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Dating surface assemblages using pottery and eggshell: assessing radiocarbon and luminescence techniques in Northeast Asia

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ABSTRACT

The vast majority of known archaeological sites in arid Northeast Asia are surface assemblages containing few or no organic remains. The lack of stratified sites and a relative absence of organic remains in surface assemblages hinders our ability to date sites, create local chronologies, and contextualize technological and socio-economic change. Such problems are common in arid regions around the world. New radiocarbon and luminescence dates on collections from the Gobi Desert of Mongolia and China are used here to assess the potential for direct dating of commonly occurring artefacts like ostrich eggshell and pottery. Direct dating also allows for the identification and sorting of mixed-age assemblages. Here, we compare dates derived from Accelerator Mass Spectrometry (AMS) on ostrich eggshell, AMS on pottery, and luminescence on pottery. Our findings show that AMS and luminescence are highly complementary methods and produce results consistent with expected archaeological ages, while ostrich eggshell dates were older than the associated site assemblages.

1. Introduction

Surface assemblages often comprise a significant proportion of the archaeological record in arid regions. Although they are frequently used to construct preliminary interpretations of chronology and land-use, they are notoriously difficult to date due to the lack of surviving organic remains and the intermixing of multiple layers of occupation (Fanning et al., 2009; Lewarch and O'Brien, 1981; Sampson, 1986; Shiner, 2009). The challenges involved in constructing chronologies without the benefit of reliable dating methods has impeded our understanding of human habitation in such environments, resulting in the archaeological marginalization of arid landscapes, and a preferential focus on less representative occupation contexts – such as rockshelters or cave dwellings (see e.g., Forssman, 2013). In order to gain a clearer understanding of human adaptive strategies and socio-economic processes within arid regions, it is essential that we continue to develop and test methods for dating the highly durable materials that survive in surface contexts.

Ratite eggshell and pottery are two particularly promising materials (Casson, 2014; Higham, 1994; Janz et al., 2009; Sampson et al., 1997). Ostrich eggshell was used for beads and containers by humans in Asia and Africa long before the invention of pottery (Janz et al., 2009; Texier et al., 2010). It is an extremely durable material which can be dated using Accelerator Mass Spectrometry (AMS) radiocarbon; in fact, the dates are more reliable than those on bone or charcoal because the eggshell is impervious to post-depositional carbon exchange (Bird et al., 2003; Freundlich et al., 1989; Janz et al., 2009; Vogel et al., 2001). Pottery also survives in many open-air sites and surface contexts and can be used to date more recent assemblages. The ability to directly date ceramics offers a wealth of opportunities for analysis of both museum collections and site assemblages where organics were not preserved.

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AMS and luminescence are the best known methods for dating pottery (see Bonsall et al., 2002).

It is especially important that archaeologists be able to understand and evaluate methods for AMS dating of pottery because the prevalence of commercial AMS laboratories, ease of analysis, and relatively fast processing times have made it an increasingly popular method of analysis. There are two areas of major concern with the accuracy of AMS dating on potsherds. The first is the influence of "old carbon," wherein clays containing carbon-rich minerals or older decomposed organics produce dates that are too old (De Atley, 1980; Johnson et al., 1988). The second potential source of error is carbon derived from aquatic foods cooked in the vessel. In the case of inland regions, a freshwater or hardwater reservoir effect is associated with the charred remains of aquatic foods and can result in ages that are hundreds of years older than the date of manufacture and use (Philippsen et al., 2010; Philippsen, 2013). The relative influence of "old carbon" and reservoir effects can be tested by using multiple dating methods and by selecting a study group that includes sherds with various types of organic and carbonaceous residues adhering to or incorporated into the paste of the sherd. Substantial influence from "old carbon" should result in older dates from sherds with blackened pastes. It is not entirely possible to negate the influence of a hardwater reservoir effect without using residue analysis to identify the use of aquatic foods, but their influence should result in older dates on organic residues adhering to the interior surface.

For this study, we focus on surface assemblages from the Gobi Desert region of Mongolia and China. Here, in arid Northeast Asia, habitation sites spanning the Last Glacial Maximum (LGM – 19,000 BC) to the beginning of a local Bronze Age (2000–1000 BC) are known almost exclusively from surface scatters of microblades and other small flake tools. Our samples were originally selected in order to date important local sites. The dates are of significant regional importance because they represent the first substantial advance towards developing a date-based chronology. At the same time, our findings contribute to an improved understanding of dating methods, drawing attention to the strengths and weaknesses of each within a regional context. The data presented here combines a series new dates with those previously published in Janz et al. 2009 and Janz 2012.

2. Geographic region of interest

The studied collections are from the Gobi Desert of Mongolia and China (Fig. 1). They were acquired under archaeologists Nels C. Nelson (1926), Alonzo Pond, and Folke Bergman in the 1920s and 1930s during major multidisciplinary scientific expeditions organized by western explorers Roy Chapman Andrews (1932) and Sven Hedin (1943), and are now curated by the American Museum of Natural History, New York and the Världskulturmuseerna, Stockholm, respectively. Limited sediment deposition and high aeolian deflation in this xeric landscape has created few opportunities for recovery of stratified sites; most were collected as surface scatters with no associated organic remains. The lithics are characteristic of early post-LGM assemblages in Northeast Asia, exhibiting a reliance on advanced microblade core technology in combination with an expedient flake technology (Janz, 2012; Zwyns et al., 2014a). The assemblages have not been directly dated, but according to local nomenclature they are considered to belong to the Mesolithic (i.e., post-LGM microblade-based assemblages without ceramics) and Neolithic (i.e., microblade-based assemblages with ceramics) periods (Derevianko and Dorj, 1992; Maringer, 1963; Okladnikov, 1962). The collections housed in New York and Stockholm have a combined geographic range that covers much of the Gobi Desert and represents a variety of environmental contexts. Moreover, they are associated with abundant archival data, were carefully curated, and have remained largely untouched since their accession. These characteristics make them an ideal sample for studying region-wide chronology.

Due to the lack of chronometric dates, the timing of local technological phases are largely based on stylistic comparisons with better-dated sites in neighbouring regions. Derevianko and Dorj (1992:170–171) suggested that the Mesolithic lasted from about 15,000 to 4000 BC, after which pottery was introduced. Newer AMS dates on wood charcoal and rodent burrow fill from Chikhen Agui, the only published post-LGM site in the Gobi Desert, agree well with that estimate. Mesolithic-type assemblages at the cave site were dated to 11,500–7000 BC (Derevianko et al., 2003, 2008). Based on his excavations at the Neolithic type-site, Shabarakh-usu (*Bayan-dzak*), Okladnikov asserted that the early Neolithic was characterized by the presence of pottery decorated with textile markings, such as net-impressions, that were similar to those recovered from Serovo-period sites in the Lake Baikal region of Siberia (Chard, 1974:82; Derevianko et al., 2003: 56; Okladnikov, 1962). New dates for the Serovo period place it at 4200–3400 BC (Weber et al., 2002), which suits Derevianko and Dorj's timeline. The Neolithic was characterised by the intensive use of dune-field/wetland habitats and the adoption of pottery, milling stones, polished stone adzes and axes, and pressure-flaked bifaces (e.g., knives, projectile points, drills). The Late Neolithic is traditionally considered to represent a period of heightened economic complexity in the late third to early second millennium BC and is transitional to the adoption of a Bronze Age pastoralist economy (Cybiktarov, 2002; Derevianko and Dorj, 1992: 177). Pastoralism gradually became the most visible form of economic organization after 1500 BC, as evidenced by dated burials and monuments containing domesticated sheep or goats and the spread of stone structures associated with pastoralist groups (Fitzhugh, 2009; Honeychurch and Amartuvshin, 2006; Houle, 2010; Tumen et al., 2014; Turbat et al., 2003; Wright, 2006). The details of these technological phases are outlined in Table 1.

