Appendix A. $^4He/^3He$ thermochronometry

In $^4He/^3He$ thermochronometry, the natural spatial distribution of radiogenic ^4He is constrained by stepwise degassing and $^4He/^3He$ analysis of a sample containing synthetic, homogeneously distributed, proton-induced ^3He (Shuster et al., 2004). Approximately 50 mg of separated apatite grains were packaged into Sn foil and exposed to ~$5x10^{15}$ protons cm^{-2} with incident energy ~220 MeV over a continuous 7 h period at the Francis H. Burr Proton Therapy Center, Boston, USA. Euhedral crystals free of visible mineral inclusions were selected; crystal dimensions were measured using a calibrated binocular microscope. Individual crystals were then sequentially heated in multiple steps under ultra-high vacuum while in contact with a thermocouple using a feedback-controlled 70 W diode laser at the BGC Noble Gas Thermochronometry Laboratory. The molar ^3He abundance and the $^4He/^3He$ ratio were measured for each heating step using calibrated pulse-counting sector-field mass spectrometry and corrected for blank contributions to ^3He and ^4He (uncertainties in blank corrections are propagated into ratio uncertainties). Stepwise $^4He/^3He$ degassing data are given in Table DR3.

Appendix B. Thermal modeling and inversion of $^4He/^3He$ data

We used a numerical model to predict an AHe age and the evolution of the $^4He/^3He$ ratio during a step-degassing analysis (Schildgen et al., 2010). The input parameters are the characteristics of the analyzed crystal (apatite size), the mean apatite (U-Th)/He age of the sample and a cooling history. All cooling histories began at 150 °C and ended after 15 Ma at the modern mean surface temperature (~5 °C). The model generates random time-temperature (*t*-*T*) paths defined by 3–10 points to ensure extensive exploration of the *t*-*T* space and predicts an evolving spatial distribution of ^4He along each cooling path, assuming a uniform spatial distribution of U and Th (defined by U and Th concentration measurements) and an effective spherical diffusion geometry with surface/volume ratio equivalent to the analyzed grain. In the numerical simulations, sample-specific He diffusion kinetics were quantified by the radiation damage and annealing model (RDAAM, Flowers et al., 2009), and assumed to apply over all model time and temperatures as a function of the observed U and Th concentrations of each sample. To fully explore possible changes in He diffusivity through time, all cooling paths began at 150 °C, well above the accumulation of radiation damage effects. Following each randomly generated cooling history, the model first calculated a (U-Th)/He age that was compared to the measured age. If the predicted age was within 1 standard deviation (SD) of the mean measured age (Table DR3), a model $^4He/^3He$ ratio evolution was calculated using the same analytical heating schedule as the sample and compared to observed ratios. This approach allows a random-search scheme to identify cooling histories that are compatible with the observations based on the computation of misfit statistics. The misfit value is defined as the goodness of fit (Ketcham, 2005), which indicates the probability of failing the null hypothesis that the model and data are different (Ketcham et al., 2000). In general a value of 0.05 or higher is considered not to fail the null hypothesis, and thus reflects an acceptable fit between model and data (gray lines), a value of 0.5 reflects a good fit (black lines in Fig. 4 of the text).

Appendix C. Thermal modeling and inversion of age-elevation profiles

We use QTQt simulation code from K. Gallagher (Gallagher, 2012) to reconstruct the thermal history of the two elevation profiles of this study by a Markov chain Monte Carlo (MCMC) sampling method. The inversion code incorporates standard He kinetic (Farley, 2002) and recent kinetic models of He diffusion proposed by Flowers et al. (2009) and Gautheron et al. (2009). The modeling proceeds from an initial randomly chosen time-temperature path and set of kinetic parameters, from which a probability that the model fits the data is calculated. Then the parameters are slightly perturbed, the probability of fitting the data is recalculated and compared to the initial model. The model with the highest probability is retained. This procedure is repeated a large number of times (200000 iterations has been chosen here), providing a large number of models with their associated probabilities that allows calculation of model statistics (probability distributions of model parameters, etc.). A full explanation of the modeling procedure is provided in Gallagher (2012). The modeling takes care of the position of each sample in their elevation relationship and allows simulating all samples together.

