# Grain-Size Characteristics of Surface Sediments and Depositional Environments of Shrub Coppice Dunes and Parabolic Dunes in the Tukai Desert, Xinjiang (Postprint)

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## Abstract

Sediment grain-size characteristics are an important reference for analyzing the evolution of grain-size composition and discriminating sedimentary environments. A systematic analysis of the grain-size distribution and grain-size parameters of surface sediments from shrub coppice dunes and parabolic dunes in the Tukai Desert, Xinjiang, was conducted, and the Sahu empirical model was used to determine the depositional environment. The results indicate that: (1) The surface sediments of shrub coppice dunes and parabolic dunes are relatively coarse, mainly composed of very fine sand, fine sand, medium sand, and coarse sand. (2) The distribution of each grain-size fraction varies among different geomorphic positions; the grain size of surface sediments tends to become finer from the windward slope to the leeward slope, and sand grains also tend to become finer from the slope base to the slope top. (3) The grain-size parameters show different variation trends between different geomorphic positions, and there are correlations among the grain-size parameters; the correlation between mean grain size and sorting coefficient, skewness, and kurtosis is weak, while there is a significant correlation among the sorting coefficient, skewness, and kurtosis. (4) The sediment formation environments are primarily aeolian and turbidity current environments.

## Full Text

## Grain Size Characteristics and Sedimentary Environment of Surface Sediments from Nebkhas and Parabolic Dunes in the Tukai Desert, Xinjiang

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## Abstract

Sediment grain size characteristics serve as crucial references for analyzing the evolution of grain composition and identifying depositional environments. This study systematically analyzed the grain size gradation and parameters of surface sediments from nebkhas and parabolic dunes in the Tukai Desert, Xinjiang, and identified depositional environments using empirical models. The results indicate: (1) Surface sediments from both nebkhas and parabolic dunes are relatively coarse, primarily composed of very fine sand, fine sand, medium sand, and coarse sand. (2) Different grain size fractions exhibit distinct distributions across various geomorphic positions. Grain size tends to become finer from windward to leeward slopes and from slope base to slope crest. (3) Grain size parameters show varying trends among different geomorphic positions and are correlated with each other. Average grain size shows little correlation with sorting coefficient, skewness, and kurtosis, whereas sorting coefficient, skewness, and kurtosis demonstrate significant mutual correlations. (4) The depositional environments are predominantly aeolian and turbidity current environments.

**Keywords:** Tukai Desert; nebkhas; parabolic dunes; grain size characteristics; sedimentary environment

## 1. Study Area Overview

The Tukai Desert is located in the southwest of Huocheng County, Xinjiang (Fig. 1) [Figure 1: see original paper], with geographic coordinates of 43°55 18 ~44°01 28 N, 80°43 47 ~80°51 18 E. This region experiences a temperate continental desert climate characterized by scarce precipitation, arid and hot conditions, large diurnal temperature variations, and frequent windy-sandy weather. The annual average temperature ranges from 13~15 °C, with an average daily temperature difference of 9.1 °C. Annual precipitation is 1400~1900 mm, while annual evaporation reaches 2550~3000 mm. The sandy soil is loose with relatively high moisture content. Vegetation is relatively abundant, dominated by *Haloxylon ammodendron*, *Caragana sinica*, *Alhagi sparsifolia*, *Achnatherum splendens*, and *Halimodendron halodendron*, with total vegetation coverage of 35%~40%. The soil is primarily semi-fixed aeolian sandy soil, supplemented by sierozem, bog soil, meadow soil, and solonchak. The desert features various aeolian landforms including parabolic dunes, compound dunes, nebkhas, beam-nest dunes, and sand ridges, with tongue-shaped dunes and incipient barchan dunes sporadically distributed in the southern part. Human activities have caused severe vegetation degradation and land desertification, leading to continuous desert expansion, enhanced overall sand mobility, and intensified wind-sand disasters.

