SUPPLEMENTARY MATERIAL

1. Field sampling

In the Lanzhou region, fluvial gravel layers on top of strath surfaces (beveled into Tertiary sandstone, Fig. A1) are typically 5~10 m thick. Excavation of gravel for construction materials has left behind numerous adits ranging in depth from 5 m - 50 m in from the cliff face. Most of these provide ready access to deeply buried gravel. We extracted approximately 2 kg of quartz pebbles from each locality. Our sampling focused on localities close to measured and sampled stratigraphic sections (Fig. A2).

2. Sample preparation

Approximately 50-70 pebbles (500-800 g) of each sample were extracted from each field sample; pebbles were crushed, ground and sieved to a size of ~0.5-1 mm. After rinsing with water several times, sieved samples were leached with a 68-70% nitric acid solution to dissolve carbonates and residual metals from crushing. Samples were then subjected to leaching in a 5% HF/HNO_3 solution to remove meteoric ^{10}Be as well as accessory minerals. Leached samples were then subject to both magnetic and heavy liquid separation to further purify the remaining quartz, and finally subjected to leaching with 1% HF/HNO_3 in the ultrasonic tank. From the purified quartz, approximately 0.25 g of each sample was weighed, dissolved with HF and HNO_3 solutions, and analyzed by ICP-OES (Inductively Coupled Plasma Optical Emissions Spectrometer) to measure Al concentrations. Typically, these ranged from 110-204 ppm, sufficiently low to merit analysis.

Following chemical procedure in the Mineral Separation Lab of Purdue University, purified quartz from each sample (~65 g) was dissolved in HF and HNO_3. We added a ^{9}Be spike of ~0.36 mg in a carrier solution. A single blank sample was also processed along with other quartz samples to control for variations in the preparation. After removal of fluorides with H_2SO_4 and removal of Fe by anion exchange, pure Al and Be were separated on cation/anion exchange columns and precipitated as hydroxides. These precipitates were dried and oxidized at 1100° C. The resultant Al_2O_3 and BeO powders were mixed with equal volumes of Ag and Nb respectively, and packed in target holders for AMS (Accelerator Mass Spectrometry) determination of $^{10}Be/^{9}Be$ and $^{26}Al/^{27}Al$.

3. Burial age calculation

Assuming a constant pre-burial erosion rate (E) and a single burial history, pre-burial accumulation of ^{10}Be [$N_{Al}(0)$] and ^{26}Al [$N_{Be}(0)$] can be modeled as:

$$N_{Al}(0) = \frac{P_{Al}}{\frac{1}{\tau_{Al}} + \frac{E}{L}}, \quad (1)$$

$$N_{Be}(0) = \frac{P_{Be}}{\frac{1}{\tau_{Be}} + \frac{E}{L}}, \quad (2)$$

Where, P_{Al} and P_{Be} are production rates of ^{26}Al and ^{10}Be in the surface, and L is the attenuation length (~60 cm, with a rock density of 2.6 g/cm^3). Radioactive mean lives of ^{26}Al (τ_{Al}) and ^{10}Be (τ_{Be}) are 1.02±0.04 Ma and 2.00±0..02 Ma (Chmeleff et al., 2010), respectively. Production rates for ^{26}Al and ^{10}Be are scaled using Stone's scheme (Stone, 2000) with a value of 5.1±0.3 ^{10}Be atoms·g^{-1}·yr^{-1} at sea level high latitude (Gosse and Phillips, 2001). In this study, production rates are averaged with a mean altitude of 3100 m and latitude of 36°N for upstream drainage basin of Lanzhou.

