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Late Pleistocene/Holocene wetland events recorded in southeast Tengger Desert lake sediments, NW China

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Abstract **The area along the eastern and southeastern margins of the Tengger Desert, NW China, which is sensitive to the summer monsoon variations, was selected for studying the environmental conditions surrounding the transition between Paleolithic foragers and Neolithic farmer/pastoralists. Short cores were obtained from four lake basins in the southwestern Tengger using a hand-driven piston coring device. Proxies from these cores were supplemented by radiocarbon ages obtained from lake sediment cores, shoreline features and spring mound deposits. Together these records provide evidence of millennial-scale climate change events from the Pleistocene-Holocene transition to the present. Lake/wetland events, representing periods of more intensive summer monsoon, occur in the records at ~12.7—11.6, ~10.1, ~9.3, ~8.0, ~5.4, ~1.5, and ~0.8 ka BP. They do suggest that century- to millennial-scale climatic cycles are characteristic of the Holocene in the southeastern Tengger Desert although the chronology must be considered extremely tentative.**

Keywords: Tengger Desert, lake fluctuations, Holocene, rapid climatic change.

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We are currently involved in a long-term multi-disciplinary project oriented towards understanding the hunter-gatherer antecedents to agriculture in northwest China and think that a fundamental aspect of this development was rapid century-to-millennial-scale environmental change in lake/wetland systems in China's northwestern deserts. Understanding the late Pleistocene/ Holocene histories of these systems is a critical aspect of this on-going project. Here we report preliminary results from paleoenvironmental studies associated with the project. An area on the eastern and southeastern margins of the Tengger Desert (38°N—40°N lat., 104°E—106°E long.) was chosen for study because of limited impacts from modern farming in the desert region and because of its sensitive location at the extreme northwestern margin of the summer monsoon (Fig. 1). Based on the results of preliminary work in the area[1—4], we selected six lake/ wetland basins for more intensive sampling and analyses.

1 Lake selection and description

Jilantai, centered about 39°40′ N, 105°40′ E, is the northeasternmost of the lakes and lies between the Tengger and Ulan Buh sandy deserts. The lake is currently a small (~55 km^2), shallow saline lake, but was apparently three to four times larger during the early Holocene[5]. Yaobahu, centered about 38°32′ N, 105°23′ E, is a small inter-dunal lake on the eastern margin of the Tengger Desert at the toe of a major alluvial fan at the foot of the highest southern peaks of the Helan Mountains. QG3 is a spring mound in the Pigeon Mountain basin, a small drainage of the Yellow River at the southern end of the Helan Mountains about 38°51′ N, 106°3′ E. Flow in the numerous springs in the basin appears to be related to groundwater supplied through alluvial fans on the southern margin of the Helan Mountains and is part of the same general groundwater system that feeds the lakes on the Tengger/Helan margin.

Toudaohu and Erdaohu are the easternmost of a series of three finger lakes in the south-central Tengger Desert. The modern lakes consist of playas and shallow ponds and are 25—30 km long (N-S) by 2—5 km wide (E-W). They are separated by extensive dune fields, with dunes reaching up to 70 m in elevation. Toudaohu is centered at 38°25′ N, 105°7′ E. Fresh-water springs along its southeastern margin support a small village and a number of hamlets. Erdaohu, centered at 38°13′ N, 104°54′ E, is about 15 km west of Toudaohu. The massive dune field that separates the two lakes encroaches on Erdaohu along its eastern margin. Chouhu is a small saline lake/playa centered at 37°35′ N, 105°11′ E in Inner Mongolia, ~2—5 km north of the border with the Ningxia Hui Autonomous Region and ~20 km north of Zhongwei, Ningxia. The lake is surrounded by dune fields on the east, south, and west, and low mountains to the north. Possible shoreline features are evident on the alluvial fans extending south from these mountains into the lake basin, but were not investigated or mapped.

