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Grain-size Characteristics of Sediment in Daniugou Peatland in Changbai Mountains, Northeast China: Implications for Atmospheric Dust Deposition

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Abstract: The grain-size distribution characteristics and grain-size parameters of sediment in two vertical sections of Daniugou peatland in the Changbai Mountains were systematically investigated. A comparative analysis of the sediment granularity using a discriminative function with Hongyuan peat, red clay, loess-paleosol, fluvial deposit as well as lacustrine deposit was also conducted. It turns out that the vertical section of Daniugou peat ash is primarily constituted by clay and silt particles, and the content of sand is relatively small. Grain-size frequency curves generally show a single-peak modality while a bimodal pattern is detected in the upper layer. The grain-size component and peak pattern of grain-size frequency curves also illustrate that peat ash materials were transported to the peatland by long-range aeolian dust during the deposition process, while there existed short-distance dust influence in peat deposition of the upper layer. Comparisons of grain-size parameters and the discriminative Y-value of Daniugou peat ash with those of typical aeolian sediments show close similarities, suggesting the possibility that atmospheric dust transport processes were involved in the accumulation of peat again. Moreover, the variations of grain-size distribution suggest the local environmental deterioration which is just the driving force of local dust elevation. Grain-size analysis of peatland sediment is demonstrated to be one effective method to extract information about regional and global environmental evolution, and more attention should be paid to current local ecological environment and to seeking a balance between economic development and environmental protection in Northeast China.

Keywords: grain-size; peatland; aeolian sediment; atmospheric dust deposition; Changbai Mountains

1 Introduction

Peatlands are the most important wetland ecosystems that are characterised by the accumulation of organic matter, which is produced and deposited at a greater rate than it is decomposed, leading to the formation of peat (Huang, 1988; Liu *et al.*, 2006). During peat deposition process, abundant information about environmental changes, whether natural or human induced, are stored in this special natural complex (Yu *et al.*, 2006a; Yu *et al.*, 2010). Those characteristics are the basis upon which to understand the sedimentological character of peatland for further studies, such as chemical analysis and source tracing.

Grain-size analysis, as an effective means, is commonly used in the discrimination of sedimentary facies and investigation of regional environmental changes (Shaanbei Team of Chengdu Institute of Geology, 1978; Sun *et al.*, 2006; Cao *et al.*, 2008). It has the advantages of simple and time-saving measurement procedures and provides considerable definitive physical understanding relative to other geochemical proxies (e.g. element content and isotope ratio).

Peat grain-size analysis is based on the granularity measurement of peat ash, which represents the inorganic mineral component of peat sediment and is composed of

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the original ash and subsequent one (Yu *et al.*, 2006b). The original ash mainly contains plant ash and is considered constant, while the subsequent ash is replenished mainly from aerosol and volcanic ash, besides the invariable replenishment of groundwater. Taking into account the low content of the original ash, from 9% to 12% (Dai and Ma, 1989), it is possible to use the total peat ash to determine the grain-size characteristics and parameters, and then to deduce the sedimentological character of the peat.

The Changbai Mountains region in Northeast China is a key place for assessing the vulnerability of ecosystems as this region is highly sensitive to anticipated warming and environmental changes (Bűchler *et al.*, 2004; IPCC, 2007). Peatland is an important ecosystem of the Changbai Mountains, and many studies have been conducted on the assessment of the vulnerability of this ecosystem and environmental changes (Jiang *et al.*, 2008; Hong *et al.*, 2009; Bao *et al.*, 2010). However, the studies related to atmospheric dust are still insufficient due to the poor understanding of the sedimentological character of the peat sequence.

In this paper, we report the new results of grain size analysis of peat ash from the Daniugou peatland in the Changbai Mountains in order to reveal the characteristics of the sedimentary facies and provide evidences for the aeolian-origin of peat ash in the study site, which may be valuable for the study of atmospheric dust tracing and regional environmental changes.