In calculation of burial ages, two scenarios are considered for our samples. In the first case, an instantaneous and complete burial to present depth is assumed, and we use the simple model suggested by Granger and Muzikar (2001). Concentration of ^{26}Al [$N_{Al}(t)$] and ^{10}Be [$N_{Be}(t)$] with a burial time t can be modeled as:

$$N_{Al}(t) = N_{Al}(0)e^{-t/\tau_{Al}}, \quad (3)$$

$$N_{Be}(t) = N_{Be}(0)e^{-t/\tau_{Be}}, \quad (4)$$

With an initial ^{26}Al/^{10}Be ratio related to an erosion rate, it decreases exponentially over time:

$$\frac{N_{Al}(t)}{N_{Be}(t)} = \frac{N_{Al}(0)}{N_{Be}(0)} e^{-t(\frac{1}{\tau_{Al}} - \frac{1}{\tau_{Be}})} \quad (5)$$

Then, burial ages and inherited erosion rates can be calculated by analytically solving these equations with measured concentrations of $^{26}Al\ (t)$ and $^{10}Be\ (t)$, and the results are plotted graphically in Figure A3, where the ^{26}Al/^{10}Be ratio ratios gradually decrease as the terrace becomes older. The inherited erosion rates are assembled in a narrow range of 0.1 – 0.2 mm/yr, showing a trend of increasing erosion rates through time that is most likely related to the contribution of sediment from the previously buried Jishi formation conglomerates. In the results, uncertainties derive from two parts; one standard error of analytical uncertainty is calculated from AMS counting statistics and from ICP-OES

measurements; systematic uncertainties include uncertainties in radioactive decay rates of ^{26}Al and ^{10}Be, production rate ratio, and absolute production rate (20%). Uncertainty acquired from each factors above is added in quadrature, and total uncertainties in our samples rang from 15 -30%.

In the second case, post-burial production of cosmogenic isotopes is incorporated in the age calculation by modeling slow burial at a constant accumulation rate. Our samples are usually dug from the middle and upper part of each gravel layer, and the accumulation rate for gravel is difficult to estimate, but we consider gravel deposition to be nearly instantaneous and assume a finite burial depth (~3 m) as the initial depth for all the samples. Upon the gravel deposition, accumulation rates of loess in the Lanzhou area ranges from ~50 - 200 m/Ma, with a average rate of 100 m/Ma, implying that samples may have experienced production by muon capture for several hundred thousand years following deposition (Granger and Muzikar, 2001). Therefore, we consider that a burial rate of 100 m/Ma is likely to be the average burial rate experienced by our samples.

When post-burial production is considered, the time rate of change of cosmogenic nuclides is calculated as:

$$\frac{dN_{Al}(t)}{dt} = -\frac{N_{Al}(t)}{\tau_{Al}} + P_{Al}(t), \qquad (6)$$

$$\frac{dN_{Be}(t)}{dt} = -\frac{N_{Be}(t)}{\tau_{Be}} + P_{Be}(t), \qquad (7)$$

where $P_{Al}(t)$ and $P_{Be}(t)$ are post-burial production rates of ^{26}Al and ^{10}Be, which are depth dependent related to burial time. In this case, production by muon capture is calculated separately, and they can be expressed as:

$$P_{Al}(t) = A_0 e^{-d/L_0} + A_1 e^{-d/L_1} + A_2 e^{-d/L_2} + A_3 e^{-d/L_3}, \qquad (8)$$

$$P_{Be}(t) = B_0 e^{-d/L_0} + B_1 e^{-d/L_1} + B_2 e^{-d/L_2} + B_3 e^{-d/L_3}, \qquad (9)$$

where d is the burial depth related to initial burial depth and loess accumulation rate, and L_i is the attenuation length for a cosmogenic isotope production reaction. L_0 is the attenuation length for spallogenic production reactions, and assigned a value of $160/\rho$ (Reedy, et al., 1994), where ρ is the density of the rock covering the sample; L_1 and L_2 are the attenuation length for negative muon capture production reactions; and L_3 is the attenuation length for fast muon production reactions. Their values are given by L_1=738/ρ, L_2=2688/ρ, and L_3=4360/ρ (Granger and Muzikar, 2001). At sea level and high latitude, the coefficients A_j and B_j are assigned values of A_0=33.75, A_1=0.72, A_2=0.16, A_3=0.19, B_0=5, B_1=0.09, B_2=0.02, and B_3=0.02 (Granger and Muzikar, 2001). For our samples, the values of A_0 and B_0 are scaled to the field area with latitude of 36ºN and elevation of 1700 m using the

