Dust storms in China: a case study of dust storm variation and dust characteristics

Q. Feng · K.N. Endo · G.D. Cheng

Abstract The paper discusses the nature of dust storms, which have inherent environmental implications. The physical, chemical and mineralogical properties of dust sediments collected in Kashi, Taklimakan desert, Kunlun mountains, Donghuang, Lanzhou, Ningxia, Xi'an, Inner Mongolia and Beijing from 1990 to 1994 were studied. The texture of most aeolian deposits ranges from silty clay to clay loam with median particle diameters (Mds) generally between 5 and 63 μm; similar to the loess of central China and the silt/fine sand in western and northern China. The dust sediments were characterized by a predominance of SiO_2 and Al_2O_3 and a high amount of K_2O with molar ratios for SiO_2/Al_2O_3 and K_2O/SiO_2 from 5.17 to 8.43 and 0.009 to 0.0368 respectively. The triple peak spectrum is the main form of mass concentration in a clear sky. In a dust storm it shows as a single peak, with quartz, feldspar, chlorite, illite, calcite and dolomite being the dominant minerals. The physical, chemical and mineralogical properties of the present atmospheric dust are similar to those of wind-blown soils in western and central China. The results suggest that aeolian deposits and the fine-grained fractions of dust sediments collected in northern China are mainly soils transported from the arid and semi-arid regions of China and Mongolia by the prevailing winds.

Résumé L'article discute de la nature des tempêtes de poussières, aux conséquences importantes sur l'environnement. Les caractéristiques physiques, chimiques et minéralogiques des sédiments de tempêtes de poussières prélevés à Kashi, dans le désert de Taklimakan, les montagnes de Kunlun, à Donghuang, Lanzhou, Ningxia, Xi'an, en Mongolie intérieure et à Pékin de 1990 à 1994 ont été étudiées. La texture de la plupart des dépôts éoliens varie des argiles silteuses aux limons argileux. La courbe granulométrique présente une valeur médiane généralement comprise entre 5 et 63 μm argileux. Les caractéristiques physiques, chimiques etrisés par une prédominance de SiO_2 et de Al_2O_3 et une forte teneur en K_2O avec des rapports SiO_2/Al_2O_3 de 5,17 à 8,43 et des rapports K_2O/SiO_2 de 0,009 à 0,0368. Un spectre à trois pics est caractéristique d'un ciel clair. Dans une tempête de poussières le spectre présente un seul pic avec quartz, feldspath, chlorite, illite, calcite et dolomite comme minéraux prépondérants. Les caractéristiques physiques, chimiques et minéralogiques de la poussière atmosphérique sont semblables à celles des sols soufflés par le vent dans la Chine de l'ouest et du centre. Les résultats de l'étude suggèrent que les dépôts éoliens et les fractions fines des sédiments prélevés dans la Chine du nord sont principalement des sols transportés de régions arides et semi-arides de Chine et Mongolie par les vents dominants.

Keywords Dust storms · Aeolian deposits · Loess · Silt · China

Mots clés Tempêtes de poussières · Dépôts éoliens · Loess · Taille de particule · Chine

Received: 9 October 2000 / Accepted: 4 September 2001

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DOI 10.1007/s10064-001-0145-y Bull Eng Geol Env (2002) 61:253–261

Introduction

In this study a dust storm is defined as having an instantaneous wind velocity of >17 m/s and a sky visibility of <500 m. Such storms are common phenomena which occur with great frequency and magnitude over the arid and semi-arid regions of the earth's land surface (Yaalon and Ganor 1973; Yaalon and Dan 1974; Goudie 1978). Desert dust is often transported over hundreds of kilometres and much of the finest material is carried over thousands of kilometres. It is estimated that wind-blown dust transported from deserts amounts to 5×10^8 t annually (Naruse et al. 1986). The dust originates; from the major deserts of the world; these arid and surrounding semi-arid lands covering 4.33×10^7 km^2 or 36% of the earth's land surface (Meigs 1953). The most severe dust storms which transport particles over thousands of kilometres begin in regions with extensive deserts, such as the Sahara and northern and western parts of China (Péwé 1981; Yang et al. 1981). Evidence from modern grain-size measurements and dust storm observations indicates that the dust has been transported mainly from the north and northwest arid and semi-arid areas of the Loess Plateau. The East Asian winter monsoon circulation is also an important agent for dust transport (An et al. 1990; Zhang et al. 1994, 1999). However, dust transportation, its composition and patterns are still not clear. The study reported here was undertaken to analyse the deposition characteristics of dust in modern times. In addition, the physical, chemical and mineralogical characteristics of the aerosols and airfall sediments collected in several places were studied in order to provide statistical information for further research.

