2 in Figure 5.3) seem similar to Type 2 handstones in the Gobi Desert archaeological collection (elongated handstones without handle). Functional analysis reveals that the Shihushan tools processed a wide range of plants (such as USOs, acorns and grasses) but also other elements (as there is evidence for abrading hard materials, such as stone); starches of USOs (*Trichosanthes kirilowii* roots, *Lilium* sp. bulbs and/or *Dioscorea* sp. and unidentified ones),

grasses (Paniceae and Triticeae), nuts (*Quercus* sp.) and of *Typha* sp. rhizomes were found in the tools (Liu et al. 2014). Despite the fact that millet-based agriculture was already widespread in China at this period, the assemblages show a higher reliance on USOs than cereals (Liu et al. 2014:740).

Group I. Normal grinding stones



Group II. Grinding stones with small depressions



Group III. Grinding stones in special forms



Figure 5.3. Ground stone tools from Shihuashan I and II. Source: Liu et al. (2014).

5.2.3 West Liao River

The Baiyinchanghan site is located in the West Liao River region, on the north bank of the Shar Murun river. The region has a MAP of 350-450 mm and a MAT of 5-8 °C. Pollen analysis revealed a prairie vegetation at the time of occupation (8.4-6.2 ky BP), composed of herbaceous plants, like *Artemisia* sp., and trees like *Birch*, *Pinus* and *Quercus* (Xu et al., 2002).

In Baiyinchanghan, starches from acorns and grasses (*Panicum miliaceum*, *Setaria* sp., *Cyclobalanopsis* sp., *Lithocarpus* sp., *Quercus* sp.) were found in *mopans* and *mobangs* associated with the local Xiaohexi (before 8.2 ky BP) and Xinglongwa (8.2-7.4 ky BP) cultures (Tao et al. 2011; see Figure 5.4). The *mopans* (see Figure 5.4.C and 5.4.D) resemble Type 1 grinding slabs in the Gobi Desert GST assemblage, while the *mobang* (see Figure 5.3.A) resembles Type 2 handstones.

Liu et al. (2016) identified a GST assemblage associated with three different periods at Baiyinchanghan: Xinglongwa (WB90-1, 7480–7310 cal yr BP; WB90-2, 7810–7630 cal yr BP), Zhaobaogou (ca. 7.2-6.4 k cal yr BP) and Hongshan (ca. 6–5 k cal yr BP). These assemblages are more diversified, composed of grinding slabs, elongated handstones (that resemble Type 2 handstones found in the Gobi Desert), pestles and disks (in the period associated with the Xinglongwa culture, tools defined as mortar-slabs are also found) (see Figure 5.5). Use-wear analysis revealed that all tools were multipurpose; the processing of plants (fibrous tubers, cereals, hard materials) and non-plant materials was identified across the three periods. Starches from USOs (including *Trichosanthes kirilowii*, *Lilium* spp., *Dioscorea polystachya*), grasses (Triticeae family, *Coix lacryma-jobi*, *Setaria italica*, *Panicum miliaceum*), and acorns (*Quercus* sp.) were found in all periods. In the tools

associated with the Hongshan culture, acorns and bean (*Vicia* or *Vigna* species) starches were also present.

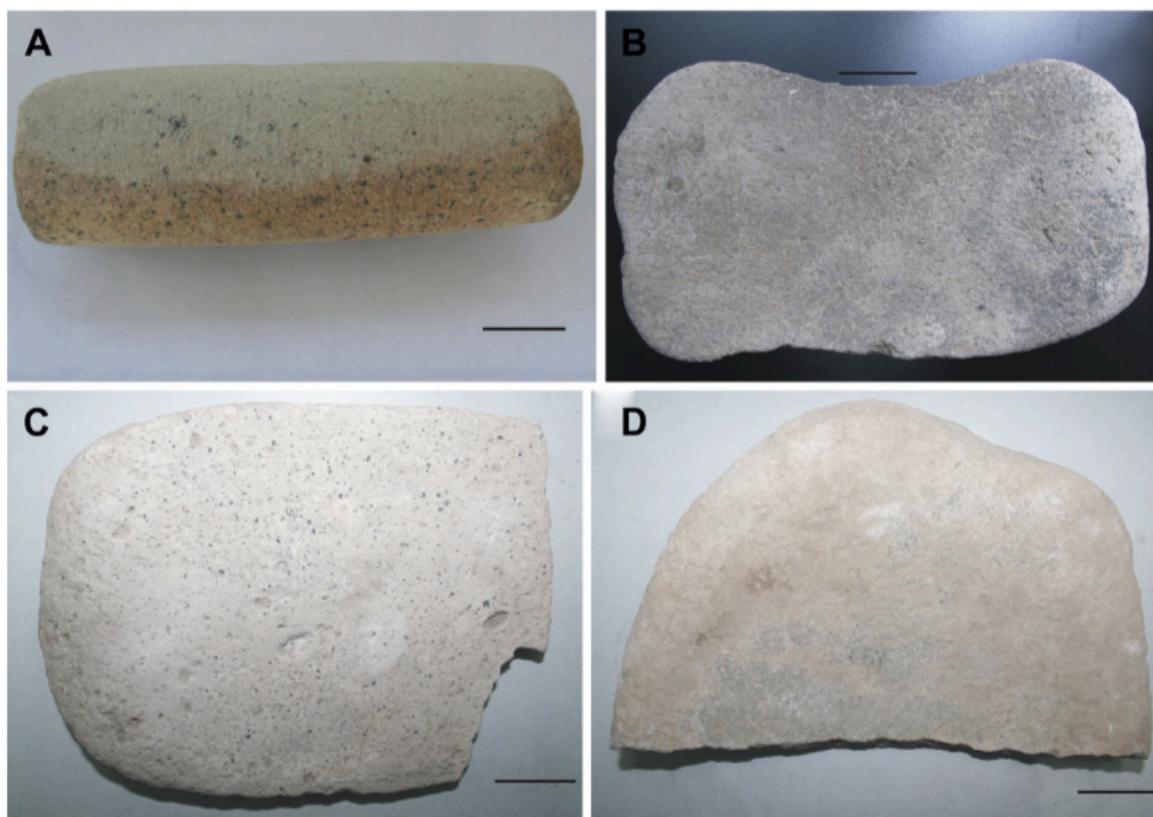


Figure 5.4. Ground stone tools from Baiyinchanghan. Source: Tao et al. (2011).



Figure 5.5. Ground stone tools from Baiyinchanghan. Source: Liu et al. (2016).

5.2.4 Gobi Desert

Research regarding the Neolithic ground stone tools from the Gobi Desert is incipient. Beyond Dubreuil et al. (2021), whose results were already presented in this thesis, additional information comes from Schneider et al. (2016). Grinding implements collected from the surface of four Neolithic northern Gobi Desert sites in the Ikh Nart Nature Reserve

have been analysed: *Ulaan Khad* (Red Rock - Ikh-78), *Burgasny Enger* (Willow Grove Slope - Ikh-28), Ikh-45 and Ikh 2 (Schneider et al. 2016).

The Ikh Nart Nature Reserve has a maximum temperature in the summer of 43°C and a minimum of -40°C in the winter (Schneider et al. 2021). Along water sources, Siberian elm (*Ulmus pumila*) and willow (*Salix ledebourina*) make up most of the available trees (Schneider et al. 2021). In the spring, herbaceous plants such as *Allium* sp., *Artemisia* sp., *Iris tenuifolia*, *Lilium pumilum* and *Heteropappus hispidus* are present in the grassland (Schneider et al. 2021).

Schneider et al. (2016) analyzed 22 GST implements; 19 were made of feldspathic sandstone, two of basalt and one of an unidentified raw material. 15 tools were classified into typological categories: nine milling platforms (which, based on the image, seems to match the Type 2 grinding slab found in the GST assemblage of the AMNH; see Figure 5.6), five handstones (Figure 5.7) and one pestle. The remaining implements were fragmented and not distinguishable between milling platforms and handstones (Schneider et al. 2016). The milling platforms are unifacial tools of rectangular/sub-rectangular outline, with evidence of manufacture in the margins and a flat active surface (matching Type 2 grinding slabs in the AMNH collection). They have an average of 13-11 cm in length, 10-6 cm in width and 2.1 cm in thickness (except from the milling platforms made of basalt, which have an average thickness of 5 cm) - a large platform of 30 x 21 x 2 cm dimensions was also found. The handstones also have a flat surface and were used "with two hands [and] in a reciprocal motion along the greater length of the milling platforms" (Schneider et al 2016:490). Both unifacial and bifacial milling platforms and handstones were found, and some implements seem to have been used in a circular motion.



Figure 5.6. Milling platform collected from *Burgasny Enger* (Ikh-28). Source: Schneider et al. (2016).



Figure 5.7. Handstone collected from *Burgasny Enger* (Ikh-28). Source: Schneider et al. (2016).

The implements from Ikh Nart and the ones analyzed in this study share a few similarities: they have comparable manufacturing techniques, thickness and emphasis on medium to coarse-grained sandstone. The morphology of the implements, however, is

distinct – as the handstone presented in Figure 5.7 seems to retain its natural shape (and all of the implements in the AMNH collection analyzed so far are manufactured).

5.2.5 Conclusion

In relation to the Gobi Desert assemblage, the Chinese *mopans* and *mobangs* have morphological similarities - the grinding slabs are both manufactured into a rectangular shape with an open surface configuration; some of the elongated handstones (particularly the ones from Shizitan 9, Baiyinchanghan and Shihushan I and II) have similar profiles and multiple used surfaces. However, most of the Northern Chinese assemblages show evidence of acorn processing, which has not yet been found in the AMNH tools; in the previous use-wear assessment of the collection (Dubreuil et al. 2021), the implements did not have traces of processing of plants with a high oil content, such as nuts. That is still the case for the sample analyzed in this study, however, more experiments are needed to confirm this absence.

Furthermore, implements associated with acorn processing in the Northern Chinese assemblages often have depressions along the active surface (Liu et al. 2014, 2016) which were not found in the Gobi Desert collection so far (the one on cat. #73/2082C does not have use-wear associated with nut processing, based on comparison with the aforementioned publications). This could be related to the difference in environments, as modern vegetation suggests an absence of nut bearing trees in the Gobi Desert.

5.3 Wild plant-use in the Gobi Desert during the Middle Holocene

As presented in the previous section, plant processing through GSTs has been present in Northeast Asia since the Upper Paleolithic. Some Middle Holocene assemblages that show evidence of wild plant use are found in the Chinese Loess Plateau, the Daihai Lake and the West Liao River. Despite the regional variability in particular species, all those areas saw an increase in forest-related plants at the time; plants associated with wetlands/marshes also appear in the pollen record, as do arid herbaceous species like *Artemisia* sp. The GSTs of those regions have evidence of processing nuts, grasses, cereals, USOs and legumes. Plants found in all assemblages are acorns (*Quercus* sp.), yams (*Dioscorea* sp.), snakegourd roots (*Trichosanthes kirilowii*) and lily bulbs (*Lilium* sp.). Use-wear and residue evidence of legume processing is found in the Shizitan and Baiyinchanghan tools; in the Shihushan sites, starches of marsh-related plants (*Typha* sp.) were identified (Liu et al. 2011, 2014, 2016; Tao et al. 2011).

