7. The New Oasis: Potential of Use-Wear for Studying Plant Exploitation in the Gobi Desert Neolithic

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Introduction

Global shifts in diet and land-use occurred throughout the terminal Pleistocene and early Holocene (Bird *et al.* 2016; Gamble 1986; Hayden 1981, 1990; Janz 2016; Keeley 1995; Popov *et al.* 2014; Redding 1988; Zeder 2012). These occurred at different times and had very different outcomes depending on the region. At a broad scale, human adaptation to northern climates is distinct and often characterized by prolonged hunting and gathering, and a very specific range of organizational changes progressing along a continuum of early and extended declines in residential mobility, intensified use of aquatic species, and more active management of natural resources. These shifts did not always lead to either long-term sedentism or domestication. Depending on the region, they preceded a wide range of other organizational shifts, including return to greater mobility, the adoption of exotic domesticates, and increasingly specialized hunting strategies (Basgall 1987; Beck and Jones 1997; Bousman and Okasnen 2012; Chatters *et al.* 2012; Fisher 2002; Habu 2004; Popov *et al.* 2014; Rosenthal and Fitzgerald 2012; Weber and Bettinger 2010; Wolff 2008).

The Gobi Desert is a compelling case study for organizational change among northern hunter-gatherers during the Holocene as the long cold winters combine with low vegetative biomass to create distinct adaptive challenges. During the early to middle Holocene there was a massive shift in ecological conditions with strong evidence of unprecedented humidification related to both the large-scale melting of glaciers following the Last Glacial Maximum (LGM) and the strengthening of the East Asian Summer Monsoon system, which carries summer precipitation across the Gobi Desert and the far eastern steppes (Herzschuh 2006; Lee *et al.* 2013; Winkler and Wang 1993). Rising groundwater levels and precipitation led to the massive expansion of freshwater lakes, rivers, and marshes (Hartmann and Wünnemann 2009; Holguín and Sternberg 2018), while stabilizing aeolian sands with vegetative groundcover (Felauer *et al.* 2012; Shi and Song, 2003; Wang *et al.* 2010; Xiao *et al.* 2004; Yang and Williams 2003; Yang *et al.* 2013). Recent research has shown that hunter-gatherers in the Gobi Desert responded to these ecological changes with a shift towards the specialized use of wetland environments (Janz 2012, 2016; Janz *et al.* 2017).

Janz (2016) has argued that the mid-Holocene Climatic Optimum (Hypsithermal/Altithermal), which coincides with the onset of the Neolithic period (c. 8.0-3.0 k cal BP), allowed hunter-gatherers to reduce residential mobility and exploit a wider range of small prey and vegetal resources newly abundant around stabilized freshwater marshes and wetlands. In this case, the shift towards Broad Spectrum Foraging was driven not by resource depression, as traditionally theorized (Binford 1968; Christensen 1980; Flannery 1969; Stiner *et al.* 2000; Stiner 2001), but rather by environmental conditions which favoured the complimentary use of both big game hunting and the exploitation of resilient, high density resources such as small, fast prey and plant foods (Janz 2016). Under this framework, we see oases as a place of ecological abundance rather than a refugium for hunter-gatherers clinging to dwindling resources under threat of aridification.

This "new oasis" theory therefore proposes that climatic amelioration can, just as environmental degradation, serve as a catalyst for diet breadth expansion and technological innovation. The theory rests on the idea that hunter-gatherers were not only camping around wetlands, but were engaged in the active use of wetland resources, as suggested by the adoption of new processing technologies, particularly grinding stone technology. The lack of direct evidence for plant exploitation, however, has led some researchers to suggest that milling technology in East Asia was adopted as an intensification strategy aimed at processing meat or bone (Elston *et al.* 2011), an idea that would counter evidence for diet breadth expansion. Ultimately, our broader program of use-wear research aims to better understand the adoption of ground stone tools (GST) among Holocene hunter-gatherers in the Gobi Desert as it potentially relates to plant use, particularly grinding and pounding tools. Here we present our preliminary results, which illustrate the potential for a more systematic approach to use-wear analysis on GST in East Asia, including as a way to understand functional morphology, mechanics of use and to identify taphonomic processes as they relate to surface preservation.

In this paper, we employ detailed analysis of 30 GST from four Neolithic sites (Baron Shabaka Well [BSW] and Chilian Hotoga Well [CHW], Jira Galuntu/Site 18 [JG] and Shabarakh-usu [SU], Subsite 2) in the Inner Mongolia Autonomous Region, People's Republic of China (PRC) (Figure 1). These sites are mostly known through surveys and collections of material undertaken during early 20th century scientific expeditions. These materials are currently housed at the American Museum of Natural History (AMNH, New York, USA). The integration of such legacy collections has been instrumental in accomplishing large-scale synthesis as well as in assessing the chronology and changes in adaptation in the Gobi Desert (Janz 2012; Frieman and Janz 2018). Our approach to GST analysis integrates morphological, technological and use-wear analysis with the aim of better understanding variability in GST types and their connection with food practices and plant processing. The analysis of surface finds from a desertic context imposes specific challenges to functional analysis. This paper therefore integrates a detailed taphonomical approach to evaluate use-wear preservation. Despite the limitation imposed by post-depositional alterations, our integrated multiple scale approach allows us to test the hypothesis that grinding systems used in the Gobi Desert following the LGM were connected with plant exploitation.

Background

The Gobi Desert spans the southernmost region of Mongolia and a large portion of the Inner Mongolia Autonomous Region of the People's Republic of China (PRC). Three biogeographic sub-regions can be distinguished (Figure 1): the East Gobi, the Gobi-Altai and the Alashan Gobi (Janz 2012: 22-26). The sites analyzed in this paper are located in the East Gobi (a desert-steppe environment of basins, small lakes, plains, and mesas dissected by numerous drainage channels, riverbeds, and dry gullies) and the Gobi-Altai (a desert to desert-steppe environment characterized mostly by sparsely vegetated gravel pavements interspersed with dune-field accumulations). The AMNH collections, along with comparable collections from the Museum of Far Eastern Antiquities/Östasiatiska museet were inventoried, analyzed and photographed by Janz as part of a larger research program to develop the first date-based chronology for the Gobi Desert region following the LGM (Janz 2012; Janz *et al.* 2015, 2017). Extensive site descriptions for the above assemblages are included in Fairservis (1993) and Janz (2012), while site dates and chronology are summarized in Janz *et al.* 2015, 2017.

Figure 1: Presentation of the studied area and location of the sites discussed in this paper. Gobi-Altai region is roughly delineated in orange, Alashan Gobi in red, and East Gobi in green.

