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CONTENTS

Preface

In this study, Vladimir Shevchenko summarizes the results of his comprehensive research on modern aeolian sedimentation in the Arctic Ocean, which has been carried out during the last about tens years. It is concentrating on investigations of the mineralogical and chemical composition as well as the grain-size distribution of aerosols and the interpretation in relation to particle transport and degree of anthropogenic pollution.

Major parts of the study were performed in close operation between the Shirshov Institute of Oceanology (IORAS) and the Alfred Wegener Institute (AWI). In this context, Vladimir Shevchenko visited several times the AWI to use the laboratory capacity at AWI. Several joint publications resulted from this past and still ongoing cooperation (e.g., Shevchenko et al. 1999, 2001, 2002, 2003; Shevchenko and Lisitzin, 2003; Smirnov et al. 1996).

R. Stein
Alfred Wegener Institute, Bremerhaven (August 2003)

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ABSTRACT

In this volume, the results of a comprehensive study of aerosols in the marine boundary layer over the seas of the Russian Arctic and the central part of the Arctic Ocean are presented. The investigations were carried out during 9 expeditions in 1991-1998. The mineral and chemical composition of aerosols, their particle-size distribution and transport ways, and the degree of anthropogenic pollution of the Arctic atmosphere were studied. A particular attention was paid to estimate horizontal and vertical fluxes of various components and to estimate the role of aerosols in the sedimentation. It has been shown that the quantitative distribution of aerosols in the Arctic is very variable and changing in time, which depends on the combination of many regional and local factors. Based on 55 measurements, average concentration of insoluble aerosols in the marine boundary layer over the Russian Arctic seas is equal to 0.23 $\mu g/m^3$ with a standard deviation of 0.19 $\mu g/m^3$. Results of measurements of aerosol particle-size distribution carried out with particle counters both *in situ* and in the laboratory, as well as the qualitative estimation of the particle sizes with a scanning electron microscope, have shown that submicron particles dominate in air, but sediments are mostly (in mass) formed by water-insoluble particles with sizes from 5 to 25 μm. According to the data of electron microscopy, coarse (>1 μm) non-salt particles of Arctic aerosols sampled by nylon mesh method, consist largely of mineral and organic matter (plant fibres, pollens, spores, diatom algae, etc.). Porous fly ash particles from 5 to 50 μm in size consisting mostly of carbon and smooth spheres from 0.5 to 10 μm in diameter, are also characteristic of the Arctic aerosol. These mostly anthropogenic particles were found in small amounts in most samples collected by nylon meshes. During all our expeditions, the content of anthropogenic particles in aerosols increased when approaching the Kola Peninsula or Norilsk. Thus, the study of the morphology of coarse (>1 μm) insoluble particles with an electron microscope indicates that the main source of the aeolian material over the Arctic seas in July-October is Eurasia, although in winter the contribution of far and very far (>10000 km) sources increases significantly. The study of mineral composition of Arctic aerosols has shown that it is characterised by strong spatial and temporal variability; in summer sources of aeolian material are situated both in the surrounding tundra and in large distance areas. In general, catastrophic pollution of the Arctic aerosols from the anthropogenic sources were not revealed in July-September. Based on geochemical studies we have succeeded in determination the main local pollution sources (Norilsk, Kola Peninsula). The balance calculations based on our data show that the contribution of aerosols to the formation of sedimentary material in the Arctic is close to the contribution of river sediments beyond the marginal filters of rivers (earlier the aeolian material in the Arctic was ignored). For many elements (Pb, Sb, Se, V etc.) the aerosol source is the primary one. Our experience shows that along with the thorough study of the aeolian material in the atmosphere, the systematic studies of lithology and geochemistry of snow cover, which lives in the central Arctic for 9-10 months, are necessary, since it is a natural collector of both dissolved and suspended aeolian material.

INTRODUCTION

The Arctic greatly influences on the environment of the Earth. Very fragile equilibrium between its physical, chemical and ecological parameters (depended on low rates of reduction of biological resources) makes the Arctic an indicator of the global change (Roederer, 1991; Bienfang and Ziemann, 1992; Kondrat'ev and Grassl', 1993; Kondrat'ev and Johannessen, 1993; Shaw, 1994; Vilchek et al., 1996; Gudkovich et al., 1997; Arctic .., 1997; Izrael', 1998).

Low temperatures and strong seasonality are typical features of the Arctic. It is reflected on the distribution and composition of aerosols and water suspended matter and on the sedimentation processes (Lisitzin, 1994). The central part of the Arctic is covered by ice the whole year; the shelf seas are covered by ice the most part of the year (Zakharov, 1996; Sea ice ..., 1997). The maximal river discharge (of Ob, Yenisey, Lena and others) takes place during 1-2 spring months (Telang et al., 1991; Gordeev et al., 1996). During this short time the main part of mineral suspended matter and allochtonous organic matter are delivered to the arctic seas (Gordeev et al., 1996). During of 2-3 months of ice-free seas the abrasion of shores is mostly active delivering much terrigenic suspended matter to the seas (Are, 1980; Kaplin et al., 1991). During the same time biological processes are also mostly active (Shirshov, 1937; Bogorov, 1938; Usachev, 1968; Smith and Sakshaug, 1990) that is connected with the maximum of solar radiation (Timerev, 1981; Andersen, 1989). Combination of maximal delivery of terrigenic components (river discharge, shore abrasion) and biogenic components (plankton) leads to high concentrations of suspended matter in summer time while in winter they are minimal. However, maximal concentrations of aerosols in the Arctic are registered in winter and in early spring (Rahn and McCaffrey, 1980; Barrie, 1986, 1996; Barrie and Barrie, 1990; Shaw, 1991, 1994; Mosher et al., 1993; Heintzenberg and Leck, 1994; Polissar et al., 1998 a, b).

Arctic aerosols have been studied insufficiently. Meanwhile, as compared to other climatic zones, the Arctic is characterised by specific conditions determining the amount, properties, and composition of the aerosol material. First of all, this is a high-latitude position of the Arctic – in the region of global divergence in the cells of vertical circulation. The stratospheric aerosol material (maximum content at the altitude about 20 km) is mixed there with the tropospheric one and drops to the cloudy ground layers, where this material deposits. This model is supported by results of studying the radioactive fallout after H-bomb testing (Lavrenchik, 1965).

The most part of the Arctic is occupied by the ocean and seas, but the data on peculiarities of aerosol distribution above seas in the high latitudes are almost absent – most observations have been conducted at polar stations situated on the land or large islands (Rahn, 1981 a, b; Vinogradova et al., 1987, 1993; Pacyna, 1991; Rovinsky et al., 1995; Koutsenogii et al., 1998).

Previously, the Arctic aerosols were mostly studied as a probable source of pollution of the polar ecosystem (Barrie, 1986, 1996; Vinogradova et al., 1987; Rovinsky et al., 1989, 1995; Pacyna, 1991; Vinogradova, 1992). Most of scientists consider the role of aerosols in delivery of matter in the Arctic to be unimportant (Darby et al., 1989; Macdonald et al., 1998).

The aim of this work is to study the Arctic aerosols and to determine the role of aerosol material in the modern sedimentation and in the formation of natural environment. Accordingly to this aim the following task were solved:

1. The study of quantitative distribution of aerosols in the marine boundary layer over the Arctic Ocean.
2. Study of granulometric composition of Arctic composition and determination of influence of various factors on the aerosol size distribution.
3. Study of genetic composition of aerosols: determination of proportions of mineral, biogenic and anthropogenic constituencies.
4. Study of mineral composition of insoluble particles to find out source regions of aerosol material.
5. Study of chemical composition of aerosols (both individual particles and total samples), determination of source regions using the tracer ratios; estimation of the degree of anthropogenic pollution of the Arctic atmosphere.
6. Determination of aeolian fluxes and comparison of aeolian input with other mechanisms of delivery of matter in the Arctic. Estimation of the role of aerosols in formation of the Arctic environment.

For solution of these tasks aerosol studies were carried out in 1991-1998 in expeditions to the Arctic onboard of Russian research vessels and German icebreaker "Polarstern". Materials from French-Russian expedition SPASIBA-91 onboard the RV "Yakov Smirnitzkii" (Scientific Program on Arctic and Siberian Aquatorium, August-September 1991, A.P. Lisitzin – chief scientist), the 49th expedition of the RV "Dmitry Mendeleev" (August-October 1993, A.P. Lisitzin – chief scientist), the 31st expedition of the RV "Akademik Mstislav Keldysh" (August-September 1993, A.M. Sagalevich – chief scientist), the 9th expedition of the RV "Professor Logachev" (August-October, 1994; G.I. Ivanov – chief scientist), the ARK XI/1 expedition of the German icebreaker "Polarstern" (July-September 1995, E. Rachor – chief scientist), the 15th expedition of the RV "Professor Logachev" (July-August 1996, G.A. Cherkashev – chief scientist), the ARK XIII/2 expedition of the German icebreaker "Polarstern" (July-August 1997, R. Stein – chief scientist), the 11th expedition of the RV "Akademik Sergey Vavilov" (August-October 1997, Yu.A. Ivanov – chief scientist), the ARK XIV/1a expedition of the German icebreaker "Polarstern" (July 1998, W. Jokat – chief scientist) have been used.

During the expeditions and laboratory studies new equipment and methods were used in close co-operation with Russian, German, French, Belgian colleagues. The Arctic aerosols have been studied within the confines of the unified global program (Lisitzin, 1972, 1996; Zhivago and Bogdanov, 1974) and by the common methods, what allows its comparison with other climatic zones.

1. ARCTIC AEROSOLS (LITERATURE REVIEW)

1.1. GEOGRAPHICAL CHARACTERISTICS OF THE ARCTIC OCEAN

The distinctiveness of the Arctic Ocean is determined, first of all, by its position in high latitudes. The Arctic Ocean is a deep basin, surrounded by shallow marginal seas and wide (up to 1500 km) shelf; its surface is about 13.1 x 10^6 km^2 (Arctic ..., 1985). Temperature of water at the surface in its central part is from –1.8 to –1.5 °C. The climate at its great expanses varies strongly from region to region.

The Arctic Basin is divided into two parts (the Eurasian Basin and the Amerasian Basin) by the Lomonosov Ridge. In turn, the Eurasian Basin is subdivided into Nansen and Amundsen Basins by the Mid-Ocean Gakkel Ridge, and the Amerasian Basin is subdivided into Makarov and Canada Basins by the Alpha and Mendeleev Ridges (Thiede et al., 1990).

Near-pole position of the Arctic Ocean and its slow water and heat exchange with the other regions of the World Ocean are the main reasons of existence of permanent ice cover in the Arctic Basin (Sugden, 1982). Solar radiation and heat transformations are the main climate-forming factors in the Arctic. Annual level of solar radiation over the most part of the Arctic Ocean is about 66 kcal/cm^2 and only at the north of the Norwegian Sea and at the west of the Barents Sea it doesn't exceed 60 kcal/cm^2 per year, moreover maximum of solar radiation is registered in May-June, when about half of the annual radiation comes to the surface of the Arctic Basin (Atlas ..., 1985).

Atmospheric circulation plays an important role both in the formation of the Arctic Ocean climate and in transport of aerosol particles. Mostly active zone of cyclonogenesis is situated in the North Atlantic (Fig. 1.1). This zone is especially active in autumn and winter (Atlas ..., 1985; Voskresensky and Petrov, 1985). The other zone of intensive cyclonogenesis is situated in the North Pacific. Anticyclones generally are build up over the cold surface. In winter more often they are observed over the East Siberia, Alaska, North-West Canada, Greenland and the Arctic Basin. Frequency of the Arctic anticyclones is low, but they are very steady and sedentary. In summer the sources of anticyclogenesis survive only over the Greenland and over the Central Arctic (Voskresensky and Petrov, 1985). The direction of resulting wind in the August is shown at the Fig. 1.2.

The highest values of wind speed generally are registered in the autumn-winter period. The stormy weather conditions (with the wind speed higher then 15 m/s) are more often in winter. They have a 10-12% frequency in the Norwegian and Barents Seas, 5-8% - in the Chukchi Sea and around 1% - in the Central Arctic (Voskresensky and Petrov, 1985). In the winter polynyas of the Arctic are been opening. Polynyas play important role in formation of cryosols and in incorporation of water suspended matter into ice (Dethleff, 1995; Zakharov, 1996). In summer the stormy activity is lower.

The highest values of average monthly relative humidity are registered in the Arctic in summer (95-97% in the Central Arctic and 90-95% in marginal seas), the lowest values are in winter (75-85%) (Voskresensky and Petrov, 1985). The amount of precipitation in the Arctic Ocean is relatively low. Lowest values of precipitation are registered in spring, highest – in the summer. In average, annual amount of precipitate over the Arctic Ocean varies from 259 mm (Burova, 1983) to 285 mm (Voskresensky and Petrov, 1985) (Table 1.1;

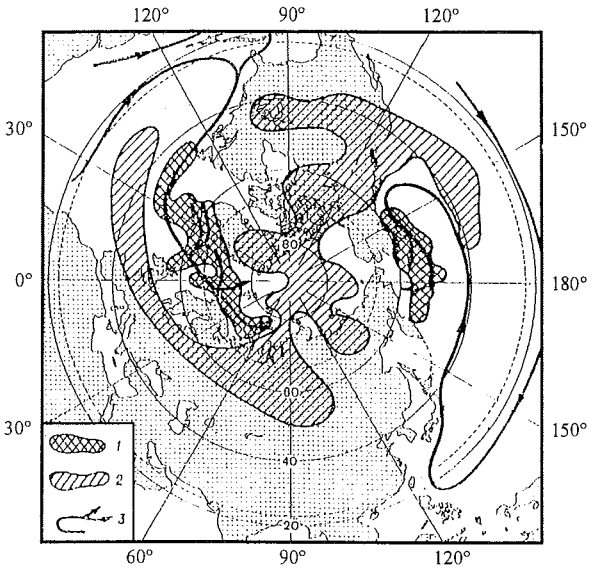

Fig. 1.1: Position of cyclonic (1) and anticyclonic (2) atmospheric centres, and scheme of warm air mass currents (3) (Moretzkii, 1976).

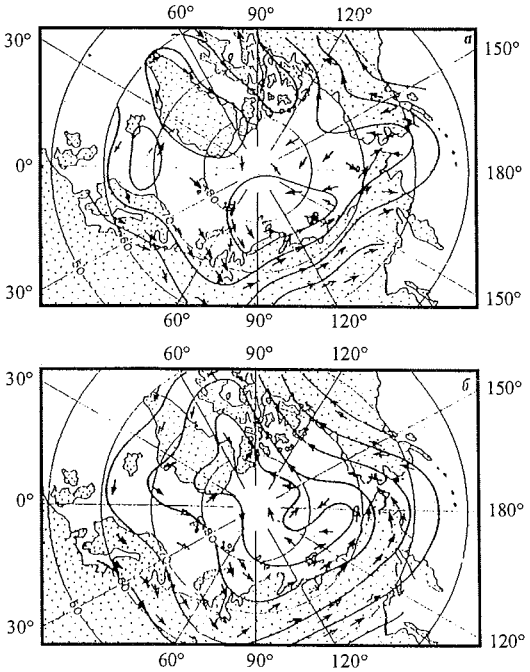

Fig. 1.2: Wind directions in the August at 850 hPa (a) and 500 hPa (b) levels (Burova, 1983).

Table 1.1: Monthly amount of precipitation in the Arctic, mm (after Burova, 1983).

Points	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
North Pole-6 drifting station	17.2	12.8	13.8	6.6	5.0	26.4	36.1	36.4	22.4	24.2	9.8	11.4	222.1
Rudolf Island	17.2	18.7	13.8	8.0	15.8	40.6	24.2	37.2	16.3	22.9	16.0	14.9	245.6
Dikson Island	32.8	21.8	25.2	14.2	36.6	66.3	25.6	69.6	54.5	39.2	27.0	31.8	444.6
Kotelny Island	13.4	6.0	5.1	7.0	11.1	23.2	27.8	19.8	16.6	23.0	11.0	13.6	177.6
Chetyrekhstol-bovoy Island	6.8	4.4	7.8	3.8	5.3	16.6	35.8	44.4	13.7	32.3	7.8	3.1	181.8
Cape Schmidt	17.2	38.2	12.6	22.0	8.7	13.8	10.4	67.3	26.6	23.6	34.6	9.2	284.2
Average for the Arctic	17.4	17.0	13.0	10.3	13.8	31.2	26.6	45.8	25.0	27.5	17.7	14.0	259.3

Fig. 1.3). At the Fig. 1.4 the annual balance of water in the atmosphere over the Arctic Ocean (Burova, 1983) is presented.

Precipitation in the Arctic generally are in the solid form (snow). They form stable snow cover, which exists more than 320 days annually near the North Pole and less than 260 days near the seasonal ice edge. Average snow depth on multi-year pack ice of the Central Arctic is 30-40 cm (Voskresensky and Petrov, 1985; Radionov et al., 1996; Bryazgin, 1997); in the Arctic seas it is 1.5 times less because of ice there is formed only in October-November (Fig. 1.5). Snow depth on the young ice is 7 cm in average in the beginning of winter, 16 cm – in January and 23 cm in April-May (Nazintzev, 1971; Buzuev et al., 1979; Bryazgin, 1976, 1997; Warren et al., 1999). Delivery of significant part of matter from the atmosphere (not only aerosols, but also dissolved substances) is connected with snow (Matishov and Golubeva, 1998).

Formation of ice cover takes place under influence of three main processes: 1 – formation of ice at cooling of sea water to the temperature lower than freezing point; 2 – movement of ice under influence of winds and currents; 3 – melting of ice (Klepikov et al., 1985). Stable formation of ice in the Arctic begins mostly at the end of September. The highest state of ice development takes place at the end of March - beginning of April, when about 15.7 mln km^2 of the Arctic are covered by ice (Gloersen et al., 1992; Zakharov, 1996). In winter only parts of Norwegian, Barents, Greenland and Baffin seas are open from the ice.

Near shores of the land and of islands in October-November fast ice is formed. It is preserved till June-July. The width of fast ice depends on local conditions. From the outer side the fast ice is supported by anchor ice (grounded hummocks). Some anchor ice bodies have 25 m thickness and 25 m isobath could be regarded as the fast ice border (Klepikov et al., 1985). Off the marine border of fast ice there is drifting ice and along this edge polynyas are formed (Zakharov, 1966, 1996; Borodachev and Frolov, 1997). One of the largest polynyas (Siberian) is situated in the Laptev Sea. Its length is 2000 km, width – more than 10 km (Dethleff, 1995). For the first time the Siberian Polynya was described by A.V. Kolchak (1909) and later by N.N. Zubov (1944). There is drifting ice of different age and thickness to the north from the fast ice and polynyas.

In the Central Arctic old pack ice is distributed, it occupies about 80% of the area, one-year ice occupies about 10%, ice ridges – about 10% and 1-2% - polynyas (Zubov, 1956; Klepikov et al., 1985; Dobrovol'sky and Zalogin, 1992). Sea ice is in permanent motion. The substantial contribution in the study of ice drift in the Arctic has been done by F. Nansen, A.V. Kolchak, N.N. Zubov, V.Kh. Buynitzky, P.A. Gordienko, Z.M. Gudkovich, E.G. Nikiforov (Gorbunov et al., 1995; Uiks, 1997).

Very valuable materials for ice drift studies have been collected during expedition onboard vessels "Fram" (1893-1896), "Mod" (1922-1924), "G. Sedov" (1937-1940) and on Soviet, American and Canadian drifting stations. Since 1979 automatic radio buoys are deployed on drifting ice. The position of these buoys few times per day is determined from satellites. Analysis of information from radio buoys gives possibility to clarify general scheme of the ice drift, to reveal complexity of daily trajectories of ice-floe drift, to study large-scale deformations of ice cover (Colony and Thorndike, 1985; Losev et al., 1994; Gorbunov et al., 1995; Pfirman et al., 1997; Kwok et al., 1998; Liu et al., 1998).

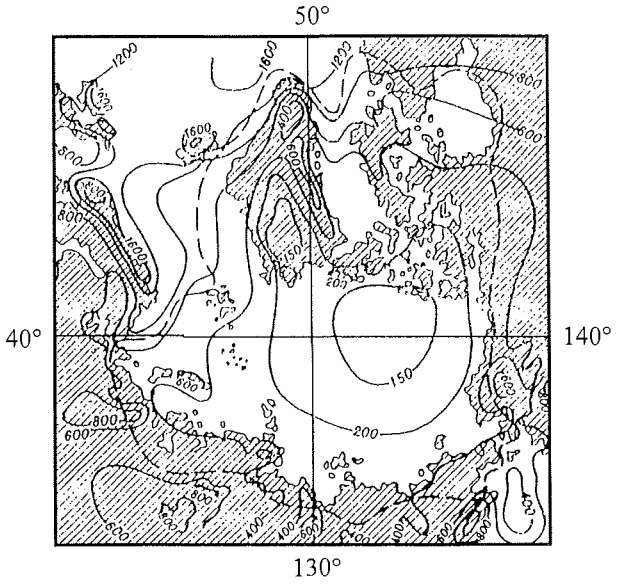

Fig. 1.3: Average annual quantity of precipitation in the Arctic (Burova, 1983).

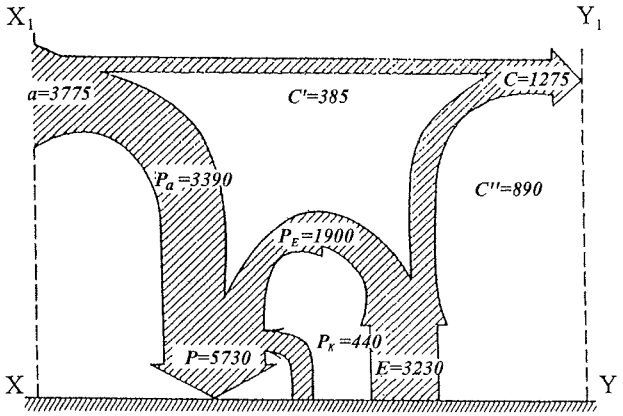

Fig. 1.4: Annual moisture balance in the Arctic Ocean atmosphere (km^3): a – water vapor advection; P_a – advectional precipitation; P_E – precipitation from local water vapor; P_K – condensation precipitation; P – total precipitation; E – evaporation; C' – advectional moisture outflow; C'' – atmospheric moisture outflow from local water vapor; C – total moisture outflow in the atmosphere (Burova, 1983).

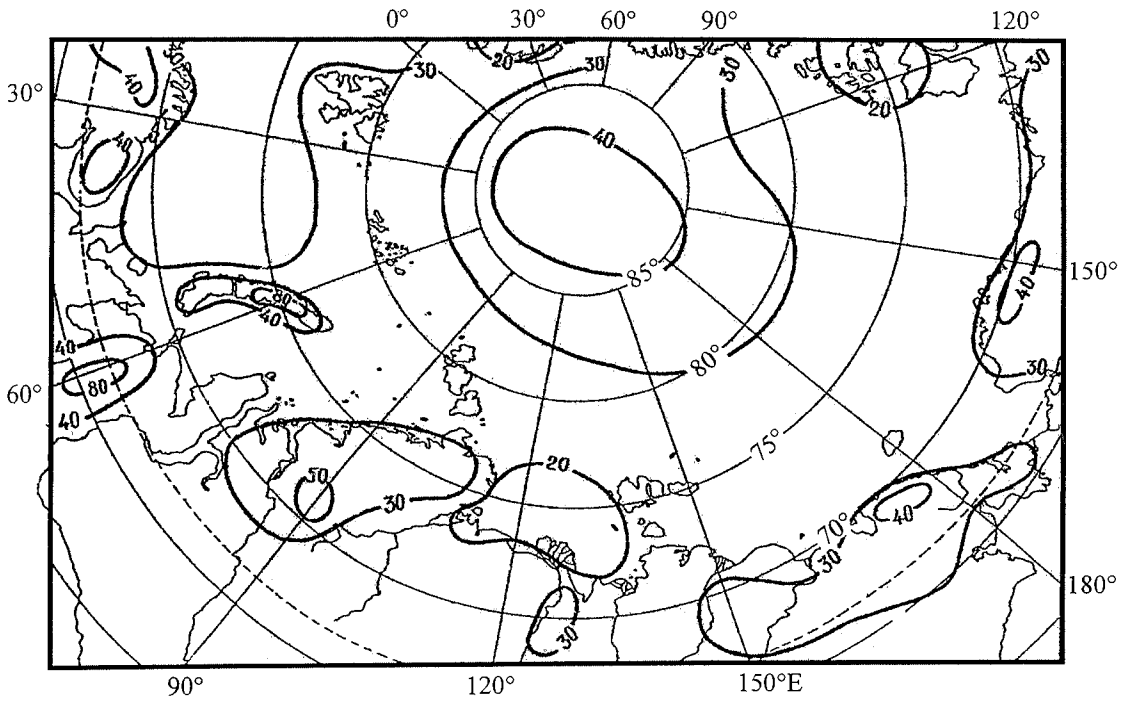

Fig. 1.5: Distribution of snow depth in the Arctic, cm (Radionov et al., 1996).

Two dominant features of the ice circulation in the Arctic basin have been revealed: the Beaufort Gyre, anticyclone circulation pattern in the Amerasian Basin, and the Transpolar Drift, a basinwide cyclone feature (Fig. 1.6). The ice-floes travel with Transpolar Drift to the Fram Strait from Chukchi Sea and East-Siberian Sea 3-4 years, from the Laptev Sea – 2-3 years, from the Kara Sea – 1-2 years (Zakharov, 1996; Pfirman et al., 1997).

Long (9-10 months) period of conservation of shore and fast ice in summer is changed by short period of active waves and partial melting of permafrost and abrasion (Aibulatov, 1993). Thousands of kilometres of Arctic sea coast retreat 2-6 m/yr under the action of shore erosion (Are, 1980, 1999). Shore erosion is a source of sediments coming into the sea from the land. But the importance of this part of sediment balance is not determined reliably till now.

The Arctic Ocean is relatively cloistered, so the river discharge influences strongly on the its hydrological and hydrochemical regimes. Total annual river water input in the Arctic Ocean is around 5100 km^3 (Ivanov, 1976; Klepikov et al., 1985). River discharge from the Eurasia is estimated to be around 2960 km^3, Eurasian rivers bring to the Arctic seas about 115 x 10^6 t of particulate suspended matter (Gordeev et al., 1996; Gordeev and Tsirkunov, 1998). The most part of annual water discharge is delivered to the Kara Sea (1478 km^3) and to the Laptev Sea (745 km^3) by great Siberian rivers Yenisey, Ob, Lena, Khatanga (Table 1.2). River discharge in the Arctic sea has strong seasonality – about 70% of annual discharge enter the seas in spring (Fig. 1.7, 1.8).

1.2. ARCTIC AEROSOLS

Aerosols are defined as relatively stable suspensions of solid or liquid particles in a gas (Brimblecombe, 1996). Particles, or particulate matter, have diameters between 0.002 μm and 100 μm (Finlayson-Pitts and Pitts, 1986). The lower end of the size range is not sharply defined because there is no accepted criterion at which a cluster of molecules becomes a particle. However, particles with diameters of ~0.002 μm have been measured and this is a smallest size detectable by condensation nuclei counters (Brimblecombe, 1996). The upper end corresponds to the size of fine drizzle or very fine sand; these particles are so large that they quickly fall out of the atmosphere and hence do not remain suspended for significant periods of time. Particles may be either directly emitted into the atmosphere (mineral dust, biogenic particles, anthropogenic material etc.) or formed there by chemical reactions; we refer to these as primary and secondary particles, respectively (Junge, 1963; Fuchs, 1964; Finlayson-Pitts and Pitts, 1986; Brimblecombe, 1996). Much dust is derived by wind to the Ocean (~1.6 x 10^9 t annually (Lisitzin, 1974)), so the dust is of important sources of terrigenous matter in the Ocean (Lisitzin, 1972, 1996; Prospero, 1981; Aibulatov and Serova, 1983; Chester, 1986, 1990; Bergametti et al., 1989; Prospero et al., 1989; Duce et al., 1991; Uematsu, 1992; Savenko, 1994; Swap et al., 1996; Arimoto et al., 1997). Volcanoes are one of sources of primary aerosol particles. The influence of volcanoes on the composition of aerosol is especially clear near the active volcanoes (Bergametti et al., 1984). Catastrophic eruptions influence on the composition of aerosols, radiation balance and the Earth climate (Lisitzin, 1972, 1996; Kondrat'ev and Pozdnyakov, 1981; Borrmann et al., 1995).

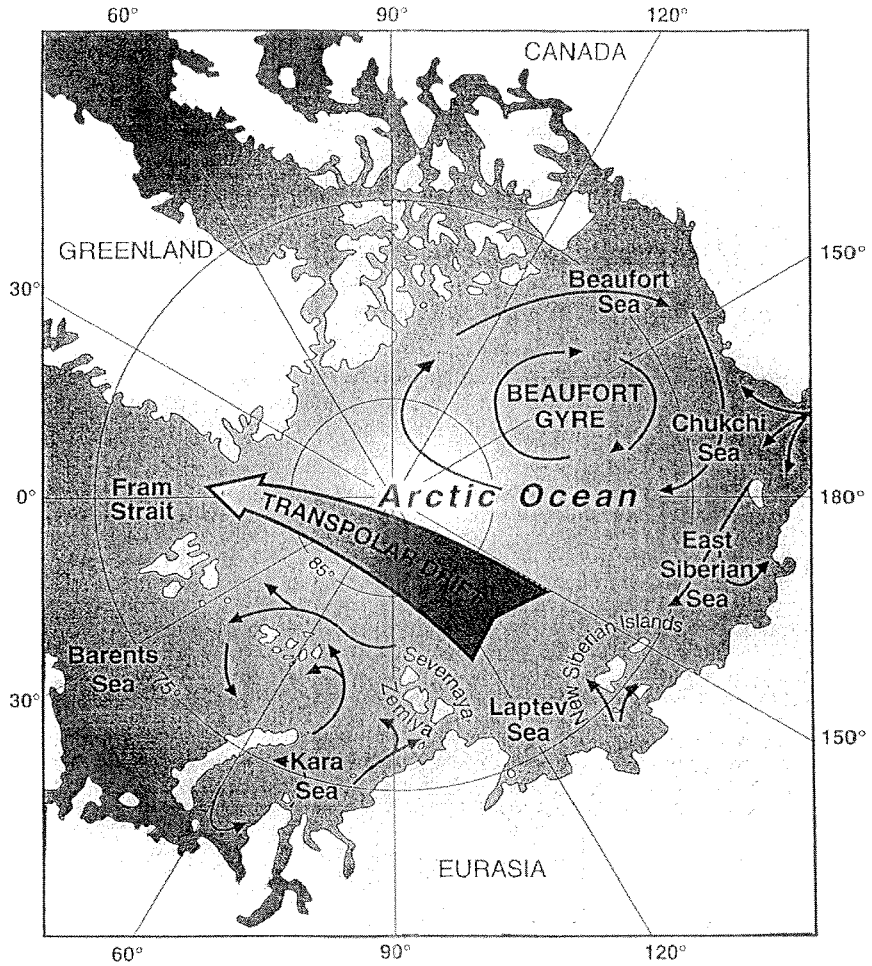

Fig. 1.6: Schematic description of the major elements of the circulation patterns of the Arctic sea ice cover (Kassens et al., 1995).

Table 1.2: River discharge from Eurasia to the Arctic (after Gordeev et al., 1996).

Rivers	Catchment area, 10^6 km^2	Water discharge, km^3/y	Suspended matter discharge, 10^6 t/y	Concentration of suspended matter, mg/l
Barents and White Seas				
Onega	57	15.9	0.3	18
Northern Dvina	357	110	3.8	35
Mezen	78	27.2	0.9	32
Pechora	324	131	13.5	80
Other rivers	570	179	3.5	20
Total	1386	463	22	47
Kara Sea				
Ob	2545	429	16.5	38
Nadym	64	18	0.4	22
Pur	112	34.3	0.6	18
Taz	150	44.3	0.9	21
Yenisey	2594	620	5.9	10
Pyasina	182	86	3.4	40
Other rivers	867	443	5.5	12
Total	6589	1478	33.2	22
Laptev Sea				
Khatanga	364	85.3	1.7	20
Anabar	100	17.3	0.4	24
Olenek	219	35.8	1.1	31
Lena	2486	525	17.6	34
Omoloy	39	7	0.13	18
Yana	238	34.3	3.5	103
Other rivers	197	40.3	0.65	16
Total	3643	745	25.1	34
East-Siberian Sea				
Total	1342	250	33.6	134
Chukchi Sea				
Total	94.2	20.4	0.7	34
Eurasian Basin				
Total	13054	2960	115	40

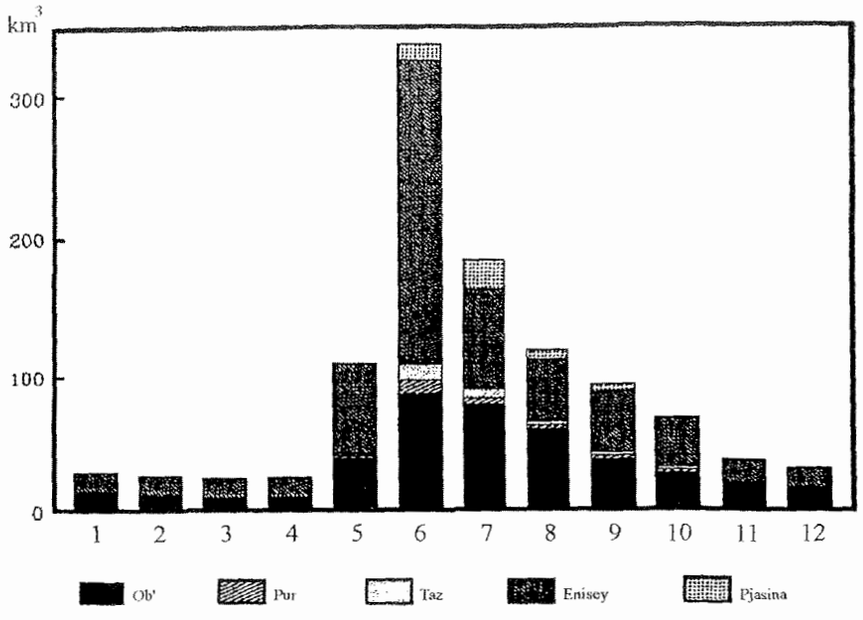

Fig. 1.7: Mean river discharge (cubic kilometres) to the Kara Sea (Pavlov and Pfirman, 1995).

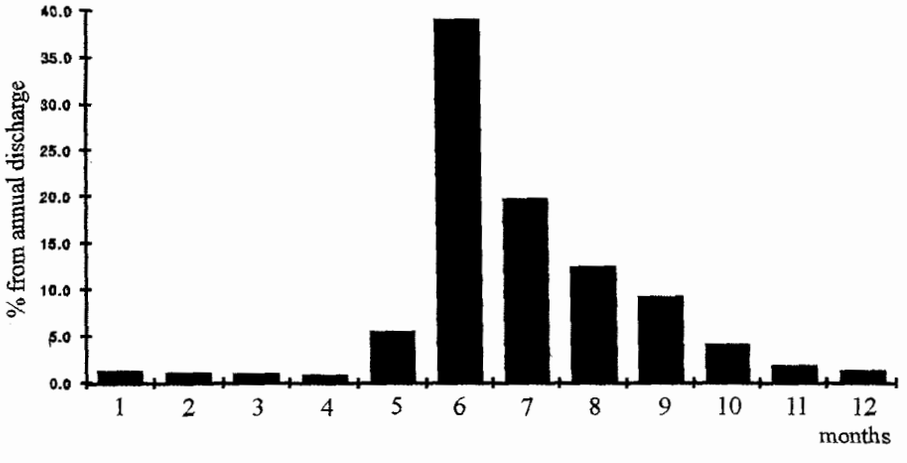

Fig. 1.8: Seasonal variability of Siberian river discharge in the Arctic Ocean (Shiklomanov and Skakalsky, 1994).

The sea could serve as a source for primary aerosol particles. Sea-salt aerosol is produced by breaking bubbles at the ocean surface. These aerosol particles are significantly enriched by many chemical elements (Quinn et al., 1975; Duce et al., 1976 a, b; Korzh, 1987, 1991; O'Dowd and Smith, 1993). The rate of generation of sea-salt particles increases markedly with increasing the wind speed (Marks, 1987; Barteneva et al., 1991; O'Dowd and Smith, 1993; Bigg et al., 1995; Piazzola and Despiau, 1997).

Among important processes of secondary particles generation there are biological processes (oxidation of terpenes and reduced sulphur compounds) and photochemical processes in upper layers of atmosphere (Kondrat'ev and Pozdnyakov, 1981; Isidorov, 1990; Russel et al., 1994; Hopke et al., 1995; Brimblecombe, 1996).

The Arctic is characterised by specific conditions determining the amount, properties, and composition of the aerosol material. The most part of the Arctic territory is occupied by seas, but the data on aerosol distribution and composition over the seas and drifting ice in high latitudes are almost absent – most studies have been carried out at polar stations situated on the land or large islands, mostly in the Norwegian, American, Canadian, and Danish sectors of the Arctic (Flyger and Heidam, 1978; Rahn, 1981 a, b; Heidam, 1984; Pacyna and Ottar, 1988, 1989; Barrie, 1986, 1996; Polissar et al., 1998 a, b, 1999; Sirois and Barrie, 1999). In the Russian Arctic only few studies on the land or large islands were carried out (Rovinsky et al., 1989, 1995; Vinogradova et al., 1993; Vinogradova, 1996, 1997; Smirnov et al., 1996 a; Vinogradova and Egorov, 1996, 1997; Fukasawa et al., 1997; Halsall et al., 1997; Hansen et al., 1997; Stern et al., 1997; Koutsenogii et al., 1998), moreover the Arctic aerosol was mostly studied as a probable source of pollution of the polar ecosystems.

Meteorological condition is one of important factors controlling distribution and composition of Arctic aerosol. In winter atmospheric conditions and dynamics depend on stable cold anticyclones (Canadian and Siberian highs). Low temperatures, small amount of precipitation are typical for this season (Raatz, 1991).

Highest concentrations of many chemical elements and compounds, mostly anthropogenic (soot, non-marine sulphate, selenium, non-crustal vanadium) are registered in Arctic aerosols at the end of winter – in the beginning of spring (Table 1.3; Fig. 1.9, 1.10). The reason of high pollution of Arctic atmosphere (formation of "arctic haze") in winter is in the position of the Arctic front, which separate cold polar air masses from warmer air masses of temperate latitudes (Raatz, 1991). In winter polar front is situated much further to the south, that promotes the transport of polluted aerosols from industrial areas to the Arctic (Barrie et al., 1981, 1989; Rahn, 1981 a; Shaw, 1982; Vinogradova and Egorov, 1996, 1997; Vinogradova, 1997; Arctic ..., 1997; Polissar et al., 1998 a, b, 1999). In summer sometime polluted air masses could arrive from mid-latitudes, but in this time precipitation is effective mechanism of cleaning atmosphere (Bailey et al., 1984; Pacyna and Ottar, 1989).

The size distribution of atmospheric aerosol is one of its core physical parameters. It determines how the various properties like mass and number density, or optical scattering, are distributed over the particle size (Finlayson-Pitts and Pitts, 1986; Brimblecombe, 1996). It has been shown that concentration of particles larger than 0.01 μm in the Arctic atmosphere in March-April during arctic haze varies from 30 to 17000 cm^{-3} (Bodhaine et al.,

Table 1.3: Concentrations of chemical elements in aerosols at the Ny-Alesund (Spitsbergen), ng/m^3 (Maenhaut et al., 1989).

Ele-ment	Winter 1983	Winter 1984	Winter 1986	Three winters	Summer 1984	Winter/ summer ratio
Na	210	310	192	230	66	3.5
Mg	66	55	30	48	18.2	2.6
Cl	85	105	30	85	40	2.1
K	44	26	28	31	3.7	8.4
Ca	41	15	36	34	7.3	4.7
Br	8	7.1	11.6	8.8	0.73	12.1
I	1.41	0.75	0.92	0.9	0.28	3.2
S	1480	570	990	830	101	8.2
Se	0.2	0.146	0.155	0.156	0.035	4.6
Al	43	28	49	40	8.3	4.3
Si	220	96	<200	134	31	4.3
Sc	0.0059	0.0034	0.0049	0.0043	0.00118	3.6
Ti	2.2	1.0	<1.5	1	<0.6	
Fe	41	13.4	16.7	17.8	5.6	3.2
Co	0.031	0.0084	<0.007	0.0096	<0.004	>2.4
Rb	0.17	<0.15	0.119	0.083	<0.08	
Cs	0.0164	0.0063	0.0085	0.0089	0.003	3
Ba	1.12	<2	0.8	<1.5	<0.7	
La	0.03	0.0129	0.0177	0.0137	0.0055	2.5
Sm	0.003	0.0024	0.0028	0.0027	0.00072	3.8
Eu	0.00096	<0.002	0.0021	0.00116	<0.001	
Th	0.0057	0.0024	0.0056	0.0037	0.00173	2.1
V	1.99	0.42	0.47	0.54	0.022	25
Cr	0.94	<0.5	<0.33	<0.4	0.56	<0.71
Mn	2.2	0.51	0.78	0.77	0.07	11
Ni	0.95	0.38	<0.25	0.29	<0.2	
Zn	9.6	2.3	4	3.9	<0.15	>26
As	1.49	0.32	0.52	0.52	0.01	52
Ag	0.0178	<0.02	0.0097	<0.018	<0.018	•
Cd	0.126	<0.3	<0.15	0.08	<0.11	
In	0.0048	0.00154	0.00132	0.00161	<0.0012	>1.34
Sb	0.22	0.048	0.108	0.092	0.0024	38
Au	<0.009	<0.0008	0.00044	<0.0009	0.00015	
Pb	8.2	1.76	2.6	3	<0.7	>4.3

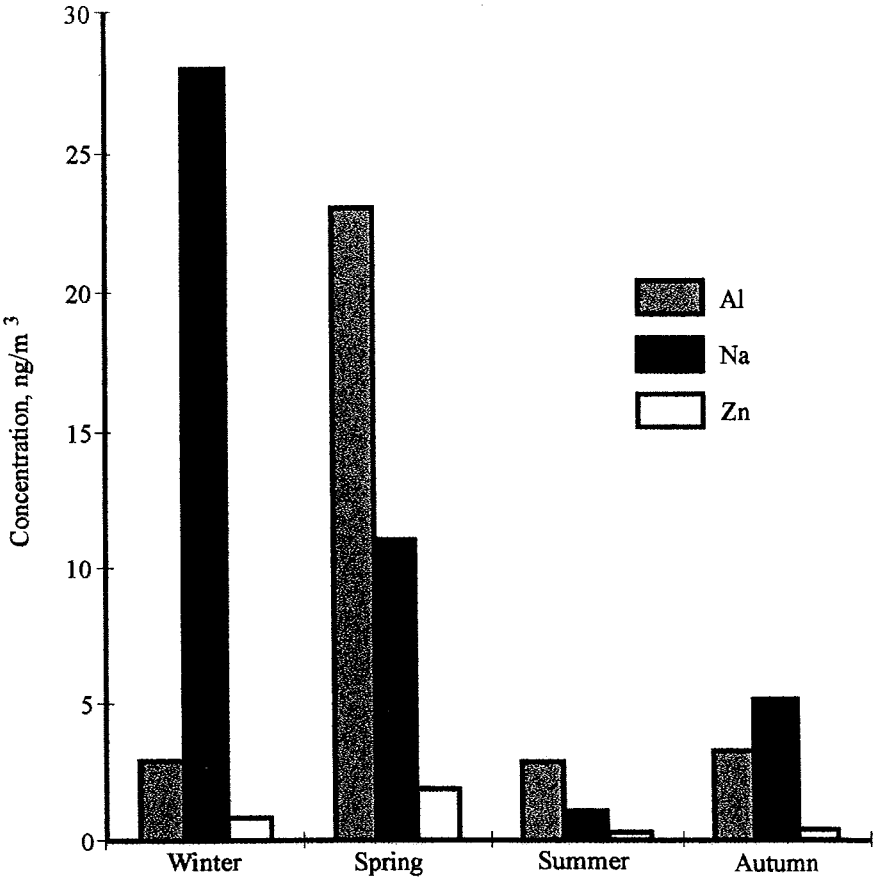

Fig. 1.9: Seasonal variability of concentrations of Al, Na and Zn from August 1998 till July 1989 at station Dye 3, Greenland (65°11'N, 43°50'W, 2479 m above the sea level) after (Davidson et al., 1993).

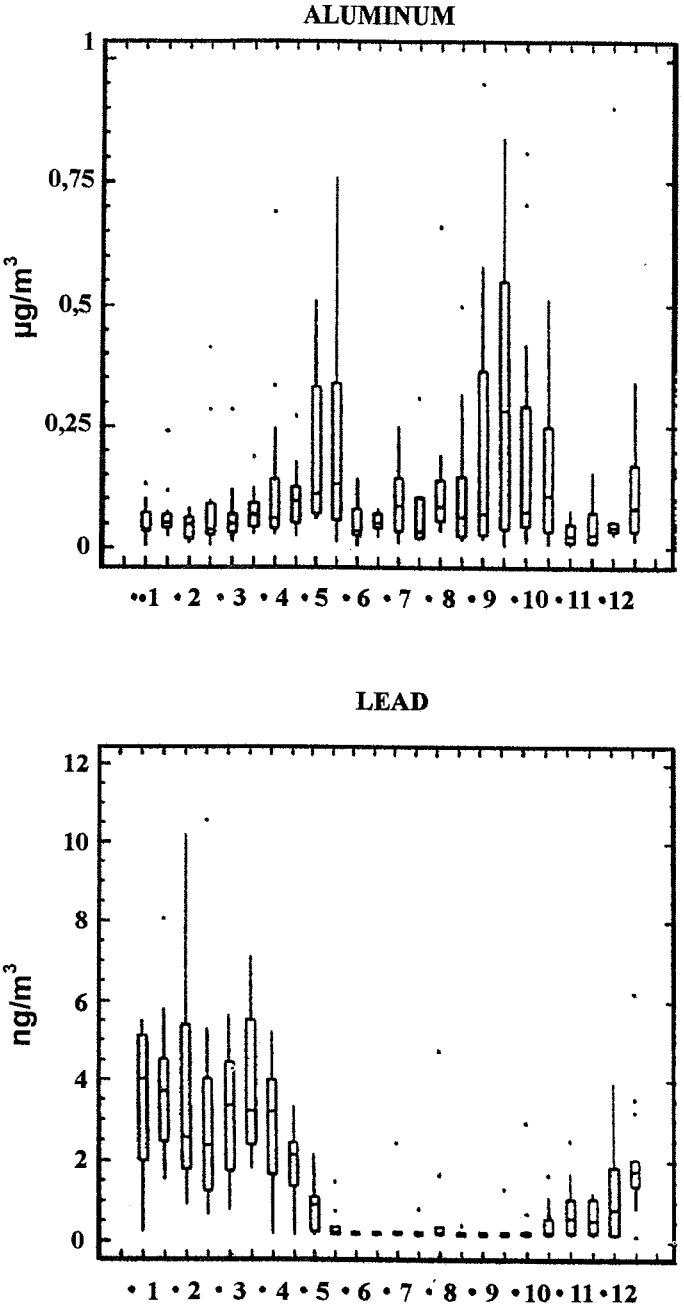

Fig. 1.10: Seasonal variability of concentration of aerosol Al and Pb at Alert station in the Canadian Arctic (82.5°N, 62.3°W) from 1980 till 1986 (Barrie and Barrie, 1990).