## 2. Methods

**2.1 Sample Collection** Based on meteorological data, remote sensing imagery, and field investigations, we collected surface sediment samples from typical parabolic dunes and nebkhas in the Tukai Desert (Fig. 1) [Figure 1: see original paper]. We selected 3 different types of dunes, collecting a total of 24 sand samples. For parabolic dunes, sampling followed the sequence: windward toe, windward middle, crest, leeward middle, leeward toe, north wing middle, north wing tip, south wing middle, and south wing tip. For typical nebkhas, sampling generally followed: windward toe, windward middle, crest, leeward middle, and leeward toe. Following the Lancaster standard, we collected surface sediments from a 0.2 m × 0.2 m area at 0–5 cm depth, with each sample weighing approximately 500 g. After sampling, we precisely located each site and recorded dune type, position, height, slope, and other information while describing geomorphic, morphological, and vegetation characteristics. Samples were sealed in bags for transport.

**2.2 Analytical Methods** Grain size analysis was performed using a Malvern Mastersizer-2000 laser particle size analyzer, with measurement ranges of 0.02–2000  m. Grain size parameters were obtained using the DISTAT software package, with classification following the Wentworth scale (subdivided into: very fine silt 0–2  m, fine silt 2–4  m, medium silt 4–8  m, coarse silt 8–16  m, very coarse silt 16–31  m, fine sand 31–63  m, medium sand 63–125  m, coarse sand 125–250  m, very coarse sand 250–500  m, and extremely coarse sand 500–1000  m, 1000–2000  m). All data were analyzed and visualized using Excel, SPSS 20, and Origin 9.0 software.

## 3. Results

**3.1 Grain Size Characteristics of Surface Sediments in Different Geomorphic Positions** Surface sediments from nebkhas and parabolic dunes in the Tukai Desert are dominated by sand fractions, with fine and medium sand constituting the largest proportions, followed by very fine sand and coarse sand; other fractions are minimal. In nebkhas (Fig. 3) [Figure 3: see original paper], the percentages of each fraction are: medium sand (37.63%), fine sand (49.46%), very fine sand (7.51%), coarse sand (3.43%), very coarse silt (0.82%), fine silt (0.45%), medium silt (0.38%), coarse silt (0.22%), very fine silt (0.12%), and extremely coarse sand (0.09%). In parabolic dunes, the percentages are: fine sand (47.11%), medium sand (38.05%), very fine sand (8.24%), coarse sand (4.12%), very coarse silt (1.24%), fine silt (0.87%), medium silt (0.45%), coarse silt (0.13%), very fine silt (0.09%), and extremely coarse sand (0.02%). Compared with nebkhas, parabolic dunes contain higher proportions of very fine sand and fine sand but lower proportions of medium and coarse sand, indicating that nebkha surface sediments are relatively coarser.

In different geomorphic positions of nebkhas (Fig. 4) [Figure 4: see original paper], medium sand content is highest at the crest (50.65%), greater in the windward middle than leeward middle, and greater at the windward toe than leeward toe. Fine sand also peaks at the crest, but shows the opposite pattern to medium sand in other positions, with higher content in leeward middle than windward middle, and higher at leeward toe than windward toe. Coarse sand content is highest at the windward toe (10.98%), followed by leeward toe, leeward middle, and windward middle, with the lowest content at the crest (5.71%). Very fine sand shows the opposite pattern to coarse sand across positions.

In parabolic dunes, grain size fractions vary by position. Fine sand content is highest in the south wing tip (52.91%), followed by leeward middle (51.85%), windward middle (51.48%), and north wing middle (50.78%), with lowest values in the north wing tip and windward toe (43.07%). Medium sand content peaks in the north wing tip (43.87%), followed by windward toe (43.89%), with the lowest content in the south wing tip (30.52%). Very fine sand is most abundant in the south wing tip (13.17%), followed by south wing middle (10.61%), with the lowest content in the north wing tip (6.16%). Coarse sand shows a pattern similar to medium sand, with highest content at the windward toe (5.67%) and lowest at the north wing tip (1.24%).

Overall, surface sediments on windward slopes are coarser than those on leeward slopes, and north wing sediments are coarser than south wing sediments. Vegetation on the dune wings reduces wind-sand flow, causing coarser sand to deposit on windward slopes while finer sand is transported and deposited on leeward slopes and the south wing.

