Appendix 1. Cosmogenic Nuclide Methods and Erosion Rate Data

(Supplemental information for "Minimal climatic control on erosion rates in the Sierra Nevada, California")

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Introduction:

Here we report (1) how cosmogenic nuclide concentrations in the quartz fraction of stream sediment samples are used to infer whole-catchment erosion rates, (2) the cosmogenic nuclide production rates that we used, (3) our cosmogenic nuclide estimates of erosion rates, including all geographic and morphologic data required in the calculations, and (4) how we model the response of cosmogenic nuclide concentrations to step changes in erosion rates.

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How cosmogenic nuclide abundances in quartz reflect long-term erosion rates:

Cosmogenic ^{26}Al and ^{10}Be are produced in quartz grains primarily by neutron spallation and muon capture (Lal, 1991). Attenuation of cosmic rays limits ^{26}Al and ^{10}Be production to the upper few meters of the landscape surface; neutron production declines exponentially with a mean free path in rock $\Lambda_n \cong 160$ g/cm^2 (Brown et al., 1992; Nishiizumi et al., 1994), while muogenic production attenuates in what can be approximated as an exponential with an *e*-folding lengthscale $\Lambda_m \cong 1300$ g/cm^2 (Brown et al., 1995a). In a steadily eroding rock with density ρ_b, the ^{26}Al and ^{10}Be concentration at the surface will be

$$N = \frac{P_n}{\left(1/\tau + \rho_b E/\Lambda_n\right)} + \frac{P_m}{\left(1/\tau + \rho_b E/\Lambda_m\right)}, \qquad (1)$$

where E is the erosion rate, N is the concentration of the radionuclide under consideration, P_n and P_m are its spallogenic and muogenic production rates, and τ is its radioactive mean life (Lal, 1991). Most previous work has overlooked nuclide production by negative muon capture, but this can lead to significant errors at quickly eroding sites (Heisinger, 1998). Fast muon reactions also contribute a small fraction to nuclide production, but are ignored here for the sake of simplicity.

Provided that the radioactive meanlife is long compared to the erosional timescale ($\tau >> \Lambda/\rho E$), equation (1) reduces to

$$N = \frac{P_n \Lambda_n + P_m \Lambda_m}{\rho_b E}. \qquad (2)$$

For typical erosion rates considered here ($E > 20$ mm/kyr), ignoring radioactive decay of ^{26}Al and ^{10}Be results in no more than 7% error for erosion rate estimates.

Measuring whole-catchment erosion rates from cosmogenic nuclide abundances in sediment:

Several studies (Brown et al., 1995b; Bierman and Steig, 1996; Granger et al., 1996) have adapted equation 2 to model nuclide accumulation in sediment draining from steadily eroding catchments. The model can be further modified to account for chemical weathering, which should selectively enrich insoluble minerals (like quartz) in regolith and thereby increase their residence time near the surface (Small et al., 1999):

$$N = \frac{P_n \Lambda_\mathrm{n} \left(f_r / f_b + \left(1 - f_r / f_b\right) e^{-\rho_\mathrm{r} h / \Lambda_\mathrm{n}} \right) + P_m \Lambda_\mathrm{m} \left(f_r / f_b + \left(1 - f_r / f_b\right) e^{-\rho_\mathrm{r} h / \Lambda_\mathrm{m}} \right)}{\rho_\mathrm{b} E} \quad , \qquad (3)$$

where ρ_r is regolith density, h is regolith thickness, and f_r and f_b are the fraction of quartz in regolith and bedrock, with (f_r / f_b) revealing the fractional enrichment of insoluble quartz due to weathering losses.

Zirconium is insoluble in most weathering reactions, and can be easily measured by XRF, making it an ideal tracer for quartz enrichment. We estimate (f_r / f_b) from the regolith-to-bedrock ratio of [Zr] in samples collected from widely distributed locations within each catchment.