The pollen assemblages and use-wear/residue evidence support the idea of an expansion of forest-steppe and wetland environments during the Middle Holocene. The same can be said for the Gobi Desert, although plant species are different. The paleoenvironmental reconstruction at Zaara Uul (Janz et al. 2021; Rosen et al. 2022) suggests that at that period plants associated with moist soils, such as reed grasses and sedges, were widespread in the East Gobi region.

Zaara Uul, associated with the Oasis 2 period, is located in the desert-steppe transition in the East Gobi. The sites are distributed between a basin and the edge of a mountain range; differently from most other Oasis 2 sites, which were discovered near

dune-fields and wetlands, Zaara Uul is located ‘at the base of an eroded volcanic cone and adjacent felsite hills’ (Janz et al. 2021:3). GSTs have been found during excavation, but have yet to be analyzed (Janz et al. 2021). Current vegetation is composed of arid-adapted shrubs, such as Siberian peashrub (*Caragana* sp.) and Saltwort (*Salsola* sp.), herbaceous plants like Sagebrush (*Artemisia* sp.), grasses (*Stipa gobica*, *Stipa glareosa*) and wild onions (*Allium polyrhizum*, *Allium mongolicum*) (Rosen et al. 2022). Siberian elm (*Ulmus pumila*) trees are found along water sources (Undarmaa et al., 2015; Rosen et al. 2022:1466).

Geomorphological data from the site reveals stream activity during the Middle Holocene, associated with the strengthening of the EASM. Evidence of the presence of water sources is based on ‘well-sorted stream-channel pebbles, floodplain build-up, and floodplain back-swamp formation from overbank flooding’ (Janz et al. 2021:13). Microbotanical evidence includes phytoliths from *Stipa* sp. grasses, woody shrubs/trees reed grasses and sedges (Cyperaceae) (Janz et al. 2021:15; Rosen et al. 2022:1471-2); the last two are plants that grow in wet environments, such as marshes and streams (Janz et al. 2021:15). The zooarchaeological assemblage also supports the likelihood of forest expansion and increased humidity, as species associates with arboreal vegetation (such as cervids) appear in conjunction with mixed-feeders and grassland species, such as equids (Janz et al. 2021).

The analysis of the GST assemblage presented in this thesis suggests that USOs, legumes and cereals were processed in the Gobi Desert during the Middle Holocene – something attested in other sites from Northeast Asia. Most wild plants used traditionally in Mongolia today (see Chapter 2, Tables 2.2 and 2.3) are associated with arid environments, as is the current condition of the Gobi Desert. However, during the Middle Holocene, the increased availability in water sources influenced fauna and flora composition (Janz et al.

2021; Rosen et al. 2022). Table 19 includes species found in the Gobi Desert that are also associated with forest-steppe, dune-fields and wetland environments. They have known medicinal and/or dietary uses and could account for the use-wear variability noted in the archaeological collection. Further information about their use and distribution is available on Appendix C, which also includes species relevant to those environments that might not have been processed with GSTs (such as fruits, who were consumed raw).

Table 5.1
USOs, legumes and cereals found in forests, wetlands and/or similar environments in Mongolia.

Plant group	Species	Common name	Environment	Parts used	Medicinal use	Dietary use
Underground Storage Organs	<i>Allium senescens</i>	German Garlic	Forests	Bulbs	X	X
			Steppes	Leaves		
			Saline meadows	Flowers		
			Dry slopes with stones and gravel			
	<i>Allium victorialis</i>	Alpine Leek Victory Onion	Forests	Bulbs	X	X
			Streamsides	Leaves		
			Shaded and moist slopes Pastures	Flowers		
	<i>Allium splendens</i>	Korean Ornamental Onion	Forests	Bulbs	X	X
			Meadows	Leaves		
			Scrubs Moist slopes	Flowers		
<i>Lilium pumilum</i>	Coral Lily	Forest margins	Bulbs	X	X	
		Grass-filled slopes				
<i>Potentilla anserina</i>	Silverweed	Wetlands	Roots	X	X	
		Grasslands	Young shoots			
		Mountain slopes Roadside	Leaves			
<i>Rheum altaicum</i>	-	-	Forests Valleys	Roots		X

Table 5.1
Continued.

Plant group	Species	Common name	Environment	Parts used	Medicinal use	Dietary use
Legumes	<i>Caragana arborescens</i>	Siberian	Forest margins	Seeds		X
		Peashrub	Woodlands	Young beans		
	<i>Astragalus mongholicus</i>	Mongolian Milkvetch	Steppes Meadows Coniferous forests Mountain areas	Roots Leaves (possibly) Seeds (possibly)	X	X (possibly)
	<i>Vicia amoena</i>	Vetch	Forests/forest margins Fixed sand dunes Riverbanks Dry slopes Grasslands Hills Wastelands	Seeds Young leaves		X
Cereals	<i>Stipa capillata</i>	Needle Grass	Mountain valleys Plains Rocky slopes	Unknown		
	<i>Calamagrostis pseudophragmites</i>	Reed-grass	Damp grass-filled slopes Riversides	Unknown		
	<i>Calamagrostis macrolepis</i>	-	Grassy slopes Mountain regions Sand-filled areas near rivers Wastelands	Unknown		
	<i>Calamagrostis epigeios</i>	Bush-grass	Damp areas, like riversides	Unknown		
Fruits	<i>Ulmus pumila</i>	Siberian Elm	Valleys Plains Slopes	Leaves Bark Fruits	X	X

This section reviewed some plant species found in Mongolia that are associated with the environments of the Oasis 2 – forest, forest-steppe, wetlands, dune-fields and grasslands. Similar plants are used traditionally in Mongolia, but the particular species and their distributions would have varied through time and under different climatic regimes, with the

HCO being notably wetter and warmer than today. This may have allowed for an expanded range among certain preferred species. Although not all plants had to have been processed with GSTs – several would simply have been consumed raw and/or did not require processing – it is clear that the grinding of roots and other plants was an important part of the diet in Mongolia during Oasis 2.

5.4 Plant processing in the Gobi Desert

Food processing includes several processes, such as grinding, fermenting, soaking and sieving. Each affects the reduced material in different ways – soaking and fermenting are chemical processes, while grinding and sieving affect the physical characteristics of the elements (Stahl 1989:172). Processing through GSTs can have several advantages – it can remove seed husks, crack nuts, facilitate their storage and increase digestibility (Stahl 1989:172).

Another consequence of food processing is that it can modify the nutritional value of foods (Stahl 1989:171; Dubreuil et al. 2023). For some plants, processing might even be a necessary step for consumption. Throughout time, plants developed adaptative responses to survive in competitive environments (for instance, areas with a lower availability of water and nutrients) and fight predators (such as micro-organisms, animals and humans). Plant Secondary Compounds (PSCs) are substances that help their survival by affecting and maintaining their growth, seeding, flowering and attracting or repelling desired/undesired agents (Teoh 2015). Although several PSCs can be positive for humans (as they can have antioxidant, anti-inflammatory, antimicrobial and other such properties), they can also be

negative. Known as Anti-Nutritional Factors (ANF), these substances are considered detrimental to human health as they affect ‘optimum nutrition’ by preventing nutrient absorption, for instance (Bello et al. 2019). Although the ideas of ‘optimum nutrition’ and universal nutritional standards have been debated (Dreze and Sen 1990) and humans can adapt to ‘suboptimal’ conditions, it does not seem to be unreasonable to consider the prevention of nutrient absorption a negative effect. Food processing can reduce the amount of PSCs and, therefore, allow for the consumption of plants that could be otherwise dangerous or ‘anti-nutritional’.

Beyond the reduction of PSCs, grinding can alter nutrient availability by reducing particle sizes, which enhances nutrient digestibility and makes otherwise difficult-to-digest elements more accessible (Stahl 1989; but see discussion in Dubreuil et al. 2023). As the size of the food consumed is directly related to the rate of digestion, grinding increases digestibility by enlarging a particle’s surface area, allowing greater exposure to digestive enzymes (O’Dea et al. 1980; Stahl 1989:173). This logic similarly applies to grinding plant materials before subjecting them to detoxification processes, such as leaching (Stahl 1989:174).

Fibers are examples of elements in which processing can bring positive consequences to the human body. They are challenging to digest - due to their resistance to hydrolysis by human pancreatic enzymes (Stahl 1989:173) - and impact the body’s transit time, which is the period it takes for food to pass through the gastrointestinal tract (Cummings et al. 1976). Some dietary fibers, such as pectin, can increase transit time (van Soest et al. 1978) and result in constipation; others (such as lignin) can reduce it (Payler et al. 1975, Spiller & Amen 1975, Jenkins et al. 1978), but result in the unabsorption of nutrients (as the food

passed too fast in the gastrointestinal tract) (Stahl 1989:173). Furthermore, fibers impact the digestibility of other nutrients by reducing their bioavailability and inhibiting the enzymatic degradation of starch (Jenkins et al. 1980; Camire & Clydesdale 1981; Lee and Garcia-Lopez 1985). By grinding fibrous materials (such as tubers), humans can remove an excess of fiber which could impact negatively their transit time and concentrate certain nutrients, such as starch (Stahl 1989:173).

Most of the species presented in Table 5.1 are known to have been processed according to various culinary preferences, although mostly through cooking. Grinding has been attested for *Potentilla anserina*, *Ulmus pumila*, and the roots of *Rumex acetosa* and *R. acetosella*. While for the first two it was related to the recipe used with the plants (they were dried and ground to make bread, noodles or to be added to other foods), in the case of *R. acetosa* and *R. acetosella* the processing is also related to the presence of ANFs in the plants (DiTomaso et al. 2013; Bello et al. 2019). These sorrels contain oxalic acid and tannins, ANFs that inhibit micronutrient absorption, irritate the digestive system, contribute to kidney stones and stomach problems (DiTomaso et al., 2013; Bello et al., 2019). Sought for their bitter, lemon-like flavor, cooking their leaves was proven to decrease the oxalic acid concentration in the plant (Tuazon and Savage 2013; Vasas et al. 2015; Bello et al. 2019). As grinding was used to process sorrel roots', it likely had the same effect.

The use-wear analysis performed here, as well as previous research on a different sample of tools from the same collection (Dubreuil et al. 2021), attest that the GST assemblage of the Oasis 2 Gobi Desert is closely connected to plant exploitation. As the period is marked by the expansion of wetlands, steppe and forest environments, more plants became available in Mongolia in the Middle Holocene. While most of them could have been

consumed raw and/or cooked, botanical research on the uses of *Potentilla anserina*, *Ulmus pumila*, *Rumex acetosa* and *R. acetosella* has recorded their processing through grinding. Although the use of GSTs can be related solely to culinary preferences (Stahl 1989), some plants have PSCs that might be detrimental to human consumption; processing them can reduce the concentration of such components and make those plants more easily digestible. The following section will discuss the relationship between the adoption of GST technology and an intensification of resource exploitation, particularly of plants.