2 Core extraction and dating

Short cores, 2—4 m in length, were extracted using a 5 cm diameter piston corer. Mid-to-late Holocene deposits in all of the basins are underlain by clean, thick dune sands, preventing deeper sampling without machine-driven equipment. Multiple cores were taken in each of the basins and the lithological descriptions presented here are composites of sections sampled in the field, descriptions of the longest and most complete cores, and dated samples from other cores. Sections/cores from Toudaohu

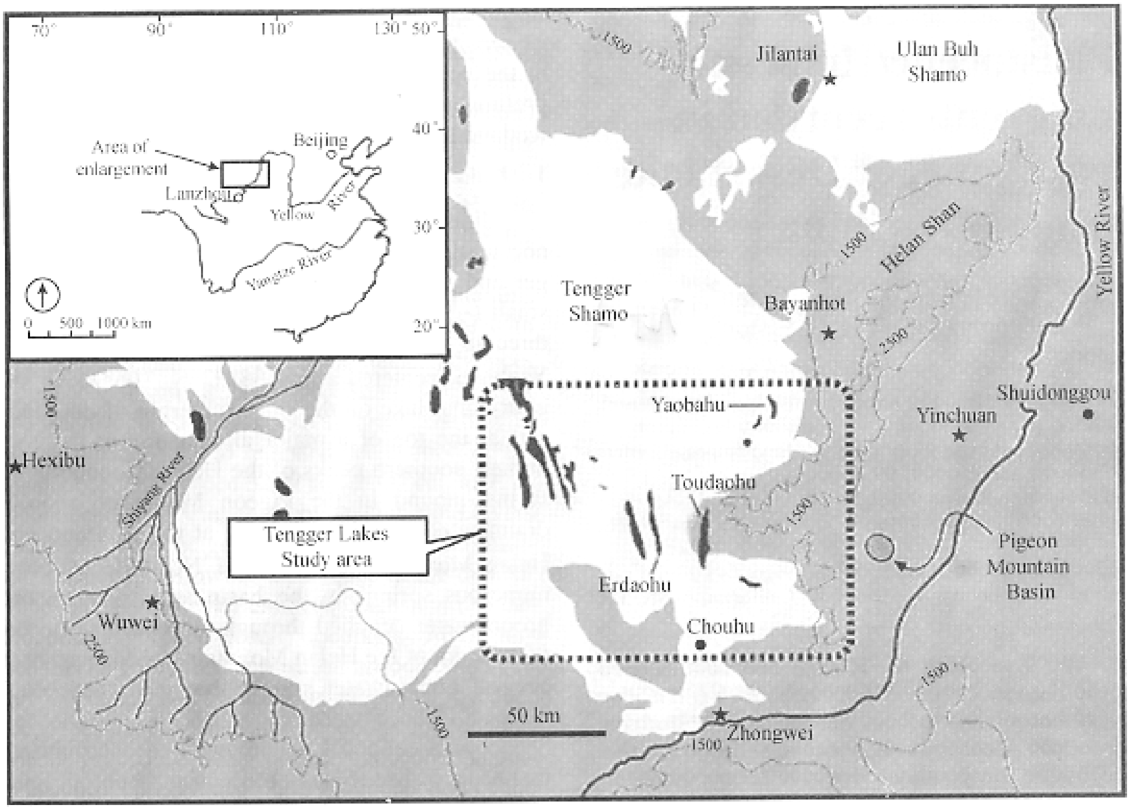

Fig. 1. Location of study area in northwest China.

were sampled at 2 cm intervals for grain size, loss-on-ignition, palynology, magnetic susceptibility, X-ray diffraction of carbonate minerals, and ostracode analyses.

Sixteen radiocarbon age estimates were obtained from a variety of samples, including freshwater clam shells (*Corbicula leana* and *C. largillierti*), charcoal, ostrich shell (*Struthiolithus* sp.), plant macrofossil remains (*Phragmites* sp.), and pollen (Table 1). Age estimates from Pigeon Mountain were obtained from culturally deposited charcoal directly associated with periods of increased spring activity, and are thus not constrained by the numerous interpretive problems which plague most age estimates from bulk soil organics[6–10]. The clam shells were examined by X-ray to detect replacement of the original aragonite by calcite, since replacement can seriously affect the reliability of the age estimate. The shells examined are 100% aragonite and the age estimates appear to be reliable, although the potential for a paleo-hard water effect has not been investigated. Leaves of *Phragmites* sp. (lu wei), an emergent marsh plant adapted to shallow water conditions, were analyzed from two Toudaohu core samples.