Cosmogenic ^{26}Al and ^{10}Be production rates in quartz at the earth's surface:

Solving equation 3 for E also requires estimates of P_n and P_m. Cosmogenic nuclide production rates in quartz at the earth's surface depend on altitude and latitude (Lal, 1958; Lal and Peters, 1967). Spallogenic production rates are scaled from sea-level, high latitude (SLHL) reference values to our samples' altitudes and geographic latitudes using Table 2 of Lal (1991). The cosmic ray muon flux to Earth's surface is not strongly sensitive to latitude (Allkofer and Jokisch, 1973). We therefore neglect latitude scaling of muogenic production rates in this analysis. Altitude scaling of muogenic production is best approximated by assuming exponential attenuation in the atmosphere, with a mean free path of 247 g/cm^2 (Rossi, 1948). Nuclide accumulation on sloped surfaces is affected by topographic shielding, which effectively reduces production both at depth and at the surface. These effects are accounted for using shielding correction factors that depend on hillslope angle as described by Dunne et al. (1999).

SLHL muogenic production rates are estimated here to be (in atoms/g/yr) $P_m = 0.11 \pm 0.01$ for ^{10}Be and $P_m = 0.81 \pm 0.11$ for ^{26}Al, based on sea level stopping rates reported by Barton and Slade (1965), chemical compound factors and nuclear capture probabilities summarized by Heisinger et al. (1997), and branching ratio estimates for production of ^{26}Al (Strack et al., 1994) and ^{10}Be (Heisinger et al., 1997). For a detailed summary of muogenic production systematics, see Stone et al. (1998b).

Based on these SLHL muogenic production rates, the overall contribution of muons to ^{26}Al and ^{10}Be production at the surface is only ~3%, in agreement with estimates of Brown et al. (1995a) and Stone et al. (1998a), but much lower than early estimates of ~20% (Lal, 1991). Previous production rate calibration studies used the early estimate of 20% production by muons. Here we use revised estimates of SLHL spallogenic production rates, that reflect the new estimate of ~3% contribution by muons. SLHL spallogenic production rates used here are (in atoms/g/yr) $P_n = 4.72 \pm 0.38$ for ^{10}Be and $P_n = 28.45 \pm 2.71$ for ^{26}Al. The SLHL P_n for ^{10}Be used in this study is an average of recalibrated estimates from four previous studies: 1) the Nishiizumi et al. (1989) work on glacial retreat in the Sierra Nevada, 2) the Clark et al. (1995) work on Laurentide ice retreat in New Jersey, U.S.A., 3) the Stone et al. (1998a) work on glacial retreat in Scotland, and 4) the Kubik et al. (1999) work on the Köfels landslide in Austria. SLHL P_n for ^{26}Al is calculated as the product of SLHL P_n for ^{10}Be and the spallogenic production rate ratio of ^{26}Al/^{10}Be, which we take to be 6.03±0.31 from data reported in Nishiizumi et al. (1989). Note that to rescale the Sierra Nevada production rates, we used ^{10}Be and ^{26}Al concentrations reported by Nishiizumi et al. (1989), revised glacial retreat ages reported by Clark et al. (1995), and, as suggested by Nishiizumi et al. (1996), geographic latitude of the calibration samples.

Measuring cosmogenic nuclide concentrations:

Table A lists the cosmogenic nuclide concentrations in quartz from sediment draining our study catchments. To measure nuclide concentrations, we first physically and chemically isolated quartz from our stream sediment samples using the techniques of Kohl and Nishiizumi (1992) and Granger (1996), and then spiked the isolates with ~ 1.25 μg ^{9}Be per gram of quartz. We then dissolved the quartz and extracted its Be and Al using ion exchange chomatography. BeO and Al_2O_3 targets were prepared for Accelerator Mass Spectrometry, which yields measurements of ^{10}Be/^{9}Be and ^{26}Al/^{27}Al (Davies et al., 1990). ^{10}Be concentrations were calculated using the ^{10}Be/^{9}Be ratio and concentration of Be in the quartz, which we know precisely from measurements of quartz masses and Be spike masses. ^{26}Al concentrations were calculated using ^{26}Al/^{27}Al and the concentration of aluminum in each quartz sample, which we measured from sample aliquots using Atomic Absorption Spectrophotometry and Inductively Coupled Plasma - Atomic Emission Spectrometry.

Estimating erosion rates:

Table B lists our erosion rate estimates, along with the geographic, morphologic and cosmogenic data that are necessary for estimating dissolution corrections, altitude and latitude scaling factors, and slope correction factors. Average hillslope gradients were measured by field surveys and from U.S. Geological Survey 7.5′ topographic quadrangles. Map names are listed after site names. Zr concentrations of regolith and bedrock were measured by XRF. Our samples of regolith and bedrock were taken from widely distributed locations within a subset of the study catchments. For catchments where no Zr concentrations are available, we used site-wide averages (weighted by inverse variance and listed next to site names) from regolith and outcrop samples. Soil depths were measured in 5 to 38 pits per catchment at a subset of our study catchments. For catchments where no soil depths are available, we used site-wide averages (listed after site names) that were calculated using soil depths from other catchments at the same site. Soil density is assumed to be 1.6±0.4 g/cm^3. Rock density is 2.7 g/cm^3.