5.5 Organizational and technological changes in the Oasis 2 and the intensification of plant exploitation

Stahl (1989) argues that food processing can indicate intensification (meaning a higher investment in subsistence efforts) regardless of resource change. The author also uses biochemical data to show the nutritional benefits of grinding (although nutritional decrease may also happen, see Stahl 1989). Hayden et al. (2017) argues against this perspective by stating that the energy spent in processing the plants would be higher than the proposed increased nutrients intakes resulting from grinding. The argument is based on different ethnographic accounts. Hayden and Cannon (1984) stated that amongst the Maya, women spent between 20 to 25 hours a week grinding maize in the 1970s; According to Egziabher et al. (1993), 23 hours a week were dedicated to dry grinding (followed by soaking and wet grinding of maize or barley) for a family of five to seven people in Ethiopia. However, the adoption of GSTs and plant processing may be motivated by values beyond increased caloric consumption. Dubreuil et al. (2023:6) argues that the connection between GSTs and intensification should not be assumed, but demonstrated, and that it is not wise to assume that the adoption of GST technology automatically means a shift towards a more intensive

exploitation of plants. The authors affirm that the *a priori* association of GSTs and plant processing is not universal, as evidence for the processing of alternative resources with GSTs exists (such as animal materials, like flesh and bone, and minerals, such as hematite, ochers and clay/temper for pottery) (Dubreuil et al. 2023:8; see also Adams 2014; Dubreuil and Goring-Morris 2021; Hayden, 1987). It is not wise, therefore, to assume that GSTs are always indicative of plant processing. However, in the Gobi Desert the association of plants and GSTs seems to be reasonable, as no evidence for the processing of other materials (animal or mineral) has been found to this day – but wear related to plant grinding/pounding is present (as demonstrated by Dubreuil et al. [2021] and the results of this thesis). Given their connection with plant processing, these implements could signify an increased investment in time and labor devoted to plant exploitation, as their use encompasses several stages (from the acquisition of raw material and plants, manufacture of tools and subsequent processing) that are time and labor consuming.

The environmental and technological changes of the Oasis 2 need to be taken into consideration to assess if the implements reflect a diet breadth expansion and/or diversification in use of plant resources. As discussed previously, not all plants require processing to be consumed – and even those do, might not necessarily be processed through GSTs (but through cooking, fermentation and soaking, for instance). Therefore, one could not argue that the plants associated with GSTs (based on the results of this study: USOs, legumes and cereals) were not consumed in previous periods. However, the scarcity of GSTs in previous periods of the Gobi Desert could suggest that those plants were not processed through grinding/pounding as often as they were during Oasis 2 – or, at the very least, not through the same strategy. Although GSTs alone cannot indicate diet breadth expansion, they

can indicate an adoption or development of new food processing techniques. Discussing diet-breadth expansion could be done when connecting this diversification of plant-processing strategies with the environmental and cultural changes of the period (regarding settlement patterns and technologies). During Oasis 2, the vegetation distribution of the Gobi Desert altered significantly due to the HCO (Janz 2016, Janz et al. 2017). Despite the fact that it cannot be argued that USOs, legumes and cereals were not consumed prior to Oasis 2 (which is highly unlikely), it is plausible that the plants exploited changed, as the vegetation altered.

The first two research questions of this study addressed the function of the GSTs, their association with particular types of plants and whether they could indicate an intensification of exploitation of resources of particular Oasis 2 environments (such as forest-steppes, dune-fields and wetlands). I hypothesized that the function of the GSTs was related to wild plant processing and, since these implements are largely restricted to the Oasis 2 period - which is singular in terms of vegetative diversity -, the adoption of such plant processing technology could be connected to the resource changes. The results of my analysis show that the tools were indeed processing wild plant resources, and that use-wear related to USO processing was prevalent, followed by legumes and cereals. Currently, there is no evidence to suggest that the implements were either used to process meat, wood or minerals, or that one tool was used to process multiple materials (however, more experiments are needed to confirm the latter).

As an identification on the species level is not possible with use-wear analysis, we do not have a definitive answer as to what particular plant communities (e.g., forests, forest-steppes, wetlands and/or dune-fields) were being exploited. However, the GST

assemblage found in the Oasis 2 does have a particular configuration (in terms of size, morphology and variety of implements) that is not seen in later periods (Janz 2012; Janz et al. 2017). The implements of this period are bigger (which affects their portability) and more formal (in terms of manufacture and specific morphologies) than later GSTs found in the Gobi Desert. This configuration could be connected to the settlement patterns of Oasis 2, in which there appear longer term residential sites associated with dune-fields and wetlands (Janz 2012; Janz et al. 2017). As the Oasis 2 GSTs are often found in those sites (Janz 2012; Janz et al. 2017; Dubreuil et al. 2021), the reduced mobility and/or reoccurring occupation associated with them, in addition to the reliability of resources in those environments, could have influenced the choice for the morphological characteristics of the tools. If resources were reliable and there was less need for transporting the tools to another area (since people were staying at those places for longer and/or returning to them), a higher time investment in the manufacture of the tools might have been justified due to their long-term curation. Having tools with a wide active surface means that you can process a higher volume of materials at a time, but big tools are usually heavier and more difficult to move. A return to increased residential mobility could have influenced a reduction in the size of and investment in GSTs during Oasis 3 (Janz 2012; Janz et al. 2017).

5.6 Conclusion

The adoption of GSTs and other technologies (such as adzes and axes) in the Gobi Desert during the Oasis 2 period has been suggested to reflect the adaptation of the inhabitants of the region to the new environment that emerged after the HCO. The expansion of forests, forest-steppes and wetlands during the Middle Holocene is hypothesized to have resulted in a change in diversity of plant species in that region, and technologies adapted to

their exploitation show the Gobi Desert populations' adaptation to that new diversity (Janz 2016). Evoy (2019) demonstrated an investment in tools associated with the exploitation of arboreal vegetation – her use-wear analysis in the axes and adzes of the Gobi Desert showed that their main function was connected to woodworking, although they were also used in hide processing.

The use-wear analysis results of the Gobi Desert GSTs cannot demonstrate that the tools were used to process resources of forested or wetland environments without identification of the plants at the species level. However, the juxtaposition of environmental change and the ubiquity and morphology of GSTs in Oasis 2 sites, does support the idea of more intensive exploitation of vegetative resources at the period.

One of the research questions of this thesis regarded the suitability of the Oasis 2 GST assemblage as a data source for micro-botanical studies. I hypothesized that they could be used in residue analysis, provided an assessment of contamination was performed to ensure that the remains found were archaeological, and not modern. The analysis of the experimental tools (see Appendix A) shows that the flour resulting from grinding can be widespread on a tool – beyond the active surface – and that the starches associated with them are often damaged. The exploratory residue analysis conducted in this study used progressive sampling in search of archaeological starches, and found that the starches recovered from these tools were mostly damaged (25 out of 32). The analyzed implements yielded low (up to 5 per slide) and moderate (more than 5 per slide, but single and isolated) amounts of starches. Some tools (3 out of 7) had starches in their breakage surface (which could indicate contamination), but the rest only had starches in the active surface (which would be less likely to be resulted from contamination). These results indicate that the Gobi Desert

collection could be suitable for micro-botanical studies, although some implements are likely contaminated, and the tools have not yielded high amounts of starches. As there are not many excavated GST implements from the Gobi Desert, the implements from the museum collection can provide useful information not otherwise available.

Regarding the limitations of this study, acquiring native plants from the Gobi Desert was not possible for this study; therefore, the reference collection relied on domesticated cereals and legumes as a proxy. Some future research suggestions include increasing the reference collection (in terms of species), which will enhance the range of use-wear variability and the confidence level of the analysis. Additionally, experimenting with native wild plants (when possible) would allow for the addition of their micro-botanical remains to the residue reference collection. Another useful addition to the reference collection would be processing different parts of the same plant; as multiple parts of plants can be used and ground, having experiments with seeds, tubers, rhizomes and/or roots of the same plant might allow for more specific identification of use-wear. Experimenting with granite implements would also be helpful, as they compose part of the upper tool assemblage; as the reference collection has focused on sandstone implements so far (they are most prevalent in the archaeological record of the Gobi Desert), experiments on granite were not performed but are necessary to assess use-wear variability on handstones made of this raw material. Furthermore, additional analysis could test the preliminary finding that particular tool types were unconnected to processing of specific plants - a wider sample could change those findings. Regarding the time and energy investment into the manufacture of the archaeological tools, attempting to reproduce the morphological types of the implements

might give some insight on the matter, which is useful to discuss ‘intensification’ (in terms of energy expenditure and nutritional intake).

In terms of the contribution of this study, the use-wear data provided can be used as a reference for future research that investigates the formation of wear patterns related to the grinding and abrading of multiple materials, including plants, animals and minerals. Furthermore, it provided an insight into strategies of plant-use adopted in the Gobi Desert during the Middle Holocene. The information discussed in this study contributes to the research on Holocene foragers' adaptations to environmental changes and functional studies of GSTs, with particular focus in the Gobi Desert.

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Appendix A

Residues analysis of the ‘Gobi Desert’ experimental collection (Laure Dubreuil)

1. Protocol

The experimental tools were observed at various magnifications through incident light microscopy (before and after washing) to record and describe the occurrence of residues of the matters processed. Samples were also taken for observation under transmitted light polarized microscopy. This appendix focuses on this second set of analysis, which was done using a Leica DM500 microscope (40× to 400×) equipped with a Leica ICC50 W camera.

The samples were taken on active surface of the tools, and on at least one of the unused surfaces. Two methods of sampling, pipette and toothbrush extraction, were initially compared. Following this exploratory phase, pipette extraction was used because it appeared easy to implement and it lowered the amount of mineral fragments present in the sample. It was also found that for better accuracy, a minimum of two slides per surface should be analyzed.

Different staining products were tested: Tripan blue for starch, Congo Red for cellulosa and damaged starches, Orange G and PSR for collagen. For comparative purposes, the ground

products were also observed under transmitted light microscope. The descriptive system under the polarized microscope is presented in Table A.1.

Table A.1
Recording system for the observations under the polarized microscope.

