ISSN 0024-4902, Lithology and Mineral Resources, 2006, Vol. 41, No. 3, pp. 215–221. © Pleiades Publishing, Inc., 2006.
Original Russian Text © L.A. Ganzei, N.G. Razzhigaeva, 2006, published in Litologiya i Poleznye Iskopaemye, 2006, No. 3, pp. 242–249.

Composition of Sand Storm Particles in the Southern Far East

L. A. Ganzei and N. G. Razzhigaeva

Pacific Institute of Geography, Far East Division, Russian Academy of Sciences, ul. Radio 7, Vladivostok, 690041 Russia
e-mail: nadyar@tig.dvo.ru

Received April 15, 2004

Abstract—Lithostructural composition of the dust storm material (DSM) sampled in the southern Far East in the spring of 2002–2004 has been analyzed. Samples were taken near Vladivostok, where the eolian dust precipitation varied from 0.1 to 6.5 g/m^2 at that time. Pelitic and fine-silt particles predominate in eolian dust. Grain size, mineral, and chemical compositions of the DSM are compared to data on the DSM in adjacent territories of China, Korea, and Japan, as well as to background data on aerosol precipitation in southern Primorye. Possible mechanisms of the eolian dust transport from inner parts of Asia at different climatic variations in the Pleistocene–Holocene are discussed.

DOI: 10.1134/S0024490206030023

INTRODUCTION

Eolian dust transport from the continent to ocean is of great importance in sedimentation in marginal seas and the NW Pacific (Lisitsyn, 1991). Dynamics of eolian processes is closely related to climatic changes in the Pleistocene. The input of a great amount of eolian dust to marine sediments was especially characteristic of glacial epoch (Irino and Tado, 2000). The main source of dust was Asia (inner parts of China and Mongolia) in the northwestern Pacific and Australia in the southern Pacific (Xiao and An, 1999; Rea, 1990). Increase in eolian dust transport is related to changes in the atmospheric circulation—activation of the winter monsoon, shift and possible intensification of a jet stream, as well as intensity and frequency of dust storms (Ono and Naruse, 1997). Active dust transport was favored by decrease in precipitation in winter and spring seasons. Dust storms were characteristic of the Minor Ice Age for the last millennium (Selivanov, 1994; Feng et al., 2002).

Based on study of the DSM composition, one can identify the eolian material in old sediments and characterize the situation favorable for its transport over long distances.

Dust storms appear due to uplift of fine dust and sand by strong winds from the Earth's surface. The dust and sand particles are entrained by turbulence into upper layers of the atmosphere and transported over large distances (Feng et al., 2002). Dust storms occupy large regions extending for thousands of kilometers and vertical dust loading in the atmosphere reaches 6–7 km. Dust storms emerge annually in Mongolia and northern China, but they rarely embrace southern regions of the Russian Far East. The fine material from inner parts of Asia is usually transported toward Korea and Japan Islands by NW winds related to powerful eastward propagating cyclones (Zhou et al., 1996; Ma et al., 2001; Ogunjobi et al., 2003). The maximal precipitation of eolian dust in Japan is observed on the western coast. The amount of DSM abruptly decreases eastward and northward, e.g., 5–10 times on Hokkaido (Ono and Naruse, 1997). In some years, the Asian DSM reached the North American territory (Husar et al., 2001; Feng et al., 2002).

Dust storms occur mostly in early springs (March–April) after dry autumns and winters with little snow when soil remains dry, loose, and grass-free (Fan et al., 1996; Zhou et al., 1996; Feng et al., 2002). Relatively high air temperature and strong wind enhance dehydration of the upper soil layer. Dust distribution over vast territories is related to the passage of powerful cyclones accompanied by strong winds (>20–30 m/s). During such periods, the cyclone passage is not precluded by the vast Siberian anticyclone located in cold seasons over Siberia, Mongolia, and Far East, because the anticyclone becomes significantly weaker in the second half of March. One of the strong dust storms was observed in Primorye in April 1956 when during several days the territory was covered with haze because of dust particles suspended in the air. Dust storm with the precipitation of yellow snow was observed in 1983 near Vladivostok. A unique weather phenomenon was observed in springs of 2002–2004 when dust storms spanned vast territories of the Russian Far East, as well as northwestern China, Korea, Japan, and adjacent sea areas. The purpose of this work is to determine the amount of material brought with dust storms and to analyze its lithostructural composition.