We attempted to extract and date pollen separates in the lake cores to assess the age of lake/wetland events represented in the lacustrine deposits. This was only partially successful due to limited pollen preservation in parts of the cores, or, in the case of Yaobahu, to sulfer in the sediments. We used a simplified version of a preparation technique devised to concentrate fossil pollen for AMS radiocarbon dating[11,12]. This simplified procedure has been used in ongoing research at Great Salt Lake, Utah, USA[13], where the pollen AMS dates from sediments surrounding a volcanic tephra of known age have been found to be as much as 700 ^{14}C years old. This sample preparation technique improves the accuracy of the radiocarbon ages, as bulk organics from the same horizons may be as much as 1700 ^{14}C years (or more) old. Toudaohu, Erdaohu, and Chouhu appear to be fed by groundwater and localized surface runoff and the pollen dates from these locations are likely close to the true depositional age or very nearly so.

3 Lithologies and analyses results

Toudaohu. A 344 cm section in the center of the basin was collected and sampled at 2 cm intervals (Fig. 2). Reed grass (lu wei) plant macrofossils, collected at 76—80 and 248 cm, derive from probable shallow-water environments and date to 1320 ± 30 and 5480 ± 40 aBP, respectively. Dates on pollen separates from the top and bottom 5 cm of the calcium carbonate layer at a nearby pit profile are 3500 ± 40 and 5380 ± 40 aBP, respectively.

Analyses of grain size, loss-on-ignition, and magnetic susceptibility are available for the Toudaohu core. These analyses, together with the core lithology, suggest that eolian sand is continuously supplied to the core site,

Table 1 Radiocarbon age estimates from the southeastern Tengger Desert margin

Corrected age*/aBP	Laboratory number	Location	Material
42510 ± 1070	Beta153118	Jilantai, early pre-glacial lake margin	clam shell
12710 ± 70	Beta 97242	Pigeon Mt., Sand I	charcoal
11620 ± 70	Beta 86731	Pigeon Mt., paleosol	charcoal
10230 ± 50	Beta 97242	Pigeon Mt., Sand II	charcoal
10120 ± 60	Beta 94119	Pigeon Mt., paleosol	charcoal
10060 ± 70	Beta 86732	Pigeon Mt., paleosol	charcoal
9990 ± 40	Beta 153199	Jilantai, early Holocene lake margin	clam shell
8020 ± 40	WW2785	Chouhu core, ~137—142 cm	pollen
7720 ± 210	Beta 97076	Jilantai, beach surface	charcoal
5380 ± 40	WW 2780	Toudaohu pit profile, 158—163 cm	pollen
5480 ± 40	Beta 146362	Toudaohu core, 248 cm	lu wei leaves
3500 ± 40	WW 2781	Toudaohu pit profile, 87—92 cm	pollen
1650 ± 40	WW 2782	Erdaohu core, 176—180 cm	pollen
1320 ± 30	Beta 146361	Toudaohu core 76—80 cm,	lu wei leaves
840 ± 40	WW 2784	Erdaohu pit profile, 70 cm	pollen

* All ages are $^{13}C/^{12}C$ corrected.