MICRO RESIDUES - TRANSMITTED LIGHT	
<i>Starch analysis</i>	
Presence absence of starch and relative abundance <i>Very high – numerous starches on 1 field of view</i> <i>High – present in each field of view or with clusters with numerous starch</i> <i>Moderate – present on the slide up to 5</i> <i>Low – present less than 5</i>	
Size and morphology <i>Rounded, oval or polyhedral starch granules; Bimodal starch granules; Very small circular starch granules</i>	
Starch alterations <i>Breakage; Cracks – opening; Deformation; Loss of birefringence</i>	
<i>Plant tissues</i>	
Presence/absence and abundance <i>Very high – numerous residues on 1 field of view (at '40); High – present in each field of view or with clusters; Moderate – present on the slide more than 5; Low – present up to 5</i>	
Opacity <i>Opaque/translucent</i>	
Patterns <i>Parallel fibers, ladder like, grid like, honeycomb, angular (crystal-like fragment) random</i>	
<i>Fibers</i>	
Presence/absence and abundance <i>Very high – numerous residues on 1 field of view (at '40); High – present in each field of view or with clusters; Moderate – present on the slide more than 5; Low – present up to</i>	
Size and morphology <i>Short/long</i> <i>Twisted or not, opaque or translucent</i>	
<i>Staining observation</i>	
Stains tested and observations <i>Rhodamine B, PSR, Lugol, Congo Red, Phloroglucinol, Orange G</i>	

2. Preliminary results

While part of the residues analysis of the experimental collection remains to be completed, a few conclusions can be drawn from the data gathered so far. The following preliminary results have informed the analysis of the archaeological sample carried out in this thesis:

- A. Fibers are often found in the samples extracted from the tools. Very commonly, these include fibers that were not part of the processed matter. Our analysis suggests that fibers contamination should be regarded as prevalent.
- B. Residues of the matter processed are found on various parts of the tool and are not strictly associated with the active surface. Regarding starches for instance, their abundance is not necessarily higher on the active surface compared to others. The presence of starch on 'non active' parts may also be related to the utilization of the tool. Therefore it seems more appropriate to use breakage plan as control for contamination rather than the non-active surfaces.
- C. Several types of alterations were observed on the starches (see Table A.2 and Figures A.1 to A.3), some affecting their birefringence, that can hinder their identification but also may be used as evidence of plant processing.

Table A.2**Starch presence, type and alteration for a sample of plant matters processed.**

<i>Plant material and sample type</i>	<i>Starch presence and types</i>	<i>Starch alterations</i>
Rhubarb flour	Small rounded	x
Grinding rhurbab (tool samples)	Small rounded and polyhedral	Ü deformed shape, some 'open' internal breakage and loss of birefringence (Figure A.1)
Soybean flour	Bimodal rounded with internal cross or middle groove	x
Grinding soybean (tool samples)	Bimodal, rounded and oval	x
Mung bean flour	Bimodal, rounded and oval	Ü cracked open and deformation (Figure A.2)
Grinding mung bean (tool samples)	Bimodal, rounded and oval	Ü cracked open and some with a split in the middle, deformation and loss of birefringence (Figure A.3)
Lily bulb flour	X (no clear starch)	-
Grinding Lily bulb (tool samples)	Small oval and rounded, some without internal cross, some with concentric circle	x

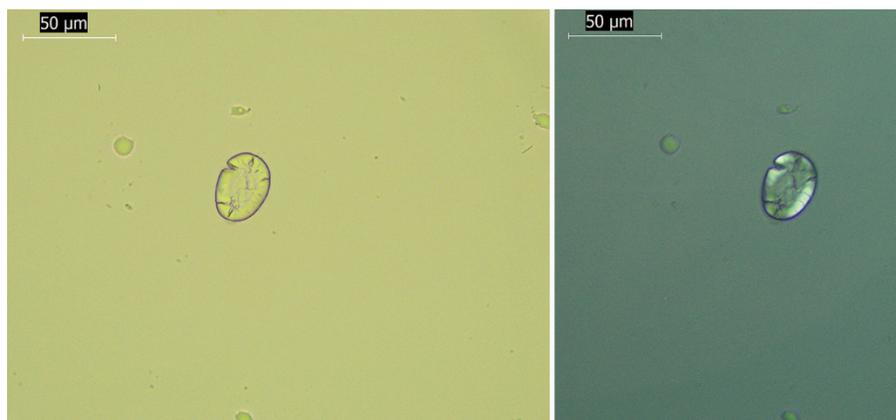


Figure A.1. Rhubarb grinding, starch from upper tool (opposite surface): crack, deformation and loss of birefringence

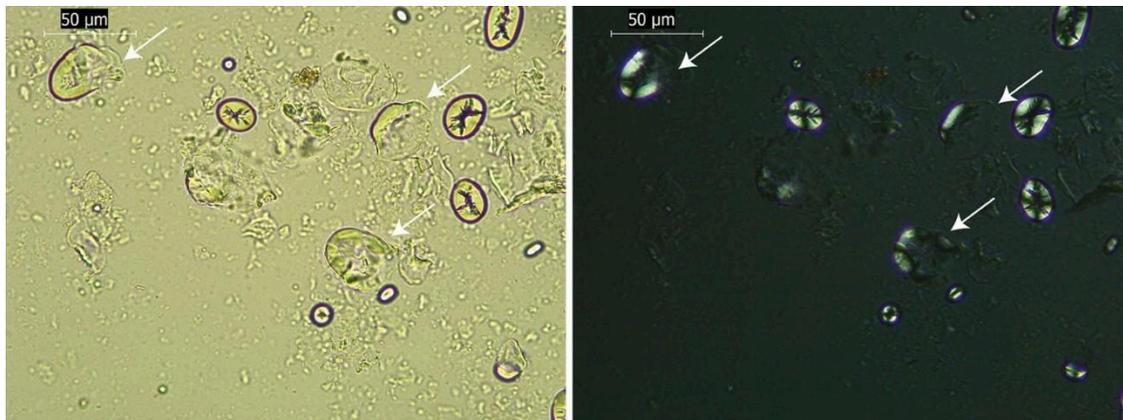


Figure A.2. Mung bean flour, deformed and crack opened starches.

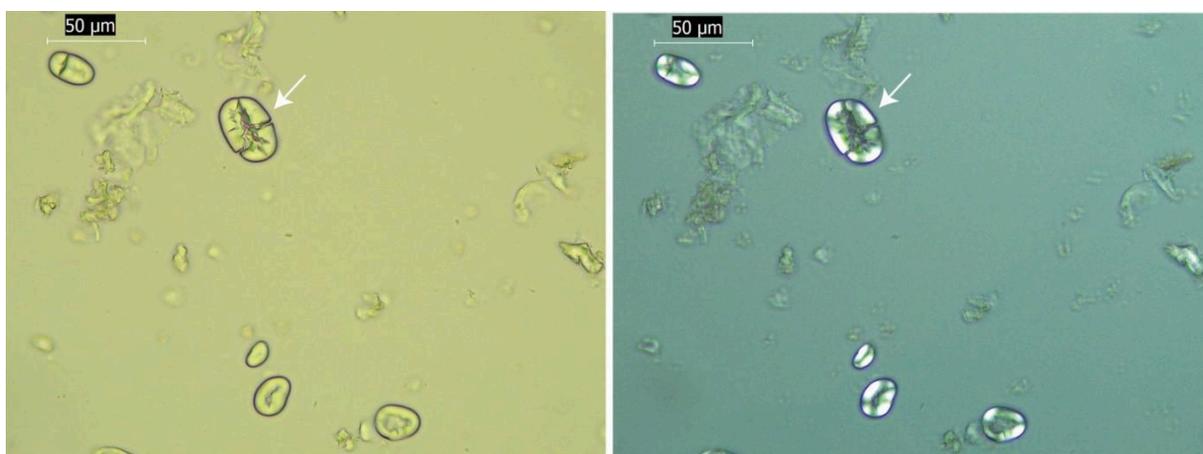


Figure A.3. Cracked starch on Mung bean upper grinding tool (opposite surface).

Appendix B

Starch granules recovered from archaeological tools with sufficient use-wear preservation

Table B.1
Starch counts and preliminary morphological description.

Type	Tool	Area and sample	Count and Relative abundance	Morphology and damage
Grinding slabs	Cat. #73/2078	Active surface, interior sample	Low (n= 3)	1 polyhedral
		Active surface, exterior sample	Absent	1 oval
		Breakage, interior sample	Absent	1 rounded All damaged
Type 1 Elongated handstone with handle	Cat. #73/2088F	Active surface, interior sample	Low (n= 1)	Interior sample Oval elongated, no damage
		Active surface, exterior sample	Absent	
		Breakage, interior sample	Low (n= 3)	Breakage 2 oval elongated, damaged 1 very small, circular, damaged
Type 2 Elongated handstone without handle	Cat. #73/2088E	Active surface, interior sample	Low (n= 2)	Oval
		Active surface, exterior sample	Absent	Polyhedral
		Breakage, interior sample	Absent	No morphological damage but loss of birefringence
Type 2 Elongated handstone without handle	Cat. #73/2243A Cat. #73/2243B Cat. #73/2747	Active surface, interior sample	Absent	
		Active surface, interior sample	Absent	
		Active surface 1, interior sample	Moderate (n= 5)	Active surface 1 1 elongated oval, damaged 1 rounded, no damage 3 too damaged to assess
Type 2 Elongated handstone without handle	Cat. #73/2088E	Active surface, interior sample	Low (n= 2)	Active surface 2 1 elongated oval, damaged 1 small circle, no damage
		Active surface, exterior sample	Low (n= 1)	Active surface, interior sample 1 polyhedral, morphological deformation and loss of birefringence

Table B.1
Continued.

Type	Tool	Area and sample	Count and Relative abundance	Morphology and damage
Type 3 Oval handstone		Breakage, interior sample	Moderate (n= 5)	1 too damaged to assess morphology
				<i>Active surface, exterior sample</i>
				Too damaged to assess morphology
				<i>Breakage</i>
				4 too damaged to assess morphology, 1 of which has lost the birefringence
				1 small circular
Type 3 Oval handstone	Cat. #73/2085C	Active surface, interior sample	Absent	
	Cat. #73/2085D	Active surface, interior sample	Absent	
	Cat. #73/2085E	Active surface, interior sample	Absent	
	Cat. #73/2528	Active surface, interior sample	Absent	
	Cat. #73/2083B	Active surface, interior sample	Low (n= 3)	<i>Active surface</i>
		Active surface, exterior sample	Absent	2 too damaged to assess morphology
		Breakage, interior sample	Low (n= 1)	1 rounded and damaged
				<i>Breakage</i>
				Too damaged to assess morphology
				<i>Active surface</i>
Type 4 Rectangular handstone	Cat. #73/2083C	Active surface, interior sample	Low (n= 3)	1 rounded with diffuse outlines and loss of birefringence
		Active surface, exterior sample	Low (n= 1)	1 elongated with morphological damage and loss of birefringence
		Breakage, interior sample	Absent	1 too damaged to assess morphology
				<i>Breakage</i>
				Polyhedral and damaged
Type 4 Rectangular handstone		Active surface, interior sample	Absent	