MATERIALS AND METHODS

The material of dust storms in 2002–2004 was collected in southern Primorye from the ice surface of frozen water basins on the Murav'ev-Amurskii Peninsula

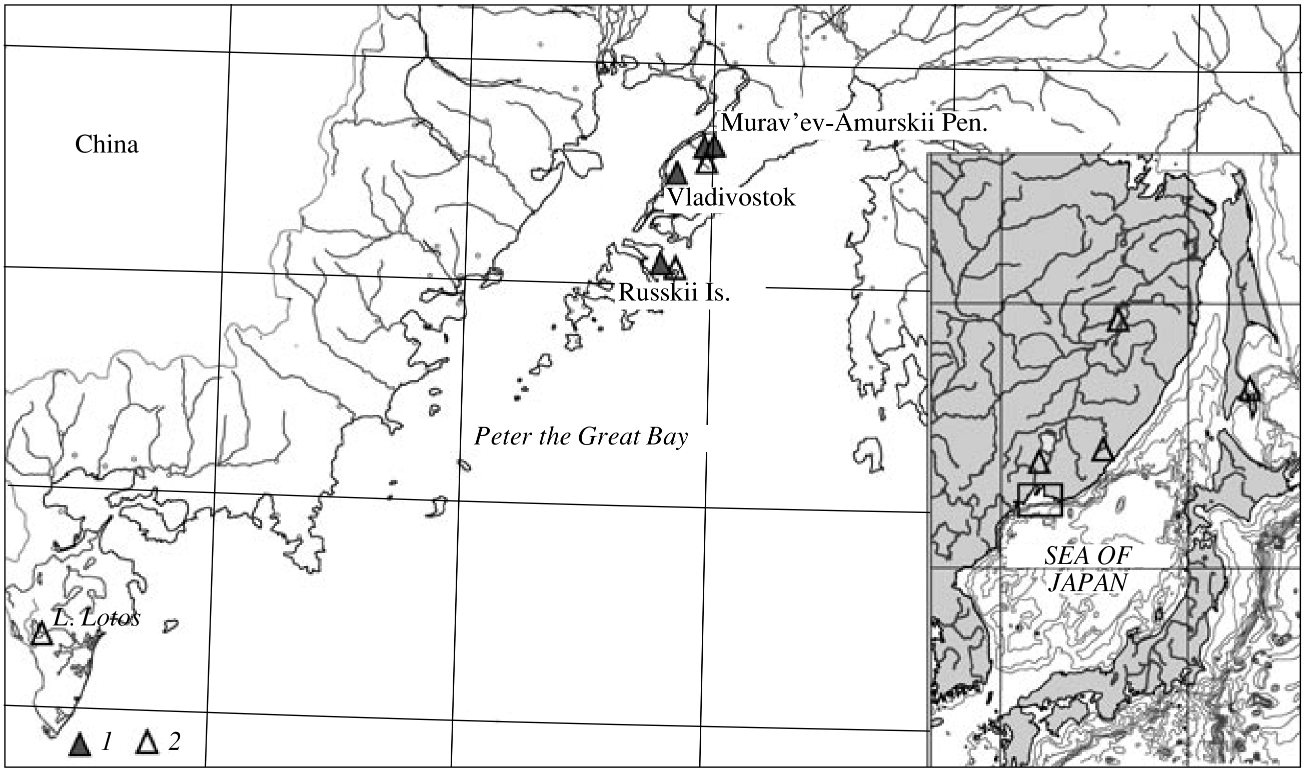

Fig. 1. Sites of the DSM (2002–2004) and eolian material sampling in Primorye. (*1*) Background aerosol material; (*2*) DSM.

(25 km away from Vladivostok) and Russkii Island (Ayaks Bay). The material was also collected in a trap located 5 m above the surface at a distance of 13 km from Vladivostok (Fig. 1). In 2002, we sampled the eolian material (ice cores) accumulated during the winter season prior to dust storms in different areas of Primorye (a nameless lake, Russkii Island; Lake Lotos, the Khasan region; Lake Vas'kovskoe, the Dal'negorsk region; and a pond in the suburb of Ussuriisk), in the Lower Amur River region (Lake Sindinskoe), and the coastal zone of southern Sakhalin. In order to extract the sediment, water was passed through the Pall Filtrationstechnik GmbH filters with a pore size of 0.45 μm. The grain size analysis of sediments was carried out at the Pacific Institute of Oceanology (Vladivostok) with a Sizer Analysette 22 device that makes it possible to analyze silty and pelitic fractions. The mineral composition was determined at the Far East Geological Institute (Vladivostok) by the X-ray structural method with a DRON-3.0 apparatus. The samples were analyzed in the air-dry, calcined, and glycol-saturated states. The chemical composition was also determined at the Far East Geological Institute (Vladivostok). Filters for microspecimens were studied by VRA-30 and JXA-5A microanalyzers.

