Paleoclimatic Change Since 988 AD Recorded by Anggertu Lake in the Tengger Desert: Postprint

Authors: Zhihong Cao, An Chengbang, Yin Liying

Date: 2018-11-13T00:00:00+00:00

Abstract

Through comprehensive analysis of multiple sedimentary climate proxy indicators including grain size, carbonate percentage content, and major chemical elements, along with precise dating of core AGE15A from Anggertu Lake in the southeastern Tengger Desert, this study reconstructs the paleoclimate change sequence for this region since 988 AD. The results indicate that the evolution of the climatic environment in the study area since 988 AD is generally consistent with paleoclimate changes in the westerlies region of northwestern China, exhibiting an alternating "cold-wet/warm-dry" pattern, albeit with a certain temporal lag. Specifically: from 988 to 1383 AD, Anggertu Lake developed from a depression into a small lake with weak chemical weathering, and the overall lacustrine climatic environment was cold and wet, with several warm fluctuations occurring during this period; from 1383 to 1560 AD, the study area experienced the Medieval Warm Period, characterized by warm and dry climate conditions, during which the lake expanded, aquatic plants flourished, and enhanced respiration led to substantial carbonate precipitation, reaching a maximum value of 8.16%; from 1560 to 1700 AD, the study area underwent the coldest period following the formation of Anggertu Lake, with increased precipitation and cold-wet climate, corresponding to the peak of the Little Ice Age; after 1700 AD, temperatures began to rise and the climate warmed, peaking around 1900 AD, when the carbonate percentage content in the sediments also reached its maximum value of 10.15%, during which time the lake continued to expand with several cold climatic fluctuations. Since historical climate reconstructions based on ancient Chinese literature generally exclude desert regions, this study utilizes lacustrine sedimentary records to infer the historical climatic and environmental evolution of Anggertu Lake in the Tengger Desert, which holds important reference value for desert research in China and provides a scientific basis for historical climate reconstruction in northwestern China.

Full Text

Preamble

DOI: 10.12118/j.issn.1000-6060.2018.06.12
Journal: ARID LAND GEOGRAPHY

---

1 Study Area and Methods

1.1 Regional Overview

Anggertu Lake is located in the Tengger Desert of Inner Mongolia, China, with geographic coordinates of 38°24 2.51 -38°24 9.22 N, 105°8 16.4 -105°7 56.5 E. The lake surface elevation is 1321 m, covering an area of approximately 0.09 km^2. The lake basin is situated in a low-lying area with a flat bottom, and the water depth is relatively shallow. The surrounding terrain is characterized by gentle slopes with sparse vegetation cover.

The elemental composition of the sediments was analyzed using an Avaatech XRF core scanner, which measures the content of major elements including Fe, Ca, Ti, Mn, Rb, and Sr. The loss-on-ignition method was employed to determine the carbonate content and organic matter percentage. Grain size analysis was conducted using a Malvern Mastersizer 2000 laser particle size analyzer. Prior to analysis, samples were pretreated with H_2O_2 and HCl to remove organic matter and carbonates, respectively.

A 166 cm sediment core (AGE15A) was retrieved from the central part of Anggertu Lake using a gravity corer. The core was subsampled at 1 cm intervals for subsequent laboratory analyses.

---

2 Results

2.1 Chronology

The chronology of core AGE15A was established using AMS ^{14}C dating. Two samples were selected for dating: at 50 cm and 160 cm depths. The ^{14}C ages were calibrated using CALIB 7.0 software with the IntCal13 calibration curve. The dating results indicate that the 50 cm depth corresponds to 1560 AD, while the 160 cm depth dates to 1018 AD. Based on these anchor points, the average sedimentation rate was calculated to be 0.203 $cm \cdot a^{-1}$ for the period 1018–1560 AD, and 0.108 $cm \cdot a^{-1}$ for the period since 1560 AD.

2.2 Geochemical Characteristics

XRF scanning results reveal significant variations in elemental composition throughout the core. The concentrations of Ti, Fe, and Mn show relatively

stable values in the upper 50 cm, but increase substantially below this depth. In contrast, Sr and Ca exhibit opposite trends, with higher values in the upper sections and lower values in the deeper sections. The Rb/Sr ratio displays notable fluctuations, with elevated values occurring at specific intervals.

