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Research Article

Paleolakes, archaeology, and late Quaternary paleoenvironments in northwestern Mongolia

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Abstract

The climatic, hydrographic, and environmental regimes of terminal Pleistocene and Holocene northwestern Mongolia are reconstructed using archaeological and pedological data sets at Bayan Nuur, a lake on the northwestern perimeter of the Altan Els dune field in eastern Uvs Province, Mongolia. The archaeological data consist of land-use patterns controlled for time via time-sensitive, diagnostic artifacts. The pedological data consist of soil classifications and radiocarbon dating of paleosols that track lake levels and water table. These data are combined using a geographic information system (GIS) to ascertain site and paleosol geographic relationships to modern lake levels at Bayan Nuur. They point to a more xeric Younger Dryas than previously recognized, significant Holocene lake regressions, and to Mid- to Late Holocene lake standstills/transgressions, the scale of which had previously been unrecognized. Combined, these data point to a complex late Quaternary picture of paleoclimate and paleoenvironment across the region and the importance of using multiple proxies, including archaeological data, in paleoecological reconstructions.

Keywords: Lake Levels, Radiocarbon, Mongolia, Archaeology, Younger Dryas, Holocene

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INTRODUCTION

Reconstructing paleolake level histories can be challenging but is clearly of considerable importance to paleoecologists and archaeologists alike (Oviatt, 1997; Guo et al., 2007; Adams et al., 2008). Such reconstructions are particularly relevant in and around Mongolia, where many Quaternary lake-level reconstructions imply considerable complexity in the regional historical ecological record (An et al., 2008). Mongolia also has a very long history of human occupation marked by laminar stone-tool technologies dating to ca. 40 ka, microblade technologies dating to the Last Glacial Maximum (LGM) and later, as well as ceramics dating mainly to the Middle and Late Holocene, Bronze Age and Iron Age artifacts, and various stone monuments that date mainly to the Bronze Age (Kuzmin, 2007; Schneider et al., 2016; Zwyns et al., 2019; Wright, 2021). For paleoecologists, the appeal of lake-level research hinges on precision in geomorphological reconstruction and, of course, having these reconstructions provide a good proxy for the water budgets that play such a critical role in determining past floral and faunal compositions (Madsen et al., 2001; Byers and Broughton, 2004; Wang et al., 2009). For archaeologists, a large part of the appeal of lake-level research is that it tracks environmental change at the spatial scale that human decision-makers operate within: the scale of watersheds and landscapes rather than the typically gross scales of many paleoclimatic–paleoenvironmental histories. This makes lake-level history reconstructions particularly appealing to archaeologists focused on small-scale societies typically associated with hunter-gatherer and early agricultural and pastoral economies (Kennett and Winterhalder, 2006; Barfield, 2011; Bettinger et al., 2015; Holguin, 2019).

The challenge lies in integrating multiple proxies (e.g., pollen, ostracods, isotopes, relict shoreline dating, etc.) into a composite picture of a given lake's history that is both accurate and precise (Mann, 2002). Within this context, we report on lake-level history reconstruction at Bayan Nuur, a small lake in Uvs Province, northwestern Mongolia, which is an area that is marked by dynamic lake-level histories (Grunert et al., 2000) and contains an increasingly refined archaeological record. Our study relies principally on characterization and radiocarbon dating of paleosols—some of which contain in-situ archaeological sites—that track water table and lake proximity, rather than more typical dating of relict shoreline features. It also relies on time-sensitive surface artifact assemblages, as well as direct dating of in situ features and deposits at archaeological sites to track lake-level elevations. The results of this study suggest that considerable revisions be made to the area's terminal Pleistocene and Middle- to Late Holocene (per Walker et al., 2018) environmental records. Consequently, we argue that this study not only helps us understand the complex climatic and environmental history of the region, but also points to the importance of using archaeological data as paleoecological proxies.

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PHYSIOGRAPHIC, ENVIRONMENTAL, AND CLIMATIC BACKGROUND

Uvs Province is in northwestern Mongolia and is bordered on the north by Russia's Altai and Tuva republics. Uvs is dominated by its namesake Uvs Nuur (the word 'nuur' means lake in Mongolian and many English speakers use the term, a convention we follow herein). Uvs Nuur is a large (3350 km^2), shallow, endorheic saline lake that occupies ∼5% of the province's surface area. It captures runoff from a 10,688 km^2 watershed centered on northern Uvs Province that extends into southern Russia and north-central Mongolia (Figure 1). Its principal water source is the Tes River, which drains substantial portions of the adjacent Zavkhan Province and nearby Khövsgöl Province in north-central Mongolia. Subsidiary streams such as the Turgen and Tarialan rivers, the Guramsanii and Zuun Tyryynii rivers, and the Borgio and Sagil rivers drain mountains to the west, south, and north of the lake, respectively. Several smaller lakes are located in the eastern portion of the Uvs Nuur watershed. Among these lakes are Shar Nuur and Doroo Nuur in Tuva, and Baga Nuur and Bayan Nuur, with the latter being the focus of our study in Uvs. These smaller lakes, especially Shar, Baga, and Bayan nuur are perched 137–227 m above Uvs Nuur's current pool elevation, immediately east of a low region of uplift marked by a southwest–northeast trending line of low mountains and hills. Shar and Bayan nuur drain into Uvs Nuur via the Nariin River and its southern tributary, the Khoid River.

Elevations in the Uvs Nuur basin range from 759 m asl (the elevation of Uvs Nuur) to nearly 4000 m asl in the Mongolian Altai south of the basin. Higher elevations in the mountains are capped by glaciers and alpine terrain, below which are larch (*Larix* sp.) forests (Hilbig, 1995). The piedmont surrounding the mountains is characterized by large alluvial fans that coalesce into steppe-covered fanglomerates drained by the aforementioned rivers, which terminate in large deltaic deposits as they approach Uvs Nuur. Large portions of the region east of Uvs Nuur are capped by Quaternary sand dunes, the Altan Els, portions of which encircle the north, south, and eastern edges of Bayan Nuur (Grunert and Lehmkuhl, 2004). Uvs Province is dry and very cold: temperatures range from −45°C to 35°C and average only ∼4°C, and precipitation averages only ∼13 cm per year (Orshikh et al., 1990).

PALEOCLIMATIC, PALEOENVIRONMENTAL, AND LAKE LEVEL HISTORIES

The Younger Dryas to Late Holocene paleoclimatic history for Mongolia is complex. This is due in large part to Mongolia's extreme contintentality, its latitude, its considerable longitudinal extent, and its marked topographic variability. Mongolia's climate is also affected by the complex interplay between the Mongolian High Pressure System and its relationship to variations in the North Atlantic Oscillation, the North Pacific Oscillation, and the East Asian summer monsoon, the latter of which is affected by the El Niño Southern Oscillation and the Intertropical Convergence Zone (Kerr, 1999; Gong et al., 2001; Hoerling et al., 2001; Tudhope et al., 2001; Visbeck, 2002). Despite the diverse forces that shape Mongolia's climate, early syntheses of late Quaternary Mongolian paleoclimate by Logatchov (1989) and Khotinsky (1989) simplified the record, recognizing a stable early Holocene (10–8 ka), a cool and wet middle Holocene (8–5 ka), a warming and drying trend in the early-to-middle Late Holocene (5–2.5 ka), and a relatively stable period in the latest part of the Holocene (after 2.5 ka) (see also Herzschuh, 2006; Chen et al., 2008).

A more recent synthesis by An et al. (2008) of relevant geomorphological research (Owen et al., 1997; Zhou et al., 1998; Li et al., 2003), lake-level histories (e.g., Fang, 1991; Dorofeyuk and Tarasov, 1998; Komatsu et al., 2001), and palynological work (Tarasov et al., 2000; Fowell et al., 2003), substantially revises these earlier generalizations. Importantly, they argued that: 1) the Early Holocene was not stable and was marked by increasing temperature and humidity over time; 2) the Middle Holocene was generally dry rather than humid, although it contained a humid phase in its earliest centuries; and 3) the Late Holocene was marked by a return to more humid conditions. Despite these gross generalizations, perhaps An et al.'s (2008) most important contribution lies in their recognition of considerable variability and deviation from their general synthesis, especially during the Middle Holocene.

