

**Supplementary File: Geological Insights from the Newly Discovered
Granite of Sif Island between Thwaites and Pine Island Glaciers**

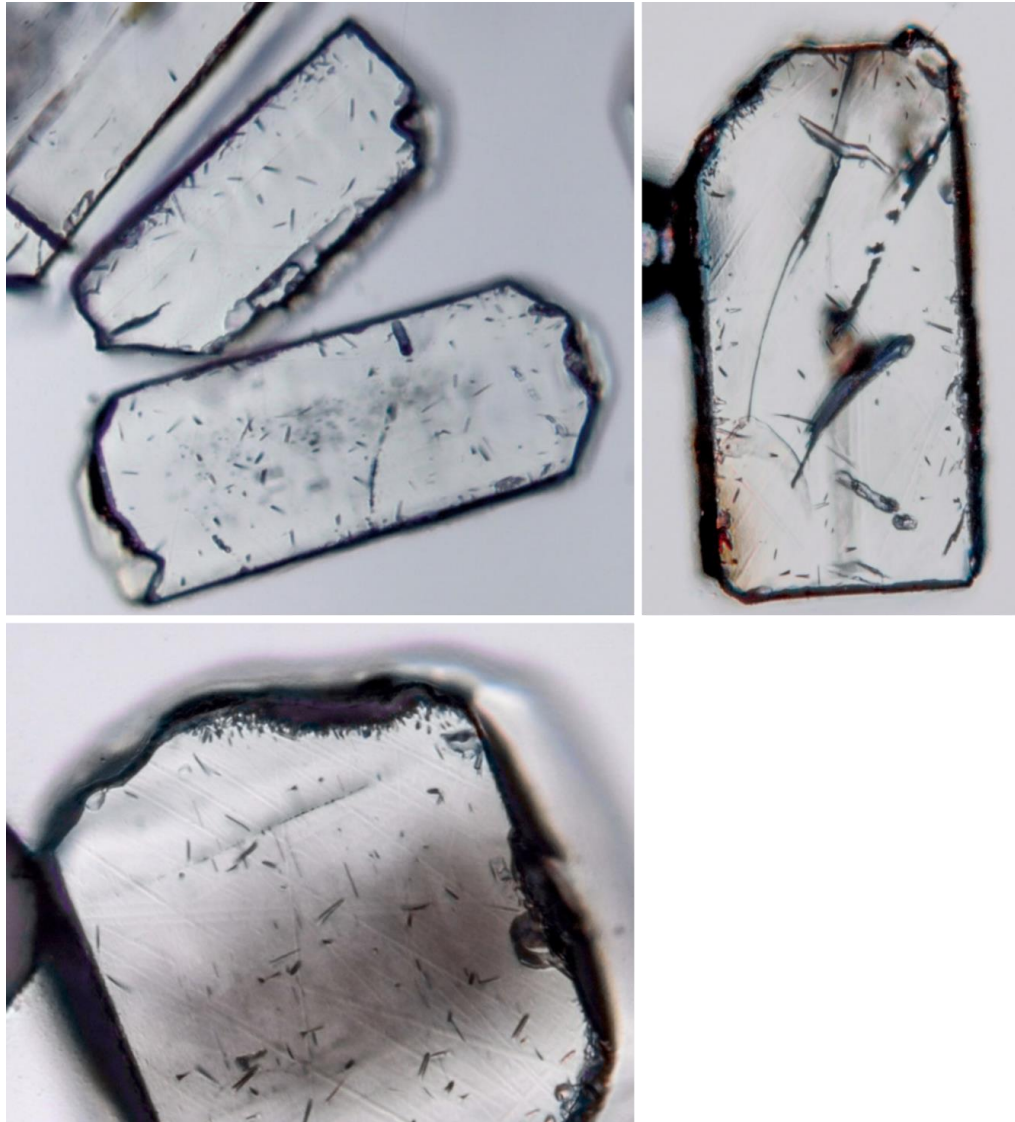


Figure S1. Images of etched apatite grains with clusters of tracks on the edge of grains indicative of 'bad neighbours' injecting parentless He.