1984; Shaw, 1984; Raatz et al., 1985 a, b; Covert and Heintzenberg, 1993). Close values of particle concentration are registered in coastal areas of the Ocean, while in marine boundary layer in remote areas they are usually lower (Table 1.4). In winter and in the beginning of spring most part of aerosol particles are in the diameter range from 0.005 to 0.2 μm, concentration of particles larger than 0.2 μm decrease with increasing diameter (Shaw, 1986).

Maximum volume (and mass) concentration of arctic aerosol particles corresponds to relatively large particles. Accordingly to volume concentration three modes could be shared out: accumulation mode (0.1÷1 μm), coarse mode (1÷10 μm) and giant particles (>10 μm) (Hoff et al., 1983; Shaw, 1984; Barrie and Hoff, 1985; Vinogradova, 1992). Accumulation mode is responsible for decreasing visibility at high air pollution level. There are many soot carbon particles in this mode. In winter the most part of particles in accumulation mode has anthropogenic origin. The highest concentration of accumulation mode particles in the Arctic atmosphere are registered in winter (Shaw, 1984). Coarse mode consists mainly from terrigenic mineral particles and sea salt. Quantity of these particles is by 4 orders lower than accumulation mode particles, but their mass in the aerosol is significant (Raatz et al., 1985 a, b). The mass % of giant mode is significant. This mode consists of sea salt, mineral particles, biogenic particles (spores, pollens, fibres), chains of soot particles (Bailey et al., 1984).

The content of carbon in Arctic aerosols is higher than 10% (Clarke, 1989); it is maximal in winter-spring time (Hansen et al., 1985, 1997; Polissar, 1993, 1994; Polissar et al., 1998 a, b, 1999). Concentration of particulate carbon in the arctic haze layer could reach 1.6 $\mu g/m^3$ (Polissar, 1994). Carbon in aerosols mainly is incorporated in biogenic particles, soot and large ash particles.

Biogenic particles (vegetation fibres, spores, pollens, diatoms, bacteria etc.) both are transported by wind from the land and are blown by wind out from sea surface microlayer. Many studies demonstrated that organic matter is one of main components of atmospheric aerosols and organic carbon content could reach 50% of mass of insoluble particles (Aston et al., 1973; Johansen and Hafsten, 1988; Isidorov, 1990; Matthias-Maser and Jaenicke, 1995; Koutsenogii, 1997).

Soot (black carbon) is an important component of aerosols – result of incomplete combustion of fuel. It is emitted in the atmosphere in the form of submicron aerosol particles and turns out a tracer of corresponding anthropogenic sources (Rosen et al., 1981; Cachier et al., 1986; Vinogradova, 1992; Polissar, 1993, 1994; Bahrmann and Saxena, 1998; Cachier, 1998). Black carbon is the most effective component in determining the absorption cross-section of atmospheric particulate matter in the visible wavelength range (Japar et al., 1986). In the Arctic reduction of snow albedo by black carbon deposition on snow could strongly influence the climate (Cachier, 1998).

Spongy carbonaceous fly-ash particles are relatively coarse (diameter from 1 to 50 μm on average). These particles are formed during combustion of fossil fuel and are mostly found in source region although occasionally they can be transported over a long range (Rose et al., 1994; Novakov et al., 1997). Carbonaceous fly-ash is accumulated in soil, glaciers and bottom sediments and they are indicator of aeolian transport of anthropogenic pollution (Renberg and Wik, 1985; Wik and Renberg, 1991; Rose, 1995).

Table 1.4: Concentration of particles with different sizes (sm^{-3}) in the atmosphere of the Arctic and other regions.

Region	Period	Particle size			Reference
		CN (condensation nucleus)	accumulation mode	D>0.01 μm	
The Arctic					
Fram Strait	July-September 1980	130			Lannefors et al., 1983
Fram Strait, central Arctic	August-October 1991	90	60	150	Covert et al., 1996
East Siberian Sea	April 1997	300			Hansén et al., 1997
Alaska, Barrow Cap	March 1983	150 ÷ 17000 average 325			Bodhaine et al., 1984 Raatz et al., 1985 a, b
Central Alaska	January-April 1984, arctic air masses	300			Shaw, 1986
Canada, Alert	January-April 1992		50 ÷ 600, average 280		Staebler et al., 1994
Spitsbergen, Ni-Alesund	March-April 1989	30	150	180	Covert and Heintzenberg, 1993
Other regions					
Antarctica, South Pole	1974 – 1984	47			Bodhaine et al., 1986
N. Atlantic, 32°N, 25°W	June 1992	20 - 300	130 ÷ 580	870 ÷ 1070	Jensen et al., 1996
Coast of the Mediterranean Sea	March 1992 - February 1993	500 ÷ 2940 average 1300			Piazzola and Despiau, 1997
Ireland, McHead Cap	December 1993 - March 1994	374* ÷ 7241**			Jennings et al., 1997
	May-August 1994	495* ÷ 6438**			

*Marine air masses
**Transformed continental air masses

Many chemical elements and compounds are delivered from the atmosphere to the surface of the Arctic Ocean and adjacent land mainly with precipitation (Rahn, 1981 b). Delivery of nutrients is especially important (Semb et al., 1984; Evtygina, 1988; Henriksen and Brakke, 1988; Volkovskaya, 1991, 1993; Glukhov et al., 1992; Reimann et al., 1997).

Based on snow samples from the central Arctic pack ice (Mullen et al., 1972; Darby et al., 1974), the aeolian dust supply may account for a sedimentation rate of about 0.02-0.09 mm/ky (Darby et al., 1989). That means, about 1-10% of the pelagic sedimentation in the Central Arctic may be of aeolian origin (Stein and Korolev, 1994).

Studies of ice cores obtained by drilling on glaciers gives us possibility to estimate Aeolian fluxes in the past. There many publications devoted to particulate matter studies in Greenland and Antarctic ice cores (Murozumi et al., 1969; Boutron et al., 1991, 1994; Candelone et al., 1995; Hong et al., 1997). That works show that concentrations of Pb, Zn, Cd and Cu significantly increased in ice formed in 1960-1980 comparatively with previous years and decreased in ice formed later than 1980. Glaciers keep the record of input both of anthropogenic and natural tracers. For example, the great volcanic eruptions are marked in ice cores by increased content of volcanic glass and sulphate (Robock and Free, 1995).

2. MATERIALS AND METHODS

Aerosol studies in the arctic marine boundary layer were carried out by the author together with his Russian and German colleagues during 9 years (1991-1999). The results mostly are obtained in the Western and Central Arctic. They are compared with literature data for other regions. For comprehensive study of the quantitative distribution and composition of aerosols we used a range of complementary and sometimes overlapping methods.

2.1. MATERIALS

Arctic aerosol studies were started by the author with samples obtained by V.M. Kuptzov and A.P. Lisitzin during Norwegian-French-Russian expedition SPASIBA-91 (Scientific Program on Arctic and Siberian Aquatorium, August-September 1991, A.P. Lisitzin – chief scientist). Samples were collected along the route from Arkhangel'sk to Tiksi onboard the RV "Yakov Smirnitzkii" and in Lena delta onboard the RV "Olkhon".

In the August-October 1993 in 49th expedition of the RV "Dmitry Mendeleev" (A.P. Lisitzin – chief scientist) we studied aerosols in the Kara, Barents and Norwegian Seas. In August-September 1993 V.N. Lukashin collected aerosol samples in the Barents and Norwegian Seas during the 31st expedition of the RV "Akademik Mstislav Keldysh" (A.M. Sagalevich – chief scientist). In August-October 1994 aerosol were sampled in the Barents Sea and Saint Anna Trough (NW Kara Sea) during the 9th expedition of the RV "Professor Logachev" (G.I. Ivanov – chief scientist; V.N. Ivanov – chief of the expedition).

Aerosol studies in the Laptev Sea were carried out in July-September 1995 during the ARK-XI/1 expedition of the RV "Polarstern", E. Rachor – chief scientist, (Shevchenko, 1997a) in the Norwegian, Greenland and Barents Sea – in July-August 1996 during the 15th expedition of the RV "Professor Logachev" (July-August 1996, G.A. Cherkashev and P. Vogt – chief scientists).

In July-August 1997 author studied aerosols in the Barents Sea, Yermak Plateau region and in the Fram Strait during the ARK-XIII/2 expedition of the RV "Polarstern", R. Stein – chief scientist (Shevchenko, 1997b). In August-October 1997 aerosol studies were carried out in the White and Barents Sea during the 11th expedition of the RV "Akademik Sergey Vavilov" (Yu.A. Ivanov – chief scientist), in July 1998 – in the central Arctic during the ARK-XIV/1a expedition of the RV "Polarstern" (W. Jokat – chief scientist).

Information about different aerosol studies is presented in Table 2.1 and in App. 1-4. Sampling places in expeditions are shown in Fig. 2.1 – 2.5.

2.2. METHODS OF EXPEDITIONAL WORK

In all expeditions we used methods which scientists from P.P. Shirshov Institute of Oceanology use more than 40 years (Lisitzin, 1996), so we could compare our results with data obtained in different parts of the World Ocean.

Table 2.1: Quantity of aerosol granulometry spectra, measured *in situ*, and of aerosol samples collected in different expeditions and used in this work.

Expedition	Time	Granulometry spectra	Mesh samples	Filtration samples
SPASIBA-91	August-September 1991		10	
49th expedition of the RV "Dmitry Mendeleev"	August-October 1993		21	14*
31st expedition of the RV "Akademik Mstislav Keldysh"	September 1993		5	
9th expedition of the RV "Professor Logachev"	August-October 1994		20	10**
ARK-XI/1 expedition of the RV "Polarstern"	July-September 1995	63	2	12**
15th expedition of the RV "Professor Logachev"	July-August 1996		5	5**
ARK-XIII/2 expedition of the RV "Polarstern"	July-August 1997	66		8**
11th expedition of the RV "Akademik Sergey Vavilov"	August-October 1997	27	2	3**
ARK-XIV/1a expedition of the RV "Polarstern"	July 1998	57		
SUMM		**213**	**65**	**52**

*Through Whatman-41 filters

**Through AFA-KhA filters

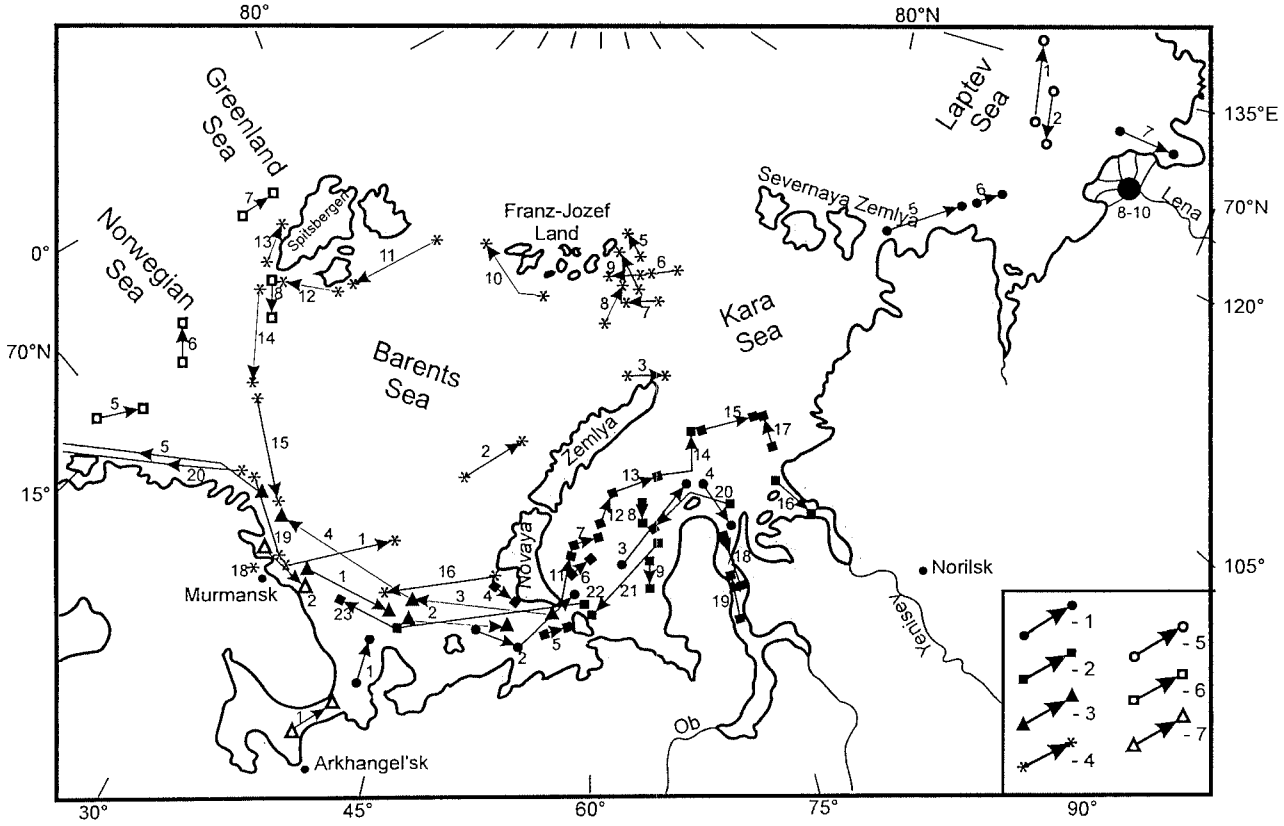

Fig. 2.1: Mesh aerosol samples: 1 – expedition SPASIBA-91; 2 – 49th expedition of the RV "Dmitry Mendeleev"; 3 – 31st expedition of the RV "Akademik Mstislav Keldysh"; 4 – 9th expedition of the "Professor Logachev"; 5 – ARK-XI/1 expedition of the RV "Polarstern"; 6 – 15th expedition of the RV "Professor Logachev"; 7 – 11th expedition of the RV "Akademik Sergey Vavilov".

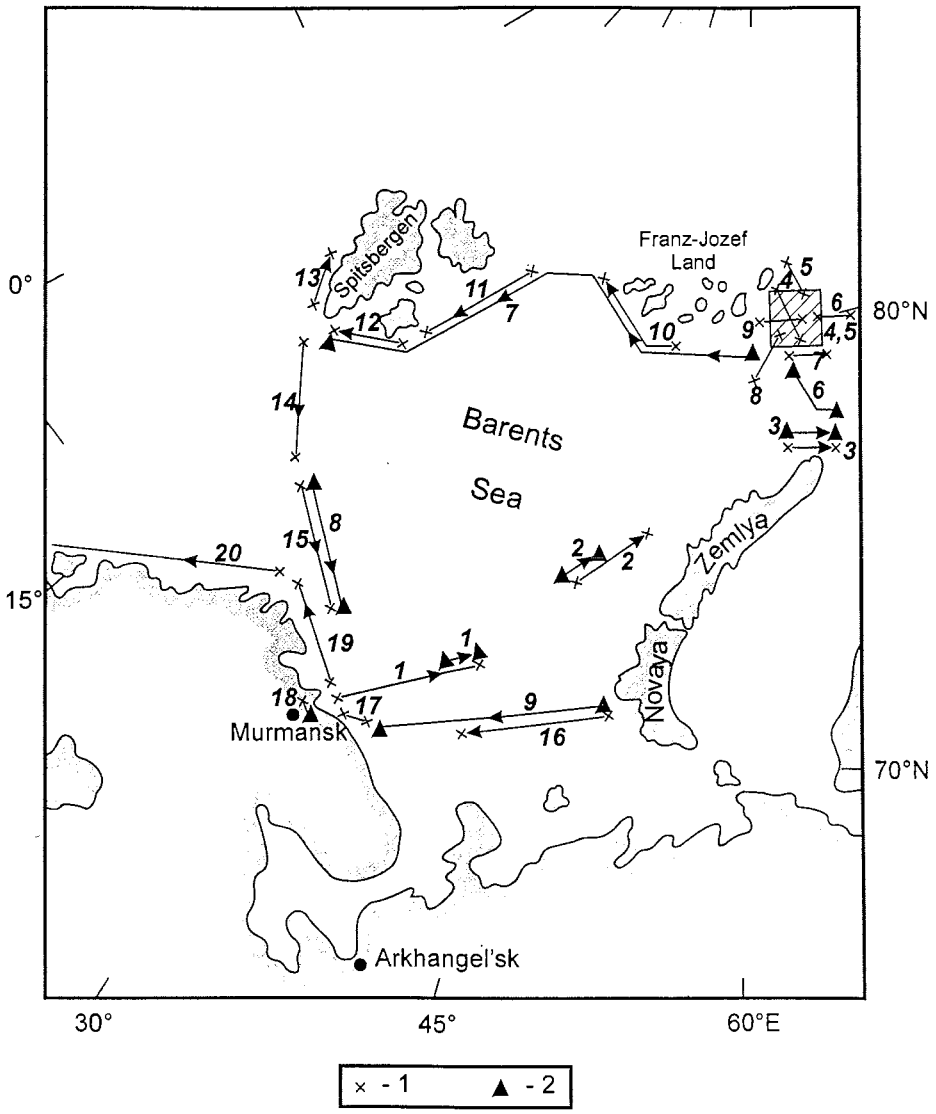

Fig. 2.2: Aerosol sampling in the 9th expedition of the RV "Professor Logachev" (August-October 1994): 1 – nylon meshes; 2 – filters AFA-KhA.

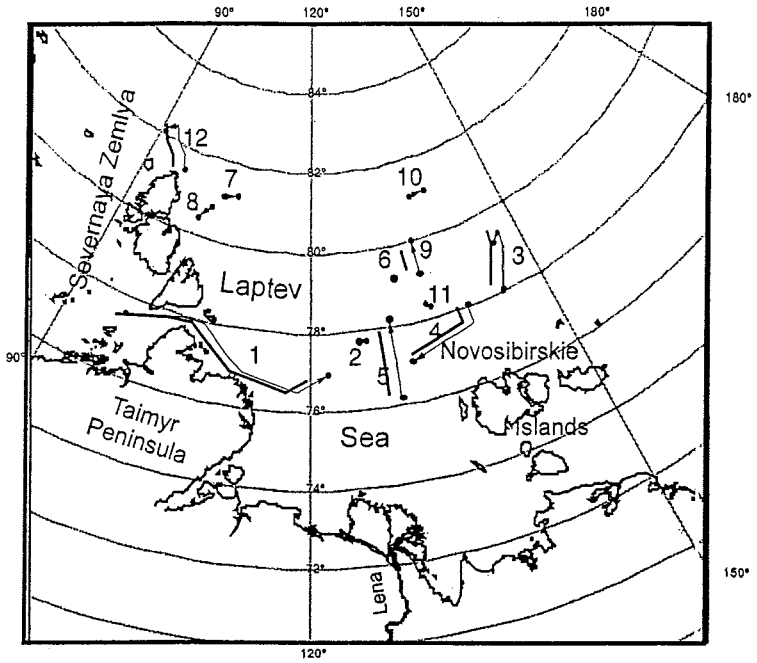

Fig. 2.3: Aerosol sampling by filtration in ARK-XI/1 expedition of the RV "Polarstern" (July-September 1995).

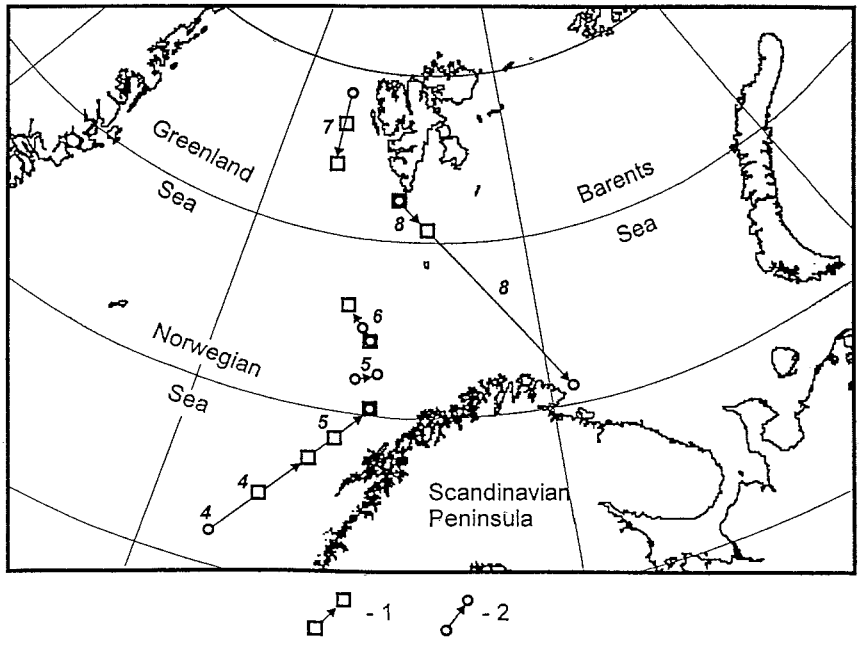

Fig. 2.4: Aerosol sampling in the 15th expedition of the RV "Professor Logachev" (July-August 1996): 1 – nylon meshes; 2 – filters AFA-KhA.

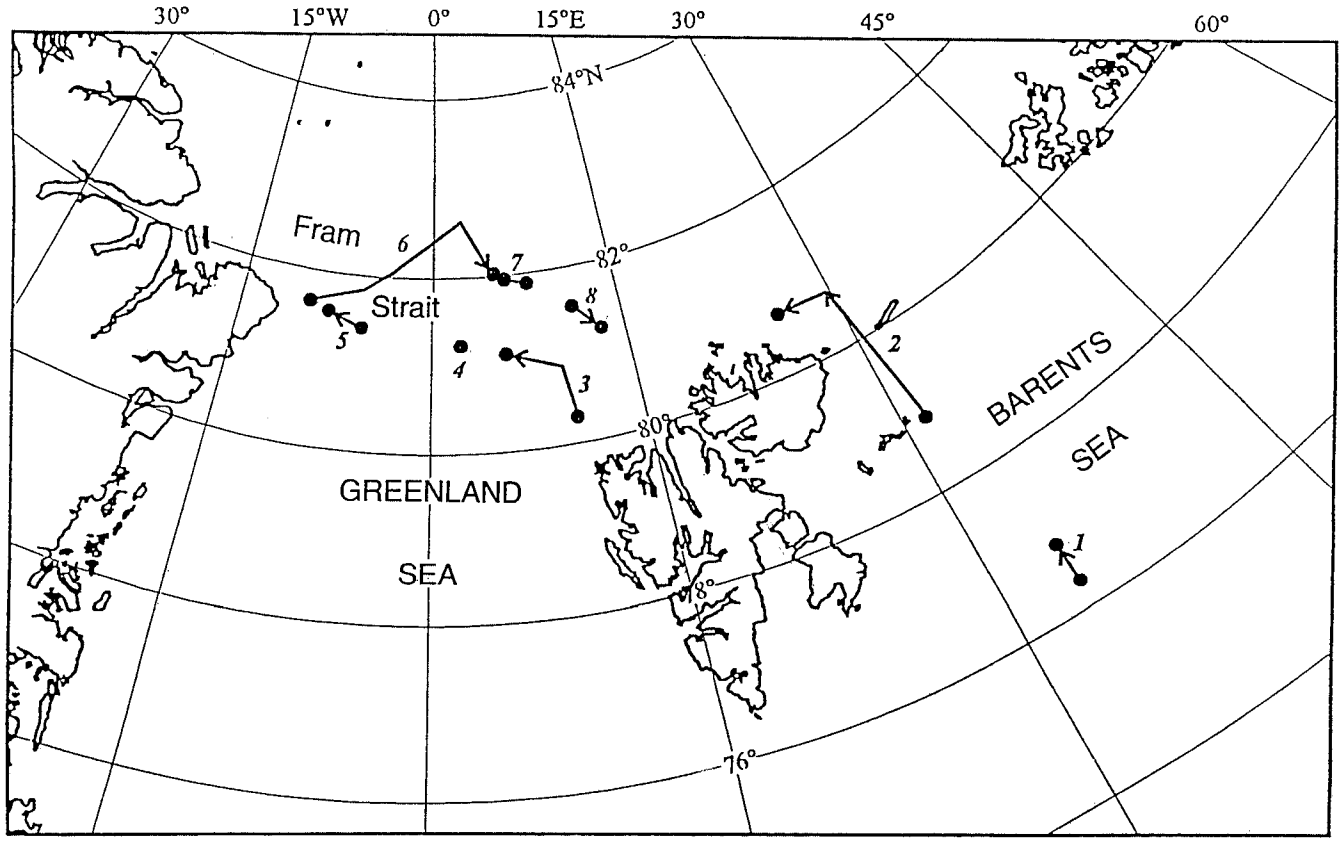

Fig. 2.5: Sampling of aerosols by filtration in the ARK-XIII/2 expedition of the RV "Polarstern".

2.2.1. Aerosol sampling

To exclude contamination from the ship, sampling was interrupted when the relative wind direction was not opposite to the ship movement. No samples were collected during rain and snow falls.

Air was filtered through AFA-Kha-20 acetate-cellulose filters (Petryanov et al., 1968) with the working surface of 20 cm^2 and Whatman-41 fibre filters, which trap both large insoluble particles and submicron particles, including particles of sea salt.

The amount of the aerosol material collected by the filters is insufficient for studying the mineral composition and the material itself is clogged with sea salt. Therefore, filtering was accompanied by sampling the aerosol by nylon meshes. This method allows collection of large amount of aerosols (Chester and Johnson, 1971). After the exposition (usually one day long) the meshes were cleaned in distilled water, the charge was removed, and the particles were separated from the water by filtering through a Nuclepore filters with the diameter 110 mm and the pore size 0.45 μm. After that filters with aerosol material were dried at 60° C.

2.2.2. Granulometric composition measurements in situ

Spectra of size distribution of aerosol particles (granulometric composition) in situ are measured by electrical mobility analysers and photoelectrical particle counters (Finlayson-Pitts and Pitts, 1986; Smirnov, 1992). In our studies we used photoelectrical counter PC-218 (Royco Inc., USA). This counter has pump (rate of pumping is 4.7 cm^3/s), light source (a lamp), photoelectrical detector, and amplifier. It registers particles in the ranges 0.5÷1, 1÷2, 2÷3, 3÷5, 5÷10 μm. It works with 220 V electric supply. The accuracy of measurements is 5%.

2.3. LABORATORY AEROSOL STUDIES

The composition of aerosol samples was studied in laboratories of P.P. Shirshov Institute of Oceanology (Moscow), Alfred Wegener Institute for Polar and Marine Research (Bremerhaven), V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry (Moscow), Institute of Marine Biogeochemistry (Montrouge), Chemical Department of Antwerpen University (Antwerpen) using modern equipment.

2.3.1. Determination of granulometric composition with electro-optical counter

Granulometric composition of insoluble samples collected by meshes was studied with CIS-1 laser electro-optical particle counter (Galai Inc., Israel) in Alfred Wegener Institute for Polar and Marine Research, Bremerhaven. The particulate matter was resuspended from nuclear filter in an ultrasonic cell following the method described elsewhere (Leinen et al., 1994) and then analysed in the range of 0.5-100 μm. This method is described in more details in (Aharonson et al., 1986).

2.3.2. Optical microscopy

Qualitative estimation of granulometric composition and proportion of biogenic and mineral particles in insoluble aerosols was carried out using

optical microscopy method. Section of nuclear filter (approximately 2 x 2 cm) was glued by Canadian balsam to the object glass, then cover glass was glued and slide was dried at 20° C. Slides were described using MIN-8 microscope with magnification up to 480 times.

2.3.3. Scanning electron microscopy.

Morphology of particles, proportion of biogenic, mineral and anthropogenic particles were studied by scanning electron microscopy in P.P. Shirshov Institute of Oceanology, Moscow using JSM-U3 microscope (Jeol Inc., Japan) with magnification from 100 to 10000 times.

Qualitative elemental composition of selected individual particles was studied in Antwerpen University by scanning electron microscope with the JXA-733 microprobe (Japan) and in Alfred Wegener Institute for Polar and Marine Research, Bremerhaven by scanning electron microscope SEM-515 with X-ray microprobe EDAX PV9900 (Philips, USA). In Antwerpen University the element composition of 400 particles with the sizes from 0.4 to 15 μm was studies in each of 10 samples in automatic regime. In Alfred Wegener Institute elemental composition of aerosol particles was studied in the manual regime. The method individual particle analysis is described elsewhere (Rojas and Van Grieken, 1992; Van Malderen et al., 1992; Bondarenko et al., 1994; Jambers et al., 1997).

2.3.4. Atomic absorption spectrometry

Atomic absorption spectrometry (AAS) is based on the measurement of the absorption of radiation by free atoms in the ground state. Several types of AAS exists, accordingly to the different atomisation techniques which can be used (Claes et al., 1998). The flame, electrothermal or graphite furnace techniques are the most common. The light source, usually a hollow cathode lamp or electrodeless discharge lamp, emits radiation of a frequency characteristic of the element present in the sample. A part of this radiation will be absorbed by the atomic vapour. The concentration of the analyte can be determined by constructing calibration curves.

In this study AAS was carried out Institute of Marine Biogeochemistry, Montrouge (France). Aerosol samples were digested by mixture of acids ($HF+HNO_3+HClO_4$) in Teflon bombs at temperature 130-140° C. After digestion Na, K, Ca and Mg were determined by flame AAS using Perkin-Elmer 272 spectrometer and Mn, Co, Cu, Zn, Cd, and Pb by graphite furnace technique using Perkin-Elmer 3030 spectrometer with HGA-500 graphite furnace block. Accuracy for Na, K, Ca, Mg and Cu was 5%, for Mn and Co – 6%, for Zn – 8%, for Cd and Pb – 10%.

2.3.5. Instrumental neutron activation analysis

The instrumental neutron activation analysis (INAA) was the main method for study the elemental composition of aerosols. In instrumental neutron activation analysis the production of a radionuclide from an analyte element after irradiation of samples by thermal neutrons in a nuclear reactor is used for the identification and quantitative determination of the element (Claes et al., 1998). Some time after the end of the irradiation, the radiation emitted by the decaying radionuclides is measured with high-resolution γ-ray spectrometers with semiconductor detectors. The elements present are identified by the

energies and relative intensities of the γ-ray lines in the spectrum. The amount of the element is related to the area of the appropriate photo-peak.

In our studies INAA was carried out in the V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry RAS, Moscow. Samples and standards were irradiated during 20 hours with neutron flux of 1.2×10^{13} neutrons cm^{-2} s^{-1} in a nuclear reactor. The radiation emitted was measured using ORTEC γ-ray spectrometer (USA). This method is described in more details in (Walter et al., 1993; Kolesov, 1994). Detection limits and accuracy of the analysis are presented in Table 2.2.

Table 2.2: Detection limits and accuracy of instrumental neutron activation analysis (D.Yu. Sapozhnikov, personal communication), ppm.

Number	Element	Detection limit	Accuracy, %
11	Na	50	2÷5
19	K	100	8÷10
20	Ca	5000	8÷10
21	Sc	0.05	2÷5
24	Cr	2.0	2÷5
26	Fe	100	2÷5
27	Co	0.05	2÷5
28	Ni	10	10÷15
29	Cu	100	15÷20
30	Zn	10	10÷15
33	As	0.8	8÷10
34	Se	0.5	10÷15
35	Br	0.3	8÷10
37	Rb	15	8÷10
38	Sr	100	10÷15
40	Zr	10	10÷15
47	Ag	1	8÷10
51	Sb	0.5	8÷10
55	Cs	0.5	8÷10
56	Ba	80	10÷15
57	La	0.2	2÷5
58	Ce	1	5÷8
60	Nd	5	10÷15
62	Sm	0.05	2÷5
63	Eu	0.03	2÷5
65	Tb	0.05	8÷10
70	Yb	0.2	5÷8
71	Lu	0.04	5÷8
72	Hf	0.2	5÷8
73	Ta	0.5	8÷10
79	Au	0.5	2÷5
90	Th	0.2	5÷8
92	U	0.2	5÷8

3. QUANTITATIVE DISTRIBUTION OF INSOLUBLE AEROSOLS IN THE ARCTIC

Concentrations of insoluble fraction of the arctic aerosols were measured by mesh method (part 2.2). The distribution of insoluble aeolian material depends on climatic zone, distance from the land, wind direction, wind speed, humidity and precipitation (Lisitzin, 1972, 1996; Zhivago and Bogdanov, 1974; Duce et al., 1976 a; Prospero, 1981; Chester, 1986, 1990; Prospero and Uematsu, 1989; Lukashin et al., 1996 a, b; Arimoto et al., 1997). In the Russian Arctic quantitative distribution of insoluble aerosols was studied in our expeditions (Shevchenko and Kuptzov, 1993; Shevchenko et al., 1995, 1999 a, c, 2000).

The highest concentration of insoluble aerosols (1.38 $\mu g/m^3$) was registered on August 19-20, 1996 in the Greenland Sea in the sample No. 7 (the 15th expedition of the RV "Professor Logachev") during north-west wind blowing from the Greenland (App. 1; Fig. 2.1). Scanning electron microscopy and chemical analysis of this sample (Chapters 5 and 7) have shown that here terrigenic material dominates. Construction of back trajectories in the Russian Hydrometeorological Centre (Moscow), carried out by T.Ya. Ponomareva, has shown that at the 1000 hPa pressure surface (at the sea level) and at 925 hPa surface air masses arrived from the NE Greenland (Fig. 3.1). It seems that we registered delivery of terrigenic matter blown out by strong wind from the Greenland coastal soils. Very strong katabatic winds (foens) are often formed during cold air running down from the Greenland ice cupola (Sugden, 1982; Katabatic ..., 1998). These winds bring much large (>2 μm) soil particles to the coastal atmosphere (Kikuchi et al., 1996).

Relatively high concentration of insoluble aerosols (0.97 $\mu g/m^3$) was registered on October 4, 1994 in the Southern Barents Sea during the wind blowing from the land with speed 9 m/s (App. 1; Fig. 2.1 and 2.2). On the October 2-3, 1994 during strong wind (11 m/s) concentration of insoluble aerosols was also high (0.55 $\mu g/m^3$). Lowest concentrations of aerosols were found in remote areas and after rain that testifies the washing out atmosphere by precipitation (Brimblecombe, 1996).

Average concentration of insoluble aerosols in the Russian Arctic is equal to 0.23 $\mu g/m^3$ (n=55 samples), which is higher than concentrations of aerosols in remote region of the World Ocean, especially in humid zones, but is much lower than aerosol concentrations in arid zones (Table 3.1). In the World Ocean the concentration of insoluble aerosols depends on climatic zonality and on the distance from the land (circumcontinental zonality). It varies from 0.01 to 0.1 $\mu g/m^3$ in the remote areas of humid zone of the Atlantic Ocean, from 0.02 to 2.34 $\mu g/m^3$ in the humid equatorial Western Pacific near islands and from 10 to 50 $\mu g/m^3$ in offshore areas of the northern arid zone of the Atlantic Ocean (Lisitzin, 1996; Lukashin et al., 1996 a). The distribution of aerosol in the Arctic is characterized by strong spatial and temporal variability (App. 1).

In the seas of the Russian Arctic the circumcontinental zonality is not very clear because the distance from the land and large islands is not very large (Fig. 2.1 - 2.5). But nevertheless, the high concentrations of insoluble aerosols were registered in dry weather conditions near the land, especially during winds blowing from the coast. For example, in August 1991 during the SPASIBA-91 expedition highest concentrations of aeolian dust (0.40÷0.46 $\mu g/m^3$) were found

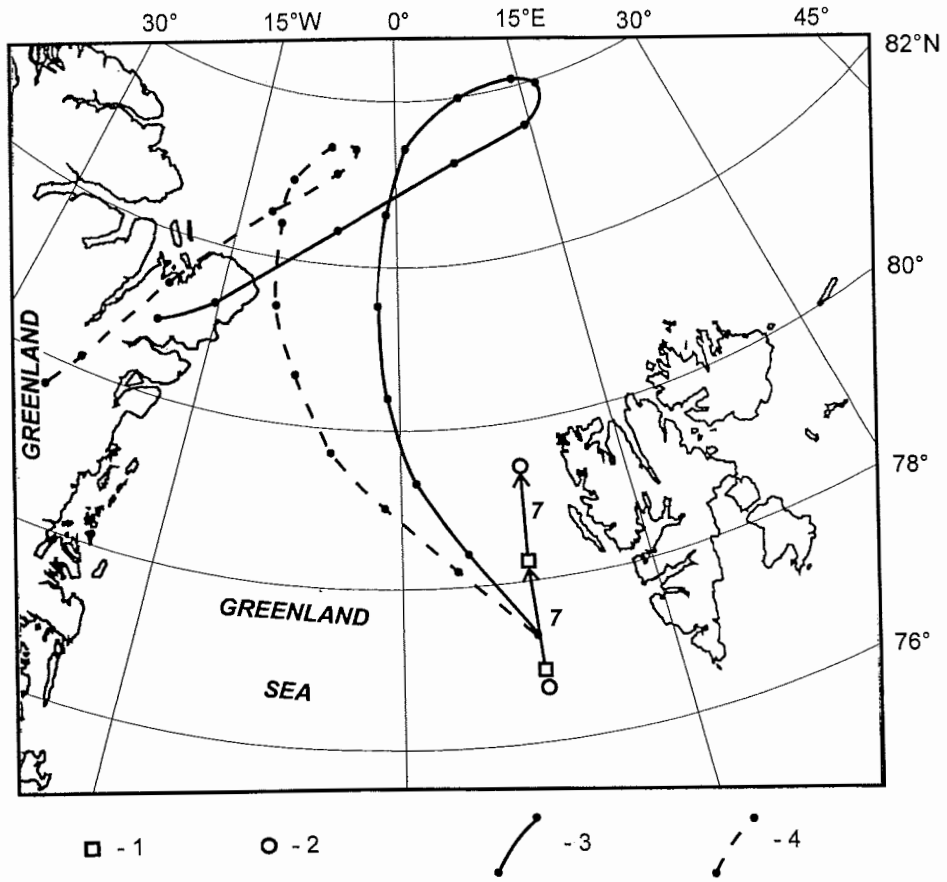

Fig. 3.1: Back trajectories of air mass movement in the area of aerosol sampling in the 15th expedition of the RV "Professor Logachev" (1 – mesh sample No. 7; 2 – filtered sample No. 7) at 1000 hPa level (3) and 925 hPa level (4). The trajectories were reconstructed for the point 77°30'N, 7°24'E at 06.00 p.m., August 19, 1996 in Hydrometeorological Centre of Russia by T.Ya. Ponomareva.

near the land when strong winds (12÷15.7 m/s) blew from the coast (samples 1, 2 and 6; App. 1; Fig. 2.1). At the end of August – beginning of September 1993 during the 49th expedition of the RV "Dmitry Mendeleev" highest concentrations of insoluble aerosols (0.66 and 0.48 μg/m^3) were found in the south-western part of the Kara Sea near Yamal Peninsula and Southern Island of the Novaya Zemlya Archipelago in dry weather. In August 1994 during the 9th expedition of the RV "Professor Logachev" long time precipitation were not registered. In that time lowest concentration of aeolian dust (from 0.13 to 0.18 μg/m^3) were registered in remote marine areas when wind blew from the open sea (samples numbers 1, 10, 11, 14, 15), but highest (from 0.49 to 0.57 μg/m^3) – in the Saint Anna Trough near to Novaya Zemlya Archipelago and Franz-Jozef Land (App.1; Fig. 2.1 and 2.2). During this expedition in beginning of October 1994 relatively high concentrations of insoluble aerosols (from 0.40 to 0.97 μg/m^3) were near the coast in the southern part of the Barents Sea (samples numbers 16, 17, 19, 20).

So, the quantitative distribution of aerosols has fast changing character; it depends on many regional and local factors.

Table 3.1: Concentration of insoluble aerosols in the marine boundary layer over seas of the Russian Arctic and in other regions of the World Ocean.

Region	Sam-ples, n	Concentrations, μg/m^3				Reference
		minimal	maximal	average	standard deviation	
Russian Arctic	55	0.02	0.97	0.23	0.19	This work
North Atlantic humid zone, remote areas		0.01	0.1			Lisitzin, 1996
North Atlantic humid zone, offshore areas			20			Lisitzin, 1996
North Atlantic arid zone, remote areas				7.7		Lisitzin, 1996
	18	1.48	65.4	18	17.4	Lukashin et al., 1996a
North Atlantic arid zone, offshore areas		10	50			Lisitzin, 1996
	3	5.8	11			Chester and Johnson, 1971
Northern arid zone of the Indian Ocean, offshore areas	4	2	4.6			Zhivago, 1975
	3	0.92	4.4			Aston et al., 1973
Equatorial zone of the Indian Ocean, remote areas	3	0.01	0.07			Zhivago, 1975
	7	0.01	0.25			Aston et al., 1973
Equatorial zone of the Pacific Ocean, western part	22	0.02	2.34	0.46	0.55	Lukashin et al., 1996b
South Atlantic arid zone, offshore areas	2	3.58	5.68	4.63	1.48	Shevchenko et al., 1994

4. GRANULOMETRIC COMPOSITION OF ARCTIC AEROSOLS

Granulometric composition of aerosols (aerosol particle size distribution) in the arctic marine boundary layer was studied during the ARK-XI/1, ARK-XIII/2 and ARK-XIV/1a expeditions of the RV "Polarstern" and in the 11th expedition of the RV "Akademik Sergey Vavilov" (Table 2.1 and App. 4; Fig. 4.1 and 4.2). The method of measurement is described in part 2.2.2.

In the Laptev Sea concentration of particles larger than 0.5 μm in the marine boundary in July-September 1995 varied from 0.09 to 24.1 cm^{-3} (7.84 cm^{-3} on average; n=189 measurements) (App. 4; Table 4.1), that is of the same order as values registered in the Norwegian Sea, at the Wrangel Island, on the Franz-Josef Archipelago and the rural regions of the Central Russia (Kajro and Dubrovin, 1987; Barteneva et al., 1991; Smirnov, 1992; Smirnov et al., 1995, 1996 a, b, 1999) and much lower than in arid areas of the Tajikistan (from 20 to 10 cm^{-3}) (Gillette et al., 1992). General view of aerosol size distribution curves in the marine boundary layer over the Laptev Sea, in other arctic regions and in Central Russia differs insignificantly (Fig. 4.3). Aerosols in these areas differ in mineral and chemical composition.

In general, concentrations of small particles (from 0.5 to 1 μm) are much higher than concentrations of large particles (App. 4; Fig. 4.3). In areas where open water occupies more than 30%, the concentration of particles larger than 0.5 μm increase with the increase of wind speed (App. 4; Table 4.1; Fig. 4.4). This could testify the input of sea salt particles from the sea surface microlayer by wind and the importance of sea salt for the chemical composition of marine aerosols, at it has been shown in other regions (Marks, 1987; Barteneva et al., 1991; O'Dowd and Smith, 1993). For example, in the north-eastern part of the Laptev Sea at times when the wind speed was more than 8 m/s, the concentration of aerosol particles larger than 0.5 μm was from 1.05 to 11.23 cm^{-3} (in average 6.52 cm^{-3} for 30 measurements at 10 sites), but at Site 17 when wind speed was 3.3 m/s we only found value of 0.09 cm^{-3} (Table 4.1).

During the fog generation the total concentration of particles larger than 0.5 μm was at the usual level, while the concentration of particles with size from 2 to 5 μm sharply increased (App. 4; Fig. 4.5) due to formation of fog droplets. This phenomenon was earlier studied under both field and laboratory conditions (Didenko et al., 1994; Bergin et al., 1995; Davidson et al., 1996; Dibb, 1996; Nilsson and Bigg, 1996); it is very significant for washing out matter from the atmosphere (suspended, colloid and dissolved substances).

In the north-western part of the Barents Sea, in the area of underwater Ermak Plateau and, in the Fram Strait in July 1997 during ARK-XIII/2 expedition of the RV "Polarstern" (App. 4; Fig. 4.2) the aerosol size distribution (Fig. 4.6) in general was similar with granulometric spectrum from the Laptev Sea summer aerosols (Shevchenko, 1997 a, b). The highest concentrations of particles larger than 3 μm in this expedition was registered in the ice-free Western Barents Sea (App. 4; Fig. 4.2 and 4.6). In this area high correlation (r=0.88 for 8 sites) between the concentration of large (>5 μm) and wind speed was revealed (Fig. 4.7). It testifies dominance of sea salt particles in the coarse fraction of aerosols. These salt particles are derived from the sea surface microlayer. In ice covered areas the concentration of particles with the size from 1 to 2 μm is than in ice-free sea, especially, at the temperature about –3° C (Fig. 4.6). This is likely the result of ice microcrystals growth in the marine boundary layer at

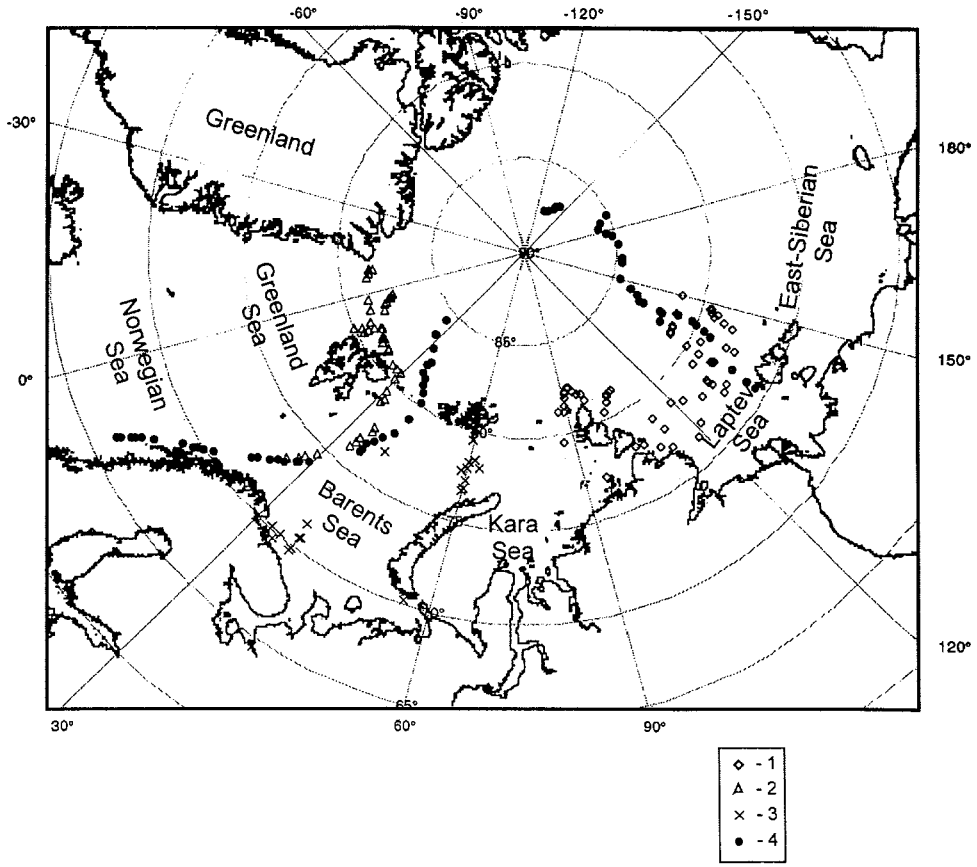

Fig. 4.1: Places, where granulometric composition of aerosols was studied:
1 – ARK-XI/1 expedition of the RV "Polarstern" (July-September 1995);
2 – ARK-XIII/2 expedition of the RV "Polarstern" (July-August 1997);
3 – 11th expedition of the RV "Akademik Sergey Vavilov" (July-August 1997);
4 – ARK-XIV/1a expedition of the RV "Polarstern" (July 1998).