2 Materials and Methods

2.1 Sampling site

Daniugou peatland is located in the southeast of Jilin Province and the northwest of the Changbai Mountains, Northeast China (Fig. 1). The elevation is about 850 m above sea level. It is a forested peatland with peat growing under sedge-shrub, and the predominant arbor is larch forest (Zhang and Niu, 1993). This area is characterized by four discernible seasons with a long winter and short summer. Cold air activity is frequent and the climate changes very much in spring and autumn. The mean annual temperature ranges from 2℃ to 5℃. The prevailing wind in Changbai Mountains area is mainly from the southwest, but from the northwest in December.

2.2 Sampling method

Two repeated peat cores were randomly collected in September 2005 with a titanium (Ti) Wardenaar peat profile sampler (Eijkelkamp, Netherland) (Wardennar, 1987) in Daniugou peatland in the Changbai Mountains (the latitude, longitude and altitude at sampling sites were determined with a portable global positioning system). The two sampling sites were named Daniugou-1 (Dg-1: 42°11′51″N, 127°41′30″E; 859 m a. s. l.) and Daniugou-2 (Dg-2: 42°11′53″N, 127°41′31″E; 856 m a. s. l.). The depth of Dg-1 and Dg-2 was 48 cm and 50 cm, espectively. The peat cores were sectioned on-site at 2-cm interval with a stainless steel band saw and then

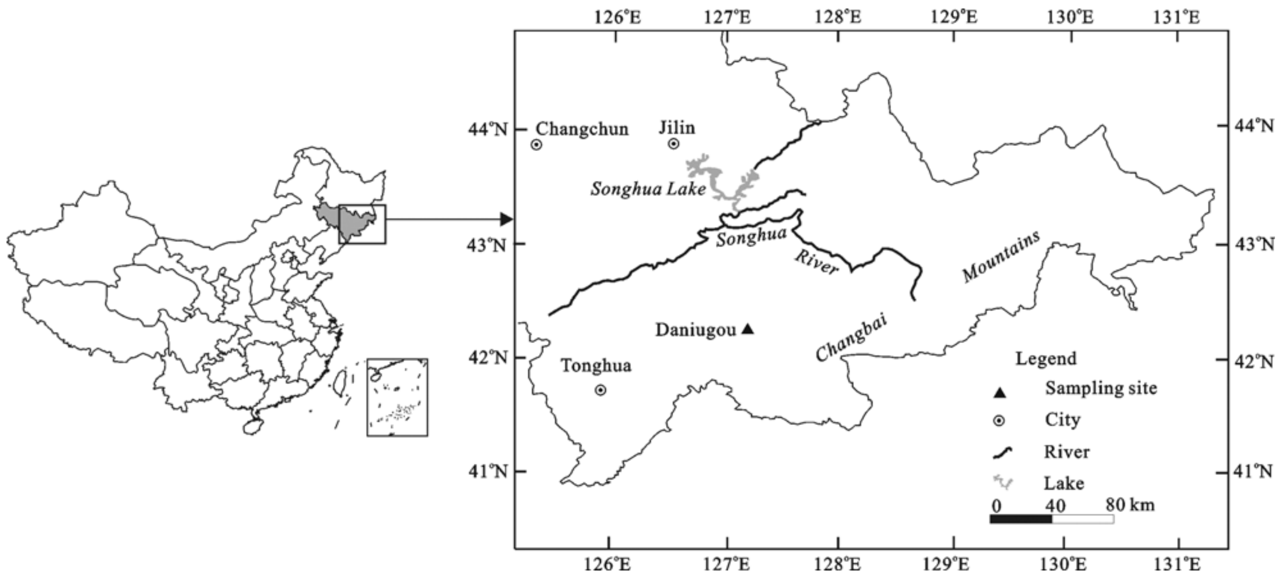


Fig. 1 Location of sampling site of Daniugou peatland in Changbai Mountains, Northeast China

stored in polyethylene plastic bags until laboratory analysis was conducted.

