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Sourcing sandstone ground stone tools from Neolithic Mongolia: a view from Ikh Nart Nature Reserve☆

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ABSTRACT

Neolithic (Oasis II) residential sites are prominent at Ikh Nart Nature Reserve in eastern Mongolia. Most ground stone tools found at these sites are made from sandstone. No sandstone outcrops exist within the boundaries of the Reserve. This paper describes the search for the source of the sandstone, how a source was located, and how that source was confirmed using thin-section petrography. Why sandstone was preferred material for ground stone tools and why Oasis II people who lived within the granitic landscape of Ikh Nart were willing to travel to obtain it is further explored.

1. Introduction and theoretical setting

An increase in the frequency, size, and refinement of milling tools (i.e., ground stone tools [GST] used for processing various substances) in archaeological assemblages worldwide is often interpreted as an indicator of a transition from a hunter-gatherer economy to agriculture and a more sedentary lifeway (e.g., Bar-Yosef, 2014; Harris, 1996; Harris and Hillman, 1989 and many others). In Mongolia, however, agriculture was not the successor to hunter-gatherer economies; rather, pastoralism was eventually the successor (Janz et al., 2017). In the Gobi-Steppe interface region of Mongolia, such as that of Ikh Nartin Chuluu Nature Reserve (Ikh Nart), the transition from the hunter-gatherer lifeway to nomadic pastoralism has not been a focus of archaeological attention until very recently for at least two reasons: (1) a research emphasis on transitions to agricultural economies in most of China and other less-arid Asian regions and (2) the Mongolian archaeological research focus on precursors to the nomadic empires of later periods in an effort to enhance Mongolian nationalism (Sériadès, 2004; Janz, 2012; Wright, 2006, 2021, and others). It is not yet clear if the transition to pastoralism was direct or if an intermediary stage of semi-sedentary subsistence dependence on wild plant abundance in a climatic-optimum period was part of the transition.

The sequence of the transition to pastoralism as a way of life, remains speculative, especially within the Ikh Nart region of eastern Mongolia, the location of our research and that of others (e.g., Janz, 2024). Pastoralism remains the economic strategy most closely identified with Mongolia of today, although globalism and mineral extraction is rapidly changing that view. Although the geographic location of Ikh Nart, within the Gobi-northern steppe grasslands, seems to fall within a hypothetical natural central crossroads for the technological and economic changes of Neolithic times in northeastern Asia, very little is known about the prehistory of the region[1] (Janz, 2012:17).

GST have been a subject of research in eastern Mongolia, Inner Mongolia province of China, and China itself (Cordeiro, 2424; Dubreuil and Savage, 2014; Dubreuil et al., 2021; He, 2024; Liu et al., 2010, 2011, 2014, 2016a, 2016b, 2018). Most of this research, however, has focused

☆ "The transition from hunter-gatherer to either sedentary agriculturist or nomadic pastoralist represents a key trajectory in the prehistory of East Asia."(Janz, 2012:16).

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[1] Lisa Janz, in her 2012 dissertation suggests that pastoral nomadism is thought to have begun during the same time period as plant cultivation, but was not widespread until the Bronze and early Iron Ages. Furthermore, the adoption of animal husbandry is usually associated with increasing aridity and the arrival of nomadic pastoralists from the west. A more nomadic lifestyle would have begun at this time. The Neolithic sites that Janz considers are mostly in dune-field environments adjacent to now-desiccated rivers and lakes, likely leading to the interpretation that before the very arid conditions that promoted nomadic pastoralism, climatic patterns were less arid, and woodlands may have been nearby.

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on determining how GST were used and what substances were processed using them. As GST are often equated with plant processing, different types of residue and use-wear studies have been moderately successful in determining the types of substances that were ground, mashed, and otherwise processed with the tools, thus providing important data about subsistence in various periods of time at these locations and associating these data with environmental and cultural changes over time.

As far as is known, no sourcing studies leading to an understanding of acquisition, production, and distribution of sandstone GST have been carried out in central Asia, despite their seemingly ubiquitous distribution and frequency at Neolithic residential sites in the region. Within the context of *châine operatoire* technological analyses, the source of the material is the beginning of the life history of tools, their production, use, and discard; these data are important to understanding past land use and cultural behaviors. In the instance of the Ikh Nart sandstone GST, for which no source is available within the > 66,772 km^2 (>2578 mi^2) Nature Reserve, extensive geological field reconnaissance, supported by thin-section petrography, has filled that knowledge gap for Ikh Nart. This is the first attempt to determine the source and acquisition of sandstone GST in prehistoric Mongolia.

The focus of this paper is narrow, but it illustrates how a question derived from observations made during fieldwork, bolstered by data derived from other regional research projects that have considered GST as valuable sources of information, can provide unexpected insights. Prehistoric inhabitants of Ikh Nart and peoples inhabiting many areas of the easternmost Gobi region (including Inner Mongolia), as well as the easternmost steppe, before, during, and after the Oasis II period, preferred sandstone for GST as is indicated in site GST assemblages of the transition period and beyond.[2] In eastern Mongolia as well as other regions of inner Asia where sandstone GST are common, both in pre-agricultural and pre-pastoral times, researchers apparently hold an assumption that sources are near the residential sites where the GST were used and discarded. This assumption has not been tested. Ikh Nart, however, contains no source of sandstone; yet, the GST that are characteristics of the Oasis II sites are mostly of sandstone (Schneider et al., 2016).