Since An et al.'s (2008) overview, much more paleoclimatic and paleoenvironmental work has been conducted in Mongolia and adjacent regions, which was well summarized by Klinge and Sauer (2019). These studies consist mainly of geomorphological and sediment core analyses focused either all or in part on reconstructing lake-level histories and associated paleoclimatic trends. Importantly, this newer research shows some general concordance with An et al.'s (2008) synthesis (Figure 2). For example, a mesic early Middle Holocene seems to have applied to the climate across much of the region, and the Late Holocene climate appears to be variable, but there are also important discrepancies. In western Mongolia, the Younger Dryas is modeled as either xeric or mesic, depending on location (Klinge and Lehmkuhl, 2013; Klinge et al., 2017). The Early Holocene has been described as generally xeric (e.g., Dirksen et al., 2016), except at Khövsgöl Nuur, where a mesic phase has been documented (Feng et al., 2013; Orkhonselenge et al., 2014). Data from northern Mongolia and southern Siberia appear to contradict the generalization of a xeric Middle Holocene (Li et al., 2013; Liu et al., 2017). It is worth mentioning here that the Ugii Nuur record in central Mongolia is contradictory: one study indicated a mesic Middle Holocene (Schwanghart et al., 2008), and another study showed that this time period was xeric (Wang et al., 2009). Finally, even in the mesic Late Holocene, lake regressions are documented in western, northern, and central Mongolia and in northern China, suggesting dynamic lacustrine and environmental histories there (Guo et al., 2007; Klinge and Lehmkuhl, 2013; Orkhonselenge et al., 2014). In sum, this recent research amplifies An et al.'s (2008) caveat, and Klinge and Sauer's (2019) comprehensive synthesis, that there was considerable variability in the timing, extent, duration, and intensity of xeric versus mesic periods across Mongolia's valleys and lake basins. This variability results in part from gross paleoclimatic trends but also from other more localized parameters, including tectonism, sand dune emplacement, and human influence.

Fortunately for those interested in the Uvs Nuur basin, considerable research has been conducted that focused on reconstructing the lake level histories of Uvs Nuur and the smaller lakes to the east, especially Bayan Nuur (Grunert et al., 1999, 2000; Grunert, 2000; Walther, 2010). This work was comprehensive, consisting of research on dune geomorphology and dating dune sediments (Grunert et al., 1999; Grunert, 2000; Naumann and Walther, 2000), mapping and dating of other geomorphological features such as abandoned lake shorelines (Walther and Naumann,

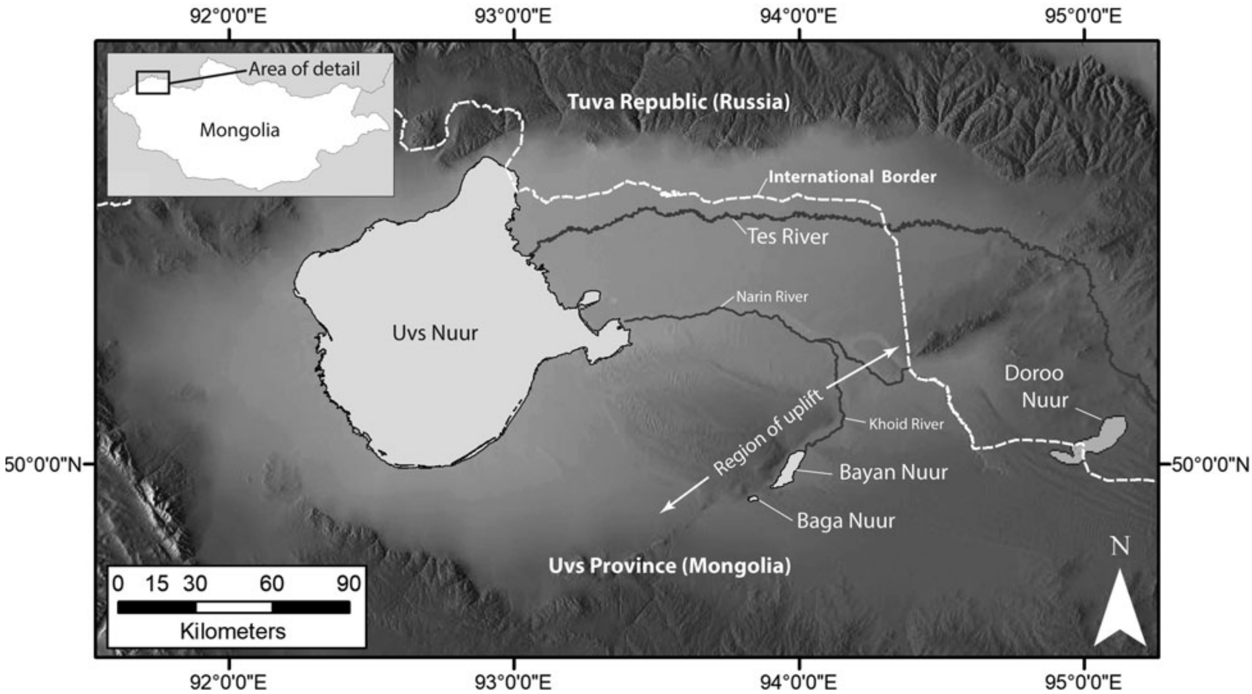

Figure 1. Map showing major lakes and landforms in and around the northern portion of Uvs Province, Mongolia. Inset map of Mongolia shows the location of the larger map of northern Uvs Province.

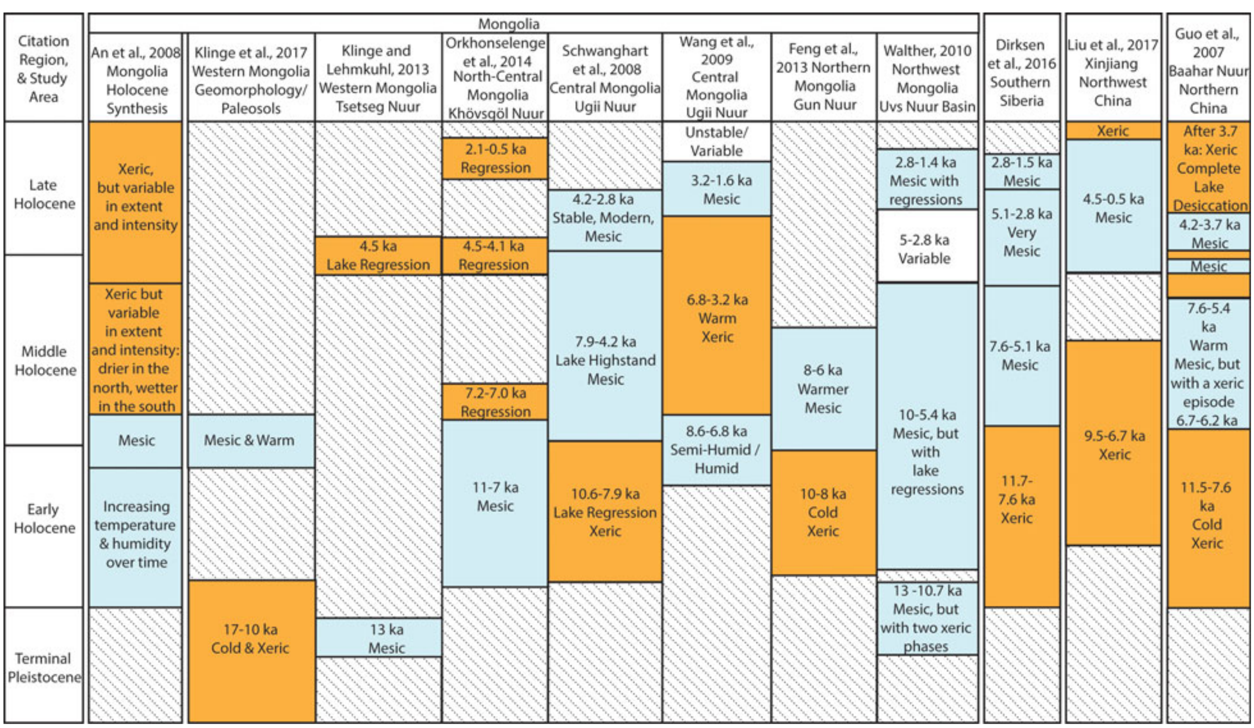

Figure 2. Terminal Pleistocene–Holocene paleoclimatic synthesis for Mongolia and surrounding regions. Xeric periods are depicted in orange; mesic periods in blue; periods with no data are hatched.