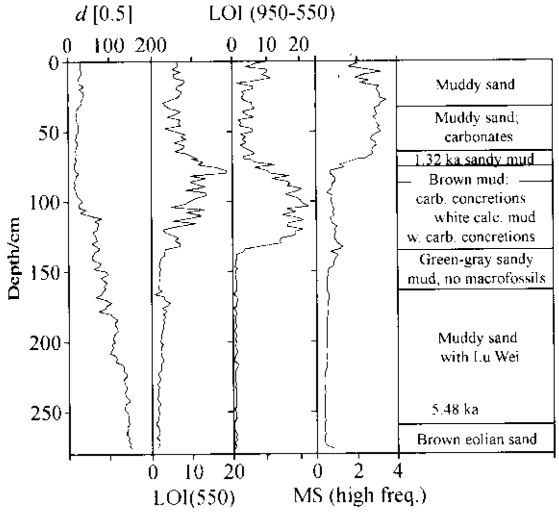

Fig. 2. Lithology and analytical results for the Toudaohu core. The first four columns show grain size (*d* [0.5]: diameter in micrometers of the 50% point in the frequency distribution curve); loss-on-ignition (LOI) at 550℃, 950℃, and the difference between the two; and magnetic susceptibility. LOI (550) is an indication of the relative amount of organic matter, and LOI (950—550) indicates the relative amount of carbonate minerals. The fifth column shows lithology and radiocarbon results. Dune sand continues beyond a depth of 454 cm.

but that the position of the water table changes through time, probably in response to regional climate controls. When the water table is relatively low (below the capillary fringe and below the level that plant roots can easily reach it) eolian sand covers the site, and the ground surface is probably dry most of the time. During periods of higher water table, eolian sand continues to accumulate, but the groundwater, which may be above or close to the ground surface, allows aquatic plants such as bulrush to colonize the site. If the water table drops slightly below the surface, or after a sufficient amount of time to precipitate calcium carbonate from the water as it evaporates or is transpired, carbonate builds up in the sand and displaces grains.

Anecdotal reports from farmers and drillers suggest that 2—10 m of sand containing thin white clay layers is deposited below the upper calcium carbonate layer. This is underlain by a thick (10—25 m) calcium carbonate deposit and a lower clean yellow sand layer which extends to an unknown depth. Informal accounts from local residents report that holes drilled for water wells revealed alternating beds of white sediments and sand in the Toudaohu basin down to approximately 110 m, suggesting that the sediments preserve a record of water table fluctuations in the basin during the Holocene, and possibly into the late Pleistocene.

Erdaohu. A 208-cm-long section was collected from the center of Erdaohu basin, ~15 km west of Toudaohu. Samples were also collected from the profile of a 130 cm deep pit excavated at the southeastern tip of Erdaohu. Pollen in a sample collected at 176—180 cm in the Erdaohu core dates to 1650 ± 40 aBP, while pollen from the 70—72 cm sample collected from the pit profile dates to 840 ± 40 aBP. Both age estimates are associated with periods of high groundwater and/or shallow lakes.

Chouhu. The wetland system in the basin currently consists of scattered ponds on a relatively flat basin floor. A 286 cm long core was collected from one of these ponds along the eastern basin margin. Pollen in a sample corresponding to a depth of 115—135 cm, dates to 8020 ± 40. Possible lake/wetland events appear to be represented in the core at depths of 1—19, 26—52, 115—135 cm, and possibly 207—257 cm (Fig. 3).

Yaobahu. Coring was initiated at the surface of what is now a small inter-dune lake and extended only to

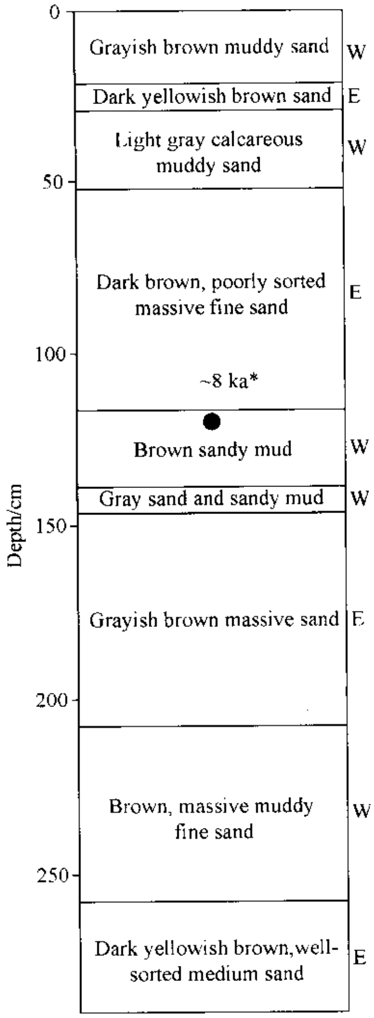

Fig. 3. Lithology of the Chouhu core.

