

Characteristics of Aerosol Composition at Jeju City, Korea

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Aerosol measurement were carried out to investigate the characteristics of its chemical composition directly affected by the local emissions of Jeju City, Jeju Island by using an eight-stage cascade impactor from Dec. 1999 to Aug. 2000. The ambient aerosol concentrations measured at Jeju City were generally very low but the fine particle concentrations were to be higher than the US standard of PM_{2.5}. The majority of sulfate were non sea salt and contained in the fine particles. In the fine particles, the concentrations of Na⁺, K⁺, Mg²⁺, Ca²⁺, Cl⁻ and NO₃⁻ had a tendency to increase during the springtime rather than the other seasons. However, the springtime sulfate and ammonium concentrations in the fine particles were slightly lower than those during the other seasons. On the other hand, associated with the coarse particles, the concentrations of ionic species except potassium and ammonium were elevated during the springtime. The calcium concentrations in the coarse particles were increased up to 8 times relative to the other seasons.

Key words : Aerosol, Jeju, Asian Dust, Enrichment factor

1. Introduction

It is well known that aerosols play important roles in the atmosphere. They scatter and absorb solar and terrestrial radiation, and can also serve as active reaction sites for chemical reactions and influence the partitioning of materials between the gas and aerosol phases. Moreover, anthropogenic particulate can be transported over long distance and entrained into the natural aerosols.^{1,2)}

Recently, emissions of anthropogenic air pollutants in northeastern Asia have been increasing drastically. Especially, China emits most of the sulfur oxides and a major fraction of the nitrogen oxides in this region. The prevailing wind in this region is westerly with frequent downward. The air pollutants emitted from China can be transported to Korea, Japan, and the North Pacific.^{3,4)} Hence there are growing the concern over the pollution of the coastal and shelf system of the East China Sea. Under this

situation, the coastal area around Jeju Island is believed to be subject to the deposition of Asian aerosols and anthropogenic air pollutants as it lies in close proximity to China and receives polluted air masses via China continent. Jeju Island is located at the northern part of the east China Sea, and surrounded by China to west, Korea peninsula to north, and Japanese Island to east. Jeju Island is one of the cleanest ones in Korea. Thus Jeju Island is an ideal place to monitor the long range transport of air pollutants in this region.

Several monitoring studies had carried out at Gosan site, located at the western edge of Jeju Island.^{5~10,15)} However those studies focused on monitoring of air pollutants or routine measurement of water soluble ion concentrations of aerosols and generally, aimed at monitoring the long range transport of air pollutants from Asia continent to the Pacific. No intensive measurement has been carried out to investigate the characteristics of aerosols directly affected by the local emissions of Jeju City, the largest city in Jeju Island.

In this paper, in order to understand the characteristics of aerosols at Jeju City, we discuss

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aerosol characteristics based on the concentrations of water soluble species.

2. EXPERIMENTAL

2.1. Description of Sampling Site

Fig. 1 showed the eastern Asian area and the sampling sites on the Jeju City, Jeju Island. The Jeju Island is a volcanic island with peak elevation of 1950 m and located in the East China Sea; about 100 km south of the Korean peninsula, about 250 km west of Kyushu, Japan; about 500 km east-northeast of Shanghai, China.

About 540,000 people live there, and there are no large pollution sources. Its emissions of air pollutants are less than 1 % wt. of the total Korean emissions and can be considered as a background site in northern Asia. Figure 1 also showed the district of Jeju City, the largest city in Jeju Island with about 250,000 inhabitants. The city is surrounded by the ocean to the north and mountain to the south.

In this study, there are two sampling sites, named as Site M and Site U. The sampling site of Site M is on the roof of the Jeju Meteorological Observatory Station building at the downtown of the city. This building has the

height of approximately 10 m and is located about 300 m south of the coastline. Near this site are residences, streets and shopping areas.

Measurement at Site U is performed on the roof of the Ocean Science College building of Cheju National University (CNU). The height of this building is approximately 20 m. The CNU is located at the outskirts of Jeju City, about 7 km south of the shore and about 300 m above mean sea level and encompassed with the forest and the dry field such as orchards.

