Grain Size Distribution Characteristics of Recent Lacustrine Sediments and Their Environmental Records from Bosten Lake, Xinjiang (Postprint)

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Abstract

This study examines the sediment grain size of a 41-cm core from Bosten Lake in Xinjiang. A sediment chronology was established using the radioisotope 210Pb dating method, the grain size-standard deviation method was employed to analyze environmentally sensitive components in the sediments, and the lake level variation history over the past 150 years was reconstructed. In the Bosten Lake core sediments, the clay fraction (<4 m) constitutes 18%, the fine silt fraction (4-16 m) 40.2%, the medium silt fraction (16-32 m) 23.3%, the coarse silt fraction (32-64 m) 13.4%, and the sand fraction (>64 m) only 5.1%. The vertical variation trends of different grain-size fractions exhibit relatively distinct differences. Extraction of environmentally sensitive components from the sediments using the grain size-standard deviation method demonstrates that the mean grain size variation of Component C2 (7.59-22.91 m) is consistent with the median grain size variation (r=0.7, P<0.01). Component C2 is sensitive to sedimentary environmental changes in Bosten Lake, and based on this, the lake level variation history over the past 150 years was reconstructed. Prior to 1940, the Bosten Lake level was generally at a historically low level for the past 150 years, with the low-water period of the 1910s–1930s representing a large-scale regional drought event. Under the combined influence of climate change and significantly intensified human activities, the lake level decreased markedly in the mid-to-late 1980s. As one of the influencing factors of sediment grain size variation, lake level can be reconstructed through the content of environmentally sensitive components in lake sediments, providing a new approach for investigating the historical variation patterns of lakes and their influencing factors.

Full Text

Grain-Size Distribution and Its Environmental Records of Modern Lacustrine Sediments from Bosten Lake, Xinjiang

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Abstract

This study established the sedimentary chronology of lacustrine sediments from Bosten Lake, Xinjiang, using the 210Pb dating method. The objectives were to investigate the grain-size distribution of core sediments (41 cm), analyze sediment components sensitive to environmental changes using the grain-size standard deviation method, and reconstruct the lake water-level history over the past 150 years. The contents of clay (<4 m), fine silt (4–16 m), medium silt (16–32 m), coarse silt (32–64 m), and sand (>64 m) in the Bosten Lake core sediments were 18%, 40.2%, 23.3%, 13.4%, and 5.1%, respectively, with obvious vertical variations in different fractions. The average grain size of component C2 (with particle size of 7.59–22.91 m) was consistent with the median particle size ($r = 0.7$, $P < 0.01$), and component C2 was very sensitive to changes in the sedimentary environment of the Bosten Lake Basin, which could be used to reconstruct the lake water level over the past 150 years. The water level of Bosten Lake was low from the 1910s to the 1930s, revealing that a large-scale regional drought occurred during this period. Under the joint effect of climate change and human activities, the water level of Bosten Lake fell significantly in the mid- and late-1980s. The change in sensitive component C2 was consistent with the change in lake water level, and the water-level fluctuation history of Bosten Lake could be reconstructed from the sensitive components in lake sediments.

Keywords: lacustrine sediment; grain size; grain-size standard deviation; environmental reconstruction; Bosten Lake; Xinjiang

1. Introduction

Lake sediments serve as important archives of environmental change, recording information about regional climate and human activities at various temporal scales [1]. Grain-size distribution is a fundamental physical property of lacustrine sediments that reflects the dynamic conditions of sediment transport and deposition, making it a valuable proxy for reconstructing past hydrological and climatic variations [2–3]. In arid and semi-arid regions, lake water-level fluctuations are particularly sensitive to climate change and human water consumption, and sediment grain-size characteristics can effectively capture these changes [4].

Previous studies have employed various methods to extract environmental information from grain-size data, including the Weibull distribution function [10], the EMMA (End-Member Modeling Analysis) algorithm [11], the BEMMA (Bayesian End-Member Modeling Analysis) model [12], the CEMMA (Cluster-based End-Member Modeling Analysis) approach [13], and the grain-size standard deviation method [14, 27]. These methods have been successfully applied to reconstruct environmental changes in lake systems [28, 29]. However, the sedimentary environment of Bosten Lake has its own unique characteristics, requiring specific investigation of which grain-size components are most sensitive to environmental changes in this system.

2. Materials and Methods

2.1 Sample Collection and Chronology A 41 cm sediment core (BTH01) was collected from Bosten Lake using a gravity corer. The core was sampled at 1 cm intervals. The 210Pb dating method was applied to establish the chronology [37]. The constant rate of supply (CRS) model was used to calculate sediment ages, with the sedimentation rate averaging 0.21 g • cm ^{2} • a ^{1}. The core bottom age was determined to be 1868 AD.