During the period from March 1990 to May 1994 two deposition events occurred in eastern China, when mineral dust was recorded at Kashi, Taklimakan desert, Kunlun mountains, Donghuang, Lanzhou, Ningxia, Xi'an, Inner Mongolia and Beijing. The individual dates were 12 March 1990 and 5 May 1993. The low deposition mass (up to 0.10 g/m^2) meant that the dust in the atmosphere was sufficient to influence areas as far away as Japan and western America where some fallout events were also recorded. Both the dust storms considered in the study were strong, i.e. the instantaneous wind velocity was higher than 20 m/s and the sky visibility lower than 200 m.

The dust material was sampled in standard deposition buckets and air-dried. Grain-size analysis was carried out using the scanning electron microscope (SEM) and micrographs randomly taken from various parts of the SEM sample, a method described by Smart and Tovery (1981). All particles on a micrograph were measured (400–1,400 counts per sample) and percentages of grain size represented as total counts in each size class. The mineralogical composition of the material was analysed by X-ray diffractometry of both tube and sedimentation samples. The 200 mg samples were oven-dried at 110 °C and then heated at 950° C. The loss on ignition (LOI) was calculated from the difference in weight between 110 and 950° C. After fusing the samples with Na_2CO_3, the amounts of SiO_2 were determined gravimetrically. The amounts of Al_2O_3 and Fe_2O_3 were determined by the ferron method (Davenport 1949) and the CaO and MgO content by the atomic absorption method. After digesting the samples with HF-H_2SO_4, the amounts of MnO were also determined by the atomic absorption method. The TiO_2 and P_2O_5 were colorimetrically determined and the K_2O and Na_2O obtained by flame photometry (Inoue and Naruse 1987). To observe the optical characteristics of aerosol particles, a spectral actinometer from the USA was used, allowing the whole wave range of solar radiation intensity to be obtained. The instrument was located in the Yinchuan station of Ningxia. This paper presents the basic characteristics of the material transported over a long range and discusses critical climatological factors that influence the deposition of dust from north China.

Dust storm variations

Based on 1,100 records of dust storm events in China, the temporal and spatial distributions of dust storm events since historic times are discussed. These were recorded as dust rain or dust haze, which usually consisted of dust and yellow fine sand, sometimes mixed with rain in a mud. In general, the thickness of the fallen dust varied from a few millimetres to several centimetres.

The earliest dust event recorded is in 1,150 B.C. (Wang 1963) but the information over the last 1,000 years is much more abundant than that from the earlier centuries (An and Liu 1984). In this paper, 1,100 historical records of dust fall events from 300 to 2,000 years A.D. were studied (excluding local dust storms). Some meteorological information is presented in the discussion of the temporal and spatial distribution of dust, its climatic background and synoptic process as well as the origin of dust.

Spatial distribution

The locations in which dust falls were recorded in historic times are shown in Fig. 1. Their distribution covers an area from Xinjiang to the coast of East China Sea and from Inner Mongolia to south of the Chang Jiang River, occasionally reaching Fujian, Guangdong and Guangxi areas. The figure suggests that the main areas where dust falls occurred are very similar to the distribution of loess in China (An et al. 1990). Three characteristics are apparent: (1) most dust storms are at high latitude, thus involving much of China; (2) the weather conditions concentrated in several areas related to strong dust storms; and (3) the main dust storms occurred in or close to the larger deserts. The dust storms studied originated to the west of Kashi, Xinjiang, east of Yulin in the Shaanxi Province, north of Fuyun, northern Xinjiang, north of Hails, Inner Mongolia, south of Hotan, Xinjiang and in the area of Golmud, Qinhai and Wuqi, Shaanxi. The areas affected by dust