The expected models are presented for alpha-recoil damage models from Flowers et al. (2009). The expected models will generally lie between the maximum likelihood model (more complex) and the maximum posterior model (less complex). The MCMC sampling calculates the uncertainty for the expected model and so draws meaningful credible intervals (more or less the Bayesian equivalent of confidence intervals). These intervals represent a 95% probability range for a given parameter, calculated so that 2.5% of the parameter values lie below and above the limits defined by the range.

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Sample	Easting *(decimal degrees)*	Northing	Elevation *(meters)*	^{4}He *(nmol/g)*	U *(ppm)*	Th *(ppm)*	Sm *(ppm)*	eU *(ppm)*	Th/U	Raw age *(Ma)*	Ft	Corr. Age *(Ma)*	Error *(Ma)*
013D27A	-120.8371	48.6243	1033	1.61	6.12	16.99	0.06	10.11	10.11	31.5	0.65	48.6	2.9
013D27B	"	"	"	1.83	10.07	24.03	0.04	15.72	15.72	23.1	0.60	38.8	2.3
												43.7	**6.9**
09CAS16Am3	-121.9142	48.8797	350	0.08	4.07	9.43	2.38	187.2	6.29	2.4	0.70	3.4	0.2
												3.4	**0.7**
09CAS18a_1	-121.9264	48.8639	854	0.09	2.09	4.82	2.36	81.76	3.22	4.8	0.79	6.1	0.2
09CAS18a_2	"	"	"	0.11	2.32	6.69	2.96	86.07	3.89	4.9	0.69	7.1	0.3
09CAS18a_3	"	"	"	0.06	2.22	4.73	2.18	103.36	3.33	3.3	0.65	5.1	1.0
09CAS18a_4	"	"	"	0.04	1.65	4.89	3.05	130.28	2.79	2.5	0.80	3.1	0.1
09CAS18a_5	"	"	"	0.04	2.01	4.6	2.34	75.61	3.1	2.4	0.78	3	0.2
												4.8	**1.8**
12Cas14ap1	-121.32201	48.63378	142	0.13	13.86	17.15	256.91	17.89	1.27	1.3	0.74	1.8	0.2
12Cas14ap2	"	"	"	0.13	7.09	14.49	200.02	10.49	2.1	2.3	0.75	3.1	0.3
12Cas14ap3	"	"	"	0.09	8.04	11.01	257.02	10.62	1.41	1.6	0.75	2.2	0.1
												2.4	**0.6**
12Cas25ap1	-121.39841	48.58596	116	0.15	13.49	5.24	27.05	14.72	0.4	1.9	0.77	2.5	0.2
12Cas25ap2	"	"	"	0.25	20.76	6.81	38.75	22.36	0.34	2.1	0.76	2.8	0.2
12Cas25ap3	"	"	"	0.27	22.26	9.8	40.00	24.56	0.45	2	0.73	2.8	0.1
												2.7	**0.2**
12Cas26ap1	-122.20283	48.81322	73	0.31	9.26	3.72	126.52	10.13	0.41	5.8	0.72	8.0	0.5
12Cas26ap2	"	"	"	3.37	77.75	24.57	97.1	83.53	0.32	7.6	0.70	11.0	0.2
12Cas26ap3	"	"	"	0.49	12.27	24.36	119.88	17.99	2.04	5.0	0.73	6.97	0.3
												8.65	**2.08**
12Cas10ap1	-121.17249	48.70697	280	0.32	11.66	0.24	272.51	11.71	0.02	5.0	0.80	6.48	0.3
12Cas10ap2	"	"	"	0.39	13.09	18.92	423.08	17.53	1.48	4.0	0.78	5.35	0.2
												5.91	**0.8**
013D28A	-121.0771	48.7167	628	2.09	33.85	5.38	0.19	35.11	35.12	11.8	0.77	15.4	0.9
013D28a2	"	"	"	2.67	36.31	6.95	0.2	79.63	37.94	13.1	0.62	20.1	0.3
013D28ap4	"	"	"	1.31	31.58	0.76	182.46	31.76	0.02	7.8	0.64	12.2	0.4
013D28ap5	"	"	"	3.15	56.3	4.66	95.7	57.4	0.08	10.4	0.70	14.9	0.3
												15.6	**3.3**