At one of our sites, Grizzly Dome, we have no soil depth or Zr data. We assume that the Zr enrichment factor at Grizzly Dome is 1.23±0.03, equal to the site-wide average of the nearby Fall River site, which, having a similar climate, should also have a similar weathering intensities (and thus Zr enrichments). We further assume that soil depth at Grizzly Dome is 40±5 cm, which is close to the median value for our study sites and should therefore be a reasonable estimate. Erosion rates estimates for Grizzly Dome are insensitive to plausible errors introduced by these assumptions, because soil depth and [Zr] are only necessary for assessing the effects of weathering dissolution on cosmogenic erosion rates, and these effects are small in our study catchments. The size of the dissolution effects are reflected in the magnitude of the dissolution correction factor, C_D, which can be quantified as

$$C_D = \left(f_r / f_b + \left(1 - f_r / f_b\right) e^{-\rho_r h / \Lambda} \right), \tag{4}$$

where Λ is the penetration lengthscale for nuclide production. Table B lists dissolution correction factors, and shows that neglecting the dissolution effect of equation 4 entirely would result in less than 14% error in erosion rates at our other six sites, implying that any erosion rate errors introduced by assuming incorrect soil depths and Zr concentrations for Grizzly Dome should be small.

Erosion rates in Table B are inverse-variance-weighted averages ± standard errors of erosion rates calculated from equation 3 for each nuclide. Erosion rate uncertainties were propagated using random and analytical uncertainties, and ignoring systematic uncertainties in production rates. Uncertainties on absolute erosion rates are therefore somewhat higher, but our analysis of climatic effects is based on comparisons between erosion rates at different sites, so relative uncertainty is what matters.

In a separate study, we documented strong sensitivity of erosion rates to tectonic forcing at three of our sites (Fall River, Grizzly Dome and Fort Sage; Riebe et al., in press). At these sites, erosion rates increase by up to 15-fold with increasing proximity to fault scarps and river canyons; rapid base-level forcing by faulting and canyon incision has affected erosion rates of proximal catchments, but has not yet propagated distally through the drainage network. Because catchment-to-catchment variations in base-level forcing could obscure any relationships between climate and erosion rates, we limited our analysis in the present work to catchments that are topographically isolated from rapid base-level lowering. Catchment erosion rates that were excluded from the analysis are marked by asterisks in Table B.

Cosmogenic nuclide data for the Fort Sage study site are reported in Granger et al. (1996). Fort Sage erosion rates have been revised for this analysis using equation 3 and our new estimates of production rates.

Assessing how step changes in erosion rates affect cosmogenic nuclide concentrations:

We had to consider the possibility that Holocene climate change has affected our cosmogenic erosion rates. In order to assess whether such an effect could impact our analysis, we asked: To what extent could plausible early Holocene erosion rate changes be reflected in our cosmogenic measurements? To answer this question, we explored how changes in landscape erosion rates affect our cosmogenic erosion rates, by modeling how cosmogenic nuclide concentrations respond after a step change in erosion rates. For the sake of simplicity, we consider the case where weathering dissolution is negligible (i.e., C_D=1). If erosion rates changed from $E_{pre\text{-}change}$ to E at some time T in the past, then the cosmogenic nuclide concentration $N_{changed}$ in a surface sample today would be:

$$N_{changed} = \frac{P_n\Lambda_{\mathrm{n}}\left[e^{\frac{-\rho_{\mathrm{b}}ET}{\Lambda_{\mathrm{n}}}}\right] + P_n\Lambda_{\mathrm{m}}\left[e^{\frac{-\rho_{\mathrm{b}}ET}{\Lambda_{\mathrm{m}}}}\right]}{\rho_{\mathrm{b}}E_{pre-change}} + \frac{P_n\Lambda_{\mathrm{n}}\left[1-e^{\frac{-\rho_{\mathrm{b}}ET}{\Lambda_{\mathrm{n}}}}\right] + P_n\Lambda_{\mathrm{m}}\left[1-e^{\frac{-\rho_{\mathrm{b}}ET}{\Lambda_{\mathrm{m}}}}\right]}{\rho_{\mathrm{b}}E} \quad .(5)$$

Equation 5, like equation 2, neglects radioactive decay, which requires that the erosional timescale is short compared to the radioactive meanlife ($\tau >> \Lambda/\rho E$). $N_{changed}$ approaches N of equation 2 for high post-change erosion rates E (which can exhume more penetration depths (Λ) per unit time, and therefore effectively erase the signature of earlier, pre-change erosion rates) and at the limit of long T (which would permit sustained, deep erosion of many penetration lengths).