1997; Walther, 1998; Lemkuhl, 1999, 2000), and on geochemical, palynological, and sedimentological analyses of cores and sections from Baga, Bayan, and Uvs Nuur (Naumann, 1999; Walther, 1999; Krengel, 2000; Naumann and Walther, 2000). Critically, this research draws attention to the fact that lake level fluctuations are linked to both large-scale climatic and to local geomorphic factors. For example, lake highstands during the LGM are linked to glaciers melting in the mountains but also to tectonism and dune formation impounding meltwater discharge. Similarly, although this previous research indicates the Younger Dryas was generally dry, it also argues that lake levels were 30–48 m higher than today, the scale of which is a conclusion we ultimately refute. In general, a synthesis of this research suggests: 1) a mesic phase in the terminal Pleistocene and Early Holocene (13–10.7 ka) that was interrupted by dry phases associated with the Younger Dryas; 2) a mesic period between 9 ka and 5.4 ka; 3) a period of rapidly alternating mesic–xeric intervals between 5 ka and 2.8 ka; 4) and a mesic period spanning 2.8–1.4 ka (Figure 2). Importantly, the levels of both Uvs and Bayan nuur peak between about 15 ka and 11 ka, regress dramatically in a punctuated fashion from 11 ka to 2 ka, and then transgress their minimum pool elevation (ca. 2 ka) in the very latest Holocene. This Late Holocene transgression flooded sand dunes and created embayments behind the exposed tops of these dunes that are visible today. These embayments trap organic materials, forming peat-like deposits (Grunert et al., 2000; Walther, 2010).

Our analyses suggest revisions and refinements to Grunert et al.'s (2000) lake-level reconstructions. These revisions have important implications regarding the late Quaternary paleoenvironmental history in the region. In particular, our findings point to a drier Younger Dryas marked by a much smaller extent of Bayan Nuur than that proposed by Grunert et al. (2000), and a standstill/transgression ca. 7.0–4.0 ka, suggesting more mesic regimes characterized the region in the late Middle and earliest parts of the Late Holocene. Like Grunert et al. (2000), our research also suggests pronounced regressions after ca. 4 ka.

METHODS

We characterized and used precision mapping and dating of surface and in-situ archaeological sites and paleosols around Bayan Nuur (Figure 3). We operated on the assumptions that: 1) archaeological sites had to be above the pool elevation of Bayan Nuur when they were occupied and hence provide a rough measure of maximum lake-pool elevations over time, and 2) paleosols characteristic of stabilized dunes, lakeshore soils, and peaty embayments approximate past lake level elevations, in particular the latter two that currently track the water table and typically occur within ~1–2 m of lake level, especially in areas proximal to the lake itself. Determining the elevations of archaeological sites and paleosols relative to current lake level was critical to this exercise.

Archaeological methods

Archaeological methods consisted of surface surveys, site recording, surface sampling, and single-site excavations. Surveys were performed using line-abreast transects following the contours of natural surface features such as the Uvs Nuur lakeshore, streams, and ridgelines (Figure 3). Sites were recorded by documenting the density and types of artifacts found at each site, with locations recorded using GPS receivers with ~3 m accuracy. Surface collections were made at most sites with denser deposits, with artifacts sampled in a 3-m-diameter area in these locations. For this study, field records and recovered artifact types were used to make very gross temporal assignations for each site because many of the sites occur in dunes and dune blowouts that often mix artifacts of different ages, often making precise temporal assignations impossible. Two sites were excavated: BN-001 and BN-003, and radiocarbon assays were performed on samples from each site. Site descriptions are provided in the results section.

Chronological archaeological sequences are not well-developed for northwestern Mongolia, so we were forced to rely principally on sequences developed for the Gobi Desert, ~1000 km to the southeast in southern Mongolia. These broad temporal classifications consist of: 1) aceramic lithic assemblages containing only stone tools or debitage that are argued to date from ca. 40 ka (Zwyns et al., 2014) to well into the Holocene (Janz, 2012); 2) aceramic microblade assemblages that often date to the LGM (ca. 27–15 ka) and Younger Dryas (13–11.7 ka) (Yi et al., 2013), but could conceivably date to as late as the Bronze Age (ca. 3 ka) (Kuzmin, 2007; Janz, 2012; Janz et al., 2017; Zhang, 2021); 3) ceramic assemblages that likely date to after ca. 8 ka, when ceramics become fairly common in Mongolia, while recognizing that the earliest ceramics in the region could date to as early as 9.6 ka (Janz, 2012; Janz et al., 2015; Schneider et al., 2016; Janz et al., 2017; Wright, 2021); 4) stone monuments such as Khirigsuurs and other stacked rock monuments that typically date from the start of the Bronze Age (ca. 4 ka) to perhaps ca. 1 ka (Janz, 2012; Ėrėgzėn, 2016; Wright, 2017; 2021); and 5) sites containing metal (typically bronze or iron) implements that date to after 5 ka (Janz, 2012; Honeychurch et al., 2021; Wright, 2021).

Paleosol characterization and dating

Soil characterization and dating was performed on a series of paleosols identified in the dune fields ringing the southern end of Bayan Nuur, most of which are exposed along the edges of deflationary areas within the dune field. Soils were characterized using standard pedological descriptions of texture, structure, and color (Buol et al., 1997; USDA, 1999). These descriptions were then compared to modern soils in the area, particularly the peaty soils that form in shallow areas adjacent to the lake itself, organic-rich mollisols that form in grassland strips adjacent to the lake shore and the spring-fed streams that feed the lake (these track the water table), and aridisols and inceptisols that form on vegetation-stabilized dunes, often containing remnant cross-bedding. Carbon samples for dating were recovered by carefully cleaning paleosol sections and collecting charcoal samples embedded within soil matrixes. Soil sampling locations and elevations were determined using a Trimble GPS receiver with submeter accuracy and a laser viewfinder to establish site and sample elevations relative to the modern elevation of Bayan Nuur. Carbon samples were dated at the Center for Applied Isotope Studies at the University of Georgia (UGAMS) and at the W.M. Keck Carbon Cycle Accelerator Mass Spectrometer Laboratory at the University of California, Irvine (UCIAMS). The Pennsylvania State Radiocarbon Laboratory prepared the samples run at the UCIAMS facility.

RESULTS

Archaeological sites

We made 466 archaeological site discoveries around Bayan Nuur, ranging from terminal Pleistocene microblade scatters to Bronze Age stone monuments. The two excavated sites (BN-001 and BN-003) occur in paleosols capped by dunes at the southern end of Bayan Nuur. Because these sites occur in paleosols, and one site contains an intact hearth feature, the sites appear to be

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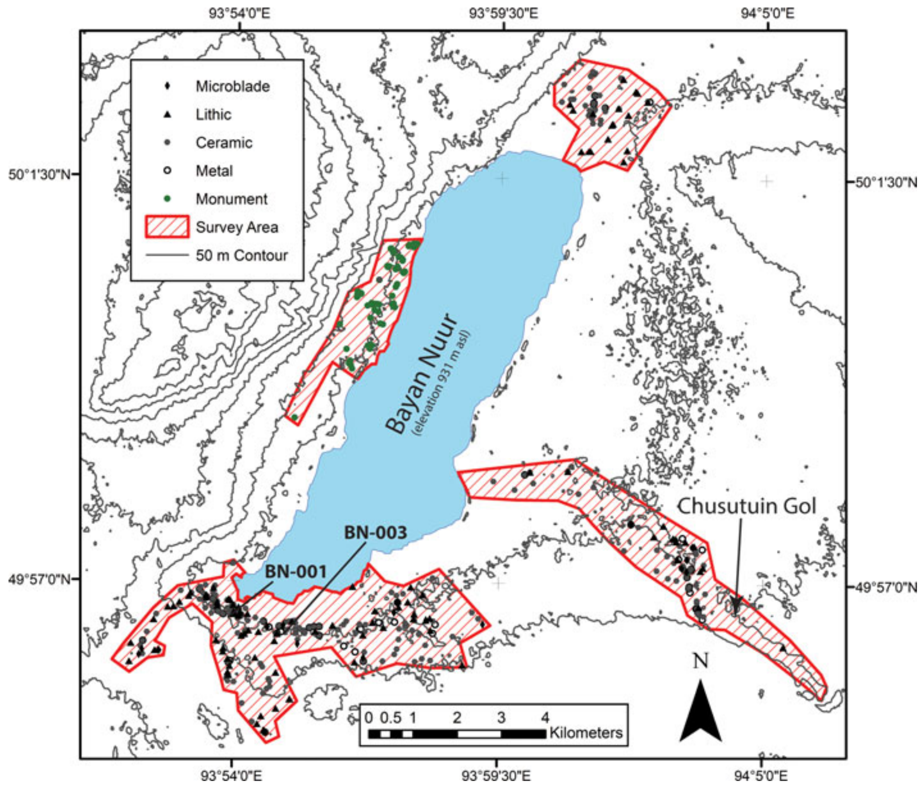

Figure 3. Contour map of the Bayan Nuur basin showing survey locations and archaeological sites by type, and location of soil sample sites BN-001 and BN-003.

primary deposits rather than deflated surface or difficult-to-date (at least with any precision) surface deposits.