Based on the elemental profiles and sedimentological characteristics, the core can be divided into three distinct zones:

- **Zone I (166–86 cm):** Corresponding to 988–1383 AD, characterized by relatively coarse grain size and low carbonate content.
- **Zone II (86–50 cm):** Corresponding to 1383–1560 AD, marked by high carbonate precipitation (8.16% of sediment composition) and increased Sr and Ca concentrations.
- **Zone III (50–0 cm):** Corresponding to 1560 AD to present, showing fine-grained sediments and the highest carbonate content (10.15%).

2.3 Grain Size Characteristics

Grain size analysis indicates that the sediments are predominantly composed of silt-sized particles. The median grain size varies significantly with depth, showing a fining-upward trend overall. Three main grain size fractions were identified: clay (<4 m), fine silt (4–16 m), and medium silt (16–32 m). The proportions of these fractions vary systematically across the three zones identified above. In Zone I, the coarse fraction (32–64 m) shows higher percentages, while in Zones II and III, the fine fractions dominate, reflecting changes in hydrodynamic conditions and sediment source areas.

---

3 Discussion

3.1 Paleoclimatic Interpretation

The physicochemical properties of the Anggertu Lake sediments provide valuable insights into paleoclimatic changes in the Tengger Desert region since 988 AD.

Period 988–1383 AD (Zone I): This interval represents the early development stage of Anggertu Lake, when small depressions gradually evolved into a cohesive lake system. The relatively coarse grain size and low carbonate content suggest weak chemical weathering in the catchment. The climate was generally cold and wet, with several warm fluctuations superimposed on this overall pattern. The Rb/Sr ratios indicate relatively low chemical weathering intensity, consistent with a cold climate regime.

Period 1383–1560 AD (Zone II): This period corresponds to the Medieval Warm Period (MWP) in the study region. The climate was characterized by warm and dry conditions. The lake expanded significantly, accompanied by rapid growth of aquatic plants, which led to massive precipitation of carbonate

minerals (accounting for 8.16% of the sediment). The increased Sr and Ca concentrations reflect enhanced evaporative concentration and biological activity. The grain size became finer, indicating a more stable water column and reduced clastic input.

Period 1560–1700 AD (Zone III, early stage): This interval represents the Little Ice Age Maximum in China. The climate became colder and wetter, with increased precipitation. The lake continued to expand, and the sediment grain size became progressively finer year by year. The carbonate content remained high, suggesting persistent evaporative conditions despite the overall cooling.

Period 1700–1900 AD (Zone III, middle stage): Temperature began to rise, reaching a peak around 1900 AD. This warming was accompanied by several wet fluctuations. The carbonate content increased to 10.15%, the highest value in the entire record, indicating optimal conditions for carbonate precipitation.

Period after 1900 AD (Zone III, late stage): The lake continued to expand, and the sediment grain size became increasingly fine. The climate showed alternating patterns of cold-wet and warm-dry conditions, reflecting the complex response of the desert lake system to regional climate change.

The observed climatic evolution pattern is generally consistent with other paleoclimatic records from northwestern China, particularly those from the westerly-dominated regions. However, there exists a temporal hysteresis when using different physicochemical proxies, likely due to differential response times of various sedimentary components to climate forcing.

---

4 Conclusions

The analysis of sediment core AGE15A from Anggertu Lake reveals that since the formation of the lake around 988 AD, the climate in the Tengger Desert region has been characterized by alternating cold-wet and warm-dry periods. The Medieval Warm Period (1383–1560 AD) and the Little Ice Age (1560–1700 AD) are clearly recorded in the sedimentary sequence. The physicochemical properties of the lacustrine sediments, including grain size, elemental composition, and carbonate content, provide reliable proxies for reconstructing paleoclimatic changes in arid and semi-arid regions. These preliminary results offer important references for studying desert paleoclimatology in northwestern China and help address the current research imbalance in these regions.

References

[1] JIA Tiefei, YIN Shan, HE Yu, et al. Holocene sediment texture and its environmental meaning of Donghaizi Lake in Ulan Buh Desert[J]. Journal of Desert Research, 2003, 23(2): 165–170.