One major barrier to analysing these collections is that they often contain artefacts from multiple phases of occupation. Millennia of intermixing across occupational episodes is expected since most localities were undifferentiated surface scatters collected from dune-field margins (e.g., Maringer, 1950: 152). Several site assemblages had remained partially buried until the time of collection and hearth sites with their own artefact cluster were sometimes recovered (Fairservis, 1993; Nelson, 1925; Pond, N.d.), but limited space usually compromised the integrity of such artefact clusters which were routinely combined with others from the same locality. Luckily, those from Shabarakh-usu (*Bayan-dzak*) were largely preserved (Nelson, 1925); but, even despite Nelson's careful approach to collection, there is still a wide range of pottery types represented, often spanning the Neolithic to early twentieth century. Nelson's (1925) notes suggest that this is because sherds were routinely collected from dune surfaces in the vicinity of Stone Age sites. This is especially evident in his description of partially buried sites Shabarakh-usu 1, Barun Daban, and Ulan Nor. Similar practices were followed by collectors working with Pond (N.d.) in 1928 and almost certainly those working with Bergman during his work on Sven Hedin's expedition. As such, we expect that the lithic assemblages will be more temporally cohesive than the ceramic component and we tried to avoid sampling sherds that were clearly younger than the Bronze Age.

Understanding millennial-scale patterns in technology and land-use was much more of a concern for this study than fine-grained dating. We had few expectations about the ages of sites because there was such an essential lack of dates; however, many diagnostic sherds are similar to those found in neighbouring

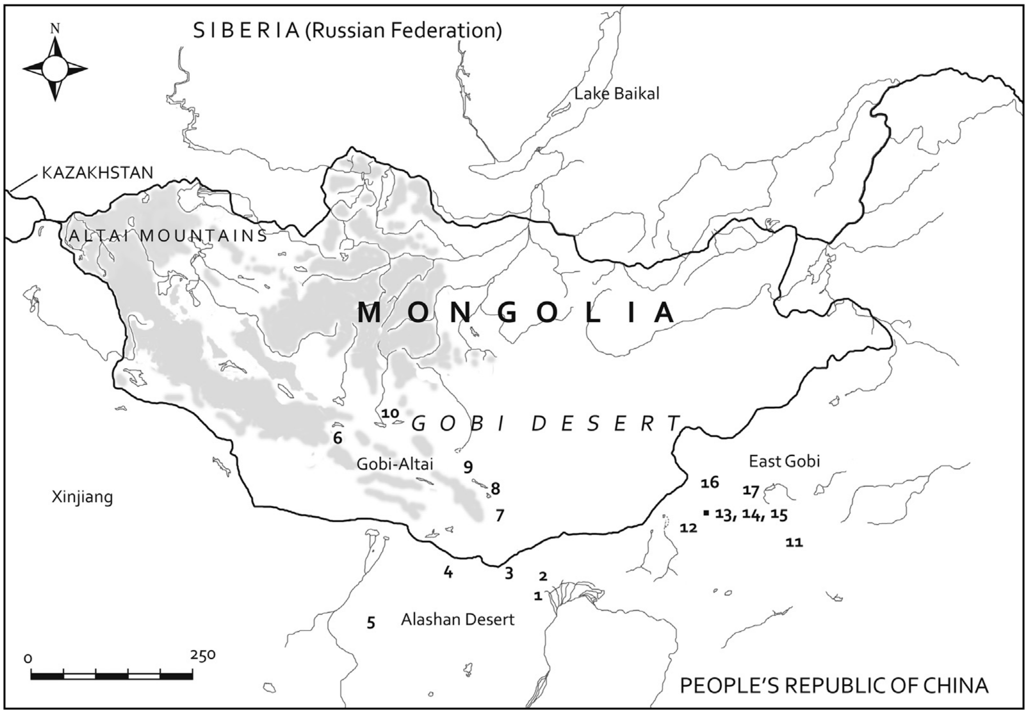

Fig. 1. Map of regions and sites mentioned in the text. 1. Jabochin-khure, 2. Gashun, 3. Yingen-khuduk, 4. Dottore-namak, 5. Mantissar, 6. Chikhen Agui, 7. Shabarakh-usu, 8. Barun Daban, 9. Ulan Nor Plain, 10. Orok Nor, 11. Shara Kata Well, 12. Baron Shabaka Well, 13. Shara Murun Crossing, 14. Ta Sur Heigh, 15. Spring Camp, 16. Alkali Well, 17. Chilian Hotoga Well.

regions and published dates from those sites serve as a rough guide (see Table 2). Consultation with other regional experts, Joshua Wright in particular, was also an important source of information on potential dates. According to the chronology outlined above, we expect Neolithic sites to range in age from 4000 to 1500 BC.

3. Materials and methods

3.1. Sample selection

All of the samples used were graciously provided for destructive analysis by the American Museum of Natural History, New York (catalogue numbers beginning with “73/ …”) and the Världskulturmuseerna (including the Museum of Far Eastern Antiquities), Stockholm (catalogue numbers beginning with “K. 13 …”). Most of the assemblages derive from deflated dune surfaces (Nelson, 1925; Pond, N.d.), but the timing of their exposure is not known. The flakes and tools were unpatinated and retained sharp edges. This, in combination with the persistence of pottery sherds and occasionally hearth features, suggests that the sites were buried for the majority of their depositional history. Sites that were still partially buried upon discovery or had retained hearth features are so noted with the results summary in Table 4.

As noted in Section 2, the samples were selected with respect to their usefulness for chronology-building. We sampled pottery and eggshell from a range of sites believed to have been occupied exclusively during the Mesolithic (Shabarakh-usu 2 *in situ*, Shabarakh-usu 6 *in situ*, Shara Murun Crossing, Alkali Wells), Neolithic (Jabochin-khure, Gashun, Mantissar 4, Mantissar 7, Shabarakh-usu subsites 1, 2, 4, 6, 7, and 10, Ulan Nor Plain, Barun Daban, Shara Kata Well) and early Bronze Age (Dottore-namak, Ta Sur Heigh). Multiple samples were selected from large dune-field/wetland scatters in order to assess both the length of occupation and the degree of intermixing (Yingen-khuduk, Mantissar 12, Orok Nor, Baron Shabaka Well). Multiple samples were selected from smaller assemblages with important diagnostic artefacts if those sites were considered to be more temporally cohesive because of their small size (Dottore Namak) or depositional context (Shabarakh-usu 1, Shabarakh-usu 4, Shabarakh-usu 10). Chilian Hotoga Well was heavily sampled because it was the only site with notable faunal remains.

Since establishing a clearer knowledge of diagnostic artefact types was essential, sherds with distinct and commonly occurring surface decorations were preferentially selected. Plain sherds associated with diagnostic artefact types were also chosen, just as

Table 1
Summary of technological characteristics for each period.