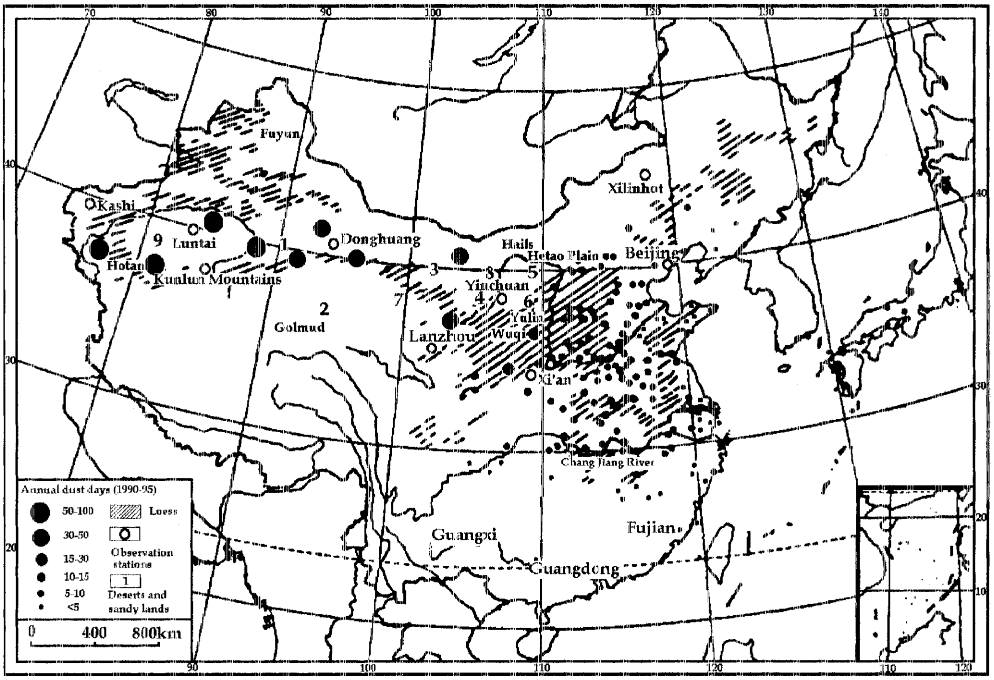

Fig. 1
Distribution, frequency and observation locations of dust and loess in China. *1* Kumtag desert; *2* deserts in Qaidam Basin; *3* Badain Juran sand desert; *4* Tengger sand desert; *5* Qubqi desert; *6* Mu Us sandy land; *7* Hexi Corridor; *8* Helan mountains; *9* Taklimakan desert

storms in China are geographically widespread and involve some 40,000 km^2. The main distribution direction is west to east, but detailed information suggests that the southern Xinjiang basin, Hexi Corridor and Helan Mountains are important regions for dust storms (Zhang 1984; Oyang 1991).

Strong dust storms (instantaneous velocity >20 m/s; sky visibility <200 m) occurred mainly in southern Xinjiang, between Donghuang and Lanzhou and in the Helan Mountain area, which distributed material in a northwesterly direction. From the historic record, over 85% of the dust storms occurred here or in northern Xingjiang and Hetao, Inner Mongolia.

As noted above, the dust storms mainly originated in or near the seven larger deserts (Fig. 1): the Taklimakan desert, the Kumtag desert, deserts in the Qaidam Basin, the Badain Juran desert, the Tengger desert, the Qubqi desert and the areas surrounding the Mu Us sandy desert (Feng et al. 2000). In the Taklimakan area, dust storms occur on some 30 to 39 days each year, compared with 15 to 18 days annually in the Qaidam areas, 13 to 34 in the Badain Juran desert areas, 14 in the areas around the Mu Us sandy desert and 37 to 58 in the area of Qubqi.

Temporal distribution

A study was also made of the years in which dust falls were recorded (Fig. 2; Zhang 1980), including the number of years in different decades and variations in the frequency of dust storms each year. From the historical records it would appear that there were frequent occurrences of dust falls between 1060 and 1090, 1160 and 1270, 1470 and 1560, 1610 and 1700, 1820 and 1890, and 1997 and 2000, with only rare occurrences noted in the other periods referred to in Fig. 2. The result of simulation of the frequency variations in Fig. 2 shows that the frequency variations better coincide with polynomial regression and the entire regression coefficient including linear, logarithmic, polynomial and exponential regression is over 0.4 (Table 1). Based on the 1,100 dust storms considered, it would appear that the frequency of dust storms has increased with time (Fig. 2), possibly associated with the increase in the regional population. Particularly in the last 200 years, the frequency of dust storms has increased rapidly compared with past centuries and during the same period there has been a population explosion in northern China (Xia and Yang 1996). The frequency of these aeolian events may indicate that the environment has deteriorated seriously in recent times, leading to further land desertification.

Although dust storms occur in different months of the year, they are most common during the early summer. Based on the 1,100 dust storms studied, it appears that “dust rain” events are concentrated in March to May and are particularly common in April when some 26% of the annual total is recorded. In the Taklimakan area, most of the dust storms occurred between April and May, with a few being reported in June and between October and January. In southern Taklimakan, dust storms were recorded for some 3 to 6 days per month between April and June. In Lanzhou and Xi’an, the historical records indicate that the phenomena occur mainly between March and May. In Ningxia, 60% of the occurrences annually are in April, 13.6% in March and 26.0% in May, with very few (0.4%) being reported at other times of the year. In northwest China, the main period of dust storms is between April and May, the earliest being recorded on 6 March and the latest on 12 July.