2.2. Sampling and Analysis

From December 1999 to August 2000, aerosols were collected with an eight-stage cascade impactor at each sampling site. The sampler was installed within the wooden shelter from the wind and the rain. The sampling heads were maintained at the height of approximately 1.5 m above roof level. Air is sampled continuously through membrane filters at a rate of 28 ℓ /min. Sampling was carried out over a period of 9 months. Each sampling time was about two weeks. Table 1 showed the sample number and the sampling period.

Cascade impactor collected ambient particles and separated them into several aerodynamic size ranges using the inertial characteristics of a particle in a fluid flow. The size range of particles deposited on each stage is 9.0~10 μm , 5.8~9.0 μm , 4.7~5.8 μm , 3.3~4.7 μm , 2.1~3.3 μm , 1.1~2.1 μm , 0.65~1.1 μm , and 0.43~0.65 μm , respectively.

All filters for cascade impactor were weighted before and after sample collection, with a microbalance of 1 μg sensitivity. The weighed filters were stored in a freezer until aerosol

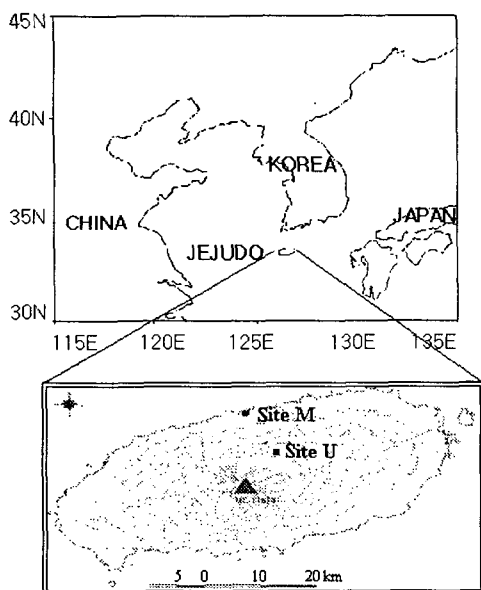


Fig. 1. The location of Jeju Island and the sampling site.

Table 1. Sample Number and the sampling period

Sample No.	Sampling period	Asian Dust Phenomena
S1	9 Dec. - 23 Dec.	
S2	19 Jan. - 2 Feb.	
S3	2 Feb. - 16 Feb.	
S4	17 Mar. - 31 Mar.	6 days
S5	3 Apr. - 17 Apr.	3 days
S6	17 Apr. - 29 Apr.	3 days
S7	9 Jun. - 29 Jun.	
S8	7 Jul. - 29 Jul.	
S9	11 Aug. - 24 Aug.	

sampling and postsampling chemical analysis.

Before chemical analyses, each filter paper was carefully divided into two parts. Half of each filter was kept for analysis of the water soluble species and the remaining for analysis of the trace elements. The results of the latter were not included in this study.

The filters were classified into two groups, that is, coarse and fine parts, and analyzed for Ca^{2+} , Mg^{2+} , Na^+ , NH_4^+ , K^+ , Cl^- , NO_3^- , SO_4^{2-} , F^- and Br^- . The chemical analysis consisted of extraction with water, shaking for 6 hr, followed by filtration using a $0.45\mu m$ cellulose acetate membrane. The filtrate was then analyzed for Cl^- , NO_3^- , SO_4^{2-} , F^- and Br^- using ion chromatography (DIONEX DX-500) ; Ca^{2+} , Mg^{2+} , K^+ and Na^+ using atomic absorption spectrophotometry ; and NH_4^+ using UV-Visible spectrophotometry.

