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Supplement of

Cosmogenic ^{3}He paleothermometry on post-LGM glacial bedrock within the central European Alps

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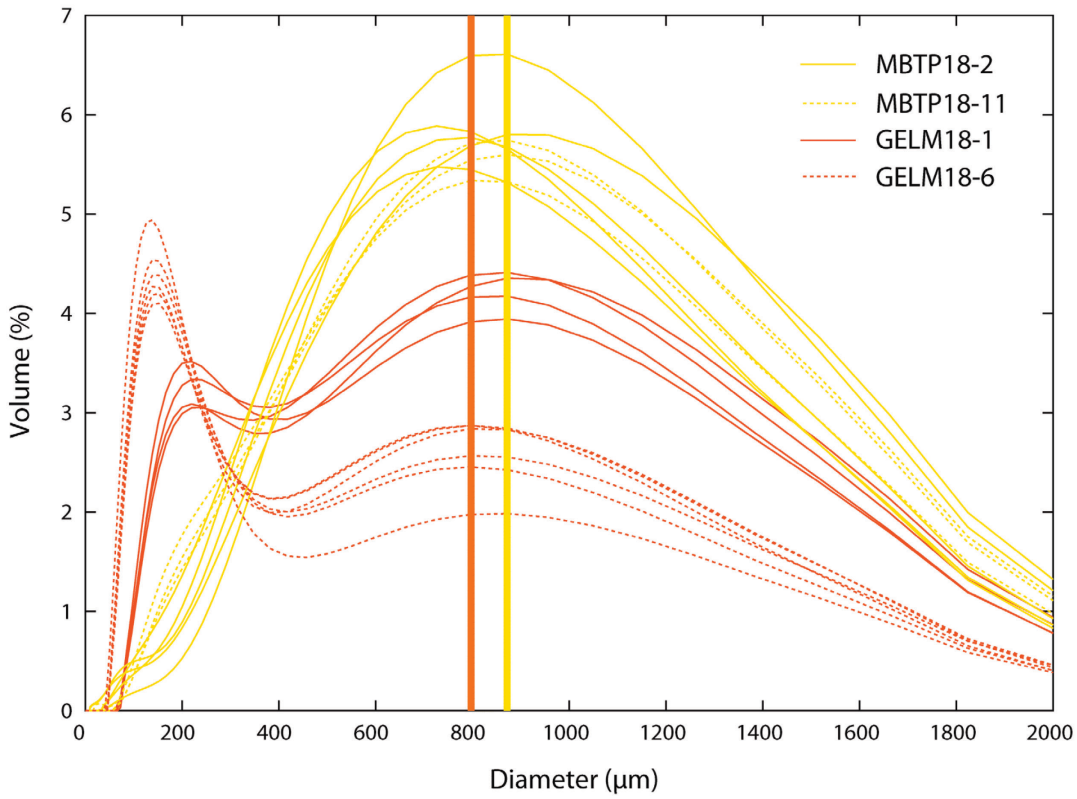

Figure S1: Grain-size distribution measured using laser diffraction after *Selfrag* crushing (fraction ≤ 1.5 mm) for two representative samples per study site: MBTP (MBTP18-2, -11) and GELM (GELM18-1, -6). Multiple lines represent replicates for each sample. Thick vertical lines indicate the averaged mode for the MBTP (yellow line) and the GELM (orange line) sites, when excluding the finer fraction (i.e. <200 µm).

