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The Mineralogy and Possible Sources of Spring Dust Particles over Beijing

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ABSTRACT

A severe Asian Dust Storm (ADS) event occurred on 16–17 April 2006 in northern China. The mineral compositions of dust samples were analyzed using X-ray diffraction (XRD). The results indicated that dust particles of the "17 April 2006" dust storm were dominated by quartz (37.4%) and clay (32.9%), followed by plagioclase (13.7%), with small amounts of calcite, K-feldspar, dolomite, hornblende and gypsum (all less than 10%). The clay fractions with diameter less than 2 μm were separated from the dust storm particles by centrifuging and were further analyzed by XRD. The results revealed that the clay species were mainly illite/smectite mixed layers (I/S) (49%) and illite (34%), with small amount of kaolinite (8%) and chlorite (9%).

In order to evaluate the feasibility of using the mineralogy to trace the sources of dust particles, the XRD results of the "17 April 2006" dustfall particles were compared with the dust particles over past years. The results confirmed that the finer dust particles represented by the ADS PM_{10} displayed a smaller quartz/clay ratio than the dustfall particles. The dust storm particles, either from the ADS PM_{10} or from the "17 April 2006" dustfall, showed a lower level of dolomite contents and lower dolomite/clay ratios compared with the non-dust storm dustfall particles. This implies that dolomite could be used to distinguish between the dust contributions from local and non-local sources. Similar trends were found for the gypsum and the gypsum/clay ratio. Moreover, the two dustfall samples had a lower level of illite/smectite mixed layers and a higher level of illite than airborne PM_{10}, implying that the dustfall particles tend to be enriched with illite in its clay fraction.

Key words: Beijing, Asian Dust Storm (ADS), mineralogy, X-ray diffraction (XRD), clay minerals, dust aerosol, mineral ratios

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1. Introduction

Asian dust storms (ADS) are mainly generated from the sandy Gobi Desert and the Loess Plateau in China and mid-Asia from March to April. Coarse dust particles with diameters greater than 30 μm are deposited near their sources, while relatively fine particles can remain airborne for several days to weeks and can be transported several thousand kilometers (Zhang and Carmichael, 1999). Estimates of atmospheric dust deposition to five Asian/Pacific regions indicated that ∼800 Tg of Asian dust from arid/semi-arid regions in Asia is injected into the atmosphere annually, half of which would be transported to the remote Pacific Ocean (Zhang, 2001).

Asian dust particles not only impose direct and indirect influences on the Earth's radiation budget (Duce et al., 1980; Uematsu et al., 1983; Leinen et al., 1994;

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Elliott et al., 1997; Buseck and Pósfai, 1999; Wang et al., 2006a) but also link the biogeochemical cycles of the land, atmosphere and ocean in East Asia and the Pacific Ocean (Zhang and Carmichael, 1999; Zhang et al., 2005). Mineral aerosol particles are highly heterogeneous, but are commonly treated as a relatively homogeneous group; this may lead to increasing uncertainty in atmospheric chemistry and climate models (Buseck and Pósfai, 1999). Intensive investigations have been conducted to study the chemical composition, sources and deposition of ADS particles (Duce et al., 1983; Uematsu et al., 1983; Iwasaka et al., 1988; Zhang et al., 1993; Zhuang et al., 2001; Kanayama et al., 2002; Wang et al., 2006b). While the mineralogy of African dust has been extensively investigated (e.g., Bergametti et al., 1989; Avila et al., 1997; Ganor et al., 2000; Falkovich et al., 2001), data on mineral compositions of ADS particles in China have been rarely reported (Shi et al., 2005; Shen et al., 2006). The mineral compositions of the ADS aerosol particles, which possibly originated from Asia and over the North Pacific Ocean, have been analyzed by Leinen et al. (1994), Merrill et al. (1994), and Arnold et al. (1998). It is known that the identification of mineral assemblages of aerosols can be a diagnostic of their sources (Bergametti et al., 1989; Merrill et al., 1994; Davis and Guo, 2000; Ganor et al., 2000). Svensson et al. (2000) showed that the clay mineralogy of the ice core samples could provide an indication of the variability in dust source areas within Asia. Therefore, the relative abundance of different mineral types in particles can be used to elucidate their sources.