3. Results and Discussion

3.1. Concentration of Aerosol

Fig. 2 showed a comparative view of airborne concentrations of PM10 aerosols. The average PM10 concentration was $38.8\pm 21.17 \mu g/m^3$ at Site M and $36.8\pm 21.65 \mu g/m^3$ at Site U, respectively and likely to be well below the Korean ambient air quality standard for PM10 ($70\mu g/m^3$ as an annual average). The annual average concentration of PM10 at Idodong Site of National Monitoring Station, which is located at downtown of Jeju City, showed $35 \mu g/m^3$ during the period of 2000.¹¹⁾ When compared to PM10 measurements from other large cities in Korea, the ambient aerosol concentrations measured at Jeju City were generally very low. The PM10 concentrations were almost half times lower in Jeju City, compared to those in Seoul, Korea.¹²⁾

As illustrated in the figure, the average concentrations of PM2.1 aerosol were $17.5 \mu g/m^3$ at Site M and $18.9 \mu g/m^3$ at Site U. Although the average concentrations of fine particles found in this study were very low compared to other cities in Korea,^{12,14)} the concentration level was to be above the U.S. EPA standard of PM2.5 ($15 \mu g/m^3$ as an annual average).

With the exceptions of springtime (S4-S6 in Fig. 2), the PM2.1/PM10 mass ratios were above

0.5, indicating that fine particles were large portion of PM10 at Jeju City. On the other hand, these ratios were below 0.4 during the springtime. High concentration of coarse particle was found during the springtime at both sampling sites. Chun et al.¹³⁾ reported that number size distributions of aerosol, observed at Seoul and Anmyondo in the west coast of Korean peninsula during Asian dust episode in April 1998, are characterized by decrease in small particles of diameter less than $1 \mu m$ and increase in large size particles between 1.35 and $10 \mu m$ (especially, $2-6 \mu m$) during heavy dust period.

3.2. The Composition of Aerosol

Table 2 showed the analytical results of aerosol measured at this study. Non sea salt (nss) concentrations of ions based on sodium ion were also given in Table 2.

As shown in Table 2, the sum of the mass fractions of ammonium, sulfate, and nitrate (referred as 2nd fraction in Table 2) of PM2.1 accounted for over 80 wt% of the total mass of water soluble species at both sites. Therefore, it could be concluded that these three species were

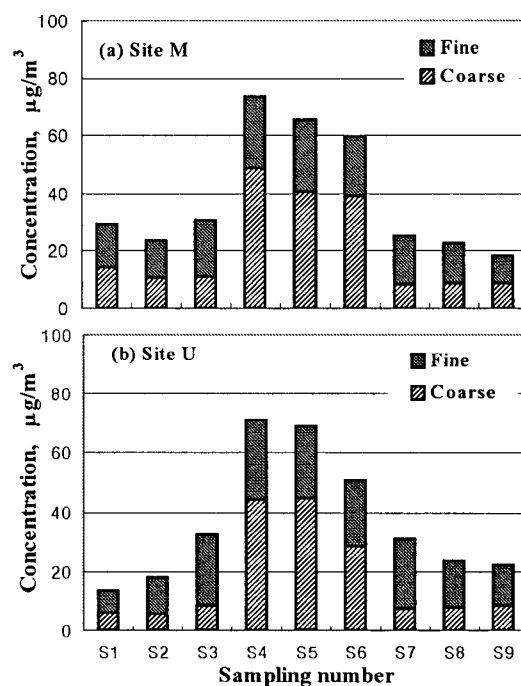


Fig. 2. The trends of aerosol concentrations with the sampling times.

Table 2. The statistical data of chemical composition for aerosol sampled at Jeju city