Technological phases	Estimated dates	Tool types
Mesolithic	15,000–4000 BC	Microblade technology; expedient core and flake tools; small, informal milling stones (“rubbing stones”); thumbnail scrapers; local cryptocrystallines
Neolithic	4000–1500 BC	Pottery; microblade technology; expedient core and flake tools; small informal milling stones; chipped macrotools; chipped and partially polished adzes and axes; thumbnail scrapers; small pressure-flaked bifaces (e.g., arrowheads, blades); highest quality cryptocrystallines
Late Neolithic to Bronze Age transition	2000–1000 BC	Pottery; microblade technology; expedient core and flake; large formal milling stones (e.g., slabs, mortars, pestles, rollers); chipped macrotools; chipped and partially or fully polished adzes and axes; thumbnail scrapers; arrowheads; whetstones?; copper slag

*Based on data from Cybiktarov, 2002; Derevianko and Dorj, 1992; Derevianko et al., 2003; Dorj, 1971; Fairservis, 1993; Janz, 2012: Chapter 3; MacKenzie, 2009; Maringer, 1963; Okladnikov, 1962; Tseveendorj and Khosbayar, 1982; Wright, 2006; Weber et al., 2002.

Table 2
Ages of key diagnostic pottery types from dated sites in Russia, Mongolia, and China. Direct dates for Gobi Desert samples are reported in column 4.

Diagnostic	Comparative ages	Source	Gobi Desert dates (95.4%)
Earliest pottery	Russia (Baikal): ~11,000–5800 BC	Kuzmin and Orlova, 2000; Weber et al., 2002.	7733–7549 BC (1 sample)
	North China: ~14,000–9000 BC	Cohen, 2003; Wu and Zhao, 2003; Xia et al., 2001.	
Net-impressed pottery	Russia (Baikal): 5800–1000 BC	MacKenzie, 2009; Weber et al., 2002.	5720–3150 BC (4 samples)
Corded	Russia (Baikal): 5800 BC–?	MacKenzie, 2009; Weber et al., 2002.	6060–1040 BC (3 samples)
	NW China: 5800–771 BC	An 1992a, 1992b; Debaine-Francfort, 1995.	
	NE China: 2200–1600 BC	Shelach, 2010.	
String-paddled pottery	NW China: 3100–1900 BC	Debaine-Francfort, 1995; Myrdal, 2004.	3023 BC–AD 500 (3 samples)
	Mongolia: 1300–200 BC	Houle, 2010.	
Coarse redware	Mongolia: AD 552–840	Uyghur to Turkic? – personal comm. Wright, 2012	880 BC–AD 500 (3 samples)
Fine redware	NW China (painted): 3100–1900 BC	An, 1992a, 1992b; Debaine-Francfort, 1995, 2001; Hung, 2011.	2640–1400 BC (1 sample)
Geometric incised	Russia (Baikal): 3000–1000 BC	Weber, 1995.	2200–960 BC (1 sample)
	Kazakhstan: 2500–1000 BC	Frachetti, 2008.	
Burnished	China: 2400–1900 BC	An, 1992b.	2710–1310 BC (1 sample)
Roller stamped	Mongolia: 10th–14th centuries AD	Liao Dynasty to Mongol period – personal comm. Wright, 2012	AD 890–1259 (2 samples)

they were used to improve the sample size at important sites. Sherds that display distinctly historic manufacturing and decorative techniques, such as wheel-turning and glazed surfaces, were not sampled as they were considered intrusive. Ceramic paste fabrics were not formally analysed. A combination of sand and organics was most common, but there was a great deal of variation, including: fine redware with untempered homogeneous paste, a spongy grey paste of unknown composition, a diverse range of sand-tempered pastes, and organic-rich clays. The quantity and grain-size of sand-tempered sherds was extremely diverse, and in some cases was probably incidental to manufacture.

Samples of ostrich eggshell from the East Asian ostrich (*Struthio anderssoni* Lowe) were selected from sites with and without pottery. The majority of our samples were fragments that were not clearly modified, but they came from sites where there was evidence of bead-making and/or hundreds of eggshell fragments (Mantissar sites, Shabarakh-usu sites, Baron Shabaka Well, Chilian Hotoga Well). Less definitive samples were also taken from aceramic sites that were interesting for chronological reasons or environmental context (Shara Murun Crossing, Ta Sur Heigh, and Alkali Wells). Even in sites with beads or bead blanks, angular fragments of eggshell were preferentially sampled to lessen the impact of destructive analysis. At sites with multiple complete or partially complete beads, we selected one or more of these clearly modified samples in order to ensure that our results were not unduly biased by unused fossil fragments.

3.2. Dating methods

3.2.1. AMS on ostrich eggshell

For this study, ostrich eggshell artefacts were prepared and analysed at the NSF – Arizona AMS Laboratory in Tucson. We used the same selective dissolution procedure outlined in Janz et al., 2009, which was designed to remove the outer layer of carbonate and avoid potential contamination (see also Bird et al., 2003; Burr et al., 1992).

3.2.2. AMS on pottery

Dating pottery using radiocarbon was first attempted in the 1950s and 1960s (see Bonsall et al., 2002). It has become increasingly popular with the advent of AMS radiocarbon dating, particularly in Northeast Asia (De Atley, 1980; Delqué Kolic, 1995; Hedges et al., 1992; Keally et al., 2003; Kunikita et al., 2007; Kuzmin and Keally, 2001; Kuzmin and Shewkomud, 2003; O'Malley et al., 1999; Yoshida et al., 2004; see also references in Bonsall et al., 2002). Radiocarbon dates on pottery are usually derived by directly dating food residues or carbonized inclusions in the ceramic paste (Hedges et al., 1992; Heron et al., 1991; Higham et al., 2010; Kunikita et al., 2007; Kuzmin and Keally, 2001), but can also be derived from carbon residues left by smoke (Delqué Kolic, 1995). Few of our samples contained visible fibres, although some had voids in the paste where organics had been combusted. In most cases the paste was heavily blackened at the core or from the

Table 3
Dose rates for luminescence-dated samples, including estimation of sediment dose rates. Total dose rate (column 4) was calculated for TL and will be slightly lower for OSL because of lower alpha efficiency.