2. The Ikh Nart project: The research setting

Beginning in 2010, an American-Mongolian archaeological team conducted intensive archaeological survey in Ikh Nart Nature Reserve, a Mongolian Protected Area. Ikh Nart is located in Dornogovi Aimag (East Gobi Province) of Mongolia, about 300 km southeast of the Mongolian capital city of Ulaanbaatar (Fig. 1). Ikh Nart is at the northern edge of the Gobi Desert, and within the Gobi-Steppe ecosystem that encompasses about 20 percent of Mongolia. Ikh Nart was set aside as a Protected Area by the Mongolian government in 1996 to protect its populations of *argali* (*Ovis ammon*), a wild mountain sheep, Siberian ibex (*Capra ibex sibirica*), and the cinereous vulture (*Aegypius monachus*), the world's largest vulture. The primary goal of the archaeological survey was to identify archaeological sites and features within Ikh Nart to develop an understanding of its cultural landscape. No previous cultural survey had been conducted within the Reserve. The survey data would be used to develop a plan to preserve and protect cultural heritage sites with this one Protected Area. The results were used to develop a Cultural Heritage appendix to a five-year planning document funded by the

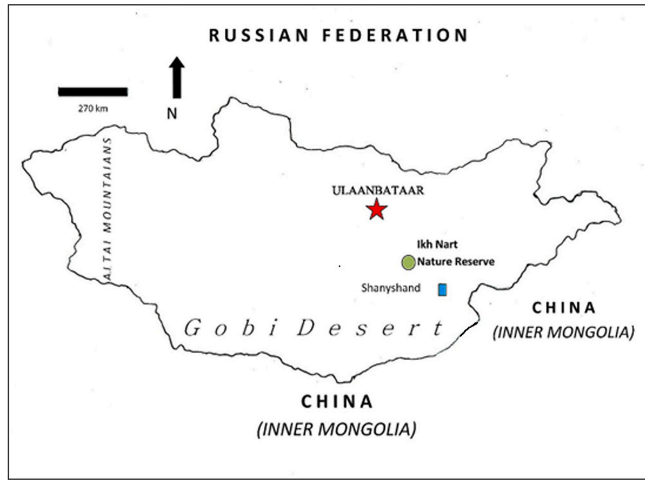

Fig. 1. Location of Ikh Nartiin Chuluu Nature Reserve in Mongolia is indicated by the green circle. Ulaanbaatar, shown as the red star, is the capital city. Shanyshand, shown as a blue box, is the closest large settlement south of Ikh Nart.

United Nations Development Programme (UNDP) Special Protected Areas Network (SPAN) Project (Reading et al., 2016). The Cultural Heritage appendix would add the preservation and protection of cultural heritage sites to the main body of the document that was focused on the preservation and protection of the natural landscape and its animals and plants; it was to be a model for other Mongolian Protected Areas.

During random-sample and non-systematic surveys between 2010 and 2019, over 200 archaeological cultural heritage sites were recorded; most could be assigned to a time or cultural period based on either feature characteristics or archaeological assemblage. Those cultural periods used were Neolithic, Bronze Age, early Iron Age, Xiongnu, Mongolian Empire, Tibetan Buddhist, Ming, Russian Influence, etc. The Ikh Nart landscape was found to be rich in both prehistoric and historic archaeological sites as well encompassing a wide variety of site types. Moreover, the frequency, distribution, and types of archaeological sites varied between the northern and the southern portions of the elongated configuration of Ikh Nart (Schneider et al., 2021; Farquhar, 2022 and see Fig. 2).

2.1. Neolithic residential sites

Prominent among these sites are Neolithic residential sites which occur most frequently along now-ephemeral drainages that flowed more regularly in the past (see Fig. 2 for the locations of major residential sites mentioned herein). Because the economic transition in Mongolia was eventually to nomadic pastoralism rather than agriculture, Janz (2012; Janz et al., 2015) developed a regional chronology for this period of transition that hypothetically included a time of optimum climatic conditions during the Middle Holocene; Janz used more appropriate names for the sites in the Gobi-Steppe environment (within which Ikh Nart lies) to reflect the economic differences in the pathway(s) from hunter-gatherer lifeways to nomadic pastoralism. Using the Janz (2012) model, the Ikh Nart sites that are the subject of this paper would be considered *Oasis II*. Accordingly, the presence of GST and Neolithic ceramics (Olzbayar, 2016) are the diagnostic artifacts that were used to identify Oasis II sites.

2.2. GST at Neolithic (Oasis II) residential sites

In 12 + years of work within Ikh Nart, remarkable similarities in the GST identified at Oasis II sites were noted: similarity in their size, morphology, and the type of stone used. The typical GST platform, i.e., the nether stone or the lower part of the pair of milling stones, is

[2] Ground stone tools (GST) include: milling platforms (metates, querns, netherstones), hand stones (manos, grinders), pestles, stone mortars, bowls, hoes, axes, adzes, and other forms. These are the stone tools used to process (pound, grind, crush, cut, polish, scrape, soften, etc., various substances into smaller-sized particles or otherwise change their natural state. Reduction in particle size can improve palatability, access to nutritional components, workability, or appearance. Other changes of state can soften, separate, and make more useable.

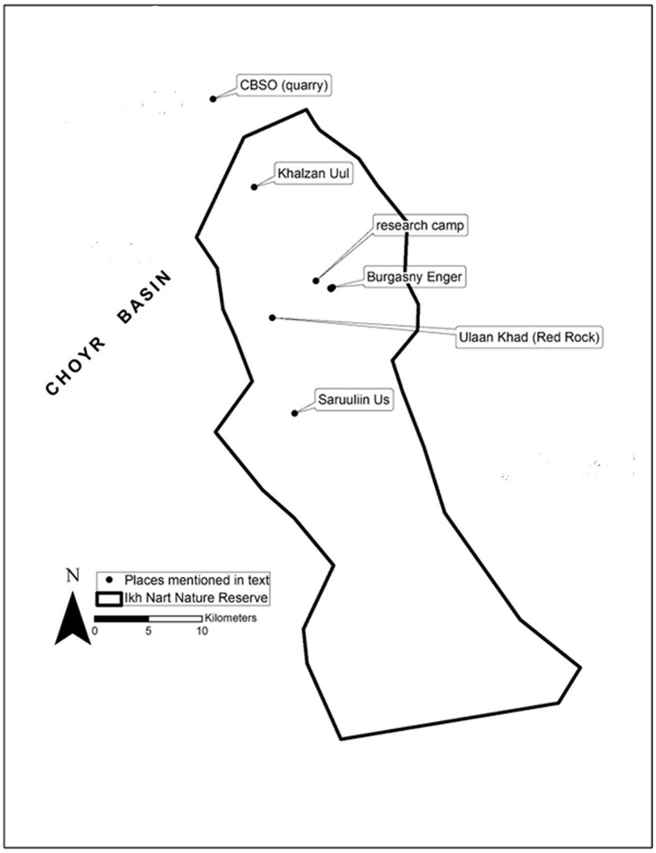

Fig. 2. Ikh Nart Nature Reserve with the locations of places mentioned in the text.The Oasis II (Neolithic) site complexes are: *Burgasny Enger*, Research Camp, *Ulaan Klad (*Red Rock*), and Saruuliin Us.* The CBSO quarry is the sandstone outcrop. *Khalzan Uul* is the location of a mineral spring and is within the *Khalzan Uul* Formation. The *Choyr Basin* is the large basin within which the sandstone quarry (CBSO) is located. [Map created by Llouise Jee]

sandstone, used unifacially (although some bifacial wear was noted on several of the tools), rectangular or sub-rectangular in plan view, and shaped and worn about the margins. The GST platform thicknesses average 2.1 cm. Most are relatively small, between 13 cm and 11 cm in largest dimension and 6 cm to 10 cm in width. A few larger, nearly complete GST platforms were also found; one measures 30 cm in length and 21 cm in width, ranges between 2 cm and 1 cm in thickness, and is worn thin at one end.

