J. Earth Syst. Sci. (2020)129 18
https://doi.org/10.1007/s12040-019-1273-8

Investigation of sources of atmospheric dust in Guiyang City, southwest China using rare earth element patterns

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MS received 21 June 2018; revised 1 July 2019; accepted 24 July 2019

Rare earth elements (REE) of atmospheric dust were used in many investigations to trace the potential sources of environmental materials. In this study, we collected atmospheric dry deposition samples monthly from May of 2009 to January of 2011 over one and half year in a typical karst urban area of Guiyang city, southwest China, and measured the contents of REE to trace the sources. The total REE contents ($\sum$REE) of the dusts ranged from 9.48 to 181 mg kg^{-1}, with an average of 93.9 mg kg^{-1}. The $\sum$REE content of atmospheric dusts is similar to the contents of local soils. All the dust samples showed slighter Ce and Eu anomalies, and the dusts deposited in dry season showed slightly positive Ce anomaly. PAAS (post-Archean Australian shale) normalized REE patterns showed that there was significant difference between the dusts of dry seasons and wet seasons. The values of PAAS-normalized La_N/Yb_N, La_N/Sm_N and Gd_N/Yb_N of atmospheric dusts were closer to those of local soils collected in dry seasons, whereas the REE characteristics and patterns of dusts were similar to anthropogenic urban air particulates in wet seasons, demonstrating that dusts were mainly originated from anthropogenic inputs.

Keywords. Rare earth elements; atmospheric dust; karst; anthropogenic inputs; southwest China.

1. Introduction

Many terrestrial ecosystems are greatly influenced by the atmospheric dust at all times (Elderfield 1988; Han *et al.* 2009; Lawrence and Neff 2009; Nickovic *et al.* 2012). The atmospheric dust could influence both local and global climate (Su and Toon 2011; Shao *et al.* 2013), transfer nutrient elements for the biosphere (McTainsh and Strong 2007; Giovagnetti *et al.* 2013; Henrik *et al.* 2015), and disperse the anthropogenic contaminants (Petzold *et al.* 2011; Pósfai *et al.* 2013). In general, atmospheric dusts were mainly from the upper continental crust (UCC) through weathering (Lawrence and Neff 2009), transported by air, and mixed with anthropogenic inputs (Okorie *et al.* 2012; Sudheer and Rengarajan 2012).

In natural systems, the rare earth elements (REE) show consistent geochemical behaviour due to their similar physico-chemical properties (Taylor and McLennan 1995; Tepe and Bau 2015; Han *et al.* 2017). The concentrations and patterns of REE are considered as a tracer of the materials in biogeochemical processes, such as the aerosols (Sholkovitz *et al.* 1993; Yadav and Rajamani 2004; Wu *et al.* 2009) and dry depositions (Yang *et al.* 2007a; Tang *et al.* 2013). In urban areas, REE geochemistry of airborne particulate matter can help to identify pollution events and as a tracer for

Published online: 20 December 2019

different hydrocarbon combustion emissions of atmospheric particulate matter (Moreno *et al.* 2008). The REE composition of dust particles is found to vary with particle size (Yang *et al.* 2007b; Xiong *et al.* 2010), Light REE (La to Nd) are enriched in fine sized particles contributed mainly through anthropogenic sources such as automobile emissions (Moreno *et al.* 2010, 2011; Suzuki *et al.* 2011).

Guiyang is the central city of the Guizhou karst region. Karst is a limestone-dominated area usually characterized by barren, rocky ground, caves, sinkholes, underground rivers. Previous studies have approved that the acid rain is a serious problem in this city and the major air pollution source is coal combustion (Xiao and Liu 2002; Han and Liu 2006; Han *et al.* 2011), whereas the alkaline atmospheric dust can neutralize acid rain (Han *et al.* 2011). The alkaline atmospheric dust of Guiyang may origin from natural inputs according to the geologic characteristics of Guizhou karst region. Previous studies have shown that there are significant seasonal variations in the content of elements in atmospheric particulate matter in Guiyang (Wu *et al.* 2008); whereas there is still a lack of specific analysis on the main sources of these atmospheric particulates (Xie *et al.* 2005; Zhao and Liu 2010).

In this study, we investigated the compositions of REE in atmospheric dust of Guiyang city in different seasons. The purpose of this paper is to reveal the geochemical characteristics of REE in the atmospheric dust, to identify the possible natural and anthropogenic sources; to assess the degree of air pollution of the air quality of Guiyang city.

2. Experimental

2.1 *Study area*

The karst area in southwestern China represented by Guizhou is one of the largest karst landforms in the world, and carbonate rocks are widely distributed throughout this region (Huang *et al.* 2012). Guiyang city is the capital and in the center of Guizhou Province. The lithological characteristic of Guiyang city is dominated by sedimentary strata, most of which are carbonate and clastic rocks (Han and Liu 2006). Sampling site of this study lies in Guiyang city (figure 1). The average altitude of Guiyang is 1050 m and its total urban area is 8034 km^2. The city is located in basins surrounded by high mountains. More than 70% of the whole area is composed of calcareous sediments (Zhao and Seip 1991). The population of this city is about 4.3 million, with hilly topography. The mountains and plateaus range from north to south, and there are scattered hills and valleys in the city. Guiyang located in subtropical monsoon zone, the annual average temperature is 15.3°C and the average total annual rainfall is about 1130 mm.