Sample	^{238}U (ppm)	^{233}Th (ppm)	K (%)	Total dose rate (Gy/ka)	Equivalent dose (Gy)			b-Value (Gy μm^2)		
					TL	IRSL	OSL	TL	IRSL	OSL
UW2355	3.72 ± 0.27	12.73 ± 1.42	2.46 ± 0.28	4.52 ± 0.35	6.83 ± 0.54	10.86 ± 0.89	11.46 ± 0.27	0.90 ± 0.12	1.90 ± 0.30	0.61 ± 0.04
UW2356	3.54 ± 0.27	13.51 ± 1.56	2.44 ± 0.15	4.99 ± 0.35	9.31 ± 1.21	4.22 ± 0.38	9.39 ± 1.36	1.35 ± 0.17	1.55 ± 0.09	1.06 ± 0.08
UW2357	2.40 ± 0.16	3.95 ± 0.81	1.98 ± 0.15	3.31 ± 0.25	19.72 ± 2.70	17.03 ± 1.35	19.66 ± 0.59	1.23 ± 0.16	0.95 ± 0.05	1.30 ± 0.04
UW2358	2.59 ± 0.20	10.29 ± 1.23	2.84 ± 0.23	4.11 ± 0.28	12.06 ± 1.19	11.83 ± 0.39	15.51 ± 0.27	0.66 ± 0.05	1.04 ± 0.06	0.51 ± 0.02
UW2359	3.57 ± 0.28	16.35 ± 1.64	4.18 ± 0.32	7.05 ± 1.54	18.4 ± 9.5	17.17 ± 1.66	22.08 ± 1.17	1.60 ± 1.05	1.64 ± 0.16	0.53 ± 0.02
UW2360	2.28 ± 0.15	2.65 ± 0.67	2.63 ± 0.22	4.88 ± 0.54	23.20 ± 2.22	14.37 ± 0.66	13.72 ± 0.40	3.74 ± 0.86	1.33 ± 0.05	1.08 ± 0.03
UW2361	3.75 ± 0.25	9.33 ± 1.31	6.67 ± 0.42	7.34 ± 0.94	4.14 ± 1.70		20.93 ± 0.35	1.88 ± 0.73	1.10 ± 0.30	0.54 ± 0.04
UW2362	2.35 ± 0.17	6.61 ± 0.96	2.62 ± 0.16	3.97 ± 0.23	25.16 ± 1.36	13.07 ± 0.58	16.55 ± 0.46	1.07 ± 0.06	1.08 ± 0.06	1.44 ± 0.07
UW2450	4.13 ± 0.27	9.41 ± 1.23	2.23 ± 0.14	5.59 ± 0.35	4.79 ± 0.40	2.53 ± 0.24	3.63 ± 0.32	2.06 ± 0.20	1.62 ± 0.20	0.81 ± 0.10
UW2451	3.47 ± 0.28	8.04 ± 1.96	2.21 ± 0.10	4.05 ± 0.31	58.2 ± 10.8	14.49 ± 0.61	21.64 ± 0.50	1.00 ± 0.21	1.41 ± 0.06	1.28 ± 0.12
UW2452	3.99 ± 0.24	6.53 ± 1.01	1.10 ± 0.06	4.85 ± 0.51	14.40 ± 1.22	7.44 ± 0.45	7.46 ± 0.15	2.74 ± 0.43	0.95 ± 0.04	0.75 ± 0.02
UW2453	4.92 ± 0.34	14.39 ± 1.68	2.90 ± 0.10	5.80 ± 0.33	43.92 ± 1.59	30.57 ± 2.66	27.61 ± 0.44	1.19 ± 0.12	0.94 ± 0.07	0.52 ± 0.01
UW2454	2.30 ± 0.17	6.21 ± 1.00	2.39 ± 0.13	3.84 ± 0.22	5.04 ± 0.35	4.47 ± 0.21	5.45 ± 0.18	1.17 ± 0.08	1.43 ± 0.06	1.25 ± 0.05
UW2859	1.98 ± 0.16	7.46 ± 1.02	1.74 ± 0.05	3.25 ± 0.21	10.35 ± 0.94		9.86 ± 0.22	1.07 ± 0.16		0.66 ± 0.06
UW2860	2.28 ± 0.15	3.88 ± 0.80	0.99 ± 0.03	2.42 ± 0.29	24.77 ± 1.18	12.01 ± 0.50	15.77 ± 0.55	1.14 ± 0.39	0.75 ± 0.04	1.46 ± 0.07
Sediment	1.7 ± 0.9	5.1 ± 3.6	1.3 ± 0.07							

interior wall to the inner core. Some had a separate layer of carbonaceous residue on the interior and/or exterior surface. Sherds with a porous light grey paste were also sampled, but expected to be low in carbon. We further tested the background signal of local clays by selecting several sherds with no visible traces of carbonized organics.

Approximately 350–400 g of pulverized sherd fragments were used as bulk samples. Previous studies (O'Malley et al., 1999; Yoshida et al., 2004) have tested the assumption that dating the interior portion is more reliable because it is less prone to external contamination and contains greater quantities of carbonized organics. Although the exterior portions are often slightly younger than the interior portions, these exterior portions had much lower carbon yields (average yield of interior portion from Acid–Alkali–Acid [AAA] treated sherds was 1.1%, compared to 0.25% for exterior portions) and so they contributed less to the date. Considering that the resulting dates from interior and exterior portions in Yoshida et al.'s study almost always overlapped, it is reasonable to assume that any contamination from young carbon in the exterior portion is negligible and might even balance low levels of old carbon naturally occurring in the clay. Just as Heron et al. (1991) asserted that samples rich in organic surface residues would counteract the interference of older signals, the presence of abundant terrestrial plant matter within the paste should do the same. We used low temperature combustion (400 °C *versus* 800–1000 °C) to further reduce the influence of old carbon (Delqué Kolic, 1995; O'Malley et al., 1999).

Analysis followed the methodology outlined by Higham et al. (2010). All dated ceramic samples underwent a standard AAA pretreatment. Bulk samples were combusted on a vacuum line with oxygen at approximately 400 °C, following the recommendations of O'Malley et al. (1999).

3.2.3. Luminescence on pottery

Luminescence measurements were made at the University of Washington Luminescence Laboratory following procedures detailed in Feathers (2009). In brief, luminescence was measured on fine-grained (1–8 μm) polymineral samples using thermoluminescence (TL), optically stimulated luminescence (OSL), and infrared stimulated luminescence (IRSL). Equivalent dose was determined by TL using the slide method (Prescott et al., 1993). The TL signal was tested for anomalous fading (athermal loss of signal through time) and a correction applied following Huntley and Lamothe (2001). OSL/IRSL was measured using the double single-aliquot regenerative dose method (Banerjee et al., 2001). In this method an IR stimulation proceeds all OSL measurements to reduce the contribution of feldspars to the subsequent OSL signal. Feldspars are sensitive to IR and often have problems with anomalous fading, while quartz is not sensitive to IR and does not fade (Huntley and Lamothe, 2001). The method reduces the contribution from feldspar and therefore reduces the effect of fading, but does not necessarily eliminate it. However, we have observed that IRSL signals in pottery are often very weak, probably because feldspar becomes less sensitive with heating, where the opposite happens with quartz (Li et al., 2013). One way to evaluate possible fading of OSL, short of the time-consuming alternative of measuring for it, is to look at the b-value (Bowman and Huntley, 1984). The b-value is a luminescence term referring to the sensitivity ratio between material irradiated with alpha irradiation and material irradiated with beta or gamma irradiation. Alphas are less effective at producing luminescence. The b-value differs for quartz and feldspar (Aitken, 1985). Therefore, it is expected to differ among TL, IRSL and OSL, as they are measured in this study. A b-value of 0.4–0.7 is typical for quartz (Lai, 2008); values much higher than that indicate the presence of feldspar and possibility of fading.

Dose rate was measured by a combination of alpha counting, beta counting, and flame photometry, the latter for potassium content, all as applied in Feathers (2009). Moisture content was estimated between 6 and 9%, based on saturated values and an assumed 30 ± 30% saturation. Dose rates are summarized in Table 3.

One problem with using luminescence to date these samples was uncertainty in determining the external dose rate, which includes both gamma and cosmic contributions. For ceramics, an associated sediment sample is often collected to measure the gamma dose rate, but no such sediments were available since the dated specimens were collected decades ago. The fact that the samples come from deflated sand deposits causes uncertainty in the average burial depth of the samples through time, affecting both gamma and cosmic dose rates. These problems were diminished by employing *fine-grained* dating (Feathers, 2003: 1496), which is less reliant on the external dose rate because the internal alpha dose rate plays a much larger role than with coarse-grained dating. We calculated the possible effect of uncertainty in the external dose rate by calculating the average dose rate from sand sediments collected by this laboratory at other localities in Mongolia. The value was 0.7 ± 0.2 Gy/ka, which is similar to sand reported in other studies from northern China (Zhao et al., 2007; He et al., 2010). Using this value, we calculated that for these samples only 16 ± 3% of the total dose rate was externally derived. The other 84% was contributed by the internal beta and alpha dose rates, measurable on the sherds themselves. The smaller contribution allows generous error terms on the external dose rate without having much effect on the total error. The error terms for the external dose rate were derived from twice the variance of the Mongolian sediments used for the average, which amounted to an error of about 50% error on the radionuclide concentrations. Increasing the error to 75% increased the total error on the dose rate to less than 1%. Decreasing it to 10% only made a difference of 1% in the total dose rate error.