Based on this research, three stages of adaptation to post-LGM environments were proposed (Janz 2012, 2016; Janz *et al.* 2017). During Oasis 1 (Mesolithic), beginning by at least 13.5 k cal BP, local hunter-gatherers were exploiting a wide range of ecozones, including upland plateaus, wetlands and rivers within low-laying basins. Tool kits were characterized by microblade core reduction strategies and retouched microlithic tools. Pottery may have been adopted towards the end of this phase, with the earliest vessels dating to 9.6 k cal BP (Janz *et al.* 2015). Oasis 2 (Early Neolithic), beginning by at least 8.0 k cal BP, represents a period of substantial changes in the organization of land-use and technology. Residential sites were consistently located around low elevation wetlands, often situated at the juncture of multiple ecozones, particularly dune-fields, upland ranges or plateaux, and open plains. Hunters would have been in a position to exploit prey across the full range of neighbouring ecozones, while on-site wetland oases provided a much broader range of small prey and edible plant foods. Microblade core reduction strategies remained important, but pottery, grinding stones, and chipped and/or polished adzes and axes were also ubiquitous. Oasis 3 (Late Neolithic/Eneolithic/Bronze Age), estimated to have begun around 5.0 k cal BP, represents another period of substantial change, during which pastoralism spread across and beyond the Gobi Desert, primarily between 4.0-3.5 k cal BP. This period marks the widespread adoption of stone monumental architecture and burial cairns, both of which incorporated domestic herd animals, especially caprines (Honeychurch 2015; Wright 2015; Wright *et al.* 2019). By 3.5 k cal BP there is direct evidence of dairying (Janz *et al.* 2020).

The sample of GST discussed in this paper originates mainly from two dune-field/wetland sites dated to Oasis 2. Baron Shabaka Well/Site 19 (BSW) is located in a narrow dune-filled valley with wind eroded hollows, extending over an area of about 0.4 x 1.2 km (Fairservis 1993; Pond 1928). The locality consists of many small sites characterized by what appear to have been temporally coherent scatters, several associated with hearths. Almost 7000 artifacts were recovered and curated from the BSW locality, including 160 individual GST. These encompass grinding slabs of different shapes and sizes, pestles or knobbed/ball-headed rollers, handstones, stone vessels/mortars (Janz 2012). Radiocarbon dates on potsherds collected from these scatters and the surrounding dunes span 6984-6773 cal BP, with one sherd dating to the Medieval period (Janz *et al.* 2015). Sixteen artifacts from BSW are included in this study (Cat. #73/2080a to 73/2092b). Fourteen GST (Cat. #73/2745c to 73/2748g) come from Chilian Hotoga Well/Site 35 (CHW), a locality described by Pond (1928) as consisting of multiple habitation sites, located on the side of an escarpment in a large wind hollow in the sand. The site was excavated to reveal a hearth site about 2.5 m in diameter, containing burned stones, bone fragments, charcoal, and one 'roller' for grinding. Excavation revealed a rich assemblage of artifacts including a fragment of ochre, ostrich eggshell fragments, drilled bivalve shells, pierced carnivore teeth, pottery, a total of 47 GST, and numerous other lithics (Pond 1928). Luminescence and radiocarbon dates on potsherds from the assemblage bracket occupation at 7740-4720 years, with emphasis on the earliest part of that range (Janz *et al.* 2015). Additionally, there are GST from two other East Gobi localities: from Jira Galuntu/Site 18 (JG) (Cat. #73/2426a, b) and Great Lake Basin/Site 31 (GLB) (Cat. #73/2710a, b) (Figure 1). There is one artifact (Cat. #73/715a) from Shabarakh-usu (Bayanzak), Subsite 2 (SU) (Gobi-Altai region) (Figure 1). There are no definitive dates for this particular subsite. Current luminescence and radiocarbon dates from Shabarakh-usu ceramics date between 6.5 and 2.5 k cal BP, indicating occupation during Oasis 2/3 and into the Bronze Age (Janz *et al.* 2015).

Methodology

Sampling strategy

The artifacts discussed here were analyzed by LD at Trent University under a study loan from the AMNH. The main objective was to determine tool function for a full range of GST types, using low and high magnification microscopes well-suited for the analysis of GSTs. As the tools analyzed mostly correspond to surface finds, assessing post-depositional damages through comparison of the various surfaces was established as a pivotal first step in our analysis.

The selection of the GST sample for this study was done by LD and LJ based on photographs and aimed at documenting the diversity of shape and raw material present in the collection. We selected implements whose surface appeared well preserved (less fragmented, with no conspicuous evidence of surface attrition or patina), presenting good potential for use-wear analysis.

Method of analysis

Our method of analysis combined morphological with technological and functional approaches. Tool shape variability is first assessed based on the most complete artifacts, taking into account their morphology in plane, longitudinal and transversal profiles, and the presence of specific features. The best-preserved artifacts were used as a reference to evaluate which type of tool a fragment might come from. Tool types are defined based on the presence of recurrent shape characteristics while the building of a typology, especially the terminology used, draws on comparison with other GST assemblages (e.g., Liu *et al.* 2014, 2016; Schneider *et al.* 2016).

The technological approach aims at differentiating between ad-hoc (pebbles, cobbles and blocks used without prior manufacture) and 'formal' tools and at reconstructing the methods and techniques employed in tool manufacture. In this study, we distinguished within the 'formal' tools, those for which evidence of manufacture is found on active and non-active surfaces (generalized) versus those for which the manufacture is more limited (generally the working surface, classified as partial manufacture). This distinction is aimed at gauging variation in investment in tool production. Examination at various magnifications is frequently required for better understanding the manufacturing process, therefore the technological approach is intricately related to use-wear analysis.

Use-wear analysis in this study is based on the examination of the surfaces of the tools at various magnifications. For the low and high magnification observations, we used a Nikon SMZ 1000 stereomicroscope with 8 to 80× magnifications range and a Nikon eclipse LV- 150 compound metallographic microscope with long distance objectives offering magnification from 50× to 500×. The metallographic microscope is equipped with DIC. Photographic documentation was acquired with a DSLR Canon EOS T2i camera and we also used Helicon Focus stacking program. Our framework for use-wear analysis has been presented in other papers (Dubreuil 2004; Dubreuil and Savage 2014; Dubreuil *et al.* 2015). Naked eye and low magnification observations focus on the configuration of the relief (especially the presence of flat levelled area called plateaux), the presence of impact marks, sheen and linear features. Specific attention is given to describing grain modifications including grain removals, microfracture, leveling and edge rounding (Adams *et al.* 2009). Table 1 provides the main lines of the system used to describe and record variation in micropolish morphology at high magnifications (for more details, see Dubreuil *et al.* 2015).

Table 1: Descriptive framework for the micropolish observed at high magnifications.

Criteria	Categories of variation		
Distribution (on the surface)	Sparse	Covering	Concentrated
Density (within the polish)	Separated	Adjacent	Connected
Microtopographic context	High topography only	Penetrating in low topography	High and low
Morphology in cross section	Domed	Sinuous	Flat
Texture	Rough	Fluid	Smooth
Contours (or limits)	Sharp	Diffuse	
Opacity	Translucent	Opaque	Trans/Opaque
Brightness	High	Medium	Low
Special features	Abraded area	Pits	Striations

An important aspect in use-wear analysis of GST, which is unfortunately often overlooked, is its usefulness for assessing the tool kinetics, especially in differentiating between tools used in pairs (combining a lower passive and an upper active implement) from those used alone as the abrader and polisher. Distinction between the two categories is not always feasible based on morphological characteristics of the tools alone. A classic example of this is the use of handstone 'look-a-like' tools in hide processing activities (Adams 1988; Dubreuil and Grosman 2009). Therefore, one of the main goals of this study is to solidly anchor our tool classification by incorporating use-wear analysis to differentiate grinding implements and abraders/polishers.