In addition to these seasonal characteristics, diurnal variations can also be recognised. In northern Shaanxi, 19% of the dust storms occurred in the morning compared

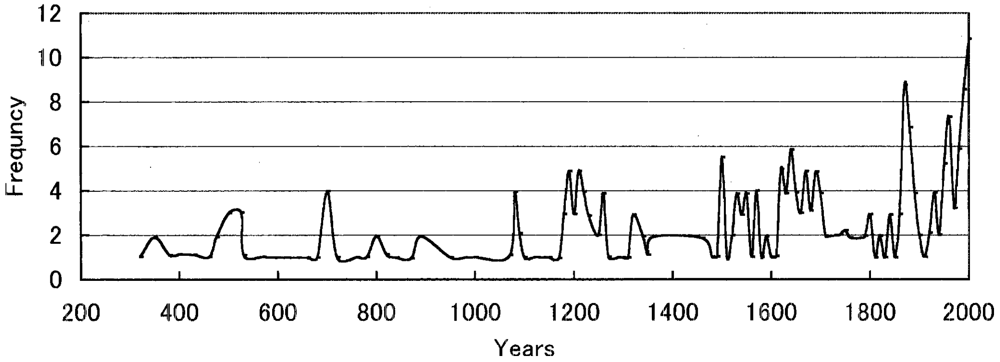

Fig. 2.
Variations in dust fall frequencies in northern China from 300 to 2,000 years A. D.

Table 1.
Some regression functions and relationship indices of frequency variations for dust falls between 300 and 2,000 years A.D.

Kinds	Regression functions	Indices
Linear regression	$Y=0.0018x+0.1174$	$R^2=0.2046$
Logarithmic regression	$Y=1.6681\text{Ln}(x)-9.327$	$R^2=0.1611$
Polynomial regression	$Y=2E\text{-}06x^2-0.0031x+2.5751$	$R^2=0.2531$
Exponential regression	$Y=0.8323e^{0.0007x}$	$R^2=0.2275$

with 63% in the afternoon and 18% at night; similar patterns have been recorded in other areas. The longest dust storm was in the Hexi Corridor and lasted for 15 h, although the average maximum length is 8 h. The spatial and temporal distribution of these events suggests that they are associated with regional climatic factors, such as temperature, aridity, etc.

Dust storms and temperature

In order to investigate the relationship between dust storm events and temperature/aridity, a study was made of the variation in temperature in north China over the last 500 years (Zhang 1980). A comparison between the mean temperature index and the frequency of dust storms shows a significant inverse correlation (Fig. 3) with a correlation coefficient of –0.59 ($P<0.001$).

The deviation of winter temperatures between the warm and cold periods is about 0.5 °C for the past 500 years in north China (Zhang 1989). The mean frequency of cold periods is 3.7 years per decade and 2.1 years per decade for warm periods. Notable cold periods were recorded between 1621 and 1700 and between 1811 and 1900, with warm periods being recorded between 1511 and 1620 and between 1720 and 1780. As can be seen from Figs. 2 and 3, most of the dust storm events in north China occurred during cold periods. Although Zhu (1973) proved that some dust storm events occurred between 690 and 710 – a warm period for China – most of the dust falls were concentrated in periods of low temperature.

A comparison of the frequency of dust storm events with the humidity in China (35–40°N) for the last 2,000 years (Zhen 1973) shows that most of the high-frequency dust storms correspond with dry spells. This is consistent with Liu's explanation that loess deposits behave as silt under dry climatic conditions (Liu 1964, 1982). It is of interest to note that the years when dust storms were prominent were often those in which El Niño occurred – for example: (1) a dust storm on 9 September 1952 may be linked with the El Niño event that occurred between August 1951 and April 1952; (2) the dust storm event on 22 April 1977 followed the El Niño of June 1976 to March 1977; (3) there was a dust storm event on 28 April 1983 and an El Niño event from September 1982 to September 1983; and (4) the dust

