

MEASUREMENT OF ^{10}Be CONCENTRATION OF MODERN FALLING DUST IN NORTHERN CHINA

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ABSTRACT. Paleoenvironmental and paleogeomagnetic tracing studies from Chinese loess ^{10}Be have progressed in recent years (Zhou et al. 2007a,b, 2010). In this approach, ^{10}Be flux determined from sediment concentration and accumulation rate may be used to recover information about paleomonsoon rainfall rates as well as past variations in the geomagnetic field strength. However, these methods require that a correction be made for residual undecayed ^{10}Be in remobilized dust. To better understand the feature of the ^{10}Be signals related to the remobilized dust, we report the first observational study on ^{10}Be concentration of modern falling dust using the 3MV multi-element accelerator mass spectrometer (AMS) in the Xi'an AMS Center. Ten samples collected at Ansai observation station (109°19'E, 36°51'N) in northern China from May 2008 to June 2009 are measured along with 3 chemical blanks. The results clearly show that the ^{10}Be content of modern falling dust is relatively uniform, with a mean value of 1.21×10^8 atoms/g, a measurement similar to that of Chinese loess (Zhou et al. 2007a) and to the value found in the study by Shen et al. (2009) on dust ^{10}Be falling near Dingbian, China ($1.25 \pm 0.06 \times 10^8$ atoms/g). Despite the fact that modern dust flux is much higher in spring relative to summer in northern China, ^{10}Be concentration in falling dust remains fairly constant. In addition, we find that dust ^{10}Be concentration is roughly independent of the local precipitation changes. This feature might be considered as an analogue to improve our understanding on the fundamental information of the source component contained in loess ^{10}Be records and its spatial/temporal distribution features.

INTRODUCTION

Cosmogenic ^{10}Be , with a half-life of 1.39 Ma (Korschinek et al. 2010), is primarily produced in the atmosphere by the spallation of cosmic-ray particles with nitrogen and oxygen (Lal and Peters 1967). Once produced in the troposphere, it quickly becomes attached to aerosols, and is removed from the atmosphere mainly through the wet precipitation process, and finally deposited in various kinds of sediments (McHargue and Damon 1991; Baumgartner et al. 1997). Unlike ^{14}C , ^{10}Be does not exchange with the atmosphere once deposited (Frank 2000), so it can be considered as a proxy for environmental tracing on long timescales. In particular, the development of the accelerator mass spectrometry (AMS) technique for ^{10}Be measurement promoted the wider application of this cosmogenic isotope in environmental tracing studies. The ^{10}Be record in loess, as well as in marine sediments or ice cores, has been broadly used for several aspects on paleoclimate variation (Shen et al. 1992; Beer et al. 1993; Gu et al. 1996), paleoprecipitation reconstruction (Heller et al. 1993; Shen et al. 2000; Zhou et al. 2007a), and for reconstructing variations in geomagnetic field intensity (Zhou et al. 2007a,b, 2010; Xian et al. 2008). Several different studies have come to the conclusion that the ^{10}Be in Chinese loess-paleosol mainly arises from 2 sources: 1) from newly produced meteoric ^{10}Be precipitated by rain or snow and 2) from the recycled eolian dust from the source region containing ^{10}Be that arrived to the ground at some earlier time but has yet to decay (Shen et al. 1992, 2009; Gu et al. 1996; Zhou et al. 2007a). However, the behavior of source component variation related to dust fall contained in the loess ^{10}Be is still being debated.

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Some studies indicated that this recycled ^{10}Be signal in loess was closely related to the dust flux; it could fluctuate dramatically depending on significant variations in the loess dust flux due to glacial-interglacial climatic changes (Gu et al. 1996; Shen et al. 2000), while later studies have suggested that the ^{10}Be concentration in recycled dust is constant, and thus independent of dust flux (Zhou et al. 2007a; Xian 2007; Xian et al. 2008). The latter argument was made on the basis that the dust falling on the Loess Plateau has been derived from a broad area including the Gobi and Taklimakin deserts, during which substantial mixing occurs, reducing variations in ^{10}Be concentration. The present study is aimed at verifying this assertion of constancy.