**3.2 Grain Size Parameters of Surface Sediments** Grain size parameters for nebkhas (Table 1) show that the average grain size (M) ranges from 1.43–2.17 Φ (mean = 1.89 Φ, SD = 0.17 Φ), falling within the fine sand range. The largest average grain size occurs at the leeward toe (1.95 Φ), followed by leeward middle, windward middle, and crest, with the smallest at the windward toe (1.43 Φ). The sorting coefficient ($\sigma$) ranges from 0.51-0.83 Φ (mean = 0.64 Φ, SD = 0.08 Φ), indicating moderate to good sorting. Sorting is poorest at the windward toe and best at the crest. Skewness (SK) ranges from -0.01-0.19 Φ (mean = 0.06 Φ, SD = 0.05 Φ), showing near-symmetrical distribution. Skewness is smallest at the crest and increases from windward toe to crest, then decreases from crest to leeward toe, with maximum values at both slope toes. Kurtosis (K) ranges from 0.93-1.24 Φ (mean = 0.99 Φ, SD = 0.05 Φ), with little variation among positions, indicating medium kurtosis.

For parabolic dunes (Table 2) , average grain size (M) ranges from 1.47–2.55 Φ (mean = 2.17 Φ, SD = 0.21 Φ), also within the fine sand range. The largest average grain size occurs at the south wing tip (2.55 Φ), followed by leeward middle, south wing middle, north wing middle, and windward middle, with the smallest at the north wing tip (2.03 Φ). The sorting coefficient ($\sigma$) ranges from 0.54-1.16 Φ (mean = 0.65 Φ, SD = 0.11 Φ), indicating moderate to good sorting. Sorting is poorest at the windward toe and best in the north wing middle. Skewness (SK) ranges from -0.08-0.41 Φ (mean = 0.06 Φ, SD = 0.08 Φ), showing near-symmetrical distribution. Skewness is smallest at the windward toe, increasing gradually to a maximum at the leeward middle. Kurtosis (K) ranges from 0.93-2.57 Φ (mean = 1.17 Φ, SD = 0.93 Φ), indicating medium kurtosis, with the highest value at the crest (2.57 Φ, narrow peak) and little variation among other positions.

**3.3 Correlations Between Grain Size Parameters** Correlation analysis of the four grain size parameters (average grain size, sorting coefficient, skewness, and kurtosis) for Tukai Desert surface sediments (Table 3) reveals that sorting coefficient, skewness, and kurtosis are highly significantly positively correlated with each other in both nebkhas and parabolic dunes ($P < 0.01$). This indicates that poorer sorting corresponds to larger kurtosis values, producing narrower peaks. In nebkhas, average grain size shows little correlation with other parameters, whereas in parabolic dunes, average grain size correlates significantly with skewness ($P < 0.05$). The non-significant correlation between average grain size and sorting coefficient suggests that as grain size becomes finer, sorting becomes poorer. The significant correlation between average grain size and skewness in parabolic dunes indicates that as average grain size increases, both skewness and kurtosis increase.

**3.4 Sedimentary Environment** Previous studies have demonstrated that grain size data and parameters can characterize sand grain origins and depositional environments. Based on Sahu' s discriminant formulas for different depositional environments:

$$\mathrm{Y(aeolian,\ beach)} = -3.5688\mathrm{M} + 3.7016\sigma + 2.0766\mathrm{SK}_1 + 3.1135\mathrm{K}$$
$$\mathrm{Y(beach,\ shallow\ marine)} = 15.6534\mathrm{M} + 65.7091\sigma - 18.1071\mathrm{SK}_1 + 18.5034\mathrm{K}$$
$$\mathrm{Y(shallow\ marine,\ fluvial)} = 0.2852\mathrm{M} - 8.7604\sigma + 4.8932\mathrm{SK}_1 + 0.0482\mathrm{K}$$
$$\mathrm{Y[fluvial(deltaic),\ turbidity]} = 0.7215\mathrm{M} - 0.4030\sigma + 6.7322\mathrm{SK}_1 + 5.0927\mathrm{K}$$

Given that all samples were collected from a modern desert environment, we first tested for aeolian origin using the first formula. Results showed that 18 samples had Y(aeolian, beach) > -2.7411, indicating an aeolian depositional environment, while 6 samples had Y(aeolian, beach) < -2.7411, indicating a beach environment. The remaining 18 samples were tested with the second formula: 6 samples had Y(beach, shallow marine) > 65.3650, indicating shallow marine or lagoon environments, while 12 samples had Y(beach, shallow marine) < 65.3650, confirming a beach environment. These 12 samples were further tested with the third formula: 6 samples had Y(shallow marine, fluvial) > -7.4190, indicating fluvial (deltaic) environments, while the remaining 6 samples had values < -7.4190, indicating shallow marine environments. Finally, all 24 samples were tested with the fourth formula, yielding values < 9.8433, indicating turbidity current environments.

