

Characterisation of individual aerosol particles on moss surfaces: implications for source apportionment

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Received 6th January 2010, Accepted 9th February 2010

First published as an Advance Article on the web 26th February 2010

DOI: 10.1039/b926876f

The size, morphology and chemical composition of 8405 particles on moss surfaces (*Hylocomium splendens*) was investigated by scanning electron microscopy and energy-dispersive X-ray microanalysis. Two moss samples from three locations in Southern Norway (Ålgård, Birkeland, Neslandsvatn) and two sampling years (1977 and 2005) each were selected leading to a total of 12 samples investigated. At all three locations, particle deposition decreased substantially with time. The major particle groups encountered include silicates, iron-rich silicates, metal oxides/hydroxides, iron oxides/hydroxides, carbonates, carbon-rich particles, silicate fly ashes, iron-rich silicate fly ashes, and iron oxide fly ashes. Between 1977 and 2005, the relative number abundance of the three fly ash groups decreased substantially from approximately 30–60% to 10–18% for the small particles (equivalent projected area diameter <1 µm), and from 10–35% to 2–9% for large particles with diameters ≥1 µm. This decrease of fly ash particles with time was overlooked in previous papers on atmospheric input of pollutants into ecosystems in Southern Norway. In general, the presence of fly ash particles is ignored in most source apportionment studies based on bulk chemical analysis. Consequently, the geogenic component (crustal component) derived from principal component analysis is overestimated systematically, as it has a similar chemical composition as the fly ash particles. The high abundance of fly ashes demonstrates the need to complement source apportionment based on bulk chemistry by scanning electron microscopy in order to avoid misclassification of this important anthropogenic aerosol component.

1. Introduction

Moss growing on the ground is a convenient and frequently used substrate for monitoring atmospheric deposition of metals.^{1–3} Mosses have two advantages over conventional precipitation sampling for atmospheric deposition studies.⁴ First, metals are strongly concentrated in the moss compared to their usually very low levels in precipitation, where analytical detection limits are often inadequate and contamination during sampling and pre-analysis often represents a problem. Second, the simple and cheap sampling procedure employed in moss surveys allows a very large number of sites to be included in the same survey,

permitting detailed geographic deposition patterns of the elements studied. Concentrations in moss give a good relative picture of the atmospheric deposition of many elements, and the results can be successfully calibrated against bulk deposition data.^{5,6} The part of the moss plant taken for analysis corresponds to the last three years growth, which defines the exposure period. Moss samples are now used on a regular basis for monitoring atmospheric deposition of metals on the European scale.^{7–9}

In Norway this approach has been used since 1976.¹⁰ Nationwide surveys employing around 500 sites were carried out in 1977 and every five years since 1985, most recently in 2005.¹¹ After drying and removal of conifer needles and other foreign material the samples were analysed by neutron activation analysis/atomic absorption spectrometry (1977 and 1985, about 25 elements) or ICP mass spectrometry (since 1990, 40–50 elements) after microwave-assisted decomposition with 14 M HNO₃. The data were subjected to principal component factor analysis,^{6,12,13}

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Environmental impact

The atmospheric input of inorganic pollutants into ecosystems is often monitored by bulk chemical analysis and using moss surfaces as sampling substrate. Factor analysis is applied to the compositional data to derive different pollution sources. In the present contribution it is shown that this approach fails to differentiate between natural soil components and anthropogenic fly ashes. Using scanning electron microscopy and X-ray microanalysis it is found that a major fraction of silicate and iron oxide/hydroxide particles collected at three locations in Southern Norway are fly ashes which were misclassified in previous work as geogenic component. Our study clearly demonstrates that source apportionment of atmospheric aerosols based on bulk chemical analysis should be complemented by electron microscopical characterization of individual particles.

which showed that the largest part of the variance is explained by only two factors. One shows high loadings for Zn, Cd, Sb, Pb, As, Mo, and V, particularly in the southern part of the country, and is ascribed to long-range atmospheric transport of pollutants (LRTPs) from other parts of Europe.^{2,12} The other is interpreted as a geogenic (crustal) component characterized by high loadings for Na, Al, Fe, and trace elements such as Cr, Th, Sc and rare-earth elements, and has so far been interpreted as contribution from windblown dust of local origin. The relative weight of the second factor has increased over time.

