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^{10}Be in desert sands, falling dust and loess in China

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ABSTRACT

Cosmogenic ^{10}Be is produced in the atmosphere, and deposits onto the surface of the earth mainly through wet precipitation and dust. Based on the analysis of ^{10}Be in Chinese loess, we believe that ^{10}Be in loess is composed of two components: locally precipitated atmospheric ^{10}Be, and windblown ^{10}Be adsorbed on the surface of silt grains. On the Loess Plateau, ^{10}Be concentrations in loess and paleosol range from $(1.4 \text{ to } 2.8) \times 10^8$ atoms/g and $(2.7 \text{ to } 4.5) \times 10^8$ atoms/g, respectively. To investigate the sources of ^{10}Be in loess, we measured ^{10}Be in sand grains from deserts in western China and falling dust from the deposition regions. The results show that the ^{10}Be concentrations in sand and dust are $(1.1–5.1) \times 10^7$ atoms/g and $(1.3–2.8) \times 10^8$ atoms/g, respectively. Loess and paleosol on the Loess Plateau both contain inherited ^{10}Be adsorbed on silt grains from dust; most of the windblown deposited loess materials do not directly come from the Gobi and other sand deserts, but mainly from the loess–desert transitional zones, which are characterized by silt and dust holding areas.

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1. Introduction

^{10}Be is formed mainly through spallation reactions of cosmic ray particles with oxygen and nitrogen in the atmosphere and surface rocks, which are called atmospheric and in situ cosmogenic ^{10}Be, respectively. The in situ produced cosmogenic ^{10}Be concentration in loess materials is very low, accounting for only ∼1% of the total ^{10}Be, therefore most of the ^{10}Be in eolian loess sequences originates from atmospheric production.

Thick eolian loess accumulated in the semi-arid northern China forms the well-known Chinese Loess Plateau, covering ∼400 thousand square kilometres (Fig. 1). The distribution of loess is controlled to a large extent by two major mountain chains, the Kunlun–Qinling Mountains and Aertai–Alashan–Great Xinganling Mountains, from west-northwest to east-southeast between 34 and 45° N [1].

The distribution of loess is also closely related to the East Asian monsoon system. Loess is formed through the deposition of dust transported by the winter monsoon from the north, whereas paleosols, interlayered with loess, are mainly linked to summer monsoon from the south. The rainfall on the Loess Plateau is mainly controlled by the vapour transported by summer monsoon [2]. Therefore ^{10}Be in the loess sequence consists of two major components, both of which are of atmospheric origin: direct sedimentation of ^{10}Be through rainfalls and ^{10}Be attached to the surface of re-settled dusts after one or multiple transportation.

2. ^{10}Be concentrations in desert sands

Eolian sand grains in deserts in arid north China are mainly fine sand (0.25–0.1 mm in diameter), which account for about 70 wt.% of the total mass of eolian sand. This is followed by ultrafine sand (0.1–0.05 mm) and medium sand (0.5–0.25 mm) of about 25 wt.% of the total mass, and less than 5 wt.% of silt (<0.05 mm), as well as minor coarse sand (1.00–0.5 mm). Ultra-coarse sand is very rare [3]. Among all the deserts in northwest China, sand grains from Taklimakan desert is the finest, whereas those from Badai Jaran desert is the coarsest [4]. The ^{10}Be concentration of sands from Chinese deserts ranges from $(1.1 \text{ to } 5.1) \times 10^7$ atoms/g, and is negatively correlated with the median of grain size (Md) (Table 1). In addition, ^{10}Be concentration of sands from different deserts negatively co-varies with the annual precipitation, i.e. high ^{10}Be concentration usually found in regions with low annual precipitation.

In addition to grain sizes and precipitation, mineralogy of the sand is also essential for ^{10}Be adsorption. For example, quartz sand should have much less ^{10}Be than sand dominated by feldspars.