RESULTS AND DISCUSSION

A series of dust storms occurred in the Russian Far East in March–April, 2002–2004: March 21–22, 25–26, and April 7–9, 2002; April 16–21, 2003, March 9–10, 2004. Their formation was promoted by a warm winter with fast thawing in the early spring when plant cover was still lacking and sediments were loose. Therefore, wind captured a greater DSM mass than usual. The DSM was transported from inner regions of China and Mongolia. Drift of powerful cyclones with great temperature gradients in the frontal zone intensified the western and northwestern winds (up to 20–25 m/s) and fast rise of lower dusty air masses to higher layers of the lower troposphere (up to the height of 5–7 km) into the jet stream zone with a velocity of as much as 80 km/h) [www.primpogoda.ru]. Periodicity of events of such a scale in China is assessed at 1 event per 10 yr (Feng et al., 2002). The material reached southern regions of the Russian Far East and Japan in one or two days. The NASA and NOAA satellite images of that period show the migration of dust cloud located below atmospheric clouds over a vast territory extending from Beijing to Korea, Yellow Sea, Sea of Japan, Primorye, and Japan. Visibility was <10 m in the Gansu Province (China), <100 m in Beijing, and <50 m in Korea. During dust storms in March, 2002, a part of airflows was entrapped by the cyclone passing from the

Sea of Japan to Kamchatka, and the dust material was transported over several thousand kilometers. A pink and yellow snowfall took place in Kamchatka. No such phenomenon had been observed in this region over the past century. On March 26–28, the Asian DSM reached the northwestern part of the United States, including Alaska and Colorado. The total area exposed to the influence of dust cloud reached 1.4 mln km^2 [www.primpogoda.ru].

Dust storms near Vladivostok were accompanied by an advective haze. Particles of yellow-gray dust were suspended in the air, and the sun became blue. The amount of dust precipitation during the first two storms in 2002 was equal to 0.05–0.11 g/m^2, which is comparable with estimates of the precipitation (0.10 g/m^2) of powerful dust storms in 1990–1993, which passed via China and carried the DSM up to Japan Islands and the western coast of North America (Feng et al., 2002). During the third dust storm, the dust cloud area reached ~40000 km^2, and the dust rose as high as 3.5 km. Several peaks of the DSM precipitation were observed (the highest peak was recorded on March 18 and 20). The precipitation was most intensive in Vladivostok (more than 6.50 g/m^2) probably due to the assistance of snowfall, which was yellow in color. In contrast to the first and second dust storms, the third storm was characterized by the DSM scattering over a relatively smaller area (Korea, Japan, southern Primorye, and adjacent sea areas). Satellite images of the dust storm show that the aerosol material of lower atmospheric layers was actively transported by airflows to valleys of the major (Partizanskaya, Shkotovka, and Razdol'naya) rivers.

The dust storm of April, 2003, is related to the cyclone with several centers of reduced pressure (982–998 GPa), which moved from northern China and Mongolia to northeast. The zone of maximal cyclone winds spanned the Amur and Khabarovsk regions, and the wind velocity was as high as in a hurricane (31 m/s) [www.primpogoda.ru]. Having reached the frontal zone, the dust partially precipitated with rain, and its concentration in the Vladivostok region exceeded 0.4 g/m^2. In addition to southern Primorye, the dust storm enveloped lower reaches of the Amur River, the Kuriles, and the Sea of Okhotsk.

The dust storm of March 9–10, 2004, is related to the cyclone with pressure at the center equal to 970–990 GPa. The dust fall near Vladivostok was accompanied by rainfall and strong wind. The total amount of the DSM was 0.37 g/m^2.

According to estimates based on the study of ice cores taken from onshore lakes, the amount of eolian material accumulated on the Primorye coast during the winter before the dust storms of 2002 varied from 0.48 (Lake Vas'kovskoe) to 3.46 g/m^2 (Lake Lotos) and 0.7 g/m^2 (sea near Russkii Island). The amount eolian material accumulated during the whole winter period was much greater in inner regions of Primorye (42.62 g/m^2 near Ussuriisk) and lower courses of the Amur River (58.65 g/m^2). Background values for offshore regions near southern Sakhalin were much lower (0.21 g/m^2).