Recently, the time trends for elements included in all six nationwide moss surveys were investigated.¹¹ Elements characteristic for the LRTP component show a strong and steady decline with time, particularly in the southern part of the country. This time trend clearly shows the success of introducing emission control strategies for atmospheric pollutants. In the southernmost part of the country where the samples studied in the present work had been collected, the Pb deposition in 2005 was only about 6% of that in 1977. Also for other elements related to the LRTP component, the deposition in 2005 in this area was less than 20% of the corresponding 1977 value.

Interestingly, the second component also shows a strong decline with time. For example, the Fe concentrations decreased by more than a factor of two when the years 2005 and 1976 are compared. An even stronger decline for Fe, as well as for other elements such as Al, Sc, and lanthanides traditionally ascribed to geogenic sources, was observed in the corresponding Swedish moss studies.¹⁴ These observations indicate that at least part of the so-called geogenic factor might be derived from anthropogenic sources as for example fly ashes from coal burning.

We, therefore, decided to study individual particles deposited on moss surfaces by scanning electron microscopy (SEM) and energy-dispersive X-ray microanalysis (EDX). This technique was shown to yield valuable information for assigning particles to specific sources.^{15–18} There are only few applications of SEM-EDX to plant surfaces. Most of them are related to local pollution studies employing tree bark,^{19,20} lichen or moss transplants deployed in the vicinity of smelters,^{21,22} or native moss samples collected near smelters.²³

The particle morphology is an important parameter for recognition of some particle groups including fly ashes, primary biological particles and soot. Anthropogenic fly ashes are overlooked in most source apportionment studies based on bulk chemical analysis. In these studies, a geogenic (crustal) component (characterized by high loadings for Si, Al, Fe, REE) is derived from factor analysis. Interestingly, the possibility that the so-called crustal component may consist of a significant fraction of fly ashes (*e.g.*, from coal burning) was discussed in detail in one of the first studies applying factor analysis to the bulk chemical composition of atmospheric aerosols.²⁴ Unfortunately, this point got lost in most subsequent work. In the present contribution we want to demonstrate the need to complement bulk analysis techniques by electron microscopy to obtain accurate estimates for the different source contributions.

2. Experimental

The size (equivalent projected area diameter), morphology and chemical composition of 8405 particles on moss surfaces

(*Hylocomium splendens*) were studied by high-resolution scanning electron microscopy and energy-dispersive X-ray microanalysis. We selected two moss samples from three locations in Southern Norway (Ålgård, Birkeland, Neslandsvatn) and two sampling years (1977 and 2005) each, leading to a total of 12 samples investigated. The sampling locations are shown in Fig. 1. The sites were selected to represent the distance from the coast where the deposition of LRTP has a maximum in each case. The years 1977 and 2005 were chosen to increase the probability of obtaining a statistically significant difference in the fly ash particle abundance.

All analyses were carried out with a field emission gun environmental scanning electron microscope (FEI ESEM Quanta 200 FEG, Eindhoven, The Netherlands) operated at 25 kV accelerating voltage. The size (equivalent projected area diameter) of the individual particles was obtained from secondary electron images. The chemical composition (elements with $Z \geq 5$) of the particles was determined by energy-dispersive X-ray microanalysis using a Si(Li) detector (EDAX, Tilburg, The Netherlands) and a counting time of 20 seconds per particle. The moss surface was studied without coating at a sample chamber pressure of approximately 1 mbar ($P_{\text{total}} = P_{\text{H}_2\text{O}}$). The particle characterization was carried out operator-controlled, as movements of the substrate (moss surface) under electron bombardment prevented the use of automated analysis procedures.

Based on the chemical composition and morphology, the particles were assigned to nine different groups. The particle classification was performed with net X-ray count rates, *i.e.*, matrix and geometric effects were not corrected for. Criteria for the definition of the particle groups are summarized in Table 1. It should be emphasized here that net X-ray count rates are sufficient for classification of particles into the different groups



Fig. 1 Sampling locations.

shown in Table 1. Quantification of the particle composition prior to classification would not lead to different particle groups.