Differentiation between the tools used in pairs or alone as abraders is partly based on the configuration of the active surface, the distribution of use-wear across this surface and within the low and high topography. Grinding with a pair of stone tools tends to create regularized surfaces, with plateaus, on which the high topography is leveled, and found at a similar range of elevation across the active surface. On abraders and polishers, the use-wear is generally more randomly distributed on the high and low topography and the leveling of the surface, if present, less generalized on the surface (depending on the type of contact with matter processed). The differences described above should be not regarded as absolute criteria, as other parameters affecting the configuration of the use surface and use-wear distribution need to be considered. For instance, for similar grinding tasks, if the active area has not been manufactured but corresponds to the natural surface of a block, cobble or pebble, the plateaux may be less regular and more randomly distributed (Dubreuil 2002). Variation is also expected if the grinding system combines stone and wooden tools (Delgado Raack and Risch 2009). Assessing the techniques of manufacture and the types of raw material used for the upper and lower implements is therefore important. In addition, assessment of the relative hardness and abrasiveness of the matter processed (based for instance on grain modification and the presence of striation or flat/striated polish) should also be taken into account as these appear as chief parameters affecting the configuration of the use surface and use-wear distribution. For instance, abrasion of mineral matter can lead to the formation of plateaux and extensive and generalized levelling of the tool active surface.

Ultimately, our goal is to contribute to defining the grinding system prevailing during Oasis 2, i.e. the various tools used, associated kinematics and processed matter(s), the arrangement of grinding workspaces including systems to retrieve the ground matter, among other aspects. As shown in ethnography, grinding implements can be used to reduce a variety of substances into fine particles, including non-food products such as mineral matters (see for a discussion Dubreuil and Goring-Morris, in press). We are currently in the process of building an experimental reference collection for Mongolian use-wear analysis as this is critical for the definitive identification of food types processed. Here, our interpretation of use-wear characteristics focuses on distinguishing between grinding mineral versus non-mineral matters, greasy versus non-greasy and suggestions about whether use-wear characteristics appear to indicate processing of plant or animal matters. These interpretations will be revisited upon the completion and publication of our experimental program. Moreover, if conclusive, results from micro-botanical residue analysis will be integrated in future publications. To achieve our goals, an important first step in the analysis, which will be discussed in the following section, has been to assess and characterize post-depositional damages in order to evaluate the feasibility of a functional analysis through use-wear study.

Taphonomic approach

Assessment of surface preservation is of primary importance in use-wear studies and especially crucial here with our sample of surface finds, exposed for a long period to weathering in a desert environment and potentially greatly impacted by post-depositional alterations (see Evoy 2019 for Gobi Desert collections).

Post-depositional alterations are defined here as surface modifications visible to the naked eye and at various magnifications, which occurred as a result of mechanical and chemical processes after the artifact was discarded (Asryan *et al.* 2014; Keeley 1980). Such alterations can greatly impact the preservation of use-wear (Evoy 2019; Keeley 1980; Levi-Sala 1996; Michel *et al.* 2019; Plisson and Mauger 1988; Werner 2018). On stone tools in general, post-depositional alterations commonly result in chipping, fracture breakage, rounding, pitting, striations, the development of patina, and polish, as well as the formation of a layer of compacted dirt and calcium carbonate ($CaCO_3$) sometime called 'concretion' (Asryan *et al.* 2014; Caux *et al.* 2018; Evoy 2019; Ugalde *et al.* 2015). Breakage and chipping can generally be identified by naked eye and/or macroscopic analyses and does not necessarily impact the entire artifact. More problematic is compacted dirt and $CaCO_3$ which cannot be easily removed (Evoy 2019; Pop *et al.* 2018). Even more problematic, because of potential overlap with use-related wear, are pitting, rounding of the high relief or grain edge, and polish formation which are all especially relevant for this study. Indeed, these last three processes are quite common on stone tools from surface contexts in desert environments (Evoy 2019; Ugalde *et al.* 2015). In such environments, tumbling in sand dunes and abrasion from windblown sediments can round the high relief, remove grains and create pitting, leave striations across the surface, and cause the formation of highly reflective surface (referred to here as 'desert polish') or the development of a dark and shiny coating called 'rock varnish' (Ugalde *et al.* 2015).

In this study, we started our observation on fracture plan(s) that appear to have been post-depositional and compared grain alteration and polish formation found on these surfaces with those present on the other parts of the tool. Post-depositional wear was expected to be distributed more widely and randomly on the tool, as opposed to wear related to use or manufacture. Comparison between various implements were carried out to characterize the 'desert polish'. In general, assessment of tool surface preservation was based on the presence, intensity and distribution of post-depositional chipping, fracture breakage, rounding, pitting, striations, and polish as well as compacted dirt and $CaCO_3$. Several states of tool surface preservation were defined, ranging from highly to mildly impacted, and interpretation of use-wear features in terms of human behavior was adjusted accordingly.

Results: Assessing grinding/pounding tool kits variability

Our sample encompasses 30 tools made of various raw materials including coarse, medium and fine-grained sandstone (n=24, 80%), as well as basalt (n=2, 6.7%), granite (n=2, 6.7%), schist (n=1, 3.3%) and quartz/quartzite (n=1, 3.3%). Five of the tools are complete (Table 2). An assessment of artifact preservation is first provided in the next section, before detailing the repartition of our sample between abraders and grinding/pounding implements and appraising the different tool kits employed for reducing matters into smaller particles.

Artifact preservation

The Table 2 (next page) presents the distribution of the most common type of post-depositional alterations observed in our sample.

These include concretion (dirt/$CaCO_3$), smoothing of the grain's edges (rounding) and enhanced surface reflectivity ('desert polish') associated with smoothing. The post-depositional polish observed in the sample is associated with rounding of the grain's edges and can be described as translucent/opaque and very bright. Locally it can present a rough 'grainy' texture and striations. Its distribution into the micro-relief is of high amplitude but the polish is generally more conspicuous on arises and prominences (Figure 2). Randomly oriented fine and isolated striations were also often observed on the tool surfaces. These may be related either to matter processed or to post-depositional alteration. These hypotheses will be explored in the future through experiments.

The tools are affected by post-depositional damages in various ways, more or less extensively (Table 2). For 6 artifacts (20%), the impact is high (extensive on the object and combining multiple types of damages), for 6 (20%) it is evaluated between moderate/high, moderate for 12 (40%), and low for 6 (20%). Even in the cases of a high impact of post-depositional processes, it is generally possible to identify the active surface and to differentiate between utilization as an abrader or as grinding/pounding implement. For these highly impacted implements however it is more problematic to rely on some of the criteria commonly used to assess the type of matter processed (e.g., rounding of the grains, distribution of use-wear within the micro-topography, sheen). Interpretation regarding the properties of the processed matter(s) were attempted when the active surface appeared moderately to mildly affected.