According to previous data, the average amount of dust precipitation during the winter period (December–March) along the coast of the Murav'ev-Amurskii Peninsula (near Vladivostok) in the 5-km-wide zone of maximal concentration of the eolian material, which was clearly distinguished by the ice color, reached 29.4 g/m^2 (Petrenko, 1986). Local sources (slopes and beaches), including anthropogenic ones, could also play a great role in the DSM accumulation. The concentration of dust delivered to the central part of the bay during the winter of 1998 decreased from 4.8 to 1.3 g/m^2 (Nedashkovsky, 2001). The amount of aerosol material accumulated near the watershed area of the Murav'ev-Amurskii Peninsula (height 250–300 m) from November to May in 1988–1992 varied from 14.59 ± 2.69 g/m^2 to 21.06 ± 2.30 g/m^2. The maximal input of eolian material from both distal and proximal sources is also confined to the early spring—March–April (6.19–9.56 g/m^2) (Elpat'evskii et al., 1993). Similar data were obtained for the coastal zone near Vladivostok (Mishukov et al., 2001) and the Sikhote Alin biosphere reserve (Kondrat'ev, 2002), where two distinct maximums of dust concentration coincide with periods of the atmosphere circulation rearrangement in spring and autumn. Thus, the volume of eolian material accumulated during one intense dust storm is comparable with the volume of precipitation on the continent for the whole winter season in years without anomalies. The volume of eolian dust precipitated in water areas can be substantially higher relative to the continental values.

Unlike the Chinese DSM, which always includes sandy fractions (Feng et al., 2002), the Primorye DSM mostly comprises pelitic particles (56.8–81.1%) with some fine silt (15.4–37.9%) and an insignificant share of coarse silt (0.3–4.6%). Modal fractions correspond to 2–7 μm (15–20 μm in the first DSM). The average grain size varies from 2.4 to 7.5 μm. The share of fine pelite does not exceed 6.4–9.6%. The DSM of 2003 exhibits a different grain size distribution: fine silt 67.6%, pelitic fractions 32.4%, including fine pelite 4.2%. The average grain size is 13 μm.

The material of the first dust storm in 2002 is characterized by a bimodal distribution curve with symmetrical (*Ka* 0.13–0.17) modes at ~2 μm (*Ma* 2.6 μm) and 15–20 μm (*Ma* 16 μm) with nearly similar contributions (Fig. 2). Although the integral curve is characterized by a moderate grading of the material (σ 1.75), distribution of particles within individual modes is distinguished for rather good grading (σ 0.9–1.4). Material of the second and third dust storms yield single-mode symmetrical distribution curves (*Ma* 4.3–4.5 μm, *Ka* 0–0.1) with a small "tail" of fine fractions and high degree of grading (σ 1.26–1.34) (Fig. 2). The DSM of 2003 is

