Supplementary material 1: Cosmogenic nuclide sampling and analysis

Samples for cosmogenic nuclide concentration were taken from the top parts of large boulders of homogeneous size (typically one meter, see Figure S1), showing no evidence of frost cracking or aeolian erosion. Furthermore, all samples were taken from parts of the boulders that showed lichen cover and/or desert varnish, that indicate no (or very slow) erosion. Significant wind erosion has been observed, however, close to the ground level (less than 30 cm above ground): fresh rock with no lichen is exposed there, and boulders are more rounded there that at the tops. Moreover, boulders used do not show smaller fragments in their immediate surroundings, suggesting that boulder breakdown has not occurred.

Sample preparation (quartz extraction and purification, Be extraction) was done at the University of Colorado at Boulder, and targets were sent for AMS measurement at Lawrence Livermore National Laboratory. Samples were first crushed with jaw crusher and plate grinder, and then sieved between 420 and 850 micrometers. Cleaning and etching with 6N HCl on a hot roll overnight, and then with 48% HF and 70% HNO₃ (in equal quantities) removed most of the “soft” minerals. Subsequent a heavy liquid (lithium heteropolytungstate) removed minerals heavier and lighter than quartz.

Quartz grains were then cleaned three times (removing meteoric ¹⁰Be, as well as residual non-quartz material) with 1/3-2/3 HNO₃ and HF on hot roll for 8 hours, 12 hours and 24 hours, respectively.

Quartz purity was tested by measuring Al concentrations with CP-AES at the University of Colorado at Boulder, and samples with high Al content (>200 ppm) were re-cleaned in 1/3-2/3 HNO₃ and HF for 24 hours, until the concentration of Al dropped below 200 ppm.

Pure quartz was spiked with ~0.35 mg of ⁹Be and fully dissolved in pure HF on hot plates.

F was removed by adding perchloric acid on a hot plate, four times until complete evaporation had occurred. Fe and Ti were removed with low-pressure chromatography and ammonium hydroxide (NH₄OH) precipitation (several hours) and then in a centrifuge (two times 15 minutes at 2900 rpm). Be and Al were separated from each other using cation exchange chromatography. Samples were oxidized in hot furnace, then packed for AMS in an Al target, and sent to Lawrence Livermore National Laboratory for ^⁹Be/^¹⁰Be measurement.

¹⁰Be concentrations were determined to the ICN standard (07KNSTD, (Nishiizumi et al., 2007). The measured ratios were corrected for process blanks that were treated in the same way as the samples. Uncertainties are given as 1σ AMS errors. Our calculated ages also include a 10% error in assumed production rates. Correction for potential erosion of the tops of boulders or for burial by snow are discussed in the text.

Time-dependant scaling factors for altitude and latitude were made with CRONUS online calculator (Balco et al., 2008) (Wrapper script: 2.2, Main calculator: 2.1, Constants: 2.2.1, Muons: 1.1), and with the four scaling schemes available: 1) (Desilets and Zreda, 2003; Desilets et al., 2006), 2) (Dunai, 2001), 3) (Lifton et al., 2005), and 4) (Lal, 1991; Stone, 2000), with a low elevation/high latitude production rate of 4.96 at/yr/gSiO₂. Average ages as well as synthetic time-independent production rate were determined from the averaging of the four calculated set of ages, which are all within the same 4-8% (table 1B). Correction for inheritance has been done with 3 buried samples (see text for details of the correction), and correction for possible boulder erosion rate has been done with CRONUS (same parameters than above, Table 1D).

Figure S1. Photographs of boulders sampled for cosmogenic ages.

Supplementary material 2: OSL sampling and analysis

1. OSL sampling

We dug a trench near the terrace riser or selected the wall of a terrace that was deeply incised. We then exploited layers at least 0.3-0.5 m below the surface, to avoid risk that the material was influenced by sunlight after it was deposited. We selected silty sand or loess and soil layers to take samples. We used a stainless tube about 20 cm in length and ~3-6 cm in diameter. We covered one end using silver paper and adhesive tape, then pounded the tube into the layer using a hammer. When we finished, we pulled the tube out quickly and covered the other end side with the silver paper and the adhesive tape in prevent further exposure. Our analysis considered only the interior part of the sample, several cm from the ends of the tube.

2. Sample treatment and measurement

Sample pre-treatment and preparation was carried out at the State Key Laboratory of Earthquake Dynamics, Institute of Geology, China Earthquake Administration. Under subdued red light, we removed from both ends of the sample about 3 cm of material, which could have been exposed to light or polluted somehow. We then removed from the fresh sample approximately 30 g of material to determine the water content, and we ground the sample until all grains passed through the 0.063 mm sieve before measuring U, Th, and K concentrations in the samples.
The remaining fresh samples were extracted and pretreated with 37% HCl and 30% H₂O₂ to remove carbonates and organic material, respectively. We then refined the material by extracting a fine silt (4–11 µm) fraction. This polymineral size-fraction was then immersed in H₂SiF₆ (30%) for at least 3-6 days with ultrasonic bathing to remove feldspar minerals. The ‘purity’ of the isolated Qz fractions was checked by IR stimulation.

All measurements were performed using a Daybreak 1100 and 2200 OSL system equipped with a combined blue (470 ± 5 nm) and infrared (880 ± 80 nm) LED unit, and a ^90Sr/^90Y beta source for irradiation. The equivalent dose of the fine-grained quartz fractions (4-11 µm) were measured using the SMAR (sensitivity-corrected MAR) protocol (Lu et al., 2007). Generally, more than six aliquots were measured to determine the natural OSL intensity, and five more aliquots were bleached, irradiated, and measured to construct the dose-response curve that brackets the natural OSL intensity. To estimate the equivalent dose \( D_e \), we used the corrected OSL intensity \( (L_i/T_i) \), where \( T_i \) is the luminescence intensity measured from a test dose). After each natural and regenerative OSL \( (L_x) \) measurement, a test dose OSL response \( (T_x) \) was measured to compensate for differences in luminescence production during the measurement of the quartz OSL signals. Figures S2 – S5 present the fine-grained quartz grain decay curves and growth curves of samples. We conducted measurements using 80% of the maximum power for both light sources. The OSL signal was detected by EMI QA9235 type photomultiplier tubes (PMT), with two U-340 filters in front of the PMT. When calculating the equivalent dose \( (D_e) \), we used the OSL signal intensity of the first 1 s integral on decay curve minus the average value of the last 10 s integral (background).

The Daybreak 582 thick source alpha counters were used to measure the dose rate contributions from U and Th and their daughter products. The alpha count rates were converted into alpha, beta, and gamma dose rates according to Aitken (1998). The K content of samples was determined using flame photometer analysis method. An \( \alpha \) efficient of 0.04±0.02 for fine-grained quartz, as suggested by Rees-Jones (1995) and Lu et al. (2007), was used. The calculation of the environmental dose rates of these samples also included the sample water content, and the influence of cosmic rays.

Figure S2-S5. OSL shine-down and growth curves for samples using the SMAR protocol.

References