Data Repository Item

Cosmogenic sample collection, preparation and analysis.

Alluvium was collected from active channel beds and sieved in the field to yield a sample with size fraction of 125-250 μm. Sample locations are listed in Table DR1. Sample preparation has been adapted from protocols of Bierman et al. (2002) and Kohl and Nishiizumi (1992). We treated the sediment in 6 M HCl on a shaker table for 24 hours to remove carbonates. Heavy liquid separation in lithium polytungstate (LST) was used to remove minerals from the sample with a density greater than quartz. Pure quartz separates were prepared by etching the remaining sediment in a solution of ~2% HF and ~1% HNO_3 with a sample to acid ratio of seven grams per litre. Three 24 hour etches in an ultrasonic bath at 40ºC were performed, with the samples rinsed between each etch. The quartz separates were spiked with 150-200 μg of Be carrier (Be 1000 mg/l standard, Spectrosol), and dissolved in concentrated HF (48%). Several fumes in $HClO_4$ converted fluorides to perchlorates, and the samples were passed through anion exchange columns to remove contaminants, principally Fe. Precipitation at pH 4.0 followed by precipitation at pH 8.5 reduced Ti and other contaminants. Be was separated from Al using cation exchange. $Be(OH)_2$ gels were precipitated and water rinsed several times before drying. Firing was performed over a butane-propane flame and the BeO mixed with Ag. See Binnie (2005) for further details.

$^{10}Be/^{9}Be$ was measured by Accelerator Mass Spectrometry using the 14UD accelerator at the Australian National University. The continuous beam monitor method of Middleton and Klein (1987) was used. Measurements were normalised to the NIST SRM 4325 standard with an assumed $^{10}Be/^{9}Be$ ratio of 3.0×10^{-11}. ^{10}Be loading incurred during sample preparation was measured by laboratory blanks prepared in tandem with every seven samples. The measured $^{10}Be/^{9}Be$ ratios of these blanks were between 11-14 $x10^{-15}$, which is due principally to ^{10}Be and ^{9}Be intrinsic to the beryllium standard. The respective numbers of atoms recorded by the blanks were subtracted from the appropriate sample measurements to yield the ^{10}Be concentrations listed in Table DR1. The 1σ uncertainty in our nuclide concentrations includes the propagated analytical uncertainty of the sample $^{10}Be/^{9}Be$ ratio, respective laboratory blank $^{10}Be/^{9}Be$ ratio and a 1% analytical uncertainty in our ^{9}Be carrier mass determinations (Table DR 1).

Cosmogenic ^{10}Be production rates

Cosmogenic nuclide production rate scaling factors, for both spallogenic and muogenic production, were calculated for each cell in a USGS National Elevation Dataset 1/9-arcsecond (approximately 10m resolution). From this, the mean production rate of each basin sampled was derived. Spallogenic production rate scaling factors for altitude and latitude were modelled using the functions of Lal (1991). The functions of Dunai (2000) were also used to derive spallogenic production rate scaling factors. The difference between the two methods at the latitudes and altitudes of the San Bernardino Mountains is within the 10% uncertainty assumed on production rates (see below). Muogenic production rate scaling factors were modelled using the functions of Stone (2000). Using the maximum and minimum elevations, we derive an approximation for the angle of overall inclination of each basin and apply the term of the equation given by Dunne et al. (1999) for slope angle shielding (Table DR2). The reduction of production rates due to modelling the effect of topographic shielding in this way ranges from 0% to <6%. Shielding by distant topography is negligible (<1%) and not included. Snow shielding effects were accounted for following Gosse and Phillips (2001), using modern snowpack data (Minnich, 1989). Reduction in production rates due to shielding by snow cover ranges from <1% to <4% (Table DR2). See Binnie (2005) for further explanation.

Cosmogenic ^{10}Be derived denudation rates

Denudation rates were derived using the model and constants given by Granger et al. (2001), assuming a high latitude, sea level spallation production rate of 5.1 atoms.g^{-1}.yr^{-1}. (Stone, 2000), and a bedrock density of 2.6 ± 0.1 g.cm^{-2}. We ignore systematic errors but assume a 10% error on both muogenic and spallogenic production rates accounts for any variability in production rates between basins due to changes in amounts of vegetative shielding, the influence of a variable geomagnetic field intensity over the different denudation rate averaging periods and time dilation effects of high energy muons (Riebe et al. 2004).

