Supporting Information

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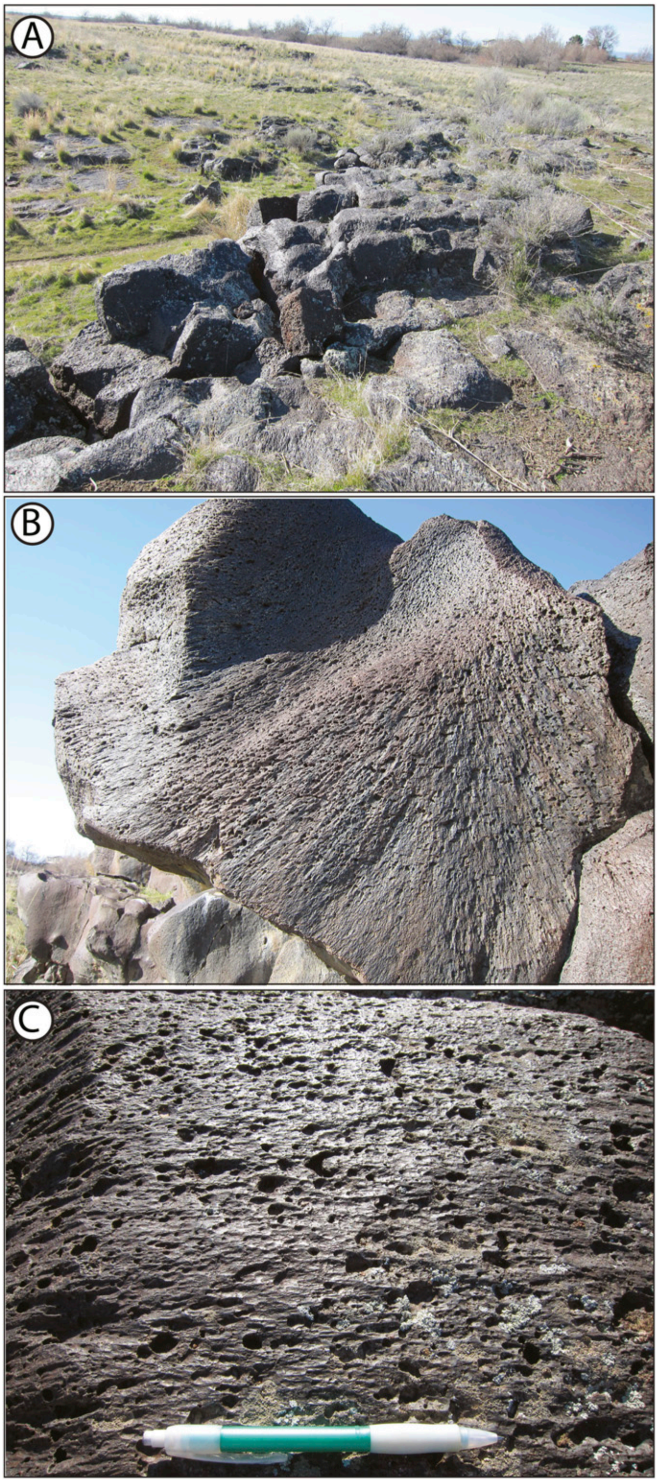

Fig. S1. Examples of scoured rock near the abandoned channel on the north side of Stubby Canyon (Fig. 2*B*). (*A*) Abraded and fluted bedrock where large-scale rock roughness in the foreground is ~1 m. (*B*) Close-up of abraded rock (~1 m in diameter) from *A* showing curvature of fine-scale flutes. (*C*) Close up photograph of fluted rock from *B* showing centimeter-scale flutes that fan out in the inferred flow direction (left to right). (Pencil for scale, 15 cm.)

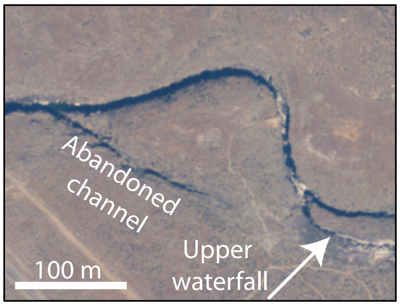

Fig. S2. Aerial orthophoto of the upstream extent of the knickzone in Pointed Canyon showing the most upstream waterfall (Fig. 3*E* and black circle in Fig. 2*B*) and the most upstream abandoned channel (Fig. 3*F* and blue dashed line in Fig. 2*B*) (US Geological Survey).