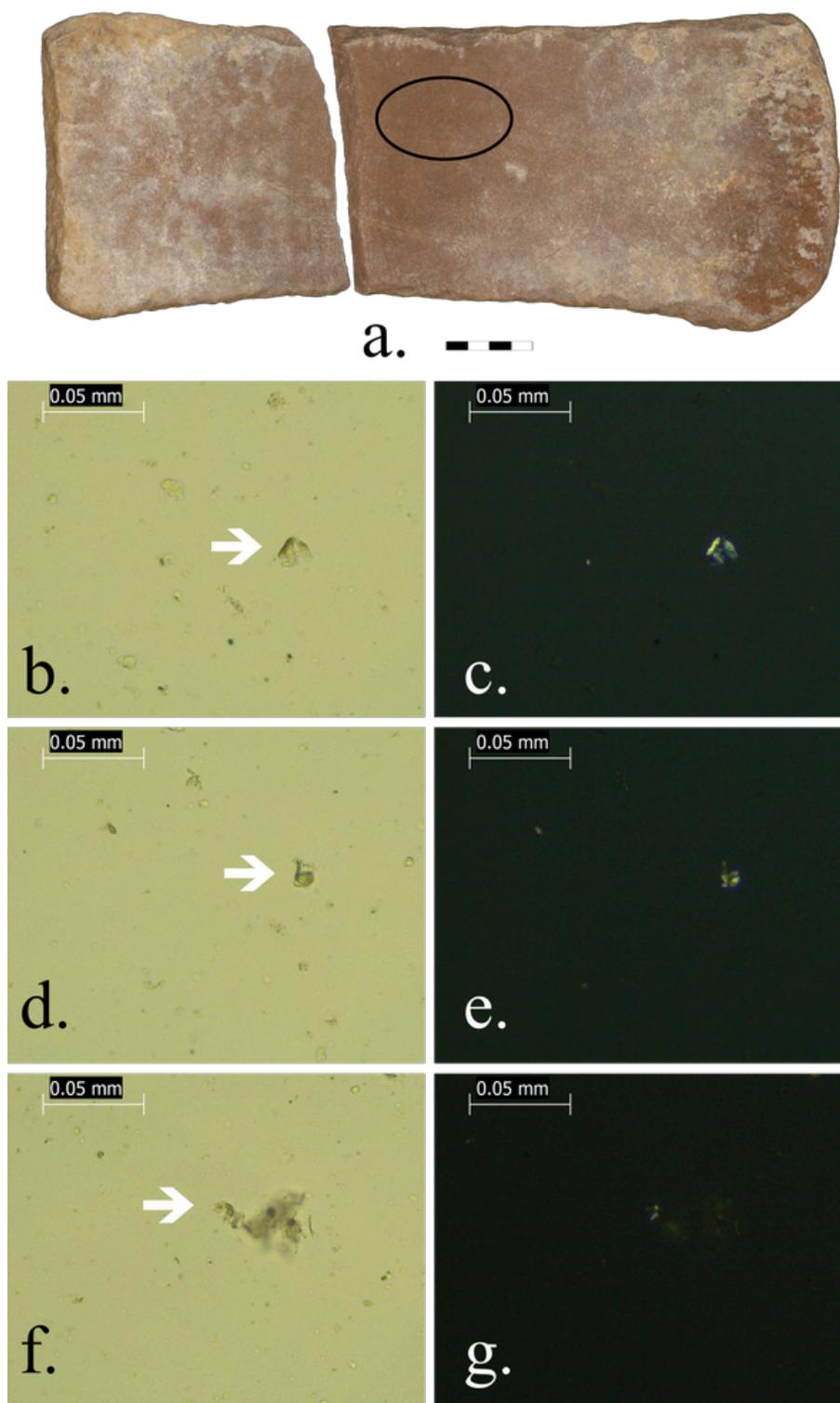


Figure B.1. Starch granules identified on the active surface of Cat. #73/2078; a) Sampled area on the tool; b, c) Polyhedral starch grain damaged without (b) and with polarized light (c); d, e) Rounded starch grain damaged without (d) and with polarized light (e); f, g) Oval starch grain damaged without (f) and with polarized light (g).

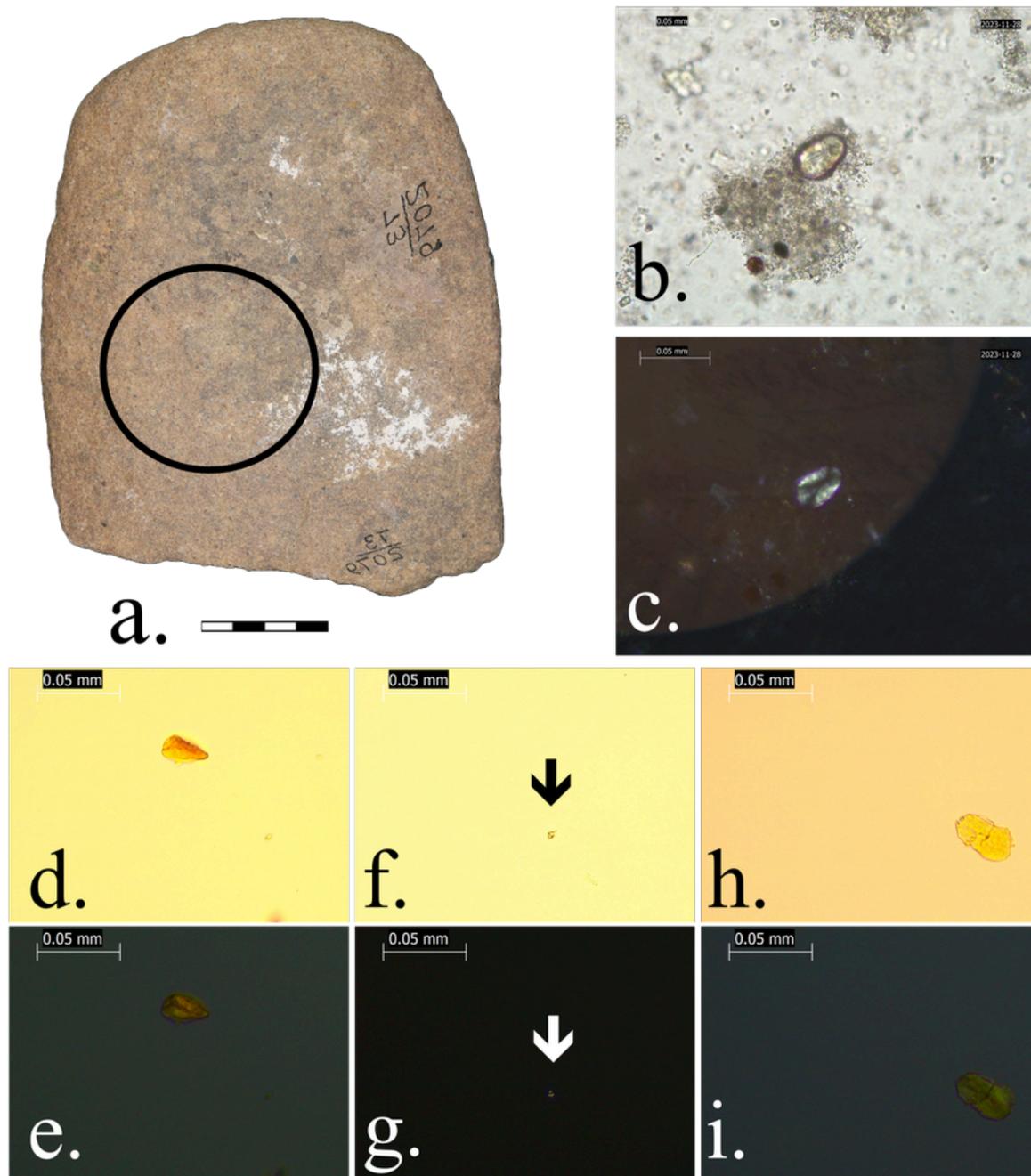


Figure B.2. Starch granules identified on Cat. #73/2079; a) Sampled area on the active surface of the tool; b, c) Oval elongated starch grain collected from the active surface, identified by Dr. Monica Ramsey (RLEA - University of Toronto) as belonging to the Fabaceae family - without (b) and with polarized light (c); d-i) Starch granules from the breakage area of the tool without (d, f and h) and with (e, g, i, respectively) polarized light.

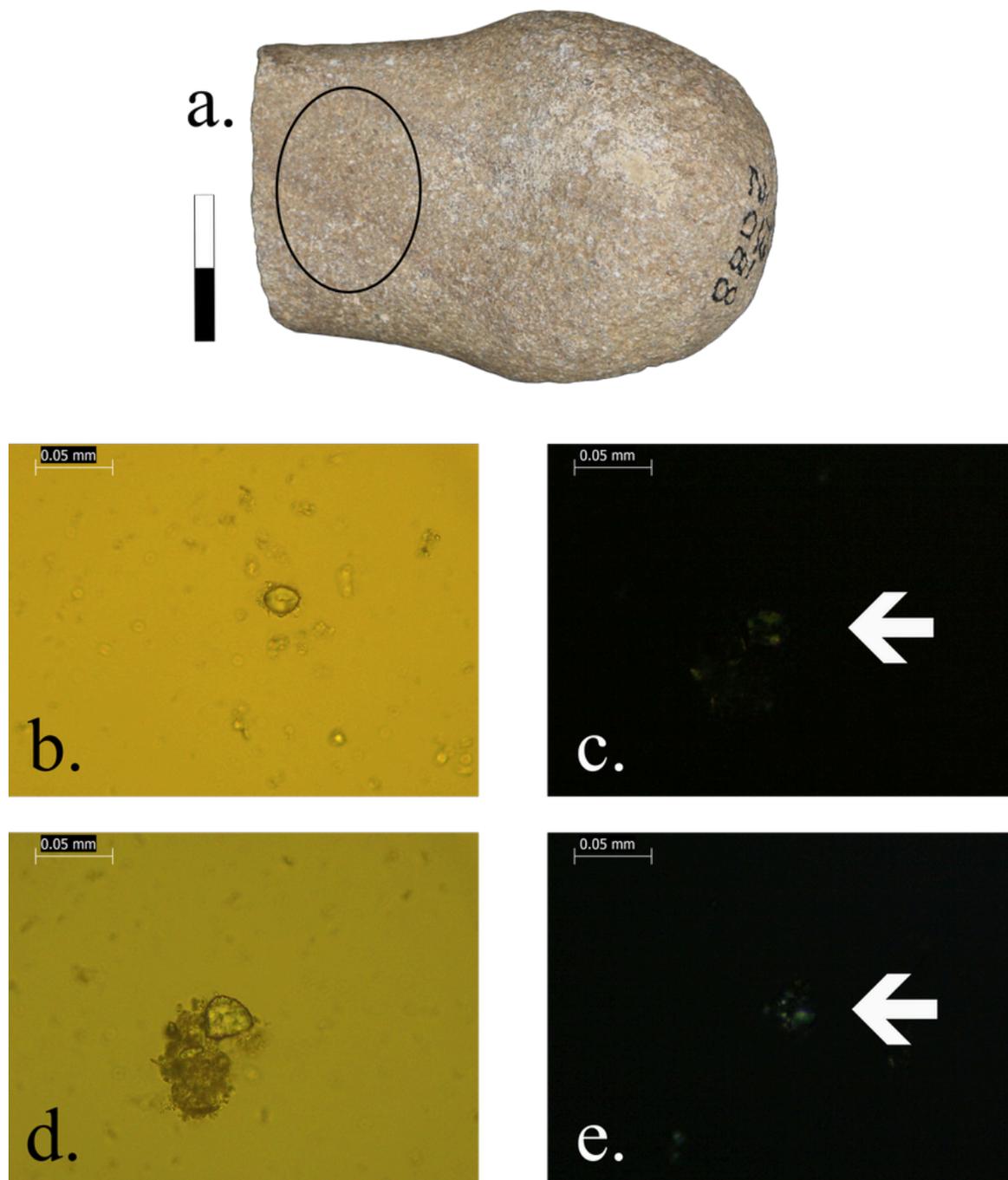


Figure B.3. Starch granules identified on the active surface of Cat. #73/2088F, both with damage associated with the loss of birefringence; a) Sampled area on the active surface of the tool; b, c) Oval starch grain without (b) and with polarized light (c); d, e) Polyhedral starch without (d) and with (e) polarized light.