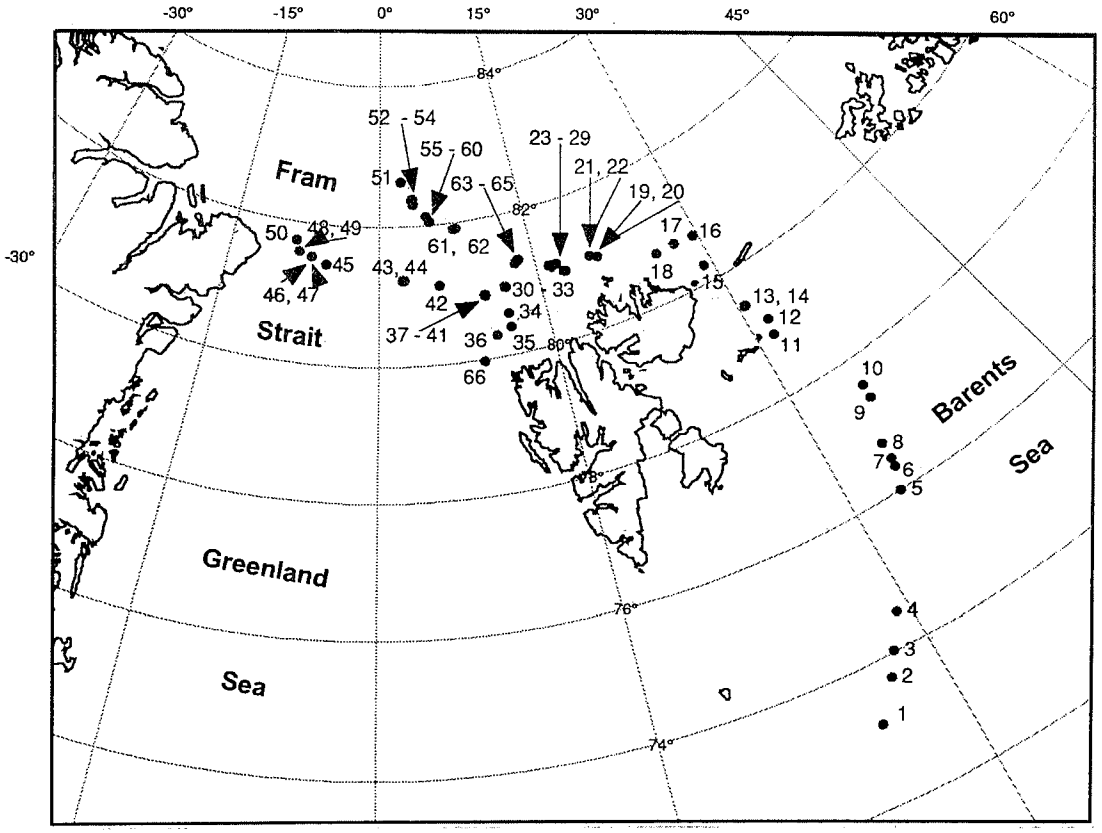

Fig. 4.2: Places, where granulometric composition of aerosols was studied in ARK-XIII/2 expedition of the RV "Polarstern" (July-August 1997).

Table 4.1: Average values of marine aerosol concentration, wind speed, and temperature in the marine boundary layer over the Laptev Sea from July 20 till September 10, 1995 (the ARK-XI/1 expedition of the RV "Polarstern") after Smirnov et al. (1996).

Weather condition	Concentration of particles, cm^{-3}					Wind speed, m/s	Visi-bility, m	Tempe-rature, °C
	>0.5 µm	>1 µm	>2 µm	>3 µm	>5 µm			
All days	7.84	2	0.22	0.06	0.01	8.6	8000	-2.2
Clear days	6.2	0.33	0.05	0.0002	0	8.1	8600	-4.2
Stormy days	10.6	2.7	0.5	0.06	0.002	14	9900	0.5
Foggy days	7	1.5	0.8	0.33	0.08	5.4	1000	-2.5

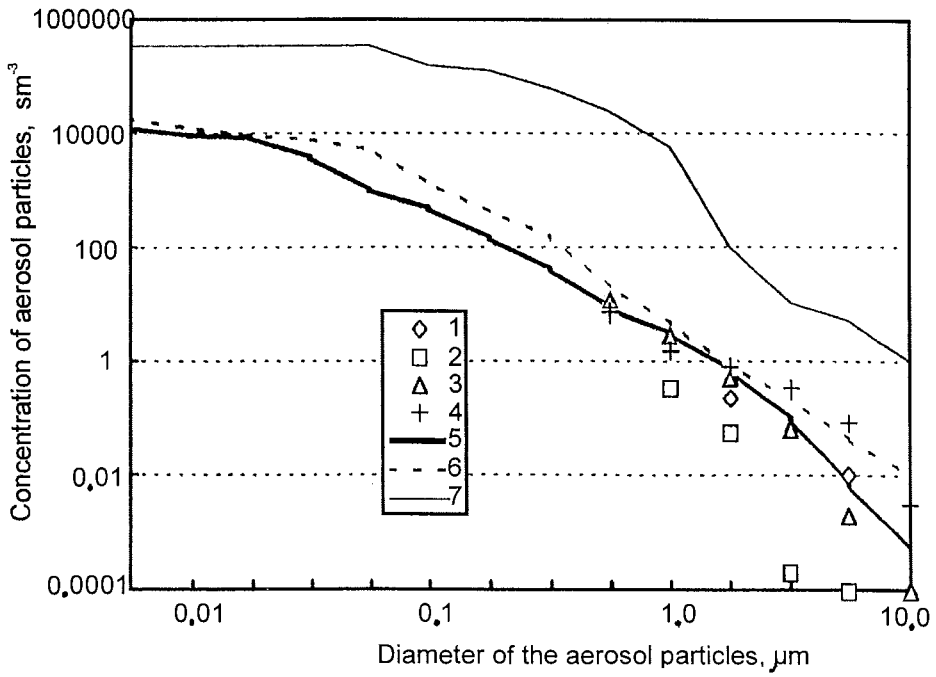

Fig. 4.3: Cumulative curve of the aerosol granulometric composition in the marine boundary layer over the Laptev Sea from July 20 to September 10, 1995 (ARK-XI/1 expedition of the RV "Polarstern") and in the other regions (Smirnov et al., 1996): 1-4 – the Laptev Sea (1 – all days; 2 – clear days; 3 – days with strong wind; 4 – foggy days); 5 – Franz-Josef Land, spring 1994; 6 – Obninsk, Kaluga Region, Russia, May 1994; 7 – Kazakhstan, dry bottom of the Aral Sea, dust storm on May 30, 1992.

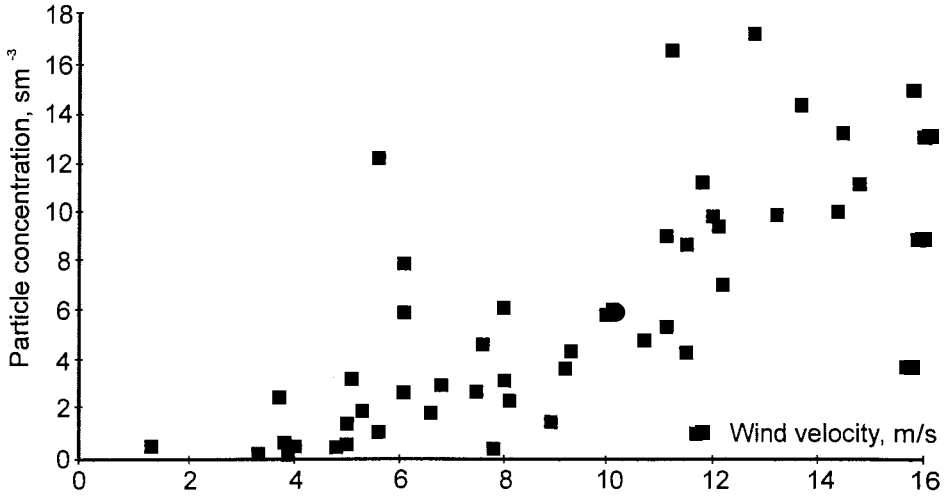

Fig. 4.4: Concentration of aerosol particles large than 0.5 μm in the marine boundary layer over the Laptev Sea vs wind velocity in July-September 1995 (ARK-XI/1 expedition of the RV "Polarstern").

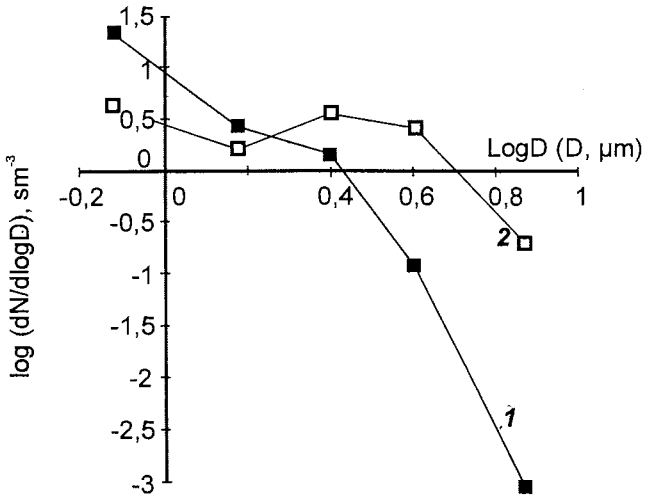

Fig. 4.5: Granulometric composition of aerosols over the Laptev Sea in July-September 1995 (ARK-XI/1 expedition of the RV "Polarstern"): 1 – fine days; 2 – foggy days.

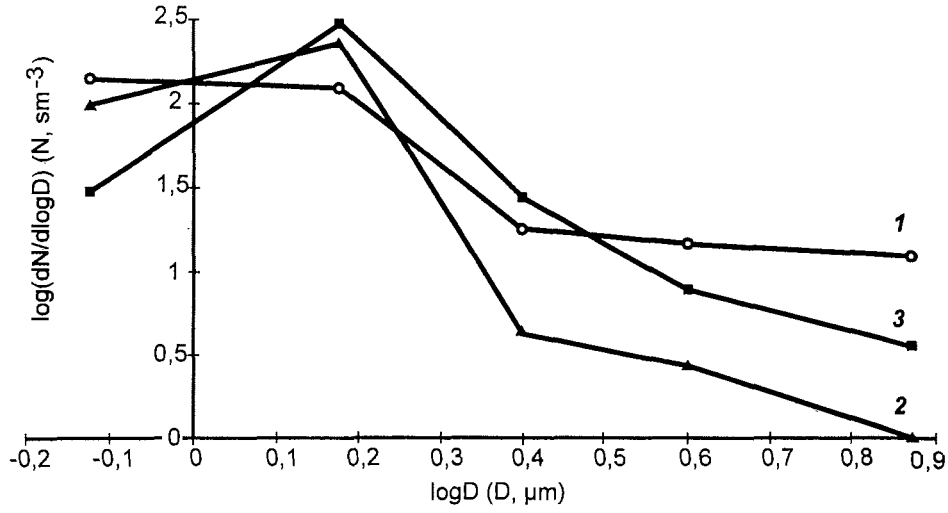

Fig. 4.6: Granulometric composition of aerosols over the western part of the Barents Sea and Fram Strait in June-July 1997 (ARK-XIII/2 expedition of the RV "Polarstern"): 1 – over the open water; 2 – over the ice cover, t_{air} >-1°C; 3 – over the ice cover, t_{air} <-3°C.

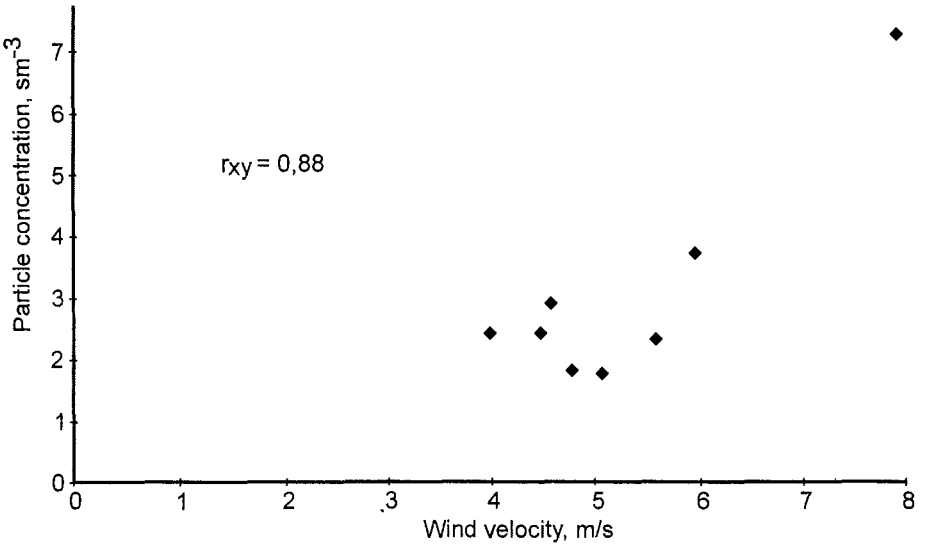

Fig. 4.7: Concentration of aerosol particles larger than 5 μm in the marine boundary layer over the western part of the Barents Sea vs wind velocity in June 1997 (ARK-XIII/2 expedition of the RV "Polarstern").

lowering the temperature as it has been described in (Bigg, 1996). The tentative processing of materials, obtained in the ARK-XIV/1a expedition of the RV "Polarstern" to the Central Arctic in July 1988, has revealed the same regularities in the aerosol particle size distribution (Shevchenko, 1999) (Fig. 4.8).

Study of aerosol size distribution in the ice-free Barents Sea in August-October 1997 during the 11th expedition of the RV "Akademik Sergey Vavilov" demonstrated that the concentration of particles larger than 2 μm increases with the increase of wind speed (App. 4; Fig. 4.9) in the same way as it was described above. So, granulometric composition of aerosols shows, that in the ice-free sea the main part of aerosols consists of sea-salt particles, deflated by the wind from the thin surface microlayer. It is confirmed by study of elemental composition of aerosols collected by filtration (in more details is in the section 7.3).

The size spectrum of insoluble particles in 30 samples, collected by nylon meshes, was examined with the Galai-CIS-1 laser counter in AWI (method is described in section 2.3.1). Common granulometric spectra of insoluble aerosol particle are presented in Fig. 4.10 and 4.11. It has been shown (Table 4.2), that the mean size of particles varies insignificantly from sample to sample (from 1.24 to 1.69 μm). Large particles (from 5 to 25 μm) make the maximum contribution to the sample volume (and, consequently, mass).

Generalisation of the results of the aerosol particle size spectra, obtained with particle counters both ***in situ*** and in the laboratory as well as the qualitative estimation of the particle sizes with a scanning electron microscope, have shown that submicron particles dominate in air, but sediments are mostly (in mass) are formed by water-insoluble particles with the sizes from 5 to 25 μm.

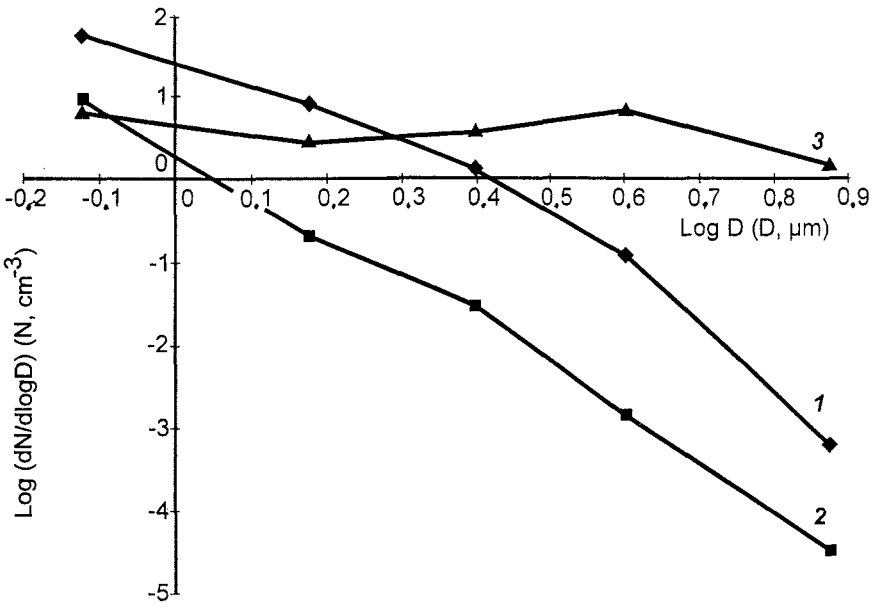

Fig. 4.8: Granulometric composition of aerosols over the central part of the Arctic Ocean in July 1998 (ARK-XIV/1a expedition of the RV "Polarstern"): over the open water; 2 – over the ice cover in fine days; over the ice cover in foggy days.

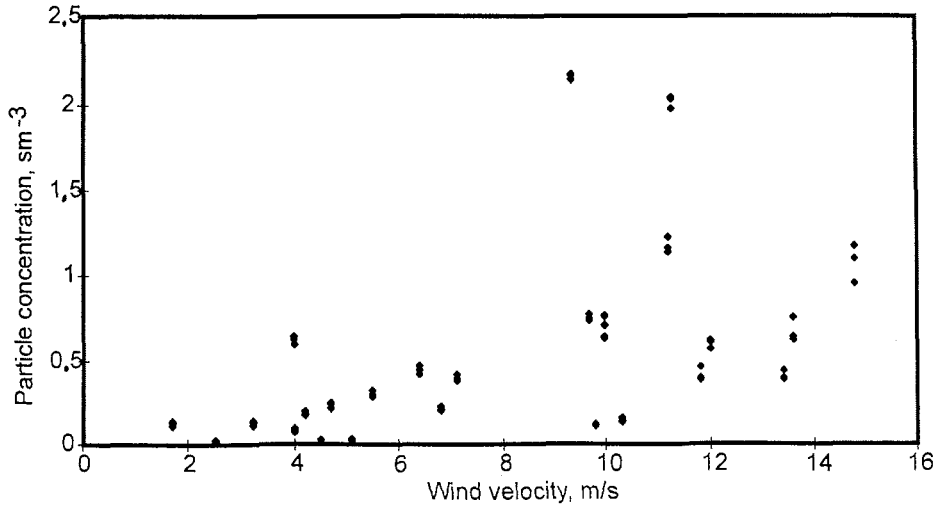

Fig. 4.9: Concentration of aerosol particles larger than 2 μm over the Barents Sea vs wind velocity in August-October 1997 (11th expedition of the RV "Akademik Sergey Vavilov").

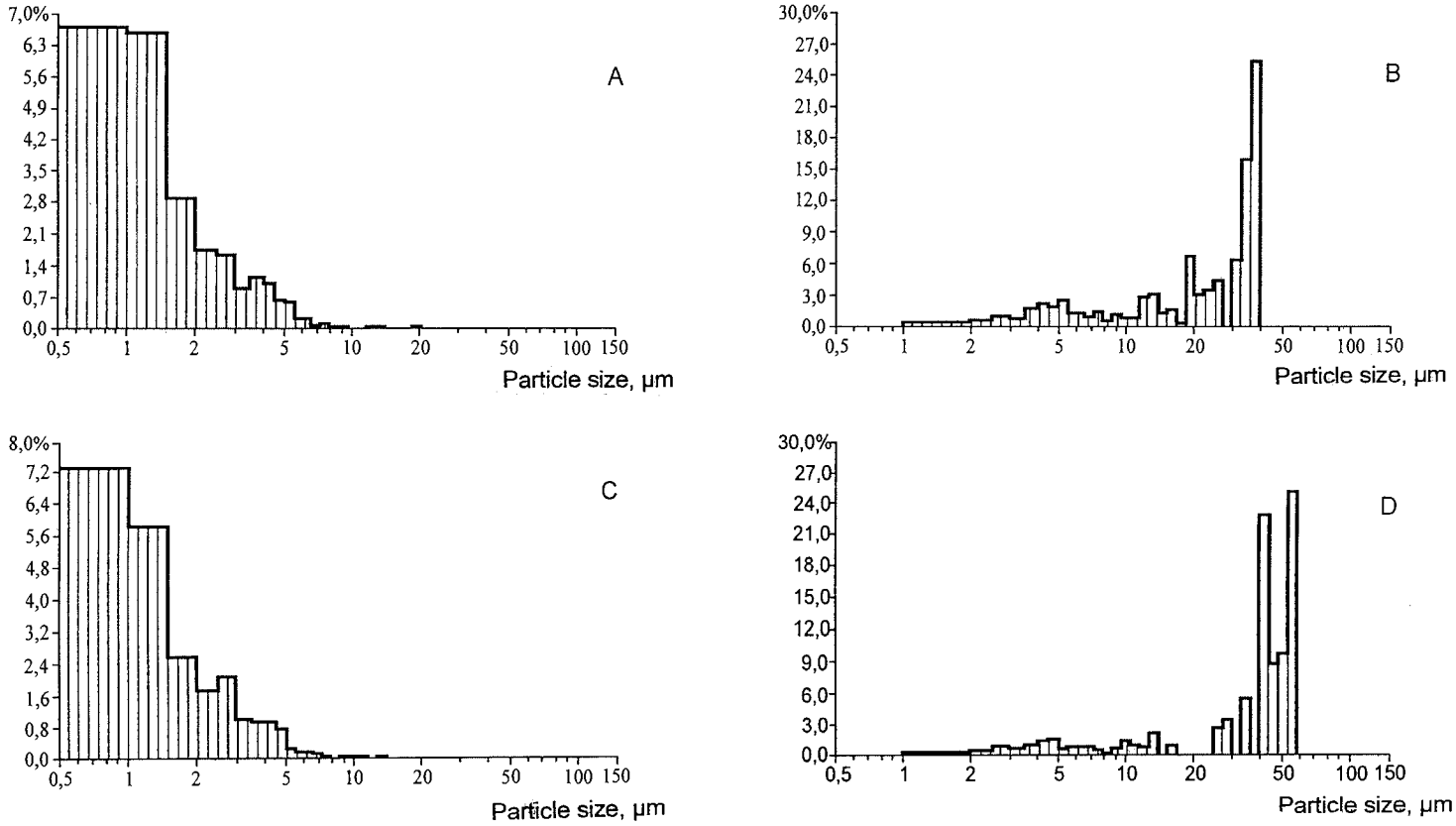

Fig. 4.10: Granulometric composition of insoluble aerosols of the Laptev Sea (July 1995, ARK-XI/1 expedition of the RV "Polarstern"): A and B – mesh sample No. 1; C and D – mesh sample No. 2; histograms of grain size: A and C – by counts; B and D – by volume.

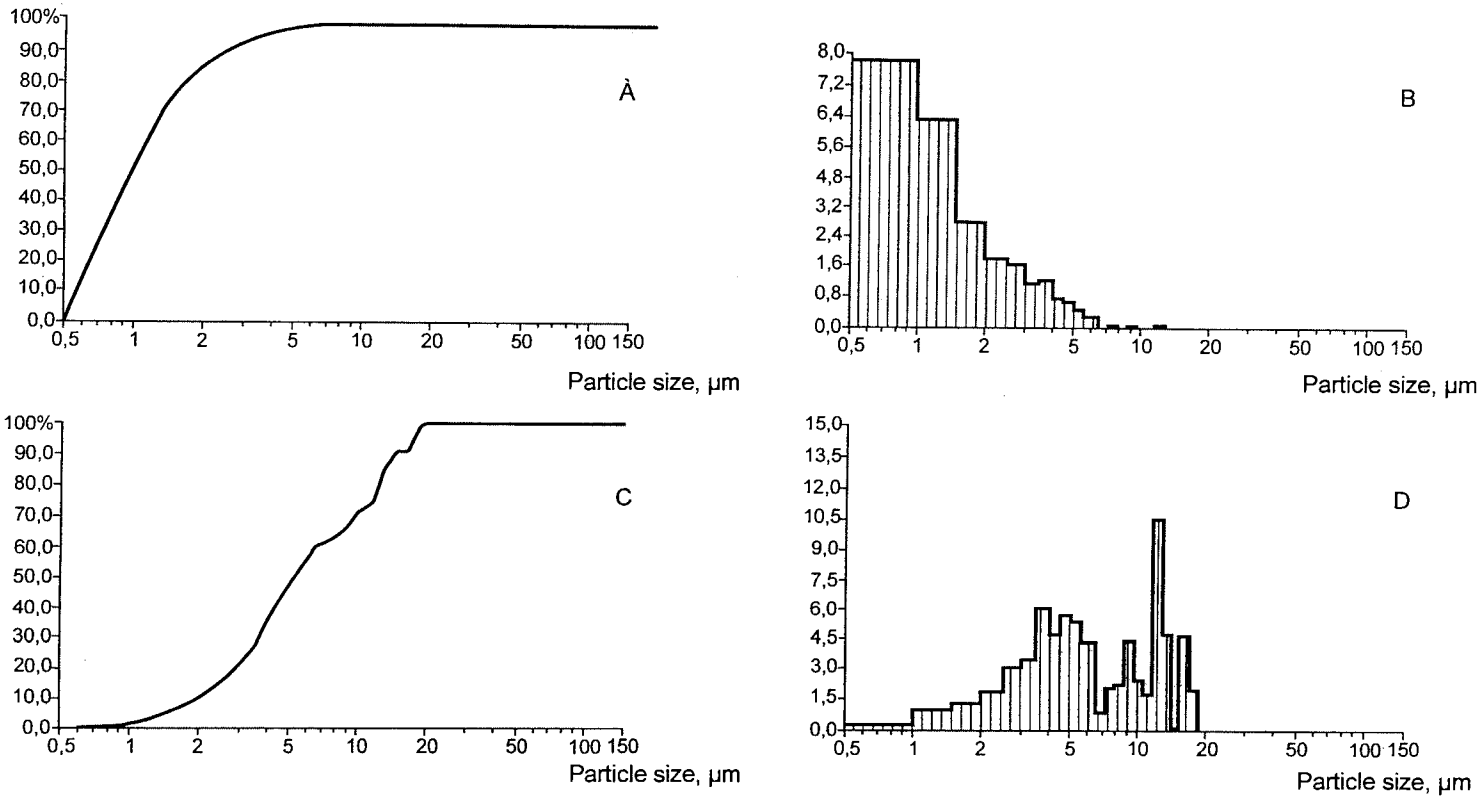

Fig. 4.11: Granulometric composition of insoluble aerosols (mesh sample No. 1 from 11th expedition of the RV "Akademik Sergey Vavilov"): A – cumulative curve of particle concentration by count; B – histogram of particle concentration by count; C – cumulative curve of distribution of particles volume; D – histogram of the particle volume concentration.

Table 4.2: Average size and granulometric composition of insoluble aerosols, collected by nylon meshes. Position and time of sampling are presented in App. 1 and on Fig. 2.1. Analysis was carried out on GALAI-CIS-1 device.

Sample	Particle size, μm		% particles of given size			
	average	standard deviation	0.5 ÷ 1 μm	1 ÷ 2 μm	2 ÷ 5 μm	>5 μm
The 49th expedition of the RV "Dmitry Mendeleev" (August-October 1993)						
3	1.34	1.15	52	34	12	2
4	1.27	1.41	57	31	10	2
5	1.64	1.51	41	35	21	3
6	1.69	1.47	38	37	21	4
7	1.46	1.46	51	31	16	2
8	1.51	1.44	47	34	17	2
9	1.43	1.44	47	38	12	3
11	1.41	1.59	50	34	14	2
12	1.50	1.62	46	36	15	3
13	1.52	1.63	47	35	15	3
14	1.58	1.93	45	36	16	3
15	1.60	1.48	42	36	19	3
16	1.55	1.47	42	38	17	3
17	1.57	1.28	43	34	20	3
18	1.44	1.30	50	32	16	2
19	1.51	1.46	48	33	16	3
20	1.52	1.34	46	34	17	3
21	1.45	1.85	48	37	13	2
22	1.36	1.58	52	34	12	2
23	1.53	1.7	45	36	17	2
ARK-XI/1 expedition of the RV "Polarstern" (July 1995)						
1	1.38	1.37	48	38	12	2
2	1.34	1.40	52	33	14	1
The 15th expedition of the RV "Professor Logachev" (August 1996)						
4	1.52	1.30	43	37	18	2
5	1.57	1.79	45	35	18	2
6	1.50	1.45	50	30	18	2
7	1.54	1.32	47	31	19	1
8	1.24	0.96	56	32	11	1
The 11th expedition of the RV "Akademik Sergey Vavilov" (August 1997)						
1	1.31	1.02	53	34	12	1
2	1.55	1.49	47	33	18	2

5. COMPOSITION OF AEROSOLS ACCORDINGLY TO ELECTRON MICROSCOPY DATA

Accordingly to the data of electron microscopy (Shevchenko et al., 1995 1997, 1998, 1999 a, c, d, 2000) coarse (>1 μm) non-salt particles of Arctic aerosols sampled by nylon mesh method consist largely of mineral and organic matter (plant fibres, pollens, spores, diatom algae, etc.) (Fig. 5.1 – 5.3).

Land soil is the main source of mineral particles. In winter the main contribution is made by long-range atmospheric transport (Rahn, 1981 a; Maenhaut et al., 1989). Plant fibres up to several hundreds micrometers long and pollens of land plants are transported by wind to the distance of hundreds kilometres; their aeolian input was registered in the northern part of Spitsbergen and in the Antarctic (Johansen and Hafsten, 1988; Kappen and Straka, 1988; Linskens et al., 1993). Plant fibres are wind-blown out of the surface of the Arctic soil rich in plant residues (Mikhaylov, 1970; Tzyganenko, 1972; Soils of USSR, 1979; Orlov et al., 1996; Goryachkin, 1998; Dobrovolsky, 1999). For example, in samples No. 10 and 12 from 49th expedition of the RV "Dmitry Mendeleev", collected in the Karskie Vorota Strait and in the western part of the Kara Sea (Fig. 2.1) in September 1993, pollens and spores (Fig. 5.1, f) constitute more than 50% of insoluble particles. Pollens and spores of land plants detected in the suspended particulate matter and in bottom sediments of Arctic seas (Matthiessen, 1999; Naidina and Bauch, 1999) come on the sea surface mostly due to the aeolian transport.

Some samples contain diatoms (for example, sample No. 17 from 49th expedition of the RV "Dmitry Mendeleev" – Fig. 5.1, g, h). Marine diatoms enter the boundary layer due to the wind blowing-out from the sea water surface, whereas fresh-water diatoms come due to the long-range transport of dust from the surface of dried-up tundra lakes, where diatoms are abundant (Getzen, 1985; Diatoms ..., 1988; Getzen et al., 1994; Polyakova, 1997; Kienel, 1999). Earlier the diatoms were found in aerosol samples from other regions of the World Ocean (Kazarina and Serova, 1995). Fresh-water and marine diatoms can come to the ice dome of the Antarctic in the vicinity of the South Pole and the ice dome of the Greenland, where they were found, only by aeolian way (Burcle et al., 1988, 1997; Ram et al., 1988; Marshall, 1996; Kelog and Kellog, 1996). Significant increase of fresh-water diatom flux was registered by sediment traps in the water column off West Africa during aeolian dust delivery from the Sahara Desert, where diatoms are abundant in drying lakes (Lange et al., 1998).

Porous fly ash particles from 5 to 50 μm in size consisting mostly of carbon and smooth spheres from 0.5 to 10 μm in diameter are also characteristic of the Arctic aerosol (Fig. 5.1, i-r; 5.2, b, e, f; 5.3, g, k, l). These particles were found in small amounts in most samples collected by nylon meshes. Porous carbonaceous particles come to the atmosphere as a result of combustion of fossil fuel at industrial plants and transport and biomass burning (Rose et al., 1994; Hueglin et al., 1997; Novakov et al., 1997). During all our expeditions, when approaching the Kola Peninsula or Norilsk, the content of porous ash particles in aerosols increased. The highest content of ash in mesh samples was registered in the sample 18 collected in October 1994 during the 9th expedition of the RV "Professor Logachev" in Kola Bay near Murmansk (App. 1; Fig. 2.1 and 2.2). These particles are accumulated in soils, glaciers,

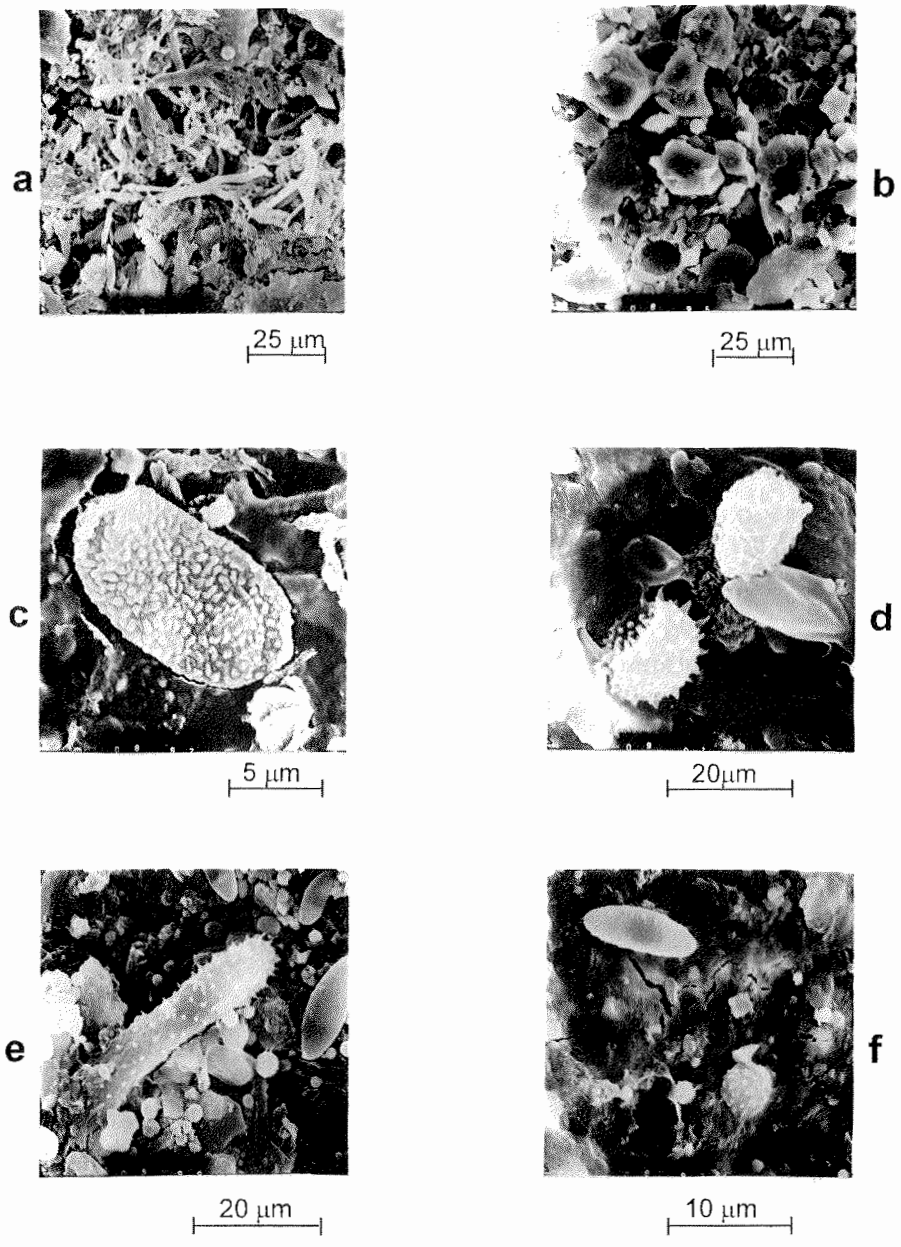

Fig. 5.1: Scanning electron microscope photographs of aerosols, collected by nylon meshes during the 49th expedition of the RV "Dmitry Mendeleev" (August-October 1993): a) plant fibres, sample No. 20; b) mineral grains, sample No. 20; c)-f) pollens (c – sample No. 3; d – sample No. 4; e – sample No. 9; f – sample No. 10). Position of samples see at Fig. 2.1.

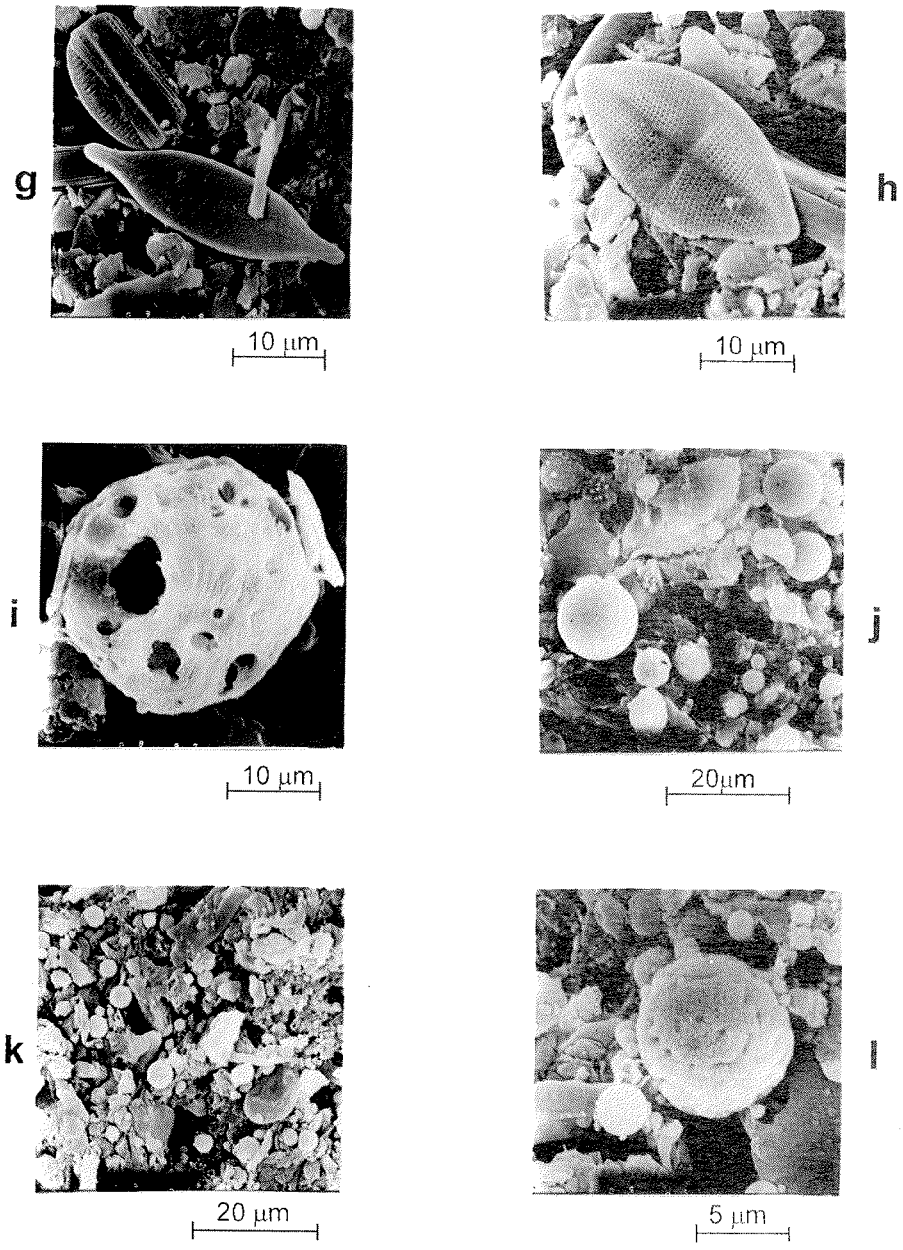

Fig. 5.1 (continue): g)-h) diatoms, sample No. 17; i) fly ash, sample No. 8; j)-k) combustion spheres (j – sample No. 10; k – sample No. 16); l) fly ash and combustion spheres, sample No. 16.

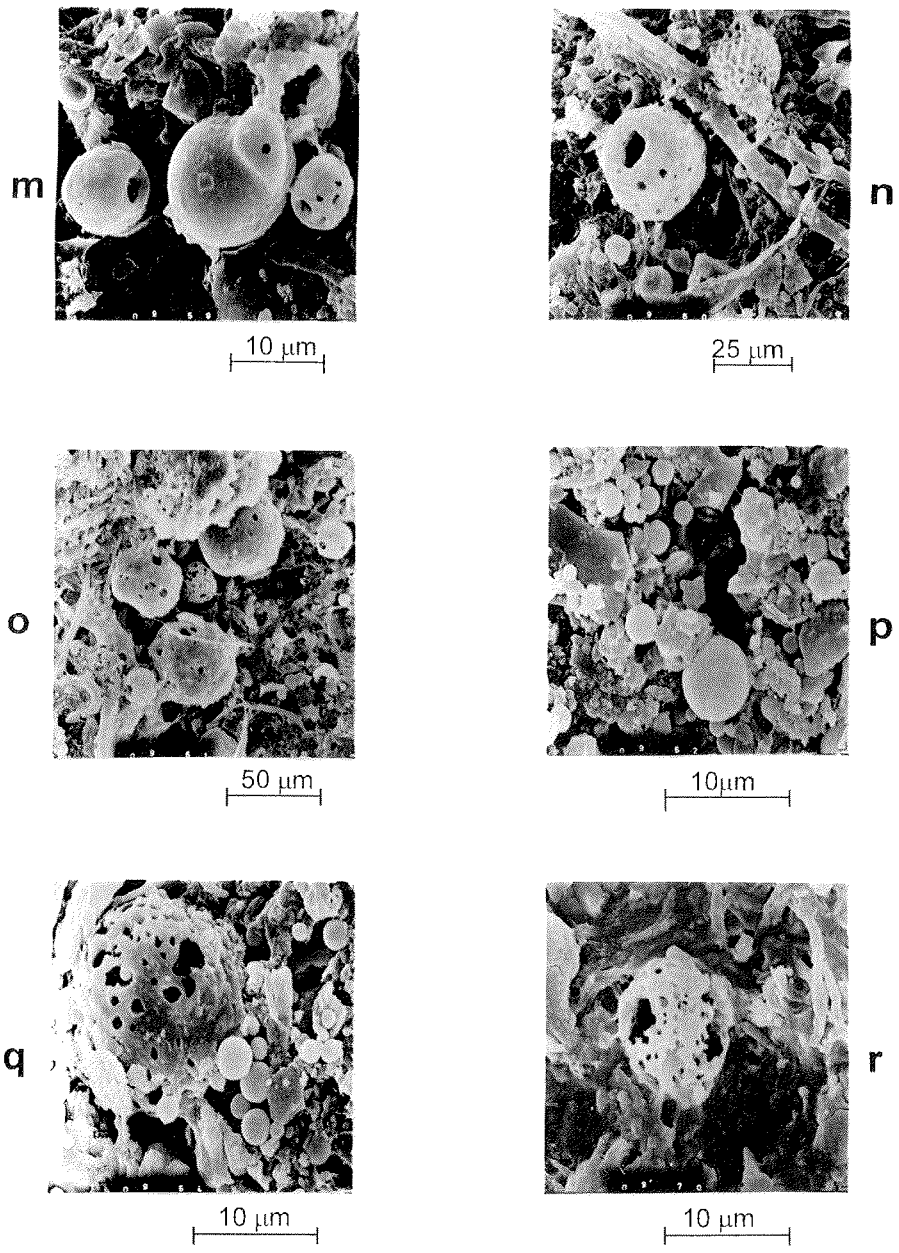

Fig. 5.1 (continue): m)-r) combustion spheres and fly ash (m – sample No. 18; n – sample No. 18; o – sample No. 18; p – sample No. 21; q – sample No. 21; r – sample No. 15).

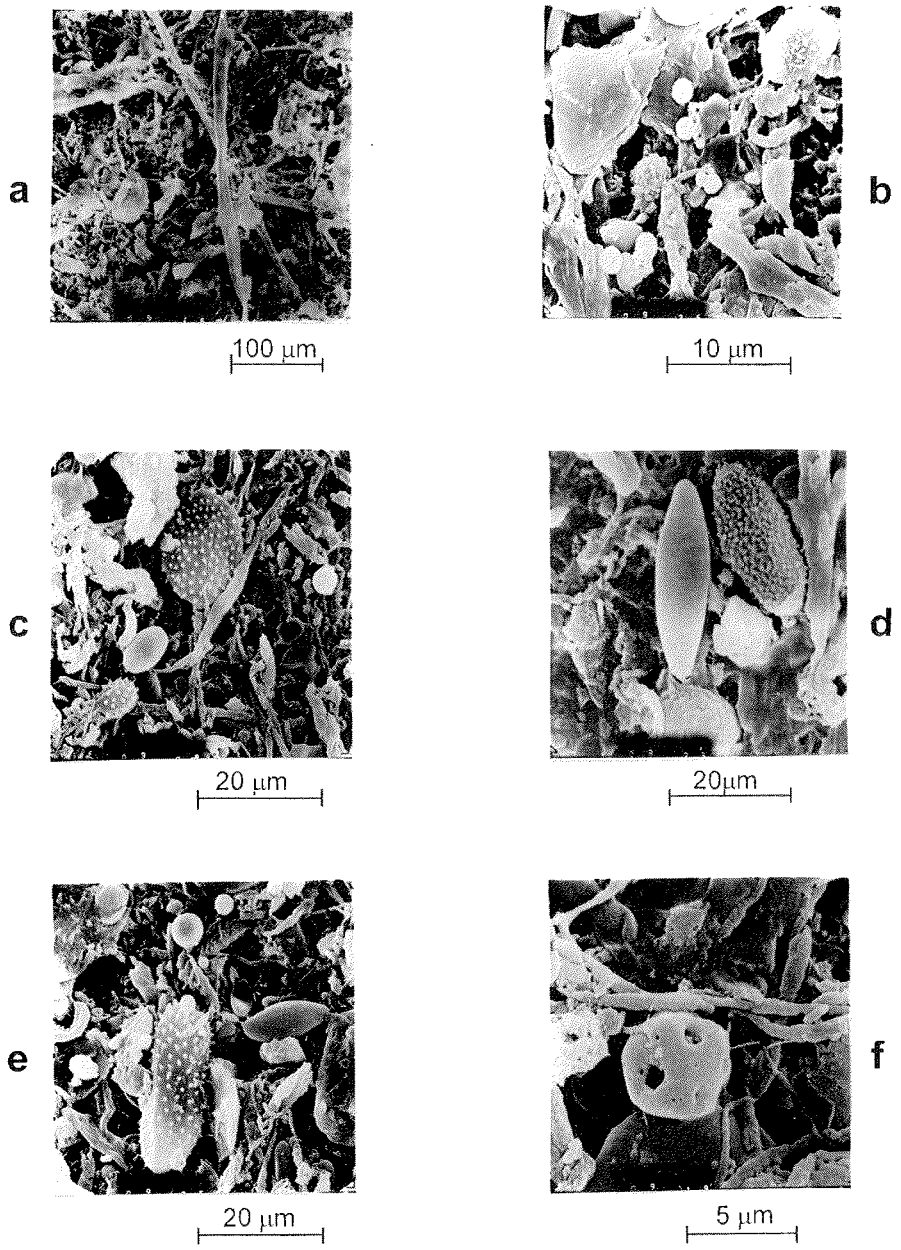

Fig. 5.2: Scanning electron microscope photographs of aerosols, collected by nylon meshes during the 31st expedition of the RV "Akademik Mstislav Keldysh" (August-September 1993): a) general view, sample No. 1; b) pollens, mineral grains and combustion spheres, sample No. 7; c) pollen, sample No. 3; d) pollen, sample No. 6; e) pollen and combustion spheres, sample No. 7; f) fly ash, sample No. 3. Position of samples see at Fig. 2.1.

