

Characteristics and Seasonal Variations of PM_{2.5}, PM₁₀, and TSP Aerosol in Beijing¹

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Objective To investigate the seasonal characteristics and the sources of elements and ions with different sizes in the aerosols in Beijing. **Methods** Samples of particulate matters (PM_{2.5}), PM₁₀, and total suspended particle (TSP) aerosols were collected simultaneously in Beijing from July 2001 to April 2003. The aerosol was chemically characterized by measuring 23 elements and 18 water-soluble ions by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) and ion chromatography (IC), respectively. **Results** The samples were divided into four categories: spring non-dust, spring dust, summer dust, and winter dust. TSP, PM₁₀, and PM_{2.5} were most abundant in the spring dust, and the least in summer dust. The average mass ratios of PM_{>10}, PM_{2.5-10}, and PM_{2.5} to TSP confirmed that in the spring dust both the large coarse (PM_{>10}) and fine particles (PM_{2.5}) contributed significantly in summer PM_{2.5}, PM_{2.5-10}, and PM_{>10} contributed similar fractions to TSP, and in winter much PM_{2.5}. The seasonal variation characteristics of the elements and ions were used to divide them into four groups: crustal, pollutant, mixed, and secondary. The highest levels of crustal elements, such as Al, Fe, and Ca, were found in the dust season, the highest levels of pollutant elements and ions, such as As, F⁻, and Cl⁻, were observed in winter, and the highest levels of secondary ions (SO₄²⁻, NO₃⁻, and NH₄⁺) were seen both in summer and in winter. The mixed group (Eu, Ni, and Cu) showed the characteristics of both crustal and pollutant elements. The mineral aerosol from outside Beijing contributed more than that from the local part in all the reasons but summer, estimated using a newly developed element tracer technique.

Key words: PM_{2.5}; PM₁₀; TSP; Seasonal variation; Sources

INTRODUCTION

The rapid industrialization and motorization plus high population density have caused serious air pollution in Beijing^[1-4]. Atmospheric aerosol, especially the fine particles, is closely related to human health^[5] because it deposits deep in the respiratory tract and increases respiratory diseases^[6]. Recent epidemiological studies have yielded a positive statistical correlation between fine particles and morbidity and mortality^[5,7-11]. Aerosols also affect climate directly by scattering and absorbing radiation or indirectly by changing the depth and albedo of the clouds^[12-13]. The direct effect of the regional haze from the anthropogenic

aerosols may result in a 5%-30% reduction of the yields of rice and wheat in China^[14]. Aerosol is now receiving worldwide attention, as it may have the potential impacts on the global climate change and the effect on the health of human beings all over the world.

Many short-term studies in Beijing on TSP and PM₁₀ (particles with dynamic diameter less than 10 μm) have been carried out since the 1980s^[1,15-16]. Much more attention has been paid to PM_{2.5} (particles with dynamic diameter less than 2.5 μm) since the 1990s^[2,17-18]. The composition and spatial variation of PM₁₀ and PM_{2.5}^[19], the size distributions^[20], and the formation characteristics of inorganic acids^[21] and dicarboxylic acids^[22] in

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Beijing aerosol have been characterized. However, most of these reported studies were based on a limited number of samples and there was a lack of long-term monitoring. TSP, PM₁₀, and PM_{2.5}, different size distribution of aerosols, have rarely been combinedly studied. Atmospheric aerosols are complex mixtures of crustal matter, organic materials, and secondary products, such as sulfate and nitrate. It is necessary to study the characteristics of TSP, PM₁₀, and PM_{2.5} simultaneously, as the different size fractions of aerosols show significantly different compositions, sources, and seasonal variations. Beijing is located in the downwind of Asian dust, which carries mineral aerosols mixed with pollutants on the pathway and invades Beijing all the time. In the long-range transport, the dust aerosols further mix with Beijing local aerosols, making Beijing aerosols more complicated. Thus estimating the contributions of inside and outside mineral aerosols to the total mineral aerosol in Beijing will provide the necessary scientific guides to control the air pollution at Beijing. In this study, we report a 3-year long monitoring of TSP, PM₁₀, and PM_{2.5} aerosols from July 2001 to April 2003 in Beijing with systematical measurement of 23 elements and 18 water-soluble ions in the aerosols, and the seasonal variations of various aerosols in Beijing. We also estimated the relative contributions of outside mineral aerosols to the total mineral aerosol in Beijing.