Species	Site M						Site U					
	Coarse			Fine			Coarse			Fine		
	Mea n	S.D.	Wt %	Mea n	S.D.	Wt %	Mea n	S.D.	Wt %	Mea n	S.D.	Wt %
(a) concentration ($\mu\text{g}/\text{m}^3$)												
NH_4^+	0.157	0.203	3.911	1.054	0.464	15.416	0.095	0.075	3.089	1.054	0.603	15.396
Na^+	0.645	0.313	16.028	0.391	0.164	5.727	0.521	0.318	16.975	0.275	0.146	4.015
K^+	0.050	0.018	1.241	0.203	0.121	2.975	0.084	0.092	2.730	0.240	0.157	3.507
Mg^{2+}	0.102	0.039	2.523	0.060	0.022	0.879	0.075	0.035	2.456	0.049	0.021	0.708
Ca^{2+}	0.325	0.358	8.065	0.147	0.138	2.144	0.346	0.375	11.272	0.183	0.152	2.677
SO_4^{2-}	0.595	0.225	14.607	3.360	0.469	49.156	0.493	0.294	16.046	3.700	0.848	54.043
Cl^-	1.123	0.569	27.898	0.372	0.206	5.446	0.502	0.311	16.325	0.205	0.145	2.996
NO_3^-	1.056	0.291	26.211	1.248	0.415	18.256	0.935	0.404	30.447	1.141	0.568	16.657
(b) non sea salt ($\mu\text{g}/\text{m}^3$)												
nss- SO_4^{2-}	0.389	0.182		3.262	0.477		0.362	0.241		3.631	0.858	
nss- Cl^-	-0.050	0.441		-0.339	0.165		-0.447	0.375		-0.295	0.194	
nss- Mg^{2+}	0.025	0.027		0.014	0.010		0.014	0.012		0.016	0.014	
nss- Ca^{2+}	0.300	0.350		0.132	0.134		0.326	0.368		0.173	0.149	
(c) mass basis												
nss- $\text{SO}_4^{2-}/\text{SO}_4^{2-}$ (%)			71.5			97.1			73.4			98.1
2nd fraction (%)			44.4			82.8			49.6			86.1
sea salt fraction (%)			43.5			11.2			33.3			7.01
Particle conc. ($\mu\text{g}/\text{m}^3$)	21.23	16.55		17.52	5.20		17.90	16.57		18.92	6.76	
(d) ratio of												
nss- $\text{SO}_4^{2-}/\text{NO}_3^-$ (molar)	0.297			1.917			0.276			2.592		
$\text{NH}_4^+/\text{nss-}\text{SO}_4^{2-}$ (equiv.)	1.030			0.863			0.900			0.774		

major components of fine particles ($\leq \text{PM}_{2.5}$). In coarse particles, on the other hand, it could be seen that the contributions of sodium ion and anion species (SO_4^{2-} , Cl^- , NO_3^-) were dominative.

The mass fraction of sea salt components (Na^+ and Cl^-) associated with the coarse size fraction was far higher than that associated with fine size fraction. Sea salt components at Site U accounted for about 30% of total water soluble aerosol mass in coarse particles but merely ~7% in fine particles. It could be also seen that these values were largely increased in the data for Site M due to the close proximity of the sampling site to the coast. Therefore, it can be concluded that the coarse particles contain more sea salt fraction than the fine particles since most sea salt particles are in coarse mode.

The average sulfate concentration was $0.55 \mu\text{g}/\text{m}^3$ and $0.49 \mu\text{g}/\text{m}^3$ in coarse particles and $3.36 \mu\text{g}/\text{m}^3$ and $3.70 \mu\text{g}/\text{m}^3$ in fine particles, at both sites, respectively. Especially, in fine particles,

sulfate was the largest component of the water soluble species and contributed about 50 wt% to the total water soluble aerosol mass at both sites. High concentrations of nss sulfate and high fraction of nss sulfate to total sulfate, typically in fine particles, can be shown in Table 2. The average nss sulfate concentrations were $0.39 \mu\text{g}/\text{m}^3$ and $0.36 \mu\text{g}/\text{m}^3$ in coarse particle, and $3.26 \mu\text{g}/\text{m}^3$ and $3.63 \mu\text{g}/\text{m}^3$ in fine particles, at Site M and Site U, respectively. The fraction of nss sulfate to total sulfate at both sites were over 70 wt% in coarse particles and 97 wt% in fine particles, respectively. It could be also seen that nss sulfate associated with fine size fraction accounted for about 90 wt% of that associated with PM_{10} . That is, the majority of sulfate were non sea salt sulfate and contained in fine particles. Thus, though Jeju City are located in coastal area, the contribution of sea salts to sulfate, especially in fine particles, was small. Similar high numbers, above 90%, had been

reported for fine particles at site of Gosan (Kosan) located at the western edge of Jeju Island. Kim, et al.⁶⁾ also reported that non sea salt sulfate in PM2.5 was about 75% of that in TSP at Gosan site during summer of 1994. Arimoto et al.¹⁰⁾ reported that the contribution of biogenic sulfur emissions to nss sulfate at Asia and the North Pacific sites was less than 11%. Thus, the contribution of biogenic emissions to nss sulfate at the sites is likely to be small. Since anthropogenic emission sources and ambient concentration of SO₂ at the sites are low, it can be concluded that most sulfate measured at both sites during this period should be transported out of the sites.