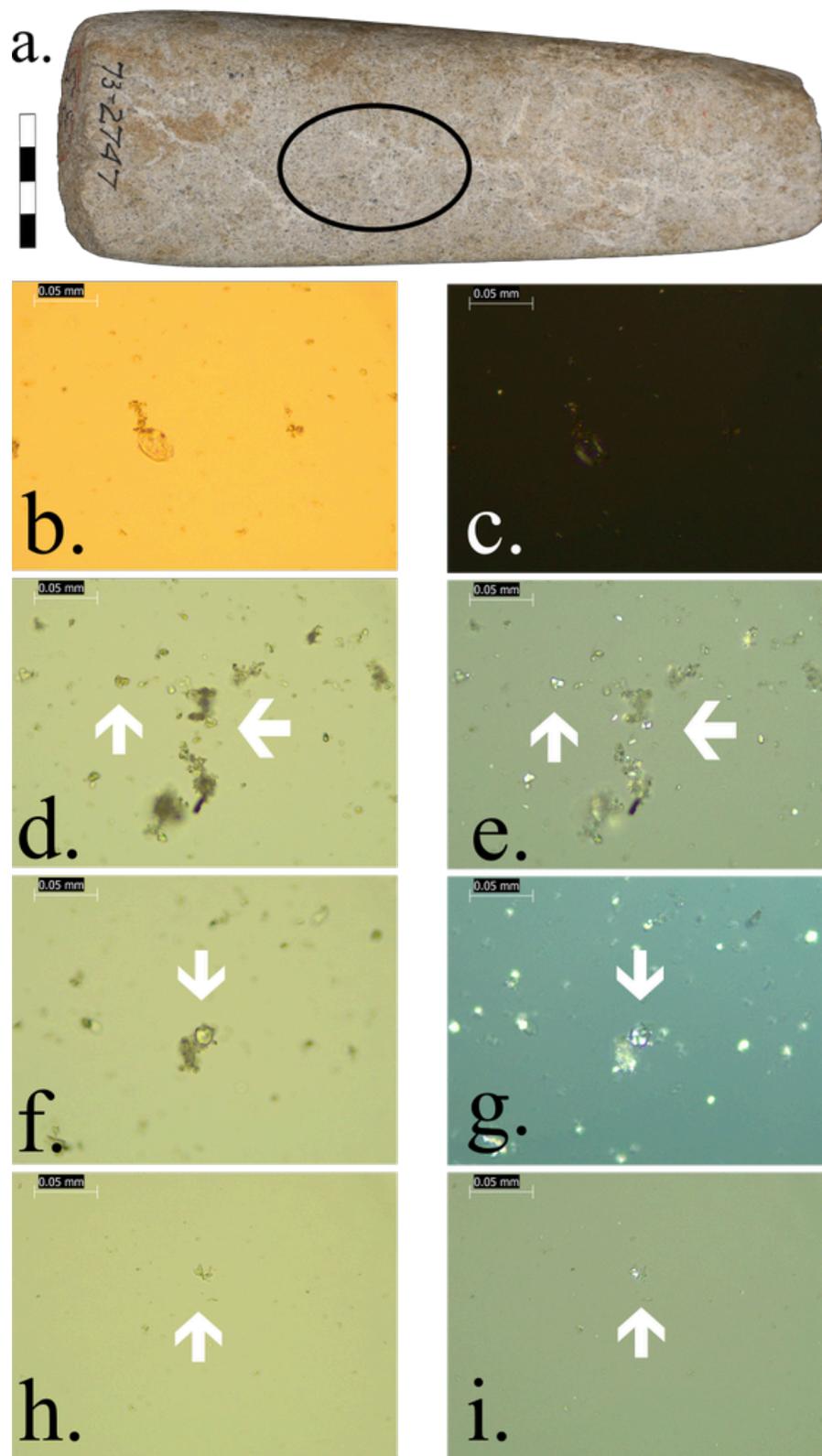


Figure B.4. Starch granules identified on the first active surface of Cat. #73/2747, a) Sampled area; b, d, f, h) Starch granules without polarized light; c, e, g, i, respectively) Starch granules with polarized light.

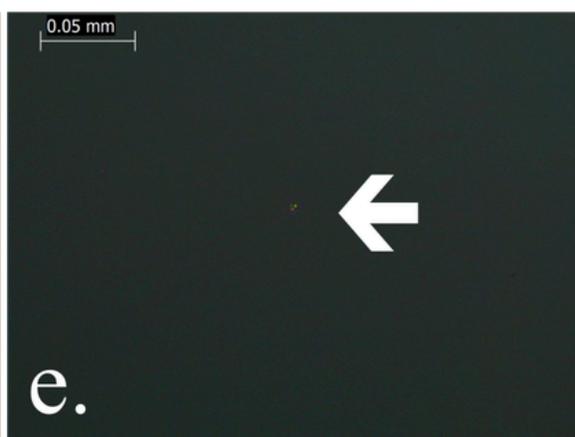
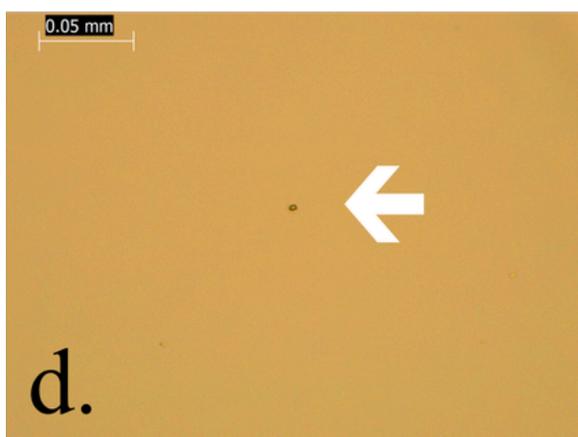
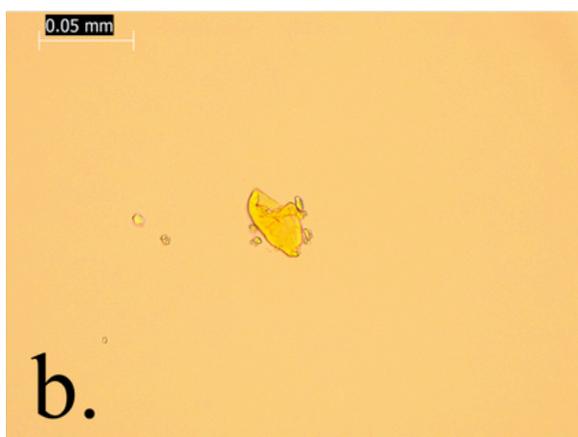


Figure B.5. Starch granules identified on the interior sample of the second active surface of Cat. #73/2747; a) Sampled area; b, d) Starch granules without polarized light; c, e, respectively) Starch granules with polarized light.

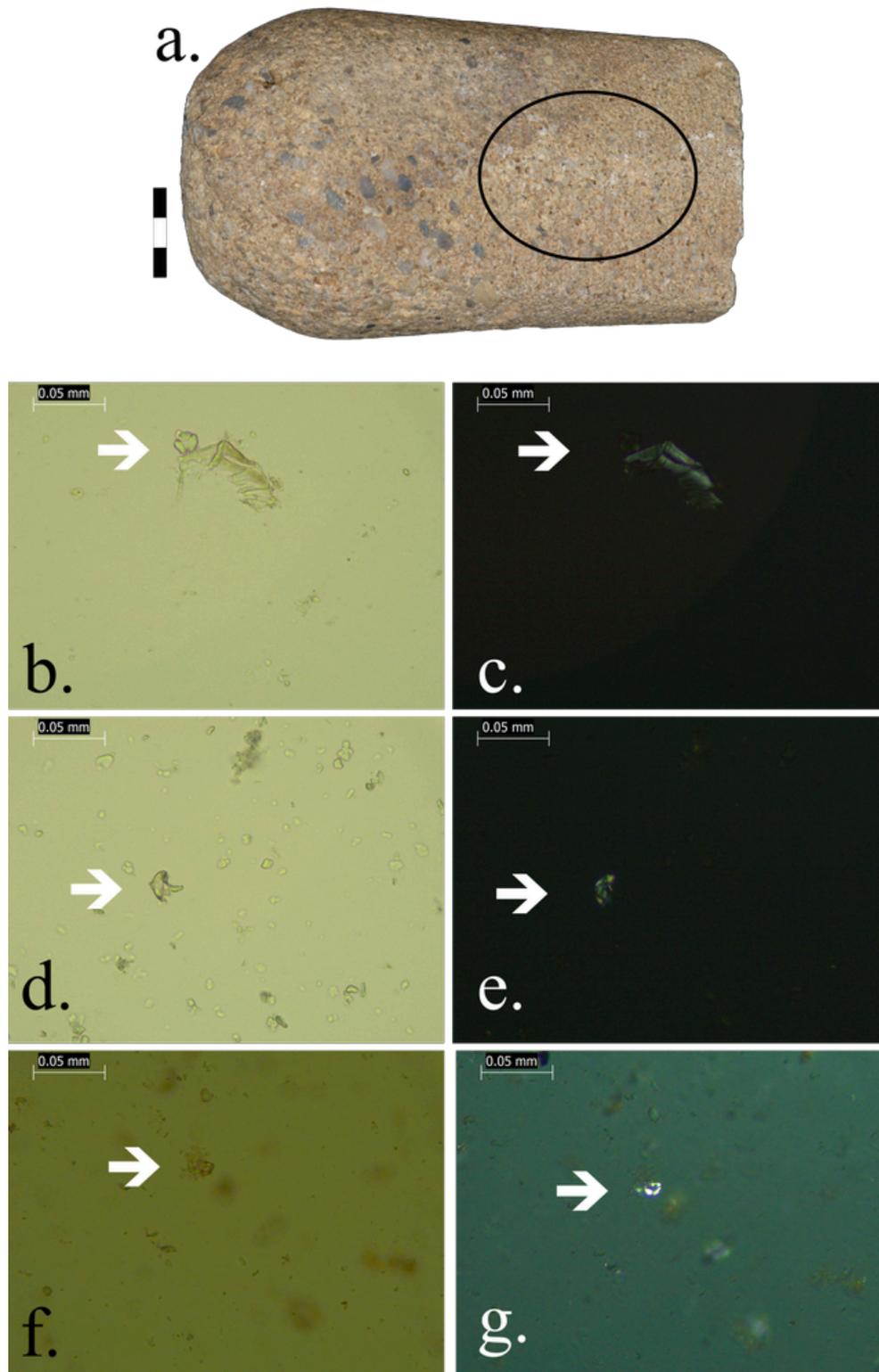


Figure B.6. Possible starch granules identified on the active surface of Cat. #73/2088E; a) Sampled area; b, c) Starch grain without and with polarized light; d-g) Possible starch granules (require further assessment).