MATERIALS AND EXPERIMENTS

Sampling

Aerosol samples of PM_{2.5}, PM₁₀, and TSP were collected simultaneously from July 2001 to April 2003 in Beijing. The sampling site was located on the roof (up to 40 m high) of the twelfth floor in the Building of Science and Technology of Beijing Normal University (BNU), which is between the 2nd and 3rd Ring Roads. All the aerosol samples were collected with medium-volume samplers manufactured by Beijing Geological Instrument-Dickel Co., Ltd. (model: TSP/PM₁₀/PM_{2.5}-2; flow rate: 77.59 L/min). TSP, PM₁₀, and PM_{2.5} were daily collected on Whatman® 41 filters (Whatman Inc., Maidstone, UK) for analysis. All the filters were weighed before and after sampling with an analytical balance (Sartorius 2004MP, reading precision 10 µg) after stabilized under a constant temperature (20°C±5°C) and humidity (40%±2%). All the procedures were strictly quality-controlled to avoid any possible contamination of the samples.

Chemical Analysis

A total of 23 elements (Al, Fe, Mn, Mg, Ti, Sc, Na, Eu, Ce, Sr, Ca, Co, Cr, Ni, Cu, Pb, Zn, Cd, V, S, As, Se, and Sb) were determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES, Model: Ultima, Jobin-Yvon Company, France) as previously described^[23]. Eleven inorganic ions (SO₄²⁻, NO₃⁻, F⁻, Cl⁻, NO₂⁻, PO₄³⁻, NH₄⁺, Na⁺, K⁺, Ca²⁺ and Mg²⁺) and 4 organic acids (acetic, formic, oxalic and methylsulfonic acid (MSA)) were analyzed with ion chromatography (IC, Dionex 600) consisting of a separation column (Dionex Ionpac AS 11), a guard column (Dionex Ionpac AG 11), a self-regenerating suppressed conductivity detector (Dionex Ionpac ED50), and a gradient pump (Dionex Ionpac GP50) as previously described^[24].

RESULTS

Size Distribution of Aerosols in Different Seasons

Table 1 shows the average 12-hour daily mass concentrations in the spring non-dust (Sp-ND), spring dust (Sp-D), summer (Su) and winter (W) dust of different sizes. TSP, PM₁₀, and PM_{2.5} were most abundant in the spring dust, and their average mass concentrations were up to 2167.4, 430.0, and 402.2 µg/m³, respectively, compared with those in spring non-dust (495.1, 243.5, and 145.3 µg/m³), summer (290.7, 179.8, and 107.2 µg/m³) and winter dust (434.6, 263.2, and 181.6 µg/m³). The average mass ratios of PM_{2.5}, PM_{2.5-10} and PM_{>10} to TSP are shown in Table 2. The average mass ratios of PM_{2.5}, PM_{2.5-10} and PM_{>10} to TSP accounted for 29%, 20%, and 61% in the spring dust, indicating that in the spring dust season, both PM_{2.5} and PM_{>10} from the long-range transport contributed the major parts to TSP. In summer dust, the average mass ratios of PM_{2.5}, PM_{2.5-10} and PM_{>10} to TSP accounted for 39%, 29%, and 45%, and in winter dust they accounted for 40%, 19%, and 47%, both of which had a size distribution similar to that in the spring dust. Zhuang *et al.*^[23] and Sun *et al.*^[25] have reported the same finding as we had here in their previous studies on Beijing dust aerosol. It was evident that the PM_{2.5} was a substantial part of PM₁₀ in all seasons, as the average ratios of PM_{2.5}/PM₁₀ were 60%, 71%, and 71% in summer, winter, and spring non-dust, respectively, as shown in Table 2. However, the average concentrations of all sizes were the lowest in summer dust, as shown in Table 1. This might be essentially due to the high volatility of some secondary ions^[26] and a better dispersion of the motor-vehicle emissions.