scheme proposed by Stone (2000). Muon production is scaled for altitude only. Because we are primarily concerned with muon production at depth, production rates of the energetic muons are attenuated equally in the atmosphere and sediment. At an elevation of 1700 m, air pressure is 190 g/cm^2 below that at sea level, equivalent to ~120 cm of sediment with density of 1.6 g/cm^3. The gravel deposit is covered by overbank silt and loess with a rock density of 1.6 g/cm^3. Initial conditions for $N_{Al}(t)$ and $N_{Be}(t)$ in equation (6) and (7) are given by equation (1) and (2). Equations of (1), (2), (6), (7), (8) and (9) are solve numerically in determining the burial age *t*. This was done by forward modeling the range of possible combinations of t and E, and then identifying the *t* and *E* pair that best reproduces the determined ^{26}Al/^{10}Be ratio and ^{10}Be concentration. For the errors in determination of concentrations of ^{26}Al and ^{10}Be will introduce dominant uncertainties in age calculation, with the result, analytical uncertainties on the concentrations of ^{26}Al and ^{10}Be are only considered, and uncertainties in the production rates, production rate ratio and radioactive decay constants are neglected.

4. Analytical expression for mixing of two sediment sources

For a mixture of two components, one of which was buried for time ($t_1 + t_2$) and another buried for a time t_2, the ^{26}Al and ^{10}Be concentrations can be written as

$$N = f[N_{i,1}e^{-(t_1+t_2)/\tau_i}] + (1-f)[N_{i,2}e^{-t_2/\tau_i}] \quad , \qquad (10)$$

where *f* is the fraction of the first component, *N* is the measured value, and $N_{i,j}$ represents the inherited values at the time of deposition. If we calculate the concentration at the time of terrace gravel deposition, then

$$Ne^{t_2/\tau_i} = f[N_{i,1}e^{-t_1/\tau_i}] + (1-f)[N_{i,2}] \quad . \qquad (11)$$

We can calculate the ^{26}Al/^{10}Be ratio R_{terr} at the time of terrace deposition as

$$R_{terr} = \{f[N_{26,1}e^{-t_1/\tau_{26}}] + (1-f)[N_{26,2}]\} / f[N_{10,1}e^{-t_1/\tau_{10}}] + (1-f)[N_{10,2}] . \qquad (12)$$

If we further assume that the sediment is derived from a landscape eroding in steady-state, then the relationship between N_{26} and N_{10} at the time of erosion can be represented as

$$N_{26} = (P_{26}/P_{10}) \cdot N_{10}/(1 + N_{10}^*) , \qquad (13)$$

where

$$N_{10}^* = N_{10}/(P_{10} \cdot \tau_{10}) . \qquad (14)$$

Equation (13) is an approximation based on the assumption that

$$\tau_{10} = 2\tau_{26} , \qquad (15)$$

which is good to within a few percent. Substituting (13) into (12) leads to an expression

for the ^{26}Al/^{10}Be ratio in the terrace:

$$R_{terr} = \{f[(P_{26}/P_{10}) \cdot N_{10,1}/(1+N_{10,1}*)e^{-t_1/\tau_{26}}] + (1-f)(P_{26}/P_{10}) \cdot N_{10,2}/(1+N_{10,2}*)\}/ \{f[N_{10,1}e^{-t_1/\tau_{10}}] + (1-f)[N_{10,2}]\} \quad (16)$$

If we now assume that the erosion rates remain unchanged over time, at the time of deposition

$$N_{10,1} = N_{10,2} \ , \quad (17)$$

then

$$R_{terr} = (P_{26}/P_{10})\{f[1/(1+N_{10,1}*)e^{-t_1/\tau_{26}}] + (1-f)[1/(1+N_{10,2}*)]\}/\{f[e^{-t_1/\tau_{10}}] + (1-f)\} \quad (18)$$

Taking advantage of the relationship in equation (15),

$$R_{terr} = (P_{26}/P_{10})\{f[1/(1+N_{10}*)e^{-2t_1/\tau_{10}}] + (1-f)[1/(1+N_{10}*)]\}/\{f[e^{-t_1/\tau_{10}}] + (1-f)\} \quad (19)$$

Simplifying,

$$R_{terr} = (P_{26}/P_{10})[1/(1+N_{10}*)[1+f(e^{-2t_1/\tau_{10}}-1]/[1+f(e^{-t_1/\tau_{10}}-1)] \quad (20)$$

Equation (20) gives the expected ratio as a function of the age of the older material the fraction in the sediment, and the concentration at the time of burial.