During April 2006, a total of 6 dust storm events occurred in Beijing in northern China, and one of them, on 17 April, had deposited large amounts of dust particles in the city of Beijing. Samples were collected in Beijing over this period and their mineralogy was determined. The air-mass back trajectories were used to trace the possible source areas of the dust storm. The X-Ray Diffraction (XRD) was used to determine the mineral composition of the dust sample. A comparison has been made of the XRD results of some other dust samples in order to expound the feasibility of using mineral compositions to trace the sources of dust particles. Several parameters including quartz/clay, dolomite/clay and gypsum/clay ratios were suggested to be used to evaluate the possible sources of ADS particles.

2. Materials and methods

2.1 *Sampling*

Samples used in this study include four dustfall samples (one ADS sample and three normal springtime samples) and two airborne ADS PM_{10} samples. Sample information is listed in Table 1.

One dustfall sample was collected during the ADS event on 17 April 2006. The collection site (39°59′37.1″N, 116°20′45.6″E) was located on campus of China University of Mining and Technology in Beijing (CUMTB), 100 m west of Xueyuan Road, and around 1 km from the northern fourth ring road of Beijing City. The dust particles were wiped off from the surface of a personal car with a clean and soft brush and then put into a self-sealing plastic bag. The car was incidentally washed on the previous day which guaranteed that the dust storm samples were not contaminated with the local surface soil.

Three springtime dustfall samples were collected in springs of 2004, 2005 and 2006. The samples were collected in an open vessel with diameter of 60 cm which was installed on the top of a five-story building on the campus of CUMTB, 18.5 m above the ground.

Two PM_{10} samples were collected at the same sampling site as the springtime dust fall samples. A Negretti selective inlet head (UK) was used to collect PM_{10} samples on polycarbonate filters (Millipore, UK) with 0.6 μm pore sizes. PM samples were collected during a severe dust storm episode on 20 March 2002 (PM_{10}) and a less severe dust storm episode on 6 April 2000 (PM_{10}).

2.2 *Experiments*

The size distribution of irregularly shaped mineral aerosol samples can be effectively determined by the commonly used laser particle size analyzer (Veihelmann et al., 2006). The size distribution is derived from intensity measurements of singly scattered light at various scattering angles close to the forward-scattering direction at a wavelength of 632.8 nm. A small portion of the dustfall sample was mixed in water and then shaken for 2 minutes in the container. The liquid suspension was put into the OMEC LE603 Laser Particle Size Analyzer (made in China) to obtain the size distribution pattern. The analyzing model is rosin-ram, with the size range from 0.1 μm to 529.95 μm.

The different phases of minerals were identified by XRD, following the Standard of the China National Petroleum Corporation (CNPC) SY/T 6210–1996 for the quantification of mineral species based on the XRD. A D/MAX-250 (Rigaku, Japan) X-ray diffractometer scanning with Cu Kα radiation at 40 kV/125 mA, the scanning speed at 2°(2θ) min^{-1}, the sampling distance at 0.01°(2θ), and the scanning range at 2.6°–50° was used for mineralogical analysis. Determinations of minerals were made according to the cards published by the Joint Committee of the Powder

Table 1. Semi-quantitative data of mineral compositions in the different types of dust samples inferred by the XRD analyses.

No.	Date	Sample types	Mineral contents (%)										Mineral ratios		
			Clay	Q	Cal	Pla	Dol	K-F	Py	Hem	Gyp	Hor	Q/Clay	Gyp/clay	Dol/clay
D1	"17 April 2006" Dust storm	Dustfall	32.9	37.4	9.2	13.7	2.4	3.4	X	X	0.3	0.7	1.14	0.009	0.07
D2	Spring of 2006	Dustfall	32.3	29.6	9.5	13.1	6.4	5.1	X	X	1.7	2.3	0.92	0.053	0.20
D3	Spring of 2005	Dustfall	28.2	29.2	16.4	10.7	9.5	3.7	X	X	1.4	1.0	1.04	0.050	0.34
D4	Spring of 2004	Dustfall	30.7	27.9	16.4	10.3	9.2	3.1	X	X	1.6	0.7	0.91	0.052	0.30
D5	"6 April 2000" Dust storm	PM_{10}	48.8	25.9	11.4	9.8	0.0	2.6	1.3	X	0	0.4	0.53	0.000	0.00
D6	"20 March 2002" Dust storm	PM_{10}	50.4	24.5	9.4	10.6	0.0	1.9	1.1	1.1	0.4	0.5	0.49	0.008	0.00

Note: Q, Quartz; Cal, Calcite; Dol, Dolomite; Gyp, Gypsum; Hor, Hornblende; K-F, Potassium feldspar; Pla, Plagioclase; Hem, Hematite; Py, Pyrite; Q/clay, Quartz/clay ratio; Gyp/clay, Gypsum/clay ratio; Dol/clay, Dolomite/clay ratio; X in the data column means that the mineral was not confirmed in the samples by XRD.