These calculations demonstrate that the formation environments of nebkhas and parabolic dunes in the Tukai Desert are primarily aeolian and turbidity current environments, suggesting diverse sediment sources and relatively complex depositional conditions. Wind dynamics, fluvial processes, and flood flows have significantly influenced the formation of these depositional environments.

## 4. Discussion

Grain size composition and wind regime are the main factors controlling the grain size characteristics of desert dune surface sediments. Grain size composition is closely related to sand sources and transport/deposition processes. In the Ebinur Lake Basin, prevailing winds are from the northwest and west-northwest, accounting for 54.98% and 18.31% of occurrences, respectively. The Tukai Desert, part of the larger Takermohuer Desert complex, experiences dominant southwest winds (70.87% of sand-driving wind frequency), followed by south winds (18.2%) and east winds (6.13%). Wind dynamics directly influence sand transport and accumulation.

Surface sediments of Tukai Desert parabolic dunes are primarily sand with some silt but no clay. Average grain size increases gradually from crest to leeward toe, with moderate to good sorting. The sediments show near-symmetrical distribution with kurtosis ranging from 0.93–1.24 Φ, indicating medium kurtosis. These characteristics differ from those reported for parabolic dunes in the Ebinur Lake Basin, which contain fine gravel and clay components, show poorer overall sorting, and exhibit mixed skewness patterns from positive to extremely negative.

The grain size characteristics of Tukai Desert parabolic dunes are consistent with findings from the Takermohuer Desert, where fine sand dominates and sediments show moderate sorting and near-symmetrical distribution. However, they differ from nebkhas in the Ebinur Lake Basin, where average grain size shows little correlation with other parameters. These differences arise from variations in wind dynamics, topography, vegetation, and sand sources, which affect sand transport and produce distinct grain size patterns across different dune types and regions.

The depositional environment of the Tukai Desert, characterized as aeolian and turbidity current environments, reflects its location in the Eurasian interior with low precipitation, Quaternary sedimentary layers derived from ancient alluvium, and strong westerly winds accelerated by the Ili Valley topography. Proximity to the Ili River provides moisture and vegetation cover. However, this study's interpretation of depositional environments based solely on grain size characteristics has certain limitations, as sedimentary environment formation is influenced by multiple comprehensive factors.

## 5. Conclusions

(1) Surface sediments of parabolic dunes and nebkhas in the Tukai Desert are primarily composed of very fine sand, fine sand, medium sand, and coarse sand, with fine and medium sand being most abundant. Different geomorphic positions show distinct grain size fraction distributions. In parabolic

dunes, fine and very fine sand peak in the south wing tip, medium sand peaks in the north wing tip, and coarse sand peaks at the windward toe. In nebkhas, medium and fine sand contents are highest at the crest, while coarse sand peaks at the windward toe. Grain size tends to become finer from windward to leeward slopes and from slope base to crest.

(2) The average grain size of parabolic dune surface sediments is slightly coarser than that of nebkhas (2.17 Φ vs. 1.89 Φ). Both dune types show similar sorting coefficients (0.65 Φ and 0.64 Φ, respectively), indicating moderate to good sorting. Skewness values (0.06 Φ) show near-symmetrical distribution, and kurtosis values (1.03 Φ and 0.99 Φ) indicate medium kurtosis. Sorting coefficient, skewness, and kurtosis are highly significantly correlated in both dune types, while average grain size shows little correlation with other parameters in nebkhas but correlates with skewness in parabolic dunes.

(3) Based on Sahu discriminant formulas, the Tukai Desert exhibits a complex sedimentary environment dominated by aeolian and turbidity current deposition, reflecting diverse sediment sources and the combined influence of wind dynamics, fluvial processes, and flood flows.

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