Table 2: Most common type of post-depositional alterations observed and assessment of tool surface alteration (x=present).

Cat. #73/	Frag/Comp	Dirt/CaCO3	Round.	Desert polish	Other	Assessment
715 a	Frag		x	x		High
2745c	Frag	Locally	x	x	Micro-chipping	High
2710 b	Frag			x		High
2091 b	Comp	Locally	x	x	Pitting	High
2085 b	Comp			Extensive		High
2081	Comp	Extensive on 1 face		Extensive on 1 face	Scraping	High on face / Low on the other
2748c	Frag		x	Affect differently the various faces		Moderate/high
2748a	Frag		x	Affect differently the various faces	Removal, crushing and micro-fracture	Moderate/high
2710a	Frag		x	Affect differently the various faces		Moderate/high
2426a	Frag	Extensive	x		Grain removals probable	Moderate/high
2080a	Frag	Extensive on 1 face	Mild	Mild generalized		Moderate/high
2748b	Frag		Mild	Affect differently the various faces		Moderate/high
2748g	Frag			Mild very light		Moderate
2748d	Frag			Possible		Moderate
2745k	Frag		x	x		Moderate
2745f	Frag			Mild very light		Moderate
2092a	Comp?	Extensive on 1 face				Moderate
2091a	Comp				Possibly grain removals	Moderate
2089b	Frag		x			Moderate
2088b	Frag		x	Mild very light		Moderate
2088a	Frag	Locally				Moderate
2087a	Frag	Extensive on 1 face				Moderate
2085a	Comp	Locally				Moderate
2083b	Frag	Locally			Flake removals	Moderate
2426b	Frag					Low
2092b	Frag					Low
2089a	Frag	Locally				Low
2083a	Frag	Locally				Low
2082b	Comp					Low
2082a	Comp	Locally				Low

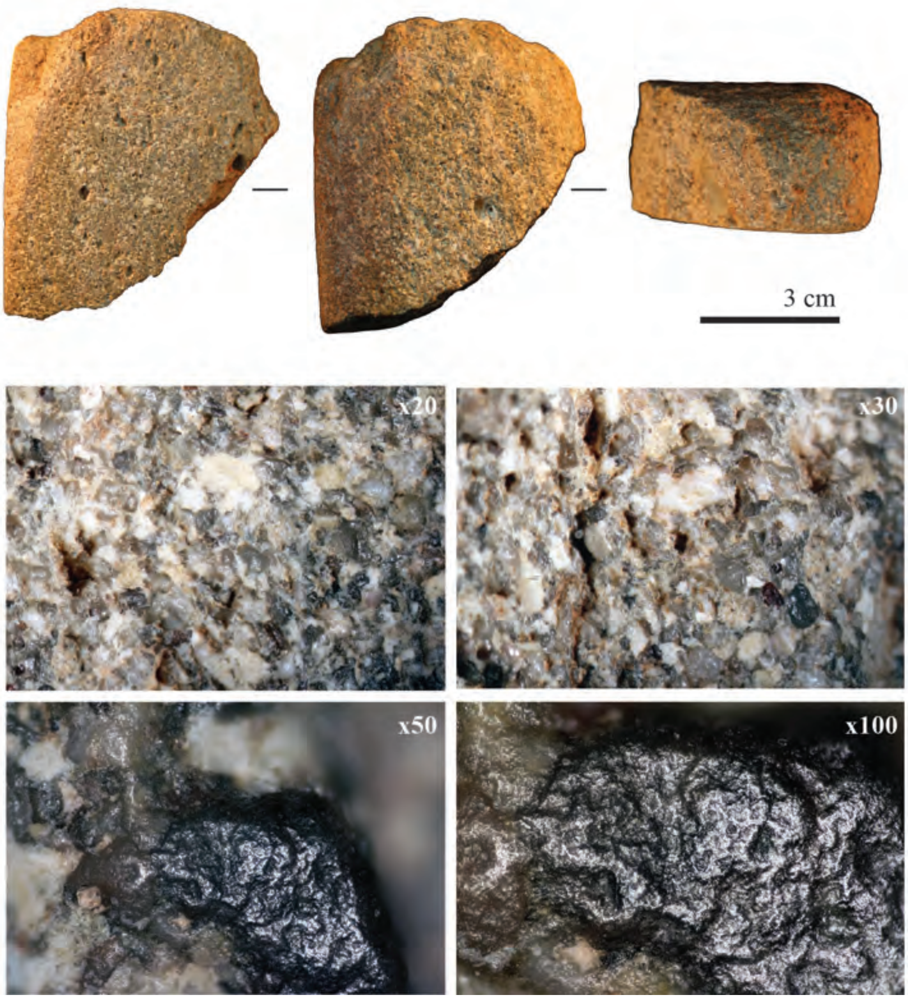

Figure 2: Post-depositional damage observed on #73/2748a. Grain rounding and reflectivity on the fracture plan at low magnifications (here shown ×20 and ×30); desert polish at high magnification (here ×50 and ×100).

Various types of grinding/pounding implements

Our analysis indicates that ten artifacts can be classified as abraders and 20 as grinding/pounding implements. Among the ten abraders, four of them will need to be reassessed after the completion of the experimental program to confirm our interpretation. There are several cases for which differentiating between abrader and grinding/pounding tools based on the shape is specifically problematic. In general, as mentioned earlier, combining morphology and use-wear observations provides stronger argument to sort between the two broad categories.

The sample of 20 grinding/pounding implements can be separated between six lower tools, 12 upper tools and two semilunar 'indeterminates'. The differentiation between lower and upper implements was made based on the overall shape of the tool and the configuration of the active surface (especially longitudinal and transversal profiles).

The lower implements

The lower implements are made of basalt (n=1) and various sorts of sandstone (n=5). All are fragmented yet thickness measurements can be provided: they range between 36 and 11 mm. Evidence of manufacture of the entire tool, including the non-active parts, is observed on all but one artefact (Cat. #73/2710b).

From the best-preserved artefacts in our sample and the complete tools present in the collection it can be said that morphologies in plan are either rectangular/elongate or oval (Figure 3). All the lower implements correspond to grinding slabs with no borders. The use surface is therefore open, suggesting that a specific system was used to collect the ground matter falling from the edges (e.g., basket, mat or piece of hide placed underneath the tool). The morphological variability in this sample is seen in the profile of the active surface which can be flat or show various degrees of concavity (see for an example of flat profile Figure 4). This variability may relate to different degrees of use or to the presence of distinct tool types and grinding systems (e.g., Stroulia *et al.* 2017). The analysis of upper grinding implements will provide additional data to discuss these hypotheses. Evidence of the chipping and flaking on the edges of the grinding slab post-dating use-wear is found on two implements and this may indicate the use of maintenance strategy for controlling the profile of the active surface.