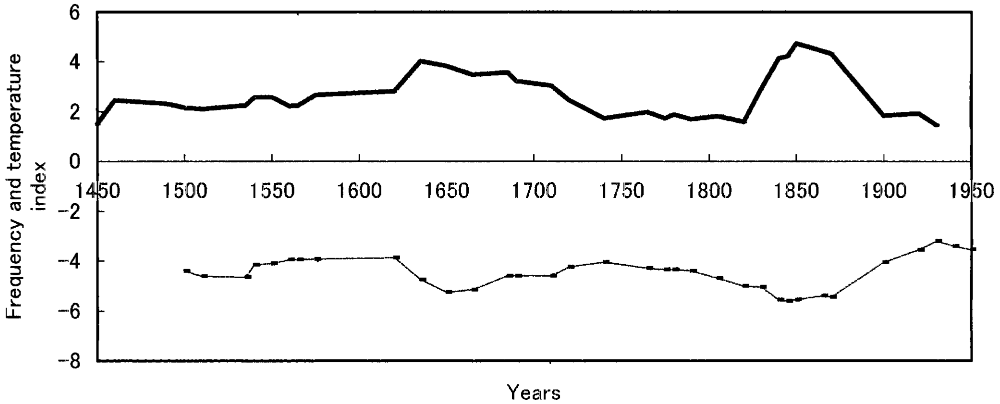

Fig. 3.
Relationship between frequency of dust falls (*solid line*) and temperature (*dotted line*) in Beijing over the last 500 years

storm on 5 May 1993 during the El Niño event of April to December of 1993.

Physical characteristics of dust falls

Based on the relationship between the particle size of airborne dust and vertical distribution, the particle size of tropospheric dust at an attitude of 6 to 10 km ranged from 1 to 100 μm and was characterised by a predominance of airborne particles with a diameter of 1 to 50 μm (Table 2). On the other hand, the stratospheric aerosol particles with a diameter of <1 μm were dominant at an altitude of >10 km. Consequently, it was considered that the clayey to silt fractions of the dust sediments accumulated in China are mainly associated with aerosols that have moved in the troposphere. The dust sediments also contained varying amounts of sand fraction (14 to 65%). The dust samples from Kashi and Lanzhou in particular had a wide range of particle sizes (Table 2). Most of the coarser fraction in these dust sediments is associated with soil materials blown by the wind from adjacent environments. Table 2 shows that the particle size of the main dust sediments ranges from 5 to 63 μm. The sample from the Taklimakan area was poorly sorted with a median particle size (Mds) of 2 to 200 μm, while the samples from the eastern areas were moderately well sorted with an Mds of 0.2 to 100 μm (Zhu and Cheng 1994). The sample from Xi'an was obtained near the loess plateau and had an Mds of between 0.2 and 80 μm, somewhat smaller than the samples of loess from the plateau with an Mds ranging from 3 to 16 μm (Table 2).

The grain size of the aerosol particles collected from a 325 m tower in Beijing was generally less than 0.4 μm, but during periods of dust storms the dominant grain size was between 0.6 and 1 μm (Qian et al. 1995) while the Mds of the well-sorted aerosol material collected on the flat roof of the building (about 10 m high) was 3.9 μm (Table 2). Pye (1987) notes that the further the distance from the source, the smaller the value of the Mds of the soils and aerosols. The results of the study are in agreement with other work on the relationships between the diameter of aerosol particles and the transport distance from their source (Middleton et al. 1986; Prospero et al. 1987). However, the particle size distribution (Mds) and soil texture of the air fall material may be influenced by the longitude, latitude and altitude of the sampling site and probably the season and meteorological conditions in China, as discussed below.

Chemical characteristics of dust

Table 3 presents the chemical components of the dust falls studied. As can be seen in the table, the material is characterised by a predominance of SiO_2 and Al_2O_3. The SiO_2/Al_2O_3 molar ratios of the dust and loess were 5.17 to 8.43 and 6.3 to 9.3 respectively (Table 3). The amount of K_2O in the dust was low (0.57 to 2.07%), being very similar to that of the loess (1.43 to 3.09%). As seen from Table 3, the K_2O/SiO_2 molar (0.009 to 0.0368) was also very close to that of the loess and aeolian soils of China (0.013 to 0.04). These results suggest that the aerosols and dust collected in China are predominantly composed of fine soil particles transported from the loess plateau, the Gobi desert and their surrounds.

Based on the characteristics of eight chemical components of dust in China, two types can be identified. The Xi'an dust was characterised by a high level of loss on ignition and CaO, smaller proportions of K_2O and greater amounts of Na_2O compared with the Beijing type which has lower levels of loss on ignition and CaO (Table 3).