2.2 *Sampling methods*

Atmospheric dust samples were collected using wet method procedures, and the collector was a bucket made of polypropylene (Ganor 2003), with 30 cm of diameter and 40 cm of height. The collectors were fixed to steel shelves, mounted on the top of a three-floor building (10 m above ground) in the Institute of Geochemistry, Chinese Academy of Sciences (26°34′16″N, 106°43′27″E, figure 1). This sampling site is located at the east-north part of Guiyang city with an elevation of 1080 m. No specific pollution sources or point sources are adjacent to the sampling site. Because the wind direction is usually east-north, the sampling site actually is located at the windward of the industrial districts of Guiyang city. Hence, it had avoided the direct industrial emission. Therefore, the sampling site has the atmosphere-environmental characteristics of residential uptown. Collecting medium was purified with glycol solution (20%), which could also depress algal and microbe growth.

The collectors were covered during rainy time, and were exposed at all other periods. Glycol solution was added to keep the bottom of the buckets submerged. Dust samples were gathered monthly. The solid and liquid mixture was fully transferred into a clean glass container, clean the sampling bucket with a small amount of ultra-pure water to ensure that all the samples in the bucket are transferred out. The samples were then transported to the lab for subsequent processing. The impurities, such as leaves and insects, were removed by a sieve screen of 1 mm apertures, so the atmospheric dust of this work was defined as the diameter <1 mm. The mixture was dried in an evaporating dish at 80°C. The amount of ethylene glycol added was strictly recorded during the whole sampling process, and the REE content was tested, which was deducted as a blank in the final test.

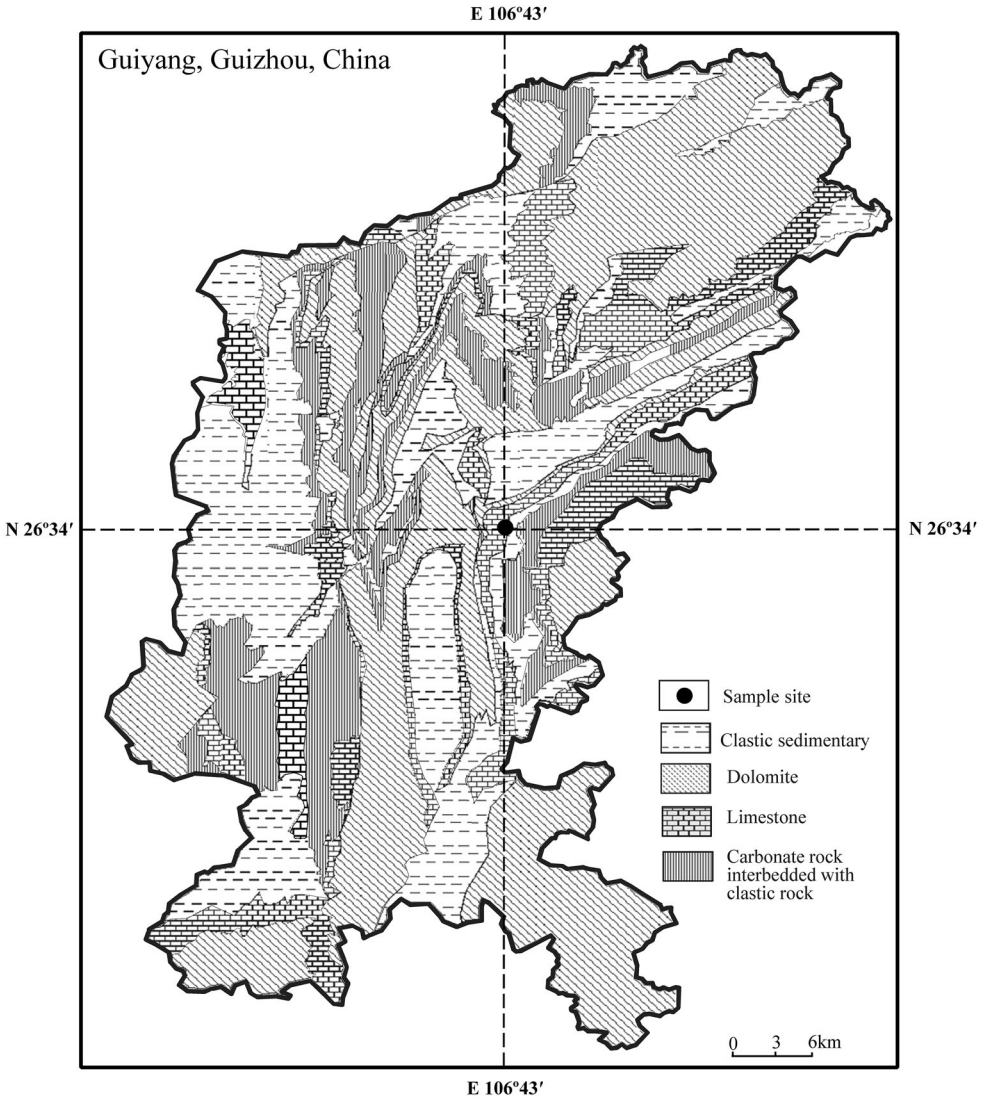

Figure 1. Geological sketch of Guiyang and sampling site of atmospheric dust.

