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Size and elemental composition of dry-deposited particles during a severe dust storm at a coastal site of Eastern China

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A B S T R A C T

Dry-deposited particles were collected during the passage of an extremely strong dust storm in March, 2010 at a coastal site in Qingdao (36.15°N, 120.49°E), a city located in Eastern China. The size, morphology, and elemental composition of the particles were quantified with a scanning electron microscope equipped with an energy dispersive X-ray instrument (SEM–EDX). The particles appeared in various shapes, and their size mainly varied from 0.4 to 10 μm, with the mean diameters of 0.5, 1.5, and 1.0 μm before, during, and after the dust storm, respectively. The critical size of the mineral particles settling on the surface in the current case was about 0.3–0.4 μm before the dust storm and about 0.5–0.7 μm during the dust storm. Particles that appeared in high concentration but were smaller than the critical size deposited onto the surface at a small number flux. The elements Al, Si and Mg were frequently detected in all samples, indicating the dominance of mineral particles. The frequency of Al in particles collected before the dust storm was significantly lower than for those collected during and after the dust storm. The frequencies of Cl and Fe did not show obvious changes, while those of S, K and Ca decreased after the dust arrival. These results indicate that the dust particles deposited onto the surface were less influenced by anthropogenic pollutants in terms of particle number.

Introduction

Dust particles play an important role in the earth's environmental evolution and conservation (Chadwick et al., 1999; Neff et al., 2008). Asian dust, which comes from the arid and semi-arid areas of northwestern China and Mongolia, spreads from the Asian continent to the northern Pacific and even to North America (Duce et al., 1980; VanCuren and Cahill, 2002). Evidence has confirmed that the dust input to the ocean fertilizes the growth of phytoplankton in the surface of sea water (Calil et al., 2011; Shi et al., 2012), and that the dust input to islands prevents the ecological degradation caused by soil erosion (Kennedy et al., 1998; Simonson, 1995). The long-distance transport and settlement of dust particles also provide nutrients to rainforest and soil formation worldwide (Swap et al., 1992; Tiessen et al., 1991). Understanding the physical and chemical properties of deposited dust particles would be greatly beneficial to the

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quantitative evaluation of their effects on and roles in the evolution and conservation of the ecosystem.

The process whereby particles settle to the surface is governed by particle deposition velocity. The dry deposition velocity of a particle is usually estimated based on particle size and density, in consideration of the resistance of the air and surface (Lin et al., 1994; Qi et al., 2006; Zhang et al., 2004). Therefore, the dust flux to the surface significantly depends on the number size distribution, mass concentration, and settling velocities of the particles. In some studies, the sediments in the deep-sea or on the Loess Plateau were evaluated by estimating the sedimentation of different geologic ages and the relation between sedimentation and Paleoclimate (Ding et al., 2001; Olivarez et al., 1991; Soreghan, 1992). The dry deposition flux of the suspended particles in numerical models was directly derived by multiplying the measured dust mass concentration with theoretically calculated dry deposition velocity. The majority of these studies did not consider the wide range of particle size or the meteorological conditions (Lawrence and Neff, 2009; Li et al., 2011).

Dry-deposited particles have rarely been directly measured and data on their morphology, size, and chemical compositions are very limited. Moreover, limited information is known about the morphology, size, and chemical composition of dry-deposited particles, and the dust deposition flux to the surface has not been well validated based on field measurements. Long-term sampling is required to obtain a measureable amount of particles because of the slow process of dry deposition (Graydon et al., 2008; Shahin et al., 2000). For instance, at least two-day samples were required for the dust deposition (Hsu et al., 2010) and more than 1 week for the dry deposition fluxes and the mass size distributions of different species (Paode et al., 1998). The problem in sampling long-term deposited particles is that short-term-deposited dust storm particles are difficult to separate from the particles deposited during the non-dust time. Therefore, dust storm samples collected over periods of several hours are necessary to accurately describe the evolution and dry deposition of particles. Moreover, the overlap of particles on a filter must be avoided to obtain the exact characteristics of the target particles. Electron microscopy analysis is an approach for characterizing the morphology and composition of particles individually. This approach accurately describes the dust particles deposited onto the surface and demonstrates dust deposition with dust passage.

In this study, dry-deposited mineral particles were collected during passage of a dust storm in Qingdao, a coastal city in China. The mineral particles deposited onto the surface were identified and investigated in terms of their morphology and elemental composition, which were obtained with a scanning electron microscope equipped with an energy dispersive X-ray instrument (SEM–EDX). The characteristics of the dry-deposited particles were compared with those of suspended dust particles previously recorded at the same site. The purpose was to specify the similarities and differences of these particles to better understand the deposition process of dust particles after long-range transport. The evolution of dry-deposited dust particles during the dust storm passage was described according to the characteristics of the particles collected in different stages.

1. Methods

The particles deposited onto the surface were collected on the roof of a building at the campus of Ocean University of China in Qingdao (36.15°N, 120.49°E) between the 16th and 24th of March, 2010, during which a dust-loaded cyclone passed through the city. The details of the sampling periods and weather conditions are listed in Table 1. The dust storm was caused by a cyclone in western and south-central Mongolia, according to satellite observations, and then was transported to Beijing by the cyclone under a strong (>10 m/sec) north-west wind (Chen et al., 2012; Wang et al., 2014). The dust loaded in the low pressure system was an extreme dust storm according to the daily mean total suspended particulates (TSP, 3400 $\mu g/m^3$) and PM_{10} (1500 to 3500 $\mu g/m^3$) measured in Beijing (Chen et al., 2012). This dust storm was an extremely strong one in its dispersion and extent of influence. The deposition and dust loading were all greater than in previous years (Hsu et al., 2013; Li et al., 2011).

The samples were passively collected onto electron microscopic Ti grids with the use of a collection cask (approximately 25 cm high). The grids were fixed on a stainless cylinder (with a height of 1 cm high and a diameter of 12 cm), which was set on the bottom of the cask. The collection time for each sample was between 12 and 31 hr, which was determined according to the status of air pollution. After collection, the grids were separately conserved in small capsules, which were sealed in a plastic bag with silica and were reserved in a refrigerator until subsequent analysis. Consequently, samples on ten Ti grids were obtained, two Ti grids for each sample. One Ti grid in each sample was analyzed in this study, and the other one was kept for further analysis. Accordingly, the results of this investigation were based on five Ti sample grids.

The particles on the grids were investigated and imaged with SEM to identify their morphology and size. About 40 images of the particles on each grid were randomly taken. The equivalent diameter of a particle, which was defined as the diameter of a circle that had the same projection area as the measured particle in the electron microscope image, was used as the particle size. Hereafter, "equivalent diameter" is expressed as "geometric size". The elemental composition of the particles in a few images was determined with the EDX spectrometer attached to the SEM. After the image was taken, every particle in the image was analyzed. The SEM was

Table 1 – Sample collection and weather condition.

Sample ID	Start (BST)	End	Weather condition
QD01	08:40 March, 16th	20:45 March, 16th	Floating dust
QD02	08:57 March, 19th	21:40 March, 19th	Blowing dust
QD03	21:50 March, 19th	21:56 March, 20th	Dust storm
QD04	22:08 March, 20th	18:40 March, 21st	Blowing dust
QD05	09:00 March, 23rd	15:45 March, 24th	Floating dust

BST: Beijing standard time (8 hr prior to GMT). QD01, QD02, QD03, QD04, and QD05 refer to samples collected in normal polluted urban atmosphere, the polluted urban atmosphere before and during the dust storm, and after the dust storm. GMT: Greenwich mean time.