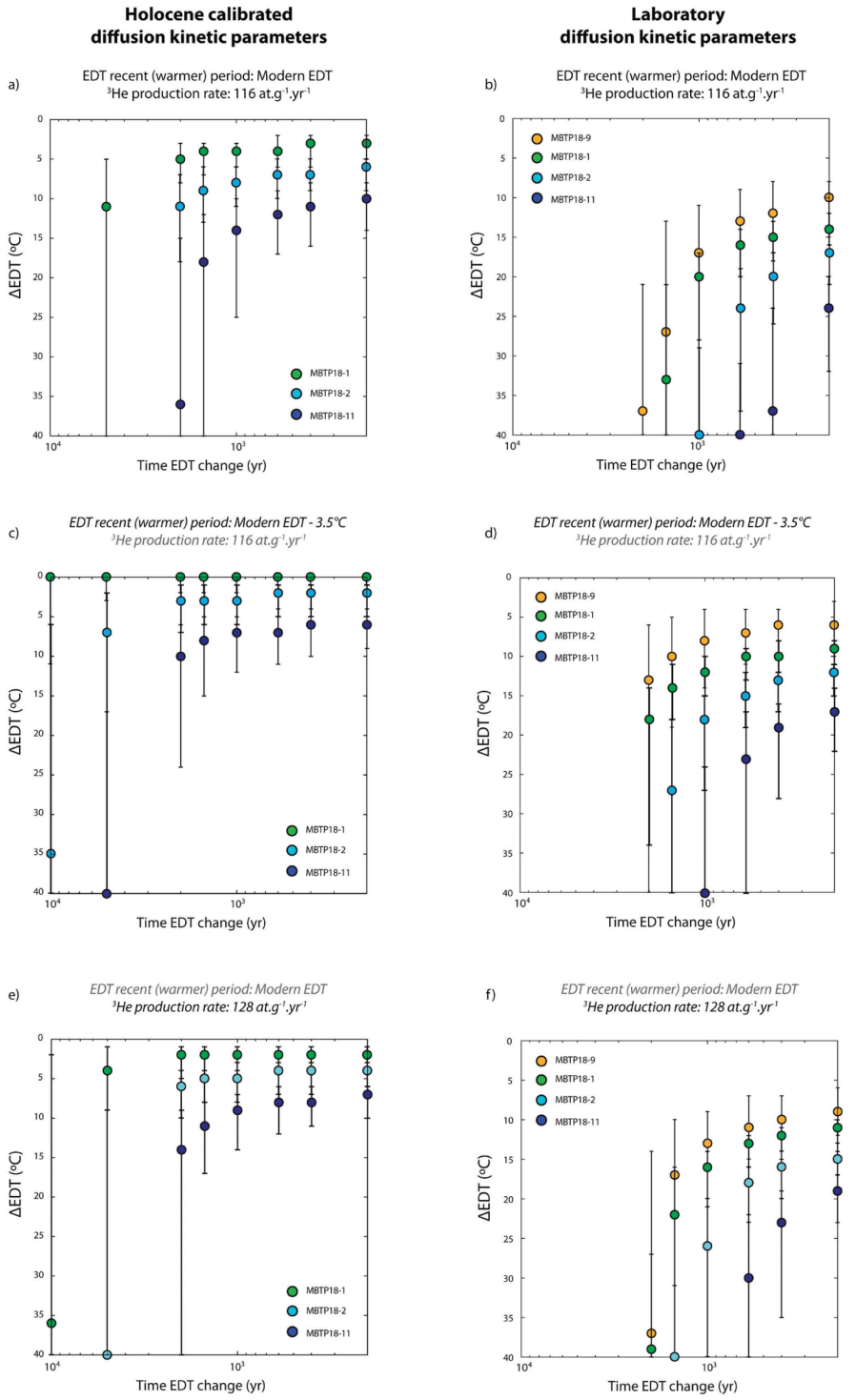

Figure S2: ΔEDT solutions as function of time of EDT change from time-varying EDT forward simulations conducted using MBTP diffusion kinetics calibrated with Holocene samples (left panels) or solely based on laboratory experiments (right panels), with a) and b): recent EDT equal to the Modern EDT and using a ^{3}He production rate of 116 at.g^{-1}.yr^{-1}; c) and d): recent EDT equal to the Modern EDT minus 3.5°C; e) and f): ^{3}He production increased by 10% (128 at.g^{-1}.yr^{-1}).