Table DR1. Apatite (U-Th)/He data for 11 isolated samples collected across the width of the North Washington Cascades. Analytical uncertainty on U, Th, Sm and He determinations is 1 sigma. Abbreviations: Raw He age: grain age before applying the Ft alpha-ejection correction factor; Ft: correction factor for alpha ejection (Farley et al., 2002); Corr He age: grain age after applying the Ft alpha ejection correction factor. Weight ages and associated standard deviations are written in bold.

Sample	Easting	Northing	Elevation	^{4}He	U	Th	Sm	eU	Th/U	Raw age	Ft	Corr. Age	Error
	(decimal degrees)		(meters)	(nmol/g)	(ppm)	(ppm)	(ppm)	(ppm)		(Ma)		(Ma)	(Ma)
Skagit Gorge													
01-1 ap2	-121.19753	48.72872	1953	0.81	24.73	4.6	225.23	25.82	0.19	5.8	0.61	9.6	0.7
01-1 ap3	"	"	"	0.98	18.59	3.28	162.01	19.36	0.18	9.3	0.66	14.1	0.7
01-1 ap4	"	"	"	3.94	97.98	14.39	1234.23	101.37	0.15	7.1	0.59	12.1	0.4
01-1ap5	"	"	"	1.52	25.51	4.06	231.58	26.47	0.16	10.5	0.78	13.4	0.3
01-1ap6	"	"	"	1.56	43.66	5.84	325.41	45.04	0.14	6.4	0.70	9.2	0.2
01-1ap7	"	"	"	1.46	34.12	6.25	290.12	35.59	0.19	7.5	0.65	11.6	0.3
01-1ap8	"	"	"	0.94	13.01	2.58	95.68	13.62	0.2	12.7	0.76	16.8	0.4
												12.4	**2.7**
01-2 ap1*	-121.19815	48.72342	1758	1.67	96.00	3.55	456.46	96.84	0.04	3.2	0.77	4.1	0.1
01-2 ap2*	"	"	"	1.56	89.82	3.31	533.62	90.6	0.04	3.2	0.67	4.8	0.1
01-2 ap3	"	"	"	14.7	382.67	14.24	3005.74	386.02	0.04	7.0	0.61	11.5	0.3
01-2 ap4	"	"	"	5.5	82.24	4.31	360.51	83.25	0.05	12.2	0.74	16.6	0.4
01-2ap5	"	"	"	5.24	79.4	4.31	389.92	80.41	0.06	12.0	0.80	15.1	0.3
01-2ap6	"	"	"	4.58	82.29	1.96	308.02	82.75	0.02	10.2	0.77	13.3	0.3
01-2ap7	"	"	"	3.54	53.39	6.13	181.23	54.83	0.12	11.9	0.75	16.0	0.4
												14.5	**2.1**
01-4 ap1	-121.20055	48.71233	1347	1.45	39.43	2.42	139.2	40.00	0.06	6.7	0.67	10.0	0.3
01-4 ap2	"	"	"	1.23	33.12	3.12	147.54	33.86	0.1	6.7	0.70	9.6	0.6
01-4 ap3	"	"	"	0.9	32.77	2.26	161.59	33.3	0.07	5.0	0.69	7.2	0.2
01-4 ap4	"	"	"	1.4	37.25	8.38	161.21	39.22	0.23	6.6	0.68	9.7	0.3
												9.1	**1.3**
01-7 ap1*	-121.20828	48.706667	680	1.54	144.8	189.26	244.7	189.28	1.34	1.5	0.69	2.2	0.1
01-7 ap2	"	"	"	0.39	15.36	3.7	453.86	16.23	0.25	4.4	0.77	5.7	0.1
01-7 ap3	"	"	"	1.93	77.85	12.91	479.25	80.89	0.17	4.4	0.72	6.1	0.2
												5.9	**0.6**
01-6 ap1	-121.20723	48.70765	904	1.9	77.62	2.47	487.08	78.2	0.03	4.5	0.71	6.3	0.2
01-6 ap2	"	"	"	2.57	106.38	2.22	471.84	106.9	0.02	4.4	0.73	6.0	0.2
01-6 ap3	"	"	"	1.73	76.07	5.87	393.33	77.45	0.08	4.1	0.60	6.9	0.3
01-6 ap4*	"	"	"	1.13	141.55	142.12	455.12	174.94	1.03	1.2	0.60	2.0	0.1
												6.4	**0.6**
01-5 ap1	-121.20407	48.71120	1155	1.58	51.47	2.66	187.41	52.1	0.05	5.6	0.75	7.5	0.2