In order to better distinguish the natural and anthropogenic sources of the atmospheric dust, five topsoil samples (0–5 cm) and the corresponding bedrock near Guiyang city were collected and tested in May 2010. The topsoil samples are the natural typical calcareous soil in a natural park which far away from downtown, and the bedrock is carbonate, which were used as the background value of deposited dust in this study.

2.3 *Analytical methods*

Dry deposition dust and soil samples were entirely ground into powder in an agate mortar and sieved (mesh size, 75 μm). Then, the powdered samples were dried in an oven at 105°C for 3 hrs before digesting. The digesting methods were summarized from Roy *et al.* (2007), Yang *et al.* (2007a), Tang and Han (2017).

(1) Put 100 mg of powder sample into a PFA sample jar (Savillex, US), and add 3 ml HNO_3 and 1 ml HF. Then, heat the jar on a hot plate at 140°C for 7 days to further break down the silicate, fluoride, and carbon compounds.
(2) Repeat the step 1 until the solution becomes clear.
(3) After the samples are completely digested, add 2 ml HNO_3 (1:1) two times to break up the fluorine compounds; Then, dry and vaporize the samples on a hot plate.
(4) Finally, dissolve the digested remainder in a 100-ml volumetric flask by using 2% HNO_3.

Table 1. *Concentrations of rare earth elements (mg kg^{-1}) and post-Archean Australian average shale (PAAS) normalized REE values of dusts, soils and bedrock of Guiyang.*

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	ΣREE	LREE	HREE	LREE/HREE	Ce/Ce*	Eu/Eu*
PAAS*	38.2	79.6	8.83	33.9	5.55	1.08	4.66	0.77	4.68	0.99	2.85	0.41	2.82	0.43						
May-09	19.2	41.7	4.06	15.3	2.99	0.62	2.72	0.44	2.61	0.53	1.44	0.20	1.36	0.20	93.4	83.9	9.49	8.84	1.09	1.03
Jun-09	16.9	35.6	3.68	14.0	2.78	0.56	2.41	0.40	2.38	0.49	1.31	0.18	1.22	0.17	82.0	73.4	8.56	8.58	1.04	1.02
Jul-09	23.2	61.2	5.25	19.7	3.88	0.78	3.47	0.55	3.17	0.66	1.83	0.26	1.78	0.25	126	114	12.0	9.53	1.28	1.01
Aug-09	19.2	41.8	4.40	16.4	3.17	0.66	2.94	0.47	2.67	0.57	1.56	0.23	1.53	0.22	95.8	85.6	10.2	8.40	1.05	1.02
Sep-09	22.5	50.2	5.00	18.7	3.50	0.80	3.81	0.56	3.10	0.68	1.81	0.26	1.71	0.25	113	101	12.2	8.27	1.09	1.03
Oct-09	27.5	62.6	5.62	20.3	3.91	0.87	4.27	0.63	3.51	0.76	2.05	0.29	1.93	0.28	135	121	13.7	8.81	1.16	1.00
Nov-09	28.0	56.2	6.07	22.5	4.45	0.95	4.43	0.71	4.06	0.88	2.37	0.35	2.32	0.33	134	118	15.5	7.65	0.99	1.00
Dec-09	35.6	69.8	8.18	29.3	5.58	1.28	6.00	0.91	4.91	1.02	2.83	0.40	2.60	0.37	169	150	19.0	7.86	0.94	1.04
Jan-10	19.4	37.8	4.04	16.1	3.31	0.74	3.39	0.53	2.92	0.66	1.78	0.26	1.80	0.26	93.0	81.4	11.6	7.02	0.98	1.04
Feb-10	2.81	6.21	0.70	2.47	0.61	0.11	0.67	0.12	0.75	0.19	0.57	0.09	0.70	0.10	16.1	12.9	3.20	4.04	1.02	0.81
Mar-10	11.8	27.2	3.26	11.5	2.29	0.47	2.51	0.40	2.44	0.57	1.62	0.25	1.76	0.25	66.2	56.5	9.80	5.76	1.01	0.91
Apr-10	13.9	32.1	3.69	14.0	2.80	0.62	2.78	0.47	2.60	0.57	1.55	0.24	1.59	0.23	77.1	67.1	10.0	6.68	1.03	1.04
May-10	3.87	10.5	1.22	4.54	1.11	0.22	0.91	0.18	1.16	0.28	0.81	0.13	0.93	0.14	26.0	21.5	4.54	4.73	1.11	1.01
Jun-10	1.34	3.53	0.40	1.46	0.37	0.08	0.37	0.08	0.56	0.13	0.43	0.07	0.58	0.08	9.5	7.2	2.30	3.12	1.11	1.03
Jul-10	7.63	19.2	2.25	8.35	1.73	0.33	1.46	0.26	1.61	0.37	1.12	0.17	1.15	0.16	45.8	39.5	6.30	6.27	1.06	0.96
Aug-10	8.11	23.2	2.77	11.0	2.49	0.51	2.13	0.39	2.36	0.57	1.60	0.24	1.61	0.23	57.2	48.1	9.11	5.28	1.11	1.05
Sep-10	11.9	32.2	3.48	13.3	2.86	0.59	2.47	0.43	2.51	0.58	1.63	0.24	1.55	0.22	74.0	64.4	9.62	6.69	1.14	1.04
Oct-10	12.7	27.7	3.18	11.3	2.24	0.43	1.96	0.34	1.86	0.45	1.39	0.20	1.30	0.20	65.3	57.6	7.69	7.49	1.00	0.97
Nov-10	30.9	62.9	7.13	26.3	5.00	1.02	4.63	0.71	3.99	0.90	2.51	0.35	2.27	0.32	149	133	15.7	8.50	0.98	1.00
Dec-10	38.0	72.1	9.46	33.6	6.21	1.31	5.95	0.90	5.11	1.11	3.11	0.44	2.99	0.40	181	161	20.0	8.04	0.88	1.01
Jan-11	33.1	68.0	8.12	30.1	5.91	1.21	5.60	0.84	4.60	1.03	2.79	0.38	2.49	0.34	164	146	18.1	8.10	0.96	0.99
Soil-1	6.06	15.7	1.56	6.94	1.75	0.36	2.03	0.39	2.66	0.63	1.96	0.31	2.16	0.33	42.9	32.4	10.4	3.10	1.18	0.90
Soil-2	4.35	13.0	1.32	5.43	1.37	0.28	1.45	0.28	1.92	0.47	1.46	0.23	1.66	0.25	33.5	25.7	7.72	3.33	1.24	0.92
Soil-3	4.19	16.3	1.34	5.38	1.28	0.25	1.29	0.25	1.70	0.39	1.21	0.19	1.37	0.20	35.3	28.7	6.60	4.35	1.57	0.91
Soil-4	5.57	16.6	1.42	5.42	1.15	0.21	1.12	0.21	1.45	0.33	1.04	0.16	1.10	0.18	36.0	30.4	5.58	5.45	1.37	0.87
Soil-5	4.70	11.9	1.34	5.67	1.36	0.30	1.55	0.29	2.00	0.48	1.50	0.24	1.72	0.27	33.3	25.3	8.05	3.14	1.09	0.95
Bedrock	0.76	0.64	0.14	0.59	0.11	0.03	0.17	0.03	0.19	0.05	0.14	0.02	0.12	0.02	3.01	2.3	0.73	3.12	0.45	1.00