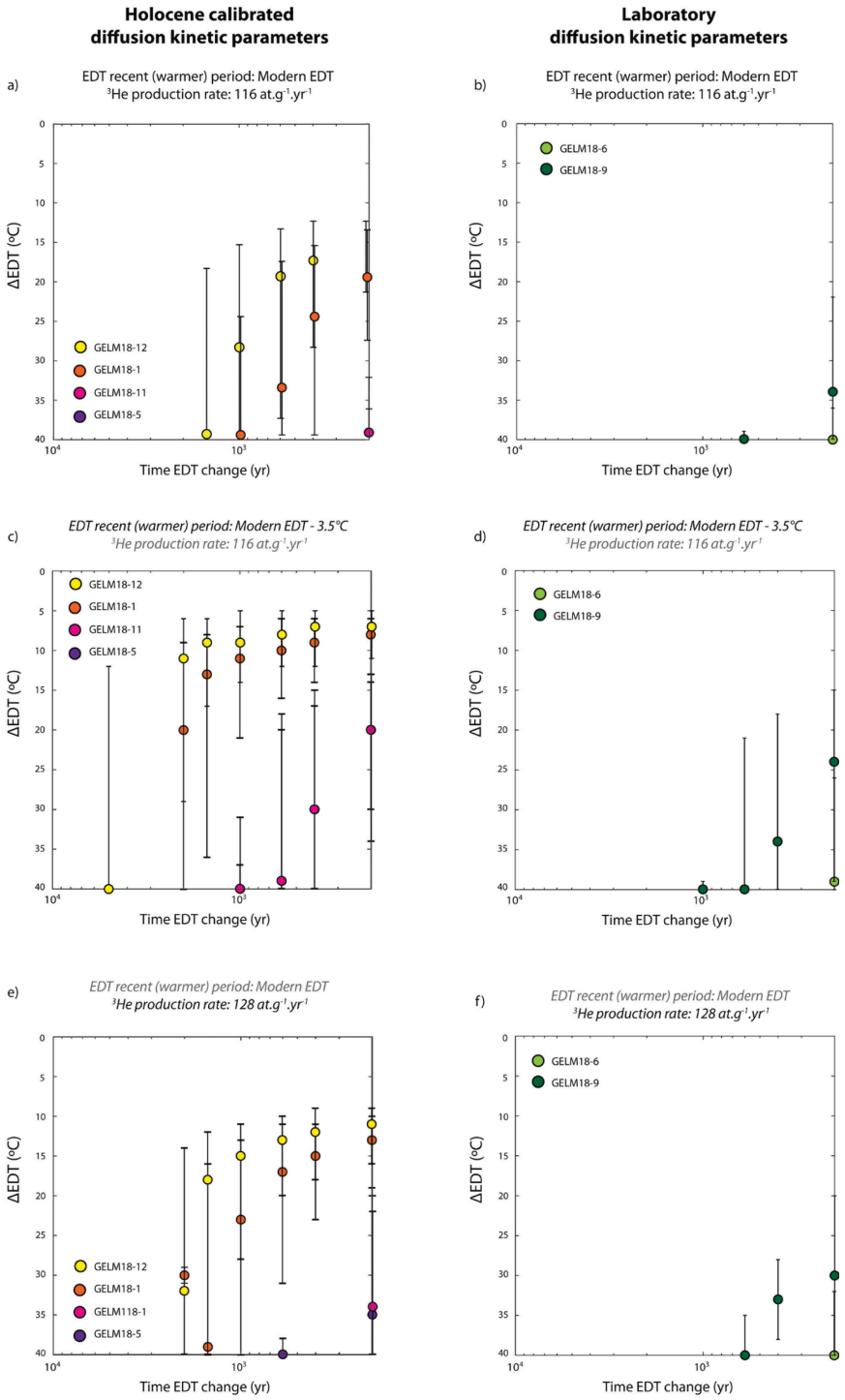

Figure S3: ΔEDT solutions as function of time of EDT change from time-varying EDT forward simulations conducted using GELM diffusion kinetics calibrated with Holocene samples (left panels) or solely based on laboratory experiments (right panels), with a) and b): recent EDT equal to the Modern EDT and using a ^{3}He production rate of 116 at.g^{-1}.yr^{-1}; c) and d): recent EDT equal to the Modern EDT minus 3.5°C; e) and f): ^{3}He production increased by 10% (128 at.g^{-1}.yr^{-1}). Only solutions for Holocene samples (GELM18-6 and -9) exist when using diffusion kinetics parameters solely based on laboratory experiments.