sand consist of dark gray to black (from sulfides) silty clay containing abundant sodium nitrate crystals. This clay probably originated primarily as a chemical precipitate formed during a period of high groundwater. Drillers' logs for two holes in the basin show alternating sand and clay beds with depth, and it seems likely that these represent alternating periods of high and low water table with sand dunes migrating over the flat floor of the basin when the water table is low. An organic mat in an alluvial fan east of Yaobahu dates to 10810 ± 210 aBP[14], but may represent a facies change in the alluvial system. Hofmann[15] dated calcium carbonate cemented root casts from dunes in the Yaobahu area to 5 945±105 aBP, suggesting that they formed under arid conditions.

Pigeon Mountain. QG3 is one of the larger spring mounds in the Pigeon Mountain Basin. Chronological controls for the earliest portion of the sequence at QG3 are provided by five AMS dates on charcoal deposited by Late Paleolithic occupants of the locality (Fig. 4). The basal post-glacial deposit is a massive, well-sorted, fine-grained eolian sand whose overall age is uncertain, but its stratigraphic position was most probably deposited at the end of the last glacial cycle. The top 20—25 cm of the lower sand represents the base of a paleosol, but the upper surface is an erosional unconformity and there is no evidence of the upper paleosol. Macrolithic debitage, found throughout this zone, is most heavily concentrated on a thin gravel stringer that occurs intermittently across the site within this zone. Charcoal from this stringer dates to 12710 ± 70 aBP. A charcoal fragment collected from basal sand at the deflationary surface dates to 11620 ± 70 aBP and provides a limiting age for the deposition of the overlying deposits. This deflationary event is overlain by a second eolian sand deposit with an incipient paleosol developed on its surface. Both macrolithic and microlithic tools and debitage occur with increasing frequency throughout the deposit. A single large piece of charcoal from the upper sand dates to 10230 ± 50 aBP. Two charcoal samples from an organic mat on the sand surface date to 10060 ± 60 and 10120 ± 60 aBP. The eolian deposition of Sand II is thus bracketed to a period of ~1600 radiocarbon years between 11.6—10 ka BP.

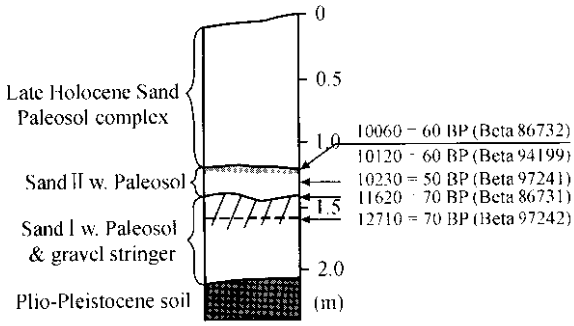

Fig. 4. Lithology and associated radiocarbon dates of the QG3 eolian/paleosol sequence, Pigeon Mountain Basin[4]. Dashed line indicates position of gravel stringer.

Jilantai. We obtained samples of clam shells from possible shoreline features of separate lake high-stands at Jilantai. A high stand with a lake margin feature containing *Corbicula largillierti* dates to 42510 ± 1070 aBP. These come from a deflated area ~5 m above the current lake surface and are likely derived from a lake margin of unknown elevation above that point. *Corbicula leana* associated with a possible high stand dating to 9290 ± 40 aBP were recovered from elevations ~2—3 m above the current lake surface. These shells have a limited distribution along the lake margin and appear to represent an area of fresh water from spring or stream sources perched on or distributed within moderately higher, but probably relatively saline, lake waters. Both species of clam occur in brackish-to-freshwater conditions, but a difference in shell morphology (*C. leana* is relatively thin walled) suggests that they have slightly different salinity and/or temperature tolerances. In general, the thin-walled *Corbicula* suggest that temperatures during the early Holocene were relatively cooler compared to at least one period of the last interglacial (F. Riedel, personnel communication, 2001).