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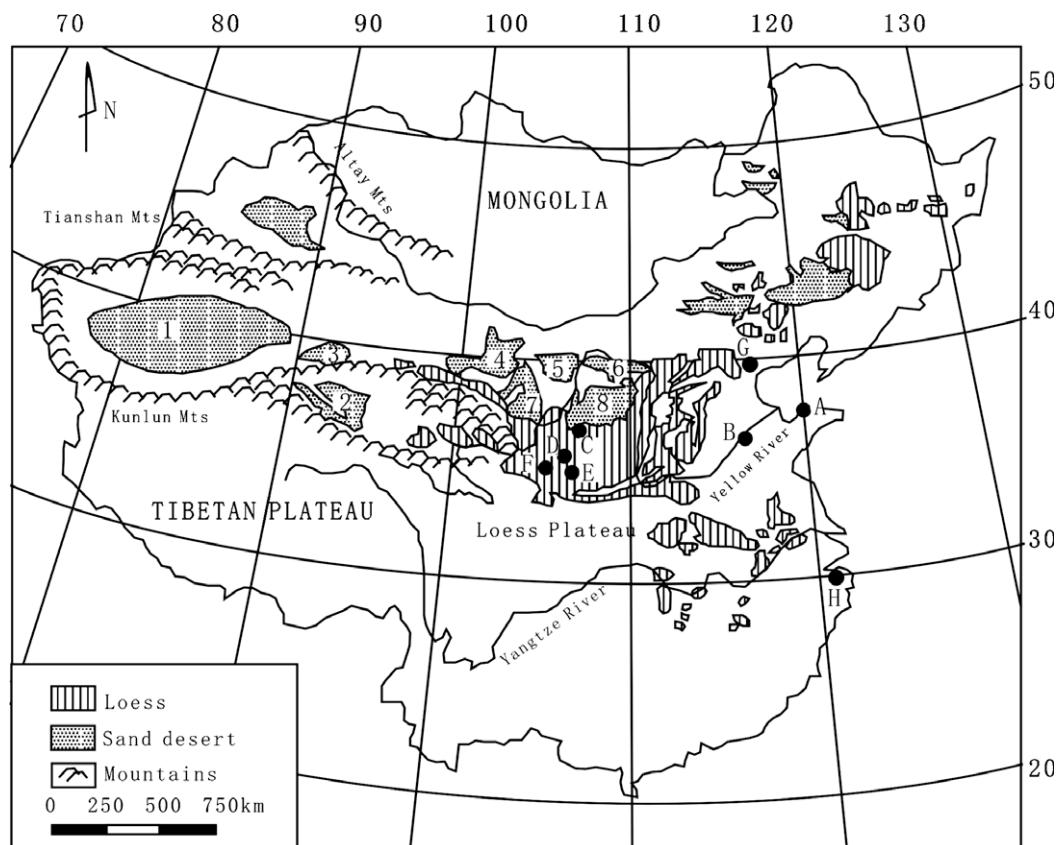 *E-mail address:* cdshen@gig.ac.cn (C.D. Shen).

Fig. 1. Sketched map showing the distribution of mountains, sand deserts, and loess, and the sampling sites in China. Deserts are marked in numbers: 1. Taklimakan Desert; 2. Qaidam Desert; 3. Kumtag Desert; 4. Badai Jaran Desert; 5. Ulan Buh Desert; 6. Qubqi Desert; 7. Tengger Desert; 8. Mu Us Desert. Sampling sites of falling dusts on the Loess Plateau and Eastern China are marked as filled circles (A. Penglai; B. Jinan; C. Dingbia; D. Huanxian; E. Xifeng; F. Longxi?G. Beijing; H. Ningbao).

Table 1
^{10}Be concentrations in Chinese desert sands.

Desert	Location	Area (km^2)	M_d (mm)	Rain fall (mm/yr)	^{10}Be (10^7atoms/g)
Taklimakan	Xinjiang	337600	0.093	30	5.14 ± 0.26
Mu Us	Inner Mongolia	32100	0.145	300	3.43 ± 0.17
Qubqi	Inner Mongolia	16100	0.153	240	2.78 ± 0.14
Badai Jaran	Gansu	49200	0.208	70	1.11 ± 0.06
Ulan Buh	Ningxia	9970	0.190	150	1.88 ± 0.10
Tengger	Ningxia	42700	0.165	110	4.38 ± 0.22
Qaidam	Qinghai	34900	0.160	40	4.92 ± 0.25

Given that quartz is more resistant to weathering than most other rock forming minerals, the negative correlation between grain size and ^{10}Be concentration may partly due to less quartz in finer sands.

^{10}Be concentrations in desert sands can also be influenced by surface runoff especially along desert margins. Mud crust in desert formed by evaporation of rain water can reflect the influence of surface runoff. We determined four desert mud crust samples (Table 2). The ^{10}Be concentrations in mud crust are systematically higher than desert sands (Table 1). This is likely due to the smaller grain size of mud crust and/or higher rainfall washes.