Diffraction Standard (JCPDS). Relative proportions of major minerals were expressed by peak intensity (CPS: counts per second) of the strongest reflection of each mineral. These proportions were then converted to weight percentages using the weighting ratios as shown in the SY/T 6210–1996 Standard.

The clay minerals with diameter less than 2 μm were further separated from the dust samples by centrifuging. Three slides of each sample were prepared for XRD analysis, including the normal directional slide, the slide saturated with glycol and the slide heated to (550±10)°C. The semi-quantitative analysis of different minerals and relative percentages of different clay species were made based on the XRD pattern, following the Standard of the China National Petroleum Corporation (CNPC) SY/T 5163–1995 for the quantification of clay mineral species based on the XRD.

The relative deviations (RD) of a mineral determined from the XRD pattern, based on the SY/T 6210-1996 and SY/T 5163-1995 standards, are as follows:

Mineral content>40%, RD<10%;
Mineral content 20%–40%, RD<20%;
Mineral content 5%–20%, RD<30%;

Fig. 1. The backward trajectories (24h starting from 2400, 16th April 2006, UTC or starting from 0800 LST 17 April 2006) of the "17 April 2006" dust storm event from the source site to the sampling site (39°92′N, 116°42′E). The star symbol represents the sampling site in Beijing. The solid squares, and triangles on the trajectories mark B-1 and B-2, respectively, and they indicate at 1000 m and 50 m height above the sampling site, respectively. The calculation was programmed online by HYSPLIT MODEL of NOAA Air resources laboratory web server at http://www.arl.noaa.gov/ready.

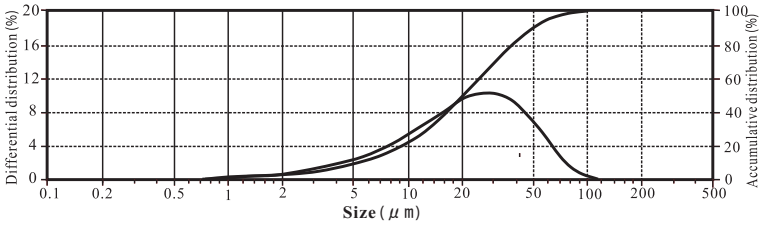

Fig. 2. Size distribution of dust particles in the ADS event on 17 April 2006.

Mineral content <5%, RD<40%;
e.g., When the content of a mineral is higher than 40%, the relative deviation is smaller than 10%.

The semi-quantitative approach as defined above will not completely represent the physical composition of the dust samples by weight. There are many sources of errors, including differences in structure and chemical composition between samples and standards, preferred orientation, overlapping peaks, counting statistics, and peak versus background statistics (Davis, 1984). We could not estimate all these errors. However, as long as standardized procedures are used and the results are used only for comparison between samples analyzed in the same way, this is a reasonable approximation (Svensson et al., 2000).

3. Sources, sizes, and mineral compositions of the "17 April 2006" ADS dustfall particles

3.1 *Source of the "17 April 2006" ADS event as reflected by the air-mass back trajectories*

From 16–17 April 2006, affected by a cyclone from Mongolia, an uncommonly severe ADS event occurred which prevailed over most of northern China. The China Meteorological Administration (www.cma.gov.cn) has estimated that the dust storm affected an area about 3.04×10^5 km^2 and about 3.3×10^8 kg of yellow mineral dust deposited in Beijing in only one night. Another value, 3.57×10^8 kg, of the dustfall was estimated for this event by a Beijing Amateur Astronomer (www.baas.org.cn/activity/2006/20060417s-and/20060417sand.htm). In addition, grade five air pollution ($\sim$500 μg m^{-3}), the most serious level in pollution grading in Beijing, was reported by the Beijing Environmental Protection Bureau. A thickness 1.5–2 mm of dustfall on the ground was observed by us on the campus of CUMTB.