Hand stones, the upper portions of the GST milling pair, are somewhat smaller, shaped, made of sandstone, and exhibit similar wear patterns as the GST platforms. Hand stones were more often found as complete artifacts than the platforms; this is likely because they are smaller, likely had less force applied to them, and thus were less subject to fracture. It is often difficult to differentiate between a GST platform (lower) and the hand stone (upper) because of minimal differences in size and shape (unlike those described by Cordeiro (2424)). With use-wear analysis this determination may be possible (cf. Dubreuil et al., 2022). This is irrelevant to our subject, however, as the source of the sandstone is the subject of this study. However, the morphology of the GST does place some limits on the source of the material (see below).

2.3. Appearance of the GST

Typical sandstone GSTs, that have been more fully described elsewhere (Schneider et al., 2016), are shown below Fig. 3 shows a typical small sandstone GST platform. This tool is bifacial, moderately worn, and light enough to be easily carried. Fig. 4 shows a much larger GST platform of sandstone, partly reconstructed. It is thin in profile, unifacial, exhibits a high degree of wear, and some evidence of rejuvenation.[3] Fig. 5(A) shows a typical sandstone hand stone. It is bifacial and well-worn. The Ikh Nart hand stones are like the Type 3 hand stones from the collections described by Cordeiro (2424). Fig. 5B shows a small sandstone pestle. Observations (non-magnified) indicate that use-wear exists only on the larger end, rather than on the sides of the pestle, thus distinguishing it from a roller (Dubreuil et al., 2022) and elongated hand stones (Types 1 and 2) as described by Cordeiro (2424).

Sandstone appears to have been a preferred rock type for processing a variety of substances as is reported by other investigators (e.g., He, 2024 [Table 5.3, Table 6.5]; Liu et al., 2011 [Shizitan site cluster]; Janz, personal communication [Zara Uul]). At one agricultural site along the Yellow River in China, sandstone tools were used for working agricultural fields and were made and distributed to nearby settlements (Ford, 2004; Webb et al., 2007). Rather than serving as milling tools, sandstone slabs were apparently used to grind the stone axes, adzes, and hoes used in agricultural practices.

Often, the materials from which GST are made is not reported by researchers, the study emphasis being on how they were used (use-wear) and/or what was processed on them (residue studies). Although a few of the Ikh Nart GST platforms and hand stones were originally thought to be sandstone, they were subsequently identified, in thin section, as made of granitic rock; they closely resemble (in morphology and material appearance) the sandstone GST. This similarity was also noted by Cordeiro (2424:29 [Table 3.1]) in her study collection.

GST morphology can provide clues to the type(s) of source outcrops; in the case of the Ikh Nart sandstone GST, they were likely obtained from outcrops that are tabular in nature. The northern half of Ikh Nart, where most of the Oasis II sites are located, is described as a *Granite Massive* (Ganbat et al., 2019) with tabular granitic outcrops common.[4]Available geological maps, field reconnaissance over several years, and inquiries of geologists familiar with the Ikh Nart area of Mongolia, failed to identify any sandstone outcrops within Ikh Nart. Geological mapping in Mongolia, however, is limited, especially at a detailed level. Moreover, most geological mapping has been focused on mineral exploitation.

3. Chronological placement of the Ikh Nart sandstone GST

Archaeological excavation within Ikh Nart is limited to that carried out by the Ikh Nart American-Mongolian archaeological team. All GST described here and elsewhere (Schneider et al., 2016) were identified and recovered from the surfaces of sites, with one exception. In the extensive excavation at Ikh-28/Ikh-9 (*Burgasny Enger*), a major Oasis II complex location (see location in Fig. 2), a typical sandstone GST platform was found in an upper stratum of the block excavation, incorporated into a hearth feature (Arlene Rosen, personal communication 2022). Ashy fill from the hearth, however, was dated later than Oasis II times at 850 +/- 30 BP (Cal CE 1150–1270 [95.4 %]).[5] That artifact was collected from the hearth during the 2022 field season and measures 12.4 cm in length, 9 cm in width, is 2 cm thick, and weighs 566 gm (see Fig. 6). It was shaped, used unifacially, and only moderately worn. At the present time, chronological placement of the GST remains problematic. Milling tools, especially heavy ones, were often left at sites and reused by later occupants (Fairservis, 1993:126); sometimes they were cached in expectation of a return to a location (Sutton et al., 1993), and/

[3] Rejuvenation consists of re-roughening a polished surface by creating divots using a hammerstone, thus increasing abraisiveness (grinding effectiveness) of the surface.

[4] Although granitic outcrops are characteristic features throughout Ikh Nart, there is no evidence that flat or relatively flat bedrock or boulder surfaces were used for milling/processing they are in many other parts of the world.

[5] Radiocarbon Date on Feature 1 at Ikh-28; BE-22-C14-11 (177-BE-22–1). It may be that GST was incorporated into the hearth as a hearth stone during the Medieval Period.

Fig. 3. Typical sandstone milling platform from Ikh Nart. [Photo by Sam Webb]

Fig. 4. Large sandstone milling platform found in fragments at *Burgasny Enger*. [Photo by Joan Schneider]

or passed down through generations (Searcy, 2011). In deflationary circumstances, such as that of desertification, surface manifestations of landscape use by peoples of several time periods can be mixed, resulting in artifacts of different periods sharing the same surface. This may be the case at Ikh Nart.