Data of PAAS come from Taylor and McLennan (1985); Ce/Ce: Ce anomaly value; Eu/Eu*: Eu anomaly value.

The digestion experiment was performed in the super clean laboratory of the Institute of Geochemistry, Chinese Academy of Sciences. The REE concentrations of the digested solutions were analyzed using an Agilent 7500a ICP-MS at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan. Interference corrections for BaO and BaOH on Eu were performed by applying a constant correction factor determined; by a single element monitor solution prior to sample analysis (Liu *et al.* 2008). Quality control was performed using the national standard reference material of China (GBW07427). In this test, the error range of standard sample (GBW07427) is ±15%, while the relative standard deviation of repeated test for the same sample is less than 8%.

3. Results and discussion

The REEs are commonly divided into three groups: light rare earth elements (LREE) from La to Nd, middle rare earth elements (MREE) from Sm to Dy, and heavy rare earth elements (HREE) from Ho to Lu (Inguaggiato *et al.* 2016). The REE data of dust were given in table 1. The PAAS (post-Archean Australian average shale) data were from Taylor and McLennan (1985).

3.1 *Characteristics of REE contents*

The total REE (ΣREE) contents of monthly deposited dust of Guiyang were diverse, which ranged from 9.48 (June 2010) to 181 mg kg^{-1} (December 2010), with an average of 93.9 mg kg^{-1}; ΣREE contents of averaged topsoil varied between 33.3 and 42.9 mg kg^{-1}, the average ΣREE value of the five topsoil was 36.2 mg kg^{-1}, bedrock had the minimum ΣREE concentration of 3.01 mg kg^{-1}. The ∑REE of most Guiyang dusts were similar to that of Beijing dusts (103 mg kg^{-1}, Tang *et al.* 2013), but higher than that of topsoil and bedrock and estimated Chinese coal values of 118 mg kg^{-1} (Dai *et al.* 2012). Monthly dust ∑REE concentrations were averaged by season (figure 2), and the seasonal variations are somewhat similar to the Mt. Everest ice core records (Zhang *et al.* 2009) and the atmospheric dust observation results of Beijing city (Tang *et al.* 2013). Dust ∑REE had a lower values in spring (Feb, Mar and Apr) of 2010 relative to the other month. ∑REE values during the spring of 2010 were close to the topsoil and bedrock. The ∑REE concentrations are relatively low in the carbonate bedrock of southwest China (Qiu *et al.* 2013), which is 3.01 mg kg^{-1} in this study, whereas it can be enriched in topsoil (Ji *et al.* 2004). The seasonal fluctuations of the ∑REE values may provide some useful information. In some cases, atmospheric dust in urban areas is the mixture of natural and anthropogenic inputs (Okorie *et al.* 2012; Sudheer and Rengarajan 2012), and the REE is usually enriched in fine atmospheric particulates than the coarse ones (Sudheer and Rengarajan 2012), the fine ones are mainly anthropogenic sources such as fired power plants and vehicular exhaust (Suzuki *et al.* 2011). Though the fine anthropogenic particulates could stay long time in the air regardless of the weather (Csavina *et al.* 2012), in dry weather, mineral particulates (quartz, carbonate rock, etc.) in surface soil are more likely to be raised to form atmospheric dust, and the content of rare earth elements in these mineral particulates is usually very low, so the decrease of ∑REE in dry season dust may be affected by the 'dilution' of these mineral particulates.