Table DR2. Apatite (U-Th)/He data from Skagit Gorge and Ross Lake profiles. Same methodoly described in Table DR1. Stars against aliquot names indicate excluded samples. Aliquot AHe ages out of the standard deviation have been excluded.

01-5 ap2	"	"	"	1.57	41.98	6,00	80.26	43.39	0.15	6.7	0.63	10.7	0.4
01-5 ap3	"	"	"	1.31	33.87	4.53	135.4	34.93	0.14	6.9	0.68	10.2	0.4
01-5 ap4	"	"	"	1.66	46.61	3.78	166.98	47.5	0.08	6.5	0.69	9.3	0.3
												10.1	**1.4**
02-1 ap1	-121.20918	48.69982	345	0.55	28.75	2.31	243.77	29.3	0.08	3.4	0.79	4.4	0.1
02-1 ap2	"	"	"	0.52	31.66	3.76	206.31	32.54	0.12	2.9	0.75	3.9	0.1
02-1 ap3	"	"	"	0.9	34.15	3.39	202.9	34.94	0.1	4.8	0.76	6.2	0.2
02-1 ap4	"	"	"	0.81	40.36	4.17	234.41	41.34	0.11	3.6	0.76	4.7	0.1
												4.3	**1,0**
02-2 ap1	-121.21158	48.69733	241	0.32	27.22	2.1	273.1	27.72	0.08	2.1	0.68	3.1	0.2
02-2 ap2	"	"	"	0.3	21.11	3.51	269.95	21.94	0.17	2.5	0.66	3.7	0.3
02-2 ap3	"	"	"	0.5	26.29	2.36	200.12	26.85	0.09	3.4	0.70	4.9	0.2
02-2 ap4	"	"	"	0.48	33.83	3.56	294.42	34.67	0.11	2.6	0.69	3.7	0.1
												3.5	**0.8**
Ross Lake													
03-1ap5	-121.0988	48.82227	1967	3.86	52.3	22.87	86.33	57.68	0.45	12.4	0.70	17.7	0.4
03-1ap6	"	"	"	6.71	78.54	21.8	107.91	83.66	0.28	14.8	0.77	19.4	0.4
03-1ap7	"	"	"	4.34	51.58	13.64	65.34	54.79	0.27	14.7	0.76	19.2	0.4
03-1ap8	"	"	"	4.25	56.26	16.04	88.02	60.03	0.29	13.1	0.82	15.9	0.3
												18.1	**1.8**
03-2 ap1	-121.09137	48.8182	1778	5.33	63.7	94.25	115.74	85.85	1.52	11.5	0.72	16,0	0.3
03-2 ap2	"	"	"	9.76	118.25	208.35	128.87	167.22	1.81	10.8	0.74	14.5	0.3
03-2 ap3	"	"	"	3.58	50.79	68.3	127.08	66.84	1.38	9.9	0.72	13.7	0.3
03-2 ap4	"	"	"	5.37	71.04	114.26	99.53	97.89	1.65	10.1	0.79	12.9	0.2
												14.3	**1.4**
03-3 ap1	-121.08283	48.80947	1617	13.54	201.78	116.61	313.77	229.18	0.59	10.9	0.73	15.0	0.3
03-3 ap2	"	"	"	11,00	171.22	103.05	194.34	195.43	0.62	10.4	0.72	14.5	0.3
03-3 ap3	"	"	"	8.58	109.14	86.55	367.35	129.48	0.81	12.2	0.71	17.3	0.3
03-3 ap4	"	"	"	10.26	147.61	121.17	384.16	176.09	0.84	10.8	0.78	13.8	0.3
												15.1	**1.5**
03-5ap5	-121.07026	48.79462	1181	1.57	20.02	3.5	236.2	20.84	0.18	13.8	0.70	19.8	2.1
03-5ap6	"	"	"	1.72	28.01	2.74	270.05	28.65	0.1	11,0	0.70	15.8	2,0
03-5ap7*	"	"	"	1.11	71.91	106.32	150.74	96.9	1.52	2.1	0.75	2.8	0.2
03-5ap8	"	"	"	1.51	36.02	3.28	284.5	36.79	0.09	7.5	0.72	10.4	0.3
												15.3	**4.7**