We know that the eolian Chinese loess is controlled by the Siberia-Mongolia high-pressure system, which dominates the winter monsoon dynamics and controls the main dust source for loess deposit in the downwind regions (An et al. 1990, 1991). Therefore, the ^{10}Be concentration measurement study on the modern falling dust process in Chinese Loess Plateau can potentially provide some fundamental information about the source ^{10}Be distributions. There have been several previous studies of ^{10}Be concentration in the falling dust process. Shen et al. (1992) measured ^{10}Be concentration data of about 2.60×10^8 atoms/g from a single sample collected from Jinan taken in April 1984. Gu et al. (1996) reported ^{10}Be concentration data from 3 falling dust events sampled from Longxi in August 1983, with values ranging from 1.41 to 2.53×10^8 atoms/g. Shen et al. (2009) recently reported additional falling dust ^{10}Be concentration data from Xifeng (April and August 1999), Dingbian (winter 1999), Huanxian (April and August 1999), Beijing (April 2006), and Ningbo (April 2007). The highest value reported by Shen et al. (2009) is $\sim 14.83 \times 10^8$ atoms/g in Ningbo, and the lowest value is 1.25×10^8 atoms/g in Dingbian. These efforts have undoubtedly contributed to our knowledge on the falling dust ^{10}Be spatial distribution; however, there is little available continuous data on ^{10}Be in falling dust, because only a single month was selected for sampling in these studies.

In our study, we collected airborne dust from the Ansai research station of soil and water conservation in the northern Chinese Loess Plateau, to conduct continuous observation studies on the modern falling dust process. We intend to establish a long-standing system for routine observation and ^{10}Be tracing studies. The present paper reports the method for modern dust sampling and preliminary results of high-precision ^{10}Be concentration measurement of 10 samples with monthly resolution in 2008 and 2009 using the 3MV multi-element AMS in the Xi'an AMS Center.

METHODS

Sampling and Measurements

The Ansai station ($36^\circ 51' \text{N}$, $109^\circ 19' \text{E}$) for dust sampling is located in a typical deeply incised hilly terrain of the northern Chinese Loess Plateau with an altitude ~ 1200 m. The mean annual temperature and precipitation is about 8.8°C and 500 mm, respectively. This site is close to the transitional zones of the Mu Us Desert and the Loess Plateau, and is optimal for measuring variations in ^{10}Be concentrations of falling dust. To ensure the sample quality, a computer automated sampling system was used to collect the modern falling dust samples (see Figure 1).

This specific system consists of 2 independent hermetic barrels (~ 40 cm diameter), designed to collect the falling dust and rainfall samples, respectively. During the dry days, one of the barrels is used to collect the falling dust continuously unless rainfall is coming, whereas the other is automatically opened for collecting rainfall samples. We note that this system is adapted to the severe field environment, even for temperatures ranging between -50°C and 9°C , and subject to strong wind conditions. In this paper, 10 dust samples from May 2008 to June 2009 were collected for ^{10}Be concentration measurement studies.