[2] LV Yuxiao, LI Baosheng, JIN Heling, et al. Major element record in Salawusu River valley responding to global change during Last Interglacial Period[J]. Journal of Desert Research, 2004, 24(2): 136-143.

[3] ZHONG Wei, TASHPOLAT, WANG Liguo, et al. Process and characteristics of historical climate and environment changes in southern margin of Tarim Basin[J]. Journal of Desert Research, 2004, 24(3): 261-267.

[4] LI Sen, SUN Wu, LI Xiaoze, et al. Sedimentary characteristics and environmental evolution of Otindag Sandy Land in Holocene[J]. Journal of Desert Research, 1995, 15(4): 323-331.

[5] ZHANG Xiaoye. Source distributions, emission, transport, deposition of Asian dust and loess accumulation[J]. Quaternary Science, 2001, 21(1): 29-40.

[6] LONG Hao, MA Haizhou, WANG Naiang, et al. Mid-holocene climate variations from lake records of NW Tengger Desert[J]. Marine Geology & Quaternary Geology, 2007, 27(3): 105-111.

[7] CHEN Fahu, WU Wei, ZHU Yan, et al. The lake of drought events recorded in the research in Alxa Plateau Mid-holocene[J]. Chinese Science Bulletin, 2004, 49(4): 1-9.

[8] ZENG Yan, CHEN Jing'an, ZHU Zhengjie, et al. Advance and perspective of Rb/Sr ratios in lake sediments as an index of paleoclimate/paleoenvironment[J]. Advances in Earth Science, 2011, 26(8): 805-810.

[9] ZHANG Xiaonan, ZHANU Can, WU Duo, et al. Element geochemistry of lake deposits measured by X-ray fluorescence core scanner in northwest China[J]. Marine Geology & Quaternary Geology, 2015, 35(1): 163-174.

[10] XIAO Shun, CHEN Fahu, QIANG Mingrui, et al. Distribution pattern of grain size in surface sediments from Sugan Lake and its potential in recording aeolian dust in arid China[J]. Acta Geographica Sinica, 2007, 62(11): 1153-1164.

[11] ZHANG Xiuye. Source distributions, emission, transport, deposition of Asian dust and loess accumulation[J]. Quaternary Science, 2001, 21(1): 29-40.

[12] LEI Guoliang, ZHANG Hucai, ZHU Yun, et al. Geochemical behavior of acid soluble and insoluble fractions and sediment[J]. Journal of Mountain Science, 2013, 31(2): 174-183.

[13] JIN Zhangdong, WANG Sumin, SHEN Ji, et al. The chemical weathering lake sedimentary records in Little Ice Age[J]. Chinese Science Bulletin, 2001, 31(3): 221-225.

[14] LI Zhuolun, ZHANG Naimeng, WANG Naiang, et al. Lake evolution and its response to climate change during the late glacial: A record from the Huahai Lake in the Hexi Corridor of northwest China[J]. Journal of Desert Research, 2014, 34(2): 342-348.

[15] LIU Qiong, PAN Baotian, GAO Hongshan, et al. Desert evolution and climate change of southern margin of Tengger Desert since Last Glacial Maximum[J]. Journal of Desert Research, 2006, 26(6): 875-879.

[16] LI Ziting, YU Junqing, ZHANG Baohua, et al. Application of loss on ignition to the study of lake sediments and environmental changes[J]. Journal of Salt Lake Research, 2006, 14(2): 67-72.

[17] PENG YJ, XIAO JL, NAKAMURA T, et al. Holocene East Asian sedimentary rocks[J]. Geochim Cosmochim Acta, 1969, 33: 1521-1552.

[18] REIMER PJ, BARD E, BAYLISS A, et al. IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 years cal BP[J]. Radiocarbon, 2013, 55(4): 1869-1887.

[19] LIU Qiong, PAN Baotian, GAO Hongshan, et al. Desert evolution and climate change of southern margin of Tengger Desert since Last Glacial Maximum[J]. Journal of Desert Research, 2006, 26(6): 875-879.

[20] ZHANG Xiaoye. Source distributions, emission, transport, deposition of Asian dust and loess accumulation[J]. Quaternary Science, 2001, 21(1): 29-40.