PM2.1 sulfate concentrations ranged from 2.43~3.99 (3.36 on average) $\mu\text{g}/\text{m}^3$ at Site M and 2.44~5.12 (3.70) $\mu\text{g}/\text{m}^3$ at Site U. Average PM2.1 nitrate and ammonium concentrations ranged from 0.58~1.86 (1.25) and 0.09~1.59 (1.05) $\mu\text{g}/\text{m}^3$ at Site M and 0.49~1.79 (1.14) and 0.13~2.01 (1.05) $\mu\text{g}/\text{m}^3$ at Site U, which are less than 50 % of PM2.1 sulfate concentrations. Nitrate, sulfate, and ammonium constituted 20~50 % of the PM2.1 mass and 10~40 % of the PM10 mass at both sites but these values were reduced during the springtime.

In the PM2.1 particles, the abundance of sea salt components were less than ~10 %, and ammonium and nitrate concentrations were less than half of the sulfate concentrations. The average equivalent ratio of NH₄⁺ to nss-SO₄²⁻ in the PM2.1 particles was approximately 0.86 at Site M and 0.77 at Site U, indicating that nss-SO₄²⁻ is not completely neutralized by NH₄⁺ due to the high concentrations of SO₄²⁻ in the PM2.1 particles rather than the weak source strength of NH₃. Thus ammonium containing particles at Jeju City could be in the form between (NH₄)₃H(SO₄)₂ and (NH₄)₂SO₄ but not with NO₃⁻.¹⁵⁾ In the coarse particles, these equivalent ratios were 1.03 at Site M and 0.90 at Site U, respectively. The average equivalent ratio of NH₄⁺ to the sum of nss-SO₄²⁻ and NO₃⁻ were 0.38 at Site M and 0.34 at Site U, respectively. The abundance of sea salt components were larger in the coarse particles than in the fine particles. These results suggest two possible ways that NH₃ neutralizes the sulfuric acid in the fine mode or NO₃⁻ in the coarse

mode can be mainly generated by the reactions between HNO₃ and/or NO₂, and sea salt. Many investigators^{16~18)} reported the possibility that ammonium and sulfate associated with the fine size fraction are in the form of (NH₄)₂SO₄ aerosol, which are associated with the fine particle size range below 2 μm . It is known that, in the atmosphere, NO_x and SO₂ gases react with ammonia gas to form NH₄NO₃, NH₄HSO₄, and (NH₄)₂SO₄ aerosol, which favor the less than 1 μm fine particle size. These acidic gases can react with sea salt particles to form NaNO₃ and Na₂SO₄ aerosol, which are associated with the coarse particle size range 3-4 μm .

Fig. 3 showed the trend of the molar ratio of nss sulfate to nitrate (nss-SO₄²⁻/NO₃⁻) with sampling time. In the fine particles, it tended to decrease from the wintertime to the springtime and then began to increase until the summertime, whose bottom appeared on April. Park et al.¹⁹⁾ reported that the average molar ratio of nitrate to nss sulfate (NO₃⁻/nss-SO₄²⁻) in TSP measurement data of Gosan site, Jeju Island between 1992 and 1999 was highest in March and then began to decrease slightly until August. Lee et al.¹⁵⁾ recommended that this ratio could be used as an index to explain major sources of sulfur and nitrogen compounds in the atmosphere. They also reported that the mean nss sulfate to total nitrate (sum of the particulate NO₃⁻ and gaseous HNO₃ concentrations) was 2.77 at Gosan site, Jeju Island. If we assume that NO_x is largely emitted in the form of NO, molar ratio of SO₂ to NO_x emission in Jeju Island is about 0.4 and this value is much lower than the molar ratio of nss sulfate to nitrate in