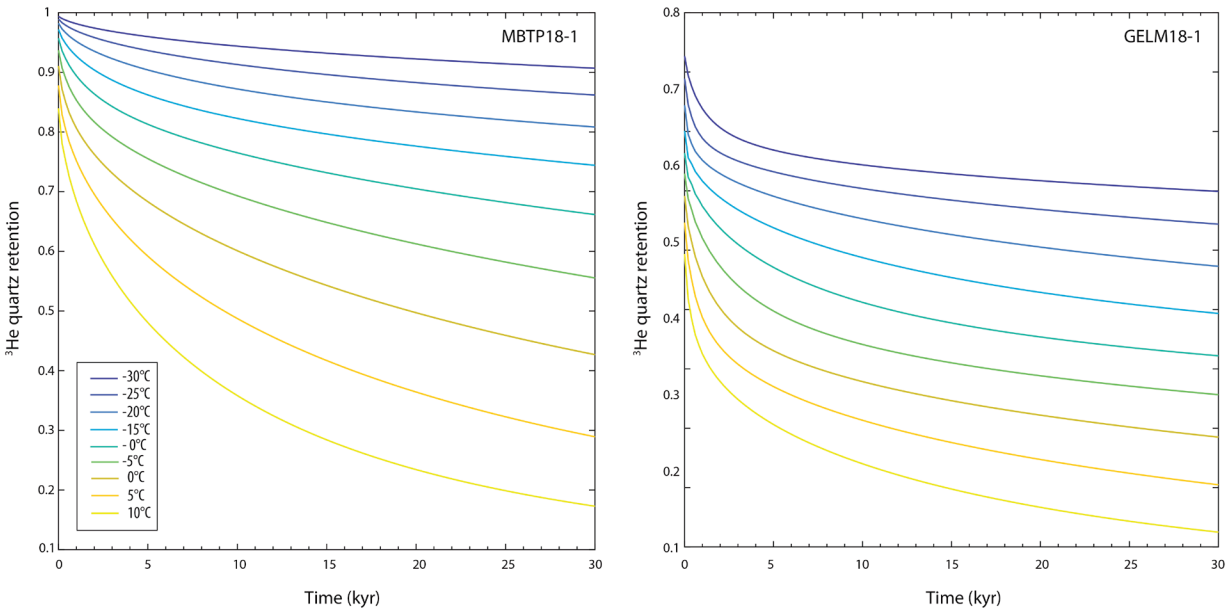

Figure S4: Evolution of quartz ^{3}He retention with time for varying IsoEDT for two example samples (left: MBTP18-1, and right: GLM18-2), using the final Holocene-calibrated diffusion kinetics parameters determined for each study site, and assuming 450 µm grain radius. The simulations were run assuming a continuous exposure to cosmic rays. Temporary rock surface coverage (e.g., cold-base ice) blocking the production of ^{3}He (e.g., cold-base ice cover) would result in lower retention values.