Figure 3: Example of complete grinding slab found at Baron Shabaka Well. Note the deeper concavity in the middle and raised platforms at both ends. Photo L. Janz.

Comparable grinding slabs with open grinding surface (called milling platforms) are described by Schneider *et al.* (2016) for sites attributed to the Neolithic (Oasis2/3) period located further west. The range of thickness is similar to what is observed in our sample (Schneider *et al.* 2016: Tab. 1). The most complete grinding slab is rectangular in plan and has elevated platforms on either end of the active surface which is concave in its middle (Schneider *et al.* 2016: Fig. 8). A very similar grinding slab, yet narrower with a less concave working surface and less pronounced platforms, was also collected at Baron Shabaka Well but was not included in our use-wear sample (Figure 3). Liu *et al.* (2014, 2016), analyzing GST from later nearby sites, have described oval-shaped 'open' grinding slabs between 55 and 8 mm thick, also with less marked platforms. The platform may correspond to an area where the matter to be ground is regrouped before being pushed onto and ground on the rest of the active surface.

In our sample, for two grinding slabs, extensive post-depositional damages preclude further use-wear analysis (Cat. # 73/2745c and #73/2710b). For the rest of the lower implements, observations suggest that the matters processed are not abrasive and mineral (Table 3).

Table 3: Types of use-wear observed on the active surface of the lower implements (LI).

Type of use-wear and distribution in the sample	Low magnifications	High magnifications (polish)
(LI-1) 73/2745k, 73/2710a and 73-2426b	Plateau of various sizes, microfractures, grain removals and leveling, occasionally smoothing	Penetrating a bit in the low topography, mildly reflective, sinuous, fluid/rough (granulated aspect) with parallel striations indicating the same main direction, as well as short isolated striations randomly oriented.
(LI-2) 73/2080a	Idem with isolated striations and generalized sheen	More restricted to the high topography and also more dense; Polish often oriented, i.e. giving the impression of a direction; with long and fine randomly oriented striations.

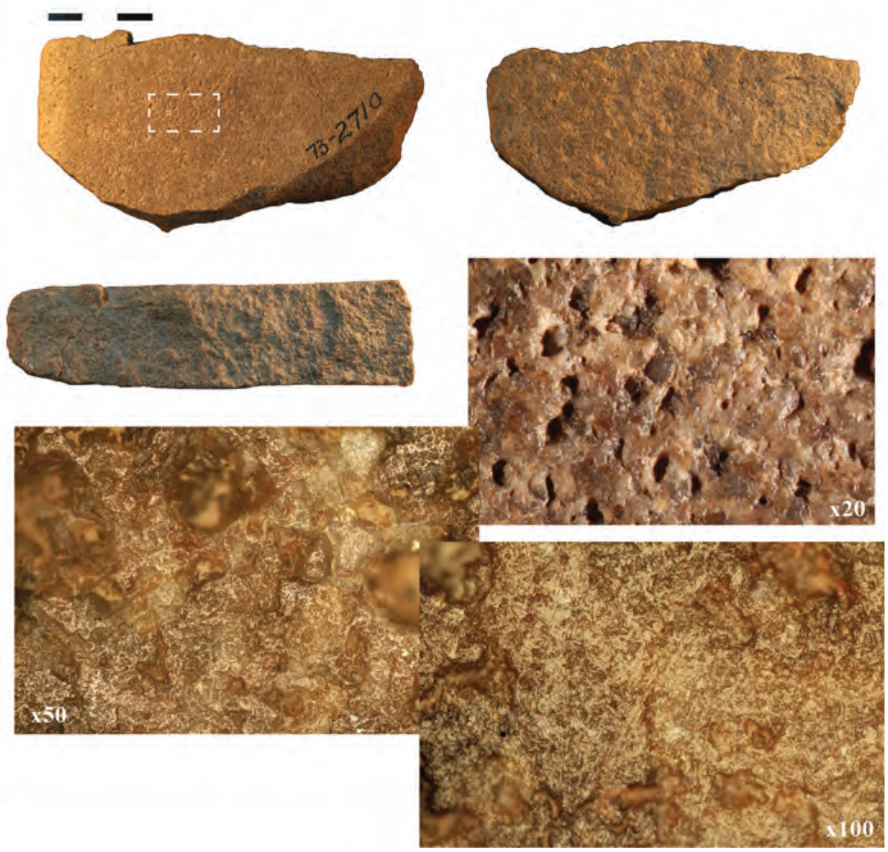

Figure 4: Example of lower implement (Cat. #73/2710a), working surface with a flat longitudinal profile. Opposite surface manufactured by pecking and smoothing. Use-wear on the centre of the working surface at low and high magnifications (type LI-1 described in Table 3).

It is possible that both types of use-wear are associated with plant processing, the second type with a rather 'dry' matter (LI-2) and the first type (LI-1) with a matter that contains some lubricant, however less than nuts, which are quite oily. These preliminary interpretations are currently being explored in our experimental program. Because of the prevalence of grouped parallel striations on all the tools, and despite the presence of randomly oriented short striations, it is suggested that the upper implements were mainly used according to a back-and-forth kinematic.

The upper implements

Two types of upper grinding implements can be distinguished in our sample. These encompass: 1) elongated or pestle-like (n=5); and 2) rectangular handstone/pounder (n=7). Type 1 is found on coarse sandstone, while the raw materials used for Type 2 are more diverse (coarse and medium grained sandstones, as well as quartz/quartzite and granite). All tools were entirely or partially manufactured.

1) The elongated and 'pestle-like' handstones (n=5)

These GSTs present an elongated body and, in general, thick ends. Two of them are pestle-like with spherical ends in which the diameter is larger than the body and seem to correspond to knobs or handles (Cat. #73/2088a and #73/2088b; Figure 5). The transversal section of the body is rounded (yet with a facet) for one, bi-convex and asymmetric for the other. A third implement is interpreted as a section of the body and presents bi-convex asymmetric transversal profile (Cat. #73/2089b). On the two most complete specimens, use-wear associated with grinding are mainly found on the body and striations indicate a main direction parallel to the width. We do not observe evidence of use of the very end in pounding activities, mainly the use-wear observed on this part of the tool can be associated with manufacture (Figure 5). The use-wear can, however, be intensive in some parts of the 'knob', for instance on the 'gorge' that forms the transition between the body and the larger rounded end. This suggests a friction with the lower implement in this part of the tool. Some polish probably related to prehension is also found on the knob. The distribution of use-wear suggests an overhanging handstone (length superior to the width of the lower implement) used according to a back-and-forth motion, the implement being regularly turned while the tool is operated. These tools were sometimes called rollers (Janz 2012; Pond 1928) and such 'rollers' are also described in the Neolithic of North and Central China, associated in some regions with footed grinding stones (Cohen 2003; Liu 2004; Liu *et al.* 2010; Liu and Chen 2012). In our sample, bi-convex profile or presence of facet on the rounded transversal profile suggest that the tool was not actually 'rolled' over the surface, but used with a back-and-forth movement. Descriptions of assemblages from Inner Mongolia dated from later periods do not mention the presence of such implements (Liu *et al.* 2014, 2016).