Survey results and analysis

The frequency of time-sensitive archaeological components identified in the survey is presented in Table 1, with summary statistics describing their elevation and distance to the modern lakeshore. What is seen in these data is that ceramics dominate artifact material types in the Bayan Nuur basin, which is perhaps a product of how many sherds can be derived from just one pot, but also perhaps indicative of the proliferation of people across the landscape beginning ca. 5 ka and thereafter into the Bronze Age (Honeychurch et al., 2021; Wright, 2021). Lithics, the least temporally diagnostic material type, are the next most-common artifact, followed by metal, monuments (concentrated on the western shore of the lake), and relatively rare microblade components. Kruskal-Wallis tests indicate differences in elevations ($X^2 = 9.793$; $p = 0.044$; df = 4) and distances to lakeshore ($X^2 = 88.761$; $p < 0.0001$; df = 4) by component type are significant, with post hoc pairwise comparisons indicating microblade components account for the significant differences in elevation and are typically found higher in elevation than other components. Monuments account for the differences in distance to lake because they are typically nearer the lake than other components. The fact that monuments are predominantly on the western side of the lake is likely partially due to the fact that this is the only part of the study area with a stable substrate formed from coalescing alluvial fans rather than sand dunes or mud flats.

Combined, these data provide only very rough estimates of lake levels over time, but these estimates are telling. Microblade components are typically 15–26 m higher in elevation than other components, even when accounting for sand dune deflation and post-depositional artifact movement in the dunes to the south and east of the lake (Table 1; Figure 4). If these microblade sites are in any way contemporaneous with BN-003 (a Younger Dryas microblade site described in succeeding subsections), this could suggest terminal Pleistocene Bayan Nuur levels were considerably higher than Holocene lake levels, and that the Holocene was therefore marked by considerable regressions, although hunting or other behaviors affiliated with microblade use may condition site location at slightly higher elevations as well. Distance to lakeshore is less informative, but the fact that nearly all Holocene components, many of which likely date to the Bronze Age (ca. 3.8–2.7 ka), are at least 3 m higher in elevation than the current lake level (and at least 24 m from the current lake edge) arguably suggests lake levels in the Early Holocene through the early Late Holocene were higher than the current lake level and therefore, a regression or series of regressions occurred in Late Holocene (Table 1; Figure 4). The fact that monuments, which postdate 4 ka, are typically nearest the lake of all components, would seem to lend credence to this assertion.

Site BN-001

BN-001 is an artifact scatter contained within and eroding out of a dune-capped paleosol (labeled ‘L7’ in our typology) at 939 m asl (9.3 m above Bayan Nuur’s current lake level). The site is comprised mainly of flaked stone-chipping debris, plainware ceramic sherds, a milling slab, ochre fragments, and faunal remains, although only the faunal remains and lithics were recovered via excavation of the in situ soils containing the site

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Table 1. Bayan Nuur archaeological component frequency and summary statistics for elevation and distance to lakeshore.

		Microblade (*n* = 20)	Lithic (*n* = 97)	Ceramic (*n* = 223)	Metal (*n* = 52)	Monument (*n* = 24)
Elevation	Mean	991.5	976.9	965.9	968.4	966.6
	Std. Dev.	40.5	33.8	24.9	24.9	15.5
	Min.	948	936	933	938	944
	Max.	1062	1061	1062	1062	982
Dist. to Lake	Mean	2615.6	1693.7	1844.8	2315.7	457.3
	Std. Dev.	1985.3	1646.5	1859.2	2157.4	303.5
	Min.	256.4	24.0	119.0	201.4	51.6
	Max.	5718.0	8431.7	6361.0	6355.2	1127.7

deposit. The ceramics and milling stone are surface deposits believed to be associated with the paleosol containing the site, but this association must be considered tentative. Critically, although much of the faunal assemblage is fragmentary, positively identified specimens consist of 17 *Equus* sp. tooth fragments and postcranial remains, nine caprine postcranial fragments, and a fragment of *Bos* sp. The paleosol is a 30-cm-thick stratum whose morphology, structure, and color are consistent with mollisols found near the modern lakeshore, meaning it was likely near Bayan Nuur's pool elevation when the site was occupied. Four radiocarbon dates (Table 2) on charcoal recovered from the paleosol place site occupation ca. 4330–4470 cal yr BP. In sum, it appears people likely captured ungulate prey and made camp near the shores of Bayan Nuur ca. 4.3 ka, maintaining and discarding stone tools, and perhaps breaking ceramics in the process.

Site BN-003

BN-003 is another artifact scatter also contained within and eroding out of a dune-capped paleosol (labeled 'L9' in our typology) at 947 m elevation (16.9 m above Bayan Nuur's current lake level). The soil itself appears to be the remnants of an aridisol characteristic of stabilized dunes rather than the peats and mollisols found near the lake's edge. The site's assemblages are very different from those of BN-001. They consist of 17 microblade cores (Figure 5) and over 825 microblades or microblade core trimming fragments often associated with LGM and especially Younger Dryas adaptations (Yi et al., 2013). The site also contains abundant faunal remains: 568 ungulate bone fragments, including antler and likely equid remains. The remains of a large ungulate, perhaps *Bos* sp., were found near an in-situ hearth feature excavated into the site's paleosol and underlying cross-bedded sands (Figure 6). The hearth itself consists of at least 14 (more stones were likely eroded from the blowout in which we discovered the feature) tabular, oxidized (likely from burning) sandstone cobbles and small boulders lining a ~65 × 50 cm depression that appears to have been excavated into the native paleosol containing the remainder of the site deposit. The depression was filled with dark-colored, charcoal-flecked sands distinct from both the sandy paleosol containing the site and the cross-bedded sands above and below the paleosol containing the site deposit.

Two charcoal samples recovered from this feature were radiocarbon dated (Table 2; Figure 6). Calibrated age distributions for accelerator mass spectrometry (AMS) measurements on these samples, one collected immediately atop the stone slabs (UCIAMS-169801) and the other collected immediately beneath them (UCIAMS-166070), overlap substantially, with the difference in the median age estimates (12,583 cal yr BP and 12,643 cal yr BP, respectively) reflecting the fold in the calibration curve over this interval. The similarity in the age distributions allows for the possibility that these two samples are the same age, likely pointing to a single occupation. A third AMS measurement (UCIAMS-167232) comes from the same piece of charcoal recovered from the top of the stone slabs (measurement UCIAMS-169801) but owing to the large error (± 120 ^{14}C years) the University of California, Irvine and Pennsylvania State radiocarbon laboratories that prepared and measured it reported it as erroneous (Table 2). Combined, these data suggest the site was occupied ca. 12,481–12,703 cal yr BP, making it a Younger Dryas occupation. Critically, the site elevation is 31 m below Grunert et al.'s (2000) Younger Dryas highstand.

Paleosols

In addition to the paleosols containing sites BN-001 and BN-003, the southern and eastern margins of Bayan Nuur contain numerous paleosols characteristic of vegetation-stabilized dunes, grassy lakeshore environments, and organic-rich, peaty, shallow-water deposits. Eight of these paleosols occur in the general vicinity of BN-001 and BN-003. Three (L4, L5, and L6) are stratigraphically below the BN-001/L7 paleosol, three (L1, L2, and L3) are near the modern lakeshore, and one (L8) is in the dunes overlooking BN-001 (Figure 3).