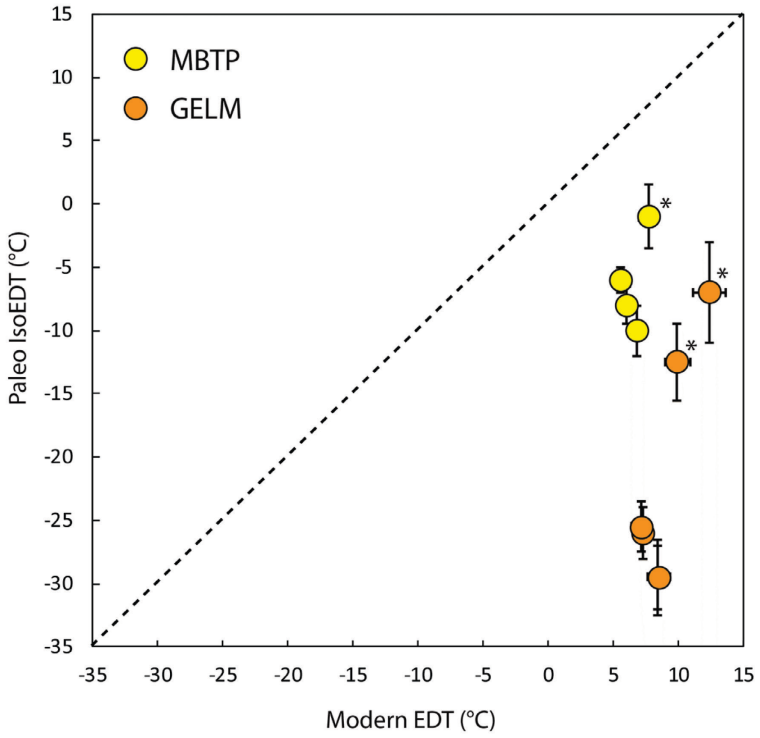

Figure S5: Comparison of modern EDTs and paleoIsoEDTs obtained using diffusion kinetics from laboratory experiments (without Holocene calibration), for both MBTP and GELM samples. The asterisks indicate the Holocene samples.

Table S1: Measured ^{10}Be and ^{3}He concentrations.

Sample	Lat./Long. (°N/°E)	Alt. (m a.s.l.)	Thickness (^{10}Be, cm)[a]	Shield.[a]	^{10}Be conc. (x10^{4} at.g^{-1})[a]	±1σ (x10^{4} at.g^{-1})	^{3}He conc. (x10^{6} at.g^{-1})[b]	Avg. unc. (x10^{6} at.g^{-1})[c]	Std (x10^{6} at.g^{-1})
MBTP18-1	45.9083/6.9311	2545	8	0.963	4.75	0.18	6.40	0.52	0.37
MBTP18-2	45.9086/6.9319	2460	8.5	0.949	4.03	0.17	6.33	0.51	0.73
MBTP18-9	45.9124/6.933	2133	6	0.656	1.60	0.08	1.87	0.33	0.26
MBTP18-11	45.9108/6.9315	2310	7	0.898	3.30	0.13	5.77	0.51	0.48
GELM18-1	46.6218/8.3257	2387	1	0.977	4.58	0.21	5.45	0.50	0.71
GELM18-5	46.6185/8.3215	2155	1	0.979	3.04	0.14	4.45	0.48	0.93
GELM18-6	46.6151/8.3212	1888	4	0.934	1.73	0.10	1.25	0.23	0.10
GELM18-9	46.6136/8.3071	1418	1	0.949	1.39	0.11	0.64	0.25	0.10
GELM18-11	46.618/8.3217	2154	1	0.986	3.17	0.12	4.59	0.40	0.19
GELM18-12	46.6221/8.3258	2402	2.5	0.929	5.67	0.26	6.15	0.62	0.37

[a]Reported from Lehmann et al. (2020; MBTP site) and Wirsig et al. (2016b; GELM site). [b]All samples for ^{3}He were collected at less than 3 cm depth, and mean ^{3}He concentrations from three replicate measurements (Table S2; 400-500 µm radii fraction) per sample were used as final ^{3}He concentrations. [c]Final uncertainty of the mean ^{3}He were estimated based on the average measurement error (1σ) between the three replicates (Table S2).

Table S2: Details of replicate measurements of ^{3}He concentrations.

Sample	Replicate	Mass (g)	^{3}He conc. (x10^{6} at.g^{-1})[a]	±1σ (x10^{6} at.g^{-1})
MBTP18-1	a	0.108	5.99	0.52
	b	0.087	6.73	0.61
	c	0.109	6.47	0.43
MBTP18-2	a	0.097	6.92	0.57
	b	0.095	6.56	0.56
	c	0.127	5.51	0.39
MBTP18-9	a	0.103	1.59	0.32
	b	0.096	1.91	0.35
	c	0.115	2.12	0.32
MBTP18-11	a	0.106	6.31	0.53
	b	0.075	5.37	0.59
	c	0.130	5.64	0.40
GELM18-1	a	0.097	5.76	0.49
	b	0.093	4.63	0.53
	c	0.094	5.95	0.49
GELM18-5	a	0.101	4.49	0.54
	b	0.083	3.50	0.46
	c	0.097	5.36	0.45
GELM18-6	a	0.111	1.37	0.24
	b	0.122	1.19	0.23
	c	0.121	1.18	0.22
GELM18-9	a	0.086	0.54	0.29
	b	0.122	0.73	0.24
	c	0.130	0.66	0.22

GELM18-11	a	0.119	4.68	0.42
	b	0.125	3.65	0.37
	c	0.102	5.43	0.42
GELM18-12	a	0.057	6.00	0.84
	b	0.091	6.09	0.60
	c	0.128	6.37	0.43

[a] ^{3}He concentration measurements were made on the 400-500 μm radii fraction, applying an analytical blank correction of 7.7 x 10^{3} at.