4. The research question: Where did Oasis II people obtain the sandstone?

Having determined that no sandstone outcrops existed within Ikh Nart, the search for tabular sandstone commenced.[6] Limited geological maps were available at the scale necessary for our purposes. A search of the geological literature resulted an article related to sandstone outcrops (Kelty et al., 2008) especially, those in the Hangay-Hentii basin north of Ikh Nart. Using the published UTM coordinates for these outcrops (Kelty et al., 2008), a systematic survey of each of the identified sandstone outcrops took place between 2017 and 2019. Hand samples were obtained, and thin sections made from each outcrop sample. Efforts (using comparative thin-section petrography) to match these thin sections with

Fig. 5. (A) Typical sandstone hand stone from Ikh Nart; (B) pestle from Ikh Nart. [Photos by Sam Webb]

Fig. 6. 6(A) The only sandstone GST found, to date, in subsurface context at Ikh Nart; the yellow arrow points to it, partially exposed in a hearth feature at Burgasny Enger. 6(B) and 6(C): plan and end views of the GST. [Photos by Joan Schneider]

Table 1
Descriptions of thin sections from 11 GST samples.

1	Clastic Sandstone	Grains are granites and clasts of minerals from decomposed granite (Ksp, quartz, plagioclase). Ksp is dominant	Small fragments in siliceous cement (crypto quartz and rarely crypto quartz hydromica.	Ksp in granite clasts are characterized by Carlsbad twinning and perthite growth.
2	Fine-grained Sandstone; Clastic Texture	Mostly quartz	Crypto quartz cement and hydromica	–
3	Deformed Leucogranite	Ksp-pertite and quartz are dominant. Muscovite is present		Granite that has been subjected to tectonic process. Quartz grains are cracked (deformed) and later recystalized
4	Undeformed Leucogranite	Ksp and quartz phenocrysts	Phenocrysts embedded in similar quartz-Ksp + muscovite ground mass	Ksp phenocrysts have Carlsbad twinning and perthitic growth and have lattice texture in ground mass
5	Medium-grained Sandstone	Grains are plagioclase and quartz and make up 10 %	Matrix consists of fine-grained arkose and siliceous and hydromica-siliceous cement	–
6	Coarse-grained Sandstone	Grains are quartz, Ksp and are greater than 500–650 μm. Grains make up 10 % of volume	Matrix is 90 % of volume and consists of fine-grained arkosic sandstone clasts and crypto quartz + yellow hydromica cement	–
7	Coarse-grained Sandstone	Clasts are mostly quartz; rarely plagioclase and Ksp	No matrix; hydromica-siliceous cement	–
8	Clast Lava	–	–	–
9	Clast Lava	–	–	–
10	Lava Sandstone	Rounded clasts of volcanic rocks	Lava cement	–
11	Coarse-grained Sandstone	Fragments of volcanic rocks and granite	–	–

the thin sections prepared from Ikh Nart sandstone GST, failed (Britton, 2019).

In 2022, Ikh Nart sandstone GST were examined by the Director of Ikh Nart Nature Reserve, Anandpurev Tumurbaatar; he is a member of a local herder family that has multi-generational experience with the landscape of Ikh Nart, its people, and the surrounding area. He, in turn, showed the sandstone GST to other local herders; one suggested a visit to an outcrop identified by the petroglyphs on its surface (see below). This relatively low and small outcrop of sandstone (Fig. 8) is located in the Choyr Basin, northwest of the northern boundary of Ikh Nart; see location in Fig. 2. Hereafter, the outcrop is referred to as "Choyr Basin Sandstone Outcrop" (CBSO). The formation of the Choyr Basin and its geomorphological relation to the Ikh Nart Granite Massive (Ito et al., 2006), forming the eastern edge of the Basin, are beyond the scope of this discussion. The Choyr Basin is now filled with Holocene alluvium.

Petroglyphs, described by the herder, were present at the site (Fig. 10). Samples of slabs of sandstone were collected from small concentrations of sandstone debris on the outcrop surface. Thin-section slides were made from sample clasts that had naturally separated from the outcrop; attempts to analyze them petrographically were thwarted because of the effects of weathering. Larger samples from the body of CBSO were taken in 2023; the larger samples allowed the removal of the weathered outer portion of the sample so that thin-section slides could be made from the inner, less-weathered portion. Thin-section petrography of these less-weathered samples determined that the material is very similar to the GST thin-sections previously made from the GST collected from Oasis II sites (see petrographic descriptions, below)—similarity in clast and mineral types and cementing substance (Batulzii, 2023).

5. Rationale for thin-section petrography as a method

Thin-section petrography is often used to describe sedimentary rocks. While sourcing obsidian (and more recently basalt and andesite) using geochemical signatures has long been used by archaeologists to source tool stone, it is not suitable for sedimentary materials for several reasons. First, sedimentary rocks are extremely variable, even within the same geological exposure. Second, when rock texture is an important characteristic to consider, as it is with GST used for abrasive tasks such as milling, understanding chemical consistency is not particularly useful. It has been hypothesized that, for GST, the texture of stone is extremely important because texture is associated with efficiency in processing tasks (Schneider, 2002a, 2002b); the stone must not be so friable that it wears away rapidly, adding stone particles to whatever was being processed. The stone must have the strength to withstand abrasive forces, should maintain the abrasiveness of the processing surface with use, and not develop polish rapidly. A polished surface, because it is less abrasive, requires periodic refurbishing (i.e., re-roughening) as is sometimes evident on GST made from granitic rock, some sandstones, and other types of stone.

Thin-section petrography has the benefit of not only identifying the minerals making up the basic structure of sedimentary and igneous rocks, but also inclusions, type of cementation in sedimentary rocks, and other textural qualities, e.g., the roundness, angularity, and sizes of clasts, the strength of the cementing substance, sizes and relative number of vesicles, and other characteristics not revealed by geochemical techniques. Rybin et al. (2018) stated, "Study of petrographic composition is important for understanding how humans exploited available resources. Stone raw material played a pivotal role in the subsistence life of paleo-populations, influencing knapping technology, tool typology, routes of population movements within the home area, and possibly the size of the region."