We can use equation 2 to infer the erosion rate that we would calculate ($E_{apparent}$) from $N_{changed}$, if we assumed that erosion rates have since been constant:

$$E_{apparent} = \frac{P_n\Lambda_{\mathrm{n}} + P_n\Lambda_{\mathrm{m}}}{\rho_{\mathrm{b}}N_{changed}} . \qquad (6)$$

Finally, we can compare $E_{apparent}$ with E to calculate percent error:

$$\%Error = 100 \times \left(\frac{E_{apparent} - E}{E}\right). \qquad (7)$$

For changes in erosion rates in which T is large (e.g., >10,000 yr), *%Error* will generally be small (<30%), unless post-change erosion rates are too low (E < ~20 mm/kyr) to effectively eliminate pre-change nuclide accumulations in time = T. Conversely, for increases in erosion rates due to recent land use, T will generally be small enough that cosmogenic nuclides will predominantly reflect erosion rates predating recent land use.

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TABLE A. COSMOGENIC NUCLIDE DATA FOR STUDY CATCHMENTS

Sample	^{10}Be/^{9}Be (10^{-15})	^{26}Al/^{27}Al (10^{-15})	[^{10}Be] (10^{5} atoms/g)	[^{26}Al] (10^{6} atoms/g)	[^{26}Al]/[^{10}Be]
Fall River:					
FR-2	48±7	302±29	0.517±0.084	0.234±0.025	4.52±0.88
FR-4	36±8	162±13	0.198±0.047	0.115±0.011	5.83±1.50
FR-5	33±7	663±60	0.395±0.085	0.258±0.027	6.53±1.56
FR-6	279±12	1009±34	2.562±0.169	0.980±0.059	3.83±0.34
FR-7	341±13	1705±100	3.412±0.215	1.092±0.084	3.20±0.32
FR-8	556±15	2835±89	5.523±0.314	2.898±0.171	5.25±0.43
FR-9	473±19	2059±69	4.758±0.305	2.215±0.133	4.66±0.41
FR-10	203±9	1253±42	2.751±0.185	1.645±0.099	5.74±0.58
Grizzly Dome:					
GD-1	108±12	422±24	0.651±0.079	0.362±0.027	5.57±0.80
GD-2	150±9	677±28	0.963±0.077	0.600±0.039	6.23±0.64
GD-3	130±9	604±23	0.905±0.075	0.624±0.039	6.90±0.72
GD-4	339±12	1381±61	1.719±0.105	1.077±0.072	6.27±0.57
GD-5	274±10	1395±51	1.807±0.112	1.120±0.069	6.20±0.54
GD-6	241±14	1462±57	1.515±0.116	0.973±0.062	6.42±0.64
GD-9	215±11	2456±160	1.717±0.123	1.293±0.106	7.53±0.82
GD-10	126±12	375±17	0.740±0.079	0.352±0.024	4.76±0.60
GD-12	70±8	206±14	0.553±0.068	0.357±0.030	6.46±0.96
GD-13	104±9	379±14	0.741±0.071	0.431±0.027	5.81±0.66
GD-14	80±10	803±41	0.610±0.080	0.417±0.030	6.83±1.02
Antelope Lake:					
AL-2	225±11	596±22	3.467±0.242	2.211±0.137	6.38±0.60
AL-3	355±12	1516±41	3.284±0.198	1.542±0.088	4.70±0.39
AL-4	402±17	2213±55	5.328±0.349	2.847±0.159	5.34±0.46
AL-5	374±20	1563±39	4.189±0.307	2.444±0.137	5.84±0.54
AL-6	424±18	3296±84	4.975±0.323	3.163±0.178	6.36±0.55
AL-7	709±20	3891±97	8.224±0.472	4.494±0.251	5.46±0.44
AL-8	256±10	1082±27	4.170±0.264	2.266±0.127	5.43±0.46
AL-9	275±13	1341±35	3.122±0.215	1.843±0.104	5.90±0.53
AL-10	278±13	1323±35	4.008±0.274	2.359±0.133	5.89±0.52
AL-11	444±12	1816±45	6.221±0.354	3.285±0.183	5.28±0.42
Adams Peak:					
AP-1	508±16	3003±150	4.351±0.137	2.617±0.290	6.01±0.69
AP-2	344±11	1751±75	3.961±0.127	2.334±0.250	5.89±0.66
AP-3	205±13	1484±72	3.030±0.192	1.990±0.220	6.57±0.84
AP-4	297±14	1870±55	4.090±0.193	2.642±0.280	6.46±0.75
AP-5	167±8	1229±46	2.538±0.122	1.584±0.170	6.24±0.73
AP-6	141±13	N.D.	3.118±0.287	N.D.	N.D.
AP-7	144±8	1011±38	2.351±0.129	1.569±0.170	6.67±0.81
AP-9	177±9	1147±40	2.560±0.124	1.661±0.180	6.49±0.77
AP-11	540±26	2342±61	5.915±0.411	2.993±0.169	5.06±0.45
AP-13	234±10	1460±42	3.239±0.209	1.813±0.105	5.60±0.48
AP-14	157±9	944±40	2.826±0.216	1.484±0.097	5.25±0.53
Sunday Peak:					
SP-1	284±16	1060±28	3.189±0.242	2.167±0.123	6.80±0.64
SP-3	522±11	1809±47	5.063±0.275	2.673±0.151	5.28±0.41
SP-4	211±11	1050±41	1.675±0.121	1.224±0.078	7.31±0.70
SP-7	158±10	1407±74	2.770±0.218	1.385±0.100	5.00±0.54
SP-8	921±33	3734±92	6.063±0.373	3.417±0.190	5.64±0.47
SP-9	498±14	2680±66	3.956±0.227	2.440±0.136	6.17±0.49
SP-19	937±24	8346±270	15.870±0.892	9.758±0.581	6.15±0.50