Geng et al.[5] describe a lacustrine Holocene sequence reaching a maximum of 8.77 m thick, consisting of fine sand, mild clay, clayey bed, mirabilite, gypsum/ halite, halite, and brine overlying Pleistocene clays, and interpret the sequence to be the result of continual regression throughout the Holocene. However, intervals of clay deposition suggest that at least two periods of higher and/or more stable lake conditions occurred after 10000 aBP. They obtained dates of 9959 ± 130 and 9940 ± 130 aBP on snail shells from early Holocene deposits at the lake periphery.

4 Discussion

Preliminary analyses and dating of multiple lake basins on the margin of the southeastern Tengger Desert suggest that intervals of high lake/wetlands events, representing periods of more intensive summer monsoon, occur in the record at ~12.7—11.6, ~10.1, ~9.3, ~8.0, ~5.4, ~1.5 and ~0.8 ka BP since last deglacial. This is a composite record, however, as many of these events are dated at only a single locality, and often by only a single radiocarbon age estimate, and this reconstruction must be considered extremely tentative. Although these records differ, in that they come from a variety of depositional environments including spring bogs, wetlands, and true lakes, fluctuations in the records all appear to represent periods of higher regional groundwater, and are thus linked.

The oldest lake high stand in our records is dated at Jilantai to 42.5 ka BP and may correspond to a period of highest lake levels during MIS 3 in the area[14,15]. The earliest part of the post-glacial record is derived from evidence for episodes of increased spring flow at Pigeon Mountain Basin between ~12.7—11.6 ka BP and at ~10.1 ka BP, with periods of decreased flow occurring from ~11.6 to ~10.1 ka BP and after ~10.1 ka BP. Other possible periods of increased spring flow on the flanks of the Helan Mountains have been dated to ~12.9 ka BP and ~10.8 ka BP[16]. At least four Holocene episodes of increased spring flow are evident in the Pigeon Mountain record, but have not been dated. At ~9.3 ka BP, freshwater streams or springs were feeding a slightly elevated lake in the Jilantai basin. This lake stand appears to have followed an episode of saline waters dating to ~9.9 ka BP[17,18] and may be related to higher lake levels dating to between ~9.7 and 7.2 ka BP[18,19]. An episode of higher groundwater at ~8.0 ka BP is represented in the record from Chouhu. This record of high groundwater episodes at ~12.7—11.6 ka BP, ~10.1 BP, ~9.3 ka BP, and ~8.0 ka BP along the western margin of the Tengger Desert during the Pleistocene/Holocene transition is consistent with widespread evidence for soil formation during these periods throughout the Loess Plateau[20].

The record is less clear for the mid-to-late Holocene deposits at Toudaohu, Erdaohu, Yaobahu, and Chouhu, which are all underlain by thick, clean, dune sand. It is possible that these sands are related to the last glacial interval, but the given evidence for a high lake stand at Jilantai during the early Holocene, together with widespread evidence of high lake stands centered at ~9.0 ka BP throughout much of central and western China during the Holocene climatic optimum[21,22], it is likely that higher groundwater and/or lakes occurred during the early Holocene in these basins as well. This suggests that extensive dune fields can form rapidly in these basins, and that the Pleistocene-to-early Holocene transition may have been a period of more intense climatic variation relative to the mid-to-late Holocene, with the basins oscillating between periods of lake/wetlands and periods of widespread dune cover. This scenario is supported by anecdotal data from driller's logs in the Toudaohu and Yaobahu basins, suggesting that deposits immediately below the base of our cores consist of alternating layers of thin clay and thicker layers of pure dune sand, but this record is yet to be confirmed.

Multiple episodes of higher groundwater are represented in all the lake basins during the mid-to-late Holocene, but we have not yet been able to date and correlate all these events. High groundwater episodes have been dated to ~5.4, and ~1.3 ka BP at Toudaohu, and to ~1.7 and ~0.8 ka BP at Erdaohu. At least two episodes of higher groundwater are evident in the Chouhu record, post-dating ~8 ka BP. Multiple high groundwater events are evident in the upper part of the Yaobahu record, but remain undated. We have not yet been able to relate these events to shoreline evidence and cannot evaluate the relative intensity of these mid-to-late Holocene high groundwater episodes. Such evidence may be tenuous, however, as these episodes appear to be related to shallow lakes or wetlands.