Denudation rate averaging times

The averaging period of denudation rate measurements derived using cosmogenic nuclide analysis are a function of the depth of nuclide production in rock and the rate at which that thickness of rock is removed by processes of denudation. The different attenuation lengths of muons and fast neutrons produce profiles of cosmogenic nuclide production which extend to different depths within the Earths surface. In order to obtain an averaging time which reflects these different profiles we took a mean of the spallogenic, fast and slow muogenic attenuation lengths, weighted by the relative contribution each production mechanism has made to the cosmogenic nuclide concentration measured in our samples. Hence, the averaging periods shown in Table DR3 should not be considered absolute values but reflect the approximate timespans over which our denudation rate measurements apply.

Mean hillslope gradient

Mean slope gradients were calculated for each sampled basin using 10 m-grid U.S. National Elevation Data set digital elevation model (DEM) data. Slope gradients derived from DEMs can be sensitive to grid size, but Zhang and Montgomery (1994) have shown that a 10 m-grid DEM will produce small errors for topography with a range of gradients similar to those in the catchments sampled here.

Designation of detachment or transport-limited basins.

We allocated those basins we sampled for cosmogenic ^{10}Be analysis as being predominantly detachment (weathering)-limited or transport-limited based on observations made in the field and observations stated in published literature. Those basins where there was significant evidence for both transport-limited and detachment-limited processes are considered as intermediate.

On the plateau surface of the Big Bear block basins 17, 18, 19 and 20 have >50% of their surface area mantled by a deeply weathered granitic horizon. This horizon is considered to have formed prior to orogenesis (Oberlander, 1972; Sadler and Reeder 1983; Meisling and Weldon 1989) and so its presence suggests denudation rates in these basins are predominantly limited by the rate of mass transport. Basins 14 and 15 also retain the weathered horizon, however, in these cases the basins are situated on the northern escarpment and there is evidence that large portions of the weathering horizon have been removed. As such we consider basins 14 and 15 to be intermediate rather than predominantly transport-limited. Basin 19 also drains the northern escarpment but unlike basins 14 and 15 the majority of the area of basin 19 lies on the plateau surface of the Big Bear block and >50% of this basin is mantled by the weathered horizon. As such we consider basin 19 to be predominantly transport-limited. Basin 16 lies on the plateau of the Big Bear block, however, the weathered mantle appears to have been mostly stripped and so we consider basin 16 to be intermediate.

There is published literature detailing the occurrence of rapid mass movement in the basins we sampled on Yucaipa Ridge block (Sadler and Morton 1989; Davis, 1998; Tan 1990; Tan and Griffen 1995; Morton and Hauser 2001). From field observations we verified that the steep terrain of this area is dominated by the occurrence of shallow landsliding, rockfall, dry-ravel and debris flow processes. As such we consider basins 1, 2, 3, 4 and 5 to be experiencing predominantly detachment-limited denudational processes. Basin 6 is also located on Yucaipa Ridge. However, doubts have been expressed as to the occurrence of rapid mass movement in this basin (Sadler and Morton 1989) and so we consider it to be intermediate. The basins sampled along the southern escarpment of the Big Bear block were all considered to be intermediate as there is no evidence to suggest either transport or detachment-limited processes dominate the denudational regime.

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TABLE DR1. SAMPLE CHARACTERISTICS