2.3 Analysis method

Granularity of the samples was determined through the measurement of the grain size of peat ash prepared by ignition of dry samples in a muffle furnace at 550℃ overnight (Beaudoin, 2003; Yu *et al.*, 2006b). An appropriate amount of ash was dissolved in 10 mL hydrochloric acid (HCl, 10%) to remove carbonate. Five to six hours later, 10 mL sodium hexametaphosphate [$(NaPO_3)_6$] as a dispersant was added, which was made by adding of 36 mL $(NaPO_3)_6$ into 1 000 mL distilled water. And then the sample solutions with a concentration of 10%–20% were ultrasonicated for 10 min prior to analysis by Mastersizer 2000 Laser Particle Size Analyser (Malvern Ltd., UK) in the State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences (Lu *et al.*, 2002). The analysis of the samples after ultrasonication should be finished in one hour, and the repeated measurement error is generally less than 3%.

2.4 Calculation method

Grain-size parameters, including mean diameter (Mean), mean square deviation (MSD), skewness (SK), kurtosis (KU) and silt and clay ratio (Kd) are calculated by using some equations (Folk and Ward, 1957; Lu *et al.*, 2001).

Based on these grain-size parameters of numerous modern aeolian and other samples with known depositional environments, an empirical function has been put forward as Equation (1) and used to discriminate between sediment populations through comparison of the discriminant value (Y) (Shaanbei Team of Chengdu Institute of Geology, 1978; Lu *et al.*, 2001).

$$Y = -3.5688Mean + 3.0716MSD^2 - 2.0766SK + 3.1135KU \quad (1)$$

3 Results

3.1 Grain-size fraction profile

Profiles of grain-size variation with depth in Dg-1 and Dg-2 cores are shown in Fig. 2. The grains of peat ash were divided into the following groups by grain-size distribution: sand (> 64 μm), silt (4–64 μm) and clay (< 4 μm). The clay fraction ranges from 0 to 27.29% (with a mean of 14.51%) for Dg-1 and from 8.04% to 44.46% (with a mean of 24.63%) for Dg-2, and it increases with depth. Silt content ranges from 57.52% to 79.14% (with a mean of 70.69%) for Dg-1 and from 54.75% to 68.81% (with a mean of 60.48%) for Dg-2, and it fluctuates in a certain range in the two cores. Sand content ranges from 3.24% to 31.54% (with a mean of 14.80%) for Dg-1 and from 0.59% to 37.10% (with a mean of 14.89%) for Dg-2, and the sand particles are signific-