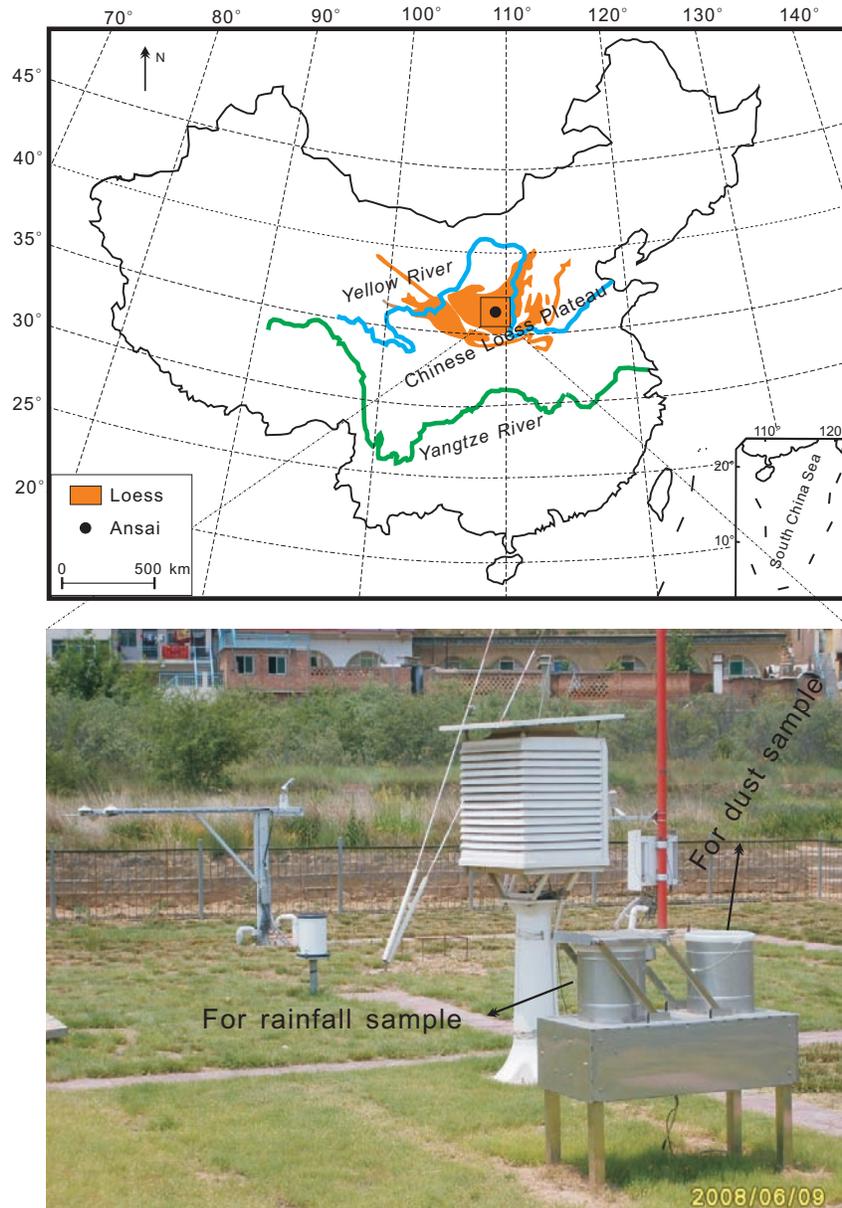


Figure 1 Map showing the location of Ansai study sites and the automated sampling system. The shaded area on the map shows the broad feature of the Chinese Loess Plateau. As for sample collection, 2 independent hermetic barrels are auto-controlled to take the modern dust and precipitation samples, respectively.

Chemical Pretreatment and ¹⁰Be Measurements

Chemical pretreatment for BeO samples of modern dust is conducted in the Xi'an AMS center using a process similar to that used for loess by Zhou et al. (2006). Compared with the procedure reported by Shen et al. (1992), several optimized procedures, such as leaching and cation resin exchange, are adopted to chemically separate the isobar ¹⁰B. This new method allows us to easily determine the

leaching curves of ^{10}B and ^{10}Be for every sample. Be appears after the third column volume of 10 mL 1N HCl, and the B has been leached in the first 3 column volumes. In addition, a simple automatic system comprised of a computer-controlled driven pump is used to control the column elutant volumes. Detailed information for ^{10}Be chemical pretreatment is given in Zhou et al. (2007c).

Using this procedure, a total of 10 BeO samples together with 3 chemical blanks were prepared. ^{10}Be measurements were made on the 3MV accelerator mass spectrometer (AMS) in Xi'an. This instrument is capable of very high-precision ^{10}Be analysis, with a low background $^{10}\text{Be}/^9\text{Be}$ ratio of 3.65×10^{-15} (occasionally as low as 1.00×10^{-15}) (Zhou et al. 2007c). To ensure high precision of the ^{10}Be analysis and minimize random errors, each sample is measured 10 times. These results are shown in Table 1, along with measurements on chemical procedural blanks.

Table 1 Measured $^{10}\text{Be}/^9\text{Be}$ ratios of the falling dust samples from Ansai and compared with the chemical blanks at 2.5MV terminal voltage.