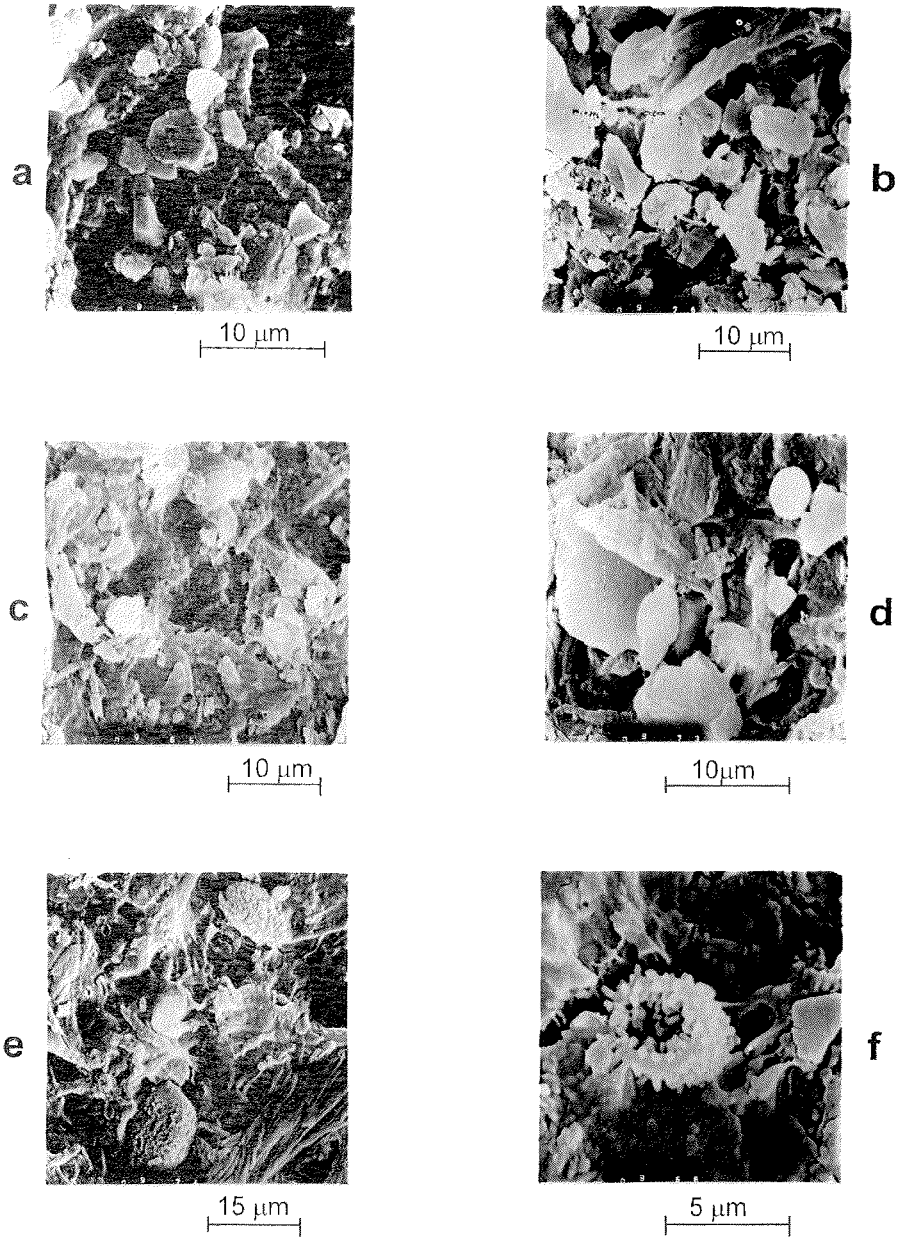

Fig. 5.3: Scanning electron microscope photographs of aerosols, collected by nylon meshes during the 9th expedition of the RV "Professor Logachev" (August-October 1994): a) mineral grains, sample No. 8; b) mineral grains and plant fibres, sample No. 9; c) mineral grains and plant fibres, sample No. 11; d) mineral grains, plant fibres and combustion sphere, sample No. 19; e) plant fibres, pollens, sample No. 20; f) pollen, sample No. 14. Position of samples see at Fig. 2.1 and 2.2.

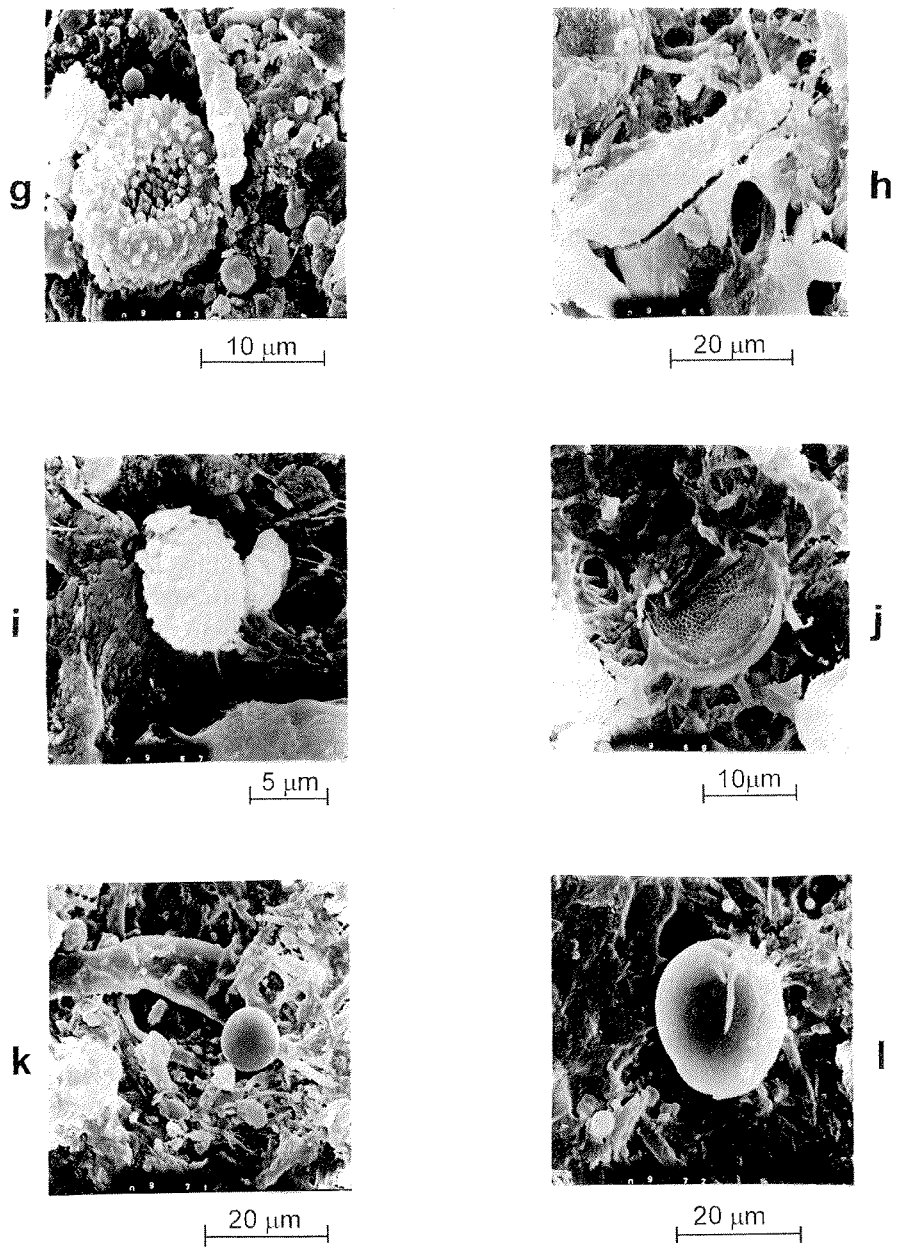

Fig. 5.3 (continue): g)-i) pollens (g – sample No. 21; h – sample No. 12; i – sample No. 13); j) diatom, sample No. 14; k)-l) mineral grains, plant fibres and combustion spheres (k – sample No. 16; l – sample No. 17).

lake bottom sediment; they are indicators of the aeolian transfer of pollutants (Renberg and Wik, 1985). The studies of the surface layer of bottom sediments in the lakes located far from industrial centres (Spitsbergen, the Shetland Islands, northern regions of Norway, Sweden, and Finland) have shown that the porous carbonaceous particles are present in all the lakes under study and their content is at the background level (Wik and Renberg, 1991; Rose, 1995). The content of the porous carbonaceous particles increases sharply in the surface layer of bottom sediments in the lakes of the Kola Peninsula located in the vicinity of mining and smelter plants (Rose, 1995). Their relatively high content was found in the surface layer of bottom sediments in lakes of other industrial regions, in particular, in sediments of the Great Lakes in the USA (Karl and Christensen, 1998).

Smooth spheres of 0.5÷1 μm in diameter are formed at high-temperature processes, and they are often referred as combustion spheres (Sheridan and Musselman, 1985). They are emitted into the atmosphere not only by smelters, but also by some other anthropogenic sources, for example, at the combustion of oil and coal, what is confirmed by their chemical composition (Savenko, 1991). Combustion spheres can be transported by air masses to long distances. They were described in Arctic aerosols by some authors (Sheridan and Musseleman, 1985; Ishizaka et al., 1989; Sheridan, 1989; Sheridan and Zoller, 1989). The highest content of combustion spheres (more than 50% of particles larger than 1 μm) was found by us in the samples No. 8 and 16, collected in the southern Kara Sea in September 1993 (the 49th expedition of the RV "Dmitry Mendeleev") under dominant income of air masses from the Norilsk region (according to the maps of baric situations, see Fig. 5.4 and 5.5 and back trajectories, see Fig. 5.6). These samples are heavily polluted by aerosol particles formed in the smog emitted by the Norilsk copper-nickel smelter with anomalous chemical composition of both the combustion spheres (see Section 7.1) and the samples as a whole (see Sections 7.2 and 7.3). In the 49th expedition of the RV "Dmitry Mendeleev" high content of combustion spheres was registered also in mesh samples No. 4 (the southern Barents Sea), 9, 11, 12 (the western Kara Sea) (Fig. 2.1). In August-September 1991 during the SPASIBA-91 expedition high content of combustion spheres was found in samples No. 5 and 6, collected relatively close to Norilsk (Fig. 2.1) (Shevchenko et al., 1999 a, d). Elemental composition of these particles is looked through in the Section 7.1. High content of combustion spheres also was registered in samples No. 17 and 18, collected in beginning of October 1994 near the Kola Peninsula (Fig. 5.3, l).

Thus, the study of the morphology of coarse (>1 μm) insoluble particles with an electron microscope indicates that the main source of the aeolian material over the Arctic seas in July-October is Eurasia, although in winter the contribution of far and very far (>10000 km) sources increases significantly.

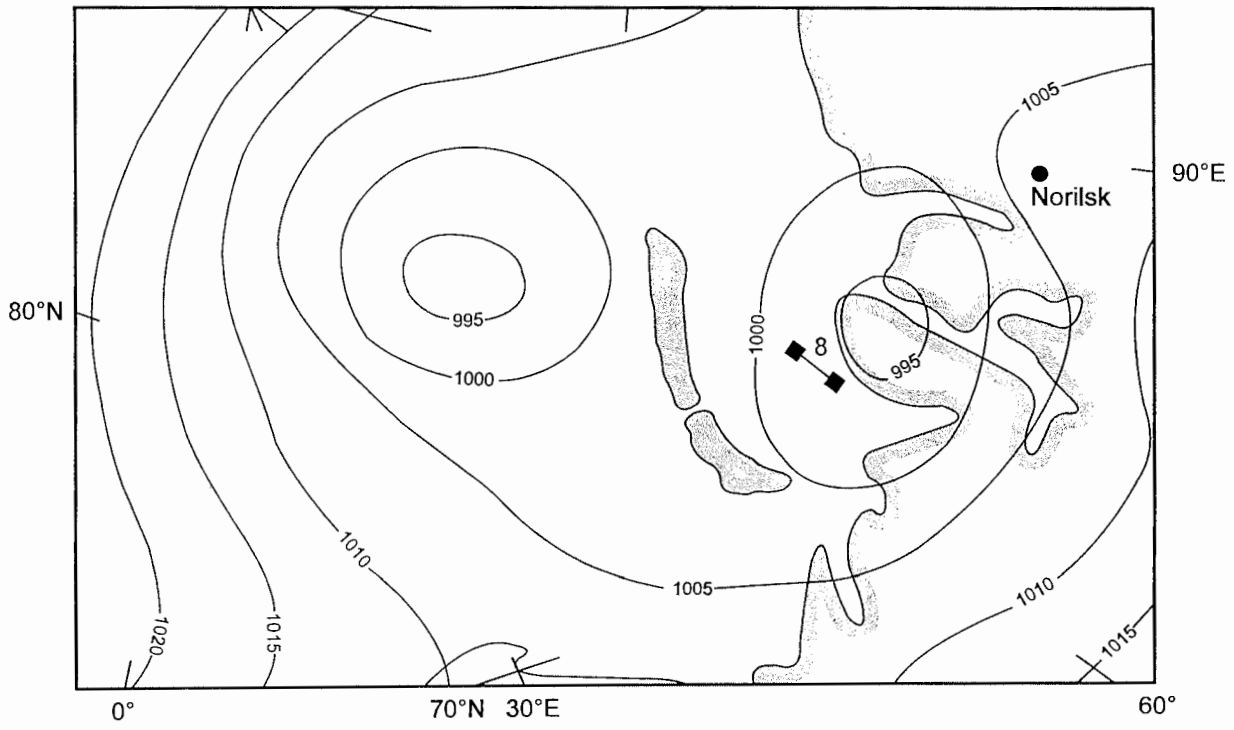

Fig. 5.4: 1000-hPa map of the Kara Sea and adjacent part of the Arctic Ocean for 06.00 UTC, September 3, 1993 during collection of mesh sample No. 8 in 49th expedition of the RV "Dmitry Mendeleev".

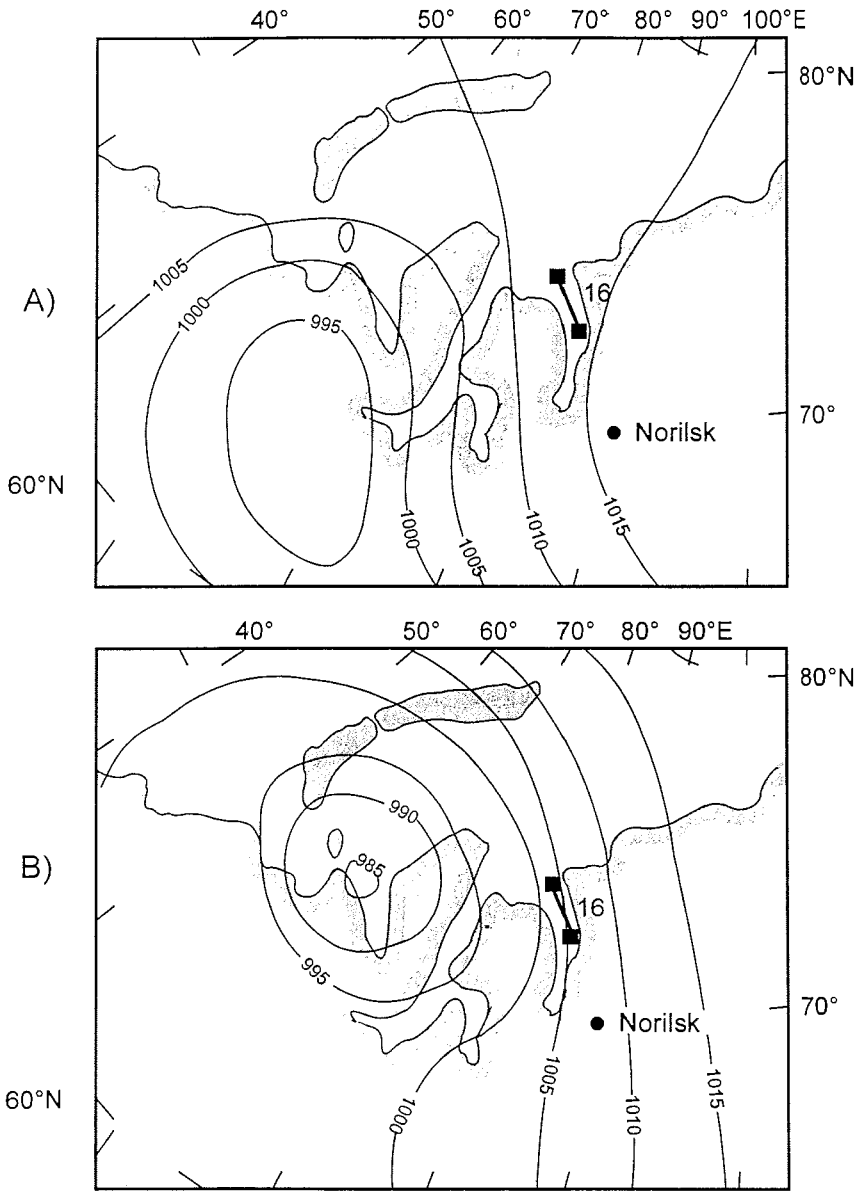

Fig. 5.5: 1000-hPa map of the Kara Sea region for time of mesh sample No. 16 collection (49th expedition of the RV "Polarstern"): A – 06.00 UTC, September 17, 1993; B – 06.00 UTC, September 18, 1993.

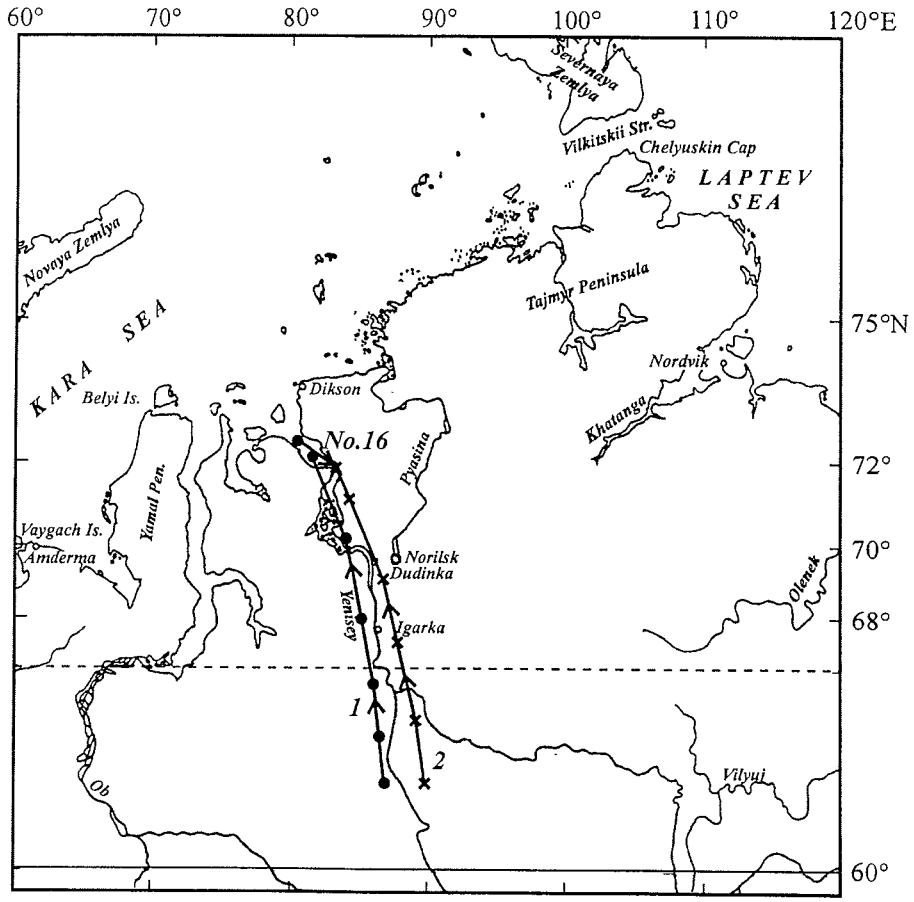

Fig. 5.6: Back trajectories of air mass transport to the place collection the mesh sample No. 16 in 49th expedition of the RV "Dmitry Mendeleev" at 1000 hPa level. Trajectories were calculated for the points 72.1°N, 85.5°E, 12.00 UTC, September 18, 1993 (1) and 71.8°N, 83.0°E, 15.00 UTC, September 18, 1993 (2) with 6 hours step in the Hydrometeorological Centre of Russia by T.Ya. Ponomareva.

6. MINERAL COMPOSITION

The mineral composition of aerosols is one of the important indicators of sources of the aeolian material (Chester et al., 1972; Lisitzin, 1972, 1996; Aston et al., 1973; Serova et al., 1981; Serova, 1988); it also affects the optics and chemical composition of aerosol. The mineral composition of aerosols collected by nylon meshes was measured by X-ray diffractometry; percentage of minerals was calculated for the crystalline phase (Serova, 1988; Serova and Gorbunova, 1997). The characteristic of the aerosol mineral composition in our samples was its high spatial and temporal variability (Table 6.1).

Quartz is the main mineral of the insoluble phase of the Arctic aerosols. Its content averaged 61.5% of the crystalline phase in mid-August – early September 1991, 33.2% in August-September 1993, and 30.4% in August-October 1994. On the average (the analysis of 47 samples collected in August-October in three expeditions), the Arctic insoluble aerosol contains 36.8% of quartz (at the standard deviation of 16.1%) (Table 6.2). Highest quartz content was measured in samples collected near the continent, and the lowest one was in open sea far away from the coastal areas (Table 6.1; Fig. 2.1 and 2.2).

The content of feldspar averaged over all the samples was 9.4% at the standard deviation of 5.2 (Table 6.2). One of the important characteristics of the aerosol mineral composition is the quartz/feldspar ratio (Q/F). The value of Q/F depends on the intensity of the weathering processes proceeding with the prevailing destruction of feldspar and conservation of quartz (Lisitzin, 1996). In shale – the main sedimentary rock of continents – the value of Q/F is close to 2 (Wedepohl, 1969). The increase of this ratio is indicative of more intense destruction (weathering) of feldspar, which is especially significant in tropics. For example, in the northern part of the Indian Ocean in the arid zone the quartz/feldspar ratio most often varies from 2 to 3 (Serova, 1988), and in the west of the equatorial humid zone of the Pacific Ocean in April-June 1990 it was, on the average, 3.7 (Lukashin et al., 1996 b). This ratio is even higher (6.8) in the eastern part of equatorial humid zone of the Atlantic Ocean near Africa (Shevchenko et al., 1994). In the Russian Arctic the surprisingly high values of the quartz/feldspar were measured. The Q/F ratio averaged over 47 samples is equal to 3.9, which indicates that the mineral aerosols in the Russian Arctic seas originated from regions with intense weathering of feldspars in soils, that is, remote sources. Soil of tundra and forest-tundra, surrounding the Arctic Ocean, is an additional source of aeolian matter in the Arctic. In tundra and forest-tundra soils intensive weathering of feldspar takes place (Zvereva and Ignatenko, 1983).

Among clay minerals, illite, chlorite, and kaolinite are the most abundant in the Arctic aerosols (Tables 6.1 and 6.2). The illite is the main clay mineral both in megaprovince of the continental crust and in suspended matter of most rivers, excepting river of the equatorial zone, in which kaolinite and montmorillonite dominate (Lisitzin and Gorbunova, 1981). If the sum of clay minerals is taken as 100%, then, according to our data, the content of illite in insoluble fraction of aerosols of the Russian Arctic was, on the average, 50.9% in August-September 1991, 41.5% in August-October 1993, 45.5% in August-October 1994; for all the Arctic expeditions the value averaged over 47 samples was 42.9% of the sum of clay minerals at the standard deviation of 10.1% (Table 6.2). In the temperate humid zone of the Northern Hemisphere (the

Table 6.1: The mineral composition of insoluble fraction of aeolian matter (>1 μm), collected in marine boundary layer in the Russian Arctic according to the results of X-ray diffractometry (analysis of V.V. Serova), % from the crystalline phase.

Sample No.	quartz	feldspars	illite	chlorite+kaolinite	montmorillonite
Expedition SPASIBA-91 (August-September 1991)					
1	54	14	10	22	traces
2	59	17	12	12	traces
3	61	13	10	16	traces
4	70	7	13	10	traces
5	72	9	12	7	traces
6	72	8	14	6	traces
8	64	8	16	12	traces
9	54	14	19	13	traces
10	48	16	16	20	traces
The 49th expedition of the RV "Dmitry Mendeleev" (August-October 1993)					
4	38	8	27	25	2
5	17	8	38	36	traces
6	36	13	15	35	1
7	27	8	22	42	1
8	35	17	18	26	traces
9	56	16	16	12	traces
11	23	8	34	34	traces
12	34	12	22	31	traces
13	23	4	25	48	traces
14	36	11	24	28	traces
15	22	7	28	43	traces
16	46	16	16	22	traces
17	43	14	16	26	traces
18	36	20	22	22	traces
19	48	18	12	22	traces
20	30	7	20	41	2
21	15	20	29	35	1
22	37	7	28	28	traces
23	31	12	24	32	1
The 9th expedition of the RV "Professor Logachev" (August-October 1994)					
1	66	7	8	16	3
2	46	traces	22.2	22.2	9.6
3	37.7	12.9	28.8	20.6	traces
4	34.5	10.2	27.7	18.1	9.5
6	23.9	4.9	35.6	35.6	traces
7	46.8	7	12.1	24.8	9.3
8	42.2	3.8	19.4	30	4.6
9	26.8	2.3	28.2	40.4	2.3
10	42.4	6	22	22	7.6
11	26.6	4.5	35.2	27.1	6.6
12	17.3	2.5	36.5	36.5	7.2
13	30	3.2	27.6	33	6.2
14	29.5	4.2	33.1	30.1	3.1
15	20.4	5.2	37.2	37.2	traces
16	17.1	19.5	27.2	36.2	traces
17	22.8	3.6	42.8	30.8	traces
18	22	11	46	21	traces
19	15.8	4.6	41.4	35.1	3.1
20	22.9	3.6	29.6	34.6	9.3
21	42.7	4.7	20	25.2	7.4

Table 6.2: Average mineral composition of insoluble aerosols in the marine boundary layer over the seas of the Russian Arctic in comparison with other regions of the World Ocean.

Expedition regions	n*	Content of minerals in crystalline phase, %										Q/F# ratio	Content of minerals, % of the sum of clay minerals						Source
		quartz		feldspars		illite		chlorite+ kaolinite		montmo-rillonite			illite		chlorite+ kaolinite		montmo-rillonite		
		avg*	std*	avg	std	avg	std	avg	std	avg	std		avg	std	avg	std	avg	std	
SPASIBA-91[1]	9	61.5	8.7	11.8	3.8	13.6	3.0	13.1	5.4			5.2	50.9	12.4	49.1	12.4			Shevchenko et al., 1999
DM-49[2]	19	33.2	10.7	11.9	4.9	22.8	6.8	30.8	8.9	1.3	0.5	2.8	41.5	7.6	56.1	7.4	2.4	1.2	Shevchenko, 2000
PL-9[3]	19	30.4	13.0	6.3	4.3	28.8	9.7	28.4	7.2	6.1	2.8	4.9	45.5	10.1	44.9	7.9	9.6	6.8	Shevchenko et al., 1998
Russian Arctic[4]	47	36.8	16.1	9.4	5.2	23.1	9.6	26.1	10.2	4.6	3.3	3.9	42.9	10.1	48.5	9.8	8.6	5.6	This work
Equatorial Atlantic[5]	4	37.3	3.8	5.5	4.5	22.5	5.4	31.3	2.9	3.4	1.2	6.8	39.3		54.7		6.0		Shevchenko et al., 1994
Equatorial Pacific[6]	13	51.9	13.1	13.9	4.2	6.9	2.3	27.3	11.2			3.7	20.2		79.8				Lukashin et al., 1996b
Tyrrhenian Sea[7]													67		33				Chester, 1986
NE Atlantic[8]													45		41		14		Chester et al., 1972

*n – number of samples; avg – average; std – standard deviation
#Q/F ratio – quartz/feldspars ratio
[1]SPASIBA-91 – International expedition in the Russian Arctic onboard the RV "Yakov Smirnitsky" and "Olkhon", August-September 1991
[2]DM-49 – the 49th expedition of the RV "Dmitry Mendeleev" to the Kara Sea, August-October 1991
[3]PL-9 – the 9th expedition of the RV "Professor Logachev", the Barents Sea and Saint Anna Trough, August-October 1994
[4]Russian Arctic – average from three expeditions, mentioned above
[5] Equatorial Atlantic – eastern part of the equatorial Atlantic, September-October 1990
[6] Equatorial Pacific – western part of the equatorial Pacific, April-June 1990
[7] Tyrrhenian Sea during air mass arrival from the Europe
[8] NE Atlantic – arid zone of the north-eastern Atlantic (from 5°N to 35°N)

Tyrrhenian Sea, at air masses coming from Europe) it was 67% (Chester, 1986). For comparison, illite content in aerosols of the equatorial humid zone is much lower. In tropics of the western Pacific Ocean in April-June 1990 it was in average only 20.2% of clay minerals (Lukashin et al., 1996 b).

The content of sum of chlorite and kaolinite, which can't be analysed separately in insoluble Arctic aerosol averaged 48.5% (Table 6.2). Chlorite is more probable component of the Arctic aerosol among these two minerals. In papers (Lisitzin, 1972, 1996; Lisitzin and Gorbunova, 1981; Chester, 1986) it was shown that illite and chlorite are most typical clay minerals of soils and bottom sediments in cold and temperate zones.

In the aeolian material collected during the SPASIBA-91 expedition only trace amount of minerals of montmorillonite group (smektites) were found. In the aerosols sampled during the 49th expedition of the RV "Dmitry Mendeleev" in the Kara Sea the average content of montmorillonite was only 0.7% of the sum of clay minerals (Table 6.2). However, it was much higher (9.6%) in the samples collected in August-October 1994in the 9th expedition of the RV "Professor Logachev". In this expedition highest content of montmorillonite was registered near Franz Josef Land (Table 6.1; Fig. 2.2).

In the soil of the Lena River banks the content of montmorillonite than 10% of the sum of all minerals (Serova and Gorbunova, 1997). The qualitative estimates of the mineral composition of soils in the Arctic tundra of Eurasia also show that the content of montmorillonite in the surface layer is usually low (Zvereva and Ignatenko, 1983). Content of montmorillonite in Quaternary morains of the Kola Peninsula is about 5% (Blazhchishin and Kheirov, 1990).

High content of smectite in surface layer of bottom sediments is registered near the Franz Josef Land (Gurevich, 1995; Nürnberg et al., 1995; Wahsner et al., 1996; Shelekhova, 1998). The most part of these islands is typical plateaus from 50 to 600 m high armoured by basalts and dolerite intrusions, forming smektite in the process of weathering (Dibner, 1957, 1970).

High content of montmorillonite (up to 30% of clay minerals) is found in aerosol samples, collected in the Indian Ocean during air masses transport from the Deccan Plateau in India where basalt are widely spread (Serova et al., 1981; Serova, 1988).

While, the distribution of smectite in surface layer of bottom sediments in the Arctic seas, used by many authors as indicator of the sources of sedimentary matter (Shelekhova et al., 1995; Nürnberg et al., 1995; Levitan et al., 1996; Wahsner et al., 1996; Shelekhova, 1998; Rossak et al., 1999), reflects mainly the composition of rocks in catchment areas of rivers flowing in these seas and of coastal outcrops.

Average composition of clay minerals in Arctic aeolian matter is close to the average composition of surface bottom sediments in the Fram Strait (Fig. 6.1). It could testify that aeolian matter released from ice in the marginal ice zone possibly plays an important role in sedimentation in the Fram Strait.

The study of mineral composition of Arctic aerosols has shown that: 1) it is characterised by strong spatial and temporal variability; 2) in summer sources of aeolian material are situated both in surrounding tundra and at the large distance.

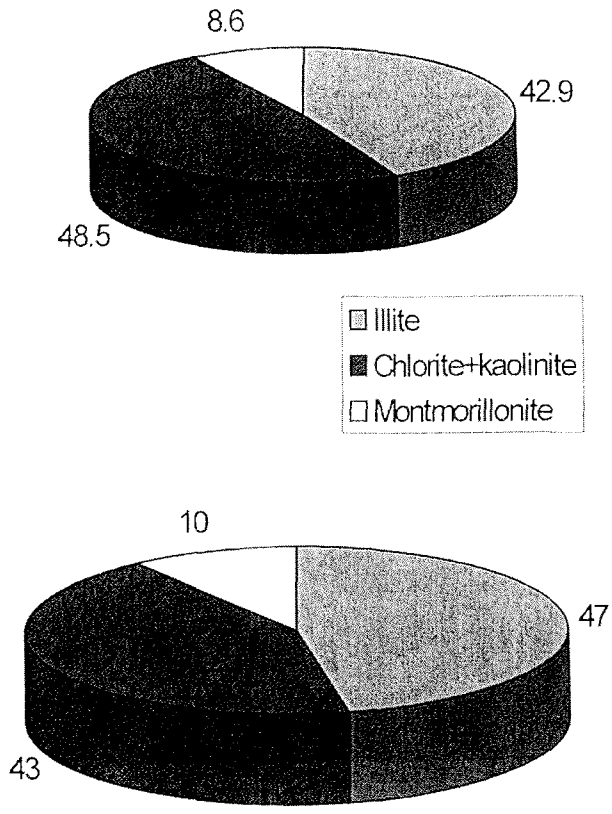

Fig. 6.1: Average composition of clay minerals (%) in aeolian matter (A) and in the surface layer of bottom sediments in the Fram Strait (Berner and Wefer, 1990; Letzig, 1995) (B).

7. CHEMICAL COMPOSITION OF AEROSOLS

The chemical composition of aerosols is determined by their sources and by the types of chemical transformation the aerosol matter is subjected to (Junge, 1963; Fuchs, 1964; Finlayson-Pitts and Pitts, 1986; Brimblecombe, 1996). Based on the current methods of analysis, we succeeded in studying the chemical composition of both individual aerosol particles and the samples as a whole collected by nylon meshes (water insoluble particles) and air filtering (all aerosol particles larger than 0.5 μm, including the sea salt). The chemical composition, like the mineral one, is one of the most important markers of aerosols.

7.1. CHEMICAL COMPOSITION OF INDIVIDUAL AEROSOL PARTICLES

The element composition of individual aerosol particles in the samples collected by meshes during the SPASIBA-91 expedition was studied with X-ray microanalysis at the Chemical Department of the Antwerp University (Shevchenko et al., 1995, 1999 a, d).

Biogenic particles and black carbon do not give main induced signals in the X-ray waveband, therefore, only the particles emitting X-ray radiation in response to e-beam bombardment were analysed in the automatic mode (the method is described in part 2.3.3). Results of analysis are presented in the Table 7.1. After the data were processed statistically, four main types of particles were recognized:

1) alumosilicates;
2) quartz;
3) Si-Fe or Fe-Si-enriched particles;
4) combustion spheres (carbon-less ash) enriched in Fe, P, Ni and some trace elements.

Grains of alumosilicates from 1 to 5 μm in diameter (on average, 1.7 μm) have irregular shape and different degree of smoothness. The X-ray spectrum of one alumosilicate particle is shown in Fig. 7.1 (a). Such the particles can be considered as soil particles transported by wind.

Quartz grains in aerosols usually have sizes from 1 to 3 μm and nearly spherical shape. Si-Fe- and Fe-Si- enriched particles are most probably the quartz grains covered with iron hydroxide film (so-called river quartz). The variations of the alumosilicates and quartz content in the samples (Table 7.1) are likely connected with variability of soil composition.

The combustion spheres enriched in Fe, P, Cl, and trace elements had the sizes from 0.3 to 3 μm. The combustion spheres enriched with such elements as Fe, Ni, Cu, Cr, Zn, Ca, Mn, and Sb were detected at manually controlling the microanalyzer. For example, a 0.5-μm sphere containing 52% Sb, 29% Si, and 19% Fe (taking into account only the elements producing the main X-ray signals) was found in the sample 1. Fig. 7.1 (b-f) show the characteristic X-ray spectra of combustion spheres from the Arctic aerosols. The highest concentration of the combustion spheres enriched with trace elements was noticed in the sample 6 taken from air mass arrived from the Norilsk region.

The qualitative element analysis of individual aerosol particles collected by nylon meshes in the Laptev Sea in July 1995 (the ARK-XI/1 expedition of the

Table 7.1: Results of X-ray microanalysis of individual aerosol particles composition. The aerosols were sampled during SPASIBA-91 expedition in August-September 1991 (Shevchenko et al., 1995, 1999 a, b).

Sample	Group	Abundance, %	Average diameter, μm	Main elements	Identification
1	1	41.0	1.8	Si	quartz
	2	32.0	1.7	Si, Al, Fe, K	alumosilicates
	3	11.0	1.9	Fe, Si	Fe-Si-rich
	4	4.0	1.0	Si, Fe	Si-Fe-rich
2	1	43.5	1.7	Si, Al, Fe, K	alumosilicates
	2	18.3	2.2	Si	quartz
	3	16.5	0.6	Cl, K, Si	fly ash
	4	10.3	1.2	Fe, Si, Cl, K	fly ash
3	1	32.0	1.7	Si	quartz
	2	28.8	1.8	Si, Al, Fe, K	alumosilicates
	3	10.0	1.3	Fe, Si	Fe-Si-rich
	4	4.3	2.7	Si, Fe, Ca	Si-Fe-Ca-rich
4	1	34.0	1.5	Si	quartz
	2	21.8	1.7	Si, Al, Fe	alumosilicates
	3	17.5	2.2	Si, Fe	Si-Fe-rich
	4	4.0	1.1	Si, Ti, Al, Fe	fly ash
6	1	35.0	1.5	Si, Al, Fe, K	alumosilicates
	2	12.8	1.3	Si	quartz
	3	12.5	1.3	Si, Fe	Si-Fe-rich
	4	8.0	1.2	Fe, Si	Fe-Si-rich
9	1	22.7	1.8	Si, Al, Fe, K	alumosilicates
	2	15.8	2.0	Si, Fe, Al, K	Si-Fe-rich
	3	9.7	2.4	Si, Fe, Mg	Si-Fe-rich
	4	7.9	1.5	Fe, Si, Al, K	Fe-Si-rich

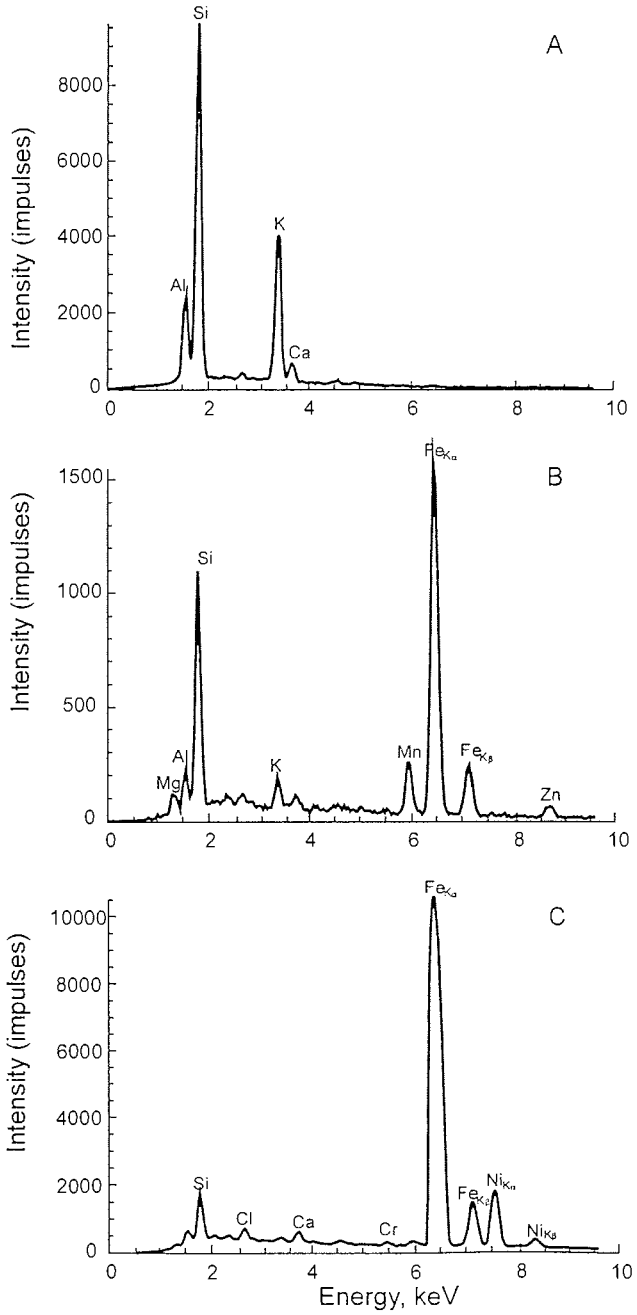

Fig. 7.1: X-ray spectra of aerosol particles collected by mesh method in SPASIBA-91 expedition: A) – angular alumosilicate particle (sample No. 6, particle size 5 μm); B), C) – combustion spheres: B) – sample No. 1, diameter 0.7 μm; C) – sample No. 6, diameter 0.5 μm.

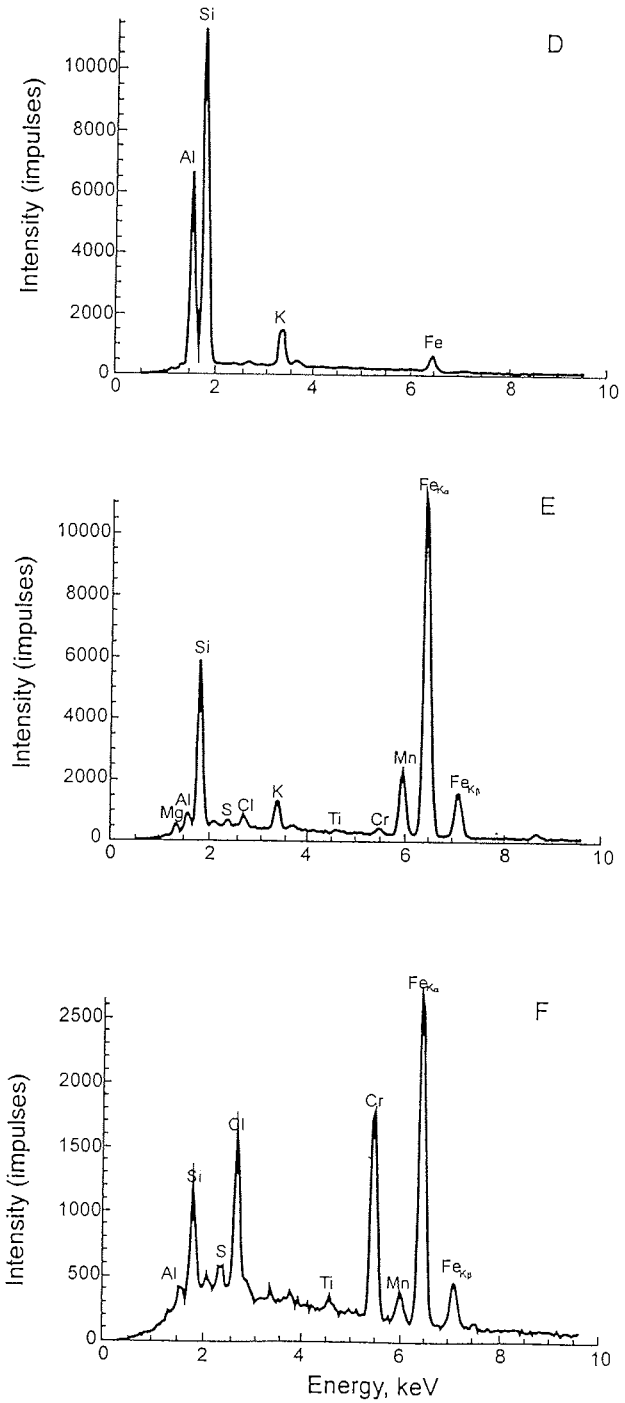

Fig. 7.1: (continuation): D)-F) – combustion spheres, sample No. 6 (D – diameter 7 µm; E – diameter 1.5 µm; F – diameter 4 µm).

RV "Polarstern", samples 1 and 2), in the Kara and Barents Seas in September-October 1993 (the 49th expedition of the RV "Dmitry Mendeleev", samples 16-18, 20, and 23), and in the Barents, Norwegian and Greenland Seas in August 1996 (the 15th expedition of the RV "Professor Logachev", samples 5-8) was carried out with the SEM-515 scanning electron microscope supplemented with the EDAX PV9900 X-ray microanalyzer (Philips, USA), at the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven (Shevchenko et al., 1999 c). It was shown that the composition of 110 combustion spheres with diameters from 1 to 10 μm varies from region to region (Table 7.2). They mainly consist of Si, Al, K, Fe, and Mg in the Laptev Sea; Si, Al, Fe, and K in the central part of the Kara Sea; Fe, Ni, Si, and Cu in the southern Kara Sea (income of aerosol from Norilsk); Si, Al, Fe, and Ni in the southern Barents Sea (influence of industrial enterprises of the Kola Peninsula). Fig. 7.2 shows the characteristic X-ray spectra of combustion spheres, collected during the 49th expedition of the RV "Dmitry Mendeleev". In samples, collected in August 1996 inorganic particles mostly are presented by quartz and alumosilicates; combustion spheres were found in all samples, but their content is low. Only in sample 8, collected during air mass transport from the Kola Peninsula, relative increase of combustion spheres was registered.

Thus, the study of the element composition of individual insoluble aerosol particles in the marine boundary layer over the Arctic seas with the electron microprobe has shown that inorganic part of aerosol consist mostly of mineral particles (predominately, quartz and alumosilicates) of land soils. Almost all the samples contain small amounts of anthropogenic ash particles enriched in Fe, Ni, Cu, Cr, Zn, Ca, Mn, and Sb. The content of ash particles increases near industrial regions (for example, Norilsk and Kola Peninsula) that could be one of tracers of anthropogenic pollution of aerosols.

7.2. ELEMENT COMPOSITION OF INSOLUBLE AEROSOLS

Carbon measured in a sample after its processing by solution of hydrochloric acid (Lyutzarev and Smetankin, 1980) is of primary importance in the arctic aerosols sampled by nylon meshes. Because of very small amount of collected aerosols, the content of non-carbonate carbon was successfully determined only in 18 samples collected in the SPASIBA-91 expedition, the 49th expedition of the RV "Dmitry Mendeleev", and in the 15th expedition of the RV "Professor Logachev" (App. 1; Table 7.3). It varies from 7.54 to 48.9%. The average content of non-carbonate carbon is 30.2% at standard deviation of 12.5%; this amounted about 60% of the organic matter. The numerous recent studies show that the organic matter is one of the main components of aerosol above both land and ocean. The content of C_{org} can sometimes achieve 60% of the total mass of insoluble aerosol particles (Aston et al., 1973; Romankevich, 1977; Isidorov, 1990; Matthias-Maser and Jaenicke, 1995; Mathias-Masser et al., 1996).

