Mineralogical Characteristics of Late Pleistocene Sediments in the Badain Jaran Desert and Their Implications: Postprint

Authors: Zhang Xinyi

Date: 2023-02-02T00:00:00+00:00

Abstract

The Badain Jaran Desert serves as an important window for studying paleoenvironmental issues such as inland Asian aridification. Taking the Barun Baori Tolgoi section on the southeastern margin of the desert as the research target, and through detailed methodological indicators including thin-section mineralogy, semi-quantitative X-ray diffraction, and grain size, this study comprehensively analyzes the mineralogical characteristics such as textural maturity and compositional maturity of the sediments to reconstruct the changes in depositional environment in this region during the Late Pleistocene. The results show that: (1) Mineral detritus deposited before 66.8 ka exhibits good sorting and rounding, with high stable mineral content; after 66.8 ka, mineral sorting and rounding are poor, stable mineral content has decreased, and clay minerals have increased. (2) Sediments deposited before 66.8 ka are dominated by medium sand, while those after 66.8 ka are dominated by fine sand. The study indicates that an abrupt change in depositional environment occurred around 66.8 ka on the southeastern margin of the Badain Jaran Desert, transitioning from aeolian sand deposition to lacustrine deposition, which may represent a typical East Asian summer monsoon intensification event, hypothesized to be associated with warming in the low-latitude western Pacific. The relevant understanding of sediment mineralogy on the southeastern margin of the Badain Jaran Desert helps to understand the transformation process of depositional environments in deserts and their driving factors, and provides data references for reconstructing millennial-scale paleoenvironmental and paleoclimatic evolution in deserts.

Full Text

Mineralogical Characteristics and Their Indicative Significance of Late Pleistocene Sediments in the Badain Jaran Desert

Zhang Xinyi[1], **Fan Xiaolu**[1], **Tian Mingzhong**[2] [1]Department of Geography, School of History, Culture and Tourism, Fuyang Normal University, Fuyang, Anhui [2]School of Earth Sciences and Resources, China University of Geosciences (Beijing), Beijing

Abstract: The Badain Jaran Desert serves as a critical window for investigating paleoenvironmental issues such as the aridification of inland Asia. This study focuses on the Barun Baori Tolgoi section on the southeastern margin of the desert, employing detailed thin-section mineralogy, semi-quantitative X-ray diffraction, and grain size analysis to comprehensively evaluate the mineralogical characteristics of sediments, including textural and compositional maturity, thereby reconstructing depositional environment changes during the Late Pleistocene. Results indicate that prior to 66.8 ka , detrital minerals exhibited good sorting and rounding, with high contents of stable minerals; thereafter, mineral sorting and rounding deteriorated, stable mineral contents decreased, and clay mineral contents increased. Sediments were dominated by medium sand before 66.8 ka and by fine sand afterward. The study reveals a dramatic shift in depositional environment around 66.8 ka on the southeastern margin of the Badain Jaran Desert, transitioning from aeolian to lacustrine deposition, likely representing a typical East Asian summer monsoon intensification event possibly associated with elevated temperatures in the low-latitude Western Pacific. These insights into the mineralogy of sediments on the southeastern margin of the Badain Jaran Desert enhance understanding of depositional environment transformation processes and their driving factors in desert settings, providing valuable data for reconstructing millennial-scale paleoenvironmental and paleoclimatic evolution.

Keywords: Late Pleistocene; mineral characteristics; depositional environment; Badain Jaran Desert; 66.8 ka

Introduction

The Badain Jaran Desert, constituting the main body of the Alashan Desert, extends from the northeastern margin of the Tibetan Plateau in the south to the Mongolian Gobi in the north, penetrating deep into the arid interior of northwestern China. This region represents a key area for investigating hotspot issues related to paleoenvironmental changes such as the aridification of inland Asia. As a transitional zone between the East Asian monsoon circulation and the westerlies, the desert is a sensitive location for responding to climate change. Reconstructing Quaternary paleoenvironments through high-resolution sedimentary sections can provide deep insights into climate change characteristics and driving mechanisms in arid regions.