The grain modifications and polish observed in our sample are presented in Table 4 (UI-1) and Figure 5.

Two items classified as elongated handstones do not have knobs and present a plano-convex, transversal section. One is complete (Cat. #73/2085a) and one is a fragment with part of the body and one end (Cat. #73/2087a). On both implements, no indication of the use of the end in pounding or grinding activities is found. On the most complete item (Cat. #73/2085a), use-wear related to grinding is found on the flattest face, the opposite surface being mostly used for prehension. On the fragmented specimen (Cat. #73/2087a), both faces show evidence of use in grinding. Low and high magnifications observations for both tools are provided in Table 4 (UI-1).

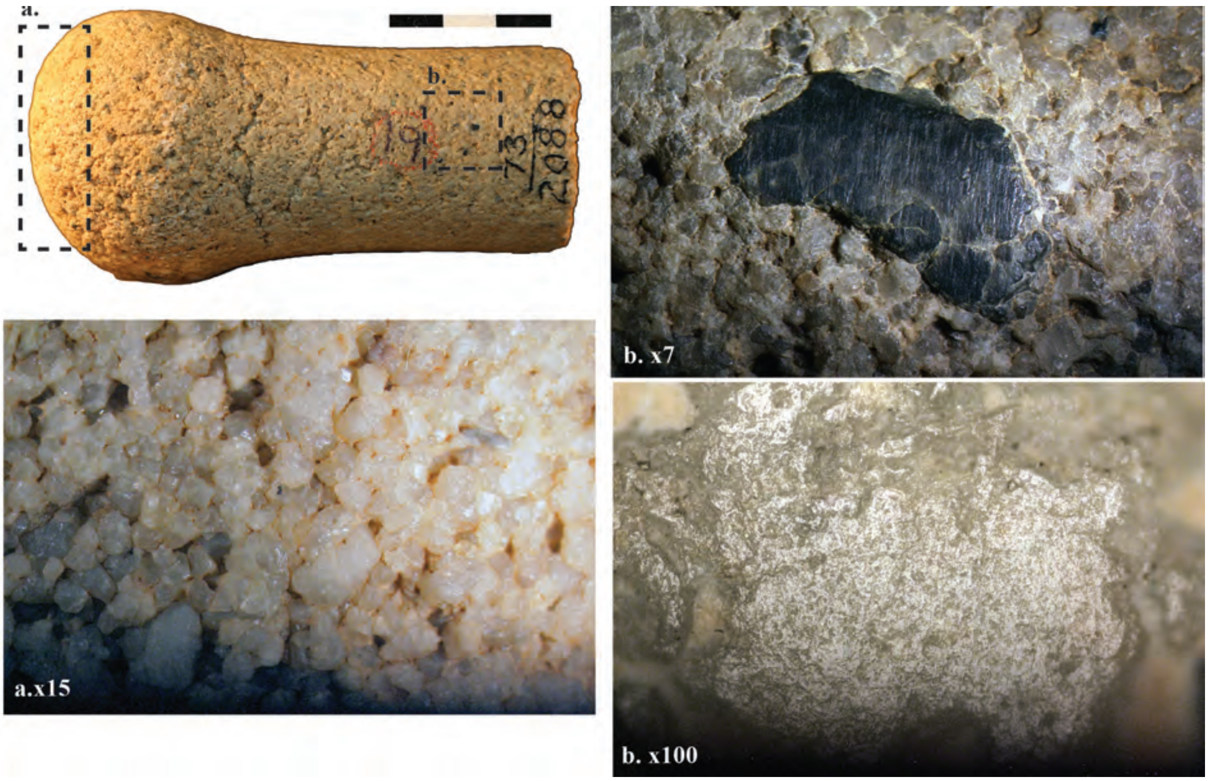

Figure 5: Pestle-like handstone with knob (Cat. #73/2088a) and associated use-wear observed on the end (a) and on the body (b) at low and high magnifications.

Table 4: Use-wear observed on the active surface of the sample of upper implements (UI).

Types of use-wear and distribution in the sample	Low magnifications	High magnifications (polish)
(UI-1) Pestle-like with knobs and elongated handstone	Plateau of various sizes, grain removals, microfractures and levelling, striations	Separated/adjacent polish, mainly on the top of levelled grains, yet penetrating a bit in the low topography. Sinuous morphology, rough texture, diffuse limits and mild reflectivity oriented or with fine grouped parallel striations, also with long or short fine striations isolated and randomly oriented; low polish development on 73/2087a.
(UI-2a and b) Rectangular handstone/pounder	Grain removals, microfractures, and levelling; more microfracture on the ends, more levelling on the long side	Observed on 4 tools UI-2a (on sandstone, 73/2748a, 73/2082a, 73/2748g): low amplitude, separated density, sinuous/flat, fluid/smooth with fine parallel striations and occasionally short striations randomly oriented. UI-2b (on granite, 73/2082b): mainly on the asperity, sinuous and rough (granulated) with patches of flat/wavy and very smooth polish. Fine, isolated, randomly orientated striations, and grouped and parallel striations.

2) The rectangular handstone/pounders

This category of upper implements consists of rectangular and thick handstone/pounders (n=7). Measurements are provided in Table 5.

Table 5: Use-wear observed on the active surface of the sample of upper implements (UI).

Ref	Preservation	Length/width/thickness in mm
73/2083 b	Frag	92/67/32
73/2748 c	Frag	66/58/33
73/2748 a	Frag	63/59/35
73/2082 a	**Complete**	**110/76/35**
73/2748 g	Frag	6/57/16
73/2083 a	Frag	82/77/26
73/2082b	**Complete**	**105/77/34**