We can further simplify if we let

$$R' = (P_{26}/P_{10})[1/(1+N_{10}*)]. \quad (21)$$

R' is calculated from equation (13), and represents the 26Al/10Be ratio at the time of deposition in an eroding landscape. Then,

$$R_{terr} = R'[1+f(e^{-2t_1/\tau_{10}}-1]/[1+f(e^{-t_1/\tau_{10}}-1)] \quad (22)$$

and

$$f = [(R_{terr}/R')-1]/[(e^{-2t_1/\tau_{10}}-1)-(R_{terr}/R')(e^{-t_1/\tau_{10}}-1)]. \quad (23)$$

The ^{26}Al/^{10}Be ratio R_{terr} at the time of gravel deposition can be derived from the measured ratio R as:

$$R_{terr} = R \cdot e^{t2(1/\tau_{26}-1/\tau_{10})}. \quad (24)$$

Equations (23) and (24) can be used to determine the fraction of previously buried sediment as a function of the burial time in the source region, burial time in the terrace (here taken to be terrace age), and the measured ^{26}Al/^{10}Be ratio.

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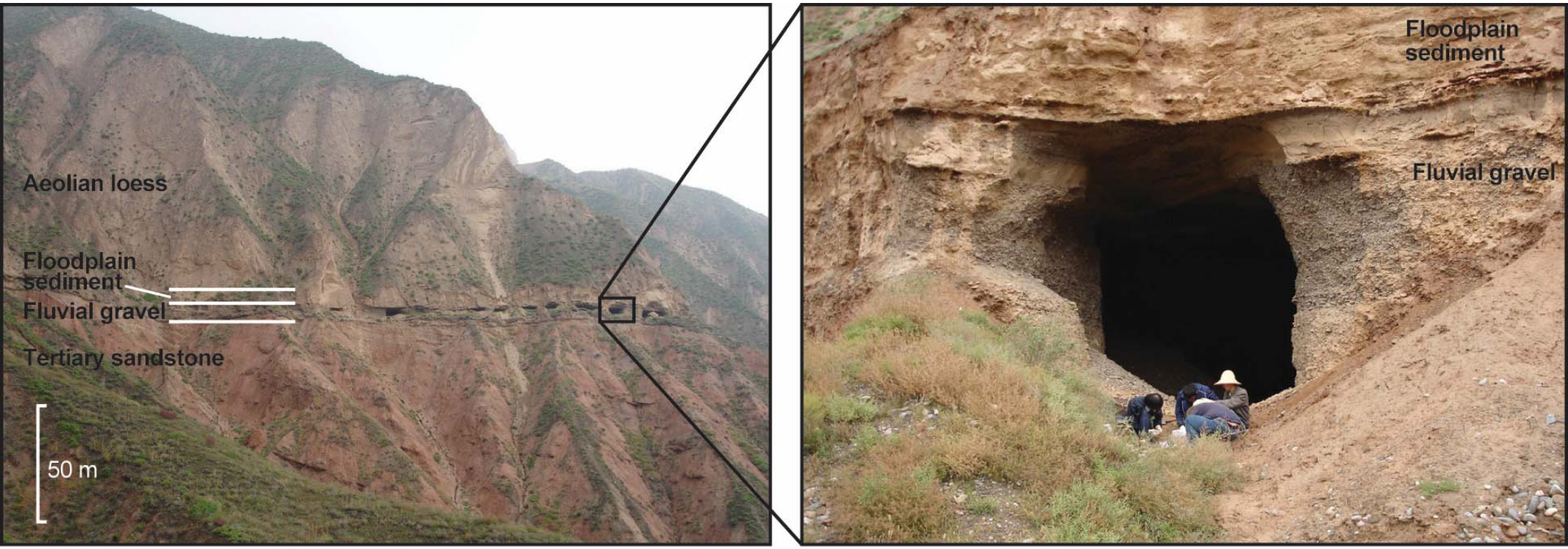
SUPPLEMENTAL FIGURE CAPTIONS

Figure DR1. Photos of the fluvial terraces and overlying loess (left) and of one of the sample sites in the gravel layer (right).