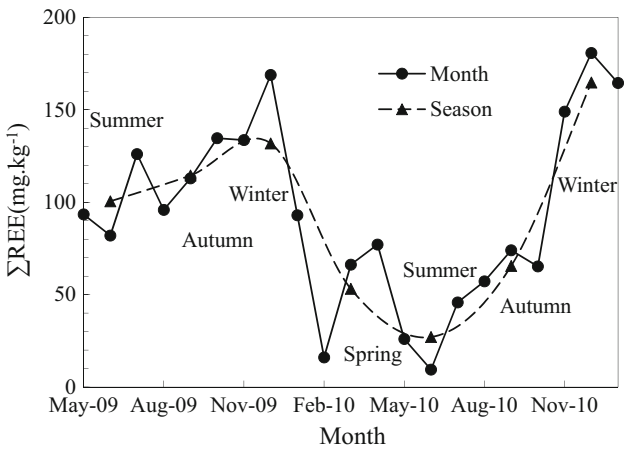

Figure 2. Seasonal variation of ΣREE content in atmospheric dust in Guiyang.

3.2 *PAAS-normalized REE patterns*

Considering that the sampling in this study is located in a typical sedimentary rock area, we chose PAAS (post-Archean Australian shale, Taylor and McLennan 1985), which is also a sedimentary rock, as the standard value for normalization analysis. The seasonal variations in REE compositions of the atmospheric dust were described using the convention of concentrations normalized to PAAS. PAAS-normalized REE patterns showed consistent pattern of dust in summer, autumn and winter of 2009, which were a series of smoothed lines and slightly depleted in LREE and HREE, whereas

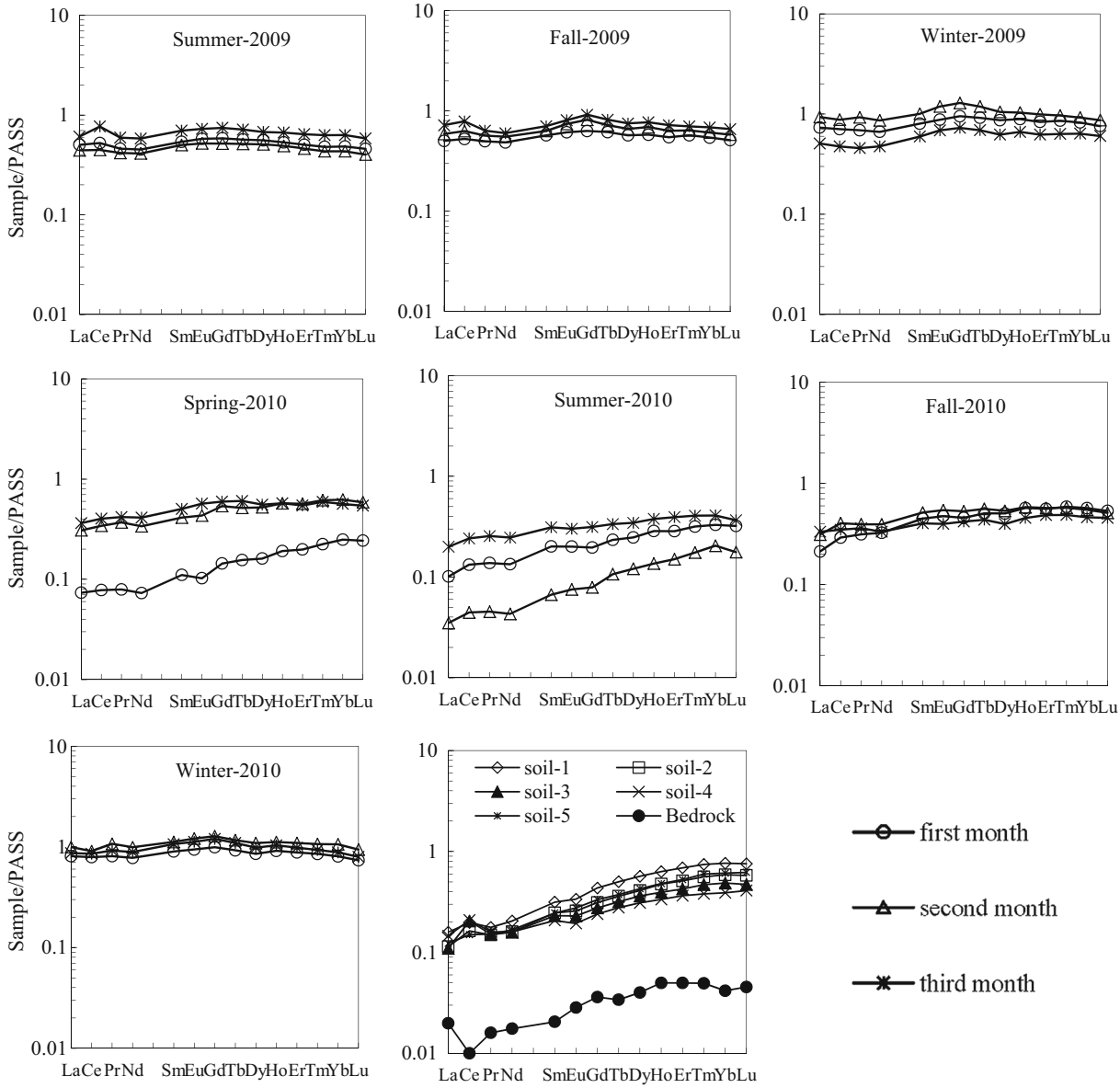

Figure 3. PAAS-normalized REE patterns of the atmospheric dust and local topsoil of Guiyang. Beijing data come from Tang *et al.* (2013).

slightly enriched in MREE compared to PAAS (figure 3). The PAAS-normalized REE patterns of dust showed Ce anomalies. The PAAS-normalized REE patterns of the dust in 2009 are similar to the patterns of Beijing dust (Tang *et al.* 2013), suggesting the dust of the two cities may have the same type of sources. PAAS-normalized REE pattern of spring and summer in 2010 were very different from those in 2009, and LREE depletion was evidenced during this period. This pattern was similar to the soils and bedrock, which could be attributed to the increased proportion of natural matters in the atmospheric dust in dry weather.