Vesicular basalt is preferred for GST in many parts of the world because of its texture. The voids in the basalt (the vesicles) provide sharp edges that maintain abrasiveness, even during heavy use. In areas where vesicular basalt is unavailable (or avoided because of cultural traditions), stones that have large and hard clasts or crystals within a finer-grain matrix, such as some sandstones and andesites, serve the same purpose: maintaining abrasiveness. The smaller and finer grains of the matrix wear away rapidly, leaving larger, sharp clasts exposed; thus, the

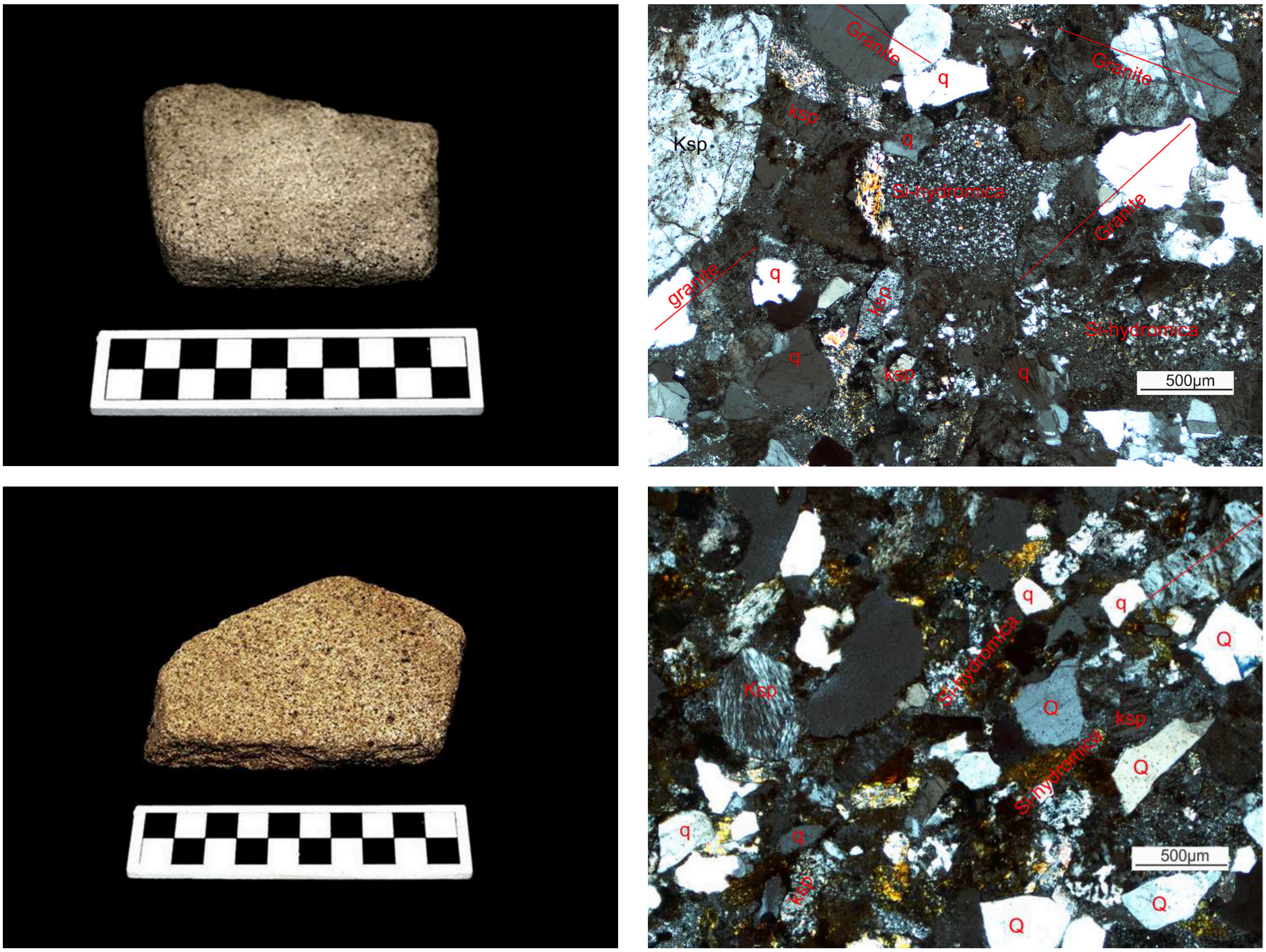

Fig. 7. (A) Fragmental GST Sample #1 from which thin section was made; (B) thin section of fragmental GST Sample #1 with geological constituents identified (polarized view); (C) fragmental GST Sample #6 from which thin section was made; (D) thin section of fragmental GST Sample #6 with geological constituents identified (polarized view). [thin-section photos by Dash Batulzii; artifact photos by Sam Webb]

Table 2
Abbreviations used as Labels in Thin Section Photographs.

Klasts		***Label***
1	Quartz	Q
2	K-feldspar	Ksp
Minerals in Matrix		***Label***
1	quartz	q
2	K feldspar	ksp
3	muscovite	ms
Cement		
Quartz + hydromica		Si + hyd.mica

abrasiveness of the working surface is maintained (*sensu* Adams, 2002). Maintaining abrasive surfaces is an advantage for people carrying out daily lengthy tasks such as processing various plant and other products. In an economic and energy-expenditure context, traveling some distance is worthwhile for people (or paying more in the marketplace) to get GST of superior stone (Abadi-Reiss and Schneider, 2010; Cook, 1973; Hayden, 1987; Schneider, 1993, 1996; Schneider and Altschul, 2000; Searcy, 2011; Tindale, 1974; and others).

5.1. Petrographic descriptions of the GST

Table 1 presents the petrographic descriptions of all GST thin-sections in our sample. Detailed petrographic descriptions of two of the GST samples are below. All artifacts and their thin sections are curated at the Mongolian Academy of Sciences, Institute of Archaeology, in Ulaanbaatar.[6]

The petrographic thin-sections made from Ikh Nart Oasis II GST revealed that the tools are typically made from a clastic sandstone (Table 1). Fig. 7 (A–D) shows two of the eleven artifact samples for which thin sections are available (see Table 2 for interpretations of the symbols in the thin-section photographs).