TABLE 1
Average Seasonal Mass Concentration of PM2.5, PM10, and TSP ($\mu\text{g}/\text{m}^3$)

Size	Seasons	Mean	SD	Min	Max	<i>n</i>
TSP	Su	290	163	22	747	66
	W	435	268	119	1770	68
	Sp-ND	495	419	3.3	2990	111
	Sp-D	2170	2560	75	10900	32
PM10	Su	180	87	11	462	63
	W	263	241	18	1620	69
	Sp-ND	244	352	25	2710	81
PM2.5	Sp-D	430	410	59	1350	14
	Su	107	61	4.1	256	63
	W	182	107	2.7	443	74
	Sp-ND	145	150	0.9	1030	75
	Sp-D	402	363	36	1390	13

TABLE 2
Average Mass Ratios of Different Sizes

Ratio (%)	Summer		Winter		Spring Non-dust		Spring Dust	
	Mean (SD)	<i>n</i>	Mean (SD)	<i>n</i>	Mean (SD)	<i>n</i>	Mean (SD)	<i>n</i>
PM2.5/TSP	38.9(19.8)	54	40.3(19.3)	59	36.0(23.4)	63	29.3(13.5)	12
PM2.5-10/TSP	29.1(23.2)	48	19.0(15.7)	49	30.6(34.7)	47	20.4(14.9)	4
PM>10/TSP	44.9(23.1)	41	47.1(21.5)	55	57.8(24.3)	57	61.3(14.4)	10
PM10/TSP	71.8(36.4)	51	52.9(21.5)	55	56.6(45.9)	66	33.8(15.6)	13
PM2.5/PM10	60.1(20.8)	55	70.9(17.6)	61	70.5(35.1)	58	75.2(36.0)	7

DISCUSSION

Characteristics and Seasonal Variation of Chemical Species

The enrichment factor (EF) of each species in TSP, PM10, and PM2.5, as shown in Table 3, has been calculated by using Al as the reference for crust source and taking the crust abundance of each element from Taylor *et al.*^[27]. Figure 1 illustrates the average seasonal variation of the elements and ions measured. Based on the seasonal variation characteristics and the EFs of each species, the 18 elements and 6 ions measured can be divided into crustal, pollutant, mixed, and secondary groups.

The crustal group includes Fe, Mg, Al, Ca, Mn, Cr, Sr, Ti, Sc, Co, Ce, and V, of which the average enrichment factor of each element is below 10. The maximum concentrations of Al, Fe, Ca, Mg, and Ti in TSP in the dust seasons can reach 739.48, 368.9, 771.43, 176.95, and 41.06 $\mu\text{g}/\text{m}^3$, 37, 31, 24, 31, and 35 times higher than the averages in the spring non-dust days (20.02, 12.03, 32.40, 5.90, and 1.18 $\mu\text{g}/\text{m}^3$), and the average concentrations of these

crustal elements in the dust seasons are 8.0, 7.9, 5.4, 5.7, and 8.9 times higher than the averages in the non-dust days, respectively (Fig. 1b). The average concentrations of these crustal elements in PM10 and PM2.5 in the dust seasons are 2.08, 1.80, 1.16, 1.93, and 1.94 times and 3.99, 3.69, 2.54, 3.83, and 3.93 times higher than the averages in the non-dust days, respectively. In summer dust these crust elements have the lowest concentrations, as shown in Fig. 1b. This may be due to the meteorological conditions in summer, such as more precipitation that washes out more particulates from the air. The pollutant group includes K^+ , F^- , Cl^- , S, Cd, As, Se, and Zn, of which the enrichment factors of each species are up to hundreds to thousands, as shown in Table 3. It is obvious from Fig. 1a that there are two different seasonal variations between TSP and PM10, PM2.5. It can be seen from Fig. 1a that these pollutant species in TSP show the highest concentration in the dust season, while in PM2.5 and PM10 there are no obvious variations of these species between the dust days and the non-dust days in spring, which may be explained by the crustal sources of these species in the coarse part of PM>10. In summer, these species

TABLE 3
Enrichment Factors of Elements in TSP, PM10, and PM2.5 in Different Seasons

