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# Geochemical investigation of dry- and wet-deposited dust during the same dust-storm event in Harbin, China: Constraint on provenance and implications for formation of aeolian loess

Yuanyun Xie *, Yunping Chi

*College of Geographic Science, Harbin Normal University, Harbin 150025, China*

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ABSTRACT

A strong dust-storm event occurred in Harbin, China on May 11, 2011. The dry- and wet-deposited dust depositions in this dust-storm event, together with the surface sediments from the potential sources, were collected to study grain size distributions, carbonate content and carbon isotopic composition of carbonate, major element, trace element and rare earth elements (REE), and Sr–Nd isotopic compositions. The results indicate as follows. The dry-deposited dusts are characterized by bimodal grain-size distributions with a fine mode at 3.6 μm and a coarse mode at 28 μm whereas the wet-deposited dusts are indicative of unimodal grain-size modes with a fine mode at 6 μm. The dust-storm depositions are influenced to a certain extent by sedimentary sorting and are of a derivation from the recycled sediments. Based on identifying the immobility of element pairs before constraining sources of dust-storm deposits using geochemical elements, in conjunction with REE and especially Sr–Nd isotopic compositions, the primary and strengthening sources for the dust-storm event were detected, respectively. The Hunsandake Sandy Land as the primary source and the Horqin Sandy Land as the strengthening source were together responsible for the derivation of dust depositions during dust-storm event. The Hunsandake Sandy Land, however, contributes less dust to the dust-storm event in Harbin compared to the Horqin Sandy Land, and the Hulun Buir Sandy Land is undoubtedly excluded from being one of the sources for dust-storm depositions in Harbin. There are not notable differences in geochemical (especially Sr–Nd isotopic) compositions between dry- and wet-deposited dusts, indicating that the wet-deposited dust is of identical derivation to the dry-deposited dust. Based on our observations, it is of interest to suggest that fine and coarse particles in the CLP (Chinese Loess Plateau) loess possibly have the same sources.



## 1. Introduction

The sediments involve a large amount of valuable information regarding provenance, tectonics and weathering in the source region, which can be obtained through geochemistry, especially immobile elements, such as Al, Ti, Th, Sc, Co, Nb, Ta, Y, Zr, Hf and the rare earth elements (REE) (Bhatia, 1983; Taylor and McLennan, 1985; Bhatia and Crook, 1986; Wronkiewicz and Condie, 1987; Feng and Kerrich, 1990; McLennan et al., 1993; Cullers, 1994a,b, 1995, 2000; Cox et al., 1995; Cullers and Podkovyrov, 2000; Gu et al., 2002; Asiedu et al., 2004; Xu et al., 2007; Ghosh and Sarkar, 2010; Hossain et al., 2010; Akarish and El-Gohary, 2011; Roddaz et al., 2012; Jorge et al., 2013; Xie et al., 2014). The use of these immobile elements in provenance determination is based on the assumption that these elements undergo little geochemical fractionation during sedimentary processes and thus are transferred into sedimentary records proportionally to their abundances in the source area (McLennan et al., 1990; Singh, 2009; Jorge et al., 2013).

The widely-distributed aeolian depositions occurring in the Chinese Loess Plateau (CLP) provide a valuable archive of information regarding Quaternary climatic changes (An, 2000; Porter, 2001) and the transporting-deposition mode of dust. For this reason, over the past several decades, loess deposits have attracted increasing attention. However, our understanding of the formation of loess remains ambiguous. One important point is that it has long been under debate whether fine grains have the identical dust sources to coarse grains in loess (Sun et al., 2002, 2004; Chen et al., 2007; Crouvi et al., 2010; Enzel et al., 2010; Amit et al., 2014). Dust

* Corresponding author.
*E-mail address:* xyy0451@163.com (Y. Xie).

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storms are the primary dust transport mechanism in loess formation (Yan et al., 2015). Provenance studies of deposited "modern loess" (i.e., dust-storm depositions) are therefore critical to provide modern analogies on interpreting loess provenance. Accordingly, the investigations of present-day aeolian dust deposits probably offer a solution to these ambiguous problems.

Meteorological methods, including satellite images and air mass back trajectory modeling, have served to monitor the dust-storm events and dust transport routes, which could preclude irrelevant source candidates (e.g., Yan et al., 2015), whereas they are often insufficient to identify strengthening sources (meaning sources, where there are new additions of dust particles to suspended plume dust during dust storm transporting) along transporting pathways of dust storms and insufficient to distinguish the relative contribution of proto-sources and strengthening sources to the dust-storm events.

Our poor understanding of contemporary dust-storm depositions, especially of dry- and wet-deposited dust during the same dust-storm event, has hindered our ability to tracing the dusts back to their sources, and has also weakened our interest in using contemporary dust-storm deposits to comprehend certain key questions (e.g., the formation of loess), because these contemporary dust-storm depositions share analogous geological processes to the accumulation of loess. To deepen our understanding of the dry- and wet-deposited dust during the same dust-storm event, we obtained dry- and wet-deposited dust samples and performed grain size and geochemical composition analyses involving major elements, trace elements, rare earth elements (REE), carbonate content and carbon isotopic composition of carbonate, as well as Sr–Nd isotopic composition. The main objective of this study is to enhance understanding of the geochemical compositions of the present-day dust depositions during dust-storm events, thereby providing a stronger base for putting reasonable constraints on primary and strengthening sources of dust-storm events, and improving our ability to draw reasonable inferences in terms of some key scientific questions such as the formation of aeolian loess in the geological past. Of special note is that testing immobility of element pairs before identifying dust sources through geochemical elements, an approach to trace dust sources adopted in this study, provides a robust reference for tracing Asian aeolian dust from source to sink.