Previous research on the Badain Jaran Desert has primarily focused on sand dunes, sand wedges, salt lakes, flood deposits, surface aeolian sands, and tufa deposits to explore paleoenvironmental evolution, paleoclimatic changes, paleowind directions, sediment provenance, and groundwater recharge. Among these, the Chagelebulu section has been the most intensively studied. Based on high-resolution proxies including major and trace elements and grain size, combined with chronological frameworks established through ^{14}C dating and other methods, the Chagelebulu section has recorded five dry-cold and warm-humid cycles since the Middle Pleistocene. During the Late Pleistocene, the dry-humid environment of the Badain Jaran Desert depended on the intensity variations of the East Asian summer monsoon, as moisture carried by westerly circulation could not reach the desert region. Holocene climate changes in the Badain Jaran Desert were influenced by the continuous weakening of Northern Hemisphere solar radiation, reflecting millennial-scale climate fluctuations and their coupling relationship with East Asian monsoon circulation variations.

Existing sedimentary records or lake core studies have predominantly emphasized climate change processes since the Holocene, with relatively limited research on the Late Pleistocene. Building upon previous studies, this paper conducts an in-depth investigation of another representative section—the Barun Baori Tolgoi (BRBG) section. Our team has previously established the chronological framework and geochemical indices for this section. The present study employs thin-section mineralogy, X-ray diffraction (XRD) semi-quantification, and grain size measurement to thoroughly investigate the mineralogical characteristics of Late Pleistocene sediments in the Badain Jaran Desert, including mineral rounding, sorting, composition, and particle size. Based on these analyses, combined with assessments of mineral textural and compositional maturity, we aim to reconstruct the depositional environment evolution during this period.

Methods

This study primarily utilizes thin-section observation, XRD semi-quantification, and grain size analysis. A total of 15 thin-section samples were collected in the field at intervals of 10–20 cm, with additional samples taken at 20 cm and 25 cm intervals around distinct stratigraphic boundaries to ensure precision and reliability. For grain size analysis, samples were collected at 10 cm intervals, totaling 28 samples, with an average sampling interval of 15 cm.

Thin-section observation provides fundamental information on mineral types, contents, sizes, sorting, and rounding in sediments. Air-dried samples were consolidated with resin and sectioned at the China University of Geosciences (Beijing) thin-section laboratory. Polarized thin sections were then examined at the SEM scanning analysis laboratory using a polarizing microscope. Minerals were identified based on their crystallo-optical characteristics, and representative minerals from each sample were photographed, completing microscopic observation of 15 thin sections.

Mineral quantification employed XRD powder diffraction. Organic matter was removed from samples, which were then air-dried and crushed to 200 mesh before being prepared and tested at the China University of Geosciences (Beijing) XRD laboratory. The instrument used was a SmartLab X-ray powder diffractometer with a test error of less than 1%. The target was Cu with a test voltage of 45 kV. A total of 15 samples were tested. The principles, methods, and testing procedures follow Huang et al. [ ].

Grain size analysis was conducted at the China University of Geosciences (Beijing) grain size analysis laboratory using a Mastersizer 2000 laser particle size analyzer with measurement accuracy better than 1% and a detectable size range of 0.03-2000 m. A total of 28 samples were tested. Sample pretreatment followed the methodology of [ ], which involves appropriate sampling based on grain size, addition of dispersant, and ultrasonic dispersion. Samples were treated with H_2O_2 to remove organic matter, cooled, treated with dilute HCl to remove carbonates, diluted with distilled water, and centrifuged to remove supernatant until the solution reached neutral pH, after which the suspension was tested.

Results and Analysis

Microscopic Mineral Characteristics

Thin-section observation presents mineral characteristics more intuitively, including mineral sorting, rounding, and percentages of stable minerals. Microscopic examination of Late Pleistocene sediments from the 280 cm section reveals an obvious mutation in mineral characteristics at the 200 cm depth (Fig. 2 [Figure 2: see original paper]). In terms of sorting, detrital minerals in the 0-200 cm interval show coarse-fine mixing with poor sorting, indicating weak transport dynamics. In contrast, the 200-280 cm interval exhibits uniform detrital mineral sizes with good sorting, suggesting strong transport conditions.

Rounding characteristics show that minerals in the 0-200 cm interval are predominantly angular to subangular with poor rounding, indicating short transport distances and proximal provenance. In the 200-280 cm interval, detrital mineral grains are mostly subangular to subrounded, with some rounded grains. For instance, at 255 cm depth, minerals with extremely high rounding appear in the field of view, indicating good rounding and long-distance transport from distant source areas.