Table S3: Natural ^{3}He and ^{4}He released amount during the 800°C heating step.

Sample	**Replicate**	**^{3}He (x10^{5} at.)[a]**	**±1σ (x10^{5} at.)**	**^{4}He (x10^{11} at.)**	**±1σ (x10^{11} at.)**
MBTP18-1	a	6.46	0.56	3.86	0.30
	b	5.83	0.53	5.14	0.39
	c	7.04	0.47	4.47	0.17
MBTP18-2	a	6.73	0.56	6.64	0.50
	b	6.25	0.54	3.92	0.30
	c	6.99	0.50	6.56	0.25
MBTP18-9	a	1.64	0.33	5.13	0.39
	b	1.83	0.33	3.74	0.28
	c	2.43	0.37	3.74	0.14
MBTP18-11	a	6.69	0.56	2.69	0.20
	b	4.03	0.44	6.32	0.47
	c	7.35	0.53	7.64	0.29
GELM18-1	a	5.59	0.48	1.79	0.14
	b	4.31	0.49	13.56	1.01
	c	5.58	0.46	2.76	0.11
GELM18-5	a	4.51	0.54	25.52	1.93
	b	2.92	0.38	2.74	0.20
	c	5.18	0.43	6.01	0.23
GELM18-6	a	1.51	0.27	0.27	0.02
	b	1.45	0.28	0.20	0.02
	c	1.43	0.27	0.17	0.01
GELM18-9	a	0.46	0.25	1.60	0.12
	b	0.89	0.29	1.90	0.14
	c	0.86	0.29	4.73	0.18
GELM18-11	a	5.57	0.50	3.63	0.27
	b	4.56	0.46	2.84	0.21
	c	5.53	0.42	2.33	0.09
GELM18-12	a	3.43	0.48	9.74	0.74
	b	5.51	0.54	2.37	0.19
	c	8.17	0.55	4.82	0.18

[a] ^{3}He amount applying an analytical blank correction of 7.7 x 10^{3} at.

Table S4: ^{3}He stepwise-heating experiment data for MBTP18-9.

Step	**Time (minutes)**	**Temperature (°C)**	**^{3}He (x10^{4} at.)[a]**	**±1σ (Stat.)[b] (x10^{4} at.)**	**±1σ (Stat. + Sensitiv.)[c] (x10^{4} at.)**
1	60	100.0	4545.5	26.8	218.7
2	120	100.0	4490.0	24.2	215.5
3	80	70.0	159.3	5.6	9.5
4	160	70.0	294.0	6.4	15.5

5	240	70.0	412.6	7.5	21.1
6	120	90.0	1071.6	12.8	52.6
7	180	90.0	1518.8	13.4	73.5
8	180	100.0	2468.7	21.3	119.2
9	60	120.0	2819.5	17.9	134.9
10	120	120.0	3925.4	21.9	187.2
11	180	120.0	3763.1	24.9	179.9
12	60	140.0	3763.9	23.8	179.7
13	120	140.0	5053.9	29.8	240.8
14	180	140.0	5802.7	27.5	275.6
15	60	160.0	5143.1	27.3	244.5
16	120	160.0	8313.4	32.7	393.5
17	180	160.0	7663.2	36.2	363.1
18	60	180.0	7649.0	32.1	361.9
19	120	180.0	11902.7	46.1	562.4
20	180	180.0	12152.2	45.9	562.5
21	60	200.0	8488.6	38.5	393.1
22	120	200.0	10957.0	45.3	506.7
23	180	200.0	8829.8	38.8	408.4
24	30	249.9	7760.8	36.0	358.9
25	60	250.0	4271.1	24.6	198.0
26	30	299.9	2572.0	18.8	119.8
27	60	300.0	919.9	12.3	44.0
28	30	324.9	209.0	5.4	11.1
29	60	324.9	64.6	3.2	4.4
30	30	349.9	7.3	2.3	2.3
31	60	349.9	-0.1	1.9	1.9
32	60	334.9	-0.9	2.1	2.1
33	60	310.0	-4.7	2.2	2.2
34	90	290.0	0.6	2.2	2.2
35	90	250.0	-1.8	2.1	2.1
36	120	250.0	-0.7	1.8	1.8
37	180	215.0	-1.1	2.2	2.2
38	120	265.0	1.0	2.0	2.0
39	90	285.0	1.0	1.8	1.8
40	60	299.9	-1.7	2.0	2.0
41	60	330.0	-0.8	1.9	1.9
42	60	359.9	2.6	2.0	2.0
43	60	379.9	-2.3	2.0	2.0
44	30	399.9	7.9	2.2	2.3
45	60	399.9	0.1	1.9	1.9
46	30	424.9	0.5	2.1	2.1
47	60	424.9	0.4	1.9	1.9
48	30	449.9	-0.5	2.0	2.0
49	60	449.9	-2.3	1.9	1.9
50	30	474.9	-1.3	1.9	1.9
51	60	474.9	-0.1	1.9	1.9
52	30	499.9	-0.1	2.0	2.0
53	30	549.9	0.8	2.1	2.1