Species	TSP				PM10				PM2.5			
	Su	W	Sp-ND	Sp-D	Su	W	Sp-ND	Sp-D	Su	W	Sp-ND	Sp-D
As	205	536	288	108	281	470	279	116	735	200	824	401
Se	4910	3830	4250	696	2890	7060	2240	1210	16400	15200	6460	3320
Sb	959	950	538	256	614	1420	824	553	2760	4650	2490	1470
Cd	509	230	166	106	237	892	278	228	1930	2430	861	699
Zn	72	43	44	32	97	115	77	50	537	347	285	184
S	948	143	222	86	568	504	285	122	2490	1520	1040	454
Cr	3.9	5.3	2.8	2.2	6.1	5.7	3.6	2.1	25.0	14.0	13.0	64.0
Sr	3.7	2.8	1.7	1.3	1.3	3.6	2.1	1.4	4.9	3.5	1.9	1.8
Co	2.2	3.1	1.6	1.4	1.2	5.0	2.0	1.4	18.0	8.4	2.9	2.9
Fe	0.8	0.9	1.1	1.1	1.0	-1.0	1.0	0.9	1.2	1.1	1.2	1.5
Mn	2.4	1.1	1.1	1.0	1.7	1.8	1.4	1.1	3.7	3.7	2.7	2.5
Mg	2.5	0.9	1.2	1.1	1.4	0.9	1.1	1.0	1.6	1.0	1.0	1.0
V	4.8	0.6	2.8	1.6	1.2	1.0	2.2	1.0	14.0	1.4	2.2	3.2
Ca	6.7	3.7	3.7	3.1	3.6	2.9	3.3	1.9	2.8	3.1	2.8	1.9
Ti	4.1	1.2	1.1	1.2	1.0	1.1	1.1	1.0	0.9	1.2	1.0	1.1
Sc	3.8	0.8	0.5	0.5	0.3	0.8	0.6	0.5	0.6	1.1	0.7	0.6

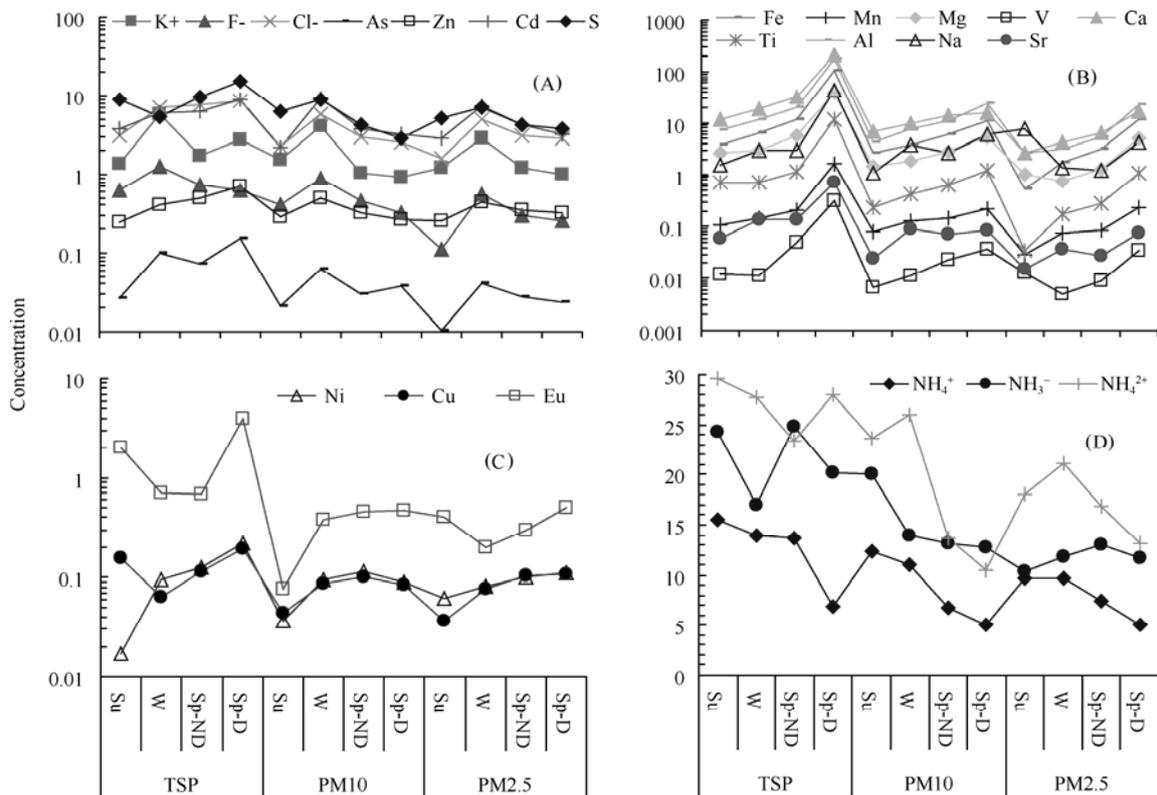


FIG. 1. Average concentrations of selected elements and ions in PM2.5, PM10, and TSP at different seasons. (Co, Cd, Sc, Eu and Ce as ng/m³, others as μg/m³)