3. ^{10}Be concentrations in falling dust

The original source of eolian sands in Asia is located in deserts and semi-arid regions to the east of the deserts in northwest China (central east part of Inner Mongolia and west part of the northeast-

Table 2
^{10}Be concentrations of Mud Crust in Chinese deserts.

Desert	Sample ID	Latitude	Longitude	Elevation (m)	Sample Type	^{10}Be (10^7atoms/g)
Qaidam	QD-009	37°20′45.5″N	97°09′13.5″E	2892	Mud crust	14.9 ± 0.9
Tengger	TG-018	39°00′22.4″N	103°34′01.7″E	1304	Mud crust	20.6 ± 0.5
Badai Jaran	BJ-024	39°17′55.2″N	101°52′24.6″E	1611	Mud crust	31.1 ± 1.0
Taklimakan	TK-074	41°64′43.3″N	83°29′01.5″E	1001	Mud crust	7.41 ± 0.3
Taklimakan	TK-103	36°48′12.3″N	82°16′08.3″E	1720	Mud crust	7.25 ± 0.3

Table 3
^{10}Be concentrations in falling dust.

Location	Time	Carbonate (%)	^{10}Be (10^8 atoms g^{-1})	Reference
Jinan	April 1984	N.M.	2.60 ± 0.10	Shen et al. [11]
Longxi	August 1983	14.1	1.56 ± 0.09	Gu et al. [5]
Longxi	August 1983	12.8	1.41 ± 0.08	Gu et al. [5]
Longxi	August 1983	10.1	2.53 ± 0.14	Gu et al. [5]
Penglai	May 1983	5.6	2.78 ± 0.15	Gu et al. [5]
Penglai	May 1983	6.3	2.70 ± 0.14	Gu et al. [5]
Xifeng	April 1999	N.M.	2.57 ± 0.06	Shen et al. [this work]
Xifeng	August 1999	N.M.	2.00 ± 0.05	Shen et al. [this work]
Dingbia	Winter1999	N.M.	1.25 ± 0.06	Shen et al. [this work]
Huanxian	April 1999	N.M.	2.06 ± 0.07	Shen et al. [this work]
Huanxian	Aug.1999	N.M.	1.81 ± 0.06	Shen et al. [this work]
Beijing	April 2006	1.21	2.05 ± 0.06	Shen et al. [this work]
Ningbo	April 2007	N.D.	14.83 ± 0.70	Shen et al. [this work]

N.M., not measured; N.D., not detected.

Table 4
^{10}Be concentrations of S_1 palaeosol and L_2 loess particles of different sizes.

Grain size (μm)	>50	40	20	10	3	0.9	0.3	0.09	0.03	0.01
S_1-Fractional mass (%)	6.0	30	12.4	17.7	11.8	11.2	5.0	4.34	2.28	0.86
S_1-^{10}Be (10^8 atoms/g)	0.70	0.95	1.40	2.80	5.80	7.40	8.10	9.46	8.60	7.90
S_1-F-$^{10}Be^a$(10^8 atoms/g)	0.04	0.29	0.17	0.50	0.68	0.83	0.41	0.41	0.20	0.07
L_2-Fractional mass (%)	6.5	42.6	15.6	12.6	7.5	10.5	2.0	3.3	1.4	0.17
L_2-^{10}Be (10^8 atoms/g)	1.25	0.95	1.40	2.05	3.30	3.95	3.49	3.53	4.59	1.97
L_2-F-$^{10}Be^b$(10^8 atoms/g)	0.08	0.41	0.22	0.26	0.25	0.42	0.07	0.12	0.06	0.003

The ^{10}Be concentrations in bulk samples are: S_1-^{10}Be = 4.03 (10^8 atoms/g); L_2-^{10}Be = 2.81 (10^8 atoms/g). Each sample was measured at least twice, resulting in an accuracy of 3–5% (1σ).
S_1-^{10}Be and L_2-^{10}Be cited from reference [7].
  a S_1-F-^{10}Be = (S1–^{10}Be) × (S_1-fractional mass).
  b L_2-F-^{10}Be = (L2–^{10}Be) × (L_2-fractional mass).

ern China). The winter monsoon controlled by Siberia–Mongolia high-pressure system raises and transports surface dusts, causing sand-storms in the downwind regions in winter and spring, which is the main source of loess deposit.