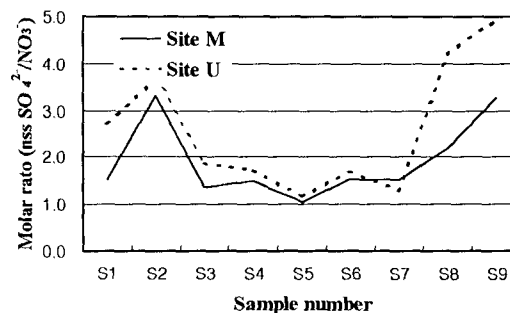


Fig. 3. Molar ratio of nss SO₄²⁻ to NO₃⁻ in the fine particles.

fine particles at Jeju City and Gosan. Therefore, the majority of nss sulfate and nitrate at Jeju City are likely from outside of Jeju Island. In general, the oxidation rate of NO_x to nitrate or HNO₃ is higher than that of SO₂ to sulfate, thus lowering the aerosol nss sulfate to nitrate ratio. Rapid dry deposition of HNO₃ would tend to increase the nss sulfate to nitrate ratio. The air in southern China is generally warmer and wetter than that in northern China and, thus the oxidation of SO₂ could be accelerated. It increases the ratio values. Based on the results of Park et al.¹⁹⁾ and Lee et al.¹⁵⁾, however, the ratio values at Jeju Island are continuously decreasing from 1992. This result suggests the existing of other nitrogen sources.

After subtracting sea salt fractions, the mean nss chloride concentrations in PM₁₀ showed negative concentration in Table 2. The cause of this result is suspected to the problem of sampling artifacts. Many investigators have reported that the aerosol collected in the marine environment are subject to sampling artifacts and may not accurately represent the actual composition. For instance, the evaporation of Cl⁻ to HCl can be occurred either in the atmosphere or in the filter, due to the interactions among Cl⁻, acidic gases, and alkaline sea salts. This process can result in negative concentration of nss Cl⁻.^{5,6,20,21)}

Thus, chloride ions tend to evaporate to form gaseous HCl, resulting in negative concentration of nss Cl⁻. Table 2 also showed that the mean concentrations of ammonium associated with fine size fraction were higher than those associated with coarse size fraction. The reason for this result might be sampling artifacts associated with sea salt fraction in aerosol. Ammonium and nitrate can also experience the same kinds of sampling artifacts. Ammonium in the particles may evaporate due to the high alkalinity of sea salt. It is also well known that the measured nitrate concentrations in marine environment were generally higher than the actual one due to the interactions between gaseous HNO₃ and NO₂ and alkaline sea salts in the particle phase.^{1,6,22)} When aerosol and sea salt collide either in the ambient air or on the filter, aerosols might be neutralized by either the adsorption of acidic gaseous species to alkaline aerosol or the evaporation of volatile alkaline species such as ammonium.⁶⁾ Wolff et al.²³⁾ also reported that all of ammonium was in fine particles. Thus, concentrations of Cl⁻, NO₃⁻ and NH₄⁺ measured in this study might contain sampling artifacts owing to reactions with sea salts.

In general, the contributions of Ca²⁺, K⁺ and Mg²⁺ to the concentration of total water soluble species were very small during this sampling