Sample #	Sample type	Time	^9Be charge	$^{10}\text{Be}/^9\text{Be}$ (10^{-12})	Standard deviation (10^{-14})	^{10}Be concentration (10^8 atoms/g)
XAB-2419	Blank	—	0.00028	0.02	0.33	—
XAB-2501	Dust	May 2008	0.00031	1.16	2.11	1.16
XAB-2502	Dust	July 2008	0.00040	0.42	2.07	0.91
XAB-2504	Dust	Aug 2008	0.00039	0.22	1.59	1.40
XAB-3673	Dust	Sept 2008	0.00022	0.23	0.62	1.44
XAB-3665	Dust	Jan 2009	0.00018	0.04	0.51	1.03
XAB-3666	Dust	Feb 2009	0.00037	0.22	0.44	1.13
XAB-3667	Dust	Mar 2009	0.00029	0.17	0.33	1.18
XAB-3668	Dust	Apr 2009	0.00035	0.31	1.09	1.26
XAB-3669	Blank	—	0.00042	0.01	0.05	—
XAB-3670	Dust	May 2009	0.00028	0.43	0.99	1.45
XAB-3671	Blank	—	0.00043	0.01	0.08	—
XAB-3672	Dust	June 2009	0.00025	0.19	1.54	1.20

The results show that the measured ratios ($^{10}\text{Be}/^9\text{Be}$) of 3 chemical procedural blanks are about 2×10^{-14} , 1×10^{-14} , and 1×10^{-14} , respectively, with an average of 1.3×10^{-14} . The 10 dust BeO samples compare well with previous measurements on Luochuan loess measured at the VERA AMS laboratory in Vienna and NSF-AMS in Tucson (Zhou et al. 2007a). Therefore, the obtained modern falling dust ^{10}Be signals can be considered a robust value for ^{10}Be concentration in the recycled dust component of Chinese loess.

SUMMARY AND DISCUSSION

Figure 2a shows the average mass-corrected ^{10}Be concentrations of modern falling dust samples from Ansai station during 2008 and 2009. The mean value is 1.21×10^8 atoms/g, which is similar to that found in loess especially during the glacial stages (Shen et al. 2000; Zhou et al. 2007a), and the adjacent Dingbian falling dust ^{10}Be concentration ($1.25 \pm 0.06 \times 10^8$ atoms/g) reported by Shen et al. (2009). The calculated relative standard deviation (RSD), which is the ratio of the standard deviation (SD) with its mean value, is $\sim 13\%$, suggesting that the dust ^{10}Be signal is relatively uniform on seasonal scales. Previous studies have proven that spring (March–May) is the season with the most frequent and strong dust storms in China (Zhang et al. 2003; Liu et al. 2004). However, there is no apparent seasonal variation in ^{10}Be concentration in falling dust. This suggests that the ^{10}Be concentration in modern falling dust is quasi-homogeneous on the seasonal scale at least.