[a]Measurements of ^{3}He were made on a quartz grain of 700μm spherical equivalent diameter and all ^{3}He abundances were background corrected using an averaged room temperature blank of $2.1 \pm 1.2 \times 10^{4}$ at.

[b]Propagated uncertainties associated with statistical error measurements and blank corrections.

[c]Propagated uncertainties associated with statistical error measurements, blank corrections and mass spectrometer nonlinear sensitivity.
Heating steps in gray were excluded from MDD models (Figure 3a) because measured ^{3}He abundances are below or close to below the detection level.

Table S5: ^{3}He stepwise-heating experiment data for GELM18-1.

Step	Time (minutes)	Temperature (°C)	^{3}He (x10^4 at.)[a]	±1σ (Stat.)[b] (x10^4 at.)	±1σ (Stat. + Sensitiv.)[c] (x10^4 at.)
1	60	100.04	21022.5	58.7	1107.4
2	120	99.99	2616.0	21.3	140.5
3	80	69.99	134.7	7.3	10.4
4	160	69.99	226.1	7.7	14.5
5	240	70	263.6	8.3	16.7
6	120	89.99	584.8	12.0	34.2
7	180	89.98	664.6	11.8	38.3
8	180	99.99	1852.6	22.8	104.1
9	60	119.97	3044.8	23.7	169.8
10	120	119.98	3754.4	26.2	210.5
11	180	119.99	3218.5	25.1	181.6
12	60	139.95	3080.2	23.9	174.5
13	120	139.98	2976.3	25.3	169.6
14	180	139.98	3045.7	21.2	173.6
15	60	159.96	2171.2	23.3	125.6
16	120	159.98	4880.1	26.7	281.8
17	180	159.98	3679.0	24.0	213.8
18	60	179.96	2683.4	19.7	156.9
19	120	179.98	4284.9	28.4	251.1
20	180	179.99	3833.4	22.4	226.2
21	60	199.96	2037.0	19.6	122.4
22	120	199.98	2328.3	19.4	140.0
23	180	199.98	1963.4	19.1	119.0
24	30	249.89	1769.6	16.4	107.6
25	60	249.94	2248.4	20.2	137.1
26	30	299.67	4103.9	22.9	249.4
27	60	300.0	-1.5	5.1	5.1
28	30	325.1	-4.7	5.0	5.0
29	30	499.9	9.0	5.2	5.3

[a]Diffusion kinetics ^{3}He measurements were made on a quartz grain of 900µm spherical equivalent diameter and all ^{3}He abundances were background corrected using an averaged room temperature blank of 4.8±4.8x10^{4}at.
[b]Propagated uncertainties associated with statistical error measurements and blank corrections.
[c]Propagated uncertainties associated with statistical error measurements, blank corrections and mass spectrometer nonlinear sensitivity.
Heating steps in gray were excluded from MDD models (Figure 3b) because measured ^{3}He abundances are below or close to below the detection level.