In four samples collected during the SPASIBA-91 expedition E. Cachier (Centre des Faibles Radioactivities, Gif sur Yvette, France) determined the concentration of black (soot) carbon. The ratio of black carbon content to that of total non-carbonate carbon in our samples varied from 0.22 to 0.27, what is typical for industrial aerosols. Earlier, the high concentration of black carbon was detected at the Alaska coast (Point Barrow) with black-to-total carbon ratio

Table. 7.2: Qualitative element composition of combustion spheres of 1-10 μm size in aerosol samples collected by nylon meshes in the Laptev, Kara, and Barents Seas in September 1993 (the 49th expedition of the RV "Dmitry Mendeleev") and in July 1995 (ARK-XI/1 expedition of the RV "Polarstern"), and analysed with X-ray microprobe EDAX PV9900 at the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven.

Region, samples	**Type of particles according to dominant chemical elements**
Laptev Sea, samples ARK-XI/1-1* and ARK-XI/1-2	1) Si, Al, K, Fe (Mg) 2) Si, Al, Fe (K, Mg) 3) P, Si, Al, S (Mg, Fe, Ca) 4) Fe, Al, P (Cu)
Southern part of the Kara Sea, samples DM-49-16**, DM-49-18, and DM-49-20	1) Fe, Ni, Si (Cu, Al) 2) Fe, Si, Ni (Cu, Al, Mg, Ca) 3) Si, Fe, Cu, Al 4) Si, Al, K (Fe) 5) Fe, Cu, Ni, Si
Central part of the Kara Sea, sample DM-49-17	1) Si, Al (K, Fe) 2) Fe, Si, Al 3) Fe, Ni, Si (Cu)
Southern part of the Barents Sea, sample DM-49-23	1) Si, Al (Ca, Fe, K, Mg) 2) Fe, Si, Ni (Al, Cu, Mg, Ca) 3) Fe, Ni, Si (Cu, Ca, Al)

*Sample 1 collected in ARK-XI/1 expedition of the RV "Polarstern"
**Sample 16 collected in the 49th expedition of the RV "Dmitry Mendeleev"

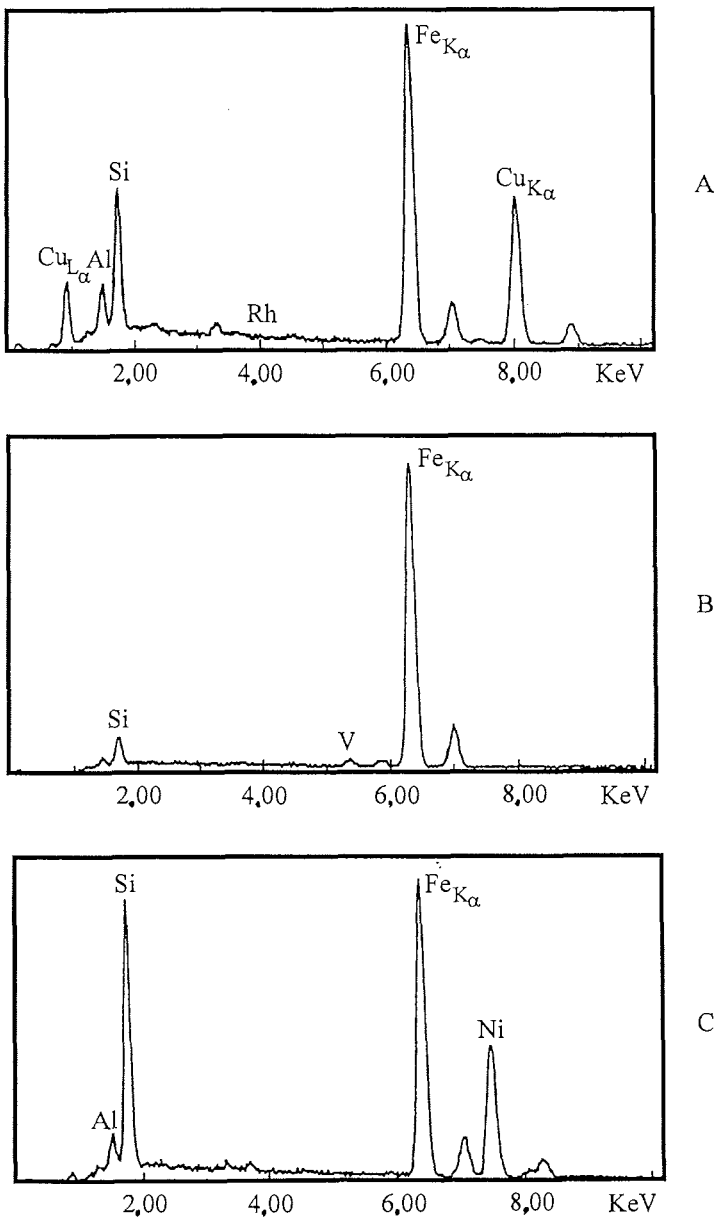

Fig. 7.2: X-ray spectra of combustion spheres in aerosols collected by meshes in 49th expedition of the RV "Dmitry Mendeleev" in September 1993): A) – sample No. 20, diameter 1.3 µm; B) sample No. 23, diameter 2.5 µm; C) sample No. 23, diameter 2 µm (Shevchenko et al., 1999 c).

Table 7.3: Content of SiO_2, Al_2O_3 and C_{org} and ratio of black carbon to organic carbon (C_{black}/C_{org}) in insoluble aerosols collected in the Arctic in summer-autumn period in comparison with literature data.

Sample	Si, %	Al, %	Si/Al	C_{org}, %	C_{black}/C_{org}
SPASIBA-91 (August-September 1991)[1]					
1				38.5	0.24
2				23.9	0.22
3				44.4	0.27
4					
5					
6					
7					
8				48.9	0.24
9					
10					
The 49th expedition of the RV "Dmitry Mendeleev" (August-October 1993)[2]					
4				36.4	
6	26.5	7.41	3.58	7.54	
9	16	5.04	3.17	19	
10	7.56	1.86	4.06	32.6	
14				36.4	
16	13.8	3.45	4.00	18.2	
17	24	6.88	3.49	9.67	
18	14.5	3.28	4.42	20	
20				29.3	
The 15th expedition of the RV "Professor Logachev" (July-August 1996)[3]					
4	5.91	1.96	3.02	39.1	
5	2.72	0.98	2.78	45.0	
6	7.63	1.80	4.24	35.7	
7	20.6	3.07	6.71	18.4	
8	8.62	1.86	4.63	41.3	
Average	13.4	2.66	4.01	30.2	
Standard deviation	7.77	1.76	1.08	12.5	
Literature data					
Polygon 15°15'N, 39°50'W[4]	24.9	10.1	2.47		
Sal Island (16°45'N, 22°57'W)[5]			2.03		
Continental clays[6]	26.23	8.58	3.06		
Earth crust[7]	28.15	8.23	3.42		
Barrow, Alaska, USA[8]					0.24
New York, USA[8]					0.27

[1]Shevchenko et al., 1999
[2]Shevchenko et al., 1999
[3]Unpublished data of Shevchenko V.P., Ivanov G.I., Isaeva A.B., Stein R.
[4]Lukashin et al., 1996 a
[5]Chiapello et al., 1997
[6]Ronov and Yaroshevsky, 1967
[7]Taylor, 1964
[8]Rosen et al., 1981

achieved 0.40 (Rosen et al., 1981). The probable sources of black carbon are the anthropogenic activity and forest fires. Recently, it was shown the black carbon consisting of submicron particles can be transported far from its sources (Cachier et al., 1986; O'Dowd and Smith, 1993; O'Dowd et al., 1993, 1997; Pueschel et al., 1997). It heavily affects the Arctic ecosystem due to its influence on atmospheric optics (strong absorption of solar radiation). On the whole, the distribution of black carbon in the Arctic atmosphere significantly varies in the time and is highly inhomogenous (Hansen and Rosen, 1985; Polissar, 1994; Hansen et al., 1997; Polissar et al., 1998 a, b, 1999).

The average content of Si in insoluble fraction of Arctic aerosols is 13.4% at standard deviation of 7.7% and the average content of Al is 2.66% at standard deviation of 1.76 (Table 7.3). Using Al as an indicator of the terrigenic matter and assuming that its mean content in the Earth's crust is 8.23% (Taylor, 1964), we have determined the content of terrigenic component in the insoluble Arctic aerosols. It averages 32.3%. Thus, the biogenic part makes about 67.7, taking into account that generally the content of anthropogenic particles is low (after data of microscopic studies, discussed in the Chapter 5). This corresponds to the results of C_{org} determination. In the humid equatorial zone of the Northern Atlantic the terrigenic matter makes about 100% of water-insoluble aerosols at the C_{org} content less than 3% (Lukashin et al., 1996 a; Chiapello et al., 1997). The average value of the Si/Al ratio (Table 7.3) for the Arctic aerosols, accordingly to our data, is 4.01, that is somewhat higher than that for the Earth crust (3.42) after S.R. Taylor (1964) and continental clays (3.06) after A.B. Ronov and A.A. Yaroshevsky (1967), but far higher than the values characteristic for aerosols of the humid equatorial zone of the Northern Atlantic, which vary from 2.03 (Chiapello et al., 1997) to 2.47 (Lukashin et al., 1996 a). Enrichment of tropical aerosols with Al is likely connected with the fact that the terrigenic sources in this case are the weathering crusts and soils of the tropical zone more rich in Al relative to Si (Perel'man, 1975, 1989).

The content of chemical elements in insoluble aerosols, collected in the SPASIBA-91 expedition, their average values and standard deviations are presented in App. 5. The content of chemical elements varies very widely. To determine the origin of aerosol, the enrichment factors were calculated relative to the average composition of the Earth's crust. For each element the enrichment factor (EF) was calculated as

$$EF=(El./Al)_{sample}/(El./Al)_{Earth's\ crust},$$

where El. and Al are the concentrations (content) of the element of interest and aluminium in the sample and in the Earth's crust (Taylor, 1964), respectively. In the insoluble aerosols, collected in SPASIBA-91 expedition, the considered elements are divided into two groups in accordance with the EF value:

1) the elements typical for the Earth's crust (EF<10) – Na, Mg, Al, K, Ca, Sc, Mn, Fe, Co, Ni, As, Rb, Cs, Ba, rare-earth elements, Hf, Ta, Th, U;
2) the anthropogenic elements (EF>10) – Cr, Cu, Zn, Se, Br, Ag, Cd, Sb, W, Au, Pb.

When meshes were washed by bi-distilled water, sea salt has been removed, therefore, the group of elements connected with sea salt had no effect. The highest EFs of aerosols by Cr, Cu, Sb, and Pb were observed in the sample 6 collected above the Laptev Sea at the southerly wind (Fig. 2.1 and 7.3). Even for nickel, which is usually classified as a crustal element, the EF in the samples 5 and 6 was more than 10 (12 and 13.5, respectively). The

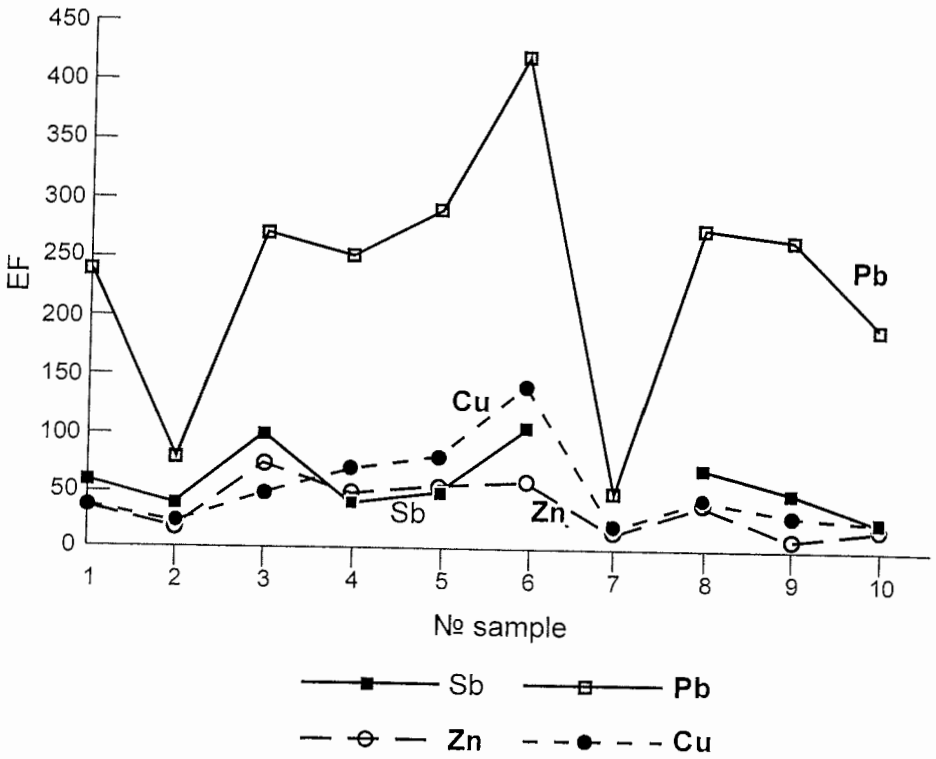

Fig. 7.3: Enrichment factors of insoluble aerosols (particles larger than 1 µm), collected during expedition SPASIBA-91, relative to average composition of the Earth's crust (Shevchenko et al., 1999 a).

samples 5 and 6 were also characterized by the largest amount of the anthropogenic combustion spheres found by the scanning electron microscopy and X-ray microprobe (Chapter 5 and section 7.1). Obviously, the main source of pollution of these samples was in the region of Norilsk.

The Norilsk Mining-Metallurgic Plant (mines and smelter) is one of the world's largest producers of copper and nickel. This plant is one of the main sources of pollution of the environment in the north-eastern part of Russia emitting the compounds of S, Se, Cu, Ni, Co, Sb, As, Pb, Zn, and Hg into the atmosphere (Vilchek et al., 1996; Arctic ..., 1997; Surnin et al., 1997).

Elemental composition of insoluble aerosols collected in September 1993 in 49th expedition of the RV "Dmitry Mendeleev" are presented in the App. 6. On the base of these data the enrichment factors were calculated relative to the average composition of the Earth's crust (App. 7). It makes possible to divided elements into two groups in accordance with the EF value: 1) terrigenic, with EF<10 (Na, Ca, Fe, Cs, Ba, Hf, Th; 2) anthropogenic, with EF>10 (Ni, Zn, As, Se, Br, Mo, Ag, Sb, Au). Such elements, as Co and Cr, occupy intermediate position – in some samples they have mostly terrigenic origin, but in other samples – anthropogenic origin.

The sample 16 taken on the September 18, 1993, in the 49th expedition of the RV "Dmitry Mendeleev" in the Yenisey estuary (Fig. 2.1) at strong (10.4 m/s) southerly wind had the highest, as compared to other samples, enrichment factor for such elements as Se (EF=22000), Ni (EF=418), and As (EF=43). The highest content of combustion spheres was also detected in the same sample (Chapter 5) taken along the path of air masses from Norilsk (Fig. 5.5 and 5.6). This confirms the earlier idea that the Norilsk region is the significant source of pollution of the Arctic atmosphere (Shaw, 1982, 1994; Pacyna, 1991), especially, above the Laptev and Kara Seas.

Earlier it was shown that the natural and anthropogenic sources of selenium in aerosols are almost equal (Ross, 1985, 1990; Mosher and Duce, 1987). The most important natural process delivering selenium to the atmosphere is generation of its organic compounds by phytoplankton, because the biogeochemical behaviour of Se is close to that of S (Mosher et al., 1987; Ellis et al., 1993). The main anthropogenic sources of atmospheric Se are the combustion of coal, oil products, and wood, as well as mining and smeltering, especially, copper production (Ross, 1985; Mosher and Duce, 1987). Enrichment of aerosols with selenium is one of the markers of functioning of copper-nickel plants. Norilsk is one of main sources of selenium in aerosols over the Kara Sea.

To reveal the geochemical relations between the elements, the correlation and factor analysis were carried out. The correlation matrix of the element composition of insoluble aerosols collected in the 49th expedition of the RV "Dmitry Mendeleev" is given in the Table 7.4. For 18 samples the critical level of 5% significance of the correlation coefficient is 0.468 (Methodic ..., 1979). Very high positive (>0.87) correlation coefficients are between the scandium (typical indicator of the terrigenic origin of sedimentary matter) and Na, Ca, Fe, Cs, Ag, Hf, Ba, Th. The main sources of these chemical elements in the water-insoluble fraction of the Kara Sea aerosols are the soils of tundra and forest-tundra, as well as the terrigenic aeolian material from more remote regions, which is transported to the Arctic by air masses (the influence of sea salt is excluded at processing the samples). The lower, but still significant,

Table 7.4: Correlation matrix of chemical composition of insoluble fraction of aerosols in the marine boundary layer over the Kara Sea (September 1993, 49th expedition of the RV "Dmitry Mendeleev"); n=18 samples, the critical level of the correlation coefficient at the 5% significance level is 0.468.

	Na	Ca	Sc	Cr	Fe	Co	Ni	Zn	Se	Br	Mo	Ag	Sb	Cs	Ba	Hf	Ir	Au	Th
Na	1.0	0.81	0.99	0.59	0.96	0.22	0.41	0.31	-0.05	0.22	0.48	0.89	-0.11	0.99	0.88	0.98	-0.01	0.36	0.98
Ca		1.00	0.88	0.85	0.90	0.02	-0.52	0.68	-0.20	0.64	0.93	0.80	0.12	0.89	0.96	0.89	0.00	0.77	0.90
Sc			1.00	0.65	0.98	0.23	0.45	0.35	-0.05	0.30	0.57	0.91	-0.10	0.99	0.93	0.99	0.01	0.48	0.99
Cr				1.00	0.74	0.05	-0.41	0.74	-0.10	0.89	0.99	0.88	0.12	0.65	0.73	0.67	0.13	0.75	0.70
Fe					1.00	0.31	0.73	0.42	0.04	0.40	0.70	0.89	-0.06	0.99	0.94	0.98	0.01	0.52	0.98
Co						1.00	0.99	-0.16	0.94	-0.10	0.46	0.06	-0.28	0.42	0.42	0.21	-0.06	-0.01	0.20
Ni							1.00	-0.53	0.97	-0.51	-0.36	0.23	-0.56	-0.35	-0.04	-0.09	-0.12	-0.33	-0.12
Zn								1.00	-0.26	0.68	0.89	0.81	0.15	0.34	0.46	0.37	0.06	0.46	0.38
Se									1.00	-0.11	0.14	0.06	-0.23	-0.01	-0.01	-0.07	-0.18	-0.07	-0.06
Br										1.00	0.87	0.85	0.22	0.28	0.43	0.34	0.14	0.82	0.36
Mo											1.00	0.92	0.06	0.57	0.84	0.62	0.98	0.69	0.63
Ag												1.00	0.20	0.93	0.81	0.85	0.80	0.75	0.91
Sb													1.00	-0.01	-0.16	-0.10	-0.10	-0.15	0.16
Cs														1.00	0.93	0.99	-0.02	0.43	0.99
Ba															1.00	0.95	-0.06	0.64	0.95
Hf																1.00	0.03	0.50	0.99
Ir																	1.00	0.06	0.01
Au																		1.00	0.51
Th																			1.00

correlation coefficients are between Sc and Cr (0.65) and Sc and Mo (0.57), whereas the correlation coefficient between Cr and Mo is 0.99; chromium also has high correlation coefficients with Br (0.89), Ag (0.88), Ca (0.85), Au (0.75), Fe (0.74), Zn (0.74), Ba (0.73), and Th (0.70). We can assume that the main source of Cr and Mo also are soils and surface rocks. Very high positive correlation coefficients (from 0.94 to 0.99) are noticed between Ni, Co, and Se, the main source of which is the smoke of the Norilsk Metallurgic Plant (smelters).

To reveal the groups of genetically related chemical elements, we used the factor analysis (Davis, 1986). In this analysis, the content of any element in each sample is considered as a result of the sum action of hypothetical sources (factors). The results of the factor analysis of the samples of insoluble aerosols collected in September 1993 in the Kara Sea are given in Table 7.5.

The first factor makes the main contribution to the total dispersion; it is equal to 77.2%. The load of Ni on this factor is abnormally high (8.63), whereas the loads of other elements are close to zero. The first factor represents the contrast role of the source of nickel as compared to the sources of other elements. This dominating source of nickel determining its biogeochemical behaviour in the Arctic aerosols is, as was noted, the anthropogenic delivery from the Norilsk region.

The contribution of the second factor is equal to 11.7%. The high positive load (>0.62) on this factor are given by Na, Ca, Sc, Cr, Fe, Zn, Br, Mo, Ag, Cs, Au, Th. The main source of these elements in the water-insoluble fraction of aerosols is the terrigenic material from the land soils and rocks. Such elements as Se, Ni, Sb, Ir, and Co have the lowest effect on the second factor. The main source of Se, Ni, and Co is the material transported by air masses from the Norilsk region. In the geochemical behaviour, cobalt is close to nickel (Perel'man, 1989), and the content of cobalt in copper-nickel ore of the Norilsk region is relatively high (Mining ..., 1987). The content of selenium in the copper-nickel ore and emissions of copper-nickel smelters is very high, too, as was noted above.

The contribution of the third factor is equal to 3.2%. The high positive load (>0.47) on this factor is given by Zn, Br, Mo, Ag, and Sb, that is, the elements which can be accumulated in vegetable fibres (Perel'man, 1989), and the high negative load is given by Na, Sc, Fe, Cs, Ba, and Th, that is, the elements typical of the mineral phase.

The contribution of the fourth and fifth factors are insignificant (2.3 and 1.9%). The difference in loads of the elements on these factors may be connected with the variety of regions, from which the crust and anthropogenic aerosols come.

In August-October 1994 aerosols were studied over the Barents Sea and the Saint Anna Trough (the NW Kara Sea) in the 9th expedition of the RV "Professor Logachev" (Shevchenko et al., 1997, 1998). 20 samples of insoluble aerosols were collected by nylon meshes (App. 1; Fig. 2.1 and 2.2). Contents of chemical elements in the samples from this expedition, average values and standard deviations are given in the App. 8, enrichment factors are given in App. 9.

The highest enrichment factors for Co, Ni, Cu, and Zn were observed in the sample 17 taken near Murmansk. That sample contains the anthropogenic

Table 7.5: Matrix of factor representation of element composition of insoluble aerosols, collected in the marine boundary layer over the Kara Sea (September 1993, 49th expedition of the RV "Dmitry Mendeleev"); n=18 samples.

Factor	I	II	III	IV	V
Part of total dispersion	77.2%	11.7%	3.2%	2.3%	1.9%
Na	0.05	0.86	-0.45	0.04	-0.16
Ca	-0.06	0.95	-0.03	0.25	-0.19
Sc	0.05	0.90	-0.40	-0.01	-0.14
Cr	0.08	0.93	-0.33	-0.07	-0.06
Fe	0.08	0.93	-0.33	-0.07	-0.06
Co	0.12	0.19	-0.28	-0.05	-0.42
Ni	8.63	0.01	0.03	-0.01	-0.02
Zn	-0.07	0.70	0.90	-0.47	-0.25
Se	0.12	-0.04	-0.20	0.08	0.59
Br	-0.06	0.63	0.55	-0.10	0.04
Mo	-0.04	0.96	0.51	-0.41	0.76
Ag	0.03	1.23	0.46	1.25	0.16
Sb	-0.07	0.02	0.48	0.14	-0.68
Cs	-0.04	0.90	-0.43	0.01	-0.12
Ba	-0.01	0.93	-030	-0.18	0.04
Hf	-0.01	0.91	-0.38	-0.06	-0.13
Ir	-0.01	0.15	0.16	0.09	0.16
Au	-0.04	0.67	0.25	-0.11	-0.05
Th	-0.01	0.92	-0.36	-0.03	-0.13

combustion spheres in a large amount (see Chapter 5). The content of most chemical elements in samples of insoluble aerosols, collected in this expedition, is lower than their average content in the Earth's crust (Taylor, 1964), what can be explained by "dilution" of insoluble aerosol with the organic matter (see Chapter 5). The content higher than in the crust was noticed only for Cr, Cu, Zn, As, Se, Br, Ag, Sb, and Au; the main source of these elements is anthropogenic. The comparison of average composition of the samples near the Franz Josef Land (samples 3-10) and near the Kola Peninsula (samples 15-19) (their position is in Fig. 2.2) has shown that the content of chromium is roughly 1.5 times higher near the Franz Josef Land, whereas the content of nickel is roughly five times higher near the Kola Peninsula (Table 7.6). The elevated content of Cr was observed in insoluble aerosols near the Franz Josef Land because the dolerites and basalts enriched with chromium are abundant there (Dibner, 1957, 1970; Taylor, 1964; Perel'man, 1989). The increase of the nickel content near the Kola Peninsula is explained by the income of aerosols polluted by emissions of the metallurgic plants of the Kola Peninsula.

In July-August 1996 aerosols were studied in the Norwegian, Greenland, and Barents Seas in the 15th expedition of the RV "Professor Logachev" (Fig. 2.1 and 2.4). Contents of chemical elements in the samples from this expedition, average values and standard deviations are given in the App. 10, enrichment factors are given in App. 11. In the sample 7 collected in the Greenland Sea on 19-20 August 1996 (App. 1, Fig. 2.4) during arrival of air masses from the Greenland (Fig. 3.1), the high content of Al and Sc (markers of terrigenic matter) and low content of Ni and Se (markers of anthropogenic source) were found (App. 10). In this sample the highest concentration of insoluble aerosols (1.38 μg/m^3) also was registered (Chapter 4); scanning electron microscopy shows the dominance of terrigenic particles in this sample (Chapter 5 and Part 7.1).

On the whole, the content of most chemical elements (Na, Al, K, Ca, Sc, Fe, Co, Rb, Zr, Cs, Ba, rare-earth elements, Hf, Ta, Th, U) in the insoluble fraction of the Arctic aerosols is lower than the mean value for the Earth's crust. The content of Cr, Cu, Zn, As, Se, Br, Ag, Sb, and Au is far higher than the average value for the Earth's crust; their main source is anthropogenic. The most significant sources of aerosol pollution in the Russian Arctic are mining and metallurgic works of Norilsk and the Kola Peninsula, as well as forest fires; episodically (especially, in winter) the influence of the far transport of pollutants from Europe, Asia, and North America is tangible.

7.3. ELEMENT COMPOSITION OF AEROSOLS (TAKING INTO ACCOUNT SEA SALT)

The element composition of aerosols as a whole was studied simultaneously in the samples obtained by filtering and by nylon meshes (see Part 2). In the case of filtering, the composition of particles larger than 0.5 μm, including particles of sea salt, was studied.

In the Laptev Sea in July-September 1995 during the ARK-XI/1 expedition of the RV "Polarstern" (Shevchenko, 1997 a; Shevchenko et al., 2000), the highest concentration of Na (1230 ng/m^3), the marker of sea salt, was observed, when the vessel moved in the open water at rather high speed of wind (on average, 11.8 m/s, sometimes up to 16 m/s). The concentration of Sc

Table 7.6: Average composition of aerosol samples collected by meshes in the Arctic and other regions.

Elements	Na	K	Ca	Sc	Cr	Fe	Co	Ni	Cu	Zn	As	Se	Br	Rb	Zr	Ag	Sb	Cs	Ba
Unit	%	%	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
SPASIBA-91																			
aver.	0.67	0.66	0.57	2.9	339	2.04	6.2	52	353	863	8	83	598	13.4		3.23	12.8	4.9	568
std	0.28	0.23	0.31	1.7	135	0.46	3.2	39	206	512	3.4	55	372	14		1.64	5.7	1.8	251
geom. mean	0.61	0.63	0.61	2.5	316	2	4.9	42	309	735	7.4	68	507	9.5		2.74	11.6	4.5	516
49th expedition of the RV "Dmitry Mendeleev"																			
aver.	0.49		1.68	7.12	276	5.01	106	3103		1881	16	61	24.4			12	35.8	1.87	577
std	0.28		0.97	3.17	164	2.63	184	4199		1391	11.8	118	15			7.1	34.4	0.84	482
geom. mean	0.41		1.38	6.3	227	4.15	39	1473		1472	12.9	19.6	19			9.4	19.3	1.6	388
9th expedition of the RV "Professor Logachev", all samples																			
aver.	0.34	5.15	0.98	2.66	376	2.32	14	41	209	1225	14.5	4.4	3.1	18.6	32.9	0.4	346	0.82	157
std	0.76	3.05	1.03	1.5	178	1.15	13.3	58	139	1244	15.2	4.1	2.5	20.3	16.6	0.33	566	0.92	85
geom. mean	0.084	4.33	0.6	2.33	342	2.12	9.7	21	164	733	6.9	2.7	1.9	13.5	29.5	0.21	115	0.49	132
9th expedition of the RV "Professor Logachev", samples No. 3-10 (near Franz-Josef Land)																			
aver.	0.56	2.85	0.78	2.87	439	2.39	14.1	20	254	2016	10.9	2.1	2.4	23	32.5	0.43	271	0.88	119
std	1.2	0.35	1.06	1.86	226	1.4	13.7	22	168	1621	13.2	1.6	2.5	35	20	0.34	370	1.17	71
geom. mean	0.073	2.84	0.45	2.4	392	2.13	10.5	11.5	219	1511	6.6	1.4	1.15	11	28.2	0.28	148	0.49	100
9th expedition of the RV "Professor Logachev", samples No. 15-19 (near Kola Peninsula)																			
aver.	0.2		1.56	2.66	298	2.28	18.9	113	230	692	34.5	7.7	3.4	14.3	40.7		37.5	0.53	153
std	0.17		1.5	1.11	128	0.29	18.5	100	115	848	5.4	3.2	1.23	3.5	13.9		3.5	0.43	85
geom. mean	0.098		1.19	2.47	279	2.26	11.8	77	197	347	34.3	7	3.2	14	39.2		37.4	0.36	126
15th expedition of the RV "Professor Logachev"																			
aver.	0.19	1.42	0.69	3.3	75	0.75	5.7	148		975	33.5	5.6	11	33.2	57			2.57	67
std	0.11	0.97	0.47	1.52	85	0.72	4.9	69		1106	37.9	5.9	9.8	33.3	58			2.12	89
geom. mean	0.15	1.18	0.54	2.9	41	0.42	4.1	136		480	11.5	2.52	6.3	20.4	33.6			1.76	34
Earth's crust (Taylor, 1964)																			
aver.	2.36	2.09	4.15	22	100	5.63	25	75	55	70	1.8	0.05	2.5	90	165	0.07	0.2	3	425

Table 7.6 (continue).

Elements	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Au	Th	U
Unts	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
SPASIBA-91																			
aver.	9.1	18.9		8.8	1.37	0.32	1.07	0.19					0.44	0.068	1.12	0.55	8.7	2.42	0.47
std	5.7	9.5		4.4	0.84	0.2	0.59	0.11					0.26	0.043	0.55	0.44	3.7	1.31	0.42
geom. mean	6.5	17		7.9	1.17	0.26	0.95	0.17					0.38	0.057	1.01	0.46	8	2.12	0.36
49th expedition of the RV "Dmitry Mendeleev"																			
aver.															2.29		16.4	3.3	
std															1.21		14.2	1.8	
geom. mean															1.9		12	2.8	
9th expedition of the RV "Professor Logachev", all samples																			
aver.	7	11.5	1.13	3.8	0.88	0.30	1.24	0.17	0.9	0.19	0.47	0.067	0.35	0.056	0.63	0.72	2.18	1.01	1.88
std	4.7	7.4	0.70	2.2	0.53	0.21	0.79	0.1	0.51	0.11	0.32	0.051	0.29	0.051	0.34	0.5	0.89	0.8	2.72
geom. mean	5.2	9	0.92	3.1	0.71	0.24	1.07	0.15	0.8	0.16	0.4	0.055	0.28	0.042	0.53	0.56	2.03	0.63	1.25
9th expedition of the RV "Professor Logachev", samples No. 3-10 (near Franz-Josef Land)																			
aver.	5.3	9	0.93	3.4	0.86	0.34	1.2	0.18	1.03	0.22	0.59	0.086	0.47	0.077	0.63	0.69	2.36	0.59	1.34
std	4.5	6.7	0.58	1.8	0.54	0.25	0.69	0.1	0.68	0.15	0.44	0.068	0.39	0.068	0.45	0.42	1.24	0.74	1.15
geom. mean	3.2	6.4	0.74	2.8	0.73	0.27	1.07	0.16	0.89	0.19	0.49	0.07	0.37	0.058	0.45	0.54	2.09	0.31	1.09
9th expedition of the RV "Professor Logachev", samples No. 15-19 (near Kola Peninsula)																			
aver.	9.1	15.2	1.51	5	1.1	0.31	1.58	0.2	1.01	0.2	0.5	0.07	0.35	0.054	0.56	0.68	2.05	1.67	1.28
std	2.9	4.4	0.39	1.3	0.27	0.18	0.8	0.07	0.29	0.07	0.23	0.042	0.25	0.045	0.14	0.49	0.8	0.24	0.72
geom. mean	8.7	14.7	1.48	4.8	1.07	0.27	1.47	0.19	0.97	0.19	0.46	0.06	0.28	0.041	0.54	0.58	1.92	1.65	1.14
15th expedition of the RV "Professor Logachev"																			
aver.	10.5	19.9		6.9	1.68	0.48		0.33					0.82	0.14	0.98	2.47	11.1	1.39	6.3
std	5.2	10		4.7	0.69	0.31		0.1					0.51	0.086	0.75	2.97	8.4	0.48	8.6
geom. mean	9.4	17.6		5.4	1.56	0.41		0.31					0.71	0.12	0.75	1.49	8.2	1.31	2.25
Earth's crust (Taylor, 1964)																			
aver.	30	60	8.2	28	6	1.2	5.4	0.9	3	1.2	2.8	0.48	3	0.5	3	2	0.004	9.6	2.7

(the marker of continental terrigenic material) in this sample is also relatively high (0.009 ng/m^3), but the sea component prevails. The enrichment factor for Na relative to the average content in the Earth's crust is very high (135). The contribution of sea salt particles to formation of aerosol composition in this region is very significant, as it was shown earlier for other ocean regions (Chester, 1990; O'Dowd and Smith, 1993; O'Dowd et al., 1997).

The highest concentration of Sc (0.023 ng/m^3) at the relatively low concentration of Na (410 ng/m^3) was observed on August, 5, in the sample 6; EF (Fe) and EF (Zn) for that sample are relatively low, and the concentrations of Cr and As and EF (Cr) and EF (As) are high (App. 12 and 13). This indicates that aerosols here are terrigenic and polluted by Cr and As. Measurements of the aerosol particle size distribution have shown that the concentration of particles larger than 0.5 μm during sampling was relatively high (11.3 cm^{-3}) (App. 4). The synoptic situation a day before was characterized by income of polar air masses from the north to the region of Khatanga through the Kara Sea and Taimyr Peninsula; on 06:00GMT of August 5, the surface centre of low pressure was located under the Severnaya Zemlya archipelago (Fig. 7.4). During sampling, the strong (from 13.5 to 15 m/s) south-easterly wind blew. Apart from the land source, the ice located near the sampling site and rich in sedimentary material (so called "dirty ice") was likely one more source of mineral aerosol particles, as it was demonstrated earlier for other regions (Maenhaut et al., 1996). Dirty ice is abundant in the Arctic (Pfirman et al., 1989; Nürnberg et al., 1994; Eicken et al., 1997). In the ARK-XI/1 expedition the RV "Polarstern" crossed a large field of sediment-laden ice. According to the NOAA AVHRR data, late in July 1995 the area covered by dirty ice in the Laptev Sea was 24000 km^2 (Kolatschek et al., 1996). Satellite image of the studied area on August 5, 1995, during the collecting the sample 6, is presented in the Fig. 7.5.

The maximum concentrations and EFs of trace elements in aerosols of the Laptev Sea were observed in the sample 4. The concentrations of both terrigenic (Sc, 0.0016 ng/m^3) and marine (Na, 240 ng/m^3) matter in that sample are low as compared to other samples, whereas the EFs for Fe, Co, Cr, and Zn were the highest in this expedition. During the sampling the weak southerly-south-easterly wind (5.5 m/s) blew. The concentration of aerosol particles larger than 0.5 μm was low (1.26 cm^{-3}). The low concentrations of Sc, Na, and aerosol particles larger than 0.5 μm indicate that the trace elements are contained mostly in the fine aerosol fraction. There exist two most probable sources of fine aerosol particles: (1) generation of salt aerosol particles at destruction of bubbles in the surface microlayer of the sea water; (2) far transport of fine particles from regions with the open surface of the sea water and from Siberia. The EF for Na in the sample 4 is high and indicative of predominately marine origin of these aerosols. As it has been noted earlier, sea salt particles are enriched with many trace elements because of fractionation in the surface microlayer of the sea water (Korzh, 1991; Duce et al., 1991; O'Dowd and Smith, 1993; Savenko, 1994).

The average concentrations of chemical elements over the Laptev Sea are compared with the literature data in Table 7.7. The average values for Na (494 ng/m^3) are close to the concentration of Na in the aerosols over the Fram Strait near the edge of an ice field (Maenhaut et al., 1996) and much higher than in the Central Arctic covered by multi-year ice (Maenhaut et al., 1996), on Arctic islands (Maenhaut et al., 1989; Vinogradova and Polissar, 1995), and in

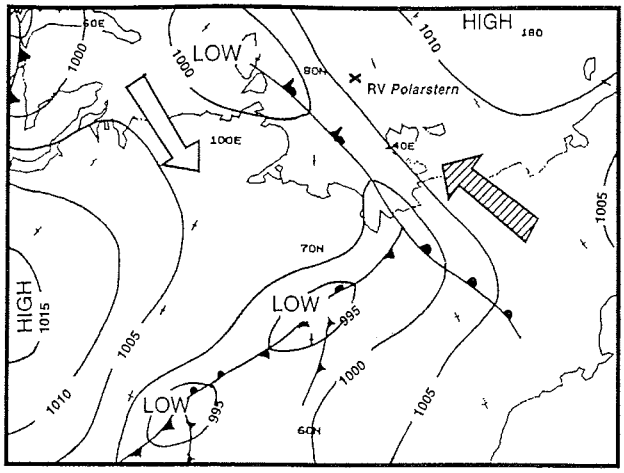

Fig. 7.4: 1000-hPa map and prevailing air masses (shady arrow – warm; non-shady arrow – cold) for 06.00 UTC, August 5, 1995. The position of the RV "Polarstern" is marked by a cross.

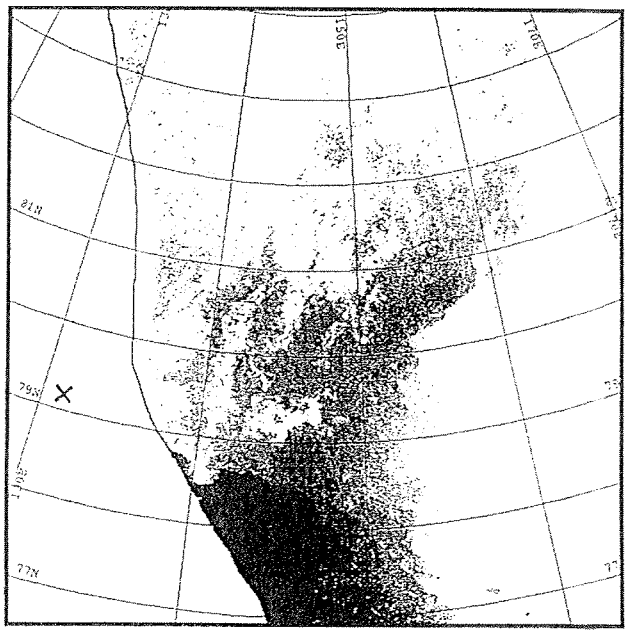

Fig. 7.5: The result of supervised classification of an AVHRR-scene from August 5, 1995: black – open water; dark grey – high sediment contents; white – low sediment contents. The position of the RV "Polarstern" is marked by a cross. The area on the left side of the image is covered by clouds.

Table 7.7: Elemental composition of arctic aerosols and aerosols from other regions, ng/m^3 (average data).

Region, period	number of samples (n)	Na	Ca	Sc	Cr	Fe	Co	Ni	Zn	As	Se	Br	Rb	Sb	Source
Laptev Sea, summer 1995	12	494		0.0081	3.97	142	0.102		15.4	0.38		1.74			This work
Kara Sea, September 1993	14	24.9		0.00022	0.044	2.81	0.0041		1.58		0.049			0.0032	Shevchenko et al., 1995
St. Anna Trough and Barents Sea, August-October 1994	10	1760	283	0.0033	5.66	135	0.30	8.2	43	0.15		0.1		0.064	Shevchenko et al., 1998
Norwegian and Greenland seas, July-August 1996	5	1517	155	0.026	0.665	800		19.1	34.2	0.64	0.28	0.5	0.87	0.098	This work
Fram Strait, June-July 1997	8	415	9.2		0.56	57		11.1	18.8	0.08	0.3	0.044	1.11	0.16	This work
Central Arctic, August-October 1991	7	20	3	<0,003	<1,1	5.9	0.019	<0,18	0.18	0.022	<0,2	0.25	0.042	0.019	Maenhaut et al., 1996
Fram Strait, August-October 1991	3	490	23	<0,004	<1	10.6	0.014	<0,2	0.19	<0,06	0.088	1.26	0.052	<0,005	Maenhaut et al., 1996
Severnaya Zemlya, April-May, 1985, 1986, 1988	22	90	180	0.014	1.6	30	0.075	6.2	5.6	1.8	0.3	4.1		0.19	Vinogradova and Polissar, 1995
Spitsbergen, Ny-Alesund, summer 1984	13	66	7.3	0.0012	0.56	5.6	<0,004	<0,2	<0,15	0.01	0.035	0.73	<0,08	0.0024	Maenhaut et al., 1989
Spitsbergen, Ny-Alesund, winters 1983, 1984, 1986	46	230	34	0.0043	<0,4	17.8	0.0096	0.29	3.9	0.52	0.156	8.8	0.083	0.092	Maenhaut et al., 1989
Canadian Arctic, st. Alert March 1985	12	234.5	62.6	0.01		50	0.032		8.5	0.349	0.081	18.5		0.06	Landsberger et al., 1990
Alaska, Point Barrow March-April 1986	280	240	53			38		4	11			25			Li and Winchester, 1990
Greenland, st. Summit (3170 m), June-August 1990	29	4.3	16	0.003		9.8	0.011		1.5	0.029	0.02	0.95			Mosher et al., 1993
North Sea, Helgoland, 1986-90									99	8	2.4			1.8	Dannecker et al., 1994
Black Sea, western part, June-September 1988	14	1400		0.08	9	420	0.25	4.9	46	1.1	0.73	0.02	1.6	0.6	Hacisalihoglu et al., 1992
Antarctida		3.3		0.00016	0.04	0.62	0.00049		0.033						Maenhaut et al., 1979

Table 7.7 (continuation)

Region, period	number of samples (n)	Cs	Ba	La	Ce	Nd	Sm	Eu	Yb	Lu	Hf	Au	Th	U	Source
Kara Sea, September 1993	14											0.003			Shevchenko et al., 1995
St. Anna Trough and Barents Sea, August-October 1994	10	0.016	0.89	0.064	0.11	0.035	0.0091	0.0021	0.0026	0.0004		0.0026		0.041	Shevchenko et al., 1998
Norwegian and Greenland seas, July-August 1996	5	0.032	3.39	1.94	2.49	0.46	0.07	0.017	0.026	0.004	0.088		0.046	0.53	This work
Fram Strait, June-July 1997	8	0.023	2.03	0.21			0.011	0.0018	0.009	0.0012	0.01		0.008	0.21	This work
Central Arctic, August-October 1991	7	<0,04	<4	<0,013	<0,3		0.0005	<0,01		<0,006			<0,03		Maenhaut et al., 1996
Fram Strait, August-October 1991	3	<0,04	<5	<0,03	<0,3		<0,003	<0,016		<0,007			<0,035		Maenhaut et al., 1996
Severnaya Zemlya, April-May 1985, 1986, 1988	22						0.01				0.064	0.066	0.018		Vinogradova and Polissar, 1995
Spitsbergen, Ny-Alesund, summer 1984	13	0.003	<0,7	0.0055	<0,02		0.00072	<0,001		<0,0004			0.0017		Maenhaut et al., 1989
Spitsbergen, Ny-Alesund, winters 1983, 1984, 1986	46	0.0089	<1,5	0.0137	<0,05		0.003	0.00116		<0,0028			0.004		Maenhaut et al., 1989
Canadian Arctic, st. Alert March 1985	12			0.029	0.047		0.004						0.0042		Landsberger et al., 1990
Black Sea, western part, June-September 1988	14	0.17	4.5	0.37	0.74		0.04	0.01	0.02				0.11		Hacisalihoglu et al., 1992

the Antarctic (Maenhaut et al., 1979). The main cause of the high concentrations of Na and other elements, typical for marine aerosols, is that the sampling was carried out in the Laptev Sea in summer, when a significant part of water surface was not ice-covered (Rachor, 1997).

The average concentration of Br in the Laptev Sea in July-September 1995 was 1.74 ng/m^3 (App. 12). This value is close to the concentration of Br in aerosols over the Fram Strait (1.26 ng/m^3) and higher, than over the pack ice of the Central Arctic (0.25 ng/m^3) (Maenhaut et al., 1996). High value of the correlation coefficient between concentrations of Br and Na (n=10 samples; r_{xy}=0.89) (Fig. 7.6) testify that the sea salt was the main source of Br in the aerosols in the marine boundary layer over the Laptev Sea in the time of our expedition. More high concentration of Br in the Arctic atmosphere is registered in spring. On the Severnaya Zemlya Archipelago concentration of Br in aerosols in the first half of April 1985 was equal to 7.5 ng/m^3 (Vinogradova and Polissar, 1995), at the station Alert (Ellesmere Island, Canadian Arctic) in middle of April 1986 it reached 75.8 ng/m^3 (Barrie et al., 1989), at the Barrow station (Alaska, USA) from the middle of March to the middle of April 1986 it was in average 25 ng/m^3, reaching 342 ng/m^3 (Li and Winchester, 1990), in the central part of Alaska in springs of 1984-1987 it was in average 5.39 ng/m^3 (Sturges and Shaw, 1993), at the Spitsbergen near Ny-Alesund at the end of April 1995 it reached 120 ng/m^3 (Lehrer et al., 1997). Apparently, such increase of concentration of Br in spring Arctic atmosphere is connected with photochemical reactions taking place in the lower troposphere at the end of polar night (Barrie and Barrie, 1990; Barrie et al., 1994 a, b; Lehrer et al., 1997).

According to our data, the average concentration of Sc in the Laptev Sea aerosols in July-September 1995 was 0.0081 ng/m^3, what is higher than in some other regions of the Arctic and Antarctic (Table 7.7). The increased concentration of scandium, which is typical terrigenic element, is connected with the closeness of the land free of snow at the time of measurement and rarely with resuspension of the mineral material from dirty ice.

Average concentrations of Cr, Mn, Fe, Co, Zn, and As are higher, than in some Arctic regions (Table 7.7), that could be explained mostly natural reasons (income of particles from the surface microlayer of the sea water, enriched with many trace elements, and resuspension of particles from the dirty ice), though in some samples anthropogenic pollution is possible also.