In order to trace the possible sources of the "17 April 2006" dust storm, air-mass back trajectories of the dust storm at different heights are shown in Fig. 1. The back trajectory at 50 m height (B-2) above the sampling site showed that the dust particles could originate from the southeasterly source. It can be seen from meteorological data that the wind speed was very low, about 1 m s^{-1}, and the low speed wind is unlikely to lift up large amounts of soil-derived dust. Moreover, no significant sources of dust storm materials are found in the southeastern area of Beijing. However, the back trajectory path at a height of 1000 m (B-1) was different from the path B-2, and it traced a source of dust material from the Inner Mongolia and/or Mongolia at the northwestern direction. It is probable that the B-1 reflected the real sources of dust particles because some large deserts exist in the Inner Mongolia of China and Mongolia (Wang et al., 2004), such as the Otindag Sandland (Cheng et al., 2005). During the "17 April 2006" dust storm period a large number of dust particles could have been lifted up by the cold front of cyclone systems in these desert areas of northern China and parts of Mongolia, and may have been transported southeastward following the wind at a height of more than 1000 m. It is speculated here that as the wind speed was slowing down during the long-range transport, dust particles fell down to the ground directly from about 1000 m height by gravitation.

3.2 *Size distribution of the "17 April 2006" ADS dustfall particles*

The number-size distribution of the dustfall sample was analyzed by the Laser Particle Size Analyzer. The result showed that the dustfall particles were distributed in the size range from 0.1 μm to 100 μm, and the size distribution displayed a unimodal size distribution pattern, with the peak being in the range of 26–33 μm and the peak value being at 27 μm (Fig. 2). Particles smaller than 27 μm and 10 μm occupied 64% and 22% of the total particles by number, respectively. It is obvious that the "17 April 2006" dustfall particles are coarser than the ADS airborne PM_{10}.

3.3 *Mineral compositions of the "17 April 2006" ADS dustfall particles*

The XRD pattern of the "17 April 2006" ADS dustfall particles was given in Fig. 2a. The semi-quantitative result of the "17 April 2006" dustfall sample analyzed by XRD revealed that dust particles were

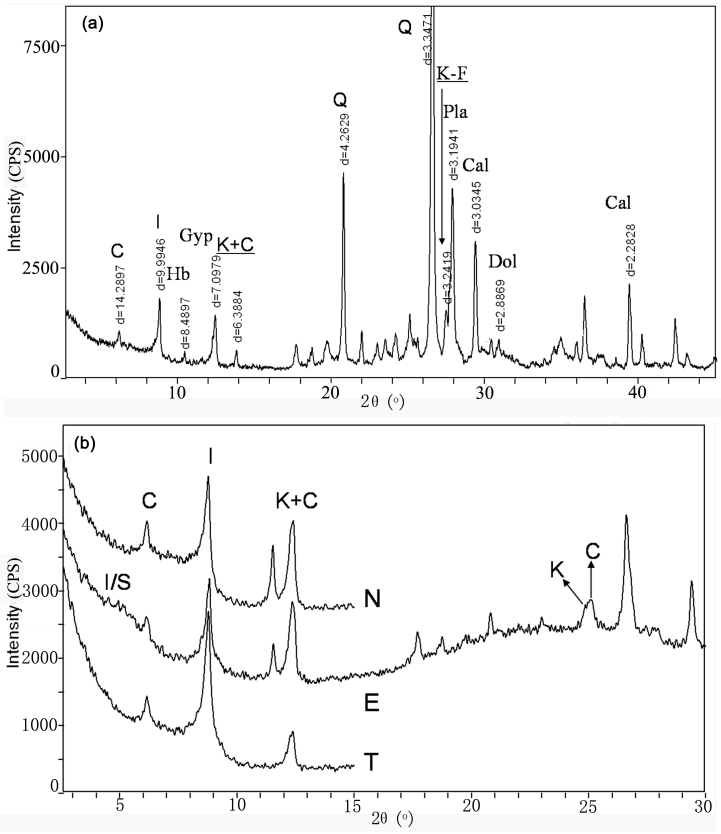

Fig. 3. (a) The XRD pattern of the dustfall collected during the "17 April 2006" dust storm. I, Illite; K, Kaolinite; Q, Quartz; Cal, Calcite; Dol, Dolomite; Gyp, Gypsum; Hb, Hornblende; K-F, Potassium feldspar; Pla, Plagioclase. (b) The XRD pattern of the clay fraction (<2 μm by sedimentation in water from dustfall) of the "17 April 2006" dustfall sample. N—the normal directional slice, E—the slice in saturation of glycol, T—the slice heated at (550±10)°C; I/S, Illite/Smectite mixed layers; I, Illite; C, Chlorite; K, Kaolinite; K+C, Kaolinite+Chlorite.