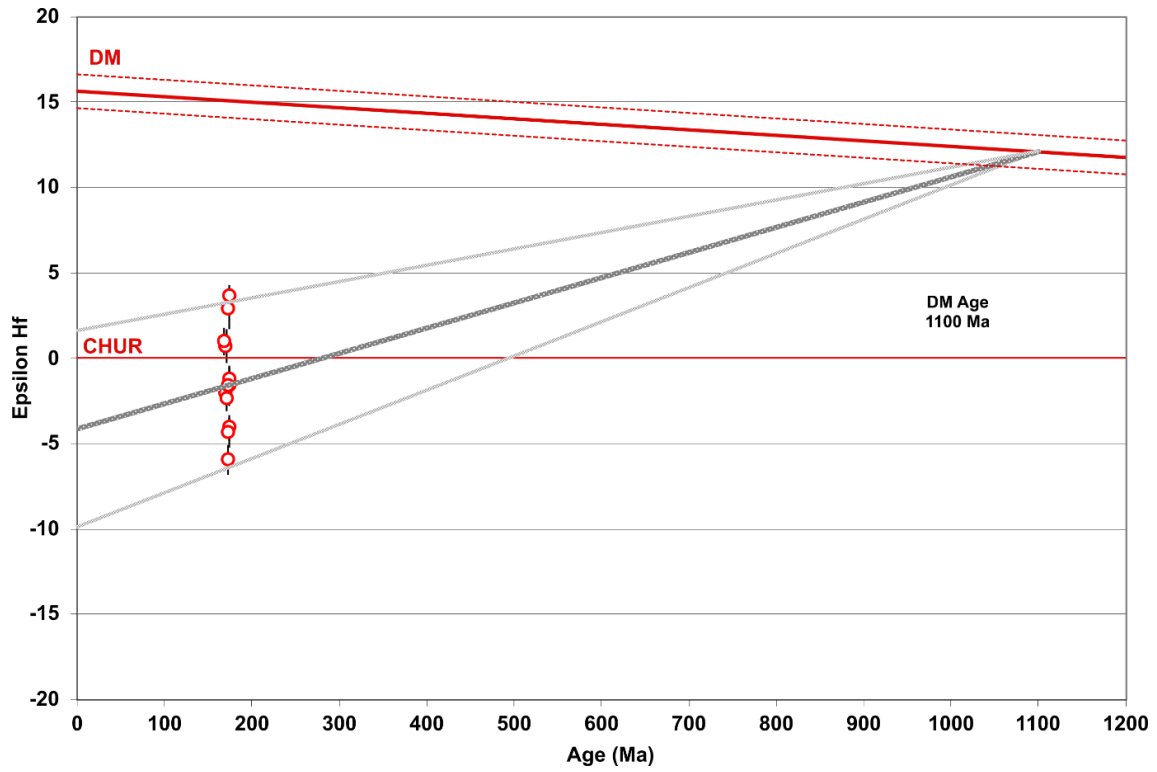


Figure S2. Plot used to estimate a single-stage depleted mantle model age from the zircon Hf isotope data. Depleted mantle (DM) data are from Vervoort and Blichert-Toft (1999).