3. Results

At all three locations, a much higher concentration of particles is found on the moss surface of samples collected in 1977 compared to samples from the year 2005. A typical example is shown in Fig. 2. Although not leading to a quantitative estimate, this figure illustrates the substantial reduction of particle deposition with time.

Typical secondary electron images and energy-dispersive X-ray spectra of the different particle groups are shown in Fig. 3. Fly ash particles can be easily and unequivocally recognized by their characteristic spherical morphology (Fig. 3a, c and e). Based on the elemental composition, three groups of fly ashes are distinguished (Table 1). Silicate fly ashes are dominated by the elements Si, Al and O (Fig. 3b), iron-rich silicate fly ashes also contain high amounts of Fe (Fig. 3d). Iron oxide fly ashes basically consist of iron and oxygen as major elements (Fig. 3f). The strong C-K α X-ray peak in the spectra originates from excitation of the substrate (moss). The three particle groups of silicates, iron-rich silicates and iron oxides/hydroxides have a similar elemental composition as the respective fly ash groups, but lack the spherical morphology (Fig. 3g and i). The group of carbonaceous particles is dominated by primary biological particles which can be recognized by their morphology (Fig. 3i), and in some cases by characteristic minor elements such as P or K. Soot, frequently observed as abundant particle group in long-range transport aerosols,^{15,25,26} is not observed.

The absolute particle number abundance of the different groups encountered is displayed in Table 2 for the two size ranges of <1 μm and $\geq 1 \mu\text{m}$ geometric diameter. The relative number abundance of the different particle groups is shown in Fig. 4. At all three locations, the relative number abundance of fly ash particles (silicate fly ash, iron oxide fly ash, iron-rich silicate fly ash) decreases substantially in both size intervals, if the year 1977 is compared to the year 2005 (Fig. 4). In 1977, the relative number abundance of fly ash particles varies at the three locations

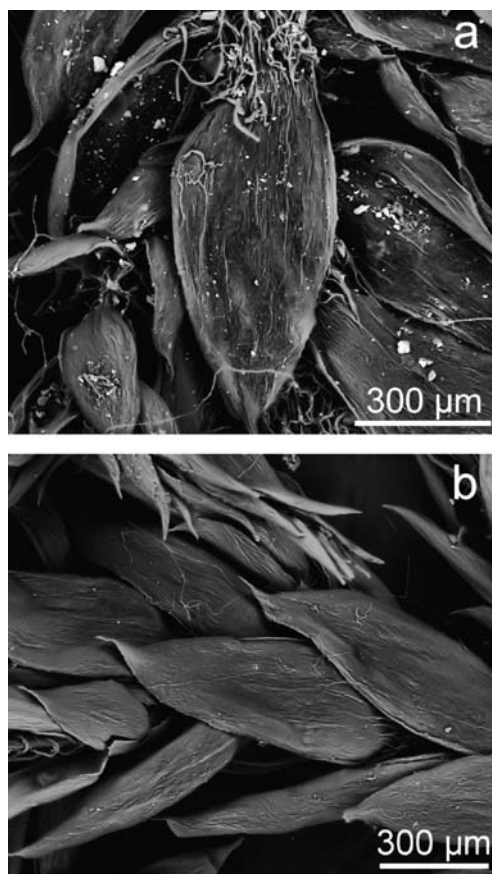


Fig. 2 Secondary electron images of moss surfaces sampled in Birkeland in 1977 (a) and 2005 (b) illustrating the substantial reduction of particle deposition with time.

between approximately 30 and 60% for the small particles (<1 μm), and between approximately 10 and 35% for the large particles ($\geq 1 \mu\text{m}$). In 2005, the relative number abundance of fly ash particles is much lower: approximately 10–18% for the small and about 2–9% for the large particles. As the fly ash component is reduced significantly, the relative abundance of the other particle groups must increase because percentages are closed data. The relative proportions of the non-fly ash particle groups seem to be more or less constant, indicating a significant local contribution from geogenic sources such as agriculture, stone quarries, etc.