Basin number	Sample location (decimal degrees) Latitude	Longitude	Quartz mass (g)	^{9}Be carrier mass (μg)	^{10}Be/^{9}Be ratio ($\times 10^{-15}$)	Laboratory blank ^{10}Be/^{9}Be ratio ($\times 10^{-15}$)	^{10}Be concentration ($\times 10^{3}$ atoms.g^{-1})
1	34.0845	-116.9685	54.47	206.5 ± 2.1	35 ± 4	13 ± 2	5.6 ± 1.1
2	34.0869	-116.9418	58.40	206.5 ± 2.1	33 ± 3	13 ± 2	4.7 ± 0.9
3	34.0486	-116.9307	52.89	207.6 ± 2.1	54 ± 4	13 ± 2	10.8 ± 1.2
4	34.0532	-116.9393	55.92	205.1 ± 2.1	57 ± 4	13 ± 2	10.8 ± 1.1
5	34.0894	-116.9554	49.61	203.4 ± 2.0	54 ± 4	14 ± 2	10.1 ± 1.2
6	34.0945	-116.9832	79.48	204.6 ± 2.0	256 ± 22	11 ± 3	42.1 ± 3.8
7	34.1854	-116.9807	58.87	205.7 ± 2.1	58 ± 5	14 ± 2	10.3 ± 1.3
8	34.1852	-116.9767	68.64	207.8 ± 2.1	114 ± 9	11 ± 3	20.8 ± 1.9
9	34.1825	-116.9483	69.88	156.5 ± 1.6	190 ± 13	11 ± 3	26.8 ± 2.0
10	34.2083	-117.0123	56.92	206.3 ± 2.1	318 ± 21	11 ± 3	74.4 ± 5.2
11	34.1702	-117.0567	71.87	206.3 ± 2.1	51 ± 6	11 ± 3	7.7 ± 1.3
12	34.1926	-116.9318	66.74	205.1 ± 2.1	384 ± 22	13 ± 2	62.0 ± 3.0
13	34.1961	-116.9268	47.61	201.2 ± 2.0	192 ± 9	14 ± 2	50.3 ± 2.7
14	34.3940	-117.0544	50.52	205.6 ± 2.1	384 ± 22	13 ± 2	101.1 ± 6.1
15	34.3967	-117.0757	29.88	208.7 ± 2.1	248 ± 15	11 ± 3	110.6 ± 7.2
16	34.2756	-117.0311	44.28	208.0 ± 2.1	324 ± 17	14 ± 2	97.3 ± 5.5
17	34.2787	-117.0631	47.08	207.3 ± 2.1	448 ± 19	14 ± 2	127.7 ± 5.8
18	34.2800	-117.0414	53.28	206.3 ± 2.1	709 ± 38	11 ± 3	180.6 ± 10.0
19	34.4040	-117.0626	27.97	155.2 ± 1.6	238 ± 17	11 ± 3	84.2 ± 6.5
20	34.3748	-117.0914	39.70	201.3 ± 2.0	649 ± 27	14 ± 2	215.1 ± 9.4

TABLE DR2. PRODUCTION RATE SCALING FACTORS

Basin number	Scaling factor of latitude and altitude		Slope of basin long-axis (α)	Scaling factor of topographic shielding*	Scaling factor of snow shielding†	Total spallogenic production scaling factor	Total muogenic production scaling factor
	spallogenic	muogenic					
1	3.79	2.03	26.8	0.98	0.98	3.65	1.98
2	4.09	2.19	39.2	0.94	0.98	3.79	2.07
3	4.44	2.30	27.9	0.98	0.98	4.26	2.25
4	3.97	2.15	29.1	0.97	0.98	3.80	2.10
5	3.82	2.11	34.6	0.96	0.98	3.61	2.02
6	2.88	1.78	19.7	0.99	0.99	2.83	1.76
7	3.81	2.10	22.8	0.99	0.99	3.71	2.07
8	4.23	2.24	17.1	0.99	0.98	4.10	2.22
9	4.33	2.27	16.0	0.99	0.98	4.20	2.26
10	3.92	2.14	18.3	0.99	0.98	3.81	2.12
11	3.63	2.03	15.5	1.00	0.98	3.55	2.02
12	4.41	2.30	19.0	0.99	0.98	4.30	2.28
13	4.36	2.28	21.3	0.99	0.98	4.24	2.25
14	3.12	1.74	12.0	1.00	0.99	3.09	1.74
15	2.93	1.68	8.8	1.00	0.99	2.90	1.67
16	4.54	2.19	15.6	0.99	0.97	4.39	2.18
17	3.79	1.96	3.9	1.00	0.98	3.71	1.96
18	3.95	2.01	5.6	1.00	0.98	3.86	2.01
19	3.28	1.79	10.1	1.00	0.99	3.23	1.79
20	3.40	1.84	5.6	1.00	0.98	3.35	1.83

* Using the equation of Dunne et al., (1999), $S=1-(3.6\times10^{6}\alpha^{2.64})$, where S is the scaling factor, and α is the slope angle of the basins long-axis. See text for discussion.

† Snow shielding is considered for production by spallation only.

TABLE DR3. AVERAGING TIME

Basin number	Denudation rate averaging period (ka)*
1	1.0
2	0.8
3	1.6
4	1.9
5	2.0
6	10.4
7	1.8
8	3.3
9	4.1
10	12.9
11	1.4
12	9.3
13	7.7
14	21.6
15	25.6
16	13.8
17	22.2
18	29.9
19	17.1
20	42.1

* See text for discussion of how averaging times are evaluated.