The bedrock-normalized REE patterns for the atmospheric dust are shown in figure 4 by using bedrock to normalize the REE distribution in order to identify the sources of REE in the atmospheric dust. From figure 4, it is clear clarification that these dust samples do not show flat REE patterns. It is clearly that the LREE distribution patterns are characterized by LREE enrichment. The LREE/HREE values of atmospheric dust varied from 3.12 to 9.53, the dust in spring and summer of 2010 showed lower LREE/HREE value than other seasons and were close to the soils (3.10–5.45) and bedrock (3.12), the dust of these seasons were more likely from natural sources; LREE/HREE values of the other seasons suggested that the dusts were more enriched in LREE, this pattern was observed in anthropogenic particulates of urban areas (Lü

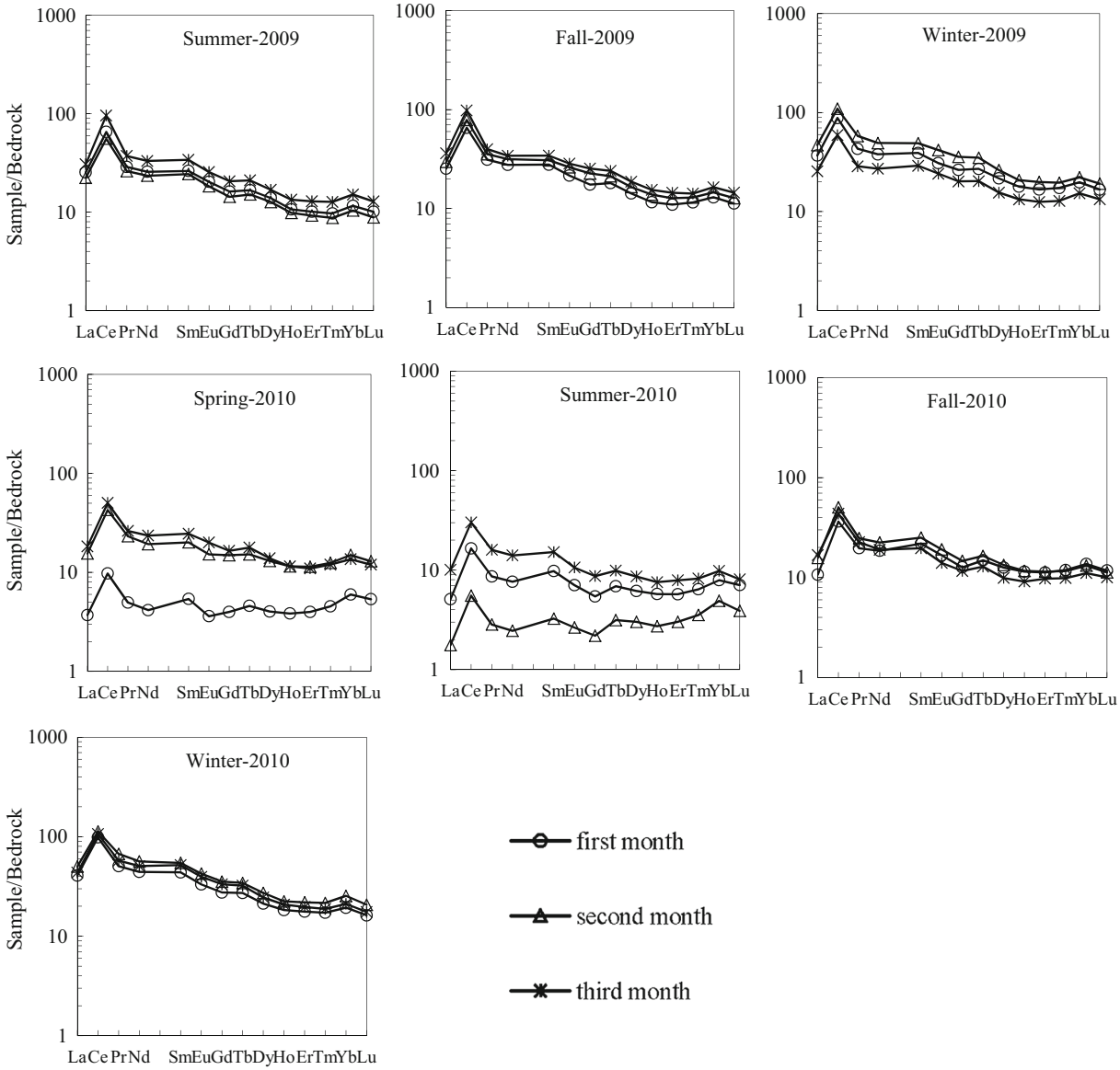

Figure 4. Bedrock-normalized REE patterns of the atmospheric dust.

et al. 2007; Moreno *et al.* 2010). Relative lower LREE/HREE and ∑REE values in dry weather overlapped the area of soils (figure 5), indicated that these dusts were potentially of natural provenance, whereas high LREE/HREE and ∑REE values suggested anthropogenic inputs might dominant in other seasons.