The concentrations of chemical elements in aerosols in the marine boundary layer over the Kara Sea in September 1993 during the 49th expedition of the RV "Dmitry Mendeleev" were close to their concentrations in other Arctic regions or lower (App. 14; Table 7.7). It is far (by one to two orders of magnitude) lower than usually in the Arctic in the late winter – early spring (Heintzenberg et al., 1981; Vinogradova et al., 1993). And it is one to two orders of magnitude lower than that over the Black and Mediterranean Sea which are under influence of the arid zone and industrial impact (Bergametti et al., 1989; Guieu et al., 1991; Medinetz and Kolosov, 1994; Medinetz et al., 1994). Thus, the air in the Arctic region under study can be considered relatively clean. The content of microelements in the Antarctic air is relatively lower (Maenhaut et al., 1979; Cunningham and Zoller, 1981; Parungo et al., 1981), what is explained by remoteness of the Antarctic from most sources of natural and anthropogenic sources.

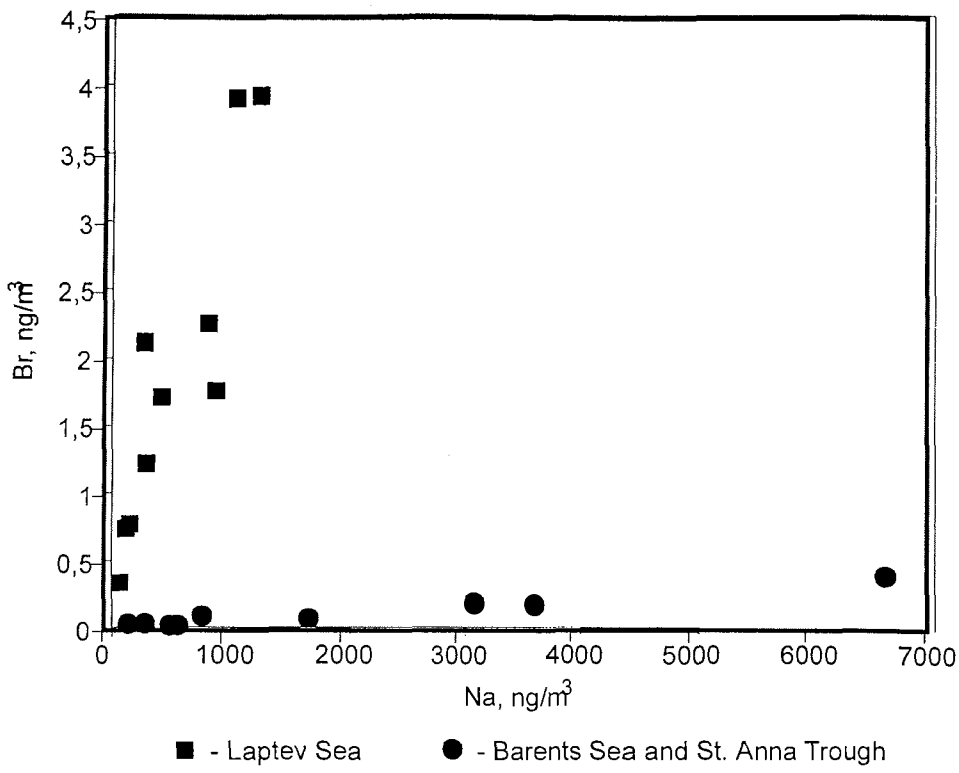

Fig. 7.6: Correlation between concentrations of Br and Na in the Laptev Sea aerosols (July-September 1995, ARK-XI/1 expedition of the RV "Polarstern"; r=0.89) and in the Barents Sea and St. Anna Trough (August-October 1994, 9th expedition of the RV "Professor Logachev"; r=0.97).

As for insoluble fraction of aerosols (Part 7.2), the highest concentrations of Se in the samples collected on Whatman-41 filters and very high EF with this element were measured in the samples 7-9 (App. 14, 15), collected in the Yenisey Gulf in air masses coming from Norilsk (Shevchenko et al., 1995). In those samples the high EF was also registered for Co. These results, along with the data of scanning electron microscopy (Chapter 5), electron microprobe analysis (Part 7.1), as well as the element composition of insoluble fraction of aerosols (Part 7.2) are indicative of significant pollution of the Kara Sea aerosols even at a far (>300 km) distance from Norilsk.

As an additional indicator of anthropogenic aerosols, we have calculated the ratios of tracer elements (Zn/Sb, As/Sb, Se/Sb) characteristic of different sources. The use of these ratios was proposed by K. Rahn and D. Lowenthal (Rahn and Lowenthal, 1984, 1985; Lowenthal and Rahn, 1985). These ratios are widely used for determination of source regions at the same time as method of back air mass trajectories (Maenhaut et al., 1989; Barrie et al., 1994 a, b; Vinogradova and Polissar, 1995; Lowenthal et al., 1997). The values of Zn/Sb and Se/Sb ratios, obtained by us for aerosols of the Kara Sea, are by an order of magnitude higher than those available in the literature for aerosols of the Norilsk region (Table 7.8). One of the main causes of this difference is likely insufficiently reliable data on the element composition of aerosols of the Norilsk region, especially for Sb, Se, and As.

It is very interesting to compare the average values of enrichment factors for the aerosols sampled by nylon meshes and by filtering through the Whatman-41 filters (Table 7.9). It is seen that for most elements the EF of the filtered samples is one to two orders of magnitude higher than that for the samples, collected by meshes. It could testify that these elements are mostly connected with submicron particles, which hardly can be collected by nylon meshes. The only exclusion is Co, for which the average values of the EF are almost the same for the both sampling methods. It is shown that the concentrations of many trace elements are higher in the finest fractions (Duce et al., 1976 a, b, 1983; Raemdonck et al., 1986; Dulac et al., 1989). Thus, the aerosol particle size distribution becomes one of the most important factors determining the aerosol chemical composition. Presence of sea-salt particles in filtration samples is important reason of their high enrichment by trace elements. Earlier we mentioned that sea salt particles are enriched with many trace elements because of fractionation in the surface microlayer of the sea water.

In the region of the St. Anna Trough and in the Barents Sea, in August-October 1994 during the 9th expedition of the RV "Professor Logachev", ten samples were collected by the air filtering through the AFA-KhA-20 filters (App. 3; Fig. 2.1 and 2.2). Concentrations of chemical elements in these samples are given in the App. 16. Their average values are compared with literature data in the Table 7.7. The concentrations of almost all elements (except for bromine and copper), measured by us, were higher than those given for Spitsbergen at the distance of about 1 km from the shore (Maenhaut et al., 1989). Moreover, our data exceed even spring values obtained at the Severnaya Zemlya Archipelago in the period of maximum pollution of the Arctic atmosphere (Vinogradova and Polissar, 1995), but in that expedition the sea was ice-covered and income of sea-salt particles was extremely low. Only

Table 7.8: Indicator ratios between elements-tracers in Arctic aerosols (elements content was taken from App. 14, App. 16, App. 18 and App. 20).

Expedition	Numbers	Zn, ng/m³	As, ng/m³	Se, ng/m³	Sb, ng/m³	*Zn/Sb*	*As/Sb*	*Se/Sb*
DM-49	1	2			0.0044	455		
1993	2	0.4		0.013	0.0019	211		6.8
	3	5.3			0.0011	4818		
	4	0.63			0.0049	129		
	5	0.97			0.0037	262		
	6	0.27			0.0016	169		
	7	0.97		0.101	0.0029	334		34.8
	8	2.56		0.038	0.005	512		7.6
	9	0.66		0.044	0.0019	347		23.2
	10	0.65			0.0025	260		
	11	1.52			0.0028	543		
	12	1.97			0.0063	313		
	14	3.75			0.0026	1442		
	average	1.58		0.049	0.0032	753		18.1
	geom. mean	1.18		0.038	0.0029	412		14.3
PL-9	1	53	0.0031		0.003	17541	1.03	
1994	2	33	0.032		0.062	539	0.52	
	3	101	0.0039		0.047	2148	0.08	
	4	43	0.43		0.11	393	3.91	
	5	22	0.0006		0.11	198	0.005	
	6	36	0.28		0.065	553	4.3	
	7	11	0.28		0.0056	1978	50	
	8	27	0.0004		0.12	222	0.003	
	9	59	0.044		0.0026	22818	16.9	
	10	45	0.44		0.11	412	4.0	
	average	43	0.15		0.064	4680	8.1	
	geom. mean	37	0.024		0.033	1136	0.73	
PL-15	4	14	0.72	0.09	0.014	1000	51.4	6.43
1996	5	11	0.06	0.07	0.003	3667	20	23.3
	6	105	1.26	1.03	0.37	284	3.4	2.78
	7	11	0.39	0.04	0.004	2750	98	10.0
	average	35.3	0.61	0.31	0.098	1925	43	10.6
	geom. mean	21	0.38	0.13	0.016	1301	24.2	8.0
ARK-XIII/2	1	36	0.35		0.59	61	0.59	
1997	2	3.56	0.12	0.25	0.028	127	4.3	8.9
	3	67	0.0042		0.041	1634	0.1	
	4	2.6			0.23	11		
	5	15	0.0048		0.06	250	0.08	
	6	23	0.00078		0.034	676	0.023	
	7	1	0.0011	0.18	0.1	10	0.011	1.8
	8	2.2		0.46	0.21	10		
	average	18.8	0.08	0.3	0.16	348	0.85	5.4
	geom. mean	8	0.0095	0.27	0.095	84	0.13	4.0
CEC*						28	0.74	1.03
MW*						46	2.6	4.4
EUR*						106	3.7	2.2
CUSSR*						45	10	1.03
Kola Peninsula**						7.8	7.2	1.1
Pechora basin**						4.7	0.96	1.8
Norilsk**						10.5	9.8	1.3
Scandinavia**						460	24	1.5

* CEC - Central Eastern coast of the USA; MW - Midle West of the USA;
EUR - Europe; CUSSR - Central part of the USSR (Lowenthal and Rahn, 1985).
**Pacyna et al., 1984, 1985

Table 7.9: Comparison of the enrichment factors of aerosols, collected by the meshes (insoluble particles with size more than 1 μm) and by filtration through Whatman-41 filters in the Kara Sea in 49th expedition of the RV "Dmitry Mendeleev" (September 1993) and through AFA-Kha in 9th cruise of the RV "Professor Logachev" (August-October 1994).

Method	Elements	Na	Cr	Fe	Co	Ni	Zn	Se	Br	Mo	La	Au
49th expedition of the RV "Dmitry Mendeleev"												
mesh	aver.	0.65	9.5	2.79	12		101	3430	34	42		14000
	stand.	0.29	5.4	1.13	18		99	5750	20	24		11480
filters	aver.	152	62	7.9	15		3550	108800	9560	3050		43300
	stand.	148	51	6.1	15		3290	84200	12210	5070		35300
9th expedition of the RV "Professor Logachev"												
mesh	aver.	1.1	40	3.9	5.1	6.1	198		13		2	5750
	stand.	1.8	23	1.4	4.7	10.3	170		13		1	3140
filters	aver.	785	470	16	90	1320	5060		420		15	5060
	stand.	1200	300	8	116	2630	3700		680		17	6210

concentrations of As, Sb, and Au, as well as already mentioned Br and Cu on the Severnaya Zemlya were higher. The variability of the aerosol element composition was very wide from sample to sample (App. 16). In this case, this represents not only temporal, but also spatial variability of the fields of element concentrations, because the sites of sampling changed in accordance with the vessel route (Fig. 2.2).

The enrichment factors for most elements in the aerosols over the St. Anna Trough and the Barents Sea in August-October 1994 are close in the order of magnitude to the average values for the Arctic islands (Fig. 7.7). Data on EF (App. 17; Fig. 7.7) and results of the correlation analysis (Table 7.10) allow (Shevchenko et al., 1998) the chemical elements to be divided into three groups: (1) the elements characteristic of the Earth's crust (Sc, rare-earth elements, Th); (2) the marine elements (Na and Br); (3) the elements of mixed marine, terrigenic, and anthropogenic origin (As, Ni, Cu, Se, Fe, Co, and Zn). The relatively high EFs of the rare-earth elements in the filtered samples (10-15) are probably connected both with the fact that the aerosols sampled by filtering consist largely of sea salt, which is characterized by high concentrations of these elements (Savenko, 1988, 1994), and with the peculiarities of the composition of soils on the land adjacent to the region of observations, in particular, Kola Peninsula.

The high value of the coefficient of correlation between the concentrations of Br and Na (n = 9 samples; r = 0.978; the critical value of the correlation coefficient for nine samples is equal to 0.798 at 1-% significance level) (Fig. 7.6) indicates that the main source of Br in the Arctic aerosols in the period of our investigation was sea salt.

The significant enrichment of the aerosol with Ni (Fig. 7.7), in our opinion, is connected not only with its direct atmospheric transport from the industrial regions, but also with its income from the sea surface microlayer enriched with Ni (Savenko, 1991, 1994), because there is strong correlation between Ni and Na concentrations (n = 10 samples; r_{xy} = 0.78).

As for the Kara Sea aerosols (September 1993), the EFs of the filtered samples from the St. Anna Trough and the Barents Sea (August-October 1994) proved to be higher than those for the samples, collected by nylon meshes (Table 7.9). This is explained by the fact that the filtering holds submicron aerosol particles enriched with a lot of chemical elements, including sea salt.

In the Norwegian and Greenland Seas, as well as in the western Barents Sea, the composition of aerosols was studied in July-August 1996, during the 15th expedition of the RV "Professor Logachev" (App. 18; Fig. 2.4). The average concentrations of the typical marine element Na and the typical terrigenic element Sc were high (1517 and 0.0026 ng/m^3, respectively) in comparison with other areas (Table 7.7). The EFs (App. 19) indicate that the main source of most elements is sea salt. However, for Ni, Zn, As, Se, and Sb the anthropogenic source is also important. The indicator ratios Zn/Sb and As/Sb (Table 7.8) show that this source is in Scandinavia.

In general, in July-September catastrophic pollution of the Arctic aerosols from the anthropogenic sources were not revealed. Based on geochemical studies we have succeeded in determination the main local pollution sources (Norilsk, Kola Peninsula).

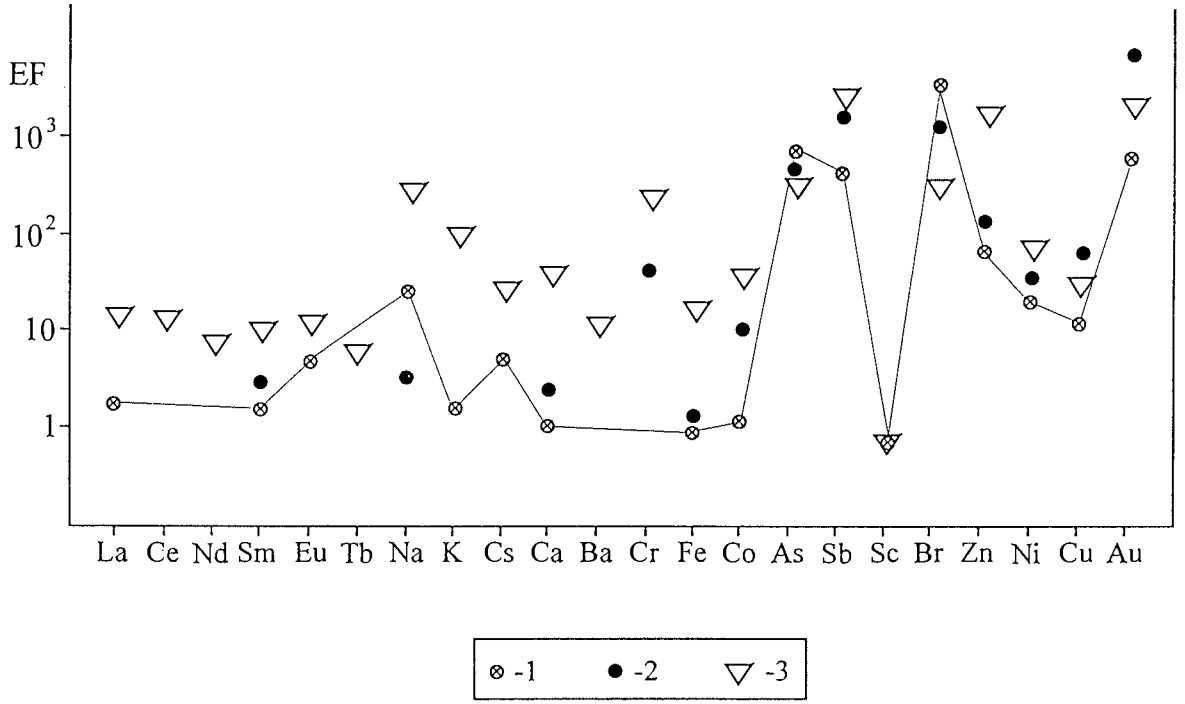

Fig. 7.7: Enrichment factors of aerosol samples collected in the Arctic by filtration: 1 – the Barents Sea and St. Anna Trough (August-October 1994, 9th expedition of the RV "Professor Logachev"); 2 – Severnaya Zemlya Archipelago, springs 1985, 1986 and 1988 (Vinogradova et al., 1983); 3 – Spitsbergen, winter 1983-1984 (Maenhaut et al., 1989).

Table 7.10: Correlation matrix of elemental composition of aerosol samples, collected by filtration through AFA-KhA filtres in 9th cruise of the RV "Professor Logachev" in August-October, 1994 (n=10 samples; r5%=0.632).

Element	Na	Ca	Sc	Cr	Fe	Co	Ni	Cu	Zn	As	Br	Sb	Cs	Ba	La	Ce	Nd	Sm	Eu	Tb	U
Na	1	0.46	-0.31	0.25	-0.21	-0.3	0.78	0.46	0.07	-0.5	0.98	-0.33	0.33	-0.15	-0.45	-0.52	-0.54	-0.5	-0.39	-0.42	-0.03
Ca		1	0.36	0.83	0.67	0.12	0.46	0.27	0.65	-0.35	0.57	-0.59	0.01	0.02	0.01	0.08	0.19	0.17	0.07	0.03	0.4
Sc			1	0.51	0.83	0.17	-0.32	-0.17	0.32	0.06	-0.23	0.09	0.13	0.19	0.51	0.62	0.56	0.42	0.14	0.11	-0.08
Cr				1	0.73	0.41	0.05	-0.09	0.7	-0.16	0.3	-0.51	0.41	-0.14	0.06	0.2	0.44	0.44	0.33	0.3	0.45
Fe					1	0.36	-0.07	0	0.63	0	-0.08	-0.2	-0.04	0.24	0.55	0.66	0.68	0.57	0.3	0.27	0.29
Co						1	-0.15	0.09	0.6	0.11	-0.31	0.27	0.15	-0.57	0.31	0.46	0.82	0.87	0.82	0.81	0.64
Ni							1	0.88	0.07	-0.42	0.84	-0.07	-0.14	-0.1	-0.04	-0.17	-0.34	-0.37	-0.35	-0.38	0.01
Cu								1	-0.01	-0.26	0.52	0.3	-0.24	-0.23	0.24	0.12	-0.10	-0.18	-0.23	-0.26	-0.07
Zn									1	-0.39	0.11	-0.34	0.01	-0.09	0	0.19	0.65	0.73	0.7	0.67	0.87
As										1	-0.47	0.29	-0.18	-0.04	0.4	0.38	0.16	0.08	-0.1	-0.06	-0.34
Br											1	-0.35	0.24	-0.1	-0.31	-0.39	-0.48	-0.47	-0.4	-0.43	-0.02
Sb												1	-0.02	-0.39	0.53	0.48	0.28	0.18	0.11	0.13	-0.3
Cs													1	-0.35	-0.17	-0.14	-0.02	0	0.08	0.07	-0.09
Ba														1	0.03	-0.02	-0.24	-0.3	-0.43	-0.42	-0.26
La															1	0.97	0.61	0.42	0.18	0.19	-0.1
Ce																1	0.78	0.61	0.37	0.37	0.07
Nd																	1	0.97	0.82	0.81	0.57
Sm																		1	0.92	0.92	0.72
Eu																			1	1	0.84
Tb																				1	0.83
U																					1

8. FLUXES OF AEROSOLS ON THE SURFACE OF THE ARCTIC OCEAN AND THEIR ROLE IN THE SEDIMENTATION

The vertical fluxes of the aerosols deposited on the sea or land surface can be estimated from the data on the aerosol concentrations and size distribution. As it was shown in the Chapter 4, away from the coastal areas the aerosol particle size distribution varies only slightly, what simplifies estimation of the vertical fluxes. The above data on mineral and chemical composition of the Arctic aerosols (Chapters 6 and 7) can be recalculated both into the values of vertical fluxes of aerosols as a whole and various minerals and chemical elements (pollutants).

This method involving some assumptions gives only rough values of the fluxes. When necessary, it can be supplemented and checked by direct determination of the fluxes by measuring the snow depth (estimations of fluxes for the period of snow cover), ice, and bottom sediments, including measurements with use of various precipitation gauges etc. Besides, in recent years the methods of the isotopic analysis of fluxes (^{210}Pb, ^{7}Be, and other cosmogenic isotopes) receive increasing development (Dutkiewicz and Husain, 1985; Todd et al., 1989; Dibb, 1992).

The knowledge of the fluxes of aerosols (not only the concentrations) gives the values specific for a given place and given synoptic situation, what is especially important when studying the regime of pollution fallout, and this apparently will be the basis for future ecological studies and monitoring.

The fluxes of the aeolian material to the sea surface in the Russian Arctic due to dry sedimentation were calculated by us on the assumption that the sedimentation rate of insoluble coarse (> 1 μm) particles, which form the most, in mass, portion of insoluble aerosols (Chapter 4), is equal to 2 cm/s (Duce et al., 1991). The fluxes in the Arctic (App. 1) make up from 0.03 to 1.68 mg m^{-2} d^{-1} (on the average 0.39 mg m^{-2} d^{-1}, at the standard deviation of 0.34 mg m^{-2} d^{-1}) or 142 mg m^{-2} y^{-1}.

We have calculated the flux of insoluble aerosols a year assuming that the dry deposition is _ of the total value (Rahn, 1981). We extend our summer data on the aerosol concentrations to the whole year, taking into account that the aerosol concentration in summer is several times lower than in winter and spring (Barrie and Barrie, 1990; Polissar et al., 1998 a, b, 1999; Sirois and Barrie, 1990), but the amount of precipitation in summer is three to four times larger than in spring (Bryazgin, 1976; Burova, 1983; Voskresensky and Petrov, 1985; Raatz, 1991). The vertical flux of aeolian particulate matter calculated under these assumptions is equal to 570 mg m^{-2} y^{-1} (1.56 mg m^{-2} d^{-1}).

The flux of the insoluble aeolian material to the drifting ice surface in the Arctic was determined independently based on the average concentration of particulate matter in the fresh snow equal to 2.19 mg/l (Mullen et al., 1972; Darby et al., 1974; Pfirman et al., 1989; Dibb, 1996; Dethleff et al., 1998; Shevchenko et al., 1999b); n=87 measurements, and the annually mean amount of atmospheric precipitation in the Arctic Ocean equal to 285 mm (Voskresensky and Petrov, 1985). This direct method gave the value of 624 mg m^{-2} y^{-1} (1.71 mg m^{-2} d^{-1}).

The value for the aeolian material flux measured in 1994 at the station Ni-Alesund on Spitsbergen by one more independent method (with a

precipitation gauge) was 212 mg m^{-2} y^{-1} (0.58 mg m^{-2} d^{-1}) (Kriews and Schrems, 1995; Kriews et al., 1996).

The average, over the three methods, vertical flux of insoluble aerosols in the Arctic comprises about 300 mg m^{-2} y^{-1}, what is far higher than formerly accepted. Of course, this value calls for further refinement.

The presented data show that the contribution of aerosols to formation of the Arctic environment is more significant and diversified than it was considered earlier. First of all, this is the case of the aerosol material total amount and its seasonal distribution. According to different estimates, the total annual income of insoluble aerosols to the Arctic Ocean (area of 13.1 x 10^6 km^2) varies from 2.8 x 10^6 t (measurements with a precipitation gauge on Spitsbergen) (Kriews and Schrems, 1995; Kriews et al., 1996) to 8.2 x 10^6 t from our data (Table 8.1). This is much less than the delivery of suspended particulate matter to the Arctic by rivers (about 245 x 10^6 t y^{-1}) (Gordeev et al., 1996; Macdonald et al., 1998). However, it should be kept in mind that the main portion of river suspension is deposited in marginal filters of rivers, at the river/sea barrier (Lisitzin, 1994 b, 1999). Only about 7% of riverine particulate matter passes through the filter, and only 5% reaches the area of the continental slope, that is, only 12 x 10^6 t y^{-1} of riverine solid material is delivered to the Central Arctic. So, contribution of the aeolian material to formation of the geochemical properties of the suspended matter, cryosols and bottom sediments in the Arctic is roughly equal to contribution of the suspended matter of rivers and ice rafted material (Table 8.1). The income of organic matter from the atmosphere is also of great significance. For many chemical elements (Pb, Sb, Se, V etc.) in the Arctic the atmospheric source is principal (Rahn, 1981 a; Mosher and Duce, 1987; Akeredolu et al., 1994).

In summer at weak anthropogenic impact, the global background aerosol is well-defined in the Arctic (Fig. 8.1). It is largely determined by alumosilicates (the Earth's crust matrix), which are complemented in summer by sea salt and plant residues from the land. The global background aerosol has quite constant size distribution and mineral composition.

In the Arctic seas and in the Central Arctic the aerosol unloads on the ice surface with snow most of year (300-360 days), but not on the sea surface as in the other zones. The zone of pack ice is characterised by round-the-year accumulation of the aeolian material for 3-15 years (Pfirman et al., 1989, 1990, 1995, 1997).

Aerosol unloading in the zone of the pack ice happens at the places of ice melting – in the northern part of the Greenland Sea. Thus, the Arctic is a giant natural accumulator of the aeolian material and attendant pollutants, which first enter into ice, i.e., are transformed into cryosols, and then, many thousands kilometers far from the places of their fallout, into water.

The aerosol delivery of nutrients (P, N, S), iron, and some other elements needed for life is of great importance for ecosystems of the Arctic, because their income with river discharge is insignificant there (Gordeev et al., 1996). Income of nutrients with rivers in the Arctic is much lower than in other climatic zones because nitrogen utilizing bacteria lives bad at low temperature and chemical weathering in cold environment is weakly developed (Ugolini, 1986; Dobrovolsky, 1998). Aerosols provide the most part of elements needed for phytoplankton bloom in melt ponds on drifting ice and in marginal ice zone (Smith, 1987; Arctic ..., 1995).

Table 8.1: Aerosol fluxes and delivery of the particulate matter into the basin of the Arctic Ocean.

Means of delivery	Methods of obtaining data	Aerosol fluxes, mg m^{-2} d^{-1}	Delivery of particulate matter, 10^6 t y^{-1}	References
Aeolian transport	Aerosol studies	1.56	7.5	This work
	Particles in the ice study	1.71	8.2	Mullen et al., 1972; Darby et al., 1974; Pfirman et al., 1989; Dibb, 1996; Dethleff et al., 1998; Shevchenko et al., 1999a, b
	Data of precipitation gauge	0.58	2.8	Kriews and Schrems, 1995
River input	Before marginal filter		245	Gordeev et al., 1996; Macdonald et al., 1998
	After marginal filter		12	Lisitzin, 1994 b, 1999
Ice transport from the Laptev Sea	Ice-rafted sediments study		4	Eicken et al., 1997

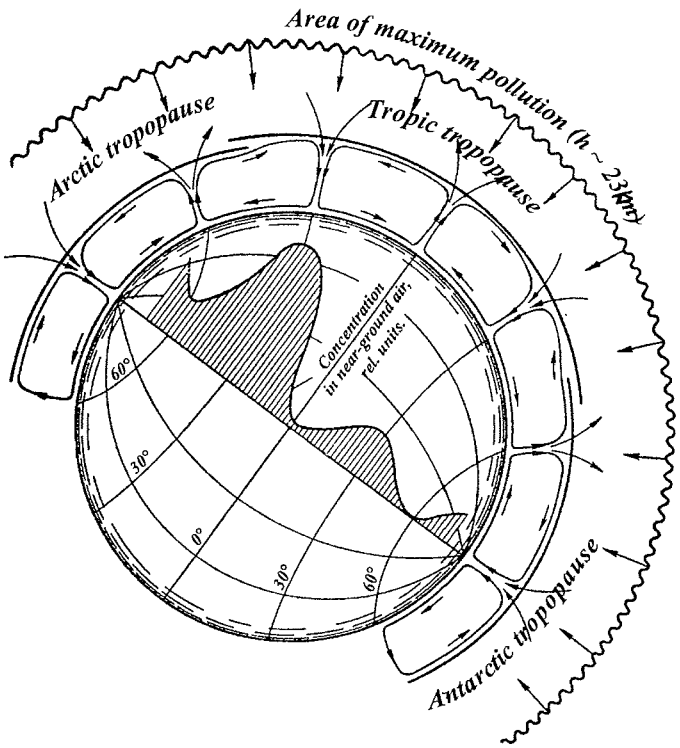

Fig. 8.1: Meridional circulation of air and distribution of radioactive fallout (shaded) at the stratospheric type of transport of sedimentary material (Lavrenchik, 1965).

CONCLUSIONS

In 1991-1998 aerosols in the Arctic Ocean and its seas were studied in nine expeditions. The results of these studies give us possibility to make following conclusions:

1. Quantitative distribution of aerosols is a fast changing value, which depends on combination of many regional and local factors. Average concentration of insoluble aerosols in marine boundary layer over the Russian Arctic seas is equal to 0.23 $\mu g/m^3$ at the standard deviation of 0.19 $\mu g/m^3$ (55 measurements). This is higher than the literature data on concentrations in open ocean areas, especially, in humid zones, but much lower than the aerosol concentrations in remote areas of arid zone.
2. Results of aerosol particle size distribution study show that submicron particles dominate in air, but sediments are mostly (in mass) are formed by insoluble particles with the sizes from 5 to 25 μm.
3. Accordingly to the data of electron microscopy, coarse (>1 μm) non-salt particles of Arctic aerosols consist largely of mineral and organic matter (plant fibres, pollens, spores, diatom algae, etc.). Porous fly ash particles from 5 to 50 μm in size consisting mostly of carbon and smooth spheres from 0.5 to 10 μm in diameter are also characteristic of the Arctic aerosol. These mostly anthropogenic particles were found in small amounts in most samples collected by nylon meshes. During all our expeditions, when approaching the Kola Peninsula or Norilsk, the content of anthropogenic particles in aerosols increased. The study of morphology of coarse (>1 μm) insoluble particles indicates that the main source of the aeolian material over the Arctic seas in July-October is Eurasia, although in winter the contribution of far and very far (>10000 km) sources increases significantly.
4. The study of mineral composition of Arctic aerosols has shown that: 1) it is characterised by strong spatial and temporal variability; 2) in summer sources of aeolian material are situated both in surrounding tundra and at the large distance.
5. In general, in July-September catastrophic pollution of the Arctic aerosols from the anthropogenic sources were not revealed. Based on geochemical studies we have succeeded in determination the main local pollution sources (Norilsk, Kola Peninsula).
6. The balance calculations, based on our data, show that the contribution of aerosols to formation of the sedimentary material in the Arctic is close to the contribution of river sediments beyond the marginal filters of rivers (earlier the aeolian material in the Arctic was ignored). For many elements (Pb, Sb, Se, V etc.) the aerosol source is the primary one.
7. Our experience shows that along with the through study of the aeolian material in the atmosphere, the systematic studies of lithology and geochemistry of snow cover are necessary, since it is a natural collector of both dissolved and suspended aeolian material. The corresponding studies of lithology and geochemistry of the sea ice, on which surface the aeolian material is first deposited and then concentrated, are necessary as well. Thus, the study of the atmospheric matter acquires a systematic and multidisciplinary character, what sharply increases the possibilities of interpretation.

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APPENDIX

App. 1: Mesh samples of aerosols, collected in the arctic seas, concentrations and fluxes of water-insoluble fraction of aerosols with size more than 1 μm on the sea surface by the dry deposition.

No.	Date-time, beginning/ end	Coordinates, beginning/ end		Wind		Concen-tration	Flux on the sea surface
		Latitude (N)	Longitude (E)	Speed (m/s)	Direction (°)	(μg/m^3)	(mg m^{-2} day^{-1})
"SPASIBA-91" expedition, the RV "Yakov Smirnitzkij", 1991							
1	14.08-08.00 14.08-16.00	67°40.2' 68°44.5'	41°39.5' 45°15.5'	12.0	45	0.44	0.76
2	15.08-11.30 15.08-22.30	69°14.1' 70°29.1'	53°02.3' 58°15.7'	13.2	70	0.40	0.69
3	17.08-01.00 17.08-16.00	71°45.7' 73°17.5'	63°02.0' 69°52.1'	12.8	60	0.24	0.41
4	17.08-23.30 18.08-12.30	73°34.0' 72°00.7'	69°40.6' 74°17.6'	9.3	45	0.10	0.17
5	25.08-13.30 25.08-20.30	77°12.5' 76°19.4'	110°58.4' 114°39.9'	9.5	220	0.18	0.31
6	25.08-21.30 26.08-00.00	76°12.9' 75°43.1'	114°37.6' 114°33.4'	15.7	190	0.46	0.79
7	08.09-09.15 08.09-21.45	73°57.4' 71°28.5'	131°25.1' 130°20.8'	12.2	140	0.08	0.14
8	11.09-19.15 12.09-09.30	72°07.4' 70°24.7'	126°58.1' 125°46.1'				
9	13.09-20.45 14.09-11.00	70°52.0' 70°52.0'	127°26.1' 127°26.1'				
10	15.09-20.00 16.09-18.00	72°32.0' 72°32.0'	127°12.5' 127°12.5'				
49th expedition of the RV "Dmitry Mendeleev", 1993							
3	24.08-08.25 25.08-09.00	64°19.5' 69°59.3'	07°30.6' 14°16.8'	6.9	330	0.02	0.03
4	28.08-09.15 28.08-13.55	70°54.0' 70°32.4'	50°49.1' 53°11.4'	16.4	5	0.26	0.45
5	29.08-03.40 29.08-12.50	70°06.2' 70°42.0'	55°11.1' 58°08.0'	4.9	0	0.06	0.10
6	30.08-14.40 30.08-21.50	71°35.5' 72°17.3'	58°49.7' 59°59.0'	8.7	340	0.66	1.14
7	01.09-10.45 01.09-16.40	72°40.1' 72°56.7'	59°04.5' 61°11.2'	6.0	315	0.20	0.35
8	03.09-22.35 04.09-02.20	73°12.5' 72°41.8'	64°40.7' 64°34.7'	4.4	180	0.14	0.24
9	04.09-19.30 05.09-01.00	71°47.0' 71°01.6'	64°37.1' 64°35.3'	8.0	180	0.48	0.83
10	07.09-15.50 08.09-07.40	70°36.0' 69°59.2'	60°23.8' 49°22.9'	15.4	20	0.06	0.10
11	13.09-09.00 14.09-07.25	70°09.2' 72°16.3'	54°28.3' 59°49.7'	3.7	0	0.03	0.05

App. 1: (continuation).

No.	Date-time, beginning/ end	Coordinates, beginning/ end		Wind		Concen-tration ($\mu g/m^3$)	Flux on the sea surface (mg m^{-2} day^{-1})
		Latitude (N)	Longitude (E)	Speed (m/s)	Direction (°)		
49th expedition of the RV "Dmitry Mendeleev", 1993							
12	14.09-12.50 14.09-17.45	73°11.9' 74°10.5'	61°35.9' 63°09.2'	4.6	315	0.18	0.31
13	14.09-17.45 15.09-03.05	74°10.5' 74°25.6'	63°09.2' 67°49.0'	4.7	0	0.15	0.26
14	15.09-03.05 16.09-03.35	74°25.6' 75°59.0'	67°49.0' 73°00.4'	5.8	0	0.05	0.09
15	16.09-06.15 17.09-16.35	75°58.8' 73°48.9'	73°36.6' 79°58.8'	3.6	180	0.03	0.05
16	18.09-11.40 18.09-19.30	72°29.8' 71°44.7'	79°49.2' 83°17.0'	10.4	190	0.21	0.36
17	22.09-21.25 23.09-18.50	74°25.0' 76°02.5'	80°23.4' 79°33.6'	4.5	110	0.21	0.36
18	26.09-09.20 26.09-24.00	72°17.6' 70°57.2'	73°38.4' 73°34.3'	11.8	70	0.06	0.10
19	28.09-09.00 28.09-15.10	70°16.1' 71°02.0'	73°33.2' 73°26.5'	4.4	50	0.18	0.31
20	29.09-11.20 30.09-04.25	72°53.4' 72°44.3'	73°14.0' 64°25.0'	8.3	45	0.05	0.09
21	30.09-09.00 01.10-06.25	72°15.9' 70°36.0'	64°29.1' 60°33.9'	7.5	290	0.03	0.05
22	01.10-10.50 02.10-09.20	70°32.4' 69°49.2'	58°30.0' 44°53.6'	11.5	345	0.02	0.03
23	02.10-10.20 02.10-19.40	69°47.8' 69°35.8'	44°18.1' 38°31.5'	5.5	270	0.05	0.09
31st expedition of the RV "Akademik Mstislav Keldysh"							
1	31.08-14.30 01.09-11.30	70°01.1' 70°04.5'	34°16.9' 43°55.6'	9.4	320	0.05	0.09
2	01.09-16.00 02.09-08.20	70°04.9' 70°06.9'	46°03.3' 53°46.7'	9.8	260	0.05	0.09
3	06.09-15.20 07.09-11.00	70°28.3' 70°37.0'	57°59.0' 46°50.6'	3.7	175	0.22	0.38
4	07.09-11.00 08.09-09.20	70°37.0' 71°05.5'	46°50.6' 31°48.7'	5.8	15	0.06	0.10
5	08.09-14.00 09.09-15.00	71°10.4' 69°44.7'	29°08.6' 15°51.7'	4.5	250	0.12	0.21

App. 1: (continuation).

No.	Date-time. beginning/ end	Coordinates, beginning/ end		Wind		Concen-tration	Flux on the sea surface
		Latitude (N)	Longitude (E)	Speed (m/s)	Direction (°)	(μg/m^3)	(mg m^{-2} day^{-1})
9th cruise of R/V "Professor Logachev", 1994							
1	05.08-19.10 06.08-18.20	69°35.0' 72°06.5'	34°18.7' 42°11.9'	5.6	25	0.16	0.28
2	07.08-13.55 08.08-09.50	73°48.4' 75°36.8'	46°10.7' 53°11.5'	7.7	305	0.29	0.50
3	09.08-10.50 09.08-17.20	77°03.7' 77°00.0'	66°47.2' 70°00.2'	3.7	185	0.57	0.98
4	10.08-16.45 11.08-08.25	79°25.2' 80°54.5'	69°59.7' 68°00.2'	9.5	245	0.30	0.52
5	13.08-01.00 13.08-14.45	80°39.8' 81°58.2'	69°59.9' 67°30.2'	3.2	255	0.32	0.55
6	21.08-08.30 21.08-14.35	80°00.0' 79°59.8'	77°36.5' 71°29.7'	3.6	240	0.21	0.36
7	02.09-03.30 02.09-21.00	79°15.0' 79°19.8'	71°40.0' 67°21.3'	3.2	205	0.49	0.84
8	03.09-12.25 04.09-11.10	78°17.4' 79°35.7'	63°59.2' 67°18.2'	7.5	300	0.51	0.88
9	06.09-09.25 07.09-06.00	80°00.0' 79°59.9'	70°31.0' 64°55.1'	4.8	330	0.27	0.47
10	08.09-12.15 09.09-10.50	78°51.6' 80°35.5'	52°35.8' 42°25.6'	2.4	5	0.16	0.27
11	09.09-12.00 10.09-00.45	79°59.1' 77°35.4'	36°46.8' 25°31.6'	0.5	230	0.14	0.24
12	09.09-12.00 10.09-00.45	77°26.8' 76°29.2'	24°58.2' 18°41.2'	3.3	170	0.27	0.47
13	10.09-08.00 10.09-24.00	76°38.8' 78°00.8'	15°20.0' 13°03.7'	5.0	100	0.39	0.67
14	13.09-17.25 14.09-16.50	75°50.0' 73°16.1'	17°32.4' 25°02.8'	8.0	240	0.13	0.22
15	14.09-17.45 15.09-20.00	73°09.8' 70°59.5'	25°19.6' 32°07.2'	7.5	250	0.18	0.31
16	02.10-09.20 03.10-16.00	71°22.1' 70°12.1'	51°52.7' 42°05.7'	11.0	185	0.55	0.95
17	04.10-09.30 04.10-14.10	69°26.8' 69°18.4'	36°08.7' 34°23.7'	9.0	190	0.97	1.68
18	06.10-10.30 08.10-11.00	69°01.0' 69°01.0'	33°02.5' 33°02.5'	5.5	230	0.14	0.24
19	08.10-20.00 09.10-15.15	69°40.2' 71°20.0'	33°28.5' 27°59.4'	9.5	220	0.40	0.69
20	09.10-16.45 10.10-17.00	71°20.0' 70°29.2'	27°13.4' 17°44.0'	11.0	220	0.42	0.73

App. 1: (continuation).

No.	Date-time. beginning/ end	Coordinates, beginning/ end		Wind		Concen-tration ($\mu g/m^3$)	Flux on the sea surface ($mg\ m^{-2}\ day^{-1}$)
		Latitude (N)	Longitude (E)	Speed (m/s)	Direction (°)		
ARK-XI/1 expedition of the RV "Polarstern", 1995							
1	23.07-13.05 24.07-06.30	77°29.7' 78°00.5'	135°46.0' 144°53.7'	7.5	85	0.09	0.16
2	30.07-23.30 31.07-16.00	77°22.4' 76°55.0'	137°30.3' 131°18.6'	5.5	90	0.04	0.07
15th expedition of the RV "Professor Logachev", 1996							
4	30.07-07.25 30.07-22.00	67°19.0' 68°33.1'	06°58.2' 10°14.1'	5.0	350	0.28	0.48
5	31.07-06.30 31.07-16.30	69°12.0' 70°10.5'	11°53.9' 14°33.0'	5.5	50	0.24	0.41
6	11.08-07.10 11.08-17.45	72°04.0' 73°00.0'	14°06.9' 11°35.9'	4.0	220	0.16	0.28
7	19.08-12.50 20.08-00.20	77°03.0' 78°17.2'	07°24.0' 07°25.6'	6.0	330	1.38	2.38
8	24.08-11.15 24.08-19.35	76°23.8' 75°29.3'	15°42.9' 18°39.8'	8.5	170	0.10	0.17
11th expedition of the RV "Akademik Sergey Vavilov", 1997							
1	27.08-22.00 28.08-03.10	65°14.4' 66°21.2'	39°40.8' 40°43.3'	7.5	60	0.30	0.52
2	30.08-21.00 01.09-00.50	70°11.5' 69°55.9'	32°35.2' 36°59.5'	11.2	130	0.06	0.10

App. 2: Aerosol samples, collected on Whatman-41 filters in the Kara Sea in September 1993 (49th expedition of the RV "Dmitry Mendeleev").

No.	Data-time (GMT) beginning - end	Coordinates beginning - end		Wind		Volume of the air (m^3)
		Latitude (N)	Longitude (E)	Speed (m/s)	Direc-tion (°)	
1	13.09-07.30 13.09-20.00	70°06.5' 71°42.6'	55°10.2' 59°04.7'	3.8	0	530
2	13.09-20.10 14.09-14.00	71°42.6' 73°26.7'	59°04.7' 61°57.8'	4.5	0	461
3	14.09-14.00 15.09-05.30	73°26.7' 74°16.0'	67°37.8' 72°54.2'	4.7	340	762
4	15.09-08.40 15.09-23.30	74°14.8' 76°00.0'	73°01.2' 73°00.0'	5.8	0	547
5	16.09-02.20 16.09-19.30	75°58.8' 74°59.9'	73°36.3' 80°00.6'	3.6	180	645
6	16.09-21.40 17.09-15.15	74°59.9' 73°30.6'	80°00.6' 79°59.6'	4.0	180	783
7	17.09-17.30 18.09-12.20	73°30.6' 72°06.3'	79°59.6' 82°12.5'	7.0	190	570
8	18.09-12.30 19.09-14.30	72°06.3' 71°02.0'	82°12.5' 83°13.2'	10.5	190	470
9	20.09-06.00 21.09-07.10	71°48.7' 72°28.8'	83°10.3' 80°02.2'	6.0	230	793
10	21.09-12.00 22.09-18.10	72°28.8' 74°31.5'	80°02.2' 80°35.4'	6.7	90	614
11	22.09-18.10 23.09-10.40	74°31.5' 76°00.0'	80°35.4' 79°57.9'	7.5	110	408
12	23.09-14.40 24.09-16.10	76°00.0' 74°59.7'	79°57.9' 73°05.2'	8.3	250	582
13	25.09-03.00 26.09-04.40	74°59.7' 72°21.9'	73°05.2' 73°42.4'	10.0	180	685
14	26.09-04.40 27.09-06.20	72°29.1' 70°03.5'	73°42.4' 73°26.2'	12.0	70	801

App. 3: Aerosol samples collected on the AFA-KhA filters over the arctic seas.

No.	Data-time (ship's) beginning-end	Coordinates		Wind		Volume of the filtered air (m^3)
		Latitude (N)	Longitude (E)	Speed (m/s)	Direction (°)	
		beginning-end				
9th expedition of the RV "Professor Logachev"						
1	06.08-16.00 06.08-21.25	71°54.0' 72°24.1'	41°18.8' 43°22.8'	5.5	20	64.6
2	07.08-12.55 08.08-01.25	73°42.3' 74°48.9'	45°45.3' 49°51.1'	8.1	350	104.6
3	09.08-10.50 09.08-16.00	77°03.7' 77°04.1'	66°47.2' 69°14.3'	4.0	180	77.3
4	10.08-10.20 13.08-14.30	79°10.7' 81°56.7'	70°00.0' 67°30.1'	4.6	240	150.5
5	16.08-13.15 23.08-16.00	80°42.9' 80°00.0'	71°28.9' 65°43.0'	3.1	210	524.0
6	29.08-08.00 04.09-11.10	77°26.3' 79°59.9'	72°00.3' 64°55.1'	6.0	320	458.9
7	05.09-08.18 09.09-24.00	79°35.0' 76°25.5'	64°26.8' 19°04.5'	2.1	170	496.5
8	14.09-08.00 15.09-20.15	74°14.1' 70°58.3'	22°22.3' 32°11.8'	7.5	250	462.7
9	02.10-09.35 04.10-14.10	71°21.5' 69°18.4'	51°46.6' 34°23.7'	10.0	185	151.7
10	06.10-10.45 08.10-14.00	69°01.0' 69°01.0'	33°02.5' 33°02.5'	5.5	230	110.4
ARK-XI/1 expedition of the RV "Polarstern"						
1	19.07-16.00 21.07-12.40	77°31.4' 76°55.3'	97°03.5' 122°07.1'	13.3	100	194.0
2	22.07-03.30 22.07-18.00	77°42.8' 77°44.4'	125°56.6' 126°44.9'	7.9	145	151.14
3	24.07-02.30 28.07-15.00	78°00.5' 79°05.1'	144°53.7' 145°56.6'	5.3	210	118.06
4	30.07-02.45 31.07-09.05	77°59.9' 76°59.1'	140°03.3' 131°50.0'	6.0	135	159.1
5	31.07-21.55 03.08-12.45	76°08.4' 78°09.8'	129°59.6' 129°58.4'	5.8	20	197.5
6	05.08-01.25 05.08-03.30	79°09.5' 79°11.3'	131°25.3' 131°26.1'	14.8	135	29.2
7	07.08-13.35 09.08-18.50	81°06.2' 81°11.5'	105°23.5' 107°30.7'	12.5	225	227.9
8	10.08-17.00 12.08-10.00	80°47.4' 80°24.9'	103°48.8' 102°05.4'	7.5	270	97.7
9	17.08-12.40 19.08-08.30	79°08.7' 79°59.3'	135°03.8' 135°04.5'	7.6	270	72.9
10	22.08-09.20 23.08-08.30	81°03.6' 81°04.3'	136°27.0' 138°55.7'	10.0	80	170.8

App. 3 (continuation).