The suspended matter in the air is composed of two parts: natural material including volcanic particles, salt from the sea and aeolian particles; and material originating from industry. The value of the relative concentration of a certain element X to ferrum metal (EF_x) is a useful index for an analysis of the sources of suspended matter:

$$EF_x=[(X/Fe)air]/[(X/Fe)crust] \tag{1}$$

where Fe is the ferrum metal; $[(X/Fe)\ air]$ represents the relative concentration of certain elements (X) to Fe in the air; and $[(X/Fe)\ crust]$ represents the relative concentration of certain elements (X) to Fe in the crust. The critical concentration of certain elements (X) to Fe in the crust has been taken from Liu (1985).

The values of EF_x for some areas of China are given in Table 4. This shows that the variations in the EF_x of most

Table 2

Particle size distributions for dust falls in China in 1994. *Mds* Median particle diameters; S_o sorting coefficient of sample; S_k standard deviation; *Kur* kurtosis

Location	Variations in Mds (μm)	Mean Mds (μm)	S_o	S_k	Kur
Kashi	0.2–200	23.21	1.27	0.756	3.802
Kunlun mountains	1–80	23.13	1.17	1.319	5.557
Taklimakan desert (Luntai)	2–200	93.54	1.43	0.117	2.316
Donghuang	2–50	17.49	0.52	2.398	7.963
Lanzhou	0.3–100	17.12	1.55	0.397	3.960
Xi'an	0.2–80	20.00	0.85	0.966	4.480
Ningxia (Yinchuan)	0.4–80	20.73	1.81	0.291	1.898
Inner Mongolia (Xilin Hot)	0.3–80	10.15	1.08	1.031	2.878
Beijing	0.2–50	3.97	0.34	1.176	8.693

Table 3
Chemical composition and physical properties of dust falls in China in 1994. *LOI* Loss on ignition

Locations	LOI (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	TiO_2 (%)	MnO (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)	SiO_2/Al_2O_3	K_2O/SiO_2
Kashi	–	56.2	8.27	3.64	0.53	0.07	10.46	2.88	2.76	2.07	0.17	6.79	0.0368
Kunlun mountains	–	61.3	8.18	4.90	0.47	0.07	9.8	2.78	2.75	1.34	0.20	7.49	0.0219
Taklimakan desert (Luntai)	–	77.21	10.17	2.20	0.38	0.05	2.65	2.87	12.52	1.73	0.22	7.59	0.0367
Donghuang	3.77	75.77	9.21	2.60	0.12	0.04	2.56	1.17	2.07	1.55	0.07	8.22	0.0205
Lanzhou	–	59.3	11.47	4.04	0.60	–	5.96	1.32	2.17	1.20	0.20	5.17	0.0203
Xi'an	13.7	62.51	6.41	4.9	0.7	0.08	6.27	2.25	1.70	1.17	0.20	8.43	0.0187
Ningxia (Yinchuan)	4.91	66.79	9.07	5.48	0.46	0.09	1.64	1.62	2.26	1.21	0.11	7.36	0.0153
Inner Mongolia (Xilin Hot)	–	71.23	11.15	4.83	0.70	–	5.36	1.14	2.1	0.77	0.10	6.39	0.0109
Beijing	2.68	63.5	10.41	5.63	0.58	0.15	0.73	1.54	2.53	0.57	0.07	6.10	0.009

Table 4
Elements of dust falls (mg/kg) in north China in 1994

Location	Cu	Zn	Pb	Ni	Co	Cr	Mn	Fe	Ti	Ca	Mg	K	Na
Kashi	0.80	1.77	2.68	0.60	0.59	0.43	1.12	1.00	1.33	4.95	1.54	1.25	1.12
Kunlun mountains	1.23	1.87	2.98	0.32	0.43	0.53	1.25	1.54	1.65	5.89	1.32	1.05	1.02
Taklimakan desert (Luntai)	0.56	1.89	3.67	0.56	0.78	0.33	1.12	12.00	1.78	5.65	1.65	1.25	1.74
Donghuang	0.73	1.93	17.00	0.67	0.6	0.70	1.10	11.00	1.36	4.89	1.91	1.21	0.87
Lanzhou	23.76	54.38	42.13	0.79	0.75	1.10	0.84	1.00	0.77	2.19	0.71	0.59	0.37
Xi'an	18.45	2.21	13.74	0.48	0.80	1.70	1.02	1.00	1.52	3.03	1.10	1.25	0.94
Ningxia (Yinchuan)	8.77	24.12	9.00	0.76	0.78	0.87	0.94	1.00	1.23	3.58	1.59	0.93	1.19
Inner Mongolia (Xilin Hot)	24.00	63.42	35.11	1.00	0.80	0.80	1.00	1.00	1.39	2.32	1.00	1.23	0.90
Beijing	25.13	79.34	78.12	2.13	0.78	0.89	1.10	1.20	1.45	2.45	1.00	1.42	0.78