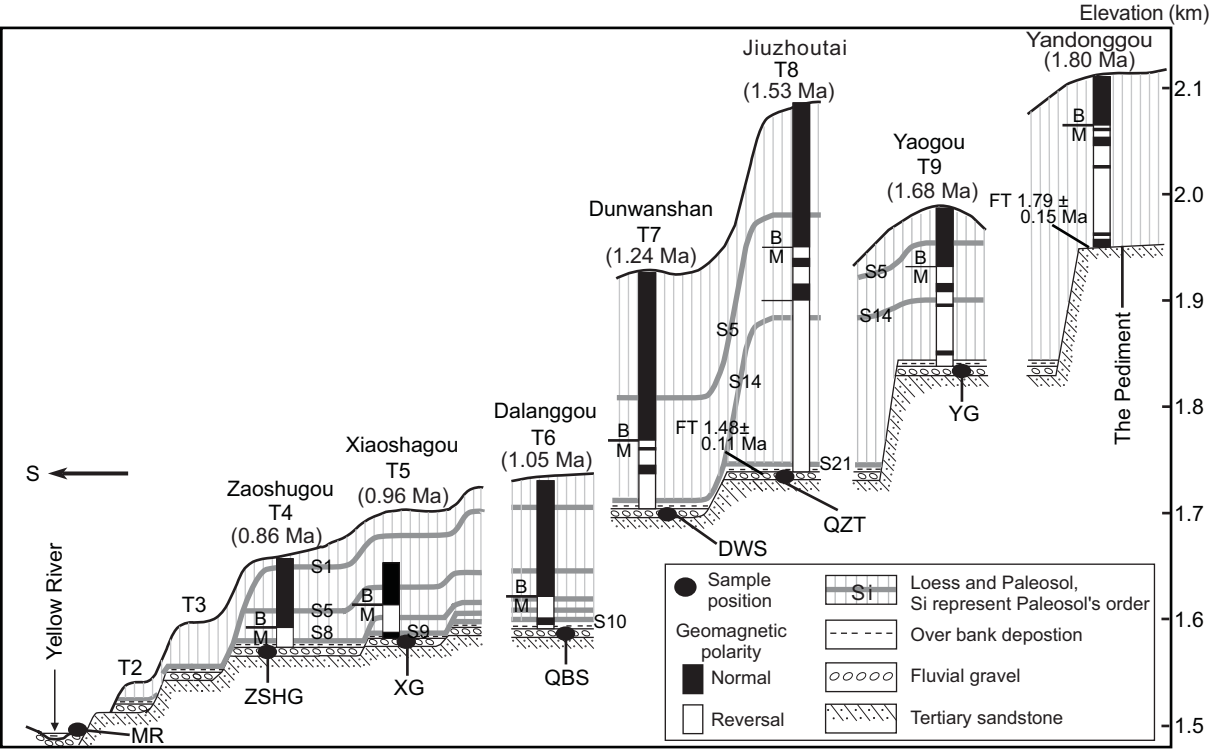
Figure DR2. Synthesis of stratigraphic and chronologic data from loess sequences overlying terrace surfaces. Magnetostratigraphy and loess-paleosol sequences are from Zhu et al., 1995 (Yandonggou and Yaogou T9), Chen et al., 1991 (Jiuzhoutai T8, Dunwashan T7), Pan et al., 2009 (Dalanggou T6, Xiaoshagou T5, Zaoshugou T4), and Pan et al., 1991 (T3 and T2). Best estimate of the age of fluvial deposits derived as in text.

Figure DR3. Logarithmic graph of $^{26}Al/^{10}Be$ ratio against ^{10}Be concentration. Solid lines represent burial time, and the steady erosion line represents 0 Ma burial in different erosion rate. With a constant erosion rate (e.g., 10 m/Ma), $^{26}Al/^{10}Be$ ratio will decrease along the dashed line. Cosmogenic burial ages and inherited erosion rates can be clearly observed from this graph.