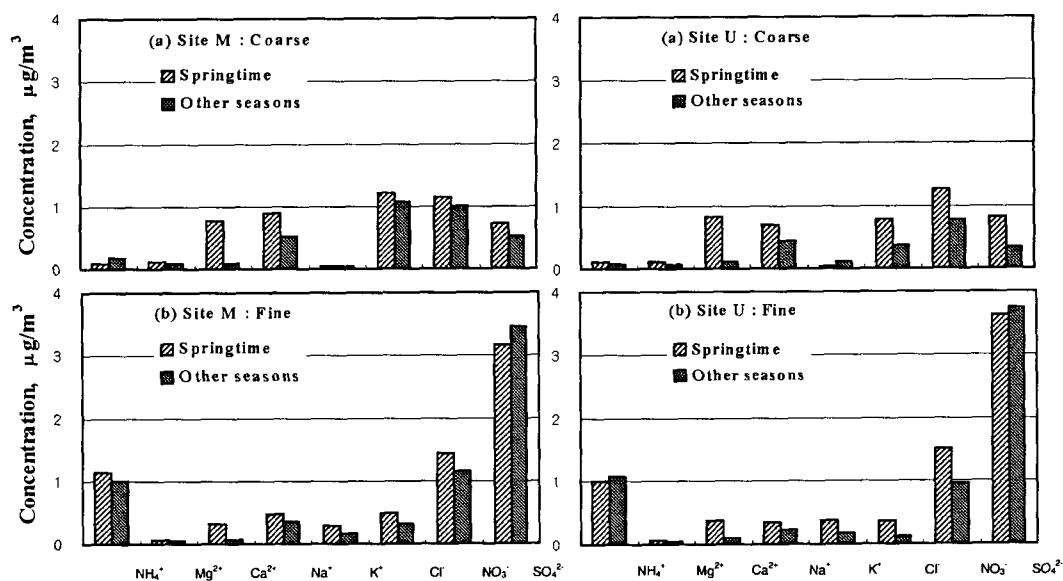


Fig. 4. The Comparison of the concentrations of water soluble ions between the springtime and other seasons.

period.

Fig. 4 showed the comparison of the concentrations of water soluble ions between the springtime and the other seasons. Associated with the fine size fraction, the concentrations of Mg^{2+} , Ca^{2+} , Na^+ , K^+ , Cl^- and NO_3^- had a tendency to increase during the springtime rather than the other seasons. Especially, the calcium concentrations during the springtime were larger ~ 5.0 (5.5 at Site M and 4.3 at Site U) times than those during the other seasons. However, the springtime sulfate and ammonium concentrations associated with the fine size fraction were slightly lower than those during the other seasons. Associated with the coarse size fraction, with the exceptions of potassium and ammonium, all the chemical species were elevated during the springtime. The calcium concentrations associated with the coarse size fraction were also increased up to 8 times relative to the other seasons. The highest concentration of calcium was measured in the springtime on 3/17/2000-3/31/2000 period. Potassium and ammonium had a tendency to decrease in their concentrations during the springtime. It can be seen that the PM10 sulfate concentrations during the springtime at Jeju City were almost the same as those during the other seasons.

Previous measurements for chemical composition of TSP at the other large cities in Korea such as Seoul, Busan and Kwangju showed no the significant differences of chemical composition of aerosol between Asian Dust period (spring-

time) and normal period while, the concentrations of F^- , SO_4^{2-} and Ca^{2+} during the springtime were higher than those of the normal period.²⁴⁾ Jang¹²⁾ reported that significant differences in concentrations of Cl^- , NO_3^- and NH_4^+ were not observed but the concentrations of Ca^{2+} , Na^+ , and K^+ appeared to be 2 fold differences between Asian Dust period and normal period. Shin et al.²⁷⁾ also reported that during the Asian Dust period, Cl^- , SO_4^{2-} , Ca^{2+} and Mg^{2+} were elevated in the size range of 2.1-7.0 μm , while there were no significant differences in the concentration of F^- and NO_3^- between both periods. Lee et al.²⁵⁾ reported that the size distributions of Cl^- , NO_3^- and SO_4^{2-} appeared to be as coarse mode but in the cases of F^- and NH_4^+ as fine mode.

3.3. Enrichment Factors

In order to identify the extent to which water and mineral aerosol influence the composition of aerosol at Jeju City, aerosol enrichment relative to seawater and crustal materials based on ratios with sodium and calcium, respectively, were calculated. The enrichment factor, which is defined as $(X/Na)_{aerosol}/(X/Na)_{seawater}$ and $(X/Ca)_{aerosol}/(X/Ca)_{crust}$, is widely used.^{4,9,26)}

Table 3 showed the enrichment factors relative to seawater and the composition of soil material in the source regions of Asian dust. Based on the enrichment factors relative to seawater, the fine particles at Jeju City was enriched in calcium, potassium, and sulfate, indicating that these species are not originating