Mineral type and content characteristics reveal that in the 0-200 cm interval, aside from large detrital minerals, certain amounts of fine-grained clay minerals are scattered among the detrital minerals, creating a mixed mineral assemblage. In the 200-280 cm interval, the sediments are dominated by large stable minerals such as quartz, K-feldspar, and plagioclase, with substantially reduced fine-grained clay mineral content. Overall, this interval shows clear mineral grain boundaries and surface morphologies with stable contents (Fig. 2 [Figure

2: see original paper]). In summary, the mineralogical characteristics below 200 cm depth in the section indicate high mineral compositional maturity and high textural maturity, while the interval above 200 cm shows the opposite characteristics, suggesting that the depositional environment at the section location changed at the 200 cm depth boundary.

Mineral Quantitative Analysis

XRD analysis provides semi-quantitative mineral information, identifying the types and contents of major minerals. The types and contents of various minerals can directly reflect environmental conditions, such as felsic minerals and clay minerals.

Felsic minerals (e.g., quartz, K-feldspar, plagioclase) are relatively stable. Their contents can, to some extent, reflect the transport distance and type of transport dynamics experienced by sediments before deposition. Throughout the section, felsic minerals are the dominant components, though their contents vary by layer. In the 200-280 cm interval, felsic mineral contents range from 95% to 100%; in the 35-200 cm interval, they range from 85% to 97%; and in the 0-35 cm interval, they range from 65% to 85%. Evidently, felsic minerals occupy absolutely dominant contents below 200 cm, consistent with the mineral composition characteristics of wind-transported aeolian deposits.

Due to the generally fine particle size of Quaternary sediments, direct macroscopic observation can only identify color, relative moisture content, and presence of plant root tubes, which is insufficient to understand the microscopic characteristics of each sedimentary layer. Clay mineral content and types in sediments effectively reflect weathering types and environmental evolution backgrounds, serving as sensitive indicators of climate change. Illite forms through potassium leaching from weathering of aluminosilicate minerals such as feldspar and mica. Under warm and humid conditions, illite can continue to lose potassium to form montmorillonite, eventually transforming into kaolinite. Therefore, cold and arid climatic conditions favor illite preservation. Although kaolinite generally constitutes a minor portion of clay minerals, its increasing content accurately reflects a shift toward warmer and more humid environmental conditions.

XRD results show that clay mineral contents below 200 cm are low, with kaolinite being the primary clay mineral at 3%-5%, and only at 265 cm does illite coexist with kaolinite. In the 0-200 cm interval, illite and kaolinite coexist extensively, with contents around 10% (reaching maximum values of 3%-10% at 100 cm and 135 cm), indicating relatively warm and humid conditions.

As lake brine salinity increases, different types of carbonate and evaporite minerals precipitate sequentially, generally in the order of carbonate minerals (e.g., calcite), sulfate minerals (e.g., gypsum, mirabilite), and chloride minerals (e.g., halite). This precipitation sequence points to enhanced lake evaporation and increased water salinity. XRD results show calcite appearing above 200 cm, with increasing content upward from 100 cm (from 3% to 10%), indicating lake water evolution toward salinization. Additionally, evaporite mineral gypsum appears at 80 cm, though no gypsum precipitates above or below this depth, indicating that lake water salinization reached a maximum at this point.

Sediment Grain Size Characteristics

Grain size composition is an important parameter for reflecting depositional environments. For instance, aeolian deposit grain size characteristics can be used to determine regional wind strength variations, humidity changes, and depositional environment information, while lacustrine deposit grain size can reflect hydrodynamic strength, precipitation amounts, lake water level, and salinity.

Based on statistical analysis, variations in content of each grain size fraction in different intervals of the section are shown in Fig. 4 [Figure 4: see original paper]. The upper and middle layers (0–35 cm and 35–200 cm layers) are dominated by fine sand with average contents of 56.32% and 61.51%, respectively, with peak fine sand contents in the fine sand range. The lower layer (200–280 cm) is dominated by medium sand with an average content of 65.33%. Coarse sand shows high content in the lower layer (200–280 cm) with an average of 14.43%, decreasing abruptly upward to low values in the middle and upper layers with averages of 7.51%–10.68%. Silt content shows opposite characteristics to coarse sand, with extremely low content in the lower layer (average 0.15%) and higher contents in the middle and upper layers of 9.45%–15.68%. Clay is absent in the lower layer, while the middle and upper layers have average clay contents of 0.73% and 6.03%, respectively, with the middle layer having the highest relative clay content.