3.3 *Ce and Eu anomalies*

The cerium (Ce) and europium (Eu) have different valence states from other REEs and vary in the abundances in different geological materials (Taylor and McLennan 1995; Laveuf *et al.* 2008; Han *et al.* 2009; Hannigan *et al.* 2010). Ce-anomaly (Ce/Ce*) and Eu-anomaly (Eu/Eu*) values of the atmospheric dusts were calculated by the following equations (Elderfield 1988; Han *et al.* 2009).

$$\mathrm{Ce/Ce^*} = 2\left(\mathrm{Ce_{Sample}}/\mathrm{Ce_{PAAS}}\right)/\left(\mathrm{La_{Sample}}/\mathrm{La_{PAAS}} + \mathrm{Pr_{Sample}}/\mathrm{Pr_{PAAS}}\right) \quad (1)$$

$$\mathrm{Eu/Eu^*} = 2\left(\mathrm{Eu_{Sample}}/\mathrm{Eu_{PAAS}}\right)/\left(\mathrm{Sm_{Sample}}/\mathrm{Sm_{PAAS}} + \mathrm{Gd_{Sample}}/\mathrm{Gd_{PAAS}}\right) \quad (2)$$

The Ce/Ce* values of the atmospheric dusts ranged from 0.88 to 1.28, with an average of 1.05, some of which showed slightly positive anomalies (figure 6). Eu/Eu* values were less variable than

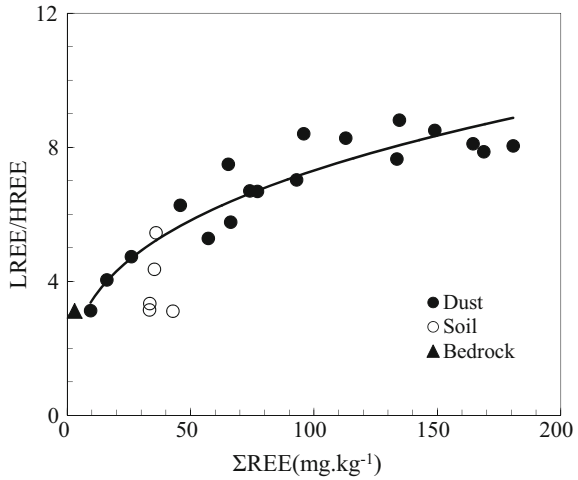

Figure 5. Bivariate plots of LREE/HREE ratios *vs.* ΣREE concentrations of atmospheric dust and local topsoil of Guiyang.

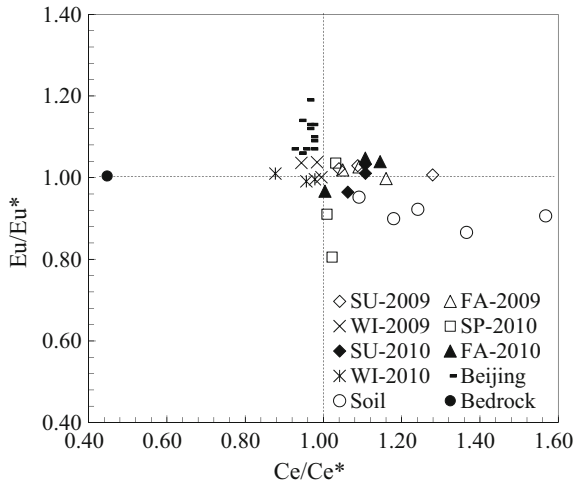

Figure 6. Ce and Eu anomalies in atmospheric dust in different seasons and topsoil in Guiyang. SU = summer, FA = Fall, WI = winter, SP = spring, Beijing data come from Tang *et al.* (2013).

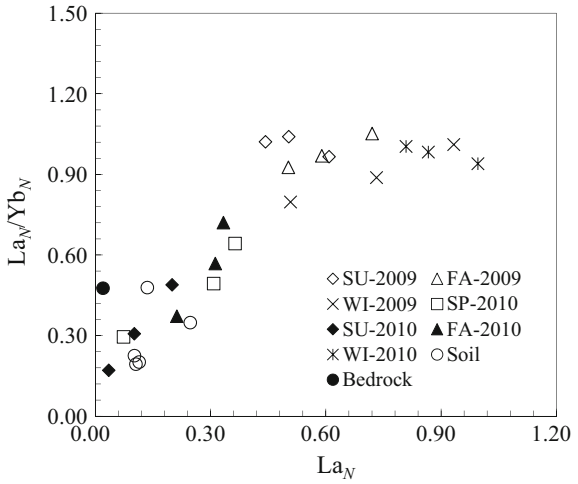

Figure 7. LREE fractionation pattern diagram of atmospheric dust and topsoil in Guiyang by La_N *vs.* La_N/Yb_N.