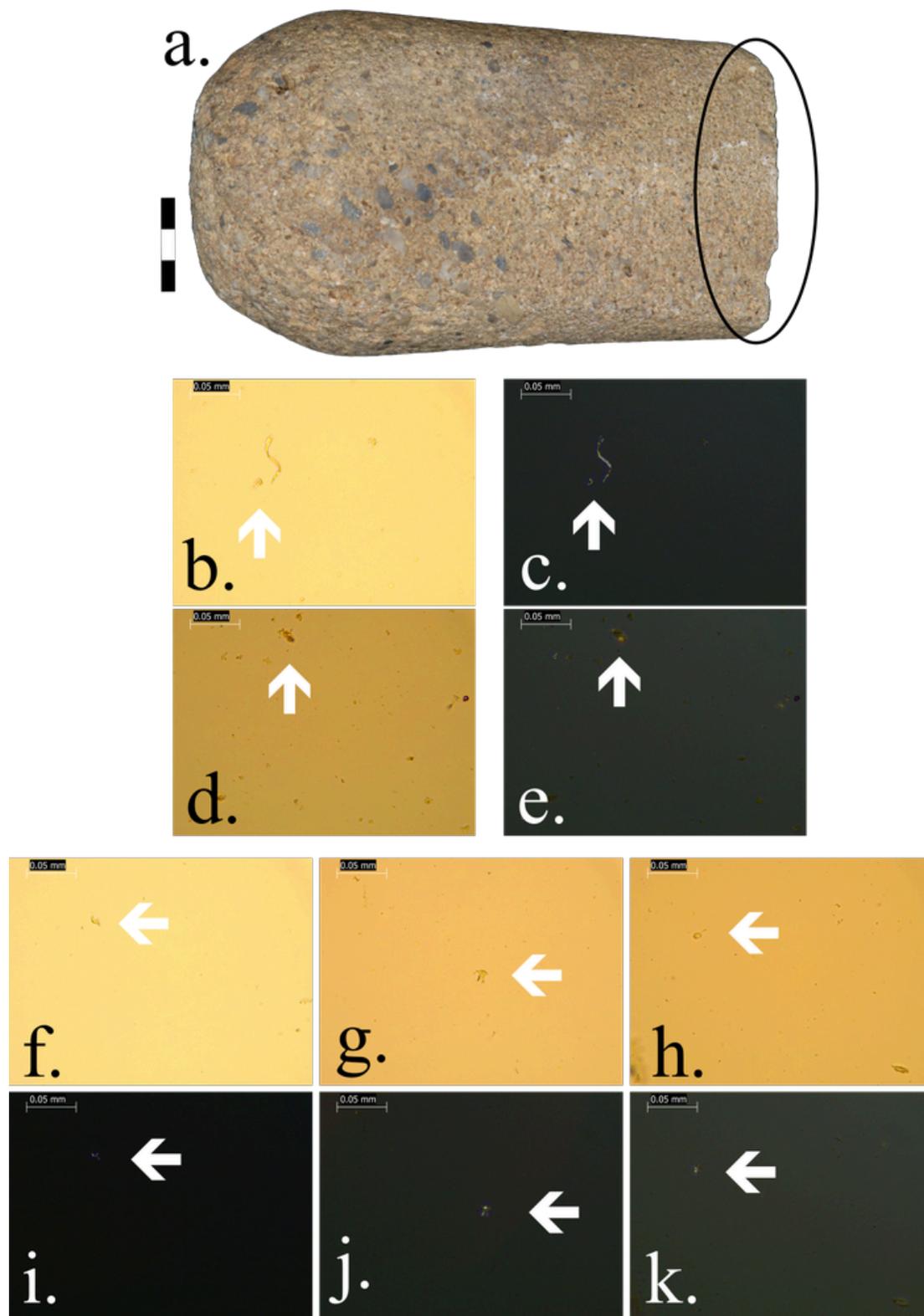


Figure B.7. Possible starch granules identified on the breakage surface of Cat. #73/2088E; a) Sampled area; b-k) Possible starch granules without (b, d, f, g, h) and with (c, e, i, j, k, respectively) polarized light (need further assessment).

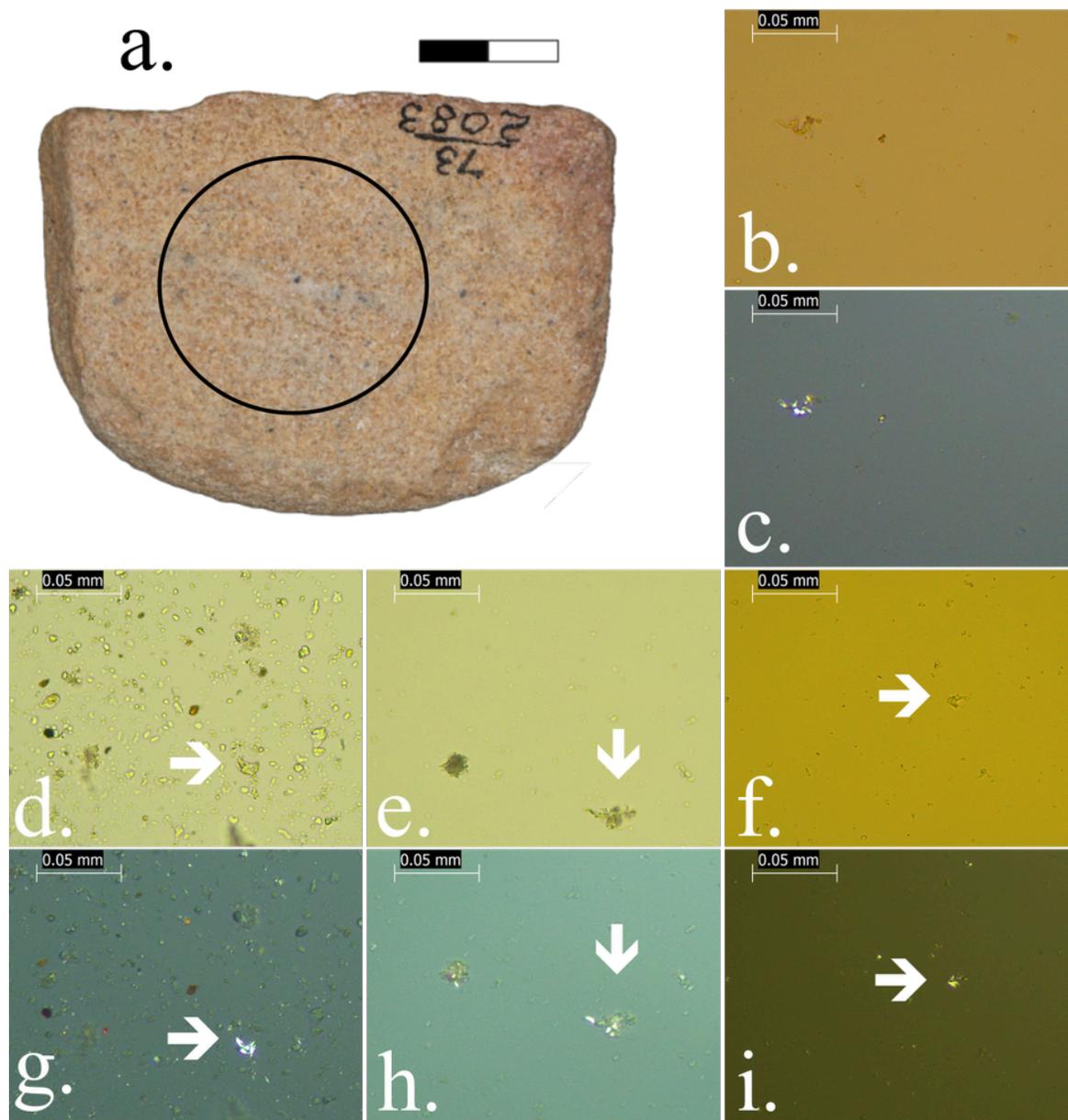


Figure B.8. Starch granules identified on Cat. #73/2083B; a) Sampled area on the active surface; b, c) Starch grain from the breakage surface without (b) and with (c) polarized light; d-h) Starch granules from the active surface of the tool without (d, e) and with (g, h) polarized light; f, i) Possible starch grains recovered from the active surface (need further assessment).

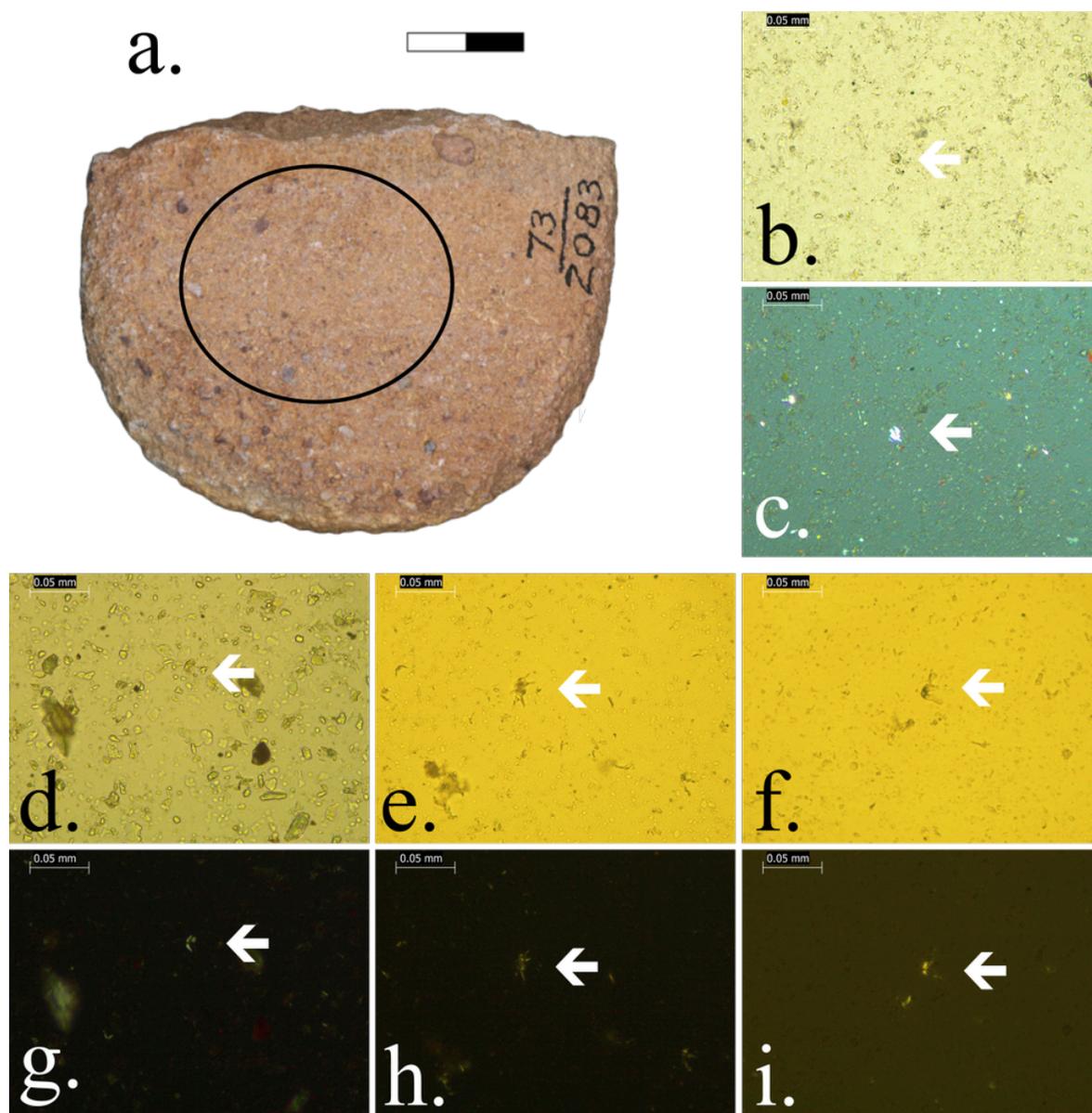


Figure 9. Possible starch granules identified on the active surface of Cat. #73/2083C; a) Sampled area; b, i) Starch granules without and with polarized light (require further assessment).