The Holocene portion of the sequence derived from our records does appear to correlate well with periods of soil formation at 9.4—9.0, 8.0—7.8, 6.3—5.8, and 1.2—0.9 ka BP, but shows anomalously high groundwater episodes at ~1.7 and ~1.3 ka BP[17,23—25]. We have combined the ~1.7 and ~1.3 ka BP records at Toudaohu and Erdaohu to suggest a high groundwater interval at ~1.5 ka BP, but it is just possible that these represent independent events or that the ~1.3 and ~0.8 ka BP age estimates represent the same episode. We have no dates for high groundwater episodes correlating with periods of possible soil formation at 2.5—3.0 and 3.8—4.4 ka BP, but these may be represented by several of the undated wetland events in the upper part of the cores. At Toudaohu, for example, groundwater was relatively high throughout the period between ~5.4 and ~1.3 ka BP.

5 Summary and conclusions

Millennial-scale climatic cycles appear to be represented in the records from the southeastern Tengger Desert area, with at least seven such cycles dating to between ~12.7 and 1.0 ka BP. Similar millennial-scale climatic cycles have been recognized in a variety of lake records from other areas of the Tengger Desert and its margins[16,26—28], and throughout arid Asia and the deserts of North Africa. These millennial-scale cycles appear, in turn, to correlate with cycles of similar duration represented in cores from Greenland[29], the North Atlantic[30], the Arabian Sea[31], and North Africa[31], and may be directly linked to these records through episodes of increased atmospheric dust derived from the Tengger Desert and adjoining areas[32—35]. It seems reasonable to assume that all these sequences are recording the same interrelated climatic events, but it is difficult to correlate a particular episode from one record to another due to limitations in sampling and dating, and to differential sensitivity to climatic events.

These episodes are likely related to millennial- to-century-scale climatic events that have been widely recognized in environmental records from arid China[25,36,37], but the relative intensity of these cycles and the nature of variability between them is less clear and will require a coordinated effort to correlate and date a diverse array of sequences. Further study is needed, focusing on high quality lake sediment documents and precise chronology.

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Holocene lake deposits of Bosten Lake, southern Xinjiang, China

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Abstract **A 9.25-m-long sediment core from Bosten Lake, Xinjiang, provides detailed information about changes in the water budget and biological acticity over the last 8400 calendar years. The chronology is constructed from six AMS radiocarbon dates on the terrestrial plant remains. Based on analyses of TOC, CO_3, detrital compounds and biogenic SiO_2, lake level fluctuations and periods of remarkably-negative water budget appeared at 8.4—8.2 cal ka, 7.38—7.25 cal ka, 5.7—5.5 cal ka, 3.7—3.4 cal ka and 3.3—2.9 cal ka, respectively. As they are in-phase with low lake levels at Sumxi Co and Bangong Co in western Tibet Plateau and with paleolakes in Inner Mongolia, a climate-induced change to somewhat drier and warmer conditions is inferred. A further drop in lake level after 1320 AD of about 200 yr duration may be attributed to a negative water balance prior to the main phase of the Little Ice Age. Deep and stable lake phases of 1500 yr and 1800 yr duration at 7.2—5.7 cal ka and 5.5—3.7 cal ka coincide with maximum moisture during the Holocene Megathermal in China. The long term trend towards aridity since about 4.3 cal ka can clearly be recognised. The reduced water budget of Bosten Lake from 640—1200 AD may be attributed to local effects.**

Keywords: Bosten Lake, Holocene, sediments, water balance, lake level, climate change.

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Bosten Lake (86°40′—87°26′ E, 41°56′—42°14′ N) is the largest freshwater body in northwestern China and covers an area of about 1000 km^2 with a maximum water depth of 14 m in the centre and southeastern part of the lake respectively. It is located in the southern part of the tectonically influenced Yanqi Basin in southern Xinjiang. The area is part of the arid region of western China with 68.2 mm mean annual precipitation and a mean annual temperature of 6.3℃[1]. Bosten Lake is mainly supplied by water from the Kaidu River drainage, which