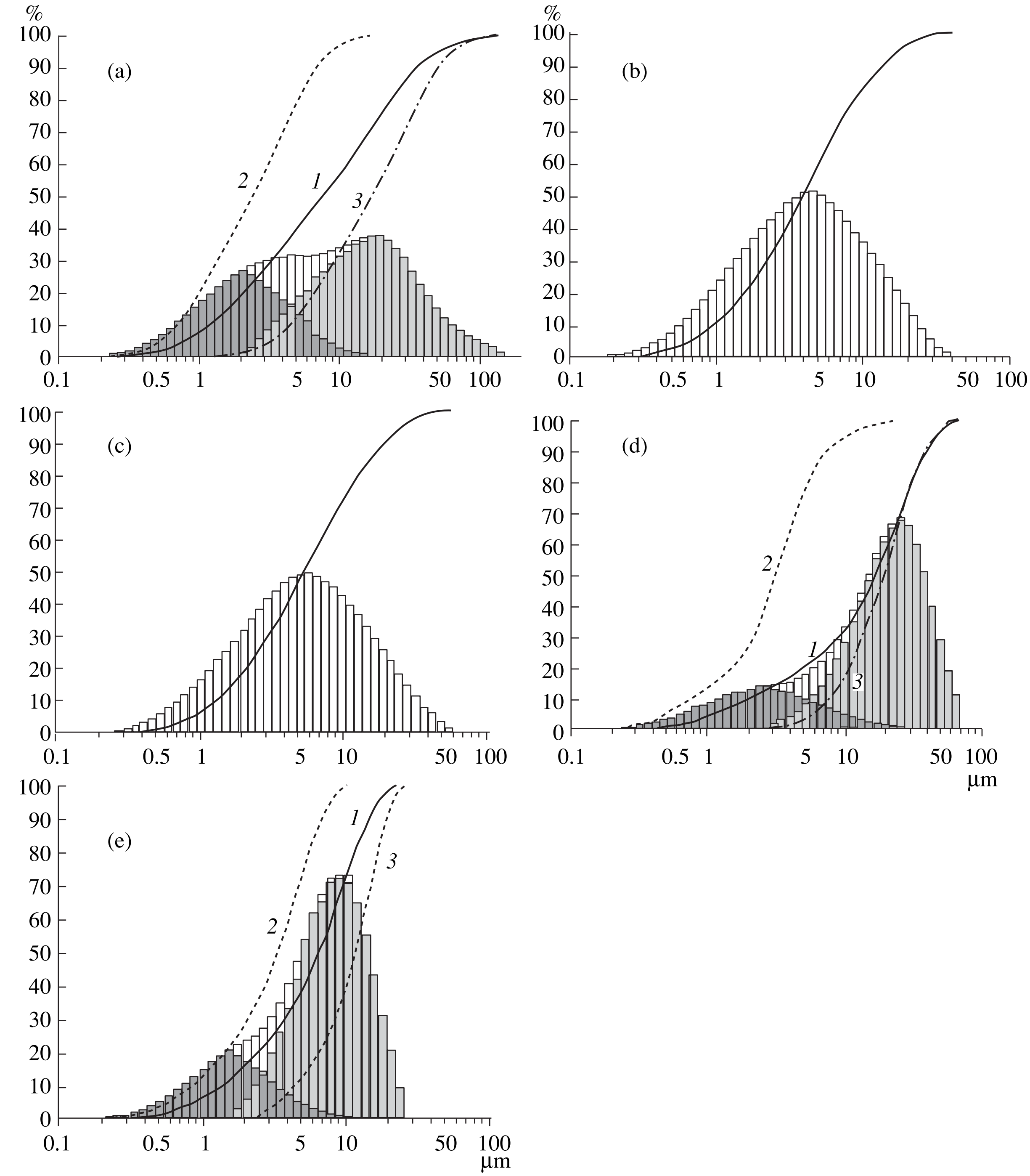

Fig. 2. Grain size compositions and cumulative distribution curves for the DSM of 2002–2004. The analysis was carried out with a Sizer Analysette 22 at the Pacific Institute of Geography, Vladivostok (A.I. Botsul, analyst). (a) March 21–22, 2002; (b) March 25–26, 2002; (c) April 7–9, 2002; (d) April 16–21, 2002; (e) March 8–10, 2003. (*1*) Integral accumulation curve; (*2*, *3*) curves of individual unimodal distributions.

characterized by a bimodal distribution curve with a clearly defined mode of relatively large particles of 20–30 μm, which is noted for an abrupt peak, good grading (σ 0.99), and positive asymmetry (*Ka* 0.44). The second mode (2–3 μm) is characterized by a flat symmetrical curve and low degree of grading. The DSM of 2004 represented by a finer material also has a bimodal distribution curve with two symmetrical modes (*Ka* 0.08–0.27) in the coarse (6–9 μm) and fine (1–2 μm) pelite zones. The coarse-grained part of the sediment is characterized by a higher grading (σ 0.80) and an abrupt curve. Unlike the storm dust of 2003, the fine-grained fraction of the sediment is best graded.

In years without dust storms (1988–1992), relatively coarser particles—fine silt (median size 12–20 μm, average grain size ~14 μm)—predominated in the aerosol material, which precipitated in southern Primorye (the Murav'ev-Amurskii Peninsula) from November to May. The sediment is well graded (Elpat'evskii et al., 1993). Structurally, this material is close to a larger mode of dust storms.

The grain size composition of the Chinese DSM strongly depends on its transport distance. The size of particles varies from 0.2 to 200 μm (from 10.1 to 93.5 μm near the provenances). The average size of the DSM of long-range transport in the Beijing region (China) is nearly 3.9 μm (Feng et al., 2002). In southern Korea, dust particles have the predominant size of 1–10 μm (maximum ~2.3–6.6 μm). Some dust storms include a finer material characterized by the bimodal distribution curves with modal fractions of ~0.1 and 3.8 μm (Chun et al., 2001; Ogunjobi et al., 2003). The composition of dust precipitation in Korea is similar to a finer mode of the Primorye DSM. In general, the grain size composition of the Primorye dust is closest to that of the aerosol material precipitated in Japan and transported by jet streams. Particles 3.3–4.7 and 4.7–7 μm in size predominate in Japan. The coarser material precipitated during the more intensive dust storms (Inoue and Naruse, 1987).

On the whole, Primorye is characterized by a distinct trend of dust particle sorting depending on its transport range. This is also clearly traced in China, where the *So* value decreases eastward from 1.81 to 0.34 (Feng et al., 2002). The Chinese DSM is characterized by abrupt distribution curves and high excess values.