4. Discussion

Our investigations clearly show that at all three locations anthropogenic fly ashes are a major component of the particles deposited on the moss surface. In addition, a substantial reduction of the relative abundance of fly ashes was observed between 1977 and 2005. It is important to keep in mind that the absolute number of particles also decreased. As the size-resolved particle number concentrations are not known, it is impossible to calculate the reduction of the fly ash particle mass. Still, our hypothesis that the so-called geogenic component derived from

Table 1 Criteria for definition of particle groups

Particle group	Classification criteria
Metal oxides/hydroxides	O plus one or more of the following elements as major element: Ti, Cr, Mo, Mn, Cu, Sn, Zn, Al
Iron oxides/hydroxides	Fe and O as major elements
Carbonates	Ca, C and O as major elements, sometimes also Mg
Silicates	Si, Al and O as major elements
Carbon-rich particles	C as major element, typical morphology and/or minor elements of biological particles (no soot morphology)
Iron-rich silicates	Fe, Si, Al and O as major elements
Iron-rich silicate fly ash	As for iron-rich silicates plus spherical morphology
Iron oxide fly ash	As for iron oxides/hydroxides plus spherical morphology
Silicate fly ash	As for silicates plus spherical morphology

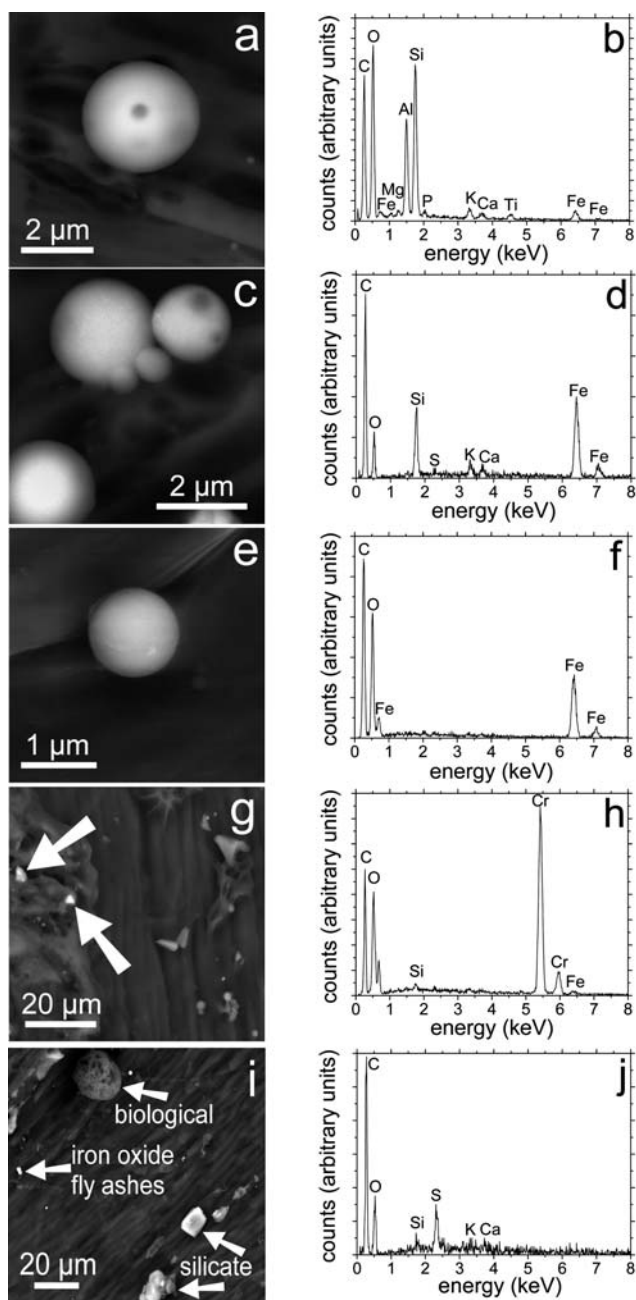


Fig. 3 Secondary electron images and energy-dispersive X-ray spectra of different particle groups: (a and b) silicate fly ash; (c and d) iron-rich silicate fly ash; (e and f) iron oxide fly ash; (g and h) metal oxides (chromium oxide); (i) several particle groups; (j) X-ray spectrum of biological particle.

principal component analysis of bulk chemical data contains a significant anthropogenic fraction is confirmed.

