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# The origin of bimodal grain-size distribution for aeolian deposits

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ABSTRACT

Atmospheric dust deposition is a common phenomenon in arid and semi-arid regions. Bimodal grain size distribution (BGSD) (including the fine component and coarse component) of aeolian deposits has been widely reported. But the origin of this pattern is still debated. Here, we focused on the sedimentary process of modern dust deposition, and analyzed the grain size distribution of modern dust deposition, foliar dust, and aggregation of the aeolian dust collected in Cele Oasis, southern margin of Tarim Basin. The results show that BGSD also appear in a dust deposition. The content of fine components (<20 μm size fraction) change with temporal and spatial variation. Fine component from dust storm is significant less than that from subsequent floating dust. Fine component also varies with altitude. These indicate that modern dust deposition have experienced changing aerodynamic environment and be reworked during transportation and deposition, which is likely the main cause for BGSD. The dusts from different sources once being well-mixed in airflow are hard to form multiple peaks respectively corresponding with different sources. In addition, the dust deposition would appear BGSD whether aggregation or not. Modern dust deposition is the continuation of ancient dust deposition. They both may have the same cause of formation. Therefore, the origin of BGSD should provide a theoretical thinking for reconstructing the palaeo-environmental changes with the indicator of grain size.



## 1. Introduction

Loess and other aeolian deposits often present bimodal grain size distribution (BGSD) with a coarse (the modal size is of >20 μm) and a fine component (the modal size is of <20 μm). Many researchers regarded that the coarse component (>20 μm) can only be transported through surface wind by saltation and/or short-range suspension (Tsoar and Pye, 1987; Pye, 1987, 1995), and that the fine component (<20 μm) can be widely dispersed and long-range transported (Windom, 1975; Glaccum and Prospero, 1980; Tsoar and Pye, 1987; Pye, 1987, 1995). Generally, different peaks of grain size distribution were suggested to delegate different sedimentary process (Middleton, 1976; Ashley, 1978; Bagnold and Barndorff-Nielsen, 1980). So, it has been regarded that two sub-components of the aeolian deposits were from different sources (Pye and Zhou, 1989; Sun et al., 2004, 2008b; Muhs and Benedict, 2006; Vandenberghe et al., 2006; Lim and Matsumoto, 2006).

Granularity is an excellent proxy for reconstructing paleo-environment changes. The motion feature of detrital particles in the airflow has been described since 1930s (Bagnold, 1941; Gillette et al., 1974; Tsoar and Pye, 1987; Pye, 1995). Based on the motion laws of aeolian dust, some researchers have long noted that there existed certain relationship between granularity and East Asia winter monsoon. So, many researchers have tried to trace the material sources of the loess on Chinese Loess Plateau (CLP) since 1960s (Liu, 1965; Liu, 1966). And later, based the granularity analysis of high resolution loess profiles, some researchers regarded the granularity has completely and systematically recorded the evolutionary of the East Asia winter monsoon since 2.6 million (Ding et al., 1994), which made it as one of three best archives of paleo-environmental changes (the other two are ice core and deep-sea sediment core).

In Northern China, two types of atmospheric circulations influence the regional climate during dust storm seasons, i.e., the East-Asia winter monsoon prevailing at low altitude and the westerlies prevailing at high altitude (Chen, 1991; Qiao and Zhang, 1994). Sun et al. (2002) and Sun et al. (2004) presented bimodal grain size distribution (BGSD) (with a coarse modal size of

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20–40 μm and a fine modal size of 2–8 μm) of loess on Chinese Loess Plateau (CLP) by mathematical fitting. They argued that the coarse component was transported by low-altitude East-Asia winter monsoon, and the fine component was transported by high-altitude westerlies (Sun et al., 2004). Similar results have also been found in Cheju Island (Korea) and Central Asian loess (Lim and Matsumoto, 2006; Vandenberghe et al., 2006). So, the fine component was used as an intensity indicator of the westerly circulation (Sun, 2004; Lim and Matsumoto, 2006). However, some other researchers suggested that most of the dusts (including both the coarse and fine components) on CLP were from the proximal sources, which were transported by the low-altitude East Asia winter monsoon (Sun et al., 2001; Sun, 2002; Prins et al., 2007). This denied the viewpoint that fine component of the loess on CLP was from a significantly different source.

To the sources of the loess on CLP, Sun et al. (2001) and Sun (2002) found that the loess was mainly from the Gobi deserts of southern Mongolia and northern China (including the Badain Jaran Desert, Tengger Desert, Ulan Buh Desert, Hobq Desert and Mu Us Desert), which were transported by the low level atmosphere circulation (Prins et al., 2007). Moreover, Sun et al. (2008a) inferred that fine quartz particles (<16 μm) on CLP were also from the Gobi deserts of southern Mongolia and northern China based on the analysis of crystallinity index of fine-grained (<16 μm) quartz and electron spin resonance signal intensity. Shi and Liu (2011) further concluded that more than 90% of fine particles of modern aeolian deposits on CLP came from the southern Mongolia and northern China being transported via the low-level atmosphere, whereas the dust from Taklimakan Desert were mainly transported further to the pacific via the upper-level westerlies.