Fig. 7A shows GST Sample #1, the GST fragment from which the thin section was made. Fig. 7B is the polarized view of the same sample thin section. It is arkose sandstone consisting of clasts, matrix, and cement; the matrix is dominant (55 %) with included clasts making up 45 %. The matrix consists of small fragments of quartz, K-feldspar, and granite with porous portions filled by silica-hydromica cement, which is crypto-quartz and rarely crypto-quartz-hydromica. Clasts are represented by fragments of granite and minerals derived from granite (such as K-

[6] Readers should note that the samples were taken from fragments of incomplete artifacts and not from artifacts that were complete or nearly complete.

Fig. 8. Surface of Choyr Basin Sandstone Outcrop (CBSO). Note the tabular nature of the low outcrop and the debris on the surface that is the result of trimming slabs of stone. [Photo by Joan Schneider]

feldspar and quartz). The K-feldspar clasts, dominant in mineral clasts, are characterized by Carlsbad twinning and perthite growth. The red lines indicate the granite clasts in the thin section. None of the clasts are rounded. The sizes of mineral clasts range upward from 1500 μm; the size of the granite fragments is greater than 600 μm.

Fig. 7C shows GST Sample #6, along with a photograph of its thin section in polarized light (Fig. 7D). This sample is fine-grained arkose sandstone in which the matrix is dominant. The larger clasts are quartz and K-feldspar, 500–675 μm or larger in size and make up 25–30 % of the volume of the rock. The other clasts are less than 500 μm in size. The matrix consists of silt-sized clasts. The porous spaces are filled by the silica-hydromica cement and silica as well as crypto-quartz. The silica-hydromica is characterized by a yellow color.

6. Choyr basin sandstone outcrop

After three field seasons of geological reconnaissance in and around Ikh Nart, as well as further afield, in 2022, an isolated sandstone outcrop in the Choyr Basin was found north-northwest of the northern boundary of Ikh Nart (see above). The Choyr Basin is a very large depression to the west of Ikh Nart; its geological origins and geomorphology are beyond the scope of this paper. A small, east-central portion of the Choyr Basin is within the boundary of Ikh Nart, and this portion of the Basin was included in the random sample survey (Schneider et al., 2021). Site types that were identified within the Basin include a Mongolian-Empire period cemetery, a quartzite quarry, single-burial features of various time periods, and scatters of Chinese ceramics (Schneider et al., 2021). No residential sites of Oasis II times were identified. Groups of camels are frequently seen, roaming the Basin.

6.1. Description of the sandstone outcrop

The sandstone outcrop in the Choyr Basin (CBSO) is generally irregularly oval in shape (see the location in Fig. 2, and appearance in Fig. 8), approximately 35 m long north-to-south and 60 m long, east-to-west, is exposed for a height of about two meters above the surrounding alluvium that covers the Basin (Fig. 8). Identifying this single outcrop does not rule out the probable presence of other small outcrops within the Basin, but it is the closest sandstone outcrop to the residential sites where the sandstone GST were found.

The tabular nature of the bedrock is evident; the thickness of the tabular slabs of stone at the outcrop is variable, but within the range of the thicknesses of the GST. On the surfaces surrounding the sandstone

Fig. 9. Red jasper cobble within a workshop locus at CBSO. [Photo by Joan Schneider]

Fig. 10. Horseshoe-shaped petroglyphs on the outcrop as described by local herdsman, seen just above the 10-cm rule. These petroglyphs were identified as ancient clan symbols.

outcrop, and on the lower reaches of the outcrop itself, are loci composed of many tabular fragments of stone removed from the outcrop. These loci closely resemble the configuration of lithic workshop loci found at other GST quarry workshops: a cluster of flakes, one or more hammerstones usually composed of cobbles of harder and more compact materials such as quartz, quartzite, and jasper, and/or broken or failed GST preforms. Large boulders with flake scars are absent (cf. Ridsky et al., in press; Schneider, 1996, 2020; Schneider et al., 1995; Spenard et al., in press), calling attention to the tabular nature of the outcrop. Thin, naturally tabular sandstone could be removed from the

Table 3
Thin section descriptions of 4 sandstone outcrop samples.

Sample #	*Rock Description*	*Clasts/Grains*	*Matrix/Ground Mass*
a	Sandstone	Grains are quartz and Ksp	Quartz, Ksp, and silica
b	Sandstone	Big grains of poly quartz and small quartz clasts and silica	
c	Sandstone	Biggest granite clast consists of Ksp and quartz, obviously from phenocrysts. Granite clast consists of small quartz and Ksp, similar to groundmass	Granite and silica minerals
d	Sandstone	Granite clasts consist of quartz, Ksp, muscovite, and silica minerals	–