For an exact quantitative comparison of the absolute number abundances of the different particle groups with bulk measured element concentrations it would be desirable to group the studied particles in more than two size intervals. However, as the number of particles on the moss surface was limited (especially for the samples collected in 2005), only two size ranges ($<1 \mu\text{m}$ and $\geq 1 \mu\text{m}$) were defined for statistical reasons. These two size ranges

represent approximately 50% of the total particle mass each. As a substantial decrease was observed in both size intervals, our general conclusion that the mass of fly ash particles decreased substantially with time is valid. It should be mentioned here again, that a quantitative comparison of the particle data with bulk chemical measurements would also require an independent determination of the size-resolved particle number concentrations. For both sampling years, such data are not available retrospectively.

In the present paper, it is not intended to establish time trends or spatial trends of atmospheric deposition of pollutants into ecosystems of Southern Norway. This goal was reached in previous publications^{2,3,6,11,13} describing the results of moss monitoring carried out over a time period of 28 years. We decided to study only samples from the years 1977 and 2005, as there is a continuous decrease of Fe and other elements of the geogenic component. Consequently, the difference in fly ash particle abundance can be expected as well to be largest for these two sampling years.

It is important to note that the decrease in Fe and other elements of the geogenic component with time is steady without any step between the different sampling years. Therefore, it can be concluded that the use of different sample preparation and bulk analysis techniques (INAA and AAS in the years 1977 and 1985; ICP-MS since 1990) has no significant influence on the bulk measured element concentrations, and element recoveries seem to be large (even for elements contained in oxides and silicates).

The major point of the present contribution is to demonstrate the need to supplement bulk chemical measurements by scanning electron microscopy in order to ensure accurate source apportionment. This is not only true for the distinction between fly ashes and natural soil particles but also for the detection of primary biological particles, a component also frequently overlooked in bulk chemical measurements.²⁷

In previous applications of principal component analysis in the nationwide moss studies in Norway,^{6,12,13} the component assigned to long-range atmospheric transport of pollutants, typically exhibiting high loadings for elements such as V, Zn, As, Se, Mo, Ag, Cd, Sn, Sb, Tl, Pb, and Bi, invariably showed low values for Fe. In contrast, data²⁸ from studies of daily aerosol samples at Birkenes, southern Norway, during 1978–1979 showed a significant association of Fe with the L RTP component (but also with the geogenic component), whereas this association was not evident during the period 1985–1986. The 1985–1986 median concentration of Fe in air at Birkenes had declined by 30% compared to the 1978–1979 values. A similar strong (41%) decrease of Fe in moss was reported²⁹ for Austria over the period 1991–2005. This decrease was comparable to that of V and Cd, but substantially less than the 70–75% observed *e.g.* for As and Pb.

Evidently, the air concentrations of Fe in large parts of Europe have decreased substantially during recent decades, but the principal component analysis appears generally not able to detect an unequivocal association of Fe with pollution aerosols. To improve the potential of PCA to do so in the case of the 1977 and 2005 moss datasets from Norway, the analysis was repeated for the approximately 50% of the sites located south of the 62° N latitude, excluding a few samples obviously affected by local point sources. The resulting factor loadings (rotated

Table 2 Absolute particle number abundance of the different groups

Particle group	Ålgård 1977 <1 µm	Ålgård 1977 ≥1 µm	Ålgård 2005 <1 µm	Ålgård 2005 ≥1 µm
Metal oxides/hydroxides	14	17	13	6
Iron oxides/hydroxides	13	17	40	31
Carbonates	9	2	8	2
Silicates	173	230	64	52
Carbon-rich particles	34	34	20	11
Iron-rich silicates	27	36	33	27
Iron-rich silicate fly ash	47	66	4	2
Iron oxide fly ash	59	18	10	3
Silicate fly ash	165	106	13	2
Total	541	526	205	136