The mineral composition of the DSM sampled in the suburb of Vladivostok is mainly represented by quartz, feldspar (mostly, plagioclase), hydromica, chlorite, kaolinite, mica, calcite, and dolomite. Amphiboles were found in dust of the first and second dust storms in 2002 and 2004; chamosite, pyrophyllite, and anatase, in dust of the third storm in 2002; gypsum, zeolite, and serpentine, in dust of the storm in 2003; and sepiolite and smectite, in dust of the storm in 2004. The share of quartz and feldspar increases in sediments with a higher concentration of fine silt. The fine dust mainly consists of clay minerals and mica. It is likely that difference in mineral composition is responsible for the appearance of two modal fractions and various degrees of DSM differentiation during its transportation. The mineral composition of the sediment corresponds to the dust composition of storms in different years in China, the source of which were arid and semiarid regions of China and Mongolia (Feng et al., 2002). The material transported from inner regions of Mongolia is characterized by a great amount of feldspars.

In terms of the content of macro- and microcomponents, the DSM studied is similar to dust storm sediments sampled in China, Korea, and Japan (Choi et al., 2001; Ma et al., 2001; Feng et al., 2002). The chemical composition of sediments in Primorye is characterized by high SiO_2 and Al_2O_3 contents that indicate the prevalence of quartz and aluminosilicates (table). The SiO_2 content varies from 59.34 to 68.5% depending on the mineral composition and reaches the maximum in the material with a high concentration of fine silt, which is likely to be mostly composed of quarts. The Al_2O_3 content (10–15%) is generally higher than in the DSM near sources and is similar to that in the dust of long-range transport in China (Feng et al., 2002) and Japan (10–20%) (Ma et al., 2001). The sediments are characterized by high K_2O contents (3.27–3.62%). The SiO_2/Al_2O_3 ratio in the Primorye DSM is equal to 3.3–6.8, which is similar to values in the dust from Inner Mongolia. Moreover, this value is slightly lower or close to the lower limit in dust (5.17–8.43) and loess from other regions of China (6.3–9.3) (Feng et al., 2002), probably, due to a higher concentration of the fine material represented by clay minerals. It is likely that the same reason is responsible for the slightly higher K_2O/SiO_2 value (0.05–0.06) in the Primorye DSM relative to the dust (0.009–0.037) and loess (0.013–0.04) in China. In general, these regularities reflect variation trends of the DSM composition depending on the transportation range.

Dust samples taken in Vladivostok are noted by low contents of Na_2O (1.22–1.25%) and S (~0.006%). In contrast, the Japanese aerosol dust, which entraps and absorbs sea salt in the course of prolonged transportation over sea waters, contains as much as 3.95% sulfur, on the average (Fan et al., 1996; Zhou et al., 1996; Ma et al., 2001). DSM samples collected in the Beijing region (China) comprise little or no sulfur (Zhou et al., 1996).

Contents of Ti and Fe in the Primorye dust are close to those in the Inner Mongolian dust (TiO_2 0.70%, Fe_2O_3 4.83%) and the DSM precipitated in Japan (TiO_2 1.51%, Fe_2O_3 6.93%) (Ma et al., 2001; Feng et al., 2002).

Like aerosol dust sampled regularly during the winter and spring seasons in years without anomalies (Elpat'evskii et al., 1993), the DSM is enriched in phosphorus and depleted in calcium. The CaO content is lower than in the DSM of Inner Mongolia, China (5.36%) and close to that in the dust of long-range transport in China and Korea (Choi et al., 2001; Feng et al., 2002). The Ca/Al ratio in the Primorye DSM (0.13–0.39) is close to values in the aerosol material (0.09–0.26), which precipitated in the Murav'ev-Amurskii Peninsula in years without anomalies (Elpat'evskii et al., 1993). Calcium is lost during the long-range transport of material. The Ca/Al ratio in the Mongolian DSM is 0.62 (Feng et al., 2002). The upper limit of the Ca/Al ratio in the Primorye dust is close to values obtained for the DSM in Japan and Korea (0.43–0.66), where the anthropogenic Ca is also added to the

Chemical composition (wt %) of the dust storm material (DSM) and aerosol particles in the southern Far East and adjacent regions

Sample	Si	Ti	Al	Fe	Mn	Mg
Dust storm, March 2002	23.12	0.44	7.94	4.64	0.08	1.72
Aerosol material, Murav'ev-Amurskii Peninsula*	–	–	5.09–7.78 (6.55)	1.92–3.41 (2.55)	–	0.36–0.72 (0.51)
Inner Mongolia, China**	33.24	0.42	5.90	3.38	–	0.69
Beijing, China**	29.63	0.35	5.51	3.94	0.12	0.93
Seoul, Korea***	–	–	6.09	3.74	0.09	1.79
Japan****	4.38–61.79 (36.60)	0–3.29 (1.64)	4.82–29.9 (14.31)	0–16.63 (5.83)	–	0.69–16.65 (3.67)