## 2. Materials and methods

### 2.1. Dust-storm process

The dust-storm weather derived from central Mongolia and mid-eastern Inner Mongolia, China (Ma et al., 2013) occurred in Harbin, Heilongjiang province, China (Fig. 1) early in the morning of May 12, 2011, and reached the peak at about 11:00–13:00 with lowest visibility. Coincidentally, Harbin experienced rain at 22:00 to clear the air and the dust suspended in the air was washed out to deposit over the ground. In addition, during the dust storm, near-surface wind was unapparent in Harbin, even in the whole northeastern area (Ma et al., 2013). The minimal wind speed at ground level denoted that local surface dust of Harbin was unlikely to be involved in dust deposits during this dust-storm event, consistent with previous study (Ma et al., 2013). Therefore, the dust-storm deposits in 2011 provide a valuable opportunity to obtain more accurate information on the dust source (Xie et al., 2014).

### 2.2. Sample collection

During the dust storm, four dry-deposited dust samples (DD1, DD2, DD3 and DD4) were collected using cylindrical glass vessels. These vessels were placed on the top of buildings 20 m above the ground surface to avoid trapping local saltation particles. The sampling vessels contain two layers of glass marbles at the bottom in order to prevent re-suspension of the settled particles. Similar methods of trapping wind-blown dust were widely adopted in different regions (e.g., McTainsh et al., 1997). The methods used should be a better choice for trapping the airborne dust during dust storms. The buildings settling sampling vessels were positioned in the university campus, which to a greater extent avoids the involvement of local-source dusts. In addition, four dry-deposited dust samples (DD5, DD6, DD7 and DD8) were collected from the hoods of different cars at the campus of Harbin Normal University, using a brush. After rain, washing out dust in the sky causing deposits over the ground, at around 0:20 in the morning, 13 May 2011, six wet-deposited dust samples (WD1, WD2, WD3, WD4, WD5 and WD6) were collected with glass vessels at the same sampling site as sample DD5.

In order to define the provenance of dust-storm depositions, the surface sediments from sandy lands deemed as potential sources were also collected from the Hulun Buir Sandy Land (13 samples) and the Horqin Sandy Land (13 samples), Inner Mongolia (see Fig. 1, for locations) to perform the same analyses as the dust-storm depositions. These sandy land samples should have constituted a sample set which appeared to be visually representative of the potential dust source areas. The fine-grained surface sediments (<63 μm, 11–30 μm, <11 μm fraction) were extracted by dry sieving. Due to the lack of samples from Hunsandake Sandy Land, REE and Sr–Nd isotopic compositions for Hunsandake Sandy Land are cited from previous studies.

### 2.3. Analytical methods

The grain size of the samples was measured using a laser particle analyzer (Malvern mastersizer-2000) at the Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, China. The grain-size distribution was calculated for 80 grain-size classes within a measuring range of 0.03–1900 μm. Sample preparation for grain size analysis included wet oxidation of organic matter by adding 10 ml of 30% $H_2O_2$ per 1.5 g dry sample. Carbonates were dissolved by boiling with 10 ml (10% HCl) over 10 min. The glass beakers were filled up with 150 ml distilled water and suspended particles were left to settle. After siphoning the supernatant water, 10 ml of 0.05 N $(NaPO_3)_6$ were added, and the residue was dispersed for 5 min in an ultrasonic bath before measurement.

Major elements were analyzed by standard X-ray fluorescence (XRF) spectrometer (AL104, PW2404) on fused glass beads at the Analytical Laboratory Beijing Research Institute of Uranium Geology. The detection limit is ~0.01 wt% and analytical precision (relative standard deviation) is <1% for major elements. Trace elements and REE were determined using an inductively coupled plasma mass spectrometer (ICP-MS, Finnigan MAT, Element I), also at the Analytical Laboratory Beijing Research Institute of Uranium Geology. The sample preparation procedure was performed following the methods proposed by Yang et al. (2007a,b). Four Standard Reference Materials (GSS, Geochemical Standard Reference Sample Soils, Ministry of Land and Resources of the People's Republic of China) for rock were used for external calibration. Analytical uncertainties (relative standard deviation) were less than 2%, suggesting a high degree of reliability of the measurements.

The carbonate content was determined using a rapid titration method following Wang et al. (2005) at the Institute of Earth Environment, Chinese Academy of Sciences, Xi'an. The uncertainty in the carbonate determination is ~1%. The samples were then allowed to react with excess 100% $H_3PO_4$ at 75 °C for 2 h. The $CO_2$ generated from the samples was cryogenically trapped and analyzed with the use of a Finnigan MAT 252 mass spectrometer.