Particle group	Birkeland 1977 <1 µm	Birkeland 1977 ≥1 µm	Birkeland 2005 <1 µm	Birkeland 2005 ≥1 µm
Metal oxides/hydroxides	98	44	8	4
Iron oxides/hydroxides	34	13	17	10
Carbonates	0	0	3	7
Silicates	625	269	205	144
Carbon-rich particles	171	76	26	21
Iron-rich silicates	119	129	24	33
Iron-rich silicate fly ash	619	108	7	0
Iron oxide fly ash	283	31	9	2
Silicate fly ash	591	68	41	4
Total	2540	738	340	225

Particle group	Neslandsvatn 1977 <1 µm	Neslandsvatn 1977 ≥1 µm	Neslandsvatn 2005 <1 µm	Neslandsvatn 2005 ≥1 µm
Metal oxides/hydroxides	19	19	9	8
Iron oxides/hydroxides	25	32	4	6
Carbonates	3	4	17	5
Silicates	650	728	278	138
Carbon-rich particles	55	55	30	21
Iron-rich silicates	125	265	28	19
Iron-rich silicate fly ash	74	22	3	4
Iron oxide fly ash	46	9	4	2
Silicate fly ash	328	75	34	10
Total	1325	1209	407	213

component matrix, varimax rotation) and the variance explained by the different components are shown in Tables 3 and 4.

In 1977, the first component explaining approximately 37% of the variance has high loadings for the elements Pb, Zn, Cd, Ni, Sb, As, Se and is interpreted as the LRTP component. Fe is not associated with this component (Table 3). The second component (explaining approximately 15% of the variance) has high loadings for Na, Al, REE, Th, Sc, Fe and represents geogenic sources. The third component with high loadings for Cl, I, and Br is interpreted as marine component. In 2005 (Table 4), the geogenic component is now explaining the largest fraction of the variance (about 46%). The influence of long-range transport of pollution is reduced compared to the year 1977, but two different sources can be distinguished. The second component (explaining about 8% of the variance) has high loadings for Cr, Ni and Fe and most likely originates from metallurgical processes. The third component with high loadings for Cd, Sb and Pb represents a traffic source. The marine component observed in 1977 cannot be detected in 2005 due to the change of analytical techniques. However, it is likely that a marine component is also present in 2005.

According to PCA, the element Fe is associated mainly with the geogenic component in 1977. In contrast, in the year 2005 this element originates from two different sources: a geogenic source as well as metallurgy. It is surprising to identify a clear industrial source for Fe in 2005, as the extent of pollution has decreased substantially. For both years, however, the fraction of atmospheric deposition associated with fly-ash particles is not recognised in PCA.

Besides studying the atmospheric input of pollutants into ecosystems, source apportionment of atmospheric aerosols is also important in urban air pollution studies. As the concentration of particulate matter seems to be correlated with a number of adverse health effects,^{30,31} source apportionment of atmospheric aerosols has found considerable attention in this context. All meaningful reduction strategies rely on an accurate determination of the different source contributions. There is a vast number of publications that apply factor analysis to the results of bulk chemical measurements of urban aerosol composition^{24,32–35} in order to determine different source categories as for example traffic, metallurgical industry, coal combustion, crustal material and sea salt. However, besides a few exemptions^{24,36} most of these studies do not address the