We determined ^{10}Be concentration in falling dust collected from East China and the Loess Plateau at different times. The ^{10}Be concentration in falling dust ranges from (1.2 to 2.8) × 10^8 atoms/g, is about an order of magnitude higher than that in the desert sands. Interestingly, the average ^{10}Be concentration increases from 1.90×10^8 atoms/g in the Loess Plateau in the west to 2.7×10^8 atoms/g in Jinan and Penglai in the east [5] or even to 14.83×10^8 atoms/g in Ningbo in the south-east [6]. This can be plausibly interpreted by the fractionation of grain size during the transportation of eolian particles by wind. The grain sizes of eolian dust decreases during its transportation from the west to the east [7], while the ^{10}Be concentration increases with decreasing grain sizes (Table 3), because ^{10}Be is mainly adsorbed on the surface of ultra-fine particles. Limited data also show seasonal variations in ^{10}Be concentration in falling dust with higher ^{10}Be concentrations in the spring compared with those in summer (Table 3). This seasonal variation in ^{10}Be concentration might be due to seasonal variations in monsoon.

4. ^{10}Be concentrations in loess

The loess and red clay sequence of the Chinese Loess Plateau preserves a successive record of eolian deposition since the late Miocene to the Present [1,8]. The ^{10}Be in several loess sequences has been previously studied [7,9–13]. The ^{10}Be concentration in loess ranges from (1.4 to 2.8) × 10^8 atoms/g, while in paleosols, it is usually about 2–3 times higher than in loess, ranging from (2.7 to 4.5) × 10^8 atoms/g [7,11].

The fractional mass (wt.%) and ^{10}Be concentrations for particles of different grain size from the S_1 paleosol and L_2 loess in the Luochuan loess sequence on the Chinese Loess Plateau are shown in Table 4. In general, the ^{10}Be concentrations are higher in fine grains than in coarse grains. The highest ^{10}Be concentrations were determined in the 900–30 nm fractions (Table 4). Fine silt (40–3 μm) is the dominant component in S_1 paleosol and L_2 loess, accounts for ∼72 and ∼78 wt.% of the total mass of the eolian sediments, respectively, and thus is the main contributor of ^{10}Be to the paleosol and loess. Given that the eolian sand in deserts is predominately fine sand (0.25–0.1 mm) and that their ^{10}Be concentrations are about an order of magnitude lower than falling dust, the silt component in the Luochuan paleosol–loess sequence is not likely to be directly originated from the deserts. This is supported by the physical features of loess [1].

The transportation of eolian dust is controlled by the intensity of wind and the distance between the source and deposition regions [14]. The loess plateau is located within 500–1000 km away from the deserts, whereas the loess particles is transported through suspending transit, which is a kind of short distance dust transit and thus cannot be transported directly from the source deserts to the loess plateau [14,15].

It is estimated that ∼50% and ∼70% of the ^{10}Be in S_1 paleosol and L_2 loess, respectively, was imported through re-settled surface dusts, assuming the ^{10}Be concentrations in imported materials are the same as the average ^{10}Be concentrations in falling dust.

5. Conclusions

The ^{10}Be concentrations in sands (>50 μm) from major deserts in China, falling dust in deposition regions and loess–paleosol

sequences were determined to identify the source of [10]Be in loess on the Chinese Loess Plateau. The results show that:

1. The [10]Be concentrations range from $(1.4 \text{ to } 2.8) \times 10^8$ atoms/g for loess, $(2.7 \text{ to } 4.5) \times 10^8$ atoms/g for paleosol, $(1.1 \text{ to } 5.1) \times 10^7$ atoms/g for sands from deserts and $(1.2 \text{ to } 2.8) \times 10^8$ atoms/g for falling dust.
2. Both loess and paleosol on the Chinese Loess Plateau inherited [10]Be from the falling dust, with $\sim$50% and $\sim$70% of the [10]Be in S_1 paleosol and L_2 loess, respectively, was collected from regions upwind.
3. The [10]Be data for desert sands, falling dust, and loess–paleosol suggest that the dust materials in loess and paleosol do not stem directly from deserts, but from the dust source regions, which is the loess–desert transitional zone located between the deserts and the loess belt.

Acknowledgements

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