In addition, the phenomena of aggregation and/or fine particles adhering to larger ones in modern dust have often been found under the scanning electron microscope (SEM) (Pye, 1987, 1995; Falkovich et al., 2001; Derbyshire et al., 1998). So, Pye (1987) and Qiang et al. (2010) argued that the fine particles of aeolian deposits could be caused by aggregation and/or fine particles adhering to larger ones, and dispersed when measurement was taken. Moreover, the post-depositional pedogenesis could also make the coarse particles smaller which increases the content of fine silt (Dixon et al., 1984; Sun et al., 2000). All of these also undermine the multi-sources origin of the aeolian deposits with BGSD or even the validity of the fine particle components as an intensity indicator of westerlies.

From the aforementioned debate, some problems could be raised: How does the fine component (<20 μm) of BGSD in aeolian deposits produce? Whether or not the two sub-peak components delegate different sources? Or can the fine sub-peak component be as an intensity indicator of the high-level westerly circulation? At present, the sedimentary process (including the origin of BGSD) of the aeolian deposits has not been completely understood yet, and this makes us hard to exactly interpret the information from the specific size fraction of aeolian deposits in reconstructing the palaeo-environmental changes. Modern dust deposition is the continuation of dust deposition in geological history. This study aims to reveal the origin of BGSD in modern dust deposition based on the observation of their temporal and spatial variation characteristics. The origin of BGSD may provide a theoretic thinking for palaeoenvironmental changes study using the indicator of grain size.

## 2. Observational sites

The sampling area Cele Oasis (80°43′–80°52′E, 36°57′–37°05′N) is situated at the southern margin of Tarim Basin and at the northern foot of Kunlun Mountains. Taklimakan sandy desert and Gebi desert surround the oasis (Fig. 1). Cele Oasis covers an area of ~184 km$^2$, which is characterized by warm arid desert climate. The mean annual temperature is 11.9 °C with a maximum of 41.9 °C and a minimum of −23.9 °C, and the mean annual precipitation is ~35 mm with a potential evaporation of ~2600 mm (Li et al., 2009). Prevailing winds are W and WWN with 94.6% westerly threshold wind (>6 m/s) (Wan et al., 2013). The mean annual dusty days (including dust storm (the horizontal visibility being influenced by aeolian dust dropped below 1 km) and floating dust (the horizontal visibility is between 1 km and 10 km)) are of 142.4 days with mean annual dust storm of 21.2 days (Figs. 1B and 2D; Wan et al., 2009). Cele Oasis ecosystem is well developed, and an oasis-desert transition zone with 20–40% vegetation coverage surrounds northwestern edge of the oasis (Mu et al., 2013).

## 3. Materials and methods

### 3.1. Field sampling

To investigate the grain size characteristics of modern aeolian deposits, the sampling cylinders were made of polyvinyl chloride pipes. The size is 15 cm of inner diameter and 30 cm of height basing on the Chinese national standards (GB/T 15265-94) (Fig. 2A). Eight sampling cylinders were laid in Cele Oasis (Fig. 1), and numbered Q1–Q8. The sampling cylinders were all fixed at the height of ~3.5 m (Fig. 2B) so as to avoid the influence of saltation efficiently (Goossens et al., 1994). We also fixed the sampling cylinders on a sample-collecting tower respectively on the heights of 1 m, 2 m, 4 m, 6 m and 8 m at the oasis-desert transition zone (Fig. 2C), and numbered T-1 m, T-2 m, T-4 m, T-6 m and T-8 m. In addition, we laid four sampling cylinders (to gather enough aeolian dust, four samples would be mixed together) at the height of ~1.5 m on the rooftop of the laboratory building (~12 m above the ground), at Cele National Station of Observation and Research for Desert-Grassland Ecosystems. The dust deposition was collected with dry method due to the extremely low precipitation and high evaporation (Goossens and Rajot, 2008; Sow et al., 2006). To avoid the influence of dust from the surrounding tall objects, all of the sampling cylinders were laid at an open area.

In this study, we collected eight dust depositions (i.e. from Q1 to Q8) in the oasis for three periods respectively (Table 1). We also collected five dust depositions for two periods from the sample-collecting tower. In addition, we continuously collected 4 samples during a dust event on the rooftop of the laboratory building and numbered D1, D2, D3 and D4. In addition, D5 was obtained from the mixing of D1, D2, D3 and D4. For comparison, five kinds of foliar dusts on different arbors (the heights of these arbors are between 5 and 25 m) were collected at a height of 1.5–2 m in the study area on August 1, 2014 (the same time as the sixth dust event). In order to gather enough dust, we picked up 50–150 mature leaves per arbor randomly. Dust on different kinds of leaves was rinsed into the beaker with distilled water respectively, and then extracted the dust after settling ~100 h.

### 3.2. Sample measurement

The grain size of bulk sample was measured with a Malvern mastersizer-2000 laser grain size analyzer in the laboratory of Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences. Measuring range of the analyzer spans from 0.02 μm to 2000 μm with 100 size classes and the outputs were controlled <2% residual errors. The bulk samples of aeolian deposits were directly measured without any pretreatment because the samples did not experience weathering and post-depositional pedogenesis. But the sample of foliar dusts were pretreated with 20% hydrogen