The highest elevation paleosols are L9 and L8, which are characterized by low organic content, pale color, and nearly granular peds typical of aridisols and weakly developed inceptisols found on the crests of modern stabilized dunes (Cooke et al., 1993; Table 3; Figure 7). The proximity to the lake and lake level when these paleosols formed is thus unknown, but they had to have formed above the maximum pool elevation of Bayan Nuur. The L9 soil is 16.9 m above the modern Bayan Nuur level (947 m asl) and contains the in situ Younger Dryas archaeological site BN-003 that includes the hearth feature described previously. Because the hearth feature was excavated by its makers into the L9 soil, the soil's minimum age is therefore that of the radiocarbon dates derived from the feature fill of ca. 12,100 cal yr BP. Given this, Bayan Nuur had to be at a minimum elevation of 947 m asl during the Younger Dryas and may indeed have been lower. The L8 paleosol, an inceptisol

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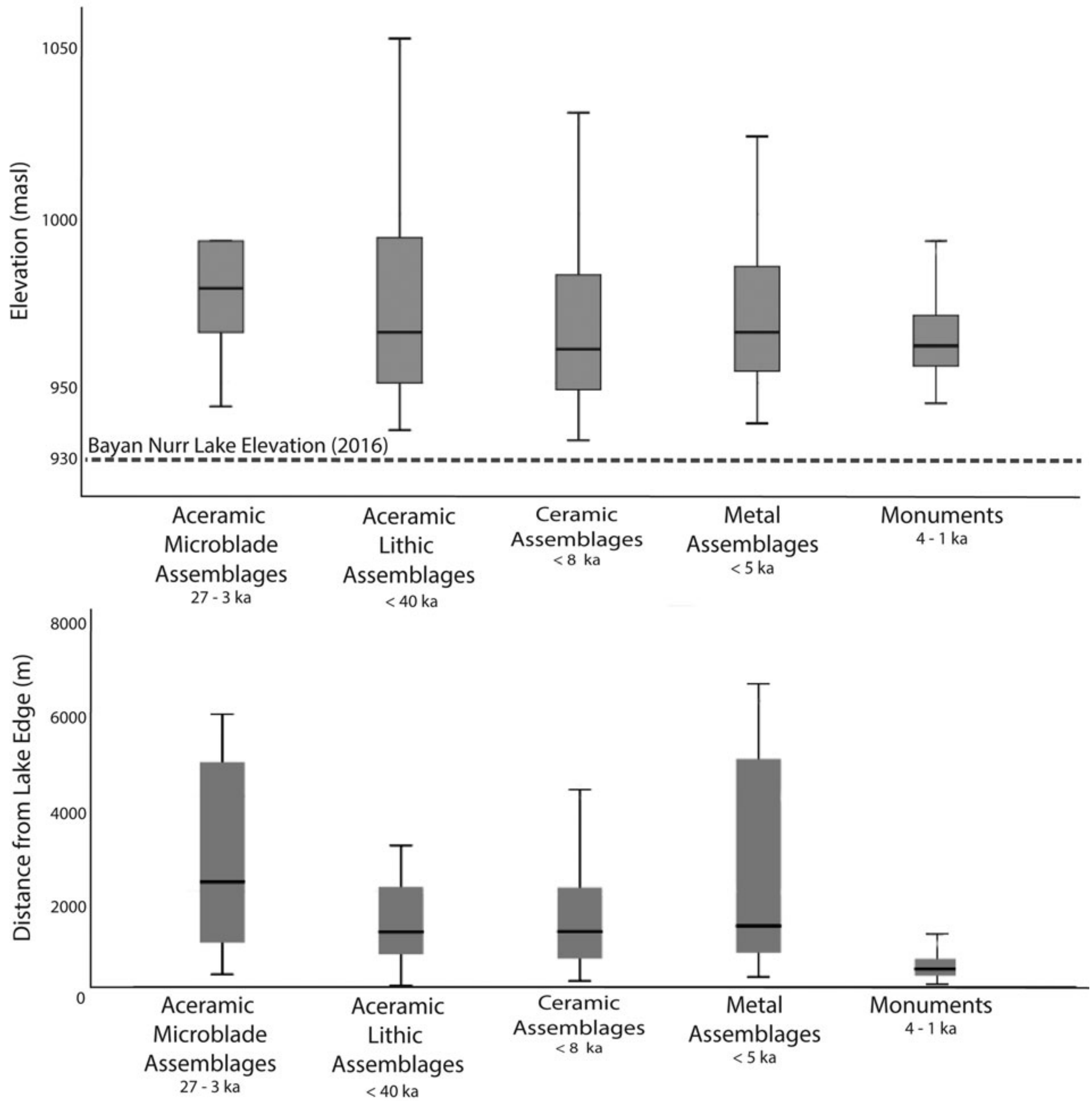

Figure 4. Boxplots depicting summary statistics for component elevations (top) and distances to modern lake edge (bottom).

characteristic of stabilized dunes and therefore unconnected to lake level or water table, provides little in the way of reconstructing lake-level histories.

The middle elevation paleosols (Figure 7) are of considerable areal extent and exposed in a dune blowout extending ∼35 m E–W. They are found at or stratigraphically below archaeological site BN-001. Site BN-001 is contained within L7, which is a dark, organic-rich, well-developed mollisol with well-developed, blocky peds. Modern soils with these characteristics are found in the grassland environments currently encircling Bayan Nuur and in oxbows and flats along its major spring-fed tributaries. The soils below this, interspersed by dune deposits, were exposed in a step trench excavated below BN-001 (Figure 8). These soils (L4, L5, and L6) are very dark, organic-rich, and contain remnant plant material (i.e., they are peaty) and are therefore characteristic of either shallow-water embayments or the edges of spring-fed streams feeding the lake. Based on their similarity to modern soils found around the lake and its main tributaries, these paleosols appear to have tracked the water table at or near historical Bayan Nuur levels, which appears to have been ∼9 m higher than the current lake level ca. 4.3 ka. Importantly, the peaty soils in the lower sections of this profile indicate that Bayan Nuur was ∼7.9–8.7 m higher in elevation between ca. 6900 cal yr BP and 5700 cal yr BP. These soils perhaps indicate transgressions that created embayments on the shoreward side of flooded dune islands or archipelagos (Grunert et al., 2000). Importantly, cross-bedded sands bracket the dated peaty paleosols, indicting that Bayan Nuur regressed to such an extent between transgressive episodes that dune emplacement took place before and then after formation of the peaty paleosols.

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Table 2. Radiocarbon dates on charcoal from the Bayan Nuur basin.

Paleosol	Archaeological Site	Lab No.	^{14}C yr BP	^{14}C yr Error	Cal yr BP[a]
L9	BN003	UCIAMS-167232[b]	9760	120	10,726–11,608
L9	BN003	UCIAMS-169801[b]	10,550	40	12,481–12,684
L9	BN003	UCIAMS-166070	10,595	30	12,496–12,703
L8		UGAMS-27654	2470	25	2374–2712
L7	BN001	UCIAMS-166069	4000	20	4417–4521
L7	BN001	UCIAMS-169796	3780	70	3979–4405
L7	BN001	UCIAMS-169797	3880	20	4240–4410
L7	BN001	UCIAMS-166068	3880	15	4246–4406
L6		UCIAMS-169798	4965	20	5602–5736
L5		UCIAMS-169799	5365	20	6007–6275
L4		UCIAMS-169800	6035	25	6793–6949
L3		UGAMS-27656	1840	20	1707–1821
L2		UGAMS-27657	3560	25	3726–3964
L1		UGAMS-27655	330	20	312–460

[a]Dates calibrated at 95.4% probability with Oxcal 4.4 (Bronk Ramsey, 2009) using the IntCal 20 calibration curve (Reimer et al., 2020).
[b]These dates are from the same piece of charcoal but because the first date (UCIAMS-167232) had such a large error, the lab ran a new sample from the same piece of charcoal resulting in the second date (UCIAMS-169801).

Figure 5. Selected microblade cores recovered from site BN-003. Samples curated at the National Museum of Mongolia, Ulaanbaatar.