TABLE A. (continued)

Sample	^{10}Be/^{9}Be (10^{-15})	^{26}Al/^{27}Al (10^{-15})	[^{10}Be] (10^{5} atoms/g)	[^{26}Al] (10^{6} atoms/g)	[^{26}Al]/[^{10}Be]
Nichols Peak:					
NP-1	81±9	745±38	1.647±0.194	0.977±0.070	5.93±0.82
NP-4	242±15	1476±64	3.040±0.242	2.141±0.142	7.04±0.73
NP-6	205±14	1129±41	2.290±0.192	1.405±0.087	6.13±0.64
NP-7	109±12	469±38	2.067±0.250	0.937±0.089	4.53±0.7
NP-10	46±11	N.D.	1.343±0.331	N.D.	N.D.
NP-14	49±7	396±51	1.393±0.218	0.781±0.108	5.61±1.17
NP-15	N.D.	783±32	N.D.	0.983±0.064	N.D.
NP-17	78±7	889±50	2.054±0.206	1.151±0.087	5.60±0.70
NP-18	116±7	1269±77	2.612±0.208	1.557±0.122	5.96±0.67

Cosmogenic nuclide data for the Fort Sage mountain site are reported in Granger et al. (1996).
Uncertainties in [^{26}Al]/[^{10}Be] are propagated from analytical uncertainties in the Al and Be analyses.
N.D. = not determined.