Appendix C

Use of forest-steppe, wetland or dune-field plants in Mongolia

Underground Storage Organs

Some of the current species that grow USOs with known uses and that are also found in forests, forest-steppe, wetlands and/or dune fields in the Gobi Desert are *Allium* sp., *Lilium* sp., *Rheum* sp., *Rumex* sp., *Potentilla* sp. and plants from the Cyperaceae family.

The genus *Allium*, from the Amaryllidaceae family, has over 200 species in Asia and is used as food and medicine worldwide. The species associated with forests and/or wetland areas (such as moist slopes and meadows) are *A. senescens* (known as the German Garlic), *A. victorialis* (known as Alpine Leek or Victory Onion) and *A. splendens* (known as the Korean Ornamental Onion). In the Asian continent they are found in Mongolia, China, Korea and Russia (but *A. victorialis* is also present in India, Japan and Kazakhstan) (Wu et al. n.d.). The bulbs, leaves and flowers of these *Allium* variants are consumed both raw and cooked (Uphof 1959; Hedrick 1972; Usher 1974; Tanaka 1976; Reid 1977; Sholto-Douglas 1978; Kunkel 1984; Brooklyn Botanic Garden 1986; Davies 1992). The stems of *A. victorialis* are also used as food in Japan (Brooklyn Botanic Garden 1986).

Commonly throughout Northeast Asia, the genus *Lilium* is composed of herbaceous, bulbous plants that have both dietary and medicinal uses. *L. pumilum* (known as Coral Lily), found in the margins of forests and in grass-covered slopes, is distributed in Mongolia, China, Korea and Siberia. Its starchy bulbs have culinary value and are consumed cooked or dry (Uphof 1959; Komarov 1968; Usher 1974; Tanaka and Nakao 1976). Coral Lily bulbs can also be used for medicinal purposes in the treatment of pulmonary and respiratory illnesses (it possesses antiasthmatic, antitussive and expectorant properties) and in cases of insomnia (as it is also a sedative) (Kariyone 1985; Yeung 1985).

When researching wild plant use amongst Mongolian herders, Yutanov (1954) noted differences in the consumption of plants of the same genus in Mongolia and Inner Mongolia. One of those cases involves *Lilium* sp. - although both regions consumed *L. pumilum*, in Mongolia *L. martagon* was preferred, as opposed to *L. concolor*, which was used in Inner Mongolia (Yutanov 1954). Both are present in Mongolia, China and Russia, but *L. concolor* also extends to Japan and Korea. While *L. martagon* is associated with forests and shady slopes, *L. concolor* is found in forests, meadows, grassy slopes, hillsides and grasslands (Wu et al., n.d.).

The genus *Rheum* is composed of herbaceous perennial plants with edible roots commonly known as Rhubarb. The wild rhubarb species associated to forest environments present in Mongolia is *Rheum altaicum* (Wu et al. 2004). No information is available regarding its dietary and medicinal purposes; however, an arid adapted species of *Rheum* (*R. nanum*) is found in Mongolia today, associated with slopes and valleys (Wu et al. 2004). The consumption of *R. nanum* roots was attested by Yutanov (1954); Mongolian herders used them as food after being dried and ground.

Plants in the genus *Rumex* found in Mongolia are perennial herbs known as docks and sorrels. *R. acetosella* and *R. acetosa* are found in margins of forests and moist/wet valleys of Mongolia, China, Russia, Korea, Japan and Kazakhstan (Wu et al. 2004). For both species, its leaves and seeds are consumed raw or cooked (Harris 1973; Triska 1975; Grieve 1984; Facciola 1990). The roots are cooked and are also dried and ground to powder to make noodles (Tanaka 1976). In the case of garden sorrels (*R. acetosa*), the flowers may also be cooked as a vegetable or used as garnish (Facciola 1990).

An herbaceous perennial plant, *Potentilla anserina* is a plant of the Rosaceae family. Present on most continents (Wu et al. 2003), it grows in grass and wetlands. Its roots can be consumed raw, cooked or dried and ground to powder (Komarov 1968; Mabey 1974; Triska 1975; Loewenfeld and Back 1980; Freethy 1985; Facciola 1990; Hatfield 1999). The species also has edible young shoots (Grieve 1984) and the leaves have been used to make tea. *P. anserina* has been employed medically due to its astringent, antispasmodic, haemostatic, diuretic and tonic properties (Grieve 1984; Chiej 1984; Launert 1981; Lust 1983). Medicines made with this plant are administered through infusions (to treat diarrhea and sore throat) (Grieve 1984) and powders (for ulcers, and hemorrhoids) (Chiej 1984; Chevallier 1996).

Although it is a type of grass (which are usually associated with cereals), plants from the Cyperaceae family (sedges) grow underground tubers that have known dietary purposes and are cultivated all over the world. They are adapted to several environments, including wetlands and sand dunes (Mishra et al. 2016:327). Sedges were recovered from the phytolith assemblage at Zaara Uul (Janz et al. 2021) and they are another potential source for dietary USOs. Nyambayar (2009) identified 132 species from 13 different genera of Cyperaceae in Mongolia.

Legumes

Some of the current legume species present in the Gobi Desert that are associated with either forest-steppe, wetlands and dune-field environments are: Siberian peashrubs (*Caragana arborescens*), Mongolian milkvetches (*Astragalus mongholicus*) and vetches (*Vicia amoena*).

The genus *Caragana* is composed of shrubs and small trees (Meng et al. 2009), and several species have edible parts and medicinal properties. The Siberian peashrub (*C. arborescens*) grows in the margins of forests and woodlands in Mongolia, China, Kazakhstan and Siberia (Wu et al. 2010). Its seeds and young beans have been consumed as vegetables, seasonings, in soups and as coffee substitutes, despite their bitter taste (Uphof 1959; Hedrick 1972:160; Usher 1974; Tanaka 1976; Reva and Lipovetskiy 1977; Facciola 1990; Solomonova et al. 2021). The plant has a high concentration of protein (36%) and oils (12.4%) (Facciola 1990). Currently in Mongolia, the roots of a species of *Caragana* more adapted to arid environments (*C. pygmaea*) are consumed as a famine food when necessary (Tanaka 1976; Kunkel 1984).

Astragalus sp. is composed of annual or perennial herbs and small shrubs (that grow up to 150–200 cm) whose fruits manifest as kidney-shaped seeds (Tutin et al. 1972; Salehi et al. 2020). *A. mongholicum* (Huang Qi) grows in steppes, meadows, coniferous forests and mountain areas and it is found in Mongolia, China, Kazakhstan, Siberia, and the Russian Far East (Wu et al. 2010). *Astragalus* sp. plants possess several medicinal properties (Amiri et al. 2020) and are a part of both traditional Chinese and Mongolian medicine. The dried roots of Huang Qi are known as *Radix astragali* and are commonly used to strengthen the immune system and metabolic, respiratory and eliminative functions (Liu et al. 2017; Balakrishnan et

al. 2021). Although there are no known dietary uses of *Astragalus* sp. in Mongolia, the leaves and seeds of the Chinese milk vetch (*A. sinicum*), which is found in wetlands in central/southern China and has been introduced to Japan, and is consumed as food (Reid 1977; Kunkel 1984; Duke and Ayensu 1985).

Finally, vetches (*Vicia* sp.) are herbaceous perennial legumes contemporaneously associated with famine foods (Francis et al. 2000). *V. amoena* is found in a variety of environments, including (but not exclusive to) forests, hills and dry slopes, grasslands, riverbanks and fixed sand dunes. They are present in Mongolia, China, Japan, Kazakhstan, Korea, the Russian far east and Siberia. Evidence for its consumption as a staple in the Neolithic is found in North Africa, Europe and Asia (Francis et al. 2000). Grinding and soaking has been used across those regions to rid the seeds of the bitterness and toxins when necessary (Francis et al. 2000). The young leaves of *V. amoena* are also known to be consumed (Tanaka 1976; Kunkel 1984). Additionally, the plant has also been used as a pot herb (Binzat 2012).

Cereals

The grasses in the phytolith assemblage recovered from Zaara Uul were mainly from the *Stipa* genus, but reed grasses and sedges were also found at the site (Janz et al. 2021). As mentioned before, the known edible parts from sedges come mainly from the tuber it grows (Mishra et al. 2016), therefore, the Cyperaceae family was likely not consumed as a cereal. The *Stipa* species found at Zaara Uul was *Stipa capillata* (Janz et al. 2021). Regarding the reed-grasses (genus *Calamagrostis*), there are three species in Mongolia: *C. pseudophragmites*, *C. macrolepsis* and *C. epigeios*. Other Poaceae species associated with

wetlands/forest-steppe/desert-steppe environments in Mongolia include, but are not restricted to: *Agropyron* sp., *Agrostis* sp., *Bromus* sp. and *Hordeum* sp. While most of these species are currently only used as forage grass, some plants of the genus *Agropyron* sp. have medicinal properties, as does the genus *Hordeum*, which is composed of wild and domesticated Barley species.

Fruits

Ulmus pumila, a tree species found in valleys, plains and slopes of Mongolia, China, Korea and Russia (Wu et al. 2004), has both dietary and medicinal value. Its fruits and leaves were consumed cooked and raw (Tanaka 1976; Kunkel 1984; Facciola 1990). The inner bark of this plant has been eaten cooked and dried, when it is ground and added to soups, as well as used to make bread (Tanaka 1976; Facciola 1990; Brickell 1990). *Nitraria sibirica*, a shrub that grows along wetlands (oases/lakeshores) in Mongolia and Russia (Wu et al. 2008), is consumed as a wild fruit by Mongolian herders (Zhang et al. 2021). Fruits of the genus *Crataegus* (composed of trees and shrubs that grow by rivers in forests [Wu et al. 2003]) are also traditionally consumed in Mongolia (Khabasgan et al. 2000).