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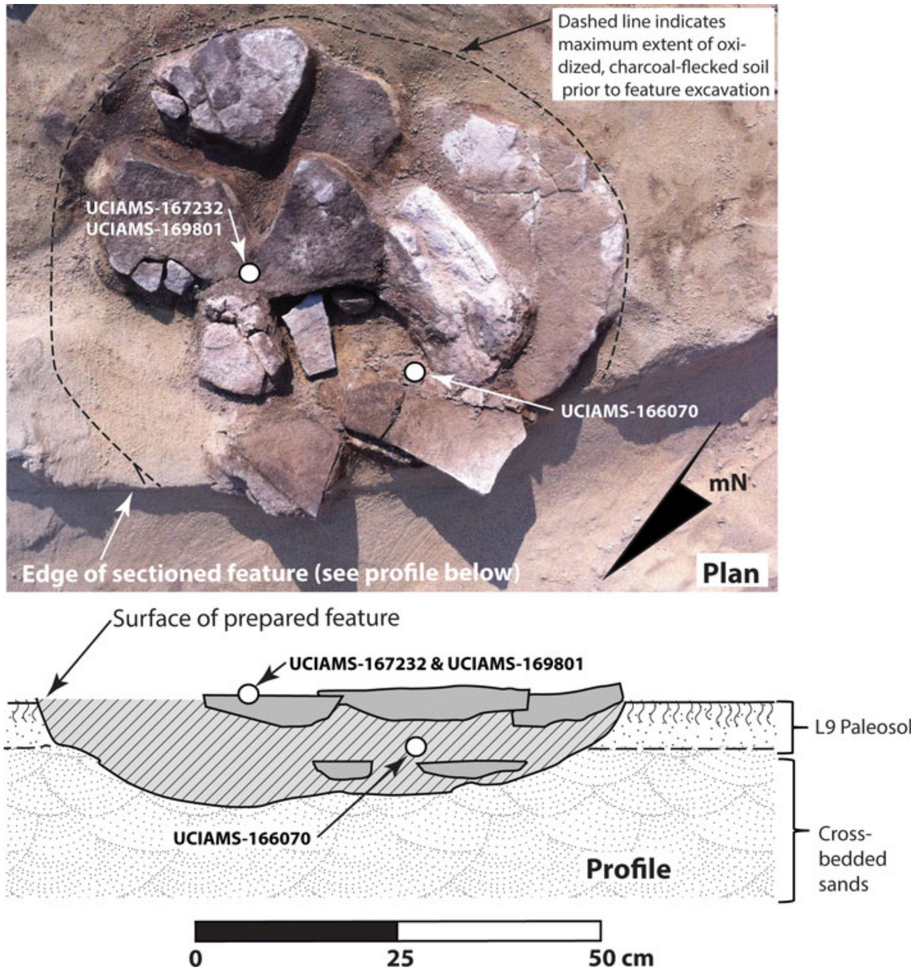

Figure 6. Site BN-003 hearth feature plan photograph (top) and schematic profile of the excavated feature (bottom). Charcoal samples (UCIAMS-#) for radiocarbon analyses collected from charcoal-stained soil in center of feature indicated by white circles; one sample collected immediately on top of one of the stone slabs (UCIAMS-167232 and -1697801); the other sample collected immediately beneath it (UCIAMS-166070). UCIAMS-167232 and 1697801 were derived from the same piece of charcoal; the labs that prepared and dated this sample determined the former (UCIAMS-167232) to be in error.

Table 3. Paleosol age estimates based on AMS dates.

Paleosol	Soil Classification	Paleoenvironment	Elevation above current Bayan Nuur level	Number of AMS dates	Estimated Age[a]
L1	Mollisol	Streamside/Shoreline	2.9 m	1	390 cal yr BP
L2	Mollisol	Streamside/Shoreline	4.1 m	1	3900 cal yr BP[b]
L3	Mollisol	Streamside/Shoreline	4.8 m	1	1700 cal yr BP
L4	Peat	Lakeshore/Embayment	7.9 m	1	6900 cal yr BP
L5	Peat	Lakeshore/Embayment	8.4 m	1	6200 cal yr BP
L6	Peat	Lakeshore/Embayment	8.7 m	1	5700 cal yr BP
L7	Mollisol	Streamside/Shoreline	9.3 m	4	4300 cal yr BP
L8	Aridisol/Inceptisol	Stabilized Dune	12.8 m	1	2600 cal yr BP
L9	Aridisol/Inceptisol	Stabilized Dune	16.9 m	3	12,100 cal yr BP

[a]Median age derived using Calib 8.2 (Stuiver et al., 2021) and the IntCal20 calibration curve (Reimer et al., 2020) at 2 σ, rounded to the nearest century.
[b]This reversal most likely results from the sample being derived from an intrusive source of old carbon.

The lowest elevation soils (Figure 7) are extensive and found near the modern Bayan Nuur shoreline. They retain characteristics found in modern soils ringing the lake: they are dark, organic-rich, and contain well-developed blocky peds. Dates on the L1 soil, nearest the lake, and the L3 soil, indicate a Late Holocene regression toward the modern lake level from the ca.

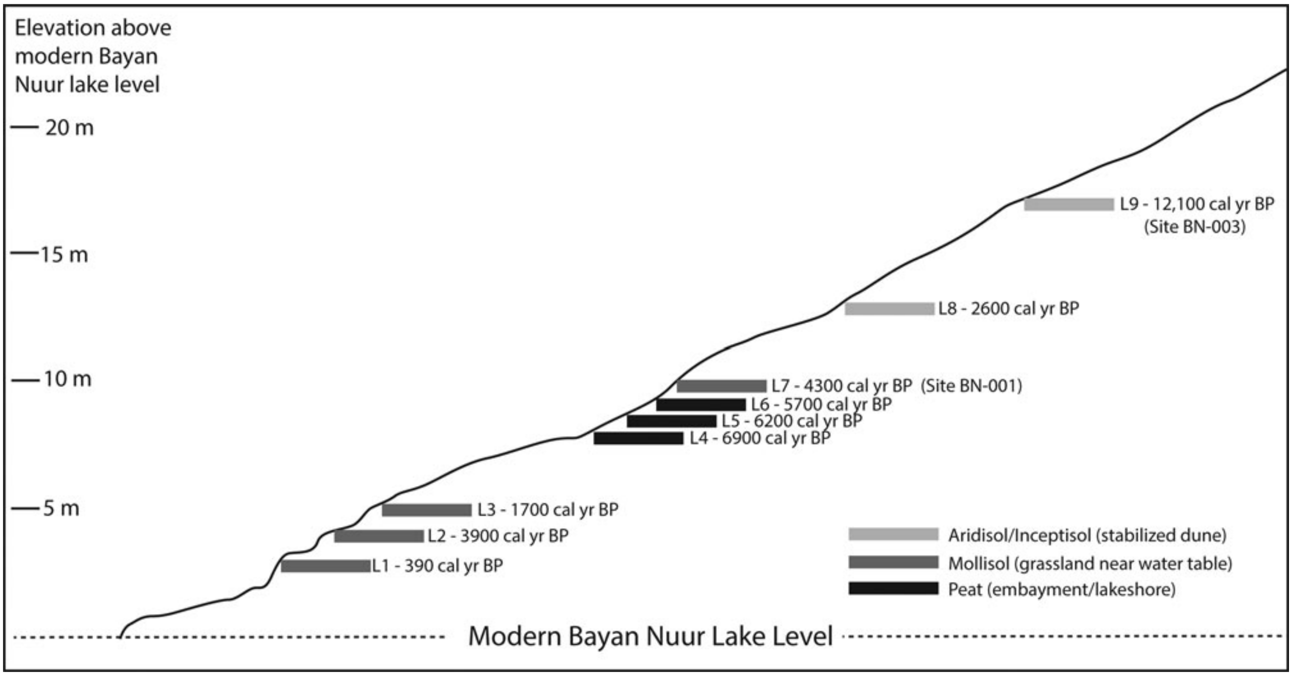

Figure 7. Composite diagram showing paleosol ages (Table 2, 3) and elevations relative to the modern elevation of Bayan Nuur.