TABLE B. STUDY CATCHMENT MORPHOLOGY AND EROSION RATES

Sample	Location			Area	Average gradient	$[Zr]_{soil}/[Zr]_{rock}$	Soil depth	Dissolution correction factor	Shielding correction factor	Erosion rate
	Altitude Min-Max (km)	Latitude (° N)	Longitude (° W)	(ha)	(m/m)		(cm)			(mm/kyr)
Fall River (Map = Brush Creek; Average $[Zr]_{soil}/[Zr]_{rock}$ = 1.23±0.03; Average soil depth = 41±3 cm)										
FR-2	0.91-0.94	39.6604	121.3607	0.7	0.48±0.03	1.18±0.11	25±4	1.04±0.03	0.87±0.01	145±31*
FR-4	0.38-0.61	39.6350	121.2783	7.4	0.70±0.02	N.D.	38±1	1.07±0.02	0.77±0.01	212±25*
FR-5	0.53-0.61	39.6361	121.2714	2.6	0.62±0.02	1.25±0.05	52±5	1.10±0.03	0.80±0.01	108±13*
FR-6	0.76-0.99	39.6385	121.3322	17.8	0.42±0.03	1.24±0.08	41±3	1.08±0.03	0.89±0.01	33±9
FR-7	0.75-1.04	39.6391	121.3311	92.9	0.17±0.01	N.D.	N.D.	1.08±0.02	0.98±0.00	30±11
FR-8	1.04-1.08	39.6586	121.3230	2.2	0.18±0.01	1.22±0.04	10±5	1.02±0.01	0.98±0.00	14±2
FR-9	1.03-1.05	39.6552	121.3269	0.4	0.16±0.01	N.D.	10±5	1.02±0.01	0.98±0.00	18±3
FR-10	0.97-0.98	39.6465	121.3434	0.4	0.18±0.01	1±0	0±0	1.00±0.00	0.98±0.00	25±2
Grizzly Dome (Map = Storrie & Soapstone Hill; Assumed $[Zr]_{soil}/[Zr]_{rock}$ = 1.23±0.03; Assumed soil depth = 40±5 cm)										
GD-1	1.33-1.47	39.8815	121.3468	1.1	0.67±0.05	N.D.	N.D.	1.08±0.02	0.78±0.03	129±15*
GD-2	1.32-1.47	39.8811	121.3473	1.1	0.59±0.05	N.D.	N.D.	1.08±0.02	0.82±0.03	83±8*
GD-3	1.30-1.45	39.8804	121.3479	1.5	0.61±0.05	N.D.	N.D.	1.08±0.02	0.81±0.03	83±9*
GD-4	1.47-1.57	39.8861	121.3308	5.2	0.16±0.05	N.D.	N.D.	1.08±0.02	0.98±0.01	61±5
GD-5	1.46-1.55	39.8863	121.3305	1.1	0.13±0.05	N.D.	N.D.	1.08±0.02	0.99±0.01	58±5
GD-6	1.46-1.51	39.8882	121.3269	8.2	0.17±0.05	N.D.	N.D.	1.08±0.02	0.98±0.01	68±6
GD-9	1.49-1.54	39.8865	121.3163	1.9	0.13±0.05	N.D.	N.D.	1.08±0.02	0.99±0.01	57±8
GD-10	0.62-1.45	39.8694	121.3691	78.0	0.63±0.05	N.D.	N.D.	1.08±0.02	0.80±0.03	99±17*
GD-12	0.55-1.47	39.8885	121.3607	102.2	0.55±0.05	N.D.	N.D.	1.08±0.02	0.83±0.03	108±12*
GD-13	0.55-1.44	39.8861	121.3616	83.6	0.55±0.05	N.D.	N.D.	1.08±0.02	0.83±0.03	86±9*
GD-14	1.68-1.50	39.8631	121.3526	99.2	0.54±0.05	N.D.	N.D.	1.08±0.02	0.84±0.03	101±11*
Antelope Lake (Map = Kettle Rock; Average $[Zr]_{soil}/[Zr]_{rock}$ = 1.21±0.07; Average soil depth = 49±8 cm)										
AL-2	1.76-1.81	40.1721	120.6464	3.0	0.35±0.06	N.D.	N.D.	1.08±0.03	0.92±0.02	34±3
AL-3	1.69-1.80	40.1801	120.6368	8.2	0.42±0.01	N.D.	45±16	1.08±0.04	0.89±0.00	41±7