Although several of the assemblages were at least partially excavated, most were recovered from undifferentiated surface scatters. We chose to calculate the dose rate based on the assumption that they had remained on the surface for most of their depositional history, rather than make arbitrary inferences about each individual sample. In this case, half the dose environment was from the air, which has negligible radioactivity (notwithstanding an overstated concern with radon fallout – Dunnell and Feathers, 1995). Burial will increase the gamma dose rate and decrease the cosmic dose rate. For example, assuming a burial of 30 cm, which would have the maximum effect on the gamma/cosmic balance, increased the external dose rate for sample K.13248: 6 (UW2355) by about 0.3 Gy and decreased the age only by 6%. Therefore, partially buried samples may be slightly younger than the dates suggest.

Luminescence ages and error terms were calculated from a custom spread sheet based on Aitken (1985, Appendix B). Final errors resulted from the propagation of random and systematic errors for the various measurement parameters. Errors were reported at 1σ, as summarized in Table 4, Column 7.

4. Results

Results of AMS and luminescence dates are summarized in Table 4. All ^{14}C dates were calibrated using Calib 7.0 (using IntCal 13) (Stuiver and Reimer, 1993; Stuiver et al., 2013). Dates derived from both methods are comparable when converted to BC and cal BC, and all dates are discussed in BC/AD with a 95.4% confidence interval (2σ).

4.1. AMS on ostrich eggshell

Many researchers have drawn attention to the potential of ostrich eggshell for providing very high resolution radiocarbon dates

Table 4
Results of chronometric dating on sherds; * indicates that the date is not reliable due to a carbon yield <0.10%. For luminescence dates, % errors range from 5.3 to 15.4% with a median of 7.9%.

Site name	Sample Catalogue#	Laboratory#	Method	$\delta^{13}C$	Material (Ceramic/Eggshell)	Reported Date (BP or a)[a]	Calendar Date (95.4%)
Jabochin-khure	K.13203:5	UW2361	OSL		C – incised	3590 ± 310	2200–960 BC
Gashun	K.13207:1	AA91693	AMS	–32.4	C – paddled	3385 ± 40	1866–1545 BC
Yingen-khuduk	K.13212:6	UW2358	OSL/corr.TL		C – fine red	4030 ± 310	2640–1400 BC
	K.13212:123	UW2357	OSL/IRSL/TL		C – net-impressed	5880 ± 360	4590–3150 BC
	K.13212:128	UW2360	OSL/IRSL/corr. TL		C – paddled	4030 ± 230	2480–1560 BC
	K.13212:184	AA87198	AMS	–2.4	E – rough bead	41,900 ± 1500	46,320–40,821 BC
Dottore-namak	K.13248:5	UW2356	OSL/corr. TL		C – paddled	2210 ± 320	780 BC–AD 500
	K.13248:6	UW2355	OSL		C – plain	2810 ± 240	1270–330 BC
Mantissar 4	K.13290:44	AA87197	AMS	–11.8	E – finished bead	14,857 ± 85	16,631–15,906 BC
Mantissar 7	K.13293:29	AA87200	AMS	–9.1	E – fragment	>49,900	–
Mantissar 12	K.13298:15	UW2362	Corr. TL		C – corded	6610 ± 730	6060–3140 BC
	K.13298:25	UW2359	OSL/uncorr.TL		C – burnished	4020 ± 350	2710–1310 BC
	K.13298:55	AA87201	AMS	–8.1	E – rough bead	>47,940	–
	K.13298:60-01	AA87202	AMS	–8.1	E – broken bead	>47,940	–
	K.13298:60-02	AA87199	AMS	–8.8	E – broken bead	>46,540	–
	K.13298:60-03	AA87203	AMS	–9.2	E – broken bead	>46,840	–
Shabarakh-usu 1 *partially buried*	73/648A	AA89869	AMS	–10.4	E – fragment	7483 ± 47	6433–6247 BC
	73/648B	AA89870	AMS	–8.4	E – fragment	8522 ± 50	7603–7506 BC
	73/654A	B9514R	AMS	–24.9	C – thick plain	2586 ± 38	825–555 BC
	73/655A	AA89872	AMS	–20.9	C – paddled	4308 ± 40	3023–2879 BC
Shabarakh-usu 2 *surface*	73/763-01	AA76420	AMS	–10.3	E – fragment	8159 ± 43	7305–7060 BC
	73/763-02	AA76421	AMS	–9.6	E – fragment	8184 ± 44	7321–7070 BC
	73/764-01	AA76419	AMS	~ –9.3	E – bead blank	7969 ± 37	7045–6703 BC
Shabarakh-usu 2 *excavated*	73/790-01	AA76416	AMS	–9.0	E – fragment	8396 ± 52	7570–7347 BC
	73/790-02	AA76417	AMS	–11.1	E – fragment	8268 ± 44	7476–7145 BC
	73/790-03	AA76418	AMS	–10.7	E – fragment	30,490 ± 780	34,144–31,035 BC
Shabarakh-usu 4 *hearth features*	73/887A	AA89873	AMS	–21.9	C – thick plain	3680 ± 76*	–
	73/890A	UW2453	OSL/IRSL		C – net-impressed	5820 ± 310	4430–3190 BC
	73/894A	AA89874	AMS	–10.0	E – fragment	7589 ± 47	6564–6376 BC
Shabarakh-usu 6 *surface*	73/984A	AA89875	AMS	–10.0	E – fragment	8473 ± 64	7599–7365 BC
Shabarakh-usu 6 *excavated*	73/998A	AA89876	AMS	–10.0	E – fragment	8254 ± 47	7459–7086 BC
Shabarakh-usu 7	73/1034-01	AA76422	AMS	–11.3	E – fragment	8054 ± 43	7139–6820 BC
	73/1034-02	AA76423	AMS	–11.6	E – fragment	38,600 ± 1000	42,397–39,193 BC
	73/1034-03	AA76424	AMS	–10.7	E – fragment	8439 ± 60	7588–7357 BC
	73/1035-01	AA76425	AMS	–11.0	E – bead blank	8081 ± 49	7184–6823 BC
Shabarakh-usu 10 *partially buried*	73/1189A-1	AA89877	AMS	–24.6	C – corded	3595 ± 41	2122–1780 BC
	73/1189A-2	UW2859	OSL/corr. TL		- " -	3490 ± 220	1920–1040 BC
	73/1190A	UW2451	OSL		C – net-impressed	5140 ± 370	>3870–2390 BC
	73/1194A	AA89878	AMS	–23.4	C – cord/paddle?	3246 ± 39	1614–1439 BC
Ulan Nor Plain *partially buried*	73/1608D	UW2454	Corr. TL		C – coarse red	2220 ± 340	880 BC – AD 480
	73/1609A	AA89879	AMS	–23.1	C – plain	5116 ± 41	3986–3797 BC
	73/1609C	AA89880	AMS	–23.3	C – plain	5061 ± 49	3965–3714 BC
Barun Daban *partially buried*	73/1702A	AA89881	AMS	–27.5	C – plain	1661 ± 42	AD 255–534
Orok Nor	73/1790A	AA89882	AMS	–9.5	E – fragment	8307 ± 56	7508–7185 BC
	73/1790B	AA89883	AMS	–9.5	E – fragment	8338 ± 55	7531–7191 BC
	73/1791K	UW2452	OSL/IRSL/uncorr. TL		C – coarse red	2550 ± 140	810–250 BC
	73/1792A	AA89884	AMS	–26.8	C – combed	10,030 ± 140*	–
Shara Kata Well *excavated*	73/466A	AA89868	AMS	–24.4	C – textured	8604 ± 51	7733–7549 BC
Baron Shabaka Well (1928 – Site 19) *hearth features*	73/2225-01	AA76426	AMS	–12.0	E – fragment	12,509 ± 59	13,134–12,371 BC
	73/2225-02	AA76427	AMS	–10.7	E – fragment	12,450 ± 74	13,064–12,249 BC
	73/2229A	AA89885	AMS	–25.7	C – net-impressed	5609 ± 47	4530–4353 BC
	73/2231A	AA89886	AMS	–24.3	C – plain	5954 ± 52	4964–4716 BC
	73/2231C	AA89887	AMS	–22.5	C – plain	5825 ± 85*	–
	73/2236A	AA89888	AMS	–23.2	C – roller-stamped	1445 ± 86*	–
	73/2237B-1	AA89889	AMS	–24.0	C – roller-stamped	3115 ± 47	1496–1263 BC
	73/2237B-2	UW2450	OSL/corr. TL		- " -	960 ± 80	AD 860–1210
Shara Murun Crossing (1928 – Site 3)	73/2303A	AA89890	AMS	–12.3	E – fragment	12,497 ± 70	13,129–12,249 BC
Ta Sur Heigh (1928 – Site 7)	73/2403A	AA89891	AMS	–11.4	E – fragment	14,129 ± 80	15,528–14,979 BC
Spring Camp (1928 – Site 16) *hearth features*	73/2526A	AA89892	AMS	–20.1	C – roller-stamped	866 ± 51	AD 1040–1259
Alkali Well (1928 – Site 26)	73/2646A	AA89893	AMS	–10.4	E – fragment	9562 ± 51	9172–8763 BC
Chilian Hotoga Well (1928 – Site 35) *hearth features*	73/2796B	AA89895	AMS	–26.7	C – plain	1866 ± 88*	–
	73/2796C-1	AA89896	AMS	–27.6	C – plain	17,120 ± 220*	–
	73/2796C-2	UW2860	OSL/IRSL		- " -	5950 ± 390	4720–2710 BC
	73/2797A	AA89897	AMS	–25.5	C – net-impressed	6728 ± 45	5720–5561 BC
	73/2800A	AA89898	AMS	–7.2	E – fragment	10,586 ± 56	10,734–10,472 BC
	73/2800C	AA89899	AMS	–6.9	E – fragment	10,103 ± 55	10,027–9452 BC