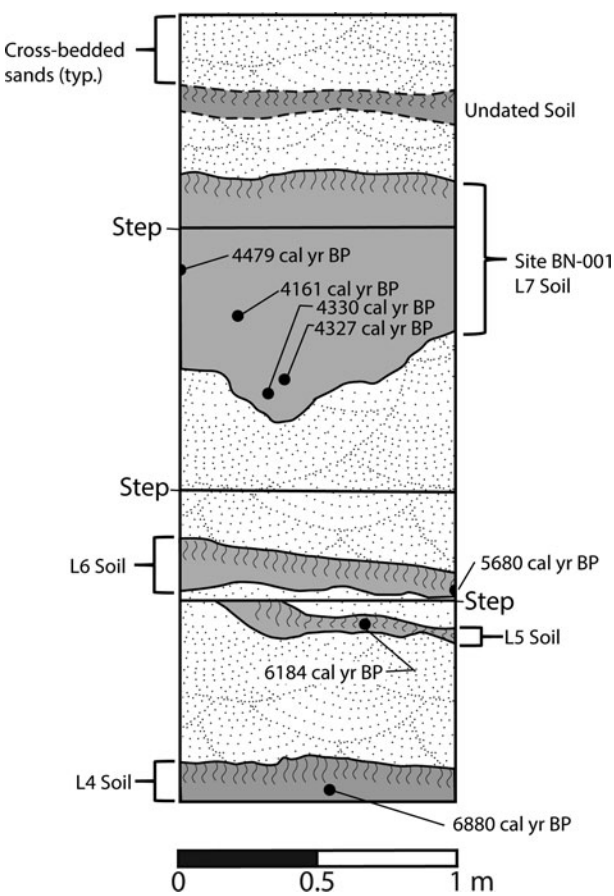

Figure 8. Composite profile of BN-001 step trench (1 m wide × 10 m long × 2.8 m deep) showing estimated radiocarbon dates. Radiocarbon dates are median 2 σ dates generated by Calib 8.2 (Stuiver et al., 2021) and the IntCal20 calibration curve (Reimer et al., 2020). Sands stippled; soils in gray with wavy lines representing rhizoliths.

4.3 ka highstand identified at site BN-001. The apparent reversal in L2 is arguably problematic in that this would imply a 5.2 m regression in the ca. 400 year interval between the development of the L7 soil at ca. 4.3 ka and the L2 soil at 3.9 ka, and then a minor (< 1 m) transgression between 3.9 ka and 1.7 ka (Figure 9). On the one hand, the magnitude of this rapid, ca. 4 ka regression might seem to suggest that the carbon dated in this soil was intrusive and derived from older deposits, perhaps similar to those associated with BN-001 and the L7 paleosol (Figure 9). On the other hand, such a Late Holocene rapid regression and then minor transgression sequence may indeed be plausible, given similar contemporaneous regressions modeled at nearby Uvs Nuur (Grunert et al., 2000), at Tsetseg Nuur in western Mongolia (Klinge and Lehmkuhl, 2013), and at Khövsgöl Nuur in north-central Mongolia (Orkhonselenge et al., 2014) (Figures 2, 9). Based on the latter model's correspondence with Grunert et al.'s (2000) Uvs Nuur lake history model that pertains to the Uvs Nuur watershed containing Bayan Nuur, we posit that this is the more parsimonious model of the two, meaning that there was likely a rapid and pronounced regression at Bayan Nuur ca. 4 ka.

Late Quaternary Bayan Nuur lake-level history

Combined pedological data and radiocarbon dating of paleosols at Bayan Nuur indicate a dynamic late Quaternary lake-level history (Figure 9). L9 soils at site BN-003 indicate lake levels were ~17 m higher in elevation than at present, but also at least 31 m lower in elevation than previous research had suggested (Grunert et al., 2000). The stratigraphic sequence of soils at and below site BN-001 indicates that between ca. 7–4.3 ka, lake levels were ~8–9 m higher in elevation than those at present, with a series of transgressions and regressions indicated by peaty soils bracketed by dune deposits ca. 7–5.7 ka. Paleosols nearer the current

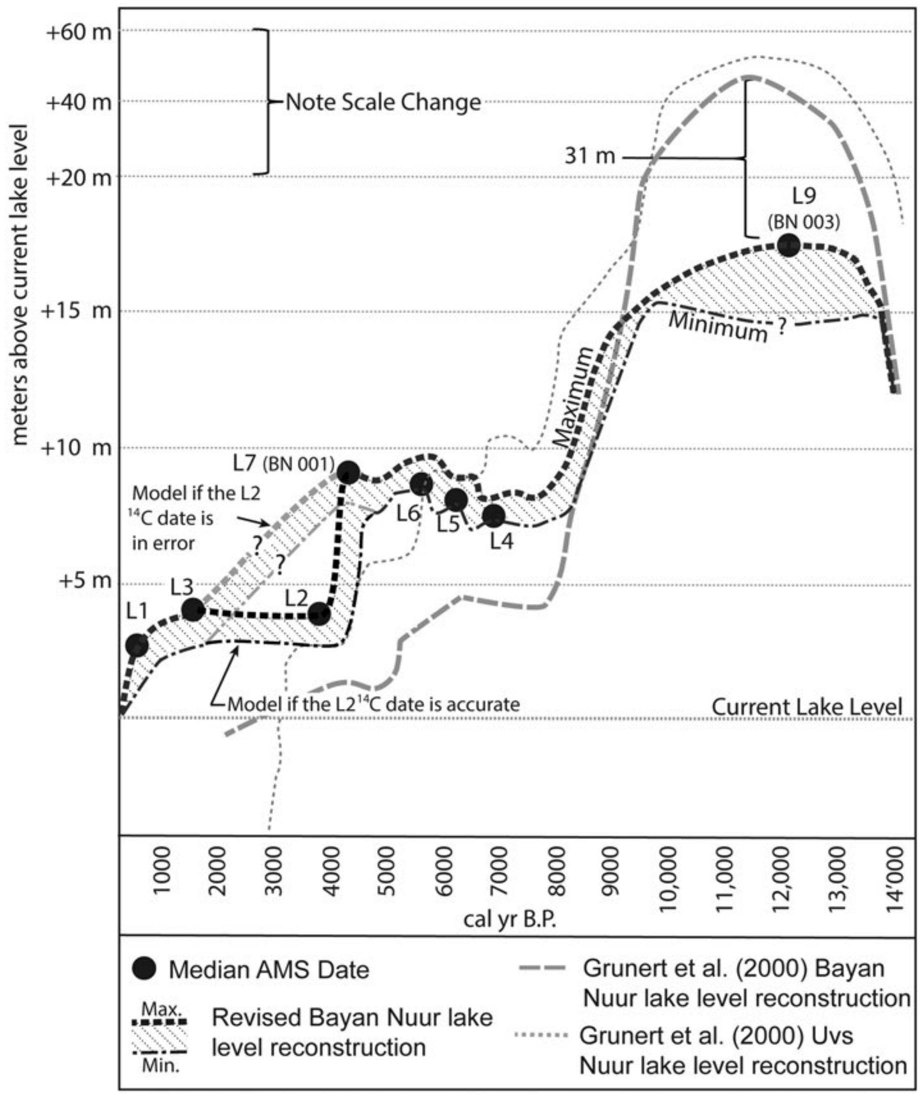

Figure 9. Bayan Nuur lake-level reconstruction compared to that of Grunert et al. (2000, figure 6). Median AMS dates from paleosol samples L1–L7, L9 (Tables 2, 3).

lakeshore indicate a Late Holocene regression, perhaps quite rapid, toward the modern lake level of 931 m asl after ca. 4 ka.

Archaeological survey data, though of only gross temporal precision, tend to support these reconstructions. Microblade components occur 15–26 m above the current lake level. If these microblade sites are contemporaneous with the Younger Dryas microblade-rich, in-situ archaeological site BN-003, it would appear the distribution of these sites track lake level during the latest part of the terminal Pleistocene (Figure 10). The archaeological data for the Late Holocene are little more difficult to interpret, but the majority of elevations for ceramic, metal, and monument components, most of which likely date to after ca. 8 ka, are more than 10 m above the current lake level (Figure 4) and therefore, at the least, do not refute the Late Holocene lake-level history reconstructed via the radiocarbon-dated paleosol sequence.

CONCLUSIONS

The most obvious and important implication of the preceding results is that terminal Pleistocene Younger Dryas lake levels at Bayan Nuur were ∼30 m lower than the estimates provided by Grunert et al. (2000), who based their assertion on radiocarbon dating of mollusks from what are ostensibly lake sediments exposed in dune fields dissected by Chustutuin Gol, a large stream draining into Bayan Nuur from the southeast (Grunert et al., 1999, 2000). It is difficult to comment on this discrepancy because we were unable to relocate Grunert et al.'s (2000) sampling location, despite the archaeological survey we conducted in this area (Figure 3). We postulate, however, that the feature they dated was either not an actual Bayan Nuur shoreline, or that the material they dated was otherwise problematic in some way. Because Bayan Nuur is fed by water draining a portion of the Altan Els dune field to the south and east, which is recharged mainly through precipitation, the implication is that the Younger Dryas was drier than Grunert et al. (2000) surmised. This is not to say the Younger Dryas in this location was truly xeric; lake levels were, after all, ∼17 m higher in elevation than those at present. What we do argue is that this mesic phase was considerably drier than previously recognized.