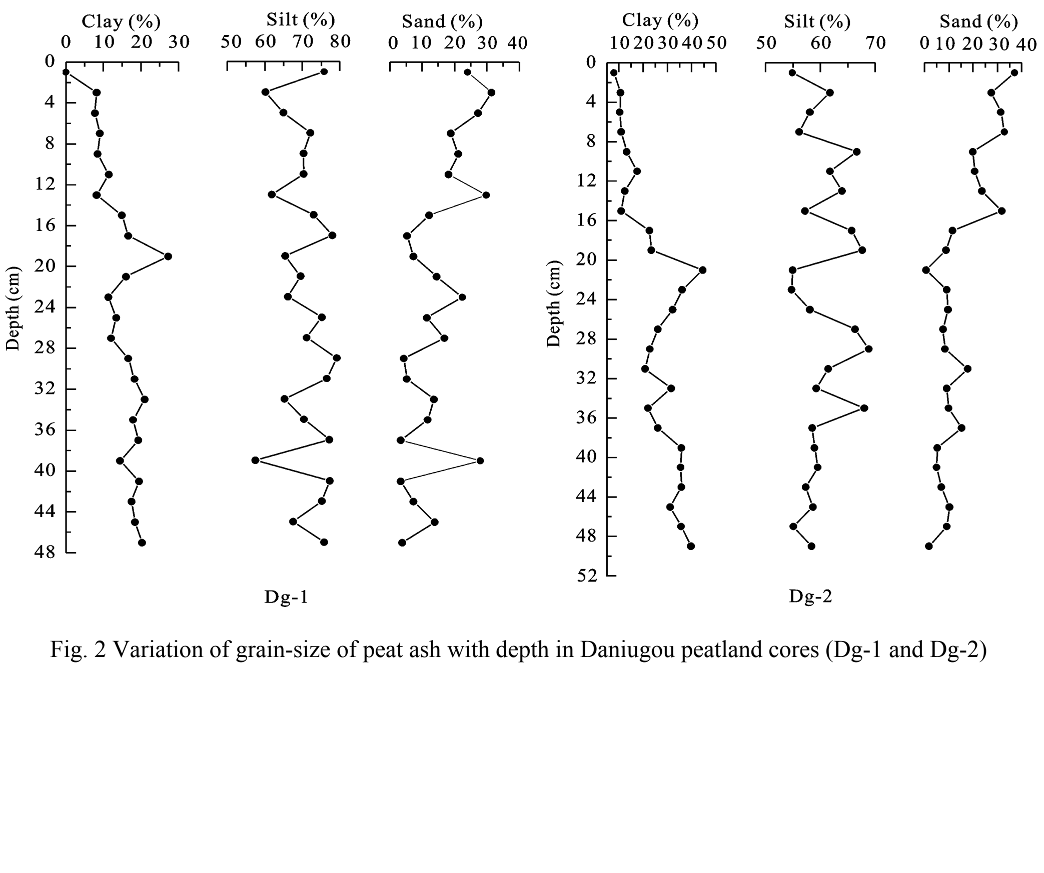


Fig. 2 Variation of grain-size of peat ash with depth in Daniugou peatland cores (Dg-1 and Dg-2)

antly enriched in the surface layer, and decreases with depth. There is an obvious trend of the grain-size distribution from coarse particle to fine one with depth downwards, and it is indicated that the dominant components of the peat ash are clay and silt rather than sand.

3.2 Grain-size frequency curves

Curves of gain-size frequency distribution and cumulative frequency in Dg-1 and Dg-2 profiles are plotted based on average grain-size content in each 20-cm interval of each profile (Fig. 3). The overall performance of frequency distribution curves is single kurtosis, while the bimodal characteristic in the upper layer (0–20 cm) is more obvious than in the other layers. The cumulative frequency curves of both profiles are reasonably similar, and there is a decreasing trend in the mean grain-size with depth: 0–20 cm > 20–40 cm > below 40 cm.

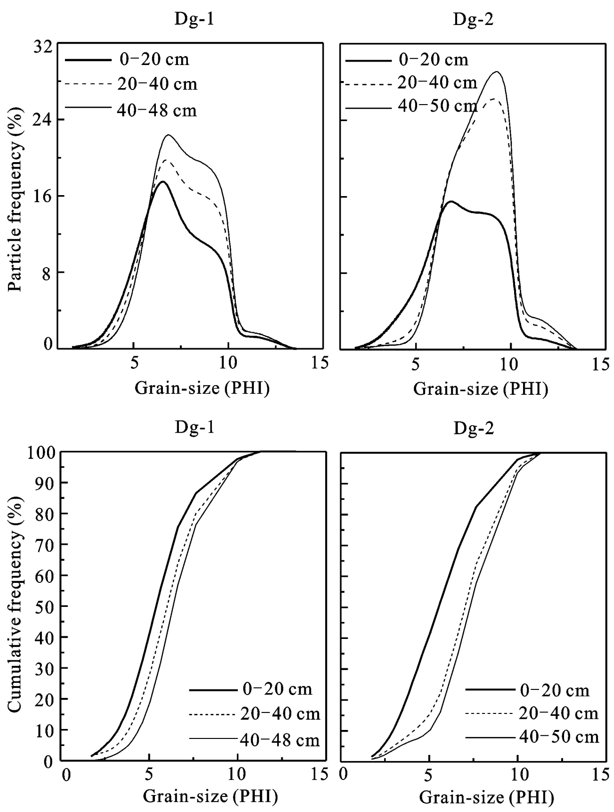


Fig. 3 Variation of grain-size frequency (%) with depth in Daniugou peatland cores (Dg-1 and Dg-2)

3.3 Grain-size parameters

Four grain-size parameters (Mean, MSD, SK and KU) are calculated, and partial calculated results of the Daniugou peatland samples were randomly selected and presented in Table 1. And some randomly selected data from other areas were also listed in Table 1 for the latter discriminated analysis. Both profiles have a similar and relative small MSD (1.23–2.21), indicating that the peat sediments are well sorted.