AL-4	1.69-1.80	40.1775	120.6382	1.9	0.43±0.02	1.37±0.13	N.D.	1.14±0.06	0.89±0.01	24±3
AL-5	1.66-1.72	40.1785	120.6288	4.5	0.34±0.10	1.28±0.38	N.D.	1.11±0.15	0.93±0.04	29±4
AL-6	1.73-1.77	40.1835	120.6384	2.6	0.26±0.02	N.D.	N.D.	1.08±0.03	0.96±0.01	24±2
AL-7	1.77-1.84	40.1623	120.6532	3.3	0.27±0.06	N.D.	N.D.	1.08±0.03	0.95±0.02	16±2
AL-8	1.66-1.87	40.1494	120.6472	111.5	0.50±0.20	N.D.	N.D.	1.08±0.03	0.86±0.10	29±4
AL-9	1.73-1.87	40.1546	120.6450	1.1	0.60±0.13	1.29±0.17	N.D.	1.11±0.07	0.82±0.07	36±5
AL-10	1.72-1.87	40.1548	120.6376	11.1	0.40±0.06	1.16±0.07	53±7	1.06±0.03	0.90±0.03	30±3
AL-11	1.59-1.87	40.1628	120.6338	52.0	0.26±0.05	N.D.	N.D.	1.08±0.03	0.96±0.02	21±2
Adams Peak (Map = Constantia; Average $[Zr]_{soil}/[Zr]_{rock}$ = 1.15±0.03; Average soil depth = 34±5 cm)										
AP-1	2.04-2.06	39.9032	120.1286	2.2	0.22±0.05	N.D.	N.D.	1.04±0.01	0.97±0.01	34±3
AP-2	2.11-2.19	39.9023	120.1351	1.1	0.45±0.02	N.D.	N.D.	1.04±0.01	0.88±0.01	36±3
AP-3	2.07-2.21	39.8987	120.1351	3.3	0.46±0.03	1.21±0.03	27±9	1.05±0.02	0.88±0.01	46±5
AP-4	2.13-2.25	39.8917	120.1409	1.9	0.67±0.05	1.07±0.04	N.D.	1.02±0.01	0.78±0.03	31±3
AP-5	1.96-2.13	39.8904	120.1339	7.4	0.34±0.04	1.14±0.07	N.D.	1.04±0.02	0.93±0.02	55±5
AP-6	1.96-2.30	39.8874	120.1339	13.4	0.49±0.06	N.D.	N.D.	1.04±0.01	0.86±0.03	44±5
AP-7	1.90-1.94	39.8828	120.1278	1.1	0.38±0.03	N.D.	N.D.	1.04±0.01	0.91±0.01	53±5
AP-9	1.93-1.94	39.8828	120.1298	0.4	0.34±0.01	N.D.	N.D.	1.04±0.01	0.93±0.00	50±5
AP-11	2.25-2.27	39.8917	120.1443	0.4	0.10±0.01	1.18±0.08	N.D.	1.05±0.03	0.99±0.00	33±4
AP-13	1.88-1.89	39.8802	120.1275	0.4	0.21±0.03	1.17±0.06	N.D.	1.05±0.02	0.97±0.01	43±4
AP-14	1.88-1.89	39.8787	120.1278	0.7	0.26±0.01	N.D.	37±7	1.05±0.02	0.96±0.00	51±6
Sunday Peak (Map = Tobias Peak; Average $[Zr]_{soil}/[Zr]_{rock}$ = 1.11±0.05; Average soil depth = 61±12 cm)										
SP-1	2.13-2.41	35.7938	118.5899	9.3	0.55±0.05	1.12±0.06	61±12	1.06±0.03	0.84±0.03	40±4
SP-3	2.26-2.40	35.7981	118.5833	5.6	0.45±0.05	1.03±0.08	N.D.	1.01±0.04	0.88±0.02	31±4
SP-4	2.26-2.28	35.8150	118.5754	1.1	0.29±0.05	N.D.	N.D.	1.05±0.03	0.94±0.02	83±11
SP-7	2.32-2.53	35.7789	118.5839	1.1	0.80±0.05	N.D.	N.D.	1.05±0.03	0.73±0.03	53±8
SP-8	2.40-2.44	35.7830	118.5915	2.2	0.21±0.05	1.14±0.07	N.D.	1.06±0.03	0.97±0.01	30±3
SP-9	2.21-2.28	35.7826	118.6024	3.0	0.31±0.05	N.D.	N.D.	1.05±0.03	0.94±0.02	38±3
SP-19	2.18-2.41	35.7878	118.5801	9.3	0.41±0.05	N.D.	N.D.	1.05±0.03	0.90±0.02	9±1