Table S1. Geochemical measurements

Sample name	Olivine mass (g)	$[^3\text{He}]_{\text{melt}}$ (10^6 at/g)	$[^4\text{He}]_{\text{melt}}$ (10^{12} at/g)	$(^3\text{He}/^4\text{He})_{\text{melt}}$ (R/R_A)	Topographic shielding factor	$[^3\text{He}]_{\text{cosmo}}$ (10^6 at/g)	Production rate ($\text{at}^{-1}\cdot\text{g}^{-1}\cdot\text{y}^{-1}$)
GB0	0.1175	0.38 ± 0.02	0.33 ± 0.02	0.83	0	—	
MB0	0.4262	0.06 ± 0.01	0.24 ± 0.01	0.19	0	—	
NB0	0.3534	0.26 ± 0.02	0.12 ± 0.01	1.60	0	—	
S1	0.166	11.9 ± 0.71	0.62 ± 0.03	13.7	0.95	11.5 ± 0.75	246
S2	0.2532	5.60 ± 0.34	0.96 ± 0.05	4.17	0.96	5.2 ± 0.34	250
S3	0.17	4.77 ± 0.29	0.44 ± 0.02	7.72	0.98	4.4 ± 0.28	255
S4	0.0937	4.73 ± 0.28	5.87 ± 0.3	0.58	0.91	4.3 ± 0.28	237
S5	0.1765	6.01 ± 0.36	17.4 ± 0.9	0.25	0.93	5.6 ± 0.36	243
W1	0.1179	12.5 ± 0.75	1.75 ± 0.1	5.10	1.00	12.1 ± 0.79	254
P1	0.306	5.63 ± 0.34	1.14 ± 0.06	3.54	0.98	5.3 ± 0.34	255
P2	0.1716	7.62 ± 0.46	0.40 ± 0.02	13.6	0.86	7.2 ± 0.47	225
P3	0.3901	3.16 ± 0.19	0.15 ± 0.01	15.5	1.00	2.8 ± 0.18	260
P4	0.3849	5.40 ± 0.32	0.12 ± 0.01	32.1	1.00	5.0 ± 0.32	261
P5	0.1213	4.82 ± 0.29	1.10 ± 0.05	3.13	0.99	4.4 ± 0.29	254
P6	0.0379	6.05 ± 0.36	196 ± 10	0.02	0.85	5.7 ± 0.37	219
MB1	0.1121	8.21 ± 0.50	1.35 ± 0.07	4.36	0.98	8.1 ± 0.53	257
NB1	0.359	15.1 ± 0.90	0.24 ± 0.01	44.2	1.00	14.9 ± 0.97	279

Samples GB0, MB0, and NB0 are shielded samples for Gooding Butte Basalt (used to correct all canyon erosion data), McKinney Butte Basalt (used to correct McKinney Butte Basalt age: MB1), and Notch Butte Basalt (used to correct Notch Butte Basalt age: NB1). Subscript "melt" is helium released by heating powdered olivine under vacuum. $[^3\text{He}]_{\text{cosmo}}$ is cosmogenic ^{3}He after subtracting the shielded component (^{3}He measured in relevant shielded sample). R_A is the atmospheric $^3\text{He}/^4\text{He}$ isotope ratio of 1.4×10^{-6} and at denotes atoms. Basalt had a bulk density of 2.8 ± 0.1 g/cm^3. Error represents ±1 SD. Production rate was calculated using the Lifton/Sato scaling scheme (1, 2) on the CRONUS ^{3}He calculator (3, 4). Uncertainty in the shielded sample affects the absolute age but does not change relative ages between canyon heads or calculated knickpoint retreat rates.

1. Lifton NA, et al. (2005) Addressing solar modulation and long-term uncertainties in scaling secondary cosmic rays for in situ cosmogenic nuclide applications. *Earth Planet Sci Lett* 239(1–2):140–161.
2. Sato T, Niita K (2006) Analytical functions to predict cosmic-ray neutron spectra in the atmosphere. *Radiat Res* 166(3):544–555.
3. Balco G, Stone JO, Lifton NA, Dunai TJ (2008) A complete and easily accessible means of calculating surface exposure ages or erosion rates from (10)Be and (26)Al measurements. *Quat Geochronol* 3(3):174–195.
4. Goehring BM, et al. (2010) A reevaluation of in situ cosmogenic He-3 production rates. *Quat Geochronol* 5:410–418.

Table S2. Sample locations and exposure ages

Sample	Canyon	Description	Latitude (°)	Longitude (°)	Elevation (m)	Age (ka)
S1	Stubby	Rim notch	42.8677	−114.863	983	46.2 ± 2.9
S2	Stubby	Rim notch	42.86765	−114.863	991	21.6 ± 1.3
S3	Stubby	Rim notch	42.86766	−114.863	990	18.0 ± 1.1
S4	Stubby	Side rim notch	42.86755	−114.866	992	19.1 ± 1.1
S5	Stubby	Side rim notch	42.86758	−114.866	993	23.8 ± 1.4
W1	Woody	Rim notch	42.85423	−114.881	972	47.2 ± 3.0
P1	Pointed	Abandoned channel	42.86739	−114.859	991	21.2 ± 1.2
P2	Pointed	Abandoned channel	42.8682	−114.858	995	32.5 ± 1.9
P3	Pointed	Strath terrace	42.86777	−114.85	990	11.3 ± 0.7
P4	Pointed	Abandoned channel	42.86727	−114.849	993	19.9 ± 1.1
P5	Pointed	Strath terrace	42.86798	−114.851	984	18.2 ± 1.0
P6	Pointed	Strath terrace	42.86783	−114.854	981	26.3 ± 1.5
MB1		McKinny Butte flow top	42.89116	−114.918	978	31.9 ± 1.9
NB1		Notch Butte flow top	42.82378	−114.706	1074	52.8 ± 3.4

Exposure ages were calculated using the CRONUS 3He Exposure Calculator (1, 2) using the Lifton/Sato scaling scheme (3, 4) (see production rate in Table S1). Error on age represents 1 SD of external uncertainty as determined by the exposure age calculator.

1. Balco G, Stone JO, Lifton NA, Dunai TJ (2008) A complete and easily accessible means of calculating surface exposure ages or erosion rates from (10)Be and (26)Al measurements. *Quat Geochronol* 3(3):174–195.
2. Goehring BM, et al. (2010) A reevaluation of in situ cosmogenic He-3 production rates. *Quat Geochronol* 5:410–418.
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