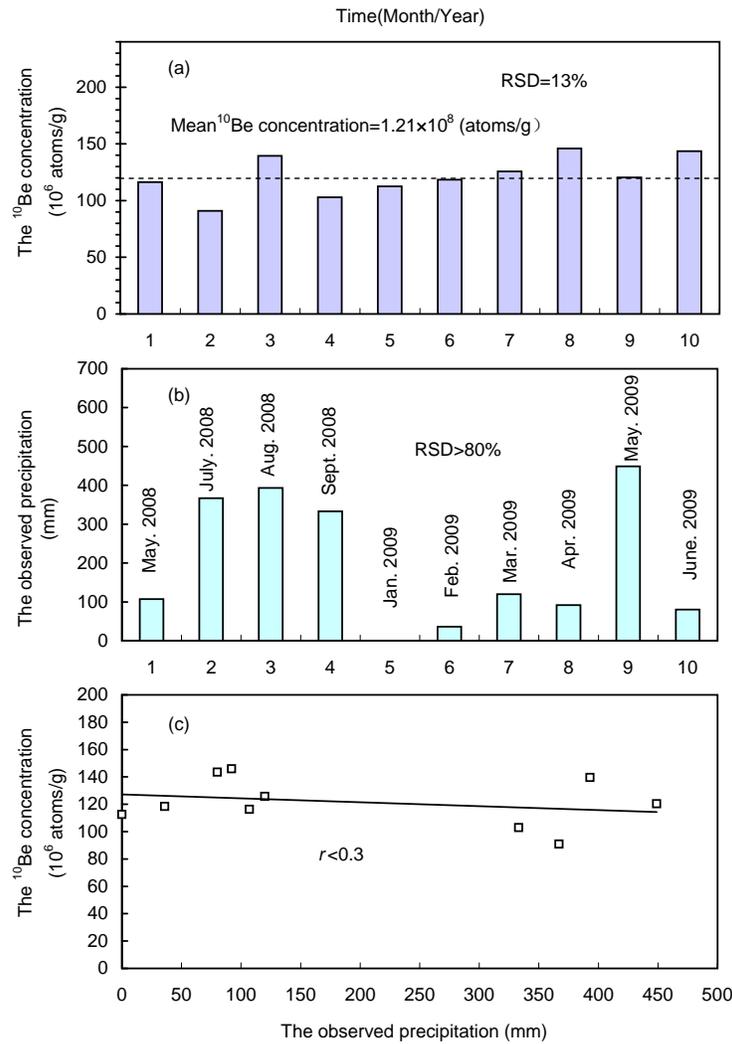


Figure 2 The mass-corrected ¹⁰Be concentration of falling dust in Ansai compared with the local observed precipitation. (a) The ¹⁰Be concentration of the dust in Ansai, with a mean value of 1.21×10^8 atoms/g and a relative standard deviation (RSD) of about 13%, suggesting that the signal is relatively uniform on a seasonal scale. (b) The observed local precipitation is of high seasonal variability in Ansai. The relative standard deviation (RSD) is >80%. (c) The correlation analysis between falling dust ¹⁰Be concentration and local precipitation, showing that the dust ¹⁰Be signal is roughly independent of the local precipitation changes (correlation coefficient $r < 0.3$).

We also compared our results with the local observed precipitation (Figure 2b), to test whether the ¹⁰Be concentration in modern falling dust also varies as a function of local precipitation. Unlike the measured falling dust ¹⁰Be concentration, the local precipitation in Ansai is of high seasonal variability with a calculated relative standard deviation (RSD) of >80%. The correlation analysis between falling dust ¹⁰Be concentration and local precipitation (Figure 2c) further indicates that the dust ¹⁰Be signal is roughly independent of the local precipitation changes (coefficient $r < 0.3$). Since our modern dust sample is continuously collected during the dry days (the computer-controlled system will automatically close the container when the rain is coming), the local precipitation variation

does not show an obvious impact on the ^{10}Be concentration of falling dust. The measured falling dust ^{10}Be concentration in Ansai can be considered to reflect the average ^{10}Be contributions from the dust source region to the Chinese Loess Plateau.

Using ^{10}Be as an environmental tracer in terrestrial loess-paleosol systems is challenging in part because variations in ^{10}Be concentration due to recycled dust, variations in precipitation, or geomagnetic field are always tightly interwoven (e.g. Shen et al. 1992; Beer et al. 1993; Zhou et al. 2007a). The present work confirms the assumption made by Zhou et al. (2007a) that the adsorbed ^{10}Be concentration in dust is relatively uniform.