Sample	Ca	Na	K	P	L.O.I.
Dust storm, March 2002	1.70	0.76	2.27	0.30	16.83
Aerosol material, Murav'ev-Amurskii Peninsula*	0.50–1.35 (1.00)	0.60–1.21 (0.77)	0.92–2.36 (1.30)	0.09–0.19 (0.13)	7.2–37.5 (26.07)
Inner Mongolia, China**	4.17	1.56	0.64	0.04	–
Beijing, China**	0.57	1.88	0.47	0.03	2.68
Seoul, Korea***	4.01	0.92	–	–	–
Japan****	1.37–55.36 (13.15)	0.44–7.42 (2.54)	0.67–5.20 (2.87)	–	–

Note: The DSM of 2002 was analyzed by S.B. Batanova at the Far East Geological Institute, Vladivostok; average values are given in parentheses; (–) not analyzed; * based on (Elpat'evskii et al., 1993); ** based on (Feng et al., 2002); *** based on (Choi et al., 2001); **** based on (Ma et al., 2001).

aerosol material (Choi et al., 2001; Kanayama et al., 2002).

The L.O.I. value in the Primorye DSM is lower than in the aerosol material sampled in normal years (Elpat'evskii et al., 1993) and close to the lower limit of the organic matter content in the Chinese DSM (Feng et al., 2002).

The microelement composition of the studied dust is similar to that of sediments of the most intense dust storms in China (Choi et al., 2001). Contents of heavy metals (Pb, Zn, and Cr) and microelements (Zr, Y, Rb, and Sr) are at the background level.

CONCLUSIONS

Unique strong dust storms over vast territories in spring periods of 2002–2004 were provoked by anomalous weather conditions: warm winter with little snow; fast and early snow thawing prior to the appearance of vegetation; and rapid rise of lower air masses, which carried away the loose material, to higher layers of the atmosphere.

In the course of dust storms in southern Primorye, the amount of dust precipitated during one event varied from 0.05–0.1 to >6.5 g/m^2. The amount of precipitation mainly depended on conditions of the spreading of dust clouds and precipitation of the DSM rather than their sizes. It has been established that the amount of material delivered during one intense dust storm is comparable with the mass of eolian material precipitated on land during the whole winter season in normal years. In marine water areas, the amount may substantially exceed the latter value. The material is composed of pelitic particles (4.5–7 μm) with a small admixture of fine silt (15–20 μm). The lithostructural composition of dust was primarily governed by the composition of provenances (Inner Mongolia and other regions of China) and the differentiation of material during its long-term transportation.

The study of conditions of formation and spreading of present-day dust storms provides insights into mechanisms of eolian dust transport from inner parts of Asia to the continental margin and Pacific Ocean in different Pleistocene–Holocene epochs. Eolian processes were activated in cold epochs due to intensification of the winter monsoon (Rea, 1990; Ono and Naruse, 1997; Xiao and An, 1999). However, active transport of the eolian material from Inner Asia was probably confined to periods of the monsoon circulation rearrangement, especially, in spring seasons. Intensification of the monsoon activity created favorable conditions for the generation of dust storms due to decrease in precipitation during winter periods. During warm periods, early thawing of snow under conditions of rare vegetation facilitated the origin of dust storms. Such situations have been observed in recent years in the Far East under conditions of progressive warming. Thus, intense and frequent dust storms could develop both in cold and warm periods of the Pleistocene due to differently oriented climatic changes. However, historical data for two last millenniums (Selivanov, 1994; Feng et al., 2002) show that eolian activity was substantially higher in cold epochs.

ACKNOWLEDGMENTS

We are grateful to I.I. Kondrat'ev, L.V. Perepelyatnikov, V.V. Zharikov, and E.B. Moiseevskaya from the Pacific Institute of Geography, Far East Division, Russian Academy of Sciences for participation in the sampling of cores and surface ice. We also thank A.I. Botsul from the same institute and A.A. Karabtsov (Far East Geological Institute, Far East Division, Russian Academy of Sciences) for assistance in the analytical processing of data.

This work was supported by the Russian Foundation for Basic Research, project no. 01-05-64591.

REFERENCES

Choi, J.C., Lee, M., Chun, Y., et al., Chemical Composition and Source Signature of Spring Aerosol in Seoul, Korea, *J. Geophys. Res.,* 2001, vol. 106, no. D16, pp. 18067–18074.

Chun, Y., Kim, J., Choi, J.C., et al., Characteristic Number Size Distribution of Aerosol during Asia Dust Period in Korea, *Atmos. Environ.*, 2001, vol. 35, pp. 2715–2721.