Table 3. Enrichment factors for various species

Site	Size	Period	Relative to Seawater					Relative to Crust						
			Mg^{2+}	Ca^{2+}	K^+	Cl^-	SO_4^{2-}	NH_4^+	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
Site M	COARSE	Total	1.4	11.0	2.4	1.0	3.8	491.3	2.1	5.4	0.7	2246.0	1900.2	1047.9
		Springtime	1.2	21.9	1.2	0.7	3.2	28.4	0.5	1.5	0.1	395.8	388.6	233.0
		Other seasons	1.5	5.6	3.0	1.1	4.1	722.7	3.0	7.3	1.0	3171.1	2656.1	1536.8
	FINE	Total	1.3	8.8	14.0	0.5	40.6	4203.7	2.2	6.0	3.5	998.3	4365.6	12520.5
		Springtime	1.3	18.0	16.5	0.6	29.2	884.0	0.7	1.9	1.4	375.9	1145.9	2469.4
		Other seasons	1.3	4.2	12.8	0.5	46.2	6195.6	3.0	8.0	4.6	1309.5	5975.4	17546.1
Site U	COARSE	Total	1.4	16.8	5.3	0.6	4.4	131.1	1.7	5.0	1.4	845.3	2278.1	715.7
		Springtime	1.4	36.0	1.3	0.7	5.3	33.2	0.4	1.0	0.1	227.8	384.7	244.8
		Other seasons	1.3	7.3	7.3	0.5	3.9	204.5	2.4	6.9	2.1	1154.0	3224.9	951.2
	FINE	Total	1.6	15.7	27.3	0.4	72.3	4491.6	1.4	3.0	4.0	375.3	3581.4	12414.1
		Springtime	1.7	29.2	30.1	0.6	44.6	673.8	0.5	1.2	1.6	247.2	1012.2	2416.4
		Other seasons	1.6	9.0	25.9	0.3	86.1	6782.2	1.9	3.9	5.2	439.4	4866.0	17412.9

from the sea. However, the values of enrichment factors for potassium and sulfate were relatively low in the coarse particle fraction rather than in the fine particles. From this result, these two species contained in the coarse particles are likely to originate from sea salts. In the case of calcium, the values of enrichment factors were increased during the springtime, without regard to the particle sizes and the sampling sites. This result suggests that the particulate calcium is associated with the mineral dust at the source regions of Asian Dust. In the case of chlorine, the values of enrichment factors were generally lower than unity, suggesting more active chlorine releasing gas-solid reactions.

Sulfate, nitrate, chloride and ammonium showed enrichments relative to crustal composition, which indicate that these species are not originating from the soils. During the springtime, however, the values of enrichment factors for these species were lower than those during other seasons.

4. Summary

A field study was carried out from Dec. 1999 to Aug. 2000 at Jeju City, Jeju Island, by using an eight-stage cascade impactor.

The ambient aerosol concentrations measured at Jeju City were generally very low. The mass fraction of sea salt components in the coarse particles was far higher than that in the fine particles.

In the fine particles, the majority of sulfate were non sea salt sulfate and concentrated in the fine particles. Based on the results of nss sulfate fraction and ratio of nss sulfate to nitrate, the majority of sulfate and nitrate were likely from outside of Jeju City. The non sea salt SO_4^{2-} was not completely neutralized by NH_4^+ due to the high concentrations of SO_4^{2-} in the $\text{PM}_{2.1}$ particles. In the fine particles, the concentrations of Na^+ , K^+ , Mg^{2+} , Ca^{2+} , Cl^- and NO_3^- had a tendency to increase during the springtime rather than the other seasons. Especially, the calcium concentrations during the springtime were larger ~ 5.0 times than those during the other seasons. However, the springtime sulfate and ammonium concentrations in the fine particles were slightly lower than those during the other seasons. On the other hand, associated with the coarse particles, with the exceptions of

potassium and ammonium, all the ionic species were elevated during the springtime. The calcium concentrations associated with the coarse size fraction were increased up to 8 times relative to the other seasons.

From the results of enrichment factors, the fine particles at Jeju City was enriched in calcium, potassium and sulfate, indicating that these species were not originating from the sea. However, potassium and sulfate in the coarse particles are likely to originate from sea salts. During the springtime, the values of enrichment factors of all the ionic species relative to crustal components were lower than those during other seasons.

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