elements in Kashi, the Kunlun mountains, Tarim basin and Donghuang are the same while the concentration of most of the elements in the air is similar to their concentration in the crust and generally close to 1. The high EF_x value of Ca is the result of a locally high proportion of Ca in the topsoil, while the elevated EF_x value for Pb in Donghuang is probably associated with the air pollution in an area where tourism results in a greater population density. Generally, the factor of EF_x in the dust sediments of most of the desert areas was lower than 10 compared with 1 in the other regions. The results show that the main elements suspended in the air are fine sands and clays with a similar distribution to that of the soils found in the desert areas (Table 4); e.g. a Cu of 23.76 in Lanzhou, 18.45 in Xi'an, 24.00 in Inner Mongolia and 25.13 in Beijing; a Zn of 54.38 in Lanzhou, 24.12 in Ningxia, 63.42 in Inner Mongolia and 79.34 in Beijing; and a Pb of 42.13 in Lanzhou, 13.74 in Xi'an, 35.11 in Inner Mongolia and 78.12 in Beijing. The above high values of EF_x in suspension may be the result of an increased proportion of clay matter, possibly associated with increased transportation distances and/or regional pollution (industrial particles) which could account for the high EF_x value of Cu, Zn and Pb.

Mineralogical characteristics of dust

The mineralogical content of the dust can represent the surrounding source environment or the aeolian conditions. In the desert region, the X-ray diffractograms indicated a predominance of quartz, feldspar, chlorite, illite, calcite, dolomite, gypsum and zeolite, with some 15 to 30% organic (spore and pollen) and non-organic matter (Table 5). The mineral content of the dust was similar; the coarse dust consisting of quartz, feldspar and carbonic carbonate while the fine dust was characterised by mica and clay minerals (Table 5). The light minerals content of the fall material was high, accounting for 90% of the total compared with a heavy mineral content of only 5% in the fluvial and aeolian sediments.

In western China (in the Tarim basin, for example), the unstable mineral content of the dust reached 45% and was characterised by hornblende, black mica and augite, while the more stable 55% was dominantly epidote, zoisite, muscovite and garnet with trace minerals including tremolite and actinolite. The light minerals were generally

Table 5.
X-ray diffractograms of dust falls in China in 1994 (%)

Locations	Quartz	Feldspar	Chlorite	Illite	Calcite	Dolomite	Diorite	Gypsum	Zeolite
Kashi	39	11	8	13	13	10	5	-	3
Kunlun mountains	34	12	8	9	11	9	6	2	3
Taklimakan desert (Luntai)	45	16	10	8	15	7	6	3	5
Donghuang	32	9	8	14	9	12	6	-	3
Lanzhou	27	7	7	9	7	4	-	6	-
Xi'an	38	9	8	10	10	4	-	6	3
Ningxia (Yinchuan)	43	13	7	12	7	4	5	6	3
Inner Mongolia (Xilin Hot)	40	17	5	8	6	6	5	-	5
Beijing	35	8	15	21	8	5	-	-	3

quartz, feldspar and calcite while the carbonic carbonate content in the falls sediment may reach 5 to 15%.

In eastern China, the unstable mineral content of the dust and surface sand is only 30% – lower than in western China – while the opaque metal mineral content in the eastern areas is some 1 to 2 times that in the western areas. The muscovite and hornblende contents in the fall sediments are lower than in western China, but the epidote content is higher.

A semi-quantitative estimate of the relative amount of the dominant clay minerals based on the intensity of their characteristic reflections is shown in Table 5. The major clay minerals of the dust sediments consisted of quartz, feldspar, chlorite, illite, calcite, dolomite, diorite and zeolite. However, there were differences in their clay mineral composition. In addition to the quartz content, the Kashi, Donghuang, Ningxia and Beijing dust contained large amounts of illite while notable amounts of calcite were found in the Kashi and Xi'an dust. Large amounts of dolomite were found in the Kashi, Donghuang and Kunlun mountains and the feldspar content was high for the Inner Mongolia and Tarim dust.

As the dust samples were only collected every 1 to 4 weeks, it is difficult to analyse the relationships between the clay mineralogy of dust and the dominant clay minerals in northern China. However, there were similarities between the mineralogical characteristics of the dust and the mineral composition of soils in north China, where dust storms frequently occurred under low atmospheric pressure during the study period. The major clay minerals of the soils in these areas consist of quartz, feldspar, chlorite, illite, calcite, dolomite and diorite.