dominated by quartz (37.4%) and clay (32.9%), followed by plagioclase (13.7%), calcite (9.2%), K-feldspar (3.4%), hornblende (0.7%) and gypsum (0.3%) (Table 1). At the same time, clay minerals (<2 μm by sedimentation in water from bulk dust samples) were separated from the dustfall samples were further analyzed by XRD. The semi-quantitative calculation from the XRD patterns demonstrated that the clay minerals were mainly I/S (49%) and illite (34%), with a small amount of chlorite (9%) and kaolinite (8%) (Fig. 3b and Table 2).

4. Comparisons of mineral compositions of dust particles between the ADS episode and normal springtime

In order to evaluate feasibility of using the mineralogy to trace sources of dust particles, the XRD results of the "17 April 2006" dust storm particles were compared with the dust particles from dust storm and non-dust storm episodes over past years. Table 1 and Table 2 also included the XRD results of two PM_{10} samples during ADS periods and the three dustfall samples of normal springtime in Beijing. It was found that the "17 April 2006" dustfall sample (D1) had similar mineral types with the other three springtime dustfall samples (D2, D3 and D4) as well as the PM_{10} samples of the "6 April 2000" and "20 March 2002" dust storm, but the relative proportions of these different mineral species varied.

It can be seen that these dust particles, representing different sources, had different mineral ratios, and in particular, the variations in the levels of quartz, clay, dolomite and gypsum were very typical in these dust samples.

Table 2. Relative percentages of clay mineral from different dust samples inferred by the XRD analyses.

No.	Date	Sample types	I/S	I	K	C	Illite/smectite ratio
D1	"17 April 2006" Dust storm	Dustfall	49	34	8	9	1.5
D2	Spring in 2006	Dustfall	46	35	9	10	1.5
D5	"6 April 2000" Dust storm	PM_{10}	78	9	6	7	1.5
D6	"20 March 2002" Dust storm	PM_{10}	79	10	5	6	1.5

Note: I/S, Illite/smectite mixed layers; I, Illite; K, Kaolinite; C, Chlorite.

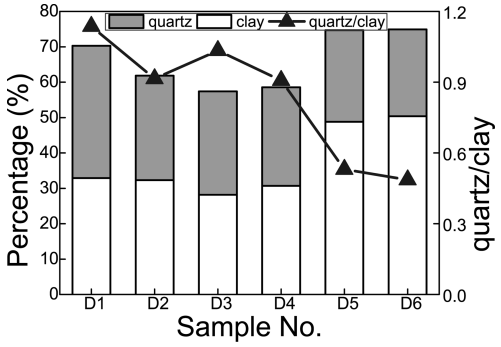

Fig. 4. The relative weight ratios of quartz and clay from XRD analysis. Sample codes D1, D2, D3, D4, D5 and D6 refer to Table 1.

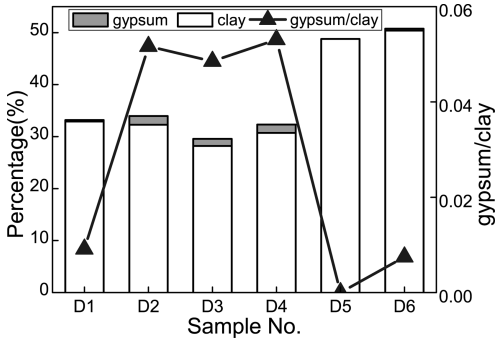

Fig. 5. The relative weight ratios of gypsum and clay of XRD analysis. Sample codes D1, D2, D3, D4, D5 and D6 refer to Table 1.