Elpat'evskii, P.V., Arzhanova, V.S., and Razzhigaeva, N.G., Aerial Component of the Material Basis for Soil Formation in the Southern Primor'e Region, *Pochvovedenie*, 1993, no. 11, pp. 5–8.

Fan, X., Okada, K., Niimura, N., et al., Mineral Particles Collected in China and Japan during the Same Asian Dust-Storm Event, *Atmos. Environ.*, 1996, vol. 30, no. 2, pp. 347–351.

Feng, Q., Endo, K.N., and Cheng, G.D., Dust Storms in China: A Case Study of Dust Storm Variation and Dust Characteristics, *Bull. Eng. Geol. Environ.,* 2002, vol. 61, pp. 253–261.

Husar, R.B., Tratt, D.M., Schechtel, B.A., et al., Asian Dust Events of April 1998, *J. Geophys. Res.,* 2001, vol. 106, pp. 18317–18330.

Inoue, K. and Naruse, T., Physical, Chemical and Mineralogical Characteristics of Modern Eolian Dust in Japan and Rate of Dust Deposition, *Soil Sci. Plant Nutrition*, 1987, vol. 33, pp. 327–345.

Irino, T. and Tado, R., Quantification of Aeolian Dust (Kosa) Contributed to the Japan Sea Sediments and Its Variation during the Last 2000 ky, *Geochem. J.*, 2000, vol. 34, no. 1, pp. 59–93.

Kanayama, S., Yabuki, S., Yanagisawa, F., and Motoyama, R., The Chemical and Strontium Isotope Composition of Atmospheric Aerosols over Japan: the Contribution of Long-Range-Transported Asia Dust (Kosa), *Atmos. Environ.*, 2002, vol. 36, pp. 5159–5175.

Kondrat'ev, I.I., Chemical Composition and Seasonal Concentration Variation of Aerosol in the Atmosphere of the Sikhote Alin Biosphere Reserve, *Meteorol. Gidrol.*, 2002, no. 2, pp. 31–42.

Lisitsyn, A.P., *Protsessy terrigennoi sedimentatsii v moryakh i okeanakh* (Processes of Terrigenous Sedimentation in Seas and Oceans), Moscow: Nauka, 1991.

Ma, C.J., Kasahara, M., Holler, R., and Kamiya, T., Characteristics of Single Particles Sampled in Japan during the Asian Dust-Storm Period, *Atmos. Environ.*, 2001, vol. 35, pp. 2707–2714.

Mishukov, V., Medvedev, A., and Slinko, E., Study of Aerosol Content at Russia Far East, *J. Ecotechnol. Res.,* 2001, vol. 7, no. 1, pp. 61–65.

Nedashkovsky, A., Content of Nutrients and Some Trace Metals (Cd, Pb, Cu) in the Ice of the Amurski Bay (the Sea of Japan). Possible Contribution of the Atmospheric Factors, *J. Ecotechnol. Res.,* 2001, vol. 7, no. 1, pp. 58–60.

Ogunjobi, K.O., Kim, Y.J., and He, Z., Aerosol Optical Properties during Asian Dust Storm Episodes in South Korea, *Theor. Appl. Climatol.*, 2003, vol. 76, pp. 65–75.

Ono, Y. and Naruse, T., Snowline Elevation and Eolian Dust Flux in the Japanese Islands during Isotope Stage 2 and 4, *Quat. Inter.*, 1997, vol. 37, pp. 45–55.

Petrenko, V.S., Eolian Factors Responsible for Fine-Grained Material Delivery to the Petr Velikii Gulf, Abstracts of Papers, *Vsesoyuz. soveshchanie "Okhrana prirodnoi sredy morei i ust'ev rek"* (All-Union Conference on Preservation of Environment of Seas and River Mouths), Vladivostok, 1986, pp. 125–126.

Rea, K.D., Aspects of Atmospheric Circulation: The Late Pleistocene (0–950, 000 yr) Records of Eolian Deposition in the Pacific Ocean, *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 1990, vol. 78, pp. 217–227.

Selivanov, A.O., Climate Variations in Eastern and Central Asia over the Last Millenniums, *Izv. Ross. Akad. Nauk, Ser. Geogr.*, 1994, no. 3, pp. 116–124.

Xiao, J., and An, Z., Three Large Shifts in East Asian Monsoon Circulation Indicated by Loess-Paleosol Sequences in China and Late Cenozoic Deposits in Japan, *Palaeogeogr., Palaeoclimat., Palaeoecol.,* 1999, vol. 154, pp. 179–189.

Zhou, M., Okada, K., Qian, F., et al., Characteristics of Dust Storm Particles and Their Long-Range Transport from China to Japan—Case Studies in April 1993, *Atmosph. Res.* 1996, vol. 40, pp. 19–31.