In addition, silt and clay ratio (Kd) of Dg-1 core ranges from 2.39 to 8.43 with an average of 5.29, and that of Dg-2 core ranges from 1.24 to 6.82 with an average of 3.12. From Fig. 4, it can be seen that it is the highest in the topmost section, and obviously decreases with depth for these two cores.

4 Discussion

4.1 Comparison of grain-size distribution of different deposits

A great deal of attention has been paid to the grain-size characteristics of wind transported sediments as well as lacustrine and fluvial sediments (Nickling, 1983; Lu *et al.*, 2001; Yu *et al.*, 2006b), so relevant studies on grain-size distribution are available to ensure the comparison of Daniugou peat with Hongyuan peat, red clay, loess, paleosol, lacustrine sediment and fluvial sediment (Table 1).

The grain-size parameters (Mean, MSD, SK and KU) of Daniugou peat deposits are quite similar to the corresponding values of Hongyuan peat, red clay, loess and paleosol, while different from those of lacustrine and fluvial sediment. Most sediments listed in Table 1 have relative small MSD, indicating that they are quite well sorted, however, the lacustrine sediment has a quite high MSD, indicating that it is very poorly sorted. Therefore, the comparison demonstrates that the material source of Daniugou peat ash resembles that of Hongyuan peat ash, red clay, loess and paleosol, but differes from lacustrine and fluvial sediment. The Hongyuan peat ash, red clay, loess and paleosol have been demonstrated to be aeolian sediments (Liu, 1985; Lu *et al.*, 2001; Yu *et al.*, 2006b), so the origin of Daniugou peat ash is considered to be aeolian.

4.2 Atmospheric dust deposition

From Equation (1), it is calculated that the discriminant values (Y values) in Daniugou peatland range between 0 and –10.08, those of the typical aeolian sediment (Hongyuan peat ash, red clay, loess and paleosol) from –1.86 to –14.57, those of the fluvial sediment from

Table 1 Statistical parameters of grain-size distribution of Daniugou peatland and other areas

Sample	Mean	MSD	SK	KU	Sample	Mean	MSD	SK	KU
Dg-1 peat	4.87	1.23	0.09	0.91	Loess**	5.76	1.74	1.06	3.69
	4.90	1.85	–0.19	1.10		5.75	1.75	1.05	3.69
	5.08	1.81	–0.10	1.06		5.81	1.74	1.03	3.61
	5.45	1.76	–0.07	1.12		5.92	1.78	0.95	3.38
	5.31	1.81	–0.05	1.16		5.92	1.74	1.00	3.52
	5.53	1.86	–0.17	1.15		5.94	1.76	0.94	3.40
Dg-2 peat	4.77	2.03	–0.18	1.06	Paleosol**	6.72	1.75	0.62	2.71
	5.24	2.03	–0.15	0.99		6.71	1.76	0.61	2.70
	5.26	2.21	–0.07	1.02		6.70	1.76	0.62	2.70
	5.10	2.15	–0.15	0.94		6.68	1.77	0.61	2.70
	5.67	1.93	–0.10	0.92		6.64	1.79	0.62	2.69
	5.85	2.19	0.04	0.93		6.58	1.83	0.59	2.66
Hongyuan peat*	6.66	1.76	0.02	0.02	Fluvial sediment**	5.35	1.81	1.32	4.14
	6.51	1.86	0.00	0.00		5.34	1.82	1.27	4.02
	6.60	1.86	0.02	0.02		5.84	1.94	0.92	3.00
	6.76	1.87	0.02	0.02		5.38	1.86	1.16	3.69
	6.96	1.85	0.01	0.02		5.75	1.82	1.04	3.36
	7.04	1.85	0.01	0.02		5.67	1.96	0.76	3.06
Red clay**	7.63	1.54	0.10	2.53	Lacustrine sediment**	7.71	17.04	0.06	0.04
	7.71	1.46	0.15	2.62		7.60	46.80	0.04	0.00
	7.52	1.45	0.15	2.70		7.76	17.34	0.05	0.03
	7.58	1.44	0.17	2.66		7.30	16.00	0.10	0.04
	7.44	1.49	0.21	2.66		7.62	16.69	0.07	0.03
	7.68	1.42	0.14	2.67		7.12	19.43	0.05	0.03