[a] Based on standard protocol, radiocarbon dates are reported in BP (Before Present), in which present refers to before AD 1950. Luminescence dates are reported in a or ka, based on years (to decade) before sample was dated, in this case 2010–2020.

(Bird et al., 2003; Freundlich et al., 1989; Janz et al., 2009; Vogel et al., 2001), and our study reaffirms the finding that samples produce high carbon yields (~11%) and low error ranges. Nevertheless, in contrast to the findings of a previous study on ostrich eggshell from archaeological assemblages in the Gobi Desert (Janz et al., 2009) and despite the reliability of AMS radiocarbon for dating ratite eggshell, the dates we obtained are not consistent with the Neolithic occupation episodes with which they are associated. Dates on ostrich eggshell artefacts, all from post-LGM human habitation sites, cover an enormous range - from >47,950 to 6433–6247 BC and pre-date potsherds from the same sites. Beads and bead-blanks covered the same range of dates as unmodified fragments.

The wide range of dates indicates that old eggshell was used more frequently than previously recognized (Janz et al., 2009; but see Kurochkin et al., 2010). This is especially true in the Alashan region where most of the eggshell from Neolithic assemblages dates to the Palaeolithic. Since there is no evidence of such early human habitation at these localities, it is certain that Neolithic inhabitants were exploiting ancient shell. Early Holocene dates on eggshell from the Gobi-Altai and East Gobi regions are more ambiguous. At Shabarakh-usu, broad similarities between Mesolithic and Neolithic microblade core technologies makes it difficult to discern whether the eggshell was a part of an earlier archaeological component, or simply scavenged from older deposits. Ostrich eggshell dates from Shara Murun Crossing, and perhaps even Alkali Wells, are within the range of associated artefacts, but they could not be cross-checked due to a lack of pottery. Unmodified fragments from the Neolithic or early Bronze Age Ta Sur Heigh site were at least 10,000 years older than typical Neolithic assemblages. Considering the overall consistency with which eggshell pre-dates archaeological components, it is clear that Neolithic inhabitants were systematically collecting and using ostrich eggshell thousands of years after the species had disappeared (see also Aseyev, 2008).

4.2. AMS on pottery

Table 5 details the date, source of carbon, and carbon yield for each AMS-dated sherd. Despite differences in the source, sherds that are visibly rich in carbon produce dates consistent with each other and with luminescence dates on the same or similar types of sherds. The majority of samples produced carbon yields of up to 0.87%. Sherds with carbonaceous residues visible to the naked eye produced strong carbon yields and agreed well with expected ages and the luminescence results. This supports the assertion that possible contamination of exterior sherd portions has a negligible impact on samples with visible carbon resulting from manufacture and/or use.

Dates from samples with carbon yields under 0.10% (marked with an asterisk in Table 4) were automatically considered unreliable as in the laboratory setting such yields often result in dates that are older than expected (Burr and Jull, 2010). Our results indicate a great deal of inconsistency. Sherds with a light grey paste (suggesting minimal carbon) or no evidence of carbonaceous materials usually had lower carbon yields (0.02–0.12%) and the resulting dates were sometimes too old and sometimes in agreement with the expected age. This inconsistency suggests that the source of such small amounts of carbon is unpredictable; the captured carbon could be derived from a range of sources that might produce results consistent with, older, or younger than the artefact (e.g., small amounts of organic matter incorporated during manufacture, ancient decomposed organics in the clay, intrusive carbon from groundwater, or from carbon rich minerals in the clay or temper). The carbon may sometimes be archaeologically derived, but uncertainty over the source makes such dates unreliable.

Even in samples with high carbon yields and low ranges of error, there is some concern that carbon-rich minerals, ancient decomposed organics in the clay, or a freshwater reservoir effect from the use of aquatic foods might make these dates too old. If older organics in the temper contributed significantly to the age of our sherds, we would expect dates obtained on sherds with blackened paste to be systematically older than dates obtained from surface residues. This is not the case. Of two AMS-dated sherds from Baron Shabaka Well (73/2229 and 73/2231A), the older date came from a sample with abundant residues on the interior surface, while the younger had a blackened core. One sand-tempered sherd from Gashun Well had carbonaceous residue on the exterior surfaces and produced dates that were consistent with similar pottery from Shabarakh-usu 10, one of which had a blackened core and the other interior and exterior surface residues (see Table 5). With a hard-water reservoir effect, we would expect pots with aquatic food residues to produce consistently older ages; therefore, dates derived from interior surface residues should be older than those derived from a blackened core or from exterior surface residues.

Table 5
Source of carbon, carbon yield, and viability of AMS date.