TABLE B. (continued)

Sample	Location			Area	Average gradient	$\frac{[Zr]_{soil}}{[Zr]_{rock}}$	Soil depth	Dissolution correction factor	Shielding correction factor	Erosion rate
	Altitude Min-Max (km)	Latitude (° N)	Longitude (° W)	(ha)	(m/m)		(cm)			(mm/kyr)
Nichols Peak (Map = Cane Canyon; Average $[Zr]_{soil}/[Zr]_{rock}$ = 1.32±0.11; Average soil depth = 30±1 cm)										
NP-1	1.09-1.16	35.5922	118.2255	1.1	0.44±0.02	1.28±0.10	33±6	1.08±0.04	0.88±0.01	42±4
NP-4	1.28-1.38	35.5853	118.2181	1.5	0.65±0.05	N.D.	N.D.	1.08±0.03	0.79±0.03	21±2
NP-6	1.18-1.38	35.5870	118.2181	2.6	0.65±0.05	N.D.	N.D.	1.08±0.03	0.79±0.03	29±3
NP-7	1.22-1.30	35.6003	118.2120	2.2	0.46±0.05	N.D.	N.D.	1.08±0.03	0.88±0.02	44±9
NP-10	1.29-1.58	35.5820	118.1808	3.3	0.68±0.05	N.D.	N.D.	1.08±0.03	0.78±0.03	55±14
NP-14	1.34-1.38	35.5783	118.1977	0.7	0.23±0.02	N.D.	28±3	1.08±0.03	0.96±0.01	66±9
NP-15	1.33-1.38	35.5781	118.1981	1.1	0.29±0.05	N.D.	N.D.	1.08±0.03	0.94±0.02	53±5
NP-17	1.12-1.17	35.5232	118.2090	5.9	0.16±0.05	N.D.	N.D.	1.08±0.03	0.98±0.01	39±4
NP-18	1.16-1.19	35.5221	118.2014	0.7	0.24±0.02	1.40±0.15	29±2	1.10±0.04	0.96±0.01	30±3
Fort Sage (Map = Doyle; Average $[Zr]_{soil}/[Zr]_{rock}$ = 1.18±0.03; Average soil depth = 26±2 cm)										
A1	1.51-1.55	40.0898	120.0624	2.1	0.25±0.01	1.06±0.05	N.D.	1.01±0.01	0.96±0.00	29±3
A2	1.46-1.55	40.0916	120.0615	4.8	0.30±0.01	1.14±0.05	20±3	1.03±0.01	0.94±0.00	24±3
A3	1.40-1.55	40.0938	120.0606	11.7	0.39±0.01	1.18±0.04	24±2	1.04±0.01	0.91±0.00	43±6
A4	1.34-1.55	40.0946	120.0601	13.2	0.41±0.01	1.18±0.03	24±2	1.04±0.01	0.90±0.00	67±7*
B1	1.55-1.58	40.0864	120.0664	1.4	0.23±0.01	N.D.	31±6	1.05±0.01	0.96±0.00	22±2
B2	1.49-1.58	40.0894	120.0664	6.7	0.33±0.01	N.D.	N.D.	1.04±0.01	0.93±0.00	36±5
B3	1.43-1.58	40.0918	120.0667	12.8	0.35±0.01	N.D.	N.D.	1.04±0.01	0.92±0.00	42±4
B4	1.39-1.53	40.0953	120.0672	4.9	0.42±0.01	N.D.	N.D.	1.04±0.01	0.90±0.00	26±3
B5	1.33-1.58	40.0972	120.0655	40.8	0.40±0.01	N.D.	N.D.	1.04±0.01	0.90±0.00	41±4*
A2(s)	1.46-1.53	40.0916	120.0615	2.7	0.34±0.01	N.A.	N.A.	N.A.	N.A.	21±5
A3(s)	1.40-1.52	40.0938	120.0606	6.9	0.45±0.01	N.A.	N.A.	N.A.	N.A.	56±10
A4(s)	1.34-1.46	40.0946	120.0601	1.5	0.63±0.01	N.A.	N.A.	N.A.	N.A.	252±78*
B2(s)	1.49-1.58	40.0894	120.0664	5.4	0.36±0.01	N.A.	N.A.	N.A.	N.A.	39±6
B3(s)	1.43-1.58	40.0918	120.0667	6.1	0.37±0.01	N.A.	N.A.	N.A.	N.A.	48±10
B5(s)	1.33-1.52	40.0972	120.0655	23.0	0.42±0.01	N.A.	N.A.	N.A.	N.A.	45±8*

Asterisk after erosion rate indicates that it was excluded from the analysis (see text).

(s) after sample name indicates erosion rate is calculated by subtraction of areas technique. See Granger et al. (1996) for details.

N.D. = not determined.

N.A. = not applicable.