in all sizes show the lowest concentration, which may be explained by the less sources of emission, such as coal burning, better dispersion of the motor-vehicles emissions due to the high temperature, and more precipitation that washes out more aerosols from the air. In winter these pollutant species in PM10 and PM2.5 show the highest concentration. This may be mainly due to more local sources of emission, such as emission from the heating in winter. It should be noted that the enrichment factors of these pollutant elements decrease in the dust days while their concentrations are higher than those in other seasons, which may be explained by the clearance of these local pollutants by the dust storms and the increase of these elements from the dust sources^[28].

Eu, Ni, and Cu are defined as the mixed elements, as they show the characteristics of both crustal and pollutant species. Their EFs are within 100, as shown in Table 3, the highest in PM2.5, and the lowest in TSP. The significant increase of these elements in TSP in dust season show the characteristics of crustal species, while the slight increase in PM2.5 might imply their mixed sources of both crustal and pollutant species.

SO₄²⁻, NO₃⁻, and NH₄⁺ are the secondary species, their sum, accounts for 20.0%, 22.4%, and 32.9% in TSP, PM10 and PM2.5, respectively. These secondary ions show high concentrations in both summer and winter. Concentrations of NH₄⁺ in the spring non-dust (Sp-ND), spring dust (Sp-D), summer (Su), and winter (W) dust are 6.8, 5.1, 12.3, and 11.0 µg·m⁻³, respectively, those of SO₄²⁻ are 13.7,

10.5, 23.6, and 26.0 µg·m⁻³, respectively, and those of NO₃⁻ are 13.1, 12.8, 20.0, and 13.9 µg·m⁻³, respectively. The results show that the concentrations of these secondary ions are generally higher in summer and winter and lower in spring. In summer the high concentration of these species is due to the secondary transformation accelerated under high humidity, high temperature, low wind speed, and strong solar radiations in this season. The high SO₄²⁻ concentration in winter is attributed to the higher concentration of SO₂ in this season, which is due to the more coal burning combined with poor dispersion and the lower rate of removal *via* wet deposition. In summer, there the sulfur oxidation rate is high and the SO₂ rate is low, suggesting that the high SO₄²⁻ could be mainly due to the secondary transformation instead of the direct local emissions. NO₃⁻ comes from NH₄NO₃ that is generally formed by the oxidation of NO_x in the gas phase of nitric acid and reaction with NH₃^[20]. The lower temperature in winter would favor the shift from the gas phase of nitric acid to the particle phase of ammonium nitrate, which could lead to the high concentration of NO₃⁻ in winter. In summer both the higher nitrogen oxidation rate and the higher emission of NH₃ contribute to the high concentration of NO₃⁻. The high O₃ concentration shown in Table 4 in summer would also favor the formation of these secondary ions through the oxidation of SO₂ and NO_x. Wang *et al.*^[20] and Sun *et al.*^[19] have further confirmed the seasonal variations of these secondary species.

TABLE 4

Average Concentrations of SO₂, NO₂, PM10, CO, and O₃ and Meteorological Conditions of Temperature (T), Relative Humidity (RH), and Wind Speed (WS)