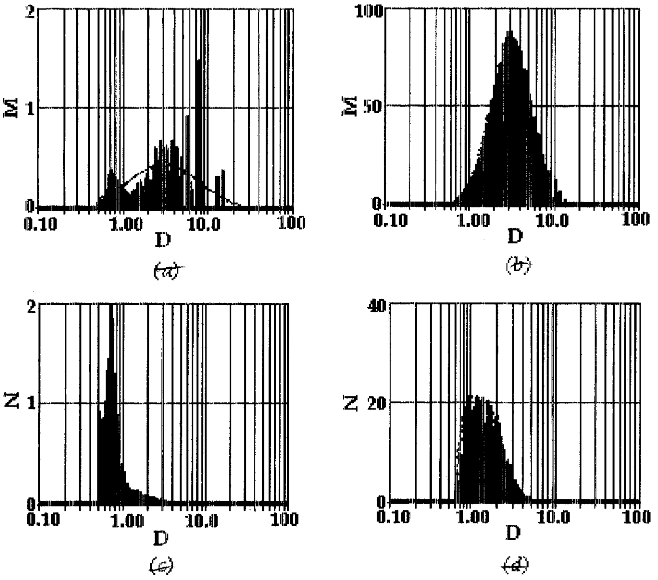

Fig. 4a–d
Number concentration spectrum and mass concentration spectrum of aerosol at Yinchuan: diameter of peak value (*D*), number concentration of aerosol (*N*) and total mass concentration (*M*) are in μm, *n*/cm^3 and μg/m^3 respectively. Particle concentration is assumed as 1 g/m^3; to convert into actual mass of sand dust, multiply by 2.7. **a** Mass concentration spectrum for background (clear sky) weather; **b** mass concentration spectrum in a dust storm; **c** number concentration spectrum for background (clear sky) weather; **d** number concentration spectrum for dust storm weather

Spectrum distribution characteristics

The aerosol spectrum of number concentration and mass concentration were observed in Ningxia (Yingchuan station); see Fig. 4. In this figure, parts a and c represent the background condition considered as clear sky while parts b and d represent dust storm weather; the mass concentration spectrum in parts a and b corresponding to the number concentration spectrum in parts c and d. The spectrum of background mass concentration showed as a triple peak type (Fig. 4a) with diameters of 0.67, 3.0 and 7.7 μm respectively. The whole spectrum coincided with the log-normal distribution through three corresponding peak value diameters. The mass concentration spectrum in dust storm weather shows a single peak type with a geometric mean diameter of 3.09 μm. Again the spectrum coincided with the log-normal distribution (Fig. 4b). In clear skies, the number concentration of the aerosol is very low, only 12.6/cm^3 (Fig. 4c). The diameter of the peak value is 0.67 μm and its distribution type typically appears as the T-distribution. The proportion of sand dust particles <1 μm is 85% and the total mass concentration is 38.3 μg/m^3. In dust storm weather, the number concentration of the aerosol increases to $345/\mathrm{cm}^3$, the peak value of the aerosol diameter is 1.1 μm, and its distribution can be fitted with the log-normal distribution, with a geometric average diameter of 1.56 μm (Fig. 4d).

As can be seen from Fig. 4, the number concentration spectrum of aerosol in clear skies has a typical single peak and can be fitted by T-distribution. In these conditions, the peak value is comparatively stable, ranging from 0.64 to 0.84 μm with variations in the topography and geographical location (You et al. 1991). In contrast, the peak value of the number concentration spectrum increases with the intensity of the dust storm and has a log-normal distribution. While the triple peak spectrum is the main form of the mass concentration spectrum in clear skies, it shows as a single peak in dust storm weather (You et al. 1991).

Conclusions

The paper gives information on the loess deposits in China and particle size and chemical analyses of particles obtained from dust storms between 1990 and 1994. It is concluded that:

1. The main sources of the airborne dust studied are the north-western deserts and areas of Inner Mongolia.
2. The dust storms are capable of transporting particles over vast distances. From the physical and chemical analyses undertaken, it is considered that such dust materials eventually form the loess and similar deposits found in China. This is probably an important contributor to soil formation, slope wash and stream sediments in eastern China and in the adjacent seas.
3. The dust storms usually occur during cold periods, particularly between March and April. Correlation between the main dust storms and reported El Niño occurrences suggest there may be a relationship between these phenomena.
4. The occurrence of dust storms has significant environmental and health implications. Man's continual encroachment into the areas around the deserts/semi-deserts is likely to exacerbate the potential for erosion. This, together with the possible changes in global climate, could pose significant problems, not only in China, but over much of the surrounding area.

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