Lab#	Catalogue#	Date (calibrated)	Dateable material	% Carbon yield	Assessment of date
AA91693	K. 13207: 1	1866–1545 BC	Surface residues	0.60	Consistent
B9514R	73/654C	825–555 BC	Blackened paste	0.40	Non-diagnostic
AA89872	73/655 A	3023–2879 BC	Blackened paste	0.15	Consistent
AA89873	73/887 A	2295–1831 BC	Grey paste	0.04	Consistent
AA89877	73/1189 A	2122–1780 BC	Blackened paste	0.48	Consistent
AA89878	73/1194 A	1614–1439 BC	Surface residues	0.13	Consistent
AA89879	73/1609 A	3986–3797 BC	Blackened paste	0.37	Non-diagnostic
AA89880	73/1609C	3965–3714 BC	Blackened paste	0.36	Non-diagnostic
AA89881	73/1702 A	AD 255–534	Blackened paste and interior surface	0.43	Non-diagnostic
AA89884	73/1792 A	10,111–9257 BC	Some greying on surface	0.04	Too old?
AA89868	73/466A	7733–7549 BC	Blackened paste and interior surface	0.34	Consistent
AA89885	73/2229 A	4530–4353 BC	Blackened paste	0.27	Consistent
AA89886	73/2231 A	4964–4716 BC	Blackened interior surface	0.17	Non-diagnostic
AA89887	73/2231C	4897–4466 BC	Grey paste	0.06	Consistent
AA89888	73/2236 A	AD 417–765	Grey paste	0.02	Consistent
AA89889	73/2237 B	1496–1263 BC	No visible carbon	0.12	Too old
AA89892	73/2526 A	AD 1040–1259	Grey paste	0.10	Consistent
AA89895	73/2796 B	43 BC–AD 379	Grey paste	0.04	Non-diagnostic
AA89896	73/2796C	19,302–18,136 BC	No visible carbon	0.07	Too old
AA89897	73/2797 A	5720–5561 BC	Blackened paste and residue on interior surface	0.87	Consistent

Samples 73/1702A, 73/1194A, 73/2231A, and 73/2797A all had blackened interior surfaces that could potentially be attributed to carbon residues from food. Samples 73/2231A and 73/2797A produced the oldest dates for their respective sites, while 73/1194A produced the youngest date from Shabarakh-usu 10. These results do not reveal a pattern that is attributable either to the effect of "old carbon" or the use of aquatic foods. At the same time, our sample size was small and sources of potential inaccuracy for local AMS dates should be considered on a case-by-case basis.

4.3. Luminescence on pottery

As expected for this sample, most of the luminescence dates had a higher range of error than those derived from AMS analysis, but they produced a range of dates that overlapped with AMS determinations. Final error terms ranged from 5.3 to 15.4%, with a median of 7.9% (see Table 4). In evaluating the luminescence dates, we compared ages derived from OSL, IRSL, and TL and ranked them in order of reliability from 1 to 5, with the highest reliability placed on those samples where all three ages agreed. TL ages were corrected for anomalous fading (following Huntley and Lamothe, 2002) except for three cases: K.13298: 25 (UW2359), where there was not enough material to conduct a fading test; K.13212: 128 (UW2360), where the corrected age was not significantly different from the uncorrected age; and 73/1791K (UW2452), where the uncorrected age agreed with OSL and IRSL. Fading rates, specified as g-values (% per decade where a decade is a power of 10), ranged from 0.5 to 14.5%, with a median of 9%.

The reliability rankings are as follows: 1) OSL, TL, and IRSL ages are in statistical agreement – K.13212: 123 (UW2357), K.13212: 128 (UW2360), and 73/1791 K (UW2452); 2) agreement in age between two of the signals and a good reason for disagreement of the third, due either to presumed fading of the IRSL signal (K.13248: 5 [UW2356], K.13212: 6 [UW2358], 73/2237 B [UW2450], K.13298: 25 [UW2359]) or because scatter in the TL curve prevented a confident fit (73/890 A [UW2453]); 3) based only on TL but corrected for fading - K.13298: 15 (UW2362) and 73/1608 D (UW2454); 4) based only OSL signals, which do not fade and are presumably dominated by quartz as indicated by low b-values – K.13248: 6 (UW2355) and K.13203: 5 (UW2361); and 5) OSL with a high b-value – 73/1190 A (UW2451). The age of the last sample should be considered a minimum, as its high b-value indicates that the signal is dominated by feldspar which is prone to fading. For Group 3, the younger derived ages suggest that the OSL and IRSL signals in these samples both fade, although fading was not measured.

5. Discussion

Abundant ostrich eggshell in Neolithic assemblages and the co-occurrence of possible bead-making tools such heavy-duty drills, and occasionally grooved stone slabs (Fairservis, 1993: 39, Fig. 14.g., 41; Maringer, 1950: 110), illustrate that bead-making was an important craft and ostrich eggshell an essential material even following the extirpation of East Asian ostriches after about 6500 BC. It is currently not known whether fresh ostrich eggshell is better for bead-making than old shell, but if hunter–gatherers used ostrich eggs for food we expect they would have relied on fresh eggshell when it was available. Direct dates on ostrich eggshell from Palaeolithic sites in Mongolia and China are broadly consistent with dates on charcoal and bone (Gao et al., 2008; Jaubert et al., 2004; Zwyns et al., 2014b). The resolution of dates from Palaeolithic assemblages is not sufficient to exclude the possibility that inhabitants were sometimes exploiting both fresh and ancient eggshell, but this should not be an issue when ostrich eggshell samples are younger than bone samples (e.g., Jaubert et al., 2004; Zwyns et al., 2014b). We recommend a cautious approach.

As in Africa, local groups may have regularly used the eggshells for vessels as well as bead-making – one bowl was discovered at the Chikhen Agui cave site (Derevianko et al., 2008). The use of eggshell for vessels might have implications for the adoption of pottery, especially since there is currently no evidence for an overlap in local pottery production and ostrich survivorship. The earliest pottery from Shara Kata Well is contemporary with ostrich eggshell from Shabarakh-usu, but the sites are hundreds of kilometres distant. Additional data is needed to support such a connection.

In contrast to ostrich eggshell, the dates obtained from pottery are consistent with our expectations (see Table 2). The narrow and continuous range of pottery dates within this sample (7733 BC to AD 1259 - see Fig. 2) cross-cuts dating methods, which is an initial indication that both methods produce acceptable results. We were able to cross-test dating methods by using both AMS and luminescence on three sherds: 73/1189A, 73/2237B, and 73/2796C. Sample 73/1189A (AA89877, UW2859), whose blackened paste yielded ample carbon, produced dates that overlapped at 2 σ. Luminescence produced the younger age range. Samples 73/2237 B (AA89889, UW2859) and 73/2796C (AA89896, UW2860) produced dates that were thousands of years older for AMS than luminescence. This result was not surprising since both had low carbon yields (0.12% and 0.07%). Sample 73/2237B from Baron Shabaka Well was dated by luminescence to AD 890–1210 and by AMS to 1496–1263 BC. The AMS date on a sherd of the same type (toothed roller-stamp) from Spring Camp (73/2526A) overlaps at 1 σ with the luminescence date from Baron Shabaka Well. This agreement in dates supports their accuracy despite a poor carbon yield (0.10%) from the grey paste of 73/2526A.