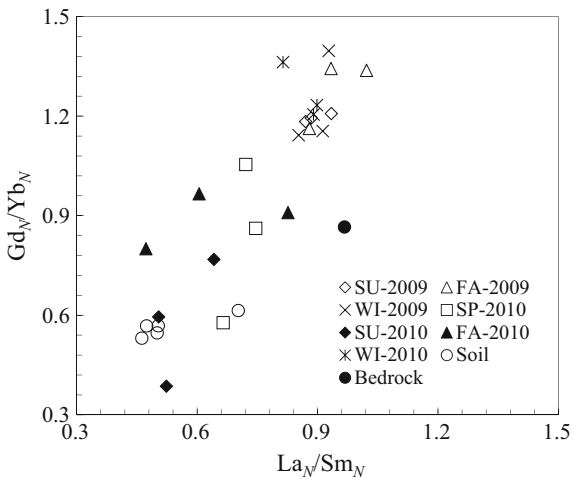

Figure 8. Total REE fractionation pattern diagram of atmospheric dust in Guiyang by La_N/Sm_N *vs.* Gd_N/Yb_N. SU = summer, FA = Fall, WI = winter, SP = spring.

Ce/Ce* values in Guiyang dusts. Ce anomalies were more obvious than Eu anomalies in Guiyang, whereas is contrary with Beijing. Positive Ce anomalies might occur in the weathering processes of limestone (Laveuf *et al.* 2008), and the positive Ce anomalies of the soils could reveal the intense chemical weathering in this karst region. Under reduction conditions, Eu exists in the form of Eu^{2+}, which is easy to fractionate with other rare earth elements. Under oxidation conditions, Eu exists in the form of Eu^{3+}, and does not fractionate. The karst surface environment belongs to strong oxidation environment, and Eu does not fractionate in general. Unlike the diverse Ce anomalies, weathering processes had no remarkable impacts on Eu/Eu* values and Eu anomalies were more likely inherited from source materials (Condie 1991; Han *et al.* 2009; Prego *et al.* 2009). The slightly negative Eu anomalies of dust in spring 2010 were consistent with the soils, which might explain this inherited relationship. Some dusts showed similar positive Ce anomalies and negative Eu anomalies as the soils, which suggested the dust may partially from local soils.

3.4 *REE fractionation*

Several representative values of PAAS-normalized La_N/Yb_N, La_N/Sm_N and Gd_N/Yb_N ratios were chosen to compare with the potential dust sources in different seasons (Sholkovitz *et al.* 1993;

Hannigan *et al.* 2010). Dust of the dry weather (spring to autumn, 2010) have similar La_N values (0.03–0.36) and La_N/Yb_N values (0.17–0.72) to local soils (figure 7). Besides, the La_N values were positively correlated with La_N/Yb_N values, which could be attributed to the mixing of different proportions of natural minerals (most of them come from carbonate bedrock) in atmospheric dust. Dust of the other seasons (summer to winter, 2009) showed higher La_N (0.44–1.00) and La_N/Yb_N (0.80–1.05) values than that of the dry season. The relatively higher La_N/Yb_N values were observed in anthropogenic related air particulates, such as the road dusts of Dhaka city (Ahmed *et al.* 2007), the aerosols of Bermuda (Sholkovitz *et al.* 1993), the urban air PMs of Spain (Moreno *et al.* 2010) and the suspended particulates Tokyo (Suzuki *et al.* 2011).

Similar seasonal variations were displayed on LREE/MREE/HREE fractionations (figure 8). The La_N/Sm_N and Gd_N/Yb_N values of the dry season were close to the local soils rather than the rest of seasons. LREE/MREE/HREE pattern of the rest seasons were of higher La_N/Sm_N and Gd_N/Yb_N values, which were more closer to the road dusts of Dhaka (Ahmed *et al.* 2007), the urban air PMs of Spain (Moreno *et al.* 2010), and the atmospheric particulates of Tokyo (Suzuki *et al.* 2011), suggesting the dusts of these seasons were more likely to be from a typical urban interior source, which is likely to be closely related to human activities, and further differentiation of their sources requires more elements and parameters analysis.

4. Conclusions

The $\sum$REE concentrations of atmospheric dusts in Guiyang showed obvious seasonal variations, which were lower in dry seasons than in other seasons. The REE content of dust in dry months is similar to that in local topsoil, which may be due to the increase of mineral particulate matter from topsoil in dry season.

Most dust samples show slight positive Ce anomaly. Positive anomalies of Ce are more evident in dry months, The Ce normal anomaly may reveal the intense chemical weathering and leaching of the surface environment in the Guizhou karst region. The anomaly values of Eu in all dust samples are close to 1, and there is no obvious seasonal difference, which probably revealed the inherited relationship between the dusts and the natural source materials.

The PAAS-normalized REE patterns of dusts in extremely dry season (spring to autumn, 2010) were different from the rest seasons of this sampling period. The bedrock-normalized REE patterns of dusts showed obvious LREE enrichment and total REE depletion, and the PAAS-normalized La_N/Yb_N, La_N/Sm_N and Gd_N/Yb_N values of Guiyang dusts were very close to that of local topsoil. In contrast, dusts of the conventional seasons (other seasons except extreme drought seasons in sampling cycle) had similar REE characteristics and patterns with representative urban air particulates, indicating that anthropogenic materials may contribute significantly to total dusts of these seasons.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (Grant Nos. 41325010; 41403109; 41661144029); Science and Technology Foundation of Guizhou Province, China (Grant No. J[2012]2331).

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Corresponding editor: Suresh Babu