Species	Units	Summer			Winter			Spring		
		Mean (SD)	Range	<i>n</i>	Mean (SD)	Range	<i>n</i>	Mean (SD)	Range	<i>n</i>
SO ₂	µg/m ³	13.5(5.5)	6-33	73	148.8(64.1)	34-371	77	58.5(38.1)	10-215	78
NO ₂	µg/m ³	61.3(12.3)	38.4-88.8	73	86.0(33.2)	27.2-203.2	77	73.7(30.1)	16.0-196.8	78
PM10	µg/m ³	119.9(47.1)	35-234	73	162.3(107.0)	29-598	77	220.5(135.6)	11-600	78
CO	mg/m ³	2.86(0.9)	1.5-5.8	73	7.72(7.71)	1.3-55.0	70	3.57(2.8)	0.8-19.0	46
O ₃	µg/m ³	116.5(45.4)	14.4-232	73	30.5(15.6)	7.2-57.6	70	74.1(22.6)	14.4-155.2	45
T	°C	26.3(3.1)	17.9-33.0	73	-2.7(2.7)	-9.1-4.0	77	10.3(4.9)	0.6-19.5	77
RH	%	70.6(13.5)	40.5-94.0	73	51.5(22.3)	17.0-96.5	77	44.9(22.3)	5.0-87.5	77
WS	m/s	2.0(0.6)	0.5-3.5	73	2.1(1.3)	0.3-6.0	77	3.1(1.3)	1.3-7.5	77

TABLE 5
Seasonal Correlations Between NH_4^+ and NO_3^- , SO_4^{2-} in TSP, PM10, and PM2.5

		Sp-D	Sp-ND	Su	W
TSP	Equation	$[\text{NH}_4^+]=0.37[\text{SO}_4^{2-}]+0.17$	$[\text{NH}_4^+]=0.60[\text{SO}_4^{2-}]+0.45$	$[\text{NH}_4^+]=1.09[\text{SO}_4^{2-}]+0.18$	$[\text{NH}_4^+]=1.14[\text{SO}_4^{2-}]+0.11$
	R ²	0.087	0.25	0.93	0.95
	Equation	$[\text{NH}_4^+]=1.18[\text{NO}_3^-]$	$[\text{NH}_4^+]=0.95[\text{NO}_3^-]+0.36$	$[\text{NH}_4^+]=2.22[\text{NO}_3^-]-0.014$	$[\text{NH}_4^+]=2.36[\text{NO}_3^-]+0.13$
	R ²	0.89	0.34	0.78	0.94
PM10	Equation	$[\text{NH}_4^+]=1.78[\text{SO}_4^{2-}]-0.11$	$[\text{NH}_4^+]=1.26[\text{SO}_4^{2-}]+0.017$	$[\text{NH}_4^+]=1.49[\text{SO}_4^{2-}]+0.15$	$[\text{NH}_4^+]=1.02[\text{SO}_4^{2-}]+0.065$
	R ²	0.89	0.90	0.82	0.77
	Equation	$[\text{NH}_4^+]=1.08[\text{NO}_3^-]+0.047$	$[\text{NH}_4^+]=1.63[\text{NO}_3^-]+0.031$	$[\text{NH}_4^+]=2.36[\text{NO}_3^-]+0.12$	$[\text{NH}_4^+]=2.30[\text{NO}_3^-]+0.096$
	R ²	0.96	0.89	0.74	0.79
PM2.5	Equation	$[\text{NH}_4^+]=1.72[\text{SO}_4^{2-}]-0.19$	$[\text{NH}_4^+]=0.92[\text{SO}_4^{2-}]+0.093$	$[\text{NH}_4^+]=1.01[\text{SO}_4^{2-}]+0.16$	$[\text{NH}_4^+]=1.16[\text{SO}_4^{2-}]+0.027$
	R ²	0.54	0.75	0.71	0.94
	Equation	$[\text{NH}_4^+]=1.32[\text{NO}_3^-]+0.036$	$[\text{NH}_4^+]=1.91[\text{NO}_3^-]+0.008$	$[\text{NH}_4^+]=1.72[\text{NO}_3^-]+0.28$	$[\text{NH}_4^+]=2.37[\text{NO}_3^-]+0.088$
	R ²	0.97	0.91	0.56	0.94

TABLE 6

Seasonal Concentrations of Local, Outside, Total Mineral Aerosol and Their Mass Percentages to the Total Mass With Different Sizes