2.2 Grain-Size Analysis Grain-size measurements were performed using a Malvern Mastersizer 2000 laser diffraction particle size analyzer with a measurement range of 0.02–2000 m [37]. Prior to analysis, samples were pretreated with 10 mL of 10% H O to remove organic matter and 10 mL of 0.05 mol • L ^{1} (NaPO) as a dispersant. The suspension was ultrasonicated for 15 minutes before measurement.

2.3 Grain-Size Standard Deviation Method The grain-size standard deviation method was used to identify environmentally sensitive components [14]. This method calculates the standard deviation of grain-size frequency distributions across all samples, highlighting particle size classes with high variability that are likely to respond to environmental changes. The formula for age calculation using the 210Pb CRS model is:

$$t = \frac{1}{\lambda} \ln \frac{\sum C_0}{\sum C}$$

where t is the sediment age, λ is the decay constant of 210Pb, $\sum C_0$ is the total inventory of excess 210Pb, and $\sum C$ is the inventory of excess 210Pb below depth d [39].

3. Results

3.1 Grain-Size Distribution Characteristics The grain-size distribution of Bosten Lake sediments showed five main components: clay (<4 m) at 18%, fine silt (4-16 m) at 40.2%, medium silt (16-32 m) at 23.3%, coarse silt (32-64 m) at 13.4%, and sand (>64 m) at 5.1%. Vertical variations in these fractions were evident throughout the core.

3.2 Identification of Sensitive Components The grain-size standard deviation analysis identified four end-member components (C1-C4) based on particle size ranges: C1 (<7.59 m), C2 (7.59-22.91 m), C3 (22.91-239.88 m), and C4 (>239.88 m). Component C2 showed the highest correlation with the median grain size ($r = 0.7$, $P < 0.01$) and exhibited significant variability, indicating its sensitivity to environmental changes in the Bosten Lake Basin [Figure 4: see original paper].

The content of component C1 ranged from 22.6% to 40.5% (average 32.5%), with a mean grain size of 3.769 m. Component C2 ranged from 34.177% to 42.4% (average 38.706%), with a mean grain size of 14.091 m. Component C3 ranged from 18.788% to 39.519% (average 28.37%), with a mean grain size of 45.135 m. Component C4 constituted less than 1% of the total sediment and was excluded from further environmental interpretation [Figure 5: see original paper].

4. Discussion

4.1 Environmental Sensitivity of Component C2 Component C2 (7.59-22.91 m) was identified as the most environmentally sensitive fraction. Its strong correlation with the median grain size suggests it effectively captures the overall sedimentary response to hydrological changes. The consistent variation between component C2 and lake water level indicates that this fraction can serve as a reliable proxy for reconstructing water-level fluctuations [Figure 6: see original paper].

4.2 Reconstruction of Lake Water-Level Changes The water level of Bosten Lake was low from the 1910s to the 1930s, corresponding to a period of regional drought documented in historical records [16-18]. This dry period is also reflected in tree-ring data from the surrounding region [42-44]. After the 1940s, lake levels began to recover, showing a rising trend until the 1980s.

In the mid- and late-1980s, the water level of Bosten Lake fell significantly due to the combined effects of climate change and increased human water consumption [Figure 6: see original paper]. This decline is consistent with regional climate patterns associated with the North Atlantic Oscillation (NAO) [45-46], which influences precipitation patterns in Central Asia. The NAO’ s positive phase during this period likely contributed to reduced precipitation and increased aridity.

The grain-size record from Bosten Lake sediments provides a high-resolution archive of these water-level changes. The sensitive component C2 effectively tracks the lake's hydrological balance, capturing both natural climate variability and anthropogenic impacts. The consistency between sediment grain-size data and instrumental records validates the use of this proxy for reconstructing past environmental changes.

5. Conclusions

1. The 41 cm sediment core from Bosten Lake spans from 1868 AD to the present, with an average sedimentation rate of 0.21 g·cm ^{2}·a ^{1}. The grain-size distribution is dominated by fine silt (4-16 m) and medium silt (16-32 m) fractions.
2. Component C2 (7.59-22.91 m) was identified as the most environmentally sensitive fraction, showing a strong correlation with median grain size ($r = 0.7$, $P < 0.01$). This component effectively records water-level fluctuations in Bosten Lake.
3. The water level of Bosten Lake was low from the 1910s to the 1930s, indicating a regional drought period. A significant water-level decline occurred in the mid- and late-1980s under the combined influence of climate change and human activities. The sensitive component C2 provides a reliable basis for reconstructing the lake' s water-level history.

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