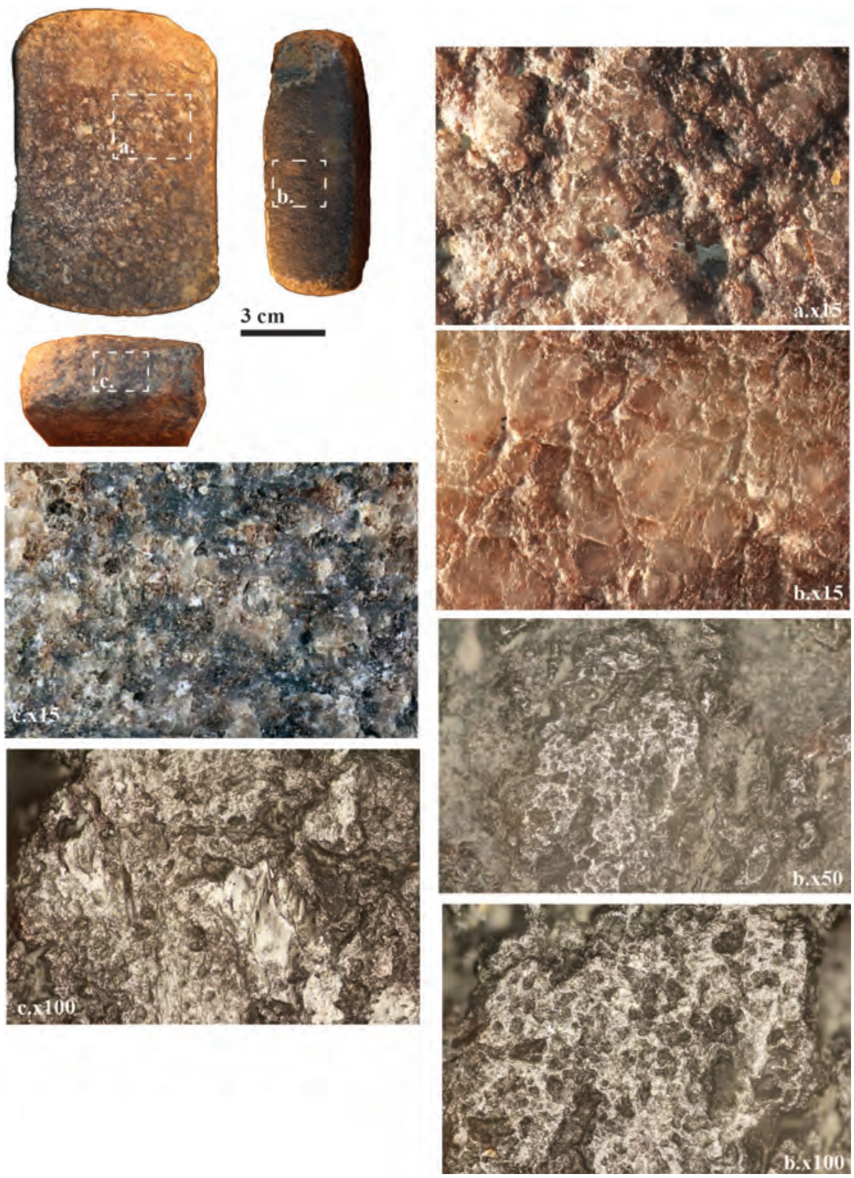

Figure 6: Example of handstone/pounder (Cat, #70/2082b) with use-wear at high and low magnifications.

They show evidence of use in grinding and pounding activities. In general, grinding is more prominent on the faces and longer sides while pounding is more prevalent on the ends of the tools (Figure 6). Well-developed striations are found on the long side of various specimens indicating a dominant back-and-forth motion. Striations tend to be less developed on the faces. While use-wear at low magnifications is very comparable in our sample, two types of polish have been observed (Table 4 UI2 a and b, Figure 4).

3) Comparative analysis of the upper implements

Results from both morphological and use-wear analysis suggest the presence of two types of upper implements, one more specially associated with grinding (elongated and pestle-like handstone), the other with a combination of grinding and pounding kinematics (rectangular handstone/pounder). In general, none of the upper implements appear to be associated with the transformation of mineral matter and the hypothesis of plant processing is favored at this stage of our analysis. The matters processed with the upper implements seem to contain some lubricant, however less than nuts or other oily plant matter. The use-wear on the rectangular handstone/pounders suggest the processing of resources that require a combination of intensive pounding and grinding. These may include for instance underground storage organ (USO) reduction or fiber processing (e.g., hemp or nettle). Alternatively, the pounding/grinding combination may also fit well with the reduction of dry meat into flour. While use-wear appears more in line with plant processing, it will be important to explore meat processing through experiments.

The semilunar GST

Our sample encompasses one complete tool (Cat. #73/2081) and one possible fragment (Cat. #73/2748b) of semilunar GST. The complete specimen (182/94/32 mm) presents a half-moon morphology in plan, a pecked border, while each face shows respectively a flat/slightly concave and a slightly convex transversal profile (Figure 7). The use-wear appears to be mainly localized on the slightly concave surface yet, because of extensive concretion, the opposite surface can only be analyzed on small areas. The overall shape of the tool seems to best fit into a handstone; however, no convex active surface has been found among the grinding slabs and so the concave active surface may indicate use as a lower implement. The fragment Cat. #73/2748b has a plano-convex transversal section, wear related to use is also mainly found on the flattest surface.

The use-wear characteristics observed on the semilunar GST are presented in Table 6 and Figure 7. The characteristics indicate the processing of non-mineral matters, most likely plants containing some lubricant (yet again not as much as nuts or other oily plants). The importance of grain microfracture in the wear formation and the moderate development of plateau may suggest combination of pounding/grinding, if the tool corresponds to a lower implement.

Table 6: Use-wear observed on the active surface of semilunar GST (indeterminate lower of upper implement, U/L).

Type of use-wear and distribution in the sample	Low magnifications	High magnifications (polish)
(U/L-1) Semilunar handstones (73/2081; 73/2748b)	No extensive plateau, wavy microtopography with grain removals, microfracture and levelling.	On 73/2081, mildly reflective polish penetrating in low topography, separated to adjacent density, sinuous/rough (granulated) to domed/smooth; Polish associated with fine, parallel and grouped striations. Also fine, long and isolated scratches, randomly oriented. 72/2748b with desert polish

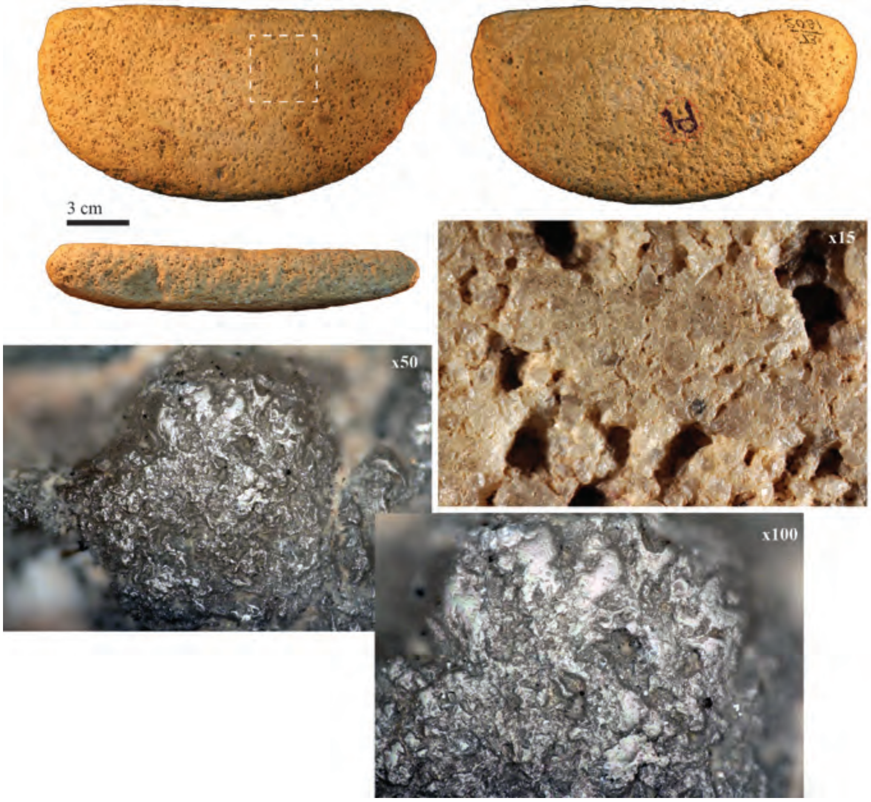

Figure 7: Example of semi-lunar handstone (Cat. #73/2081) and associated use-wear observed on the slightly concave active surface at low and high magnifications.