[21] CHEN Jing' an, WANG Guojiang. Sediment particle size distribution and its environmental significance in Lake Erhai, Yunnan Province[J]. Acta Mineralogica Sinica, 1999, 19(2): 175-182.

[22] ZHANG Xiaonan, ZHANU Can, WU Duo, et al. Element geochemistry of lake deposits measured by X-ray fluorescence core scanner in northwest China[J]. Marine Geology & Quaternary Geology, 2015, 35(1): 163-174.

[23] ZENG Yan, CHEN Jing'an, ZHU Zhengjie, et al. Advance and perspective of Rb/Sr ratios in lake sediments as an index of paleoclimate/paleoenvironment[J]. Advances in Earth Science, 2011, 26(8): 805-810.

[24] JIANG Qinfeng, LIU Xingqi, SHEN Ji. Grain-size characteristics of Wulugu Lake sediments and its paleoclimatic and paleoenvironmental significance[J]. Marine Geology & Quaternary Geology, 2010, 30(6): 35-42.

[25] JIN Zhangdong, WANG Sumin, SHEN Ji, et al. The chemical weathering lake sedimentary records in Little Ice Age[J]. Chinese Science Bulletin, 2001, 31(3): 221-225.

[26] LI Mingqi, JIN Heling, ZHANG Hong. Advances of climate research in the Little Ice Age[J]. Journal of Desert Research, 2005, 25(5): 731-737.

[27] ZHU Liping. Grain-size characteristics and their Paleo-environmental significance of ChenCo Lake sediments in southern Tibet[J]. Progress in Geography, 2002, 21(5): 459-467.

[28] CAO Zhihong, AN Chengbang, YIN Liying, et al. Climate change derived from Anggertu Lake in the Tengger Desert since 988 AD[J]. Journal of Desert Research, 2018, 38(6): 1175-1183.

[29] PROKOPENKO A, et al. Sedimentary carbonate and isotopic composition in Bositen Lake and responding to glacial activity[J]. Acta Geologica Sinica, 2007, 18(12): 1658–1671.

[30] LI Zhongwei, JIN Heling, ZHANG Hong. Holocene aeolian deposits and environmental evolution in Yili Valley, Xinjiang[J]. Marine Geology & Quaternary Geology, 2013, 33(1): 34–44, 77.

[31] CHEN Xiuling, LI Zhizhong, LING Zhiyong, et al. Holocene aeolian deposits and environmental evolution in Yili Valley, Xinjiang[J]. Marine Geology & Quaternary Geology, 2010, 30(6): 35–42.

[32] LI Zhongwei, JIN Heling, ZHANG Hong. Holocene aeolian deposits and environmental evolution in Yili Valley, Xinjiang[J]. Marine Geology & Quaternary Geology, 2013, 33(1): 34–44, 77.

[33] CHEN Fahu, WU Wei, ZHU Yan, et al. The lake of drought events recorded in the research in Alxa Plateau Mid-holocene[J]. Chinese Science Bulletin, 2004, 49(4): 1–9.

[34] LONG Hao, MA Haizhou, WANG Naiang, et al. Mid-holocene climate variations from lake records of NW Tengger Desert[J]. Marine Geology & Quaternary Geology, 2007, 27(3): 105–111.

[35] ZHANG Xiaoye. Source distributions, emission, transport, deposition of Asian dust and loess accumulation[J]. Quaternary Science, 2001, 21(1): 29–40.

[36] LEI Guoliang, ZHANG Hucai, ZHU Yun, et al. Geochemical behavior of acid soluble and insoluble fractions and sediment[J]. Journal of Mountain Science, 2013, 31(2): 174–183.

[37] CHEN Fahu, WU Wei, ZHU Yan, et al. The lake of drought events recorded in the research in Alxa Plateau Mid-holocene[J]. Chinese Science Bulletin, 2004, 49(4): 1–9.

[38] LONG Hao, MA Haizhou, WANG Naiang, et al. Mid-holocene climate variations from lake records of NW Tengger Desert[J]. Marine Geology & Quaternary Geology, 2007, 27(3): 105–111.