Size	Seasons	Concentrations ($\mu\text{g}/\text{m}^3$)				Percentages (%)		
		Mass	Mineral	Mineral (Local)	Mineral (Non-local)	Mineral	Mineral (Local)	Mineral (Non-local)
TSP	Su	290.7	117.8	76.6	41.2	41	26	14
	W	434.6	192.7	57.8	134.9	44	13	31
	Sp-ND	495.1	328.3	157.6	170.7	66	32	34
	Sp-D	2167.4	2760.2	993.7	1766.5	127	46	82
PM10	Su	179.8	69.2	47.1	22.2	39	26	12
	W	263.2	122.3	25.7	96.6	46	10	37
	Sp-ND	243.5	175.1	64.8	110.3	72	27	45
	Sp-D	430.0	339.3	88.2	251.1	79	21	58
PM2.5	Su	107.2	37.4	7.1	30.3	35	7	28
	W	181.6	50.1	25.5	24.5	28	14	14
	Sp-ND	145.3	86.2	23.0	63.2	59	16	43
	Sp-D	402.2	326.1	87.3	238.8	81	22	59

Sources of Mineral Aerosol From Outside Beijing

The contributions of mineral aerosol from inside and outside Beijing to the total mineral aerosol were also estimated, using an element tracer (the ratio of Mg/Al) technique recently developed by our group^[19,29]. The equation of (Mg/Al) (aerosol) = $m \times (\text{Mg}/\text{Al})$ (local) + $n \times (\text{Mg}/\text{Al})$ (non-local) was used to estimate the relative contributions to the total mineral aerosols from both inside and outside Beijing. In the equation (Mg/Al) (aerosol), (Mg/Al) (local), (Mg/Al) (non-local) are the average ratios of Mg/Al in aerosols of the soil samples collected from all over

Beijing and outside Beijing respectively, m and n denote the relative contributions in percentage (%) of the mineral aerosols to the total mineral aerosol from inside and outside Beijing respectively, and the sum of them is one. The total mineral aerosol in the samples was estimated using the following formula^[30],

$$\text{Mineral aerosol} = 1.16 (1.90\text{Al} + 2.15\text{Si} + 1.14\text{Ca} + 1.67\text{Ti} + 2.09\text{Fe})$$

where the factor of 1.16 is to compensate for the exclusion of those oxides of Mg, Na, K, and H₂O from the calculation. Si concentrations were

estimated on the basis of the Si/Al ratio (4.0) as previously described^[27,31]. Table 6 lists the relative contributions of both local Beijing and outside Beijing aerosols to the total mineral aerosol with various sizes in Beijing in different seasons and their mass percentages to the total mass of the aerosols. In summer the mineral aerosols from outside Beijing contribute 81%, 32%, and 35% of the total mineral aerosols in PM_{2.5}, PM₁₀ and TSP, respectively, while in winter the outside mineral aerosols contribute 69%, 79%, and 70% to the total mineral aerosol in PM_{2.5}, PM₁₀ and TSP, respectively. The mineral aerosol from outside Beijing contributes more than that from the local area to the total mineral of all sizes in most seasons except for summer in Beijing.

It also can be seen that the mineral aerosol contributes most of the aerosols in dust time, and the least in summer in TSP, PM_{2.5} and PM₁₀. The great contribution of outside mineral aerosols explains the significance of long-range transport to the local air pollution in Beijing.

CONCLUSION

Particulate matter samples were collected from 2001 to 2003 in Beijing. A total of 23 elements and 18 water-soluble ions were measured. The samples were divided into four categories: spring non-dust, spring dust, summer, and winter dust. TSP, PM₁₀, and PM_{2.5} are most abundant in spring dust and the least in summer dust. The average mass ratios of PM_{>10}, PM_{2.5-10}, and PM_{2.5} to TSP have confirmed that in winter PM_{2.5} contributes much to TSP, in spring dust season both PM_{>10} and PM_{2.5} contribute to TSP significantly, and in summer PM_{2.5}, PM_{2.5-10} and PM_{>10} contribute similar fractions to TSP. The seasonal variation characteristics of the elements and ions can be used to divide them into crustal, pollutant, mixed, and secondary groups. The crustal elements, such as Al, Fe, and Ca, are the highest in the dust season, the pollutant elements and ions, such as As, F⁻, and Cl⁻, are the highest in winter, and the secondary ions (SO₄²⁻, NO₃⁻, and NH₄⁺) are the highest in both summer and winter. The mixed group (Eu, Ni, and Cu) shows the characteristics of both crustal and pollutant species. The contributions of mineral aerosols from outside Beijing can be estimated with a newly developed element tracer technique.

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