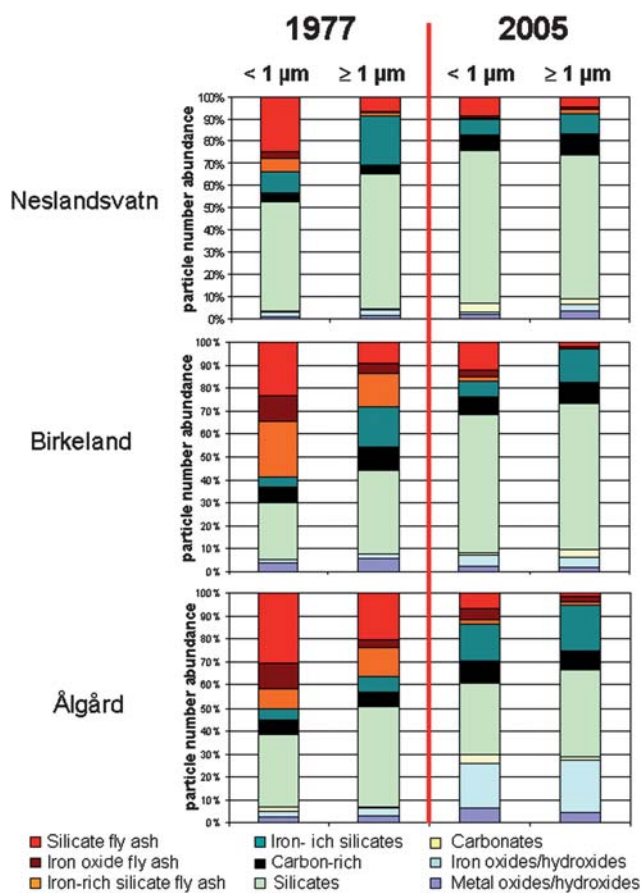


Fig. 4 Relative number abundance [%] of the different particle groups.

possible inclusion of fly ashes into the crustal component. The crustal component usually accounts for a large fraction of PM_{10} and is often assumed to be irreducible, as it is considered to be of natural origin.

According to numerous detailed electron microscopic investigations, however, fly ash particles were shown to be as a substantial compound of aerosols in urban, rural and industrialized areas. For example, a bimodal distribution of silicate particles was observed³⁷ in the downwind of Berlin (Germany), with the smaller particles (maximum at 0.3–0.5 μm equivalent projected area diameter) consisting predominantly of fly ashes and the larger particles (maximum at 1–2 μm diameter) predominantly of soil particles. In the urban Rhein-Main area (Germany) and adjacent rural areas a significant fraction of all silicate and transition metal oxide/hydroxide particles were fly ashes, although the contribution of local industry to PM_{10} is rather small in this area.^{18,25} In urban and industrial areas of Shanghai (China), fly ashes were found to be one out of two major $PM_{2.5}$ components.³⁸ In the Philadelphia (USA) area, the crustal component of the coarse particle fraction ($PM_{2.5}$ to PM_{10}) consisted of approximately 7–62 mass% fly ashes.³⁹ Even at Helgoland (Germany), a remote island in the North Sea some times influenced by polluted air masses from the continent, almost all Fe-rich particles and up to 16% of the silicate particles were fly ashes.¹⁵ These examples clearly demonstrate that assuming the so-called crustal component to be of natural origin is often not correct. We thus recommend that source apportionment based on bulk chemical techniques or even single particle mass spectrometry is complemented by scanning electron microscopy (at least on a sub-group of the samples).

Table 3 Principal component analysis for moss samples from 1977. Factor loadings and explained variance for the first five principle components

Element	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Comp. 5
Na	-0.118	0.834	0.181	0.229	-0.093
Cl	0.290	0.324	0.619	0.026	0.002
V	0.388	0.063	0.227	0.688	0.046
Al	0.132	0.849	0.042	0.335	0.050
Mn	-0.162	-0.206	-0.290	0.158	0.570
I	0.187	0.040	0.791	0.122	-0.071
Pb	0.872	0.071	0.226	0.161	0.185
Zn	0.795	0.109	0.041	0.168	0.154
Cu	0.549	0.186	0.127	0.090	0.123
Cd	0.850	0.035	0.144	0.041	0.007
Ni	0.739	0.124	0.119	0.334	0.073
Mo	0.668	0.239	0.193	-0.137	-0.162
Br	0.251	0.119	0.824	0.040	-0.245
Sb	0.826	0.076	0.400	0.176	0.128
As	0.789	0.118	0.346	0.208	0.176
La	0.146	0.768	-0.036	-0.142	-0.075
Sm	0.208	.909	0.044	0.022	0.015
Th	0.100	0.711	0.296	-0.031	0.190
Se	0.709	0.048	0.524	0.205	-0.012
Cr	0.291	0.445	0.376	0.295	-0.067
Ag	0.561	0.036	-0.175	-0.069	-0.260
Cs	0.121	0.098	0.057	-0.055	0.735
Sc	0.132	0.795	0.093	0.429	0.049
Rb	0.279	0.068	-0.186	-0.105	0.780
Fe	0.143	0.641	0.129	0.687	0.002
Co	0.204	0.434	-0.028	0.645	-0.147
Variance	36.6%	15.3%	8.5%	5.1%	4.8%