In terms of proportion of each grain size fraction, the middle and upper layers follow the sequence of fine sand > silt > clay, while the lower layer differs significantly, following the sequence of medium sand > coarse sand > fine sand > silt. Additionally, the grain size composition characteristics of aeolian sand collected from nearby sand dunes, used as a reference sample, are similar to the lower layer of the BRBG section, with medium sand as the main component.

Grain size frequency curves visually display sample grain size distribution characteristics. The upper layer frequency curve shows slight positive skewness with a skewness coefficient of 0.07–0.33, with peaks concentrated in the 200 m range. The lower layer shows a symmetric distribution with a peak of 317–356 m, corresponding to the medium sand fraction with a peak content of 7.94%–10.86%. Overall, sediments in all layers show unimodal patterns, indicating stable sediment sources for each layer, but significant source changes exist between the lower and middle-upper layers. Moreover, the reference sample from nearby sand dunes shows a peak grain size of 317 m, and the lower layer sediments exhibit similar frequency distribution characteristics to this aeolian sand (Fig. 5 [Figure 5: see original paper]).

In mathematical statistics, standard deviation corresponds to the sorting coefficient of grain size. This coefficient is an important parameter for measuring grain size concentration, with smaller sorting coefficients indicating better sorting. Sorting characteristics of section sediments are as follows: the upper layer sorting coefficient (σ) ranges between 0.55–1.03, classified as well sorted ($0.50 \leq \sigma < 1.00$) to moderately well sorted ($1.00 \leq \sigma < 2.00$); the middle layer sorting is similar to the upper layer; the lower layer sorting coefficient is 0.40–0.67, classified as well sorted ($0.50 \leq \sigma < 1.00$) to very well sorted ($0.35 \leq \sigma < 0.50$). The 200 cm boundary thus represents a significant difference in depositional environments between the lower and middle-upper layers.

Discussion

Different depositional environments exhibit obvious differences in sediment grain size frequency curves and peak magnitudes. Applying the principle of uniformitarianism and comparing modern depositional environment characteristics is an effective method for analyzing and inferring depositional environments of different intervals in the section. River deposits represented by the Heihe and Shiyang Rivers show bimodal patterns with peak grain size ranges of 5-10 m and 80–400 m. Aeolian deposits represented by the Badain Jaran Desert and Horqin Sandy Land show unimodal patterns with good sorting and peak grain sizes of 200–300 m. Lacustrine deposits show large spatial variations, complex types, and poor sorting.

The grain size frequency curves of each interval in the BRBG section are all unimodal, indicating single-source supply characteristics. However, the entire section shows obvious changes above and below 200 cm. The lower layer (200–280 cm) has coarser grain sizes dominated by medium sand, with good sorting, no clay content, and peak grain sizes of 317–356 m, consistent with aeolian deposit peak grain sizes (317 m). Additionally, the lower layer sediments share similar characteristics with locally collected aeolian sand from sand dunes, jointly indicating that the lower layer represents an aeolian depositional environment prior to 66.8 ka.

The middle-upper layer (0–200 cm) is dominated by fine sand, with peak grain sizes gradually decreasing upward from 317 m to 252 m and then to 200 m. Minerals are poorly rounded and sorted, with increased clay minerals such as kaolinite and illite. Therefore, the middle-upper layer is inferred to represent lacustrine deposition, indicating that the section location developed a lake above the original aeolian deposit substrate.

The BRBG section is located on the southeastern margin of the Badain Jaran Desert, near the Yabulai Mountains but deep in the desert interior, where alluvial and diluvial deposits are absent. Therefore, two main depositional types exist: aeolian deposition and saline lacustrine deposition. Below 200 cm is aeolian deposition, while above 200 cm to the surface is lacustrine deposition. This facies change indicates that a lake developed above the original aeolian deposit substrate. Combined with modern dune evolution characteristics, two main causes may explain this depositional facies change in the BRBG section: (1) sand dune migration, where active sand dunes in desert regions can shift positions under wind action, with wind erosion and transport causing changes in sand dune locations and consequently altering the area of interdunal lakes; and (2) salt lake water level rise, where climate change and other factors cause substantial increases in regional water supply, leading to expanded lake area and elevated water levels, so that originally non-lacustrine areas become covered by lakes and subsequently deposit a lacustrine sediment layer.

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

Source: ChinaXiv —Machine translation. Verify with original.