4.1 *The variations of quartz contents and quartz/clay ratios in the dust samples*

It can be seen from Fig. 4 that the clay fractions in the dustfall samples (D1 to D4) (28.2%–32.9%) were obviously lower than those of the ADS PM_{10} (D5 and D6) (48.8%–50.4%). The quartz content in the "17 April 2006" dustfall sample (37.4%) was higher than those of the three springtime dustfall samples (27.9%–29.6%), and all dustfall samples had higher quartz levels than the ADS PM_{10} samples (24.5%–25.9%). It was noticed that the different dust samples had different relative weight ratios of quartz and clay (quartz/clay). The quartz/clay ratio of the "17 April 2006" dust storm dustfall particles (1.14) was higher than those of the springtime dustfall particles (0.91–1.04). The average quartz/clay ratio with small difference in dustfall samples (D1–D4) was about 1.00, which were obviously higher than those of the ADS PM_{10} (D5 and D6, averaged 0.51). In the analyzed samples, the particles in the dustfall samples are relatively larger than those of airborne PM_{10}, and the storm dustfall particles are coarser than the springtime dustfall particles.

The previous work by Zhang and Carmichael (1999) and Zhang and Iwasaka (2004) indicated that the sizes of dust particles of long-range transport during ADS episodes not only controlled its gravitational settling but also influenced the sediment flux of mineral dust. It also showed that only relatively fine particles could be transported up to several thousand kilometers. The relative content of quartz in dust storm particles during the long-range dispersion had decreased much faster than the relative content of clay, i.e. the quartz relative to clay settled down more easily along the transport path during their dispersion (Glaccum and Prospero, 1980). It is suggested that the sediment flux of mineral dust during ADS is not only controlled by the particle sizes but also influenced by the particle mineralogy. Therefore, it is essential to clarify the sizes and mineral compositions of dust particles when considering sediment flux during ADS episodes.

4.2 *The variations of gypsum contents and gypsum/clay ratios in the dust samples*

In the analyzed dust samples, the gypsum showed an interesting variation. All the springtime dustfall samples (D2 to D4) had higher contents of gypsum than the ADS dustfall sample (D1) and the two ADS PM_{10} samples (D5 and D6) (Fig. 5). The contents of gypsum in the "17 April 2006" dustfall (D1) and ADS PM_{10} were below 0.4% (Table 1) and the relative weight ratios of gypsum and clay (gypsum/clay) were smaller than 0.01. In contrast, the contents of gypsum in three springtime dustfall samples were higher than 1% and the gypsum/clay ratios were around 0.05. The

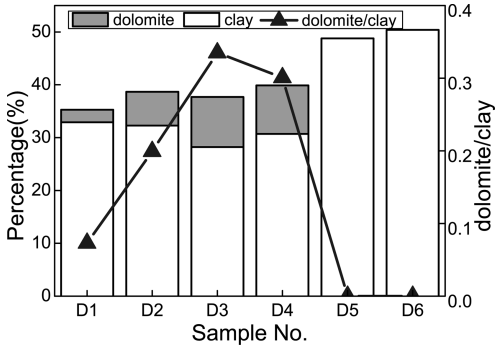

Fig. 6. The relative weight ratios of dolomite and clay of XRD analysis. Sample codes D1, D2, D3, D4, D5 and D6 refer to Table 1.

gypsum/clay ratios of the D2–D4 normal springtime dustfall samples were apparently higher than those of the ADS D1 dustfall and PM_{10} samples. These results indicated that the dust storm samples had lower gypsum contents and gypsum/clay ratios, compared with the non-ADS samples.

High levels of gypsum in the springtime dustfall samples (D2 to D4) could be explained by the fact that the gypsum in the air tends to be formed by the secondary chemical reaction in atmosphere with the precursor SO_2 being often emitted from the local anthropogenic sources (Zhou and Tazaki, 1996; Moreno et al., 2004). The pure secondary gypsum minerals are present as euhedral elongated crystals under the SEM (Shao et al., 2006), therefore, the high levels of gypsum content and gypsum/clay ratios could indicate a local anthropogenic source of mineral aerosol particles while the low level of these parameters might be associated with a non-local source of the dust particles in Beijing.