Conclusion and discussion: Toward a better understanding of the grinding and pounding tool kit of Gobi Desert Oasis 2 period

One of the main goals of this study is to explore, through morphological, technological and use-wear analysis, the relationship between GST technology and plant processing in the Gobi Desert during the Neolithic period (Oasis 2). Another goal is to contribute to better characterizing the grinding and pounding systems used. While our sample derives from surface finds, an important initial step in the analysis has been to assess post-depositional damages and especially its impact on use-wear preservation. Identification and effects of post-depositional damage should be carefully considered with regard to its impact on use-wear analysis.

Our observations suggest that the tools are diversely affected. On highly impacted artifacts, use-wear formation could still be employed to determine whether the tools were used in abrading or in grinding/pounding activities, and helped in developing a better understanding of the typology. Indeed, making such a distinction is not always possible solely on the basis of the tool morphology. The use of multiple lines of evidence hence offers more secure identification and allow better characterization of the tools used in grinding and pounding activities, potentially associated with the processing of plants for their consumption. In this study, various types of grinding/pounding tools have been characterized; interestingly, they all show substantial investment in manufacture (see also Janz 2012: table 3.6 p.202).

The lower implements in general present many similarities, including an 'open' grinding surface, undelimited by a border and a dominant use according to a back-and-forth motion. Some of the grinding slabs are very thin, showing exhaustive use of the tool. Main differences are found in the configuration of the grinding surface which can be flat to concave in profile. In addition, the most complete artefacts in the collections illustrate the use of elongated rectangular as well as oval grinding slabs in plan, some implements displaying raised 'resting' platforms at both extremities. The semilunar GST may represent an additional distinct type of lower implement (smaller with a half-moon morphology in plan), however at this stage of the analysis their use as lower or upper implements (or in combination) still remain to be established.

In contrast, there is a more distinct range of tool types among the upper implements. The elongated and knobbed pestle-like handstones present evidence of use on their body according to back-and-forth motion along their width, while the knob may correspond to a prehensive feature. This last interpretation should be tested on a larger sample. These tools appear suited for use with the elongated 'open' grinding-slabs previously described. It is interesting to note that at BSW, a 'grinding bar with knob' was found associated with such a grinding slab (Pond 1928; Fairservis 1993: 124).

The second type of upper implements identified in our sample, the rectangular handstone/pounders, combine intensive pounding and grinding. At least some of the grinding slabs in our sample appear too thin to withstand such pounding activities. In addition, the use-wear on the grinding-slabs is clearly dominated by grinding. The semilunar GST, on the other hand, exhibit more grain microfractures and limited formation of plateau and could have been used as a lower implement for pounding/grinding operations. We need to expand our sample to test this hypothesis.

At this stage of the analysis, the use-wear types on the grinding and pounding tools examined suggest the processing of vegetable matter(s), some more 'dry' (some of the grinding slabs) but more often rather 'soft' or 'wet' i.e., containing some lubricant, yet not in the range of nuts or other oily plants. The ongoing constitution of an experimental database will provide more data to inform the interpretation of the use-wear patterns observed in our sample. Future research should also focus on enlarging the sample of tools analyzed.

The preliminary results of residues analysis carried out by Schneider *et al.* (2016) on GST implements from the Neolithic in the Gobi Desert similarly suggest an association with plant processing. Liu and colleagues (2014, 2016), using starch grain analysis on GST from Inner Mongolia, have found possible evidence for the use of USO (*Lilium* sp., *Dioscorea polystachya*, *Trichosanthes kirilowii*, and *Typha* sp.), grains (Paniceae and Triticeae grasses, *Coix lacryma-jobi*), legumes, and nuts (*Quercus* sp.) in the somewhat younger Neolithic sites of Shihushan I and II (SHI is dated to 6530–6440 cal BP and thought to post date SHII) (Figure 1). In relation to our sample, non-native species were unlikely to have been exploited during the earlier phase represented in this study and there is no evidence for the establishment of nut-bearing trees in the Gobi Desert during this time.

However, many edible species of Liliaceae, Poaceae, and Fabaceae species are present in Mongolia. There is an overall lack of knowledge about potential dietary importance to hunter-gatherers as imported domestic species have overwhelmed the use of indigenous ones. Several native species do continue to be used, including: *Lilium pumilum* (bulbs), *Allium* spp. (bulbs and greens), *Rheum nanum* (roots used for flour, stalks as a fruit), *Chenopodium* spp. (seeds for flour), and Rumex spp. (greens) (Jigjidsuren and Johnson 2003). Within the Triticeae tribe, there are seven species of *Hordeum* (barley) in Mongolia (Jigjidsuren and Johnson 2003). *Caragana* spp. (peashrub) is also very common in the Gobi Desert and has been widely used as a food source in other regions. Fibre plants include *Urtica* spp. (nettle) and *Cannabis* sp. (hemp). Future research will focus on distinguishing grinding of three plant types: grass seeds, legumes, and root/bulb/tubers. It is likewise critical to all microbotanical research in arid East Asia that we continue to build reference collections for edible native USO and seeds, in particular for Liliaceae species, *Rheum nanum*, *Chenopodium* spp., *Hordeum* spp., and *Caragana* spp. Future research will also focus on exploring which type of activities and resources required the use of a combined pounding and grinding kinematic, as observed in some of the GST. Toward this aim, experimentations with fibres processing and reduction of dry meat into flour will contribute testing further the connection suggested here between Oasis 2 GST technology and plant exploitation in the Gobi Desert.

Overall, this analysis supports the hypothesis that Oasis 2 represents a temporary shift towards broad spectrum foraging during the Neolithic. The ubiquity of GST in Oasis 2 sites across arid Mongolia and China (Janz 2012; Liu and Chen 2012; Zhao *et al.* 2021) highlights a reorganization in subsistence that included high investment in processing plant foods, including the manufacture of elaborate and specialized tools. Plant foods were clearly a critical resource during this time. This represents an emphasis on efficiently processing seeds or USOs for carbohydrates. Although we do not yet have a clear understanding of early to middle Holocene palaeoecology, the emphasis on technology designed to exploit plant resources suggests that they were both reliably available and abundant enough to drive changes in technological, and perhaps logistical, organization. Continuing research is critical to understanding both human diet and Holocene palaeoecology in arid East Asia and will continue to test the "new oasis" hypothesis with a focus on confirming plant use and the types of plants targeted.

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