[39] ZHANG Xiaoye. Source distributions, emission, transport, deposition of Asian dust and loess accumulation[J]. Quaternary Science, 2001, 21(1): 29–40.

[40] ZHANG Xiaonan, ZHANU Can, WU Duo, et al. Element geochemistry of lake deposits measured by X-ray fluorescence core scanner in northwest China[J]. Marine Geology & Quaternary Geology, 2015, 35(1): 163–174.

[41] ZENG Yan, CHEN Jing'an, ZHU Zhengjie, et al. Advance and perspective of Rb/Sr ratios in lake sediments as an index of paleoclimate/paleoenvironment[J]. Advances in Earth Science, 2011, 26(8): 805–810.

[42] JIANG Qinfeng, LIU Xingqi, SHEN Ji. Grain-size characteristics of Wulugu Lake sediments and its paleoclimatic and paleoenvironmental significance[J].

Marine Geology & Quaternary Geology, 2010, 30(6): 35-42.

[43] LI Mingqi, JIN Heling, ZHANG Hong. Advances of climate research in the Little Ice Age[J]. Journal of Desert Research, 2005, 25(5): 731-737.

[44] ZHANG Xiaoye. Source distributions, emission, transport, deposition of Asian dust and loess accumulation[J]. Quaternary Science, 2001, 21(1): 29-40.

[45] CHEN Jing' an, WANG Guojiang. Sediment particle size distribution and its environmental significance in Lake Erhai, Yunnan Province[J]. Acta Mineralogica Sinica, 1999, 19(2): 175-182.

[46] LI Zhongwei, JIN Heling, ZHANG Hong. Holocene aeolian deposits and environmental evolution in Yili Valley, Xinjiang[J]. Marine Geology & Quaternary Geology, 2013, 33(1): 34-44, 77.

[47] ZHU Liping. Grain-size characteristics and their Paleo-environmental significance of ChenCo Lake sediments in southern Tibet[J]. Progress in Geography, 2002, 21(5): 459-467.

Abstract: Reconstruction of Chinese paleoclimatic changes based on ancient written records basically seldom covered the desert regions. The study on ancient climate change based on records from lakes in deserts is a weak point and needs to be strengthened. Research on physicochemical properties of lacustrine sediment, such as the particle size, the chemical elements and the percentage composition of carbonate, is one of the most important methods of inverting the history of local climate change. In this paper, the paleoclimatic/environmental changes of Tengger Desert, Inner Mongolia, China, since 988 AD are investigated by acquiring a 166 cm long sediment core from the Anggertu Lake in the desert. The physicochemical analyses mainly focus on the characteristics of grain size, X-ray Fluorescence (XRF) core scanning, loss-on-ignition, and precision dating. The results show that during 988-1383 AD, the Anggertu Lake was developed into small lakes from depressions and the chemical weathering in the lake was weak. The climate was overall cold and wet accompanied by several warm fluctuations. The period of 1383-1560 AD was in the Medieval Warm Period when the climate was warm and dry in the study area. The Anggertu Lake was expanded with rapid growth of aquatic plants resulting in precipitation of massive carbonate, which accounted for 8.16% of the lake sediment. With the arrival of Little Ice Age Maximum in China (1560-1700 AD), the coldest period came after the formation of the Anggertu Lake. The precipitation was increased and the climate went colder and wetter. After 1700 AD, the particle size of lake sediment was getting finer year by year and Anggertu Lake continued to expand. The temperature began to rise, reaching its peak in 1900 AD along with several wet fluctuation during this period (1700-1900 AD). In addition, the percentage of carbonate reached 10.15%. After the formation of the Anggertu Lake, the climate in the study area is characterized by alternating "cold-wet" and "warm-dry" . This kind of climatic evolution property of lacustrine sediment

was consistent with what other indicators revealed in northwest westerly region of China. However, there exists a temporal hysteresis by using physicochemical analyses. These preliminary results can provide important references to study the paleoclimatic changes of deserts in northwestern China. At the same time, this paper has improved the unbalanced research work on arid and semi-arid area in China.

Keywords: lake sediment; characteristic of grain size; X-ray Fluorescence (XRF) core scanner analysis; climate change; Tengger Desert

Note: Figure translations are in progress. See original paper for figures.