Table 4 Principal component analysis for moss samples from 2005. Factor loadings and explained variance for the first five principle components

Element	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Comp. 5
Li	0.615	0.553	0.035	0.091	0.108
Be	0.499	-0.152	0.096	0.095	-0.147
B	0.111	-0.013	0.216	0.862	0.041
Mg	0.197	0.149	0.267	0.384	0.038
Al	0.535	0.493	-0.085	0.613	0.046
Ca	0.162	0.094	0.263	0.397	0.027
Sc	0.720	0.657	-0.061	0.063	0.053
Ti	0.743	0.582	0.023	0.083	0.011
V	0.537	0.694	0.247	0.131	0.082
Cr	0.530	0.768	0.097	0.114	0.050
Mn	0.055	-0.016	0.098	-0.081	0.131
Fe	0.703	0.677	0.023	0.087	0.033
Co	0.509	0.578	0.190	0.105	0.008
Ni	0.307	0.709	0.301	0.089	0.077
Cu	0.118	0.139	0.186	0.862	0.055
Zn	0.060	0.075	0.631	0.001	0.042
Ga	0.732	0.600	0.049	0.215	0.062
As	0.347	0.096	0.233	0.099	0.809
Rb	0.109	-0.059	0.119	-0.040	-0.026
Sr	0.021	0.113	-0.028	0.799	-0.081
Y	0.981	0.088	0.066	0.048	0.041
Zr	0.723	0.079	0.431	0.131	0.093
Nb	0.664	0.004	0.368	0.076	-0.395
Mo	0.176	0.104	0.404	0.074	0.758
Rh	0.076	0.259	0.398	0.341	-0.529
Ag	0.108	0.089	0.133	0.000	0.901
Cd	0.063	0.014	0.778	0.099	0.166
Sb	0.118	0.109	0.830	0.098	0.074
Cs	0.087	0.048	0.080	0.043	0.059
Ba	0.071	0.200	-0.070	0.176	-0.029
La	0.951	0.188	0.117	0.089	0.056
Ce	0.953	0.205	0.096	0.078	0.059
Pr	0.954	0.234	0.076	0.069	0.050
Nd	0.953	0.243	0.065	0.065	0.048
Sm	0.965	0.207	0.067	0.065	0.050
Eu	0.709	0.434	-0.016	0.110	-0.047
Gd	0.956	0.250	0.059	0.059	0.065
Tb	0.966	0.193	0.048	0.048	0.072
Dy	0.981	0.107	0.059	0.044	0.053
Ho	0.981	0.103	0.051	0.060	0.022
Er	0.979	0.152	0.051	0.043	0.024
Tm	0.978	0.116	0.046	0.035	0.029
Yb	0.979	0.128	0.043	0.039	0.051
Lu	0.907	0.201	0.043	0.026	0.226
Ta	0.047	0.199	0.120	0.009	-0.235
W	0.315	0.147	0.407	0.141	0.141
Pt	0.222	-0.152	0.335	-0.011	0.072
Hg	0.036	0.163	.156	-0.007	-0.040
Tl	0.037	0.062	0.025	-0.028	0.053
Pb	0.086	0.118	0.733	0.144	0.179
Bi	0.057	-0.065	0.163	0.083	0.044
Th	0.928	-0.047	0.161	0.047	0.130
U	0.847	0.148	0.143	0.070	0.127
Variance	45.9%	8.2%	6.7%	5.2%	4.2%

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