Table DR2. Apatite (U-Th)/He data from Skagit Gorge and Ross Lake profiles. Same methodoly described Table DR1
Stars against aliquot names indicate excluded samples.

04-1 ap4	-121.05947	48.77934	692	2.27	60.82	30.42	106.45	67.96	0.51	6.2	0.68	9.1	0.3
04-1 ap1	"	"	"	3.51	71.16	30.29	126.5	78.28	0.44	8.3	0.68	12.2	0.3
04-1 ap2	"	"	"	1.83	49.64	20.1	101.19	54.37	0.42	6.2	0.76	8.2	0.2
04-1 ap3	"	"	"	18.11	305.79	131.8	492.24	336.76	0.44	10.0	0.68	14.7	0.4
04-1ap5	"	"	"	2.15	39.42	22.44	80.48	44.7	0.58	8.9	0.72	12.4	0.3
04-1ap6	"	"	"	1.75	37.81	18.09	74.57	42.06	0.49	7.7	0.80	9.6	0.2
04-1ap7	"	"	"	2.16	41.39	23.97	87.75	47.02	0.59	8.5	0.77	11.0	0.2
												11.0	**2.2**
04-2 ap1	-121.06124	48.7818	916	2.69	45.32	25.64	139.01	51.35	0.58	9.7	0.72	13.4	0.4
04-2 ap2	"	"	"	1.83	36.98	20.85	131.37	41.88	0.58	8.1	0.79	10.2	0.3
04-2 ap4	"	"	"	2.14	38.98	19.75	103.97	43.62	0.52	9.1	0.74	12.2	0.3
04-2ap5	"	"	"	0.82	15.15	9.57	82.73	17.4	0.65	8.6	0.70	12.3	0.3
04-2ap6	"	"	"	0.99	26.68	15.06	84.46	30.22	0.58	6.1	0.73	8.3	1.5
												11.3	**2.0**

Table DR2. Apatite (U-Th)/He data from Skagit Gorge and Ross Lake profiles. Same methodoly described Table DR1. Stars against aliquot names indicate excluded samples.

SG 02-1 Step	Temp (°C)	Duration (hours)	^{3}He (x 10^{6} atoms)	(+/-)	$^{4}He/^{3}He$	(+/-)
1	180	1.00	0.042	0.004	383	127
2	225	0.50	0.023	0.002	273	186
3	260	0.38	0.051	0.005	273	92
4	300	0.51	0.131	0.01	505	67
5	300	0.66	0.092	0.008	592	93
6	310	0.66	0.097	0.008	615	98
7	330	0.46	0.088	0.007	732	116
8	340	0.45	0.074	0.006	920	162
9	350	0.48	0.097	0.008	862	123
10	350	0.66	0.071	0.006	1248	221
12	370	0.53	0.138	0.010	1112	120
13	400	0.48	0.127	0.010	1308	163
14	410	0.50	0.058	0.005	1588	435
15	420	0.56	0.023	0.003	2169	1578
16	440	0.63	0.019	0.002	1630	1826
17	475	0.50	0.007	0.001	1619	4863

Table DR3: Stepwise 4He/3He degassing data for SG 02-1.