No.	Data-time (ship's) beginning-end	Coordinates		Wind		Volume of the filtered air (m^3)
		Latitude (N) beginning-end	Longitude (E) beginning-end	Speed (m/s)	Direction (°)	
ARK-XI/1 expedition of the RV "Polarstern"						
11	01.09-08.40 02.09-10.30	78°22.8' 78°15.5'	134°49.2' 135°23.5'	13.5	170	87.2
12	08.09-16.05 10.09-00.50	81°24.3' 82°04.3'	97°32.8' 91°01.7'	10.6	340	147.8
15th expedition of the RV "Pofessor Logachev"						
4	29.07-10.25 31.07-16.30	65°56.2' 70°10.5'	3°58.7' 14°33.0'	5.1	0	66.2
5	02.08-17.05 08.08-15.40	71°42.2' 72°00.2'	13°28.0' 14°43.3'	6.4	130	194.7
6	11.08-07.10 11.08-10.20	72°04.0' 72°22.4'	14°06.9' 13°17.9'	4.0	220	9.5
7	13.08-07.50 20.08-07.30	76°51.5' 79°28.0'	7°22.8' 7°46.5'	5.1	190	104.7
8	24.08-11.15 26.08-13.50	76°23.8' 70°28.8'	15°42.9' 31°20.3'	8.0	165	60
ARK-XIII/2 expedition of the RV "Polarstern"						
1	27.06-14.35 27.06-23.45	76°18.4' 76°50.2'	33°28.3' 33°45.9'	4.8	300	46.0
2	29.06-16.40 01.07-23.15	78°52.9' 80°45.0'	31°17.4' 24°59.1'	3.7	130	194.7
3	07.07-19.50 11.07-11.10	80°19.0' 81°08.4'	10°20.2' 5°39.4'	4.6	125	94.7
4	12.07-09.50 12.07-18.30	81°13.9' 81°13.5'	2°18.8' 2°37.2'	7.9	215	69.3
5	15.07-15.10 17.07-08.15	81°26.0' 81°34.5'	5°22.0'W 8°11.5'W	4.1	170	144.7
6	18.07-08.20 26.07-04.00	81°41.6' 82°02.8'	9°01.5'W 5°18.1'	4.4	170	256.7
7	26.07-13.10 27.07-18.15	81°59.2' 81°54.4'	5°44.5' 7°59.1'	8.0	195	178
8	29.07-19.00 31.07-07.25	81°33.4' 81°18.5'	11°36.3' 13°31.3'	8.9	215	98
11th expedition of the RV "Akademik Sergey Vavilov"						
1	25.08-14.25 26.08-16.00	64°32.1' -//-	40°30.6' -//-	3.0	275	136
2	27.08-22.00 28.08-03.10	65°14.4' 66°21.2'	39°40.8' 40°43.3'	7.5	60	41.3
3	30.08-21.00 01.09-00.50	70°11.5' 69°55.9'	32°35.2' 36°59.5'	11.2	130	115.3

App. 4: Aerosol size distribution over the Arctic seas in summer.

No.	Date-time (UTC)	Coordinates		Wind		Visi-bility (m)	Temp. (°C)	particles/cm³				
		Latitude (N)	Longitude	Direction (°)	Speed (m/s)			0.5-1 µm	1-2 µm	2-3 µm	3-5 µm	5-10 µm
ARK-XI/1 expedition of the RV "Polarstern", July-September 1995												
1	19.07-17.00	77°09.43'	95°06.4'E	40	6.6	1924	-2.9	1.21	0.24	0.19	0.12	0.008
2	20.07-06.00	77°57.00'	104°53.9'E	56	8.0	636	-0.3	1.57	0.68	0.34	0.43	0.11
3	20.07-10.00	77°54.10'	107°03.5'E	51	7.5	9999	0.6	2.28	0.38	0.027	0.002	0.000
4	20.07-17.10	77°17.71'	110°10.7'E	144	15.7	9999	5.0	2.98	0.81	0.12	0.005	0.000
5	20.07-20.00	76°52.55'	112°16.2'E	138	14.4		1.6	6.53	2.92	0.65	0.086	0.009
6	21.07-06.00	76°27.80'	118°34.0'E	154	16.0	7636	2.2	7.37	5.08	0.66	0.12	0.006
7	21.07-11.00	76°47.86'	121°07.6'E	154	14.5	9999	1.8	7.70	4.70	0.90	0.077	0.002
8	22.07-06.35	77°43.96'	126°04.2'E	165	9.2	9999	0.4	2.41	1.18	0.13	0.005	0.000
9	24.07-02.30	78°00.51'	144°53.7'E	101	7.8		-2.0	0.29	0.04	0.002	0.000	0.000
10	25.07-04.35	78°33.27'	145°40.5'E	123	5.1	9999	-1.2	2.43	0.72	0.04	0.001	0.000
11	25.07-16.30	78°58.71'	147°20.7'E	140	8.9	9999	-0.7	1.40	0.037	0.002	0.000	0.000
12	26.07-17.00	79°27.12'	148°06.1'E	142	5.0	9999	-1.2	0.41	0.11	0.001	0.000	0.000
13	26.07-22.30	79°27.57'	148°06.8'E	185	3.9	9999	-0.1	0.093	0.14	0.009	0.000	0.000
14	27.07-14.50	79°29.39'	148°13.2'E	295	4.8	9999	-1.3	0.37	0.017	0.000	0.000	0.000
15	27.07-18.45	79°22.02'	147°28.3'E	300	4.0	9999	-1.3	0.26	0.15	0.034	0.000	0.000
16	28.07-05.30	79°08.89'	146°21.3'E	255	2.5	323	-0.7	1.26	0.50	0.65	0.61	0.065
17	30.07-04.35	77°59.26'	140°05.8'E	154	3.3	9999	1.6	0.092	0.002	0.000	0.000	0.000
18	30.07-12.20	77°31.10'	140°01.1'E	147	5.6	9999	3.9	0.64	0.32	0.044	0.006	0.000
19	31.07-07.30	77°01.30'	132°15.0'E	110	6.1	9999	3.4	1.28	1.17	0.18	0.044	0.005
20	01.08-03.00	76°53.14'	129°59.5'E	333	5.3	2642	1.6	1.60	0.19	0.05	0.002	0.000
21	02.08-03.00	77°42.20'	130°02.8'E	49	1.3	9999	-2.1	0.28	0.06	0.019	0.004	0.000
22	02.08-10.20	77°51.21'	130°02.3'E	46	3.8	9999	-1.8	0.51	0.037	0.001	0.000	0.000
23	03.08-10.10	78°03.93'	129°60.0'E	95	6.8	9918	-2.3	2.75	0.102	0.047	0.008	0.000
24	05.08-01.25	79°09.50'	131°25.3'E	136	14.8	1257		10.01	1.07	0.17	0.012	0.000
25	06.08-11.00	78°24.74'	122°11.9'E	300	5.0	9999	-0.2	1.34	0.047	0.001	0.000	0.000
26	06.08-15.30	78°44.44'	119°11.5'E	186	8.1	9999	-0.1	2.23	0.12	0.03	0.000	0.000

App. 4 (continuation).

No.	Date-time (UTC)	Coordinates		Wind		Visi-bility (m)	Temp. (°C)	particles/cm^3				
		Latitude (N)	Longitude	Direction (°)	Speed (m/s)			0.5-1 µm	1-2 µm	2-3 µm	3-5 µm	5-10 µm
ARK-XI/1 expedition of the RV "Polarstern", July-September 1995												
27	07.08-13.35	81°06.17'	105°23.5'E	201	15.9	9999	-0.6	6.04	2.52	0.43	0.052	0.005
28	07.08-17.35	81°08.11'	105°33.7'E	203	12.2	9999	-0.9	4.02	2.61	0.42	0.039	0.001
29	08.08-21.00	81°14.16'	106°51.2'E	236	10.0	9999	-1.4	4.19	1.46	0.21	0.008	0.000
30	09.08-18.50	81°11.51'	107°30.7'E	285	10.1	2668	-2.1	4.04	1.69	0.25	0.012	0.000
31	10.08-17.00	80°47.41'	103°48.8'E	238	6.1	9999	-3.0	4.71	0.89	0.30	0.001	0.000
32	12.08-04.20	80°25.32'	102°00.6'E	330	12.8	9999	-2.7	13.23	3.24	0.65	0.13	0.004
33	17.08-12.40	79°08.67'	135°03.8'E	274	7.6	9999	-2.9	4.51	0.05	0.01	0.000	0.000
34	19.08-05.00	79°59.12'	134°59.4'E	247	6.1	1879	-2.9	7.37	0.03	0.34	0.100	0.04
35	22.08-09.00	81°03.64'	136°30.0'E	68	10.7	9999	-3.5	4.73	0.057	0.000	0.000	0.000
36	22.08-14.45	81°04.65'	136°15.9'E	82	11.5	9999	-3.6	4.30	0.043	0.000	0.000	0.000
37	22.08-16.00	81°04.98'	136°12.0'E	81	11.7	9999	-3.8	1.05	0.008	0.000	0.000	0.000
38	22.08-20.30	81°03.15'	136°37.2'E	86	9.8	9999	-3.1	0.26	0.06	0.000	0.000	0.000
39	23.08-04.40	81°03.02'	138°16.5'E	83	9.3	3009	-3.0	4.26	0.096	0.002	0.000	0.000
40	23.08-08.30	81°04.26'	138°55.7'E	90	8.0	1120	-2.9	5.63	0.49	0.037	0.000	0.000
41	25.08-20.15	81°12.40'	143°24.7'E	151	12.1	9999	-0.2	9.30	0.19	0.059	0.002	0.000
42	27.08-04.30	81°12.65'	150°13.7'E	270	5.6	747	-1.1	11.44	0.44	0.15	0.047	0.104
43	31.08-20.25	79°22.97'	138°13.3'E	271	2.3	732	-7.7	6.93	2.31	1.52	0.24	0.17
44	01.09-12.40	78°24.51'	134°51.1'E	187	11.1	9999	1.0	3.82	0.81	0.67	0.045	0.000
45	01.09-20.30	78°20.66'	135°00.8'E	164	13.7	9999	1.3	10.83	2.91	0.65	0.11	0.000
46	02.09-09.10	78°15.00'	135°23.4'E	153	15.8			11.23	2.72	0.98	0.12	0.000
47	06.09-13.25	78°45.59'	112°43.1'E	241		9999	-1.2	2.31	0.07	0.01	0.000	0.000
48	07.09-04.25	77°55.66'	113°31.8'E	292		9999	-1.5	17.98	1.23	0.15	0.004	0.000
49	07.09-06.00	77°55.54'	113°32.0'E	298	9.0	9505	-1.7	15.46	0.90	0.19	0.004	0.000
50	08.09-16.05	81°24.31'	97°32.8'E	347		3036	-7.1	8.75	0.34	0.007	0.000	0.000
51	08.09-19.50	81°45.85'	96°36.2'E	335	12.0	9999	-7.6	9.81	0.1	0.034	0.005	0.000
52	08.09-22.05	81°49.26'	95°40.3'E	321	11,8	9999	-7.2	11.05	0.23	0.050	0.007	0.000
53	09.09-00.00	82°04.16'	94°24.4'E	345	13,2	9999	-6.8	9.87	0.1	0.028	0.012	0.000

App. 4 (continuation).

No.	Date-time (UTC)	Coordinates		Wind		Visi-bility (m)	Temp. (°C)	particles/cm^3				
		Latitude (N)	Longitude	Direction (°)	Speed (m/s)			0.5-1 µm	1-2 µm	2-3 µm	3-5 µm	5-10 µm
ARK-XI/1 expedition of the RV "Polarstern", July-September 1995												
54	09.09-02.00	82°18.11'	93°21.1'E	339	11.5	9999	-7.2	8.65	0.13	0.018	0.000	0.000
55	09.09-04.20	82°21.16'	92°55.5'E	352	11.2	9999	-7.5	16.52	0.067	0.006	0.000	0.000
56	09.09-19.20	82°08.44'	91°21.8'E	351	7.5	9999	-9.7	14.51	0.096	0.017	0.000	0.000
57	09.09-22.40	82°04.2'	90°59.4'E	354	7.3	9999	-10.7	19.75	0.065	0.007	0.000	0.000
58	10.09-07.20	82°04.6'	90°59.4'E	349	2.6	9999	-10.7	11.79	0.019	0.000	0.000	0.000
59	10.09-16.50	81°54.3'	90°54.5'E	24	0.7	9999	-8.0	17.51	0.034	0.007	0.000	0.000
60	10.09-22.15	81°26.3'	89°38.4'E	8	2.5	9999	-7.3	16.90	0.041	0.002	0.000	0.000
61	11.09-00.10	81°10.3'	89°00.7'E	13	2.9	9999	-7.0	18.48	0.031	0.000	0.000	0.000
62	11.09-04.25	81°10.4'	87°30.2'E	11	4.7	9999	-6.8	20.79	0.002	0.000	0.000	0.000
63	11.09-13.35	79°33.5'	87°01.5'E	2	10.1	9999	-4.9	23.84	0.26	0.009	0.000	0.000
ARK-XIII/2 expedition of the RV "Polarstern", June-August 1997												
1	26.06-16.40	73°08.4'	26°00.5'E	350	8.0	9999	2.9	26.09	29.50	3.03	4.04	7.15
2	26.06-20.00	73°42.1'	27°26.8'E	341	6.0	9999	2.4	38.58	43.80	3.87	2.80	3.65
3	26.06-21.50	74°01.8'	28°09.8'E	351	5.6	9999	2.6	71.38	10.24	4.62	4.86	2.26
4	27.06-00.30	74°29.9'	29°15.7'E	330	4.6	9999	1.7	37.04	47.97	2.44	2.20	2.85
5	27.06-09.15	75°59.8'	32°59.5'E	297	4.0	9999	-0.6	33.83	54.43	1.80	2.12	2.38
6	27.06-15.15	76°20.0'	33°29.0'E	296	4.5	9999	-0.8	18.53	67.98	2.62	2.08	2.37
7	27.06-16.20	76°27.2'	33°35.3'E	294	5.1	9999	-0.5	29.34	64.49	2.13	1.80	1.71
8	27.06-22.25	76°42.1'	33°35.8'E	277	4.8	8843	-1.0	28.25	63.57	3.07	2.92	1.77
9	28.06-08.30	77°21.8'	34°38.7'E	253	2.0	9999	0	37.70	54.22	5.25	1.63	0.21
10	28.06-11.15	77°34.2'	34°40.5'E	220	1.3	9999	0.3	37.93	52.37	1.60	2.41	1.71
11	29.06-16.40	78°52.9'	31°17.4'E	36	1.4	9999	-0.6	46.08	50.89	1.95	1.13	0.73
12	29.06-19.00	79°07.0'	31°34.4'E	100	2.9	4520	-0.6	61.89	35.47	1.44	1.19	0.67
13	29.06-22.00	79°26.7'	30°33.3'E	70	2.4	9999	-0.6	62.30	30.59	1.26	1.20	0.58
14	30.06-02.00	79°26.8'	30°27.1'E	48	2.5	9999	-0.6	60.20	35.77	1.44	0.91	0.43
15	30.06-10.05	80°14.5'	29°10.7'E	17	2.6	9999	-0.3	60.27	33.08	1.32	1.18	0.47
16	30.06-20.30	80°41.2'	29°31.0'E	20	1.9	9945	-0.4	67.32	30.14	1.28	0.84	0.45

App. 4 (continuation).

No.	Date-time (UTC)	Coordinates		Wind		Visi-bility (m)	Temp. (°C)	particles/cm³				
		Latitude (N)	Longitude	Direction (°)	Speed (m/s)			0.5-1 µm	1-2 µm	2-3 µm	3-5 µm	5-10 µm
ARK-XIII/2 expedition of the RV "Polarstern", June-August 1997												
17	01.07-12.30	80°42.6'	27°45.0'E	337	6.9	9810	-0.5	45.47	52.63	0.73	1.07	0.45
18	01.07-18.00	80°42.2'	26°00.5'E	337	6.5	9999	-0.3	42.03	53.53	0.70	1.37	0.35
19	02.07-18.46	81°00.0'	20°54.2'E	305	6.3	9999	-2.4	50.29	47.73	0.72	1.09	0.32
20	02.07-21.10	81°03.3'	20°11.4'E	277	4.0	5312	-2.8	43.89	56.78	0.79	1.14	0.37
21	03.07-19.02	80°58.4'	17°36.8'E	117	4.3	9999	-0.5	17.02	84.52	0.12	0.12	0.009
22	03.07-21.30	80°58.7'	17°25.0'E	164	2.5	9999	-0.1	23.65	76.54	0.11	0.14	0.014
23	04.07-09.15	81°06.1'	16°55.3'E	246	6.8	9999	0.3	33.48	65.60	2.28	1.81	1.50
24	04.07-23.45	81°05.0'	16°25.1'E	166	4.6	9999	0.5	34.61	62.57	2.44	1.70	0.91
25	05.07-02.45	81°06.3'	16°14.8'E	185	3.1	9999	0.3	31.95	65.80	1.62	1.91	1.77
26	05.07-09.25	81°06.7'	16°17.9'E	119	3.6	9999	1.1	40.68	59.94	0.37	0.41	0.10
27	05.07-15.00	81°06.3'	16°14.4'E	116	2.1	9999	0.4	41.32	58.82	0.26	0.26	0.065
28	05.07-17.15	81°06.6'	16°14.7'E	79	3.4	9999	0.9	44.85	57.82	0.13	0.08	0.017
29	05.07-22.00	81°06.8'	16°10.4'E	56	3.1	9999	0.2	13.90	88.29	0.14	0.092	0.027
30	06.07-14.10	80°58.1'	11°51.7'E	324	2.7	9999	1.4	5.12	97.33	0.13	0.057	0.011
31	06.07-15.00	80°58.1'	11°51.3'E	337	1.6	9999	0.4	8.28	92.92	0.11	0.046	0.011
32	06.07-18.15	80°58.3'	11°49.6'E	268	0.4	9999	2.9	22.34	78.56	0.12	0.053	0.015
33	06.07-23.50	80°58.7'	11°45.6'E	101	2.5	9999	0.2	19.64	81.41	0.06	0.058	0.001
34	07.07-08.25	80°35.6'	11°42.1'E	98	3.6	9999	0.9	14.64	87.74	0.18	0.082	0.001
35	07.07-11.25	80°23.9'	11°40.8'E	129	0.6	9999	1.0	19.41	82.30	0.07	0.05	0.000
36	07.07-19.50	80°19.0'	10°20.2'E	35	2.8	9999	1.0	10.74	91.46	0.13	0.032	0.001
37	08.07-20.00	80°54.2'	09°52.2'E	156	3.1	9999	1.1	10.53	90.93	0.11	0.032	0.001
38	08.07-20.00	80°54.2'	09°50.3'E	173	3.9	9999	1.3	6.78	95.86	0.096	0.035	0.002
39	08.07-23.50	80°54.9'	09°49.3'E	174	4.9	9999	1.8	10.19	88.97	0.104	0.031	0.002
40	09.07-02.30	80°55.2'	09°50.8'E	175	5.5	9999	2.7	11.35	87.04	0.074	0.028	0.000
41	09.07-04.25	80°55.4'	09°53.0'E	202	6.3	9999	2.8	16.05	85.64	0.093	0.052	0.002
42	11.07-10.00	81°08.1'	05°46.7'E	210	7.1	8109	-0.4	13.98	82.18	0.11	0.037	0.001
43	12.07-09.50	81°13.9'	02°18.8'E	208	8.1	3952	-0.7	8.20	95.37	0.25	0.02	0.002

App. 4 (continuation).

No.	Date-time (UTC)	Coordinates		Wind		Visi-bility (m)	Temp. (°C)	particles/cm³				
		Latitude (N)	Longitude	Direction (°)	Speed (m/s)			0.5-1 µm	1-2 µm	2-3 µm	3-5 µm	5-10 µm
ARK-XIII/2 expedition of the RV "Polarstern", June-August 1997												
44	12.07-14.25	81°13.9'	02°30.4'E	219	8.9	9999	-0.3	8.50	95.75	0.22	0.025	0.001
45	15.07-15.10	81°26.0'	05°22.0'W	312	5.6	9756	-0.9	7.04	95.08	0.30	0.017	0.000
46	16.07-08.20	81°31.6'	06°49.3'W	138	2.8	662	-3.1	9.97	87.50	5.28	1.51	1.16
47	16.07-11.00	81°31.3'	06°48.7'W	138	2.9	646	-3.3	8.74	87.62	5.48	1.62	1.17
48	17.07-02.35	81°34.8'	08°10.6'W	81	4.6	8145	-2.7	8.24	88.73	3.92	1.95	0.81
49	17.07-06.20	81°34.8'	08°11.0'W	34	4.4	8659	-2.0	11.88	86.28	3.27	1.59	0.65
50	18.07-08.48	81°44.0'	08°35.4'W	37	1.9	9864	-0.3	36.96	66.15	0.37	0.03	0.000
51	22.07-05.30	82°37.5'	02°29.4'E	178	7.6	9860	-1.3	59.56	46.02	0.1	0.006	0.000
52	23.07-04.30	82°22.6'	03°41.4'E	48	9.0	8348	-0.6	74.76	31.24	0.005	0.000	0.000
53	23.07-09.55	82°22.2'	03°31.7'E	38	6.7	9972	-0.2	71.43	32.31	0.058	0.004	0.000
54	24.07-16.30	82°18.1'	03°42.0'E	218	5.1	9999	1.1	61.38	39.09	3.68	1.77	0.79
55	25.07-09.05	82°07.4'	05°00.4'E	200	3.6	9972	0.2	61.87	38.48	3.94	1.66	1.28
56	25.07-10.10	82°07.3'	05°00.7'E	205	2.5	9972	0.2	61.91	38.74	3.62	1.88	1.02
57	25.07-15.00	82°02.6'	05°18.4'E	188	4.0	9999	0.2	60.70	38.15	3.76	2.51	0.4
58	25.07-16.50	82°02.5'	05°18.0'E	195	4.6	9999	0.2	58.64	38.53	5.12	2.61	0.69
59	25.07-21.25	82°02.7'	0517.1'E	209	5.1	9881	0.2	59.41	37.11	3.52	2.72	0.56
60	26.07-02.50	82°02.8'	05°17.6'E	174	3.8	9864	-0.7	58.45	35.99	4.82	3.25	1.32
61	27.07-08.40	81°53.9'	07°41.3'E	221	8.2	9566	-1.2	31.54	68.32	0.36	0.11	0.002
62	27.07-17.05	81°54.2'	07°57.1'E	219	9.1	9540	-0.9	11.94	90.80	1.01	0.39	0.063
63	30.07-21.45	81°16.1'	13°11.6'E	221	10.1	9621	1.5	7.91	89.30	1.72	0.64	0.24
64	31.07-04.00	81°18.2'	13°25.7'E	201	9.7	9648	1.8	13.41	89.75	0.42	0.043	0.000
65	31.07-07.20	81°18.5'	13°31.3'E	201	13.5	9793	2.8	16.60	83.76	2.22	0.42	0.27
66	03.08-15.35	79°58.1'	8°58.2'E	180	10.0	9756	4.8	10.86	88.47	2.86	0.57	0.30
11th expedition of the RV "Akademik Sergey Vavilov", August-September 1997												
1	25.08-14.25	64°32.1'	40°30.6'E	270	4.0			5.29	91.39	0.59	0.021	0.000
2	30.08-21.00	70°11.5'	32°35.2'E	120	9.4		10.5	4.49	47.20	1.84	0.32	0.000
3	31.08-05.15	69°42.2'	33°44.9'E	125	10.0		10.3	6.37	41.26	0.64	0.091	0.000

App. 4 (continuation).

No.	Date-time (UTC)	Coordinates		Wind		Visi-bility (m)	Temp. (°C)	particles/cm^3				
		Latitude (N)	Longitude	Direction (°)	Speed (m/s)			0.5-1 µm	1-2 µm	2-3 µm	3-5 µm	5-10 µm
11th expedition of the RV "Akademik Sergey Vavilov", August-September 1997												
4	31.08-10.15	70°06.0'	34°27.3'E	130	11.3		10.0	6.48	43.17	1.73	0.27	0.000
5	31.08-13.20	70°04.9'	34°31.1'E	140	11.2		9.4	17.55	36.88	1.07	0.092	0.000
6	31.08-22.40	69°41.8'	36°59.5'E	130	13.6		6.8	7.14	44.17	0.52	0.14	0.003
7	01.09-00.00	69°54.6'	37°00.5'E	140	14.8		7.8	6.70	45.09	0.82	0.23	0.001
8	01.09-08.45	70°33.9'	37°06.3'E	155	13.4		7.8	6.37	50.76	0.27	0.13	0.000
9	01.09-12.00	70°36.4'	37°07.2'E	185	11.8		6.5	8.19	50.49	0.35	0.056	0.000
10	02.09-13.35	71°25.7'	36°39.9'E	186	9.7		9.0	2.20	50.42	0.59	0.15	0.000
11	06.09-02.00	76°55.5'	40°01.3'E	200	3.2		2.2	8.01	42.29	0.11	0.0026	0.000
12	10.09-12.20	80°11.6'	55°42.0'E	180	2.5		-3.8	7.04	50.26	0.034	0.000	0.000
13	10.09-12.20	80°20.6'	56°05.8'E	65	4.0		-3.8	6.99	50.56	0.091	0.000	0.000
14	11.09-11.15	79°32.5'	59°24.3'E	15	1.7		-2.8	7.14	43.40	0.14	0.003	0.000
15	13.09-04.00	76°50.2'	60°00.0'E	170	4.7		4.8	21.21	28.75	0.20	0.040	0.000
16	13.09-08.09	76°43.4'	59°58.3'E	110	10.0		6.2	11.76	44.90	0.56	0.088	0.000
17	13.09-21.00	77°21.1'	60°00.0'E	190	4.2		3.2	21.27	29.24	0.16	0.029	0.000
18	16.09-10.10	78°28.7'	61°22.8'E				2.0	9.48	40.51	0.28	0.04	0.000
19	18.09-09.45	77°46.9'	58°21.4'E	140	6.4		3.6	11.93	37.93	0.37	0.066	0.000
20	19.09-12.30	78°21.6'	59°59.7'E	130	7.1		2.1	15.70	34.77	0.34	0.074	0.000
21	19.09-16.00	78°01.2'	60°01.6'E	130	12.0		2.8	14.18	38.02	0.42	0.16	0.006
22	20.09-18.20	78°04.4'	62°55.3'E	170	5.5		1.6	24.83	24.70	0.27	0.027	0.000
23	22.09-10.00	76°12.3'	62°37.4'E	180	9.8		5.2	4.30	46.13	0.12	0.000	0.000
24	22.09-16.02	76°15.2'	62°31.9'E	190	10.3		5.4	5.42	46.18	0.14	0.005	0.000
25	23.09-10.55	76°15.7'	62°37.5'E	180	4.5		5.4	10.74	39.52	0.036	0.000	0.000
26	23.09-14.10	76°15.3'	62°29.1'E	210	51		5.2	11.47	39.89	0.04	0.000	0.000
27	29.09-11.35	70°14.9'	56°00.0'E	185	6.8			4.78	45.85	0.16	0.052	0.000
ARK-XIV/1a expedition of the RV "Polarstern", July 1998												
1	30.06-08.00	66°21.4'	09°35.4'E	27	8.1	1031	12	71.78	10.71	1.60	0.22	0.004
2	30.06-09.30	66°33.6'	09°51.2'E	30	9	643	11.5	72.30	7.16	0.72	0.12	0.000

App. 4 (continuation).

No.	Date-time (UTC)	Coordinates		Wind		Visi-bility (m)	Temp. (°C)	particles/cm³				
		Latitude (N)	Longitude	Direction (°)	Speed (m/s)			0.5-1 µm	1-2 µm	2-3 µm	3-5 µm	5-10 µm
ARK-XIV/1a expedition of the RV "Polarstern", July 1998												
3	30.06-12.30	67°00.7'	10°27.0'E	28	9.3	2217	11.1	1.67	3.28	0.13	0.015	0.000
4	30.06-14.10	67°10.8'	10°40.6'E	30	9	2096	10.8	17.41	3.00	0.46	0.027	0.000
5	30.06-16.25	67°29.9'	11°07.6'E	24	10.6	1653	9.7	24.20	2.92	0.27	0.012	0.000
6	30-06.20.30	67°59.9'	12°04.8'E	20	11.5	2766	8.9	17.73	2.69	0.23	0.043	0.000
7	01.07-05.40	69°11.6'	14°34.0'E	350	6.9	5134	7.8	26.76	3.72	0.17	0.012	0.000
8	01.07-09.07	69°34.5'	15°43.2'E	330	5.4	5010	8.3	4.72	2.63	0.19	0.006	0.000
9	01.09-10.00	69°40.9'	16°02.0'E	340	5.3	4125	8.5	7.97	1.16	0.071	0.004	0.000
10	01.07-12.35	69°57.5'	16°57.5'E	350	5.7	1605	8.3	12.82	3.44	0.32	0.030	0.000
11	01.07-16.50	70°17.8'	17°55.7'E	10	6.2	7156	8	11.14	2.22	0.08	0.018	0.000
12	02.07-04.20	71°45.0'	22°13.1'E	345	10.5	9793	5.2	5.67	0.33	0.006	0.000	0.000
13	02.07-06.12	72°00.0'	22°56.7'E	355	10.8	9891	5.2	3.47	0.61	0.02	0.000	0.000
14	02.07-10.10	72°30.7'	24°35.4'E	350	9	9837	4.6	7.51	0.42	0.012	0.000	0.000
15	02.07-12.15	72°45.3'	25°21.2'E	350	7.5	9918	4.6	9.22	0.64	0.014	0.000	0.000
16	02.07-14.25	73°00.1'	26°10.3'E	340	4.8	9918	4.6	2.66	0.24	0.033	0.000	0.000
17	02.07-18.40	73°30.1'	27°50.3'E	320	5	9918	5	2.64	0.057	0.002	0.000	0.000
18	02.07-19.10	73°33.8'	28°02.5'E	305	5.8	9945	5	3.48	0.22	0.008	0.000	0.000
19	02.07-22.10	73°54.9'	29°14.5'E	320	6.2	9945	5	5.72	0.20	0.013	0.000	0.000
20	04.07-04.25	76°05.7'	35°44.4'E	75	1	1386	-1.6	1.98	0.051	0.000	0.000	0.000
21	04.07-05.10	76°15.0'	35°50.2'E	220	1.2		-2.2	1.22	0.063	0.000	0.000	0.000
22	04.07-07.28	76°41.1'	35°42.5'E	245	2.8	145	-2.2	1.88	0.81	0.64	1.42	0.43
23	04.07-10.10	77°03.0'	36°44.0'E	225	4.3	422	-1.1	7.48	0.064	0.037	0.000	0.000
24	04.07-13.04	77°30.0'	37°48.2'E	240	5.4	9940	-0.4	7.66	0.048	0.000	0.000	0.000
25	04.07-16.14	78°01.9'	39°41.7'E	245	4.2	9810	-0.2	2.15	0.084	0.000	0.000	0.000
26	04.07-22.15	79°06.2'	40°30.5'E	275	4.4	9864	-0.4	2.85	0.043	0.000	0.000	0.000
27	05.07-04.40	80°08.6'	40°35.3'E	280	5.3		-1.7	3.37	0.056	0.002	0.000	0.000
28	05.07-07.23	80°36.2'	39°22.3'E	295	4.7	9837	-1.6	2.93	0.12	0.048	0.000	0.000
29	05.07-11.35	81°00.0'	37°38.3'E	290	3.9	9763	-0.8	3.27	0.028	0.000	0.000	0.000

App. 4 (continuation).

No.	Date-time (UTC)	Coordinates		Wind		Visi-bility (m)	Temp. (°C)	particles/cm^3				
		Latitude (N)	Longitude	Direction (°)	Speed (m/s)			0.5-1 µm	1-2 µm	2-3 µm	3-5 µm	5-10 µm
30	05.07-15.05	81°24.0'	37°11.0'E	270	4.6	9918	-1.2	4.66	0.072	0.006	0.000	0.000
31	05.07-18.45	81°30.6'	34°49.6'E	260	6.1	9837	-1.3	4.69	0.11	0.005	0.000	0.000
32	06.07-00.10	81°58.9'	34°49.8'E	250	6.3	1173	-2.4	4.51	0.095	0.006	0.000	0.000
33	06.07-08.53	82°15.0'	34°50.0'E	235	9.7	9733	-0.8	4.10	0.012	0.000	0.000	0.000
34	06.07-17.45	82°49.7'	31°52.8'E	250	9.2	9837	-0.2	2.26	0.013	0.000	0.000	0.000
35	07.07-05.15	83°26.8'	27°23.2'E	285	4.8	775	-1.7	3.57	0.069	0.034	0.000	0.000
36	07.07-17.15	84°20.0'	25°55.0'E	225	4.8	9837	-0.4	2.89	0.058	0.005	0.000	0.000
37	12.07-20.45	87°31.1'	130°45.8'W	350	7	9783	0.4	3.37	0.11	0.008	0.000	0.000
38	12.07-22.40	87°26.8'	136°02.0'W	330	7.5	9864	0.6	2.93	0.072	0.000	0.000	0.000
39	13.07-05.25	87°08.2'	139°37.1'W	295	8	9864	0.1	3.06	0.072	0.001	0.000	0.000
40	13.07-06.35	87°01.3'	141°35.7'W	295	8.3	9891	0.1	2.94	0.070	0.002	0.000	0.000
41	13.07-09.25	86°50.7'	144°20.8'W	275	7	9817	-0.6	3.88	0.026	0.000	0.000	0.000
42	16.07-10.45	85°08.0'	171°25.9'W	10	1.9	2783	-0.5	2.28	0.050	0.011	0.011	0.000
43	17.07-10.15	85°30.7'	174°16.5'W	135	3.8	9945	-0.3	1.36	0.041	0.000	0.000	0.000
44	18.07-18.05	85°45.7'	177°55.3'W	75	10.6	9869	-0.1	0.67	0.011	0.000	0.000	0.000
45	19.07-08.30	85°22.1'	177°35.7'E	190	2	189	0	2.10	0.98	0.78	0.57	0.019
46	19.07-15.10	85°03.5'	176°01.1'E	205	3.9	3847	-0.3	0.82	0.038	0.000	0.000	0.000
47	19.07-21.43	84°50.1'	169°59.0'E	140	3.8	9891	-1.4	0.44	0.017	0.000	0.000	0.000
48	20.07-05.55	84°39.6'	161°37.5'E	240	0.7	9891	-1.1	1.60	0.057	0.000	0.000	0.000
49	20.07-06.55	84°34.2'	160°00.0'E	240	1.9	9864	-0.8	1.43	0.039	0.000	0.000	0.000
50	20.07-16.30	84°33.5'	149°58.7'E	345	2.7	5093	-0.7	1.55	0.13	0.006	0.000	0.000
51	21.07-04.50	83°51.8'	146°22.5'E	360	4.5	9918	-0.2	1.18	0.032	0.001	0.000	0.000
52	21.07-14.30	83°30.0'	144°19.0'E	305	3.2	9864	-1.8	1.22	0.038	0.000	0.000	0.000
53	21.07-17.45	83°15.6'	142°23.0'E	315	3.6	9864	-1.7	1.23	0.035	0.000	0.000	0.000
54	21.07-19.45	83°00.7'	142°08.9'E	325	4.6	9918	-1.7	1.36	0.054	0.000	0.000	0.000
55	22.07-07.45	82°00.1'	141°51.9'E	295	3.7	4998	-0.2	2.10	0.28	0.021	0.000	0.000
56	22.07-09.00	81°52.1'	141°43.6'E	295	2	265	-0.2	1.50	1.10	0.76	0.3	0.031
57	22.07-14.25	81°48.3'	137°56.1'E	300	3.7	661	-1.5	0.95	0.67	0.39	0.074	0.015

App. 5: Elemental composition of coarse aerosol fraction (>1 μm) in the western part of the Russian Arctic in August-September 1991 ("SPASIBA-91" expedition): average, standart deviation and geometrical means of elements, enrichment factors (EF) (Shevchenko et al., 1999 a).

No. of the samples	Na %	Mg %	Al %	K %	Ca %	Sc ppm	Cr ppm	Mn ppm	Fe %	Co ppm
	AAS	AAS	SP	AAS	AAS	INAA	INAA	AAS*	INAA	AAS*
1	0.70	0.97	2.43	0.57	1.10	3.9	370	260	2.5	8.5
2	0.98	0.77	2.74	0.91	0.47	6.8	260	360	2.8	7.9
3	0.48	0.56	1.68	0.46	0.48	3.4	440	190	2.35	8
4	0.76	0.47	1.44	0.54	0.83	2.2	240	145	1.6	7.4
5	0.66	0.57	1.24	0.61	0.72	1.4	230	155	1.5	9.2
6	0.20	1.21	1.39	0.87	0.88	1.1	587	280	2.1	10.1
7	1.11	0.50	2.05	0.74	0.29			180		3.5
8	0.45	0.36	1.19	0.34	0.88	2	450	155	1.69	4.6
9	0.44	0.27	1.78	0.50	0.27	2.2	315	140	2.21	2.8
10	0.93	0.30	2.35	1.09	0.86	2.9	162	230	1.65	0.46
Aver.	0.67	0.60	1.83	0.66	0.57	2.9	339	210	2.04	6.2
Std.	0.28	0.30	0.54	0.23	0.31	1.7	135	72	0.46	3.2
Geom. mean	0.61	0.54	1.76	0.63	0.61	2.5	316	200	2	4.9
EF	1.8	1.5	1	1.1	0.7	1	21	1.1	2.3	2
Std. EF	0.7	0.9	0	0.4	0.3	0.3	12	0.3	0.5	1.3

No. of the samples	Ni ppm	Cu ppm	Zn ppm	As ppm	Se ppm	Br ppm	Rb ppm	Ag ppm	Cd ppm	Sb ppm
	INAA	AAS*	AAS*	INAA	INAA	INAA	INAA	INAA	AAS*	INAA
1	29	390	1080	12	200	460	10	5.2	2.05	19
2	33	260	562	14	18	740	38	3.1	0.48	12
3	46	350	2040	8.7	92	460		4.7	7.92	21
4	31	470	800	7.6	83	360		5.3	8.01	8.3
5	118	460	890	4.8	80	1340		3.1	4.23	8.4
6	121	840	1200	5.1	55	320	4.5	3.3	2.18	19.4
7		155	400						0.85	
8	42	240	870	5.6	102	1020	4.6	2.5	5.03	10.8
9	29	190	220	6.1		500		1.2	1.83	11
10	16	175	570		36	180	10	0.7	3.65	5
Aver.	52	353	863	8	83	598	13.4	3.23	3.62	12.8
Std.	39	206	512	3.4	55	372	14	1.64	2.70	5.7
Geom. mean	42	309	735	7.4	68	507	9.5	2.74	2.64	11.6
EF	4.9	48	29	3.9	7040	675	0.4	195	81	59
Std. EF	4.7	37	19	0.7	3990	587	0.3	107	68	29

App. 5 (continuation).

No. of the samples	Cs ppm	Ba ppm	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Gd ppm	Tb ppm	Tm ppm
	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA
1	4.7	940	12.1	27	11.8	1.9	0.46	1.35	0.24	0.1
2	6.9	570	19.1	38.9	17	3.1	0.75	2.2	0.39	0.17
3	7	780	10.8	22.2	8.2	1.5	0.35	1.2	0.22	0.11
4	5.8	280	10.3	16.2	7.1	1.2	0.36	0.85	0.14	0.006
5	4	250	5.6	12	3.8	0.74	0.18	0.47	0.09	0.033
6	5.7	700	0.57	7.3		0.4	0.06			
8	4	810		14	5.2	0.91	0.29	0.54	0.10	0.047
9	1.1	370	3.7	13.2			0.13			
10	5.3	420	10.7	19	8.4	1.23	0.32	0.9	0.16	0.076
Aver.	4.9	568	9.1	18.9	8.8	1.37	0.32	1.07	0.19	0.079
Std.	1.8	251	5.7	9.5	4.4	0.84	0.20	0.59	0.11	0.056
Geom. mean	4.5	516	6.5	17	7.9	1.17	0.26	0.95	0.17	0.054
EF	7	5.2	0.8	0.8	0.9	0.7	1	0.6	0.7	0.6
Std. EF	4	2.8	0.4	0.2	0.2	0.3	0.5	0.2	0.2	0.3

No. of the samples	Yb ppm	Lu ppm	Hf ppm	Ta ppm	W ppm	Au ppm	Pb ppm	Th ppm	U ppm
	INAA	INAA	INAA	INAA	INAA	INAA	AAS*	INAA	INAA
1	0.55	0.091	1.2	0.5		13.2	1320	3.6	0.23
2	0.91	0.15	2.2	0.54	2.7	7.6	550	5.1	0.95
3	0.58	0.078	1.7	0.48	8.5	6.6	1040	2.9	0.22
4	0.26	0.034	0.73	0.29	10.4	10.2	810	1.9	
5	0.16	0.024	0.5	0.25	3.6	7	820	1.3	
6			0.49	0.44	6.1	4.6	1340	0.76	
7							300		
8	0.25	0.041	1	1.6	7.5	10.2	760	1.9	
9			1.1		6.2	14.8	1080	1.8	
10	0.4	0.058	1.2	0.33		4	980	2.5	
Aver.	0.44	0.068	1.12	0.55	6.4	8.7	900	2.42	0.47
Std.	0.26	0.043	0.55	0.44	2.7	3.7	324	1.31	0.42
Geom. mean	0.38	0.057	1.01	0.46	5.9	8	834	2.12	0.36
EF	0.5	0.5	0.9	3.1	20	3600	232	1	0.4
Std. EF	0.2	0.2	0.3	3.5	10	1700	102	0.3	0.3

AAS – flaming atomic-absorption spectrometry
AAS* – atomic-absorption spectrometry with graphite furnace
SP – spectrophotometry
INAA – instrumental neutron-activation analysis

App. 6: Content of chemical elements in aerosol samples collected by meshes (>1 μm) in the Kara and the Barents seas in August-October 1993 (49th expedition of the RV "Dmitry Mendeleev").

No. of sample	Na %	Ca %	Sc ppm	Cr ppm	Fe %	Co ppm	Ni ppm	Zn ppm	As ppm	Se ppm
5	0.37		7.6	285	4.34	13.5	220	2500		9.7
6	1.13	0.91	13.7	150	5.08	24.8		740	17.4	5
7	0.46		5.8	150	2.8	9.7		980		4.8
8	0.24		2.8	220	2.24	7.3		1150		10
9	0.05	0.17	1.36	23	0.41	2.4		380		2.85
10	0.21	0.98	4.13	260	2.48	11.2		1430	5.3	5.7
11	0.31	3.04	6.6	520	4.26	23		3100		21
12	0.45	1.21	7.1	260	4.9	146	2500	2000		24
13	0.99	1.53	5.5	140	1.93	37		640		
14	0.32	1.23	6.8	360	4.58	31	520	1550		18
15	0.58	3.09	9.5	720	9.1	56	960	3500		16.5
16	0.48	0.93	9.2	220	9.94	720	13100	1250	32	460
17	0.89	1.36	13.4	140	4.64	25		440	9.4	6.1
18	0.64	1.52	7.8	210	9.32	440	8000	1000		230
19	0.57	1.51	8.1	210	7.28	84	1350	2300		16.5
20	0.56	1.23	8.2	330	6.14	153	3000	1900		90
21	0.28	3.19	4.1	290	5.1	58	440	6000		17.5
22	0.37	3.24	6.4	480	5.68	66	940	3000		96
aver.	0.49	1.68	7.1	276	5.01	106	3103	1881	16.0	61
std.	0.28	0.97	3.2	164	2.63	184	4199	1391	11.8	118
geom. mean	0.41	1.38	6.3	227	4.15	39	1473	1472	12.9	19.6

No. of sample	Br ppm	Mo ppm	Ag ppm	Sb ppm	Cs ppm	Ba ppm	Hf ppm	Ir ppm	Au ppm	Th ppm
5	31.5			89			2.5	0.49	16	3.8
6	3.7	7.6		3.75	3.3	450	4.15	0.044	1.5	6.7
7	14			16.5	1.4		1.4	0.18	7.4	1.8
8	15.5			44			1.3	0.17	5.9	1.2
9	2.95	1.05	1.3	0.81	0.34	58	0.27	0.012	2.85	0.48
10	15.4	12.6	6	6.6	1.15	330	1.45	0.098	8.8	2.55
11	46		3.4	32.5	1.5	620	3.8	0.35	25	2.9
12	24			22.5	2.1	610	2.7	3.4	17	1.6
13	31.5	16.5		23.5		610	1.9		11.5	5.7
14	31.5	24.5	23.5	66	2.1	380	2.6	0.24	23	3.7
15	48.5	52	12.5	14	2.2	1850	4.6	0.39	34.5	4.8
16	18.5		22.5	14.5			1.9	0.06	11	2.6
17	6.3			3.25	3.2	690	4.1	0.036	9.4	6.7
18	18		9.7		1.2	710	2.4	0.08	15	3.4
19	19.5	14	13.5		1.8		2	0.06	9.5	3
20	30	12.5	11.5	38.5	2.2		2.1	0.1	18	4.5
21	25.5	17	11	110		44	1	0.11	15	1.6
22	56	29	17.5	87			1.1	0.16	63	2.7
aver.	24.4	18.7	12.0	35.8	1.9	577	2.3	0.35	16.4	3.3
std.	15.0	14.1	7.1	34.4	0.8	482	1.2	0.80	14.2	1.8
geom. mean	19	13.4	9.4	19.3	1.6	388	1.9	0.13	12	2.8

App. 7: Enrichment factors of aerosol samples collected by meshes (>1 μm) in the Kara and the Barents seas in August-October 1993 (49th expedition of the RV "Dmitry Mendeleev").