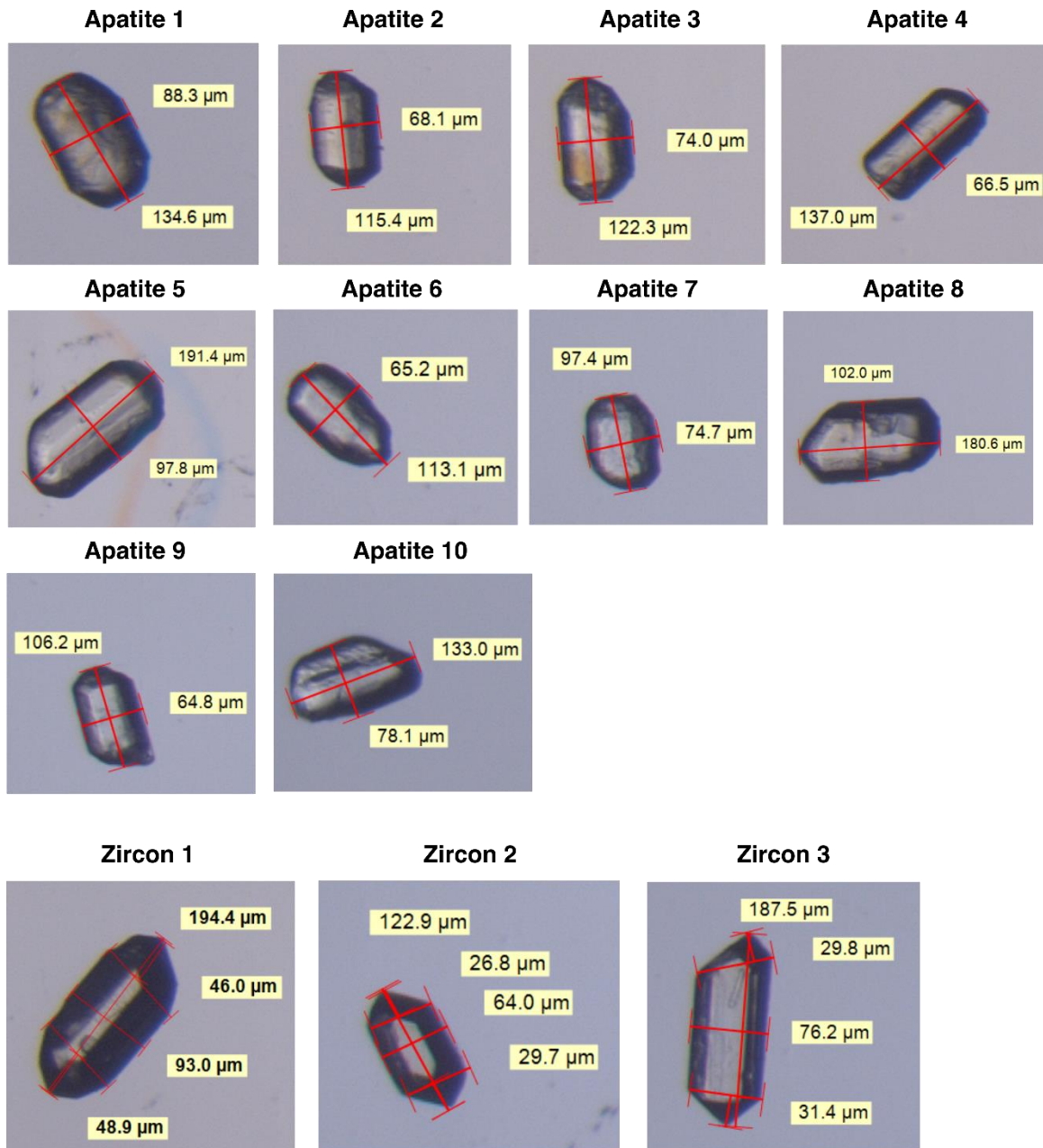


Figure S3. Images of 10 apatite and 3 zircon grains selected for (U-Th)/He dating, showing their dimensions in microns.

Table S1. U-Pb zircon data. Data from grains highlighted in red are not used in age calculations as they are either discordant or inherited. Also shown are the secondary standard results, using Forest Center Gabbro (FC; Paces and Miller, 1993), Braintree Complex (R33; Mattinson, 2010) and GJ1 zircons (Jackson et al., 2004).