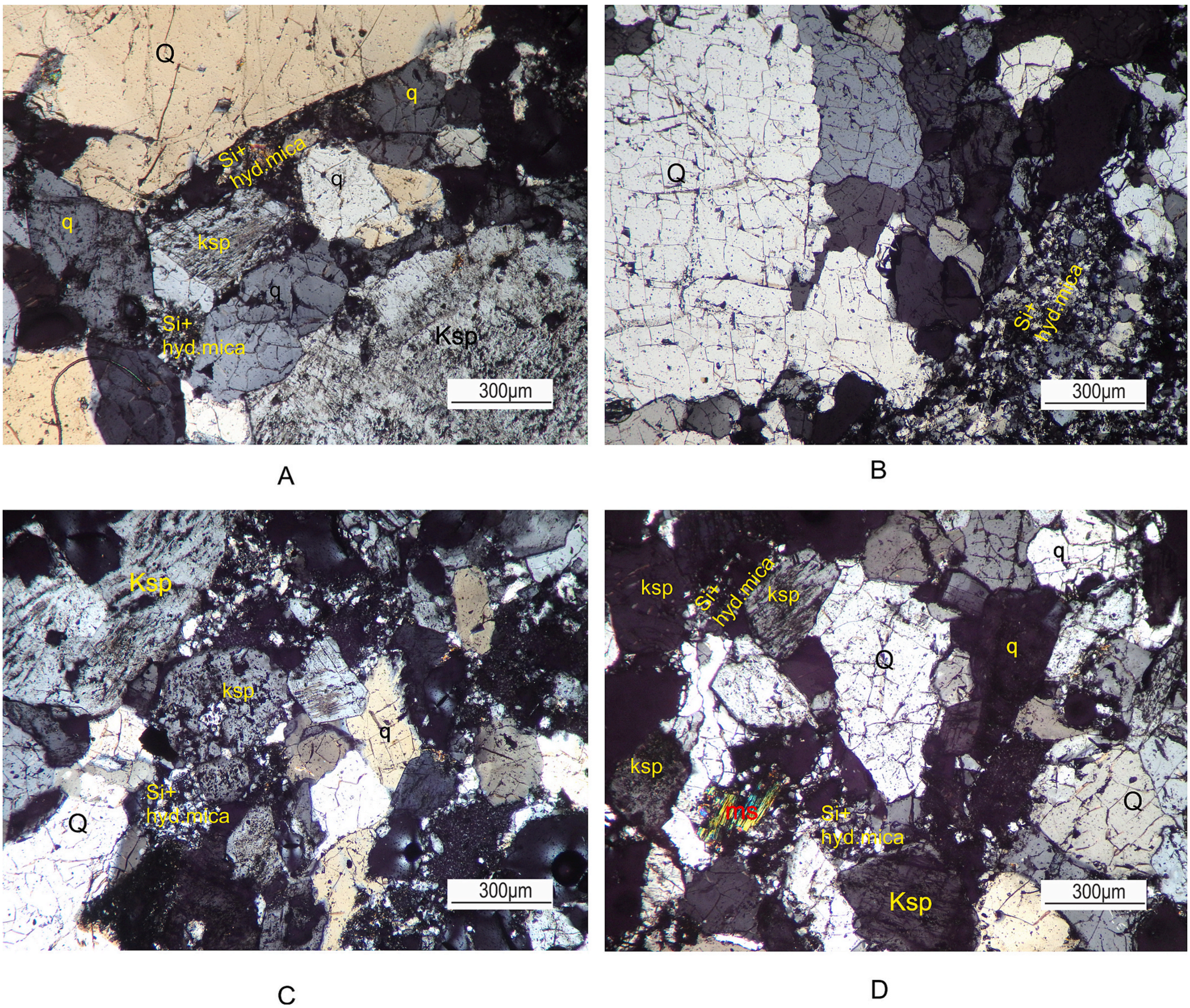

Fig. 11. (A-D). Thin sections (polarized views) of each of four samples taken from the CBSO. [Thin-section photos by Dash Batulzii]

outcrop, trimmed, shaped about the edges (with minimal effort), and used.[7] Non-local cobbles of pure quartz, cryptocrystalline, and volcanic rock are present within loci (Fig. 9); these were likely used as hammerstones to trim irregularities from the thin tabular slabs of sandstone before the slabs were carried away.

The inconspicuous CBSO is marked with petroglyphs of an ancient clan symbol (Fig. 10) and more recent Buddhist writings. This fact supports the hypothesis that the marked outcrop is likely the source of many of the GST found at the Oasis II sites in Ikh Nart because it is a location of special note (personal communication Yadmaa Tserendagva 2022).

Sandstone GST, found as isolated artifacts, within assemblages of smaller surface sites, and as major components of four large sites fall within the northern half of Ikh Nart. Each of the larger Oasis II sites is centered on a major drainage (now ephemeral). These sites are Ikh-28

[7] Flat surfaces are difficult to achieve by shaping naturally rounded rocks and boulders. Therefore, it would have been advantageous to obtain stone with a naturally flat surface. This is especially true of the Ikh Nart GST because of their relatively small sizes. It may be that the sizes reflect the sizes of the sandstone slabs available from the CBSO. Other quarried outcrops of the Choyr Basin sandstone may be identified with additional reconnaissance.

and Ikh-9, *Burgasny Enger* [Willow Grove Slope]), Ikh-78 (*Ulaan Khad* [Red Rock]), Ikh-2 (in proximity to the Ikh Nart Research Camp), and Ikh-152 (*Saruuliin Us* [White Water]). The map-based distances from these major Ikh Nart Oasis II residential sites to the CBSO quarry range between 19 km and 29.8 km (see Fig. 2). The CBSO quarry was probably accessed by traveling from the higher elevation of the Ikh Nart plateau, following the stream-cut canyons, to the Basin below.

6.2. Petrographic description of the CBSO sandstone

Thin sections from the 2023 sampling of the CBSO are described petrographically in Table 3. Photographs of the thin sections are shown in Fig. 11(A–D). All four samples from the outcrop are arkosic sandstone formed in an alluvial fan or fluvial apron environment. They are composed of mineral clasts that are represented by quartz and potassium feldspar (Ksp), as well as by granite clasts, which are the predominate clast type. The largest clasts range from 2.0 × 1.8 mm to 2.5 × 2.2 mm. The smaller clasts consist of quartz, potassium feldspar, and to a lesser extent, muscovite and tourmaline. The poorly sorted clasts of quartz and potassium feldspar are dissected by cracks filled with clay minerals which have a blackish color in thin section.[8]

7. Results and discussion

Petrographic comparisons of thin sections and their interpretation make it probable that the GST found at Oasis II residential sites, as well as isolated artifacts on the Ikh Nart landscape, originated within the Choyr Basin. Based on more advanced GST research and its results across the international spectrum, however, there are many questions about the sandstone GST at Ikh Nart that remain as-yet unanswered. For example, is the CBSO quarry of the Lower Khalzan Uul Formation (Ito et al., 2006) the sole source? Other similar outcrops may have been exploited, but remain undiscovered or covered by alluvium. Was the sandstone obtained during special trips to the quarry area (primary procurement [*sensu* Binford, 1979:259-261]) as was the case at other GST quarries (cf. Rosen and Schneider, 2001; Schneider, 1993, 1996; Schneider et al., 1995)? Alternatively, were they gathered when Oasis II people happened to be in the vicinity of the CBSO quarry (embedded procurement [*sensu* Binford, 1979:259-261]; Wilke and Schroth, 1989:146-148)? Were the GST personal items that were carried about in this early Mongolian society? Their small size made them readily portable and this society was likely a mobile one. Or are the small sizes of GST a result of sandstone natural configuration at outcrops? What substance(s) was (were) processed using the GSTs? At this point in time, cooked starch has been found on a few of the Ikh Nart GST. Were these starches remains of root crops or above-ground plant parts? Were the GST procured and/or used by males or females or both? What characteristics of sandstone made it preferable to the readily available granitic stone for GST? Did the Ikh Nart GST have values other than economic ones?