4.3 *The variations of dolomite contents and dolomite/clay ratios in dust samples*

Shi et al. (2005) reported the absence of dolomite in ADS samples and presence of the dolomite in non-ADS samples in Beijing and suggested that this can be used to distinguish the sources of the dust particles. Similarly, in the "17 April 2006" dust storm dustfall sample, the level of dolomite was very low, at 2.4%, and both the dustfall and airborne PM_{10} samples collected during dust storm episodes had lower dolomite levels than the three springtime dustfall particles (Table 1). The relative weight ratios of dolomite and clay (dolomite/clay) also showed an interesting variation. The dolomite/clay ratios of the dust storm particles (D1, D5 and D6) were all below 0.07, which was obviously lower than those of the normal springtime dustfall particles (0.2–0.34) (Fig. 6). This implies that dolomite and the dolomite/clay ratio of dust particles could be used to differentiate the dust contributions from local sources and non-local dust storms in Beijing.

It is interesting that, different from the ADS particles in Beijing, dolomite was a common mineral species in dust storm samples around Dunhuang (Shen et al., 2006) which was attributed to the source regions on the north margin of Tibetan Plateau (Li et al., 2007). In fact, the air-mass back trajectories reflected that the dust storm particles collected in Beijing during the "17 April 2006" dust storm (this paper), as well as "20 March 2002" dust storm episodes (Shao et al., 2007) were sourced from Inner Mongolia, a source region different from the north margin of Tibetan Plateau. Similarly, dolomite was also an important mineral species in dust storm samples originated from Sahara and its adjacent areas (Avila et al., 1997; Falkovich et al., 2001). This suggested that absence and presence of dolomite could be used to trace the sources of dust particles in global dust storm events.

The higher levels of dolomite were not only found in the non-ADS springtime dustfall particles in Beijing, but also in the non-ADS spring PM_{10} samples around Beijing (up to 7%, Lü and Shao, 2006). These non-ADS dolomite particles were believed to be resuspended from local surface soil or road dust, as a significant amount of dolomite was found in the surface soil (about 3.1%) and road dust (as high as 16%) in Beijing (Shao et al., 2006).

4.4 *Comparisons of clay species in dust samples of the "17 April 2006" dust storm with other dust samples*

In general, clay minerals are enriched in dust plumes that are transported over long distances because the smaller particles could remain in the air longer, (Zhang and Carmichael, 1999). The clay particles in the atmosphere would produce great effects on global climates (Arnold et al., 1998; Pósfai and Molnar, 2000). The clay mineral species from the ADS dust samples were mainly I/S, illite, smectite, chlorite, and kaolinite (Shao et al., 2007). To obtain the detailed mineral compositions of clay, semi-quantitative results of XRD patterns of clay minerals (<2 μm sedimentation in water from the bulk dust sample) separated from the dustfall (D1 and D2) and airborne PM_{10} (D5 and D6) samples were obtained. The separated clay samples were processed under three different conditions, including the normal directional slide, the slide saturated with glycol and the slide heated to 550±10°C. The clay mineral compositions in "17 April 2006" dustfall (D1) (Fig. 2b) were very similar to those of the springtime dustfall samples (rep-

resented by D2), and the "6 April 2000" ADS PM_{10} (D5) was similar to the "20 March 2002" ADS PM_{10} (D6) (Table 2). However, there is a great distinction in relative proportions of different clay species between the dustfall samples and the ADS PM_{10}. Compared with the PM_{10}, the dustfall samples had a lower level of I/S and a higher level of illite.

5. Conclusions

(1) The XRD analysis of the "17 April 2006" dustfall samples showed that quartz and clay minerals were the main mineral species, accounting for 37.4% and 32.9%, respectively, followed by plagioclase (13.7%), with small amounts of calcite, K-feldspar, hornblende and gypsum (all less than 10%).

(2) The general decreasing trend in contents of quartz and quartz/clay ratios was in association with the decreasing particle sizes, implying that both the particle sizes and particle mineralogy are two major factors in controlling the sediment flux of mineral dust during the ADS.

(3) The contents of dolomite and the dolomite/clay ratios in the springtime dustfall samples were greater than those of the ADS samples. This difference could be used to differentiate between the dust contributions from local sources and from non-local dust sources. The similar trends were found for the gypsum and the gypsum/clay ratios, with the ADS particles having lower levels of gypsum and gypsum/clay ratios than the springtime dustfall samples.

(4) The relative proportions of different clay species in clay fractions were obviously different between the dustfall samples and the airborne PM_{10}. Compared with the airborne PM_{10}, the dustfall samples had a lower level of I/S and a higher level of illite.

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