Notes: Mean, mean diameter (PHI); MSD, mean square deviation; SK, skewness; KU, kurtosis

Sources: * After Yu *et al.*, 2006b, and samples were from Hongyuan peatland in eastern Tibetan Plateau; ** After Lu *et al.*, 2001, and samples of red clay, loess and paleosol were from Luochuan in Shaanxi Province; the fluvial sediment samples were from Qingyang in the north of the Loess Plateau; the lacustrine sediment samples were from Daihai Lake in Inner Mongolia Autonomous Region

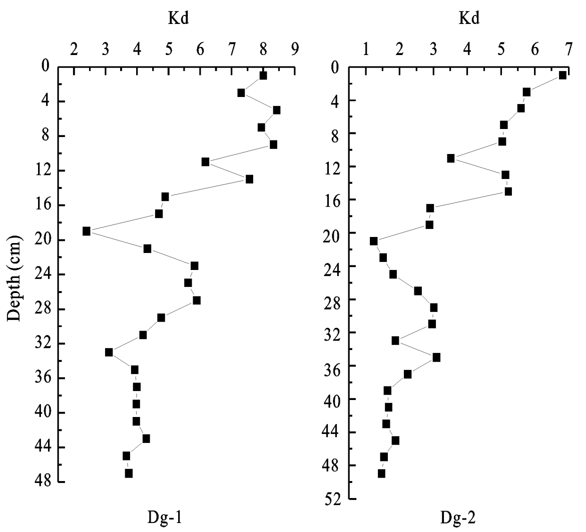
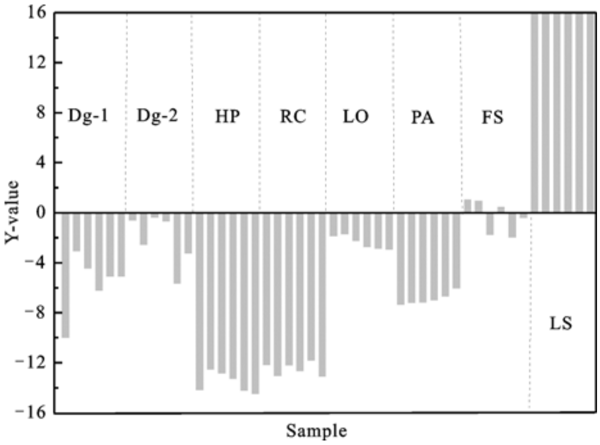


Fig. 4 Variation of silt and clay ratio (Kd) with depth of Daniugou peatland cores (Dg-1 and Dg-2)

–2.03 to 1.34, and those of lacustrine sediment from 760 to 1 134 (Fig. 5). This similarity of discriminant results suggest that the source of the Daniugou peat ash is agreement with the material sources of Hongyuan peat ash, red clay, loess and paleolsol, while different from fluvial and lacustrine sediments.