Preliminary laboratory analysis of residual plant parts on selected Ikh Nart GST indicate that some sort of cooked starch may have been processed with them (Schneider et al., 2016). Methods and techniques to identify plants and plant parts on GST and other artifacts are now well-established archaeological tools; use-wear and replicative studies continue to provide insights into past cultural behaviors in the Gobi-Steppe region (Cordeiro, 2424; He, 2024). It is anticipated that these types of studies will more fully inform our understanding of GST use at Ikh Nart and why sandstone was a preferred material in this granite landscape. Descriptive accounts of archaeological sites, ethnographic data, and laboratory studies worldwide have broadened the horizons of archaeology (e.g., Cordeiro, 2424; Dubreuil et al., 2021; He, 2024; Kraybill, 1977; Liu et al., 2011, 2014; Yang et al., 2016; Yohe et al., 1991, and others) and inform us that GST were often used to process many differing substances, including medicinal ones, and that many factors and variables (other than the availability of plant resources) have their effect during the times of and in the locations of cultural transitions.

We know other cultures imbued GST and other household items with social, spiritual, and ceremonial values (e.g., He, 2024; Tindale, 1974; Searcy, 2011). What are the connections between GST use and the transition to pastoralism in Mongolia (Rosen et al., 2022; Janz et al., 2021, 2024; Evoy, 2019)? The temptation exists to directly attribute a climatic optimum to an opportunity to exploit nearby resources and settle in for longer periods of time but, as He (2024) and Hodder (2023) point out, there are not simple/single explanations forcultural changes and the tools and other accessories that accompany these changes, or vice versa. The "entanglements" (*sensu* Hodder, 2023 and others) of natural, social, and temporal factors represented in the archaeological assemblages that scientists attempt to interpret are interwoven, obscure, and often indecipherable.

A small piece of the Oasis II puzzle can be provided to those attempting an explanation of the complexity of the period(s) of transition(s) from the hunter/gatherer way of life to nomadic pastoralism: Oasis II people living on the granitic plateau of Ikh Nart used sandstone GST, but the sandstone was not immediately available to them. They had to travel to get it or had to trade with others. Thus, the procurement of sandstone is just one element in defining the extent of their cultural landscape. Other elements might include sourcing of pastes and tempers from which ceramics were made or identifying the sources of cryptocrystalline rocks from which the blade cores, blades, scrapers, and other tools were made.

8. Synopsis and final comments

Using comparative petrographic thin-section analysis, a probable source of sandstone from which the majority of Ikh Nart Oasis II (Neolithic) GST were made has been identified: an inconspicuous quarry source at some distance from the major Oasis II centers of residential life within Ikh Nart. The uniform morphology and composition of GST tools provoked inquiry and aided the search for their source.

The Oasis II GST were made from very hard, fine-grained arkose sandstone composed of large clasts (including clasts of granite) in a matrix of smaller clasts and cemented with silica. The arkose sandstone (where feldspar is dominant) led to GST longevity under regular heavy use; due to the texture of the sandstone; the GST had the advantage of retaining abrasiveness with use and wear, thus not requiring much periodic renovation or replacement. It is likely that GST had multipurpose functions as has previously been found by Liu and others (He, 2024; Liu et al., 2011, 2014, 2016a, 2016b).

The relationship between GST and food provisioning is about to enter the forefront of Mongolian archaeological inquiry as it has in other regions of the world (e.g., Nelson and Lippmeier, 1993; Liu et al., 2016a, 2016b, and many others) where a myriad of laboratory analytical procedures has recognized remnants of plant proteins, starches, and phytoliths as well as animal proteins and lipids on GST and other household and ceremonial items. The ability to geologically source tool materials, in addition to determining how GST were used and what was processed

[8] This type of arkosic sandstone, or "arkose," can form wherever block faulting of granitic rocks occurs, and the rates of uplift, erosion, and deposition are so great that chemical weathering is outweighed, and feldspar can survive in a relatively unaltered state. These rocks are usually reddish, generally immature, very poorly sorted, and frequently interbedded with arkose conglomerate. Alluvial fans or fluvial aprons were the main depositional environments. The source of the granite clasts is medium-grained granite. The various size clasts are mostly in contact with each other and are sometimes surrounded by silica cement composed of crypto quartz and opal. In thin section, the detrital texture is sometimes composed of grain, matrix, and cement. It is sometimes difficult to obtain such a texture if granite clasts are joined (see Fig. 11C and 11D).

with them will enhance our understanding of circumstances of transitions. The results of the study described here demonstrates that one geological method (comparative thin-section petrography) can be used to establish that the cultural landscapes of humans of the past can be further defined by the sourcing tool stone and many other materials This study may encourage others to give more attention to ancient domestic practices in Mongolia during the transition from a hunting-gathering lifeway to nomadic pastoralism as well as in other periods of transition. Oasis II people living around the streams and marshes of what is now Ikh Nart sought very hard, fine-grained stone composed of larger clasts of minerals and granite in a matrix cemented by silica to make most of their GST. The stone was located at a lower elevation and at some distance from where they were living on the Ikh Nart granite plateau. It is not yet certain (1) how the GST were used, (2) what substance(s) was (were) processed with them, (3) why this sandstone was sought out when the Oasis II residential sites are surrounded by granitic outcrops, (4) how GST are apparently associated with Oasis II lifeways, or (5) if obtaining the sandstone was a primary or embedded procurement strategy or obtained through trade. Sandstone seems to be a preferred material for GST throughout the steppe region of central Asia (L. Liu, personal communication 2024; L. Janz, personal communication, 2022), but determining the source(s) of the sandstone and methods of GST production has not been a subject of archaeological inquiry in this region. In-depth research into the period that encompasses the transition to pastoralism in the Gobi-Steppe region has just begun (e.g., Cordeiro, 2424; Dubreuil et al., 2021; Farquhar, 2022; Janz, 2016; Janz et al., 2017, 2021, 2024; Rosen et al., 2019, 2022). There is much to be learned and much work to do.

CRediT authorship contribution statement

Joan S. Schneider: Writing – original draft, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Dash Batulzii:** Writing – review & editing, Resources, Methodology, Formal analysis. **Susan H. Gilliland:** Writing – review & editing, Resources, Investigation, Conceptualization. **Gantulga Bayasgalan:** Writing – review & editing, Resources, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request to the corresponding author.

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