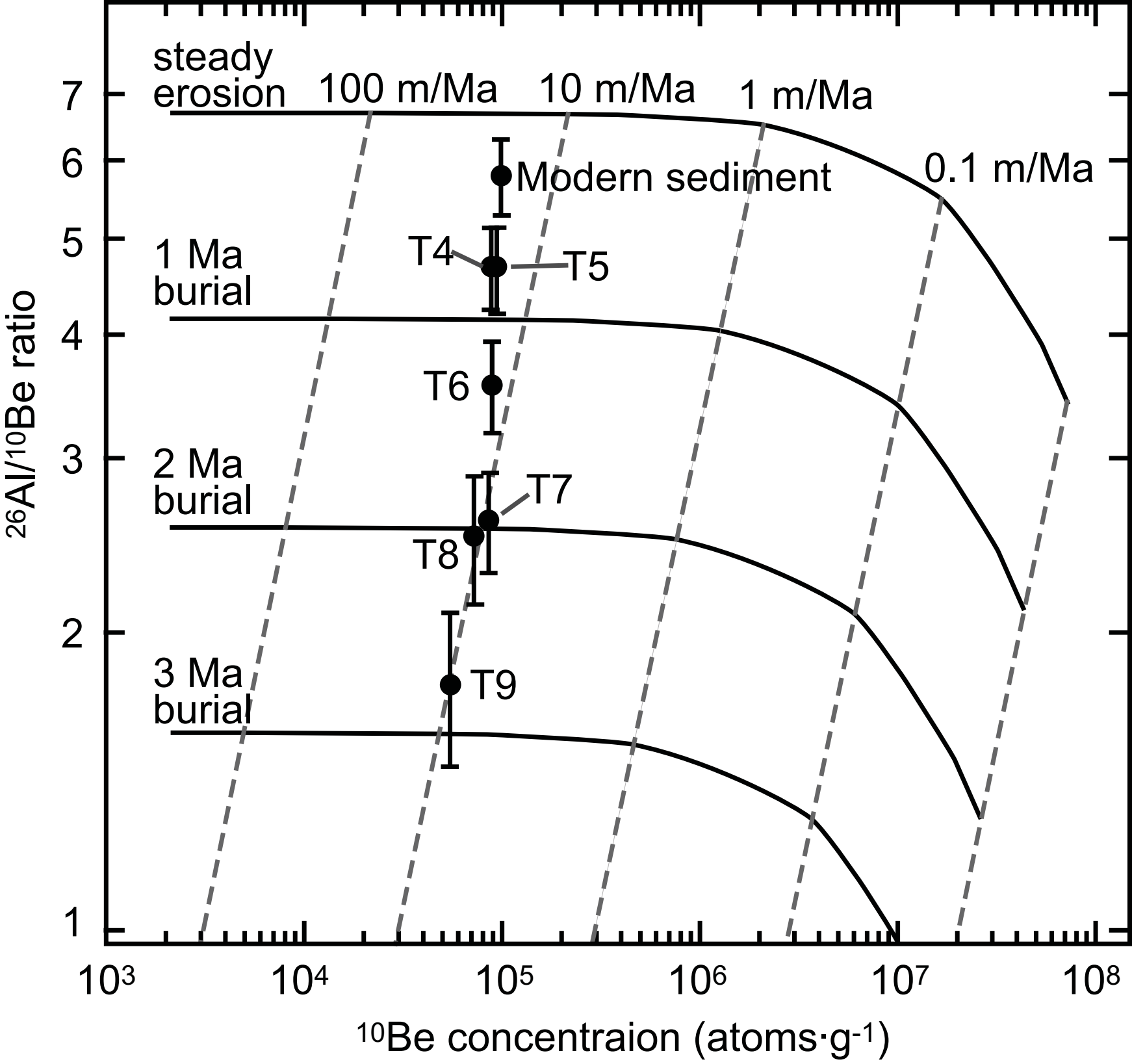


Xiaofei HU, Figure A1.eps

Figure DR1.



Xiaofei HU, Figure DR2.



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