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REFERENCES

- An ZS, Liu TS, Lu YC, Porter SC, Kukla G, Wu XH, Hua YM. 1990. The long-term paleomonsoon variation recorded by the loess-paleosol sequence in Central China. *Quaternary International* 7–8:91–5.
- An ZS, Kukla GJ, Porter SC, Xiao JL. 1991. Magnetic susceptibility evidence of monsoon variation on the Loess Plateau of central China during the last 130,000 years. *Quaternary Research* 36(1):29–36.
- Baumgartner S, Beer J, Wagner G, Kubik P, Suter M, Raisbeck GM, Yiou F. 1997. ^{10}Be and dust. *Nuclear Instruments and Methods in Physics Research B* 123(1–4):296–301.
- Beer J, Shen CD, Heller F, Liu TS, Bonani G, Beate D, Suter M, Kubik PW. 1993. ^{10}Be and magnetic susceptibility in Chinese loess. *Geophysical Research Letters* 20(1):57–60.
- Frank M. 2000. Comparison of cosmogenic radionuclide production and geomagnetic field intensity over the last 200,000 years. *Philosophical Transactions of the Royal Society of London Series A* 358(1768):1089–107.
- Gu ZY, Lal D, Southon J, Caffee MW, Guo ZT, Chen MY. 1996. Five million year ^{10}Be record in Chinese loess and red-clay: climate and weathering relationships. *Earth and Planetary Science Letters* 144(1–2):273–87.
- Heller F, Shen CD, Beer J, Liu XM, Liu TS, Bronger A, Suter M, Bonani G. 1993. Quantitative estimates of pedogenic ferromagnetic mineral formation in Chinese loess and palaeoclimatic implications. *Earth and Planetary Science Letters* 114(2–3):385–90.
- Korschinek G, Bergmaier A, Faestermann T, Gerstmann UC, Knie K, Rugel G, Wallner A, Dillmann I, Dollinger G, Lierse von Gostomskie C, Kossert K, Maiti M, Poutivtsev M, Rimmert A. 2010. A new value for the half-life of ^{10}Be by heavy-ion elastic recoil detection and liquid scintillation counting. *Nuclear Instruments and Methods in Physics Research B* 268(2):187–91.
- Lal D, Peters B. 1967. Cosmic ray produced radioactivity on earth. In: Sittler K, editor. *Handbook of Physics*. Volume 46/2. Berlin: Springer. p 551–612.
- Liu XD, Yin ZY, Zhang XY, Yang XC. 2004. Analyses of the spring dust storm frequency of northern China in relation to antecedent and concurrent wind, precipitation, vegetation, and soil moisture conditions. *Journal of Geophysical Research* 109(D16):D16210, doi: 10.1029/2004JD004615.
- McHargue LR, Damon PE. 1991. The global beryllium-10 cycle. *Reviews of Geophysics* 29(2):141–58.
- Shen CD, Beer J, Liu TS, Oeschger H, Bonani G, Suter M, Wöflfi W. 1992. ^{10}Be in Chinese loess. *Earth and Planetary Science Letters* 109(1–2):169–77.
- Shen CD, Beer J, Heller F, Kubik PW, Suter M, Liu TS. 2000. ^{10}Be -susceptibility model and quantitative estimates of pedogenic ferromagnetic material flux in Chinese loess. *Nuclear Instruments and Methods in Physics Research B* 172(1–4):551–4.
- Shen CD, Beer J, Kubik PW, Sun WD, Liu TS, Liu KX. 2009. ^{10}Be in desert sands, falling dust and loess in China. *Nuclear Instruments and Methods in Physics Research B* 268(7–8):1050–3.
- Xian F. 2007. The study of the data analysis for the past 80ka paleo-geomagnetic field tracing and paleoprecipitation reconstruction from ^{10}Be in loess of China [PhD dissertation]. Beijing: Graduate University of Chinese Academy of Sciences.
- Xian F, An ZS, Wu ZK, Beck JW, Yu HG, Kang ZH,

- Cheng P. 2008. A simple model for reconstructing geomagnetic field intensity with ¹⁰Be production rate and its application in loess studies. *Science in China Series D* 51(6):855–61.
- Zhang XY, Gong SL, Zhao TL, Arimoto R, Wang YQ, Zhou ZJ. 2003. Sources of Asian dust and role of climate change versus desertification in Asian dust emission. *Geophysical Research Letters* 30(24):2272, doi: 10.1029/2003GL018206.
- Zhou WJ, Zhao X, Lu XF, Lin L, Zhengkun W, Peng C, Wengnian Z, Chunhai H. 2006. The 3MV multi-element AMS in Xian, China: unique features and preliminary tests. *Radiocarbon* 48(2):285–93.
- Zhou WJ, Priller A, Beck WJ, Wu ZK, Chen MB, An ZS, Kutschera W, Xian F, Yu HG, Liu L. 2007a. Disentangling geomagnetic and precipitation signals in an 80-kyr Chinese loess record of ¹⁰Be. *Radiocarbon* 49(1): 139–60.
- Zhou WJ, Chen MB, Xian F, Song SH, Wu ZK, Jull AJT, Liu WG. 2007b. The mean value concept in mono-linear regression of multi-variables and its application to trace studies in geosciences. *Science in China Series D* 50(12):1828–34.
- Zhou WJ, Lu XF, Wu ZK, Zhao WN, Huang CH, Li LL, Cheng P. 2007c. New results on Xi'an-AMS and sample preparation systems at Xi'an-AMS center. *Nuclear Instruments and Methods in Physics Research B* 262(1):135–42.
- Zhou WJ, Xian F, Beck JW, Jull AJT, An ZS, Wu ZK, Liu M, Chen MB, Priller A, Kutschera W, Burr GS, Yu HG, Song SH, Cheng P, Kong XH. 2010. Reconstruction of 130-kyr relative geomagnetic intensities from ¹⁰Be in two Chinese loess sections. *Radiocarbon* 52(1):129–47.