Arid and semiarid areas of the northern China make up 30% of the country′s total land area and are dominated by dust-generating weather system, and the large-scale dust storms occurring in these areas can result in dust deposition in the central Pacific, thousands of kilometers away (Duce *et al.*, 1980; Zhang *et al.*, 1997; Chen *et al.*, 2003). The prevailing wind direction in the Changbai Mountains area is southwest, and this area belongs to the domain of atmospheric transport trajectory of soil-dust from the northern China and Mon-



HP, Hongyuan peat; RC, red clay; LO, loess; PA, paleosol;
FS, fluvial sediment; LS, lacustrine sediment
Sources: Shaanbei Team of Chengdu Institute of Geology, 1978;
Lu *et al*., 2001

Fig. 5 Discriminant value (Y-value) of grain-size distribution of Daniugou peatland cores (Dg-1 and Dg-2) and other areas

golia (Jie *et al*., 2004). As a result, Daniugou peat land is presumably influenced by blowing out dry continental air masses. The sediment particles, especially clay and silt particles in the study area were brought in by atmospheric dust deposition. This result is consistent with the conclusion found by Zhao *et al*. (1997) that soil pedogenesis in the Changbai Mountains was influenced by tropospheric aeolian dust transported from arid and semiarid regions in China and Mongolia.

4.3 Local environmental deterioration as evidenced by grain-size distribution

The variation of the clay particles in Daniugou peat ash represents the history of long-distance atmospheric dust input, due to the long-distance transport of the finer suspended particles and the slightly pedogenic modification to the grain-size of peat ash (Patterson and Gillette, 1977; Leys and Mctainsh, 1996; Lu *et al.*, 2001; Merefield, 2002). Long-distance dust deposition produces fine deposits, and local dust arising from human activities, particularly vehicle and livestock movements, produces relatively coarse material (Mctainsh *et al.*, 1997). The increasing content of the clay fraction and the decreasing amount of the sand fraction with depth (Fig. 2) suggest that the contribution of long-distance soil-dust production to aeolian deposits in Daniugou peatland decreases with time, presumably as a result of recently ecologically sustainable exploitation of arid and semiarid lands in the northern China. In addition, single kurtosis reflects that materials were transported by single force before sedimentation, while bimodality shows the mixing action of water and wind (Nickling, 1983; Sun *et al.*, 2002; Wang *et al*., 2003). Therefore, the bimodal characteristics of the frequency distribution curves in the upper layers (Fig. 3) suggest that the surface of peat cores has more coarse particles and that local dust from anthropogenic disturbance have made greater contribution to peat deposition gradually.

Kd was first used in loess stratigraphy studies to indicate the dry-cold climate as well as bioclimatic conditions in dust source regions (Liu, 1985). It is also useful for recent atmospheric deposits with the implication that the larger value reflects the dry-cold climate, the bad land cover or the ecological environmental degradation, vice versa (He *et al.*, 2005). The mean Kd of Daniugou peat ash, 3.12–5.29, is higher than the corresponding values of Lanzhou dust deposits, 2.85–3.96 (Dai *et al*., 1995), and Luochuan loess, 0.91–2.26 (Liu, 1985). This illustrates that local environment deterioration makes the dry coarse particles increase easily and the local dust input to Daniugou peatland seriously. The increasing trend of Kd in Daniugou peat ash towards the surface (Fig. 4) is coincident with the periods of rapid growth in urban population, economic development, and agricultural exploitation in Northeast China (Deng *et al*., 2004). Therefore, the grain-size distribution reflects regional environmental changes to some extent, which is critical to regional sustainable development.

5 Conclusions

The dominant components of sediment in Daniugou peatland in the Changbai Mountains, Northeast China are clay and silt rather than sand particles. Analysis of grain-size parameters and comparison of them between Daniugou peatland and other sediments using a discriminative function demonstrates that the peat ash in Daniugou peatland mainly results from the addition of tropospheric aeolian dust by long-distance transport from the northern China and Mongolia. Moreover, there is also the short-distance material source for Daniugou peat formation. The local environmental deterioration is evidenced by grain-size distribution and the results may therefore be helpful in informing the decision-making process towards sustainable development. However, more detailed studies are needed to investigate the peat archives of atmospheric dust deposition comprehensively due to the complexity of peat formation process and the effects of anthropogenic disturbance on modern peat evolution. Nonetheless, this study demonstrates that similar grain-size work on peatland sediment elsewhere could provide valuable information on both regional and global environmental changes.

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