It is difficult to extrapolate the Bayan Nuur data to the larger Uvs Nuur watershed because Bayan Nuur is 173 m higher in

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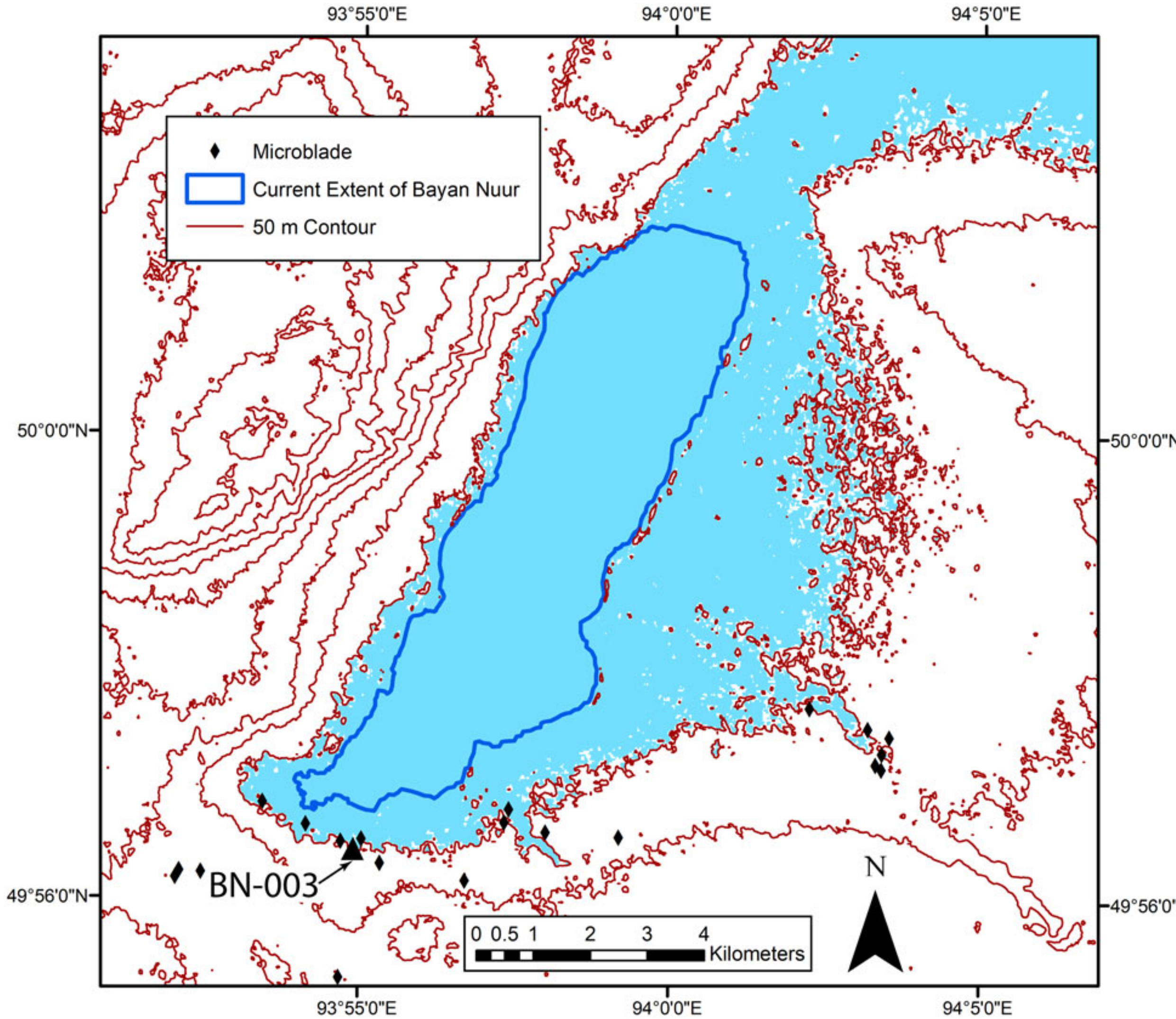

Figure 10. Contour map showing reconstructed Younger Dryas Bayan Nuur lake level (light blue shading), the modern Bayan Nuur lake level (dark blue outline) and sites with microblade components.

elevation than Uvs Nuur, Uvs Nuur is fed by several rivers rather than groundwater, and a stabilized dune is alleged to have blocked each basin from the other at least at one point during the Pleistocene–Holocene transition (Naumann, 1999). Grunert et al. (2000), however, made such extrapolations based on the supposition that precipitation largely drove lake levels across Uvs Province. If such extrapolations are warranted, meaning that Bayan Nuur can stand in as any sort of proxy for Uvs Nuur, then we might expect to see similar reductions in water volume and lake levels across the Uvs Nuur basin during the Younger Dryas (Figure 9).

Another implication is that during the late Middle Holocene, Bayan Nuur lake levels were marked by a series of small-scale transgressions and regressions within a generally stable phase between ca. 7–4.3 ka. This is shown by lakeshore paleosols that are interspersed with dune deposits 8–9 m higher than the current lake level, and by archaeological site distribution that is consistent with this interpretation. This reconstruction does not refute Grunert et al.'s (2000) Middle–Late Holocene Bayan Nuur lake-level reconstruction where they argued for a 7.3–3.2 ka transgressive phase within a longer trans-Holocene trend of lake regression, but it does indicate that the temporal span and elevational scale of this standstill/transgression at Bayan Nuur was greater than they recognized (Figure 9). This would seem to suggest a more mesic late Middle and early Late Holocene than indicated by prior reconstructions.

Finally, the data we present indicate post-4-ka lake regressions akin to those postulated by Grunert et al. (2000). Grunert et al. (2000), however, only noted the paleosols proximal to Bayan Nuur but did not date them, basing their estimates for Late Holocene Bayan Nuur regressions instead on extrapolation from the Uvs Nuur data. Our data therefore provide greater precision to Grunert et al.'s (2000) model by providing direct AMS dating of these soils.

The preceding summaries are consistent with many other Quaternary lake histories in Mongolia and southern Siberia (Figure 2). In both Uvs Province (Walther, 2010) and in Khovd Province immediately south of Uvs (Klinge and Lehmkuhl, 2013), a Younger Dryas mesic phase was identified that was present across western Mongolia. Nearly every study to date in the region argues for an Early Holocene xeric phase marked by substantial regressions, a pattern we infer at Bayan Nuur as well. The Bayan Nuur data also correlate with a series of studies in Northern Mongolia (Feng et al., 2013), southern Siberia (Dirksen et al., 2016), and Northern China (Guo et al., 2007) that reveal a Middle Holocene mesic phase, suggesting this pattern extended over a vast swath of the region roughly ca. 8–4 ka. The correlations between the Bayan Nuur data and those recorded at Ugii Nuur in central Mongolia are particularly striking (Schwanghart et al., 2008), although Wang et al. (2009), working at the same lake, reconstruct this period as warm and xeric rather than mesic. A Late Holocene xeric phase was also noted by many studies across the region (Guo et al., 2007; An et al., 2008; Klinge and Lehmkuhl, 2013; Orkhonselenge et al., 2014; Klinge and Sauer, 2019), but many other studies record this time as mesic. Combined, the data from Bayan Nuur show strong correlations with the regional record during the Younger Dryas and the late Middle Holocene, but the complexity of the Late Holocene record attested to by An et al. (2008) is made clear in these comparisons, perhaps affected by tectonism (Owen et al., 1997), dune emplacement (Naumann and Walther, 2000), and other localized parameters.

The importance of lake-level history reconstructions to archaeologists is clear because these studies provide paleoenvironmental context for any serious study of human–land relationships, especially in arid regions (Bedwell, 1970; Louderback and Rhode, 2009; Kotlia et al., 2011). What our study shows, however, is that archaeological settlement pattern, and especially excavation data, can be used to not only reconstruct past behavior in a paleoecological context, but can also be used to reconstruct paleoecological context, an inversion of most human paleoecological studies (Grayson and Cannon, 1999; Adams et al., 2008). These sites also can be used as a check on more traditional paleoecological studies, and can provide precision in ecological reconstruction, as our revision to the Younger Dryas record at Bayan Nuur has shown. Archaeological data thus serves as another valuable proxy in paleoecological reconstruction, reiterating the importance of multiple proxies in historical ecology (Mann, 2002).

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