No.	Na	Ca	Sc	Cr	Fe	Co	Ni	Zn	As	Se
5	0.45		1	8.3	2.23	1.6	8	103		560
6	0.77	0.35	1	2.4	1.45	1.6		17	16	161
7	0.74		1	5.7	1.89	1.5		53		360
8	0.80		1	17.3	3.13	2.3		129		1570
9	0.34	0.67	1	3.7	1.18	1.6		88		922
10	0.47	1.26	1	13.8	2.35	2.4		109	16	607
11	0.44	2.44	1	17.3	2.52	3.1		148		1400
12	0.59	0.90	1	8.1	2.70	18	103	148		1490
13	1.68	1.47	1	5.6	1.37	5.9		148		
14	0.44	0.96	1	11.6	2.63	4	22	148		1165
15	0.57	1.72	1	16.7	3.74	5.2	30	148		765
16	0.49	0.54	1	5.3	4.22	69	418	148	43	22000
17	0.62	0.54	1	2.3	1.35	1.6		148	9	200
18	0.76	1.03	1	5.9	4.67	50	301	148		12900
19	0.66	0.99	1	5.7	3.51	9.1	49	148		900
20	0.64	0.80	1	8.9	2.93	16	107	148		4830
21	0.64	4.12	1	15.6	4.86	12	31	148		1880
22	0.54	2.68	1	16.5	3.47	9.1	43	148		6600
aver.	0.65	1.37	1	9.5	2.79	12	111	148	21	3434
std.	0.29	1.02	0	5.4	1.13	18	137	148	15	5774
geom. mean	0.61	1.1	1	7.9	2.56	5.5	59	148	17	1349

No.	Br	Mo	Ag	Sb	Cs	Ba	Hf	Au	Th
5	36			1290			2.41	11600	1.15
6	2	8		30	1.77	1.7	2.22	602	1.12
7	21			313	1.77		1.77	7020	0.71
8	49			1730			3.40	11600	0.98
9	19	11	300	66	1.83	2.2	1.46	11500	0.81
10	33	45	457	176	2.04	4.1	2.57	11700	1.41
11	61		162	540	1.67	4.9	4.22	20800	1.01
12	30			349	2.17	4.4	2.79	13169	0.52
13	50	44		470		5.7	2.53	11500	2.38
14	41	53	1086	1070	2.26	2.9	2.80	18600	1.25
15	45	80	414	162	1.70	10.1	3.55	20000	1.16
16	18		769	173			1.51	6580	0.65
17	4			27	1.75	2.7	2.24	3860	1.15
18	20		391		1.13	4.7	2.26	10600	1.00
19	21	25	524		1.63		1.81	6450	0.85
20	32	22	441	520	1.97		1.88	12100	1.26
21	55	61	843	2950		5.6	1.79	20100	0.89
22	77	66	859	1500			1.26	54100	0.97
aver.	34	42	568	710	1.81	4.5	2.36	14000	1.07
std.	20	24	281	807	0.29	2.3	0.78	11500	0.40
geom. mean	26	33	501	345	1.78	4.0	2.25	10400	1.01

App. 8: Content of chemical elements in aerosol samples collected by meshes (>1 μm) in the Barents Sea and in the St. Anna Trough in August-October 1994 (9th expedition of the RV "Professor Logachev").

No. of samples	Na %	K %	Ca %	Sc ppm	Cr ppm	Fe %	Co ppm	Ni ppm	Cu ppm	Zn ppm
1	0.092		0.02	2.28	605	3	7.5	11	150	1220
2	0.03	1.63	0.93	1.7	485	1.9	8.4	13	155	650
3	0.62	3.1	0.46	2.3	735	3.2	16.9	59	625	3490
4	0.21		0.88	1.42	250	1.7	7.3	20	200	780
5	3.48		3.35	3.9	810	5.5	46	48	365	4860
6	0.01		0.45	1.2	375	1.4	3.8	9	150	1620
7	0.008	2.6	0.07	1.4	490	1.7	6.4	3	230	2090
8	0.11		0.43	5	325	2.4	15.2	3	140	
9	0.01		0.33	6	180	1.9	8.5	5	200	600
10	0.02		0.26	1.7	345	1.3	8.3	13	120	670
11	0.31		0.43	2.5	345	1.2	2.9	8	35	1960
12	0.03	8.2	1.13	1.7	330	1.8	19.2	28	210	390
13	0.58	7.6	1.02	5.6	250	5	25.4	41	330	560
14	0.3	3.8	1.05	1.3	220	1.5	3.9	58	95	820
15	0.03	9.1	0.72	1.7	210	1.9	3.3		60	530
16	0.38		4.2	2.5	350	2.7	6.5	41	205	560
17	0.25		0.68	1.5	500	2.2	36	240	355	2155
18	0.32		0.83	3.7	225	2.4	42	145	315	46
19	0.01		1.37	3.9	205	2.2	6.9	25	215	170
20	0.01		1	1.8	280	1.4	4.8	14	25	110
aver.	0.34	5.15	0.98	2.66	376	2.32	14.0	41.3	209	1225
std.	0.76	3.05	1.03	1.50	178	1.15	13.2	58.4	139	1244
geom. mean	0.084	4.33	0.60	2.33	342	2.12	9.7	20.8	164	733

No. of sample	As ppm	Se ppm	Br ppm	Rb ppm	Zr ppm	Ag ppm	Sb ppm	Cs ppm	Ba ppm	La ppm
1		1.5	0.59	12.4	55		1580		100	4.75
2		0.69	0.89	15	18	0.55	30	0.4	180	2.5
3	1.5	3.4	0.19		20		120	3.4	220	8
4	7.9	3.7	0.22		74	0.64	60	1.2	50	2.22
5	34.1	3.5	0.68	85	49	0.97	825		150	1.23
6		0.63	2.84	8.5	13	0.51		0.54	60	0.26
7		0.49	4.29	8.4	19	0.61		0.2	40	3.48
8	5.8	0.77	7.3		23	0.11	80	0.49	130	9.37
9		3.7	2.94	2.4	32	0.05		0.17	210	13.1
10	5.2	0.45	0.41	10.8	30	0.14		0.19	90	4.66
11	6.2	4.9	3.87	33.5	20			0.1	210	5.49
12		2	9.16		27			0.6	350	9.21
13		12.5	4.93	12				1.6	270	19.9
14	0.4	0.73	5.91		34			0.6	110	4.71
15		5	2.14					1.12	210	5.7
16	38.4	10.6	5.06	13.7	56		40	0.7	110	8.35
17		10.6	3.53	11	37	0.01		0.13	34	7.85
18		8.5	4	13.4	29			0.58	160	13.6
19	30.7	3.6	2.24	19.2			35	0.1	250	10
20		11.5	1	15.2	23			2.71	210	6.4
aver.	14.5	4.44	3.11	18.6	32.9	0.40	346	0.82	157	7.0
std.	15.2	4.06	2.51	20.3	16.6	0.33	566	0.92	85	4.7
geom. mean	6.9	2.66	1.94	13.5	29.5	0.21	115	0.49	132	5.2

App. 8 (continuation).

No. of sample	Ce ppm	Pr ppm	Nd ppm	Sm ppm	Eu ppm	Gd ppm	Tb ppm	Dy ppm	Ho ppm	Er ppm
1	7.7	0.65	2	0.4	0.38	0.7	0.11	0.64	0.14	0.38
2	5.1	0.62	2.6	0.75	0.23	1.1	0.16	0.87	0.18	0.45
3	12.6	1.18	3.1	0.6	0.6	0.65	0.1	0.51	0.1	0.26
4	4.5	0.54	2.2	0.59	0.29	2.7	0.4	2.5	0.54	1.51
5	3.9	0.72	4.5	1.9	0.21	1.7	0.26	1.57	0.36	0.99
6	0.77	0.135	0.79	0.33	0.83	1	0.15	0.8	0.172	0.44
7	6.8	0.75	3	0.72	0.15	0.61	0.102	0.61	0.15	0.43
8	16.5	1.7	6	1.34	0.38	0.98	0.136	0.7	0.14	0.31
9	20	1.8	5.5	1.07	0.07	0.96	0.138	0.73	0.152	0.38
10	7.2	0.6	1.8	0.34	0.22	1.03	0.147	0.78	0.154	0.36
11	6.6	0.49	1.16	0.19	0.13	0.4	0.058	0.32	0.067	0.17
12	15	1.45	4.4	0.98	0.17	0.6	0.08	0.4	0.075	0.17
13	31.5	3	9.6	2.05	0.62	3.1	0.38	1.5	0.24	0.5
14	5.1	0.32	0.77	0.11	0.04	0.65	0.105	0.6	0.135	0.37
15	10.6	1.2	4.4	1.15	0.39	1.11	0.134	0.61	0.112	0.23
16	15	1.6	5.5	1.2	0.23	1.3	0.166	0.82	0.167	0.38
17	12	1.12	3.3	0.68	0.1	1.3	0.2	1.24	0.29	0.82
18	22	2.1	6.8	1.4	0.57	3	0.32	1.3	0.22	0.44
19	16.4	1.55	4.85	1.05	0.27	1.2	0.18	1.07	0.23	0.64
20	10.7	1.08	3.5	0.8	0.17	0.8	0.102	0.48	0.086	0.19
aver.	11.5	1.13	3.8	0.88	0.30	1.24	0.17	0.90	0.19	0.47
std.	7.4	0.70	2.2	0.53	0.21	0.79	0.10	0.51	0.11	0.32
geom. mean	9.0	0.92	3.1	0.71	0.24	1.07	0.15	0.80	0.16	0.40

No. of sample	Tm ppm	Yb ppm	Lu ppm	Hf ppm	Ta ppm	Au ppm	Th ppm	U ppm
1	0.055	0.3	0.05	0.9	1.2	2.45	0.2	12.6
2	0.061	0.32	0.05	1.26	0.19	2.89	0.58	0.66
3	0.039	0.19	0.03	0.54	0.75	3.72		3.9
4	0.23	1.28	0.22	0.17	1	2.59	0.15	1.05
5	0.15	0.83	0.14	1.13	0.31	4.57		0.51
6	0.06	0.32	0.05	0.74	0.13	1.41	0.16	1.26
7	0.068	0.41	0.07	0.28	1	2.24	0.09	
8	0.042	0.2	0.03	0.78	0.71	0.91	1	0.88
9	0.051	0.27	0.04	1.31	1.33	1.95	1.93	0.89
10	0.05	0.25	0.035	0.08	0.27	1.48	0.2	0.87
11	0.025	0.13	0.02	0.55	0.19	1.98	0.17	1.32
12	0.022	0.1	0.015	0.44	0.75	1.56	0.87	1.22
13	0.055	0.25	0.031	0.8	0.73	1.68	2.4	0.5
14	0.054	0.3	0.05	0.6	0.41	2.34	0.71	1.38
15	0.027	0.12	0.016	0.71	0.4	3	1.38	0.61
16	0.048	0.23	0.031	0.48	0.77	2.74	1.77	1.3
17	0.13	0.7	0.12	0.58	1.5	1.2		1.2
18	0.049	0.19	0.024	0.35	0.35	1.4	1.59	0.8
19	0.095	0.51	0.081	0.66	0.4	1.9	1.93	2.47
20	0.024	0.104	0.014	0.27	2	1.67	2	2.3
aver.	0.067	0.35	0.056	0.63	0.72	2.18	1.01	1.88
std.	0.051	0.29	0.051	0.34	0.50	0.89	0.80	2.72
geom. mean	0.055	0.28	0.042	0.53	0.56	2.03	0.63	1.25

App. 9: Enrichment factors of aerosol samples collected by meshes (>1 µm) in the Barents Sea and in the St. Anna Trough in August-October 1994 (9th expedition of the RV "Professor Logachev").

No.	Na	K	Ca	Sc	Cr	Fe	Co	Ni	Cu	Zn
1	0.4			1	58	5.1	2.9	1.4	26	170
2	0.2	10	2.9	1	63	4.4	4.3	2.2	36	120
3	2.5	14	1.1	1	70	5.4	6.5	7.5	109	475
4	1.4		3.3	1	39	4.7	4.5	4.1	56	173
5	8.3		4.6	1	46	5.5	10.4	3.6	37	390
6	0.1		2.0	1	69	4.6	2.8	2.2	50	424
7	0.1	20	0.3	1	77	4.7	4.0	0.6	66	470
8	0.2		0.5	1	14	1.9	2.7	0.2	11	
9			0.3	1	7	1.2	1.2	0.2	13	31
10	0.1		0.8	1	45	3.0	4.3	2.2	28	124
11	1.2		0.9	1	30	1.9	1.0	0.9	6	246
12	0.2	51	3.5	1	43	4.1	9.9	4.8	49	72
13	1.0	14	1.0	1	10	3.5	4.0	2.1	24	31
14	2.2	31	4.3	1	37	4.5	2.6	13.1	29	200
15	0.2	56	2.2	1	27	4.4	1.7		14	98
16	1.4		8.9	1	31	4.2	2.3	4.8	33	70
17	1.6		2.4	1	73	5.7	21.0	47	95	450
18	0.8		1.2	1	13	2.5	10.0	11.5	34	4
19			1.9	1	12	2.2	1.6	1.9	22	14
20	0.1		2.9	1	34	3.0	2.3	2.3	6	19
aver.	1.1	11	2.3	1.0	40	3.9	5.1	6.1	39	200
std.	1.8	17	2.1	0	23	1.4	4.7	10.3	28	170
geom. mean	0.5	23	1.6	1.0	32	3.6	3.7	2.6	28	103

No.	As	Se	Br	Rb	Zr	Ag	Sb	Cs	Ba	La
1		289	2.3	1.3	3.2		76300		2.3	1.5
2		179	4.6	2.2	1.4	102	1941	1.7	5.5	1.1
3	8	650	0.7		1.2		5740	10.8	5.0	2.6
4	68	1146	1.4		6.9	142	4650	6.2	1.8	1.1
5	107	395	1.5	5.3	1.7	78	23300		2.0	0.2
6		231	20.8	1.7	1.4	134		3.3	2.6	0.2
7		154	27.0	1.5	1.8	137		1.0	1.5	1.8
8	14	68	12.8		0.6	7	1760	0.7	1.3	1.4
9		271	4.3	0.1	0.7	3		0.2	1.8	1.6
10	37	116	2.1	1.6	2.4	26		0.8	2.7	2.0
11	30	862	13.6	3.3	1.1			0.3	4.3	1.6
12		518	47.4		2.1			2.6	10.7	4.0
13		982	7.7	0.5				2.1	2.5	2.6
14	4	247	40.0		3.5			3.4	4.4	2.7
15		1294	11.1					4.8	6.4	2.5
16	188	1866	17.8	1.3	3.0		1760	2.1	2.3	2.4
17		3109	20.7	1.8	3.3	2		0.6	1.2	3.8
18		1011	9.5	0.9	1.0			1.1	2.2	2.7
19	96	406	5.1	1.2			985	0.2	3.3	1.9
20		2811	4.9	2.1	1.7			11.0	6.0	2.6
aver.	61	726	13.2	1.2	2.2	70	14540	2.3	3.4	2.0
std.	60	847	12.8	1.3	1.6	61	24760	3.2	2.3	1.0
geom. mean	34	503	7.3	1.3	1.8	30	4800	1.6	2.9	1.6

App. 9 (continuation).

No.	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er
1	1.2	0.8	0.7	0.6	3.1	1.3	1.2	2.1	1.1	1.3
2	1.1	1.0	1.2	1.6	2.5	2.6	2.3	3.8	1.9	2.1
3	2.0	1.4	1.1	1.0	4.8	1.2	1.1	1.6	0.8	0.9
4	1.2	1.0	1.2	1.5	3.7	7.7	6.9	12.9	7.0	8.4
5	0.4	0.5	0.9	1.8	1.0	1.8	1.6	3.0	1.7	2.0
6	0.2	0.3	0.5	1.0	12.7	3.4	3.1	4.9	2.6	2.9
7	1.8	1.4	1.7	1.9	2.0	1.8	1.8	3.2	2.0	2.4
8	1.2	0.9	0.9	1.0	1.4	0.8	0.7	1.0	0.5	0.5
9	1.2	0.8	0.7	0.7	0.2	0.7	0.6	0.9	0.5	0.5
10	1.6	0.9	0.8	0.7	2.4	2.5	2.1	3.4	1.7	1.7
11	1.0	0.5	0.4	0.3	1.0	0.7	0.6	0.9	0.5	0.5
12	3.2	2.3	2.0	2.1	1.8	1.4	1.2	1.7	0.8	0.8
13	2.1	1.4	1.3	1.3	2.0	2.3	1.7	2.0	0.8	0.7
14	1.4	0.7	0.5	0.3	0.6	2.0	2.0	3.4	1.9	2.2
15	2.3	1.9	2.0	2.5	4.2	2.7	1.9	2.6	1.2	1.1
16	2.2	1.7	1.7	1.8	1.7	2.1	1.6	2.4	1.2	1.2
17	2.9	2.0	1.7	1.7	1.2	3.5	3.3	6.1	3.5	4.3
18	2.2	1.5	1.4	1.4	2.8	3.3	2.1	2.6	1.1	0.9
19	1.5	1.1	1.0	1.0	1.3	1.3	1.1	2.0	1.1	1.3
20	2.2	1.6	1.5	1.6	1.7	1.8	1.4	2.0	0.9	0.8
aver.	1.6	1.2	1.2	1.3	2.6	2.3	1.9	3.2	1.7	1.9
std.	0.7	0.5	0.5	0.6	2.6	1.6	1.4	2.6	1.5	1.8
geom. mean	1.4	1.1	1.1	1.1	1.9	1.9	1.6	2.5	1.3	1.4

No.	Tm	Yb	Lu	Hf	Ta	Au	Th	U
1	1.1	1.0	1.0	2.9	5.8	5910	0.2	45.0
2	1.6	1.4	1.3	5.4	1.2	9350	0.8	3.2
3	0.8	0.6	0.6	1.7	3.6	8896		13.8
4	7.4	6.6	6.8	0.9	7.7	10032	0.2	6.0
5	1.8	1.6	1.6	2.1	0.9	6445		1.1
6	2.3	2.0	1.8	4.5	1.2	6463	0.3	8.6
7	2.2	2.1	2.2	1.5	7.9	8800	0.1	
8	0.4	0.3	0.3	1.1	1.6	1001	0.5	1.4
9	0.4	0.3	0.3	1.6	2.4	1788	0.7	1.2
10	1.3	1.1	0.9	0.3	1.7	4788	0.3	4.2
11	0.5	0.4	0.4	1.6	0.8	4356	0.2	4.3
12	0.6	0.4	0.4	1.9	4.9	5047	1.2	5.8
13	0.5	0.3	0.2	1.0	1.4	1650	1.0	0.7
14	1.9	1.7	1.7	3.4	3.5	9900	1.3	8.6
15	0.7	0.5	0.4	3.1	2.6	9706	1.9	2.9
16	0.9	0.7	0.5	1.4	3.4	6028	1.6	4.2
17	4.0	3.4	3.5	2.8	11.0	4400		6.5
18	0.6	0.4	0.3	0.7	1.0	2081	1.0	1.8
19	1.1	1.0	0.9	1.2	1.1	2679	1.1	5.2
20	0.6	0.4	0.3	1.1	12.2	5103	2.5	10.4
aver.	1.6	1.4	1.3	2.1	3.4	5750	0.65	6.6
std.	1.6	1.5	1.5	1.3	3.4	3140	0.70	9.5
geom. mean	1.1	0.9	0.8	1.7	2.7	4790	0.62	4.3

App. 10: Contents of chemical elements in aerosol samples collected by meshes (>1 μm) in the Norwegian, Greenland and Barents seas in July-August 1996 (15th expedition of the RV "Professor Logachev").

No.	Al	Si	P	Na	K	Ca	Sc	Cr	Fe	Co	Ni
	%	%	%	%	%	%	ppm	ppm	%	ppm	ppm
4	1.96	5.91	0.16	0.16	2.45	0.23	4.4	76	1.34	13.4	258
5	0.98	2.72	0.10	0.03		0.24	1.0	26	0.06	1.97	113
6	1.80	7.63	0.86	0.30	1.28	0.70	3.3	6	0.44	6.48	159
7	3.07	20.6	0.10	0.16	0.52	0.91	4.9	46	1.69	5.66	72
8	1.86	8.62	0.23	0.28		1.35	2.9	219	0.22	1.12	140
aver.	1.93	9.10	0.29	0.19	1.42	0.69	3.30	74.6	0.75	5.73	148
std.	0.75	6.81	0.32	0.11	0.97	0.47	1.52	84.8	0.72	4.87	69.4
geom. mean	1.82	7.37	0.2	0.15	1.18	0.54	2.90	41.3	0.42	4.05	136

No.	Zn	As	Se	Br	Rb	Sr	Zr	Cs	Ba	La	Ce
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4	163	0.3	3.8	4.75	3.8	128	27.3	1.81	8.2	11.4	21.5
5	108	15.4	0.5	7.18		210	30.8	0.41	40.8	4.2	7.2
6	1707	92.7	13.7	19.3	80.7		70.4	4.75	222	11.8	23.3
7	332	9.7	0.4	0.66	27.9	24	4.8	0.99	50.3	7.1	13.8
8	2567	49.4	9.8	23.3	20.2	6.2	152	4.90	11.8	17.9	33.7
aver.	975	33.5	5.64	11	33.2	92	57	2.57	67	10.5	19.9
std.	1106	37.9	5.91	9.75	33.3	95	58	2.12	89	5.21	10
geom. mean	480	11.5	2.52	6.32	20.4	44.7	33.6	1.76	33.8	9.36	17.6

No.	Nd	Sm	Eu	Tb	Yb	Lu	Hf	Ta	Au	Th	U
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4	2.3	1.58	0.26	0.44	0.46	0.094	1.00	0.90	12.0	1.21	20.4
5	2.4	0.92	1.00	0.21	0.89	0.182	0.21		23.1	0.64	1.79
6	7.0	2.22	0.45	0.41	1.66	0.274	0.93		14.4	1.81	8.52
7	9.1	1.14	0.25	0.24	0.70	0.122	2.19	0.62	3.3	1.60	0.33
8	13.5	2.53	0.42	0.34	0.38	0.052	0.56	5.90	2.8	1.69	0.56
aver.	6.9	1.68	0.48	0.33	0.82	0.145	0.98	2.47	11.1	1.39	6.3
std.	4.7	0.69	0.31	0.1	0.51	0.086	0.75	2.97	8.4	0.48	8.6
geom. mean	5.4	1.56	0.41	0.31	0.71	0.124	0.75	1.49	8.2	1.31	2.2

App. 11: Enrichment factors of aerosol samples collected by meshes (>1 μm) in the Norwegian, Greenland and Barents seas in July-August 1996 (15th expedition of the RV "Professor Logachev").

No.	Al	Si	P	Na	K	Ca	Sc	Cr	Fe	Co	Ni
4	1	0.88	6.4	0.28	4.9	0.23	0.84	3.2	1.00	2.25	14.4
5	1	0.81	8.0	0.11		0.49	0.38	2.2	0.09	0.66	12.7
6	1	1.24	37	0.58	2.8	0.77	0.69	0.27	0.36	1.19	9.7
7	1	1.96	2.6	0.18	0.67	0.59	0.60	1.2	0.80	0.61	2.6
8	1	1.35	9.7	0.52		1.44	0.58	9.7	0.17	0.20	8.3
average	1	1.25	12.8	0.34	2.8	0.70	0.62	3.3	0.48	0.98	9.5
std.	0	0.46	14.0	0.21	2.1	0.46	0.17	3.7	0.40	0.79	4.6
geom. mean	1	1.2	8.6	0.28	2.1	0.59	0.60	1.9	0.34	0.73	8.2

No.	Zn	As	Se	Br	Rb	Sr	Zr	Cs	Ba	La	Ce
4	10	0.7	319	8.0	0.18	1.43	0.69	2.5	0.08	1.6	1.5
5	13	72	84	24.1		4.7	1.57	1.15	0.81	1.18	1.01
6	111	235	1253	35	4.1		1.95	7.2	2.4	1.80	1.8
7	13	14	21	0.71	0.83	0.17	0.08	0.88	0.32	0.63	0.62
8	162	121	867	41	0.99	0.07	4.07	7.2	0.12	2.6	2.5
average	62	89	509	21.9	1.5	1.6	1.7	3.8	0.74	1.6	1.5
std.	71	95	533	17.3	1.8	2.2	1.5	3.2	0.96	0.75	0.72
geom. mean	31	29	229	11.5	0.88	0.54	0.92	2.7	0.36	1.4	1.3

No.	Nd	Sm	Eu	Tb	Yb	Lu	Hf	Ta	Au	Th	U
4	0.34	1.11	0.91	2.05	0.64	0.79	1.40	1.9	12600	0.53	32
5	0.72	1.29	7.00	1.96	2.49	3.06	0.59		48500	0.56	5.6
6	1.14	1.69	1.71	2.08	2.53	2.51	1.42		16460	0.86	14.4
7	0.87	0.51	0.56	0.71	0.63	0.65	1.96	0.83	2210	0.45	0.33
8	2.13	1.87	1.55	1.67	0.56	0.46	0.83	13.1	3100	0.78	0.92
average	1.04	1.29	2.3	1.70	1.4	1.5	1.24	5.3	16600	0.64	10.6
std.	0.67	0.53	2.6	0.57	1.0	1.2	0.54	6.8	18900	0.18	13.1
geom. mean	0.88	1.18	1.6	1.6	1.1	1.1	1.14	2.7	9280	0.62	3.8

App. 12: Content of chemical elements in aerosol samples collected by filtration through AFA-KhA filters in the Laptev Sea in July-September 1995 (ARK-XI/1 expedition of the RV "Polarstern"), ng/m^3.

No.	Na	Sc	Cr	Mn	Fe	Co	Zn	As	Br
1	1230	0.0086	0.41	1.04	105	0.12	1.4		3.92
2	260	0.003	0.66				22	0.145	2.11
3		0.0039		0.34			3.7	0.068	0.37
4	240	0.0016	2.64	0.21	150	0.19	20		
5	110		0.71	0.11	65	0.022	3		0.74
6	410	0.023	22.6	4.86	360	0.23	12	1.03	1.71
7	870		1.58	0.45	66				1.76
8	800	0.0047	2.87	1.25	74	0.049	1.6		2.25
9	140	0.015	4.12	4.69	300		11	0.14	0.77
10	60		1.64	0.34	56	0.022	10		0.34
11	1030	0.01	3.9	0.53	160	0.13	80	0.76	3.9
12	280	0.0031	2.57	0.55	85	0.05	5.1	0.12	1.22
aver.	494	0.0081	3.97	1.31	142	0.102	15.4	0.38	1.74
std.	412	0.007	6.3	1.75	106	0.079	22.5	0.41	1.26
geom. mean	334	0.0059	2.1	0.66	115	0.073	7.7	0.23	1.31

App. 13: Enrichment factors of aerosol samples collected by filtration through AFA-KhA filters in the Laptev Sea in July-September 1995 (ARK-XI/1 expedition of the RV "Polarstern").

No.	Na	Sc	Cr	Mn	Fe	Co	Zn	As	Br
1	135	1	10	2.8	4.8	12	51		4010
2	81	1	48					590	6190
3		1		2			300	215	840
4	140	1	360	3	37	105	3930		
6	17	1	215	4.9	6.1	9	165	550	650
8	160	1	135	6.2	6.2	9	105		4210
9	9	1	60	7.2	7.8		230	115	450
11	96	1	86	1.2	6.3	11	2510	930	3430
12	84	1	180	4.1	11	14	515	470	3460
aver.	90	1	137	3.9	11.3	27	976	478	2910
std.	55	0	114	2.1	11.5	38	1443	291	2060
geom. mean	65	1	91	3.4	8.7	16	364	390	2040

App. 14: Content of chemical elements in aerosol samples collected by filtration through Whatman-41 filters in the Kara Sea in September 1993 (49th expedition of the RV "Dmitry Mendeleev"), ng/m^3.

No.	Na	Sc	Cr	Fe	Co	Zn	Se	Sb	Au
1	19	0.0001	0.05	2.95		2.00		0.0044	0.00008
2	20	0.0001	0.05			0.40	0.013	0.0019	
3	3	0.0002	0.01		0.001	5.30		0.0011	
4	8	0.0001	0.03	1.80	0.001	0.63		0.0049	0.00088
5	8	0.0001	0.03	0.94		0.97		0.0037	0.00019
6	5	0.0000	0.02	1.00		0.27		0.0016	
7	14	0.0002	0.15	2.78	0.009	0.97	0.101	0.0029	
8	7	0.0006	0.13	5.99	0.007	2.56	0.038	0.005	
9	4	0.0002	0.03	2.51	0.008	0.66	0.044	0.0019	
10	7	0.0000		0.89		0.65		0.0025	
11	59	0.0006	0.05	4.94	0.001	1.52		0.0028	0.00570
12	108	0.0005	0.07	5.13	0.004	1.97		0.0063	0.00780
13	78	0.0001		1.26	0.002	0.45			
14	9	0.0003	0.05	3.56	0.005	3.75		0.0026	
aver.	25	0.0002	0.04	2.81	0.004	1.58	0.049	0.0032	0.00290
std.	33	0.0002	0.03	1.78	0.003	1.46	0.037	0.0016	0.00360
geom.mean	13	0.0001	0.04	2.29	0.003	1.10	0.038	0.0029	0.00090

App. 15: Enrichment factors of aerosol samples collected by filtration through Whatman-41 filters in the Kara Sea in September 1993 (49th expedition of the RV "Dmitry Mendeleev").

No.	Na	Sc	Cr	Fe	Co	Zn	Se	Sb	Au
1	161	1	102	10.5		5710		4346	4120
2	227	1	39			1504	70500	2474	
3	13	1	10		2	8200		590	
4	86	1	77	8.2	10	2330		6342	56600
5	103	1	80	5.0		4190		5585	14100
6	210	1	202	19.7		4250		8767	
7	64	1	53	5.5	42	1541	224700	1605	
8	12	1	49	4.0	10	1380	29040	946	
9	23	1	41	5.7	38	1196	110900	1234	
10	387	1		20.5		12100		16119	
11	87	1	16	3.0	2	755		492	49800
12	216	1	34	4.3	7	1324		1481	92000
13	508	1		3.4	12	989			
14	30	1	36	5.0	16	4240		1023	
aver.	152	1	62	7.9	15	3550	108800	3920	43300
std.	148	0	51	6.1	15	3290	84210	4490	35300
geom.mean	88	1	47	6.4	9.9	2500	84500	2280	27260

App. 16: Content of chemical elements in aerosol samples collected by filtration through AFA-KhA filters in the Barents Sea in August-October 1994 (9th expedition of the RV "Professor Logachev"), ng/m^3.

No.	Na	K	Ca	Sc	Cr	Fe	Co	Ni	Cu	Zn	As
1	6600	1780	620	0.0015	7.74	93		36	0.33	53	0.0031
2	3600		220	0.0038	7.65	86	0.34	0.1	0.01	33	0.032
3	560		375	0.0026	7.77	194	1.11	0.1	0.13	101	0.0039
4	280		53	0.002	3.65	47	0.31	0.1	0.047	43	0.43
5	490		100	0.0038	2.10	36	0.01	0.2	0.094	22	0.0006
6	1650	160	100	0.0026	3.27	83		2.8	0.015	36	0.28
7	490	20	200	0.0012	4.43	32	0.09	0.4	0.034	11	0.28
8	3080	180	230	0.0019	3.24	106	0.32	39	0.47	27	0.0004
9	760		530	0.0066	8.57	363		1.3	0.01	59	0.044
10	135		400	0.0072	8.15	308	0.78	2.7	0.24	45	0.44
aver.	1760	215	283	0.0033	5.66	135	0.30	8.2	0.14	43	0.15
std.	2080	555	192	0.0021	2.52	116	0.38	15.3	0.16	25	0.19
geom. m.	930	180	220	0.0028	5.08	98	0.21	1	0.064	37	0.024

No.	Br	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd
1	0.39	0.003	0.011			0.0046	0.002		0.0011	0.00026	0.0012
2	0.16	0.062	0.073		0.016	0.046	0.0065	0.023	0.0068	0.0021	0.0073
3	0.021	0.047	0.0091		0.048	0.13	0.02	0.084	0.027	0.0082	0.032
4	0.029	0.11	0.014		0.13	0.19	0.017	0.044	0.011	0.0033	0.013
5	0.016	0.11		0.5	0.038	0.071	0.0076	0.026	0.006	0.002	0.0076
6	0.068	0.065		2.68	0.029	0.058	0.0057	0.019	0.005	0.00036	0.0014
7	0.02	0.006	0.0006	1.47	0.001	0.005	0.00085	0.003	0.001	0.00032	0.0012
8	0.19	0.12	0.0037	1.15	0.12	0.15	0.011	0.025	0.0043	0.00064	0.0019
9	0.087	0.003	0.0086	3.1	0.12	0.19	0.016	0.05	0.011	0.0019	0.006
10	0.026	0.11	0.01		0.14	0.25	0.024	0.072	0.017	0.0024	0.0089
aver.	0.10	0.064	0.016	0.89	0.064	0.11	0.011	0.035	0.009	0.0021	0.0081
std.	0.12	0.049	0.022	1.18	0.057	0.085	0.0078	0.028	0.008	0.0024	0.0094
geom. m.	0.057	0.033	0.0081	1.48	0.039	0.062	0.0076	0.028	0.006	0.0013	0.0046

No.	Tb	Dy	Ho	Er	Tm	Yb	Lu	Ta	Ir	Au	U
1	0.0002	0.001	0.0002	0.0006	0.00009	0.0005	0.00011	0.003	0.001	0.0019	0.076
2	0.0011	0.006	0.0012	0.0027	0.00038	0.0018	0.00029	0.014	6E-04	0.0016	0.001
3	0.0045	0.025	0.0052	0.014	0.00190	0.01	0.00160			0.0093	0.24
4	0.002	0.012	0.0025	0.0068	0.00093	0.0047	0.00080	0.039		0.0041	0.03
5	0.001	0.005	0.0012	0.0029	0.00038	0.0019	0.00029		2E-04	0.0003	0.0019
6	0.0002	0.001	0.0003	0.0009	0.00013	0.0008	0.00013	0.009		0.0001	0.002
7	0.0002	9E-04	0.0002	0.0004	0.00005	0.0003	0.00004			0.0005	0.0022
8	0.0003	0.002	0.0003	0.0008	0.00011	0.0006	0.00009		2E-04	0.0005	0.0009
9	0.0009	0.005	0.0012	0.0031	0.00040	0.002	0.00033	0.034	5E-04	0.0019	0.046
10	0.0013	0.007	0.0015	0.004	0.00054	0.0029	0.00045	0.03	0.002	0.0063	0.0072
aver.	0.0012	0.007	0.0014	0.0036	0.00050	0.0026	0.00041	0.013	4E-04	0.0026	0.041
std.	0.0013	0.007	0.0015	0.0041	0.00057	0.003	0.00046	0.016	8E-04	0.0031	0.074
geom. m.	0.0007	0.004	0.0008	0.0021	0.00029	0.0015	0.00024	0.016	5E-04	0.0012	0.0081

App. 17: Enrichment factors of aerosol samples collected by filtration through AFA-KhA filters in the Barents Sea in August-October 1994 (9th expedition of the RV "Professor Logachev").

No.	Na	K	Ca	Sc	Cr	Fe	Co	Ni	Cu	Zn	As
1	3960	1210	212	1	1100	23		6750	84	10700	24
2	870		30	1	440	8.8	79			2750	101
3	200		77	1	660	29	380		20	12260	18
4	130		14	1	400	9.1	135		9	6810	2660
5	120		14	1	120	3.7	2	15	10	1790	2
6	590	66	20	1	280	12.4		320	2	2880	1290
7	380	18	87	1	810	10.4	67	98	11	2880	2810
8	1480	99	64	1	370	21	140	5830	96	4300	3
9	110		43	1	290	22		59		2830	81
10	17		29	1	250	17	95	110	13	1960	740
aver.	785	140	59	1	470	16	90	1320	25	5060	775
std.	1200	378	60	0	300	8	116	2630	35	3700	1120
geom. mean	370	140	44	1	390	13	74	420	18	3990	148

No.	Br	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd
1	2220		51			1.1	3.5		2.6	3.1	3.3
2	380	1790	139		3.1	4.4	4.6	4.7	6.5	9.9	7.7
3	70	1980	26		13.6	18	21	26	38	58	51
4	130	6050	51		47	35	22	17	21	30	27
5	37	3280		7	7.3	6.8	5.4	5.4	6.0	9.4	8.1
6	230	2710		53	8.0	8.1	5.8	5.6	7.6	2.6	2.2
7	145	510	4	63	0.6	1.5	1.9	1.8	3.0	4.8	4.0
8	870	6550	14	30	43	28	15	10.1	8.1	6.1	4.1
9	120	44	10	24	13.4	10.6	6.7	6.0	6.2	5.3	3.7
10	32	1720	10		14.7	12.6	8.7	7.9	8.6	6.1	5.0
aver.	420	2460	30	18	15	13	9	8	11	14	12
std.	680	2290	43	24	17	11	7	8	11	18	16
geom. mean	215	1660	24	26	10	8	7	7	8	9	8

No.	Tb	Dy	Ho	Er	Tm	Yb	Lu	Ta	Au	U
1	2.9	5.1	2.8	3.1	2.8	2.2	3.1	22	6600	400
2	6.7	10.6	5.5	5.5	4.6	3.5	3.3	41	2340	2
3	43	72	37	42	34	29	26		19800	750
4	24	44	23	27	21	17	18	210	11400	120
5	6.6	10.3	5.5	5.9	4.6	3.7	3.3		410	4
6	2.2	4.0	2.3	2.6	2.3	2.1	2.2	39	140	6
7	3.3	5.1	2.4	2.6	2.1	1.6	1.5		2110	15
8	3.3	5.7	3.1	3.2	2.5	2.1	2.0		1470	4
9	3.4	5.9	3.3	3.7	2.8	2.3	2.2	57	1540	57
10	4.4	7.2	3.9	4.3	3.4	2.9	2.8	45	4800	8
aver.	10	17	9	10	8	7	6	42	5060	137
std.	13	23	12	13	11	9	8	64	6210	249
geom. mean	7	11	6	6	5	4	4	52	2690	33

App. 18: Content of chemical elements in aerosol samples collected by filtration through AFA-KhA filters in the Norwegian, Greenland and Barents seas in July-August 1996 (15th exped. of the RV "Prof. Logachev"), ng/m^3.

No.	Na	K	Ca	Sc	Cr	Fe	Ni	Zn
4	640			0.0105	0.45			14
5	1230	600	145	0.0033	0.06	275	1.2	11
6	3140	2420	295	0.075		2200	45	105
7	750	140	24	0.0125	1.48	330		11
8	1825	900		0.028	0.67	400	11	30
aver.	1517	1015	155	0.026	0.67	801	19.1	34.2
std.	1021	987	136	0.029	0.60	934	23.0	40
geom. mean	1276	654	101	0.016	0.40	532	8.4	22

No.	As	Se	Br	Rb	Sr	Zr	Sb	Cs
4	0.72	0.09	0.3	0.71			0.014	
5	0.06	0.07	0.4	0.06	0.62	1.34	0.003	0.002
6	1.26	1.03		3.38	106	88	0.37	0.092
7	0.39	0.04		0.12	0.64	6.4	0.004	0.002
8	0.77	0.15	0.79	0.09	10.3	12.5		
aver.	0.64	0.28	0.50	0.87	29.4	27.1	0.098	0.032
std.	0.45	0.42	0.26	1.43	51.3	40.9	0.182	0.052
geom. mean	0.44	0.13	0.46	0.27	4.6	9.9	0.016	0.007

No.	Ba	La	Ce	Nd	Sm	Eu	Tb	Yb
4					0.01			
5	0.21	0.027	0.047	0.005	0.0035	0.0021	0.0006	0.0015
6	12.6	7.6	9.6	1.6	0.26	0.058	0.035	0.057
7	0.33	0.019	0.057	0.061	0.024	0.0035	0.0057	0.0165
8	0.42	0.11	0.26	0.16	0.05	0.0053	0.0105	0.029
aver.	3.39	1.94	2.49	0.46	0.07	0.017	0.0130	0.026
std.	6.14	3.77	4.74	0.77	0.11	0.027	0.0152	0.0235
geom. mean	0.78	0.14	0.29	0.094	0.026	0.0069	0.0060	0.0142

No.	Lu	Hf	Ta	Th	U
4				0.043	0.029
5	0.0003	0.0036	0.0073	0.015	
6	0.0084	0.25	0.21	0.120	0.92
7	0.0028	0.0105		0.015	
8	0.0047			0.035	0.65
aver.	0.004	0.088	0.11	0.046	0.53
std.	0.0034	0.14	0.14	0.043	0.46
geom. mean	0.0023	0.021	0.039	0.033	0.26

App. 19: Enrichment factors of aerosol samples collected by filtration through AFA-KhA filters in the Norwegian, Greenland and Barents seas in July-August 1996 (15th expedition of the RV "Professor Logachev").

No.	Na	K	Ca	Sc	Cr	Fe	Ni	Zn
4	57			1	9.4			420
5	350	191	23.3	1	4	33	107	1050
6	39	34	2.1	1		11.5	176	440
7	56	12	1	1	26	10.3		275
8	61	34		1	5.3	5.6	115	340
aver.	113	68	8.8	1	11.2	15.1	133	505
std.	133	83	12.6	0	10.1	12.2	38	310
geom. mean	77	40	3.7	1	8.5	12.2	129	450

No.	As	Se	Br	Rb	Sr	Zr	Sb	Cs
4	840	3770	250	16.5			145	
5	220	9300	1070	4.4	11	54	100	4.4
6	205	6040		11	83	155	540	9
7	380	1410		2.3	3	68	35	1.2
8	340	2360	250	0.79	21.6	60		
aver.	400	4580	525	7	30	84	205	4.9
std.	260	3160	475	6.6	36	48	230	3.9
geom. mean	345	3710	405	4.3	16	76	130	3.6

No.	Ba	La	Ce	Nd	Sm	Eu	Tb	Yb
4					3.5			
5	3.3	6	5.2	1.2	3.9	11.7	4.4	3.3
6	8.7	74	47	16.8	12.7	14.2	11.4	5.6
7	1.4	1.1	1.7	3.8	7	5.1	11.1	9.7
8	0.78	2.9	3.4	4.5	6.5	3.5	9.2	7.6
aver.	3.5	21	14.3	6.6	6.7	8.6	9	6.6
std.	3.6	35	22	7	3.7	5.1	3.2	2.7
geom. mean	2.4	6.1	6.1	4.3	6	7.4	8.5	6.1

No.	Lu	Hf	Ta	Th	U
4				9.4	23
5	3.5	8	24	10.4	
6	4.9	24	30	3.7	100
7	9.9	6.2		2.8	
8	7.4			2.9	190
aver.	6.4	12.7	27	5.8	104
std.	2.8	9.8	4.2	3.7	84
geom. mean	6	10.6	27	4.9	76

App. 20: Concentrations of chemical elements in aerosol samples collected by filtration through AFA-KhA filters in the north-western part of the Barents Sea and in the Fram Strait in June-July 1997 (ARK-XIII/2 expedition of the RV "Polarstern"), ng/m^3.

No.	Na	Ca	Cr	Fe	Ni	Zn	As
1	1100		2.2		44	36	0.35
2	89	32.9	0.13	1.03	4.1	3.56	0.12
3		2.11	0.18	1.06	4.2	67	0.0042
4	250		0.4	2.89		2.6	
5	63	1.04	0.3	13.8	4.9	15	0.0048
6	12	0.62	0.19	12.1	8.8	23	0.00078
7	150		0.16	108		1	0.0011
8	1250		0.89	260	0.66	2.2	
aver.	415	9.2	0.56	57	11.1	18.8	0.08
std.	525	15.8	0.71	97	16.3	23.1	0.14
geom. mean	165	2.6	0.34	10.6	5.3	8	0.0095

No.	Se	Br	Rb	Sb	Cs	Ba	La
1		0.052	3.37	0.59		1.7	0.54
2	0.25	0.042	0.77	0.028	0.019	1	0.098
3				0.041	0.00021	0.16	0.25
4		0.022		0.23	0.1	3.97	0.38
5				0.06		0.21	0.023
6		0.036	0.3	0.034	0.016		
7	0.18	0.025	0.62	0.1	0.0012	1.94	0.16
8	0.46	0.084	0.51	0.21	0.00031	5.26	0.039
aver.	0.3	0.044	1.11	0.16	0.023	2.03	0.21
std.	0.15	0.023	1.27	0.19	0.039	1.92	0.19
geom. mean	0.27	0.039	0.76	0.095	0.0037	1.13	0.13

No.	Sm	Eu	Yb	Lu	Hf	Th	U
1	0.034	0.0022	0.0163	0.0024	0.028	0.014	0.046
2	0.0031	0.00041	0.0038	0.00062	0.0021	0.0026	0.18
3	0.021	0.0023	0.0045	0.00053	0.021	0.016	0.95
4	0.00043	0.0049	0.029	0.0029		0.01	0.0115
5	0.00069		0.00062	0.00014	0.0014	0.001	
6		0.00043	0.0048	0.00055	0.00078	0.009	0.021
7	0.0056	0.00067	0.0052		0.0051	0.0053	0.011
8	0.013	0.002	0.0074		0.012		0.27
aver.	0.011	0.0018	0.009	0.0012	0.01	0.0083	0.21
std.	0.013	0.0016	0.0093	0.0012	0.011	0.0056	0.34
geom. mean	0.0047	0.0013	0.0056	0.00075	0.005	0.006	0.066

App. 21: Concentrations of chemical elements in aerosol samples collected by filtration through AFA-KhA filters in Arkhangelsk, the White and the Barents seas in August-September 1997 (11th expedition of the RV "Akademik Sergey Vavilov"), ng/m^3.

No.	Na	Ca	Sc	Cr	Fe	Co	Ni
1*	81	650	0.0059	1.62	61	0.77	0.16
2**	97	980	0.044	0.61	213	0.24	0.85
3***	8900	1150	0.0043	1.56	88	0.07	0.48

No.	Zn	As	Se	Br	Rb	Sb	Cs
1	18	0.56	0.001	0.66		0.32	
2	46		1.50	1.02		0.058	0.103
3	0.87		0.23	16	1.08	0.080	

No.	Ba	La	Ce	Nd	Sm	Eu	Tb
1	0.37	0.19	0.27	0.067	0.0077	0.0010	0.0018
2	1.21	1.16	1.54	0.34	0.032	0.015	0.0090
3	0.26	0.13	0.22	0.078	0.013	0.019	0.0033

No.	Yb	Lu	Hf	Ta	Au	Th	U
1	0.0061	0.001	0.029	0.036	0.017	0.004	0.36
2	0.046	0.0094	0.0048	0.035	0.03	0.24	1.32
3	0.015	0.0029	0.071	0.020	0.0095	0.075	0.68

*Arkhangelsk, port; **White Sea; ***Barents Sea

App. 22: Enrichment factors of aerosols collected by filtration through AFA-KhA filters in Arkhangelsk, the White and the Barents seas in August-September 1997 (11th expedition of the RV "Akademik Sergey Vavilov").

No.	Na	Ca	Sc	Cr	Fe	Co	Ni
1*	12.8	58	1	60	4.0	115	8.0
2**	2.1	12	1	3	1.9	4.8	5.7
3***	1900	141	1	80	8.0	14	33

No.	Zn	As	Se	Br	Rb	Sb	Cs
1	960	1160	75	990		5930	
2	332		15140	206		146	17.3
3	64		23500	32700	61	2050	

No.	Ba	La	Ce	Nd	Sm	Eu	Tb
1	3.2	24.0	16.8	8.9	4.8	3.1	7.5
2	1.4	19.5	12.9	6.1	2.6	6.4	5.0
3	3.1	22.3	18.8	14.3	10.8	81	18.8

No.	Yb	Lu	Hf	Ta	Au	Th	U
1	7.6	7.7	37	67	15800	1.6	501
2	7.7	9.5	0.8	8.9	4280	12.7	247
3	26	29	121	51	12150	40	1290

*Arkhangelsk, port; **White Sea; ***Barents Sea