These new AMS and luminescence dates significantly improve our understanding of Gobi Desert archaeology. Our findings demonstrate that the Gobi Desert Neolithic began much earlier than 4200–4000 BC. Sherd 73/466A, excavated at the Shara Kata Well site, represents the earliest known example of pottery in Mongolia and the Gobi Desert, and is well within the date range for

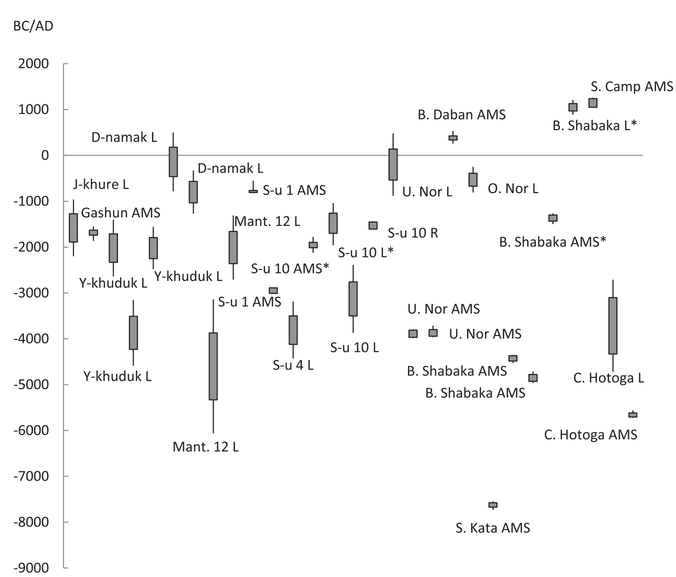

Fig. 2. Results of dates on Gobi Desert pottery sherds, excluding samples with carbon yields below 0.10%. AMS dates are calibrated and all dates are expressed in BC/AD with a 2σ range of error. * Dates derived from the same sherd.

early pottery in Northeast Asia (see Table 2). According to the regional tradition of categorizing ceramic-bearing sites as Neolithic, the date would extend the Gobi Desert Neolithic to 7733–7549 BC. However, since we have a limited understanding of how this small riverside assemblage relates to the distinct dune-dweller Neolithic sites (see Janz, 2012: 144–155), a categorization based solely on pottery-use should be avoided. Dates from Chilian Hotoga Well more reliably extend the classic dune-dweller Neolithic to at least 5720–5561 BC, while dates from Mantissar 12 plausibly support an age of about 6000 BC. Moreover, the presence of large formal milling stones at early sites such as Baron Shabaka Well and Chilian Hotoga Well suggest that these tools were an integral part of Early Neolithic adaptation to dune-field/wetland habitats (*contra* Okladnikov, 1962: 89).

Dated diagnostic sherds further refine our understanding of changes in Neolithic pottery over time. Net-impressed sherds all produced early dates and can be considered characteristic of the Early Neolithic. Unlike in the Lake Baikal region, this style of pottery does not seem to continue into the Late Neolithic (MacKenzie, 2009; see Table 2). String-paddled pottery is diagnostic of the Late Neolithic and probably continues into the Iron Age, which began in Mongolia around 700 BC (Honeychurch and Amartuvshin, 2006). The adoption of this surface treatment, which is functional as well as decorative, may represent a shift in manufacturing techniques. The fine, high-fired red-ware and burnished pottery from the Alashan region are reminiscent of and contemporary with those used by agropastoralist Qijia (2400–1900 BC) of northwestern China (Debaine-Francfort, 1995, 2001; An, 1992b; Janz, 2012: 413). Likewise, the luminescence date on a geometric-incised sherd from Jabochin-khure (K.13203:5) corresponds with dates on similar sherds from Bronze Age (2500–1000 BC) pastoralist sites much farther west in Kazakhstan (Frachetti, 2008: 166, Fig. 52), Bronze Age sites in Xinjiang (Debaine-Francfort, 2001), and Eneolithic sites around Lake Baikal (Weber, 1995: 107, Fig. 4d.). Such sherds have been found across the Alashan and Gobi-Altai regions. Fine redware, burnishing, and the incised designs all suggest a burgeoning relationship with herders in eastern Central Asia, whose influence and material culture was spreading across East Asia at this time (Frachetti, 2002). Along with the string-paddled finish, these types can be considered diagnostic of the Late Neolithic, for which we suggest an age of 3000–1000 BC. A toothed roller-stamp decoration can be assigned to the Medieval Period based on samples 73/2237B and 73/2526A.

Multiple dates from large sites confirm that many assemblages combine occupation episodes spanning several millennia (Fig. 2). Twentieth century collection practices contributed to an even wider range of dates; the lack of other artefacts from later periods suggests that the sherds represent continued use of nearby springs or wells rather than intensive occupation of dune-field/wetland sites (Janz, 2012: Chapter 6). The high degree of intermixing makes it difficult to reliably interpret the relationship between dated sherds and other contemporary diagnostic artefacts, but multiple dates on pottery at Dottore-namak, Shabarakh-usu 10, and Baron Shabaka Well were consistent enough to suggest that occupation episodes occurred within a 500–1000 year period (see Table 4). The low diversity of dates for Baron Shabaka Well, a very large assemblage where individual site clusters were combined during collection, may alternately be a product of sampling. Unrecognized occupation episodes pre-dating the adoption of pottery might also be represented in some assemblages since technological differences that distinguish the Mesolithic are subtle (see Table 1). In general, the majority of dates suggest that large dune-field/wetland sites were inhabited intensively throughout the entire Neolithic and were used sporadically in later times.

6. Conclusions

Consequently, this study contributes to local chronology and shows that direct dating pottery using both luminescence and AMS can provide reliable results. Limitations on space do not allow us to fully discuss the implications that these dates have made in the context of local chronology. The most basic findings are outlined above, and are described in greater detail elsewhere (Janz, 2012). With respect to chronometry, the ability to use both luminescence and AMS as tandem methods of dating pottery within the same site, and even on the same sample, makes their use appealing in its application to surface assemblages and beyond. The varied strengths of AMS and luminescence make the two methods highly complementary. Luminescence can be used to date ceramics that do not exhibit carbon-rich pastes or residues (see also Sampson et al., 1997) and to verify AMS results. AMS supports luminescence with its higher precision on samples older than 1000 years, but luminescence can offer an equal or even narrower range of error for more recent periods even in the absence of associated sediment samples.

Our results show that sherds with visible organic and carbonaceous residues are suitable for AMS dating, which can be carried out on bulk samples as long as they yield adequate carbon. Light grey pastes do not produce adequate carbon yields, although it is possible to use sherds whose exterior surface shows blackening from carbonaceous residues. AMS dates on ceramic sherds are suspect when the carbon yield is less than ~0.15%, and are unreliable when it is below ~0.10%. Potential sources of error are the presence of ancient carbon in the clay or residues derived from aquatic foods; however, we found no clear evidence for either factor in our sample. The use of low temperature combustion (Delqué Kolic, 1995; O'Malley et al., 1999) and samples rich in carbon should, in most cases, mitigate the influence of any "old carbon" naturally occurring in the paste. Although we see no clear evidence of a hardwater reservoir effect in this sample, the problem of using organic residues from aquatic sources needs to be examined more closely. Compositional analyses of organic residues would greatly contribute to our understanding of local food systems and benefit researchers working with AMS dating. Developing a calibration curve for local inland water systems would be useful for any contexts where there is evidence for the consumption of aquatic foods. Nevertheless, in comparison to the many problems associated with AMS dating on archaeological bone and charcoal (Bird et al., 2014; Olson and Broecker, 1958; van Klinken, 1999), our study suggests that potential sources of error are comparatively minimal in this context.

Finally, we strongly caution researchers on all continents against using ratite eggshell alone to date archaeological assemblages until it can been shown that the dates are representative. In Northeast Asia, the fact that humans were using ostrich eggshell from older contexts makes it unreliable for dating Neolithic habitation sites and puts serious limitations on our ability to date pre-ceramic surface assemblages.

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