Grain No.	U (ppm)	Th (ppm)	Th/U	²³⁸ U/ ²⁰⁶ Pb	±s.e.	²⁰⁷ Pb/ ²⁰⁶ Pb	±s.e.	²⁰⁷ / ²³⁵ Age	±s.e.	²⁰⁶ / ²³⁸ Age	±s.e.	²⁰⁷ / ²⁰⁶ Age	±s.e.	Grain Concordia Age	±s.e.	Disc. (%)
<i>Arizona Geochronology Centre - SIA</i>																
1	220.0	121.7	0.55	36.41	0.7069	0.0529	0.0009	183.52	4.45	174.88	3.35	296.18	41.33	175.11	3.36	5.3
2	172.5	97.2	0.56	37.35	0.8939	0.0517	0.0009	169.27	6.25	170.49	4.02	152.18	75.16	170.44	4.01	-0.8
3	77.8	34.3	0.44	36.07	0.5992	0.0529	0.0012	186.23	4.66	176.14	2.88	316.18	49.37	176.16	2.89	6.1
4	157.6	69.6	0.44	36.42	0.8259	0.0507	0.0010	167.80	4.70	174.88	3.92	69.08	47.84	173.71	3.87	-4.5
5	1207.5	531.0	0.44	36.92	0.6779	0.0661	0.0018	210.45	6.33	172.37	3.13	661.45	59.60	170.41	3.13	22.0
6	643.6	231.4	0.36	37.75	0.6856	0.0500	0.0005	167.11	3.22	168.61	3.03	146.03	24.17	168.20	2.99	-1.0
7	114.2	45.1	0.40	35.70	0.7277	0.0487	0.0008	168.58	4.18	178.02	3.58	38.00	41.84	176.07	3.52	-6.0
8	513.3	167.5	0.33	37.59	0.7434	0.0495	0.0006	165.48	3.68	169.23	3.31	112.05	32.56	168.41	3.26	-2.5
9	155.8	101.1	0.65	38.76	0.8284	0.0515	0.0007	169.01	3.97	164.21	3.47	236.73	31.92	164.64	3.48	3.1
10	304.1	159.5	0.52	36.63	0.5392	0.0498	0.0005	171.33	2.79	173.63	2.52	139.65	23.18	173.14	2.49	-1.5
11	233.2	127.4	0.55	37.11	0.8577	0.0500	0.0008	168.49	4.95	171.12	3.90	131.76	51.27	170.86	3.88	-1.7
12	93.9	34.9	0.37	36.46	0.7069	0.0500	0.0009	172.44	4.22	174.26	3.34	147.61	42.63	174.07	3.32	-1.1
13	85.4	44.8	0.52	36.37	0.5415	0.0505	0.0011	166.17	4.84	174.88	2.57	43.73	66.68	174.50	2.56	-5.5
14	300.8	176.3	0.59	36.77	0.5834	0.0504	0.0006	175.43	3.27	173.00	2.71	208.37	29.46	173.25	2.71	1.5
15	734.9	747.7	1.02	38.98	0.8985	0.0719	0.0020	217.27	6.96	163.58	3.73	848.13	56.25	156.80	3.71	31.7
16	171.3	103.7	0.61	35.88	0.7585	0.0516	0.0009	177.91	4.57	177.39	3.69	184.78	43.13	177.45	3.68	0.3
17	544.6	199.0	0.37	36.94	0.8226	0.0503	0.0006	172.53	4.08	172.37	3.79	174.62	29.56	172.41	3.77	0.1
18	165.7	82.2	0.50	36.52	0.6752	0.0507	0.0008	174.07	3.92	174.26	3.18	171.50	37.17	174.24	3.17	-0.1
19	151.9	81.9	0.54	49.50	0.8776	0.0538	0.0009	140.23	3.21	128.92	2.26	336.24	38.53	128.53	2.27	9.0
20	111.4	37.3	0.33	36.44	0.6716	0.0494	0.0008	172.95	3.86	174.26	3.16	155.19	36.98	174.11	3.15	-0.8
21	48.4	24.7	0.51	35.57	0.6195	0.0497	0.0014	161.67	5.16	178.65	3.07	0.00	65.22	177.37	3.04	-10.8
22	64.3	37.1	0.58	36.47	0.7836	0.0521	0.0013	170.73	5.28	174.26	3.70	122.07	60.82	174.00	3.68	-2.2
23	615.9	528.1	0.86	38.07	0.8419	0.0846	0.0044	256.59	12.86	167.35	3.65	1179.20	103.20	163.68	3.63	47.5
24	236.6	91.1	0.39	36.59	0.8203	0.0494	0.0007	165.82	4.09	173.63	3.84	55.78	34.55	171.10	3.74	-5.1
25	157.0	74.1	0.47	36.11	0.7082	0.0507	0.0007	172.95	5.39	176.14	3.41	129.63	64.97	175.98	3.40	-2.0
26	93.5	56.7	0.61	35.78	0.7729	0.0501	0.0009	169.95	4.43	178.02	3.79	59.07	43.84	176.38	3.73	-5.1
27	87.4	50.2	0.57	35.82	0.6279	0.0499	0.0010	169.78	4.39	177.39	3.06	64.97	52.50	176.69	3.04	-4.8
28	85.3	29.8	0.35	36.21	0.6696	0.0497	0.0009	174.58	4.25	175.51	3.20	161.99	44.26	175.44	3.19	-0.6
29	499.0	479.5	0.96	37.42	0.8210	0.0496	0.0006	170.81	3.99	169.86	3.67	183.97	30.19	170.06	3.65	0.6
30	107.5	44.4	0.41	16.45	0.3324	0.0542	0.0008	377.70	7.89	380.49	7.46	360.63	33.08	379.48	7.25	-0.9
31	440.8	431.1	0.98	36.66	0.8055	0.0494	0.0007	173.72	4.23	173.63	3.77	175.03	34.48	173.64	3.75	0.1
32	260.0	145.3	0.56	37.24	0.5671	0.0497	0.0007	163.06	3.09	171.12	2.57	47.56	32.94	169.71	2.53	-5.2
33	298.8	209.2	0.70	36.26	0.7200	0.0498	0.0008	166.34	3.99	175.51	3.45	37.73	40.44	173.49	3.38	-5.9
34	150.8	69.9	0.46	35.01	0.8182	0.0502	0.0009	176.89	4.95	181.78	4.19	111.95	45.93	180.97	4.15	-3.0
35	255.4	118.8	0.47	35.59	0.5870	0.0529	0.0006	187.32	3.47	178.65	2.91	298.18	27.16	179.07	2.93	5.2
36	1430.4	1155.1	0.81	43.38	0.9083	0.0631	0.0009	178.42	4.16	147.22	3.04	614.84	31.40	139.64	3.04	21.8
37	135.1	51.3	0.38	35.90	0.6183	0.0501	0.0011	170.38	6.49	177.39	3.01	74.11	89.31	177.21	3.00	-4.4

38	595.6	195.3	0.33	37.92	0.8464	0.0505	0.0007	169.52	4.06	167.98	3.70	191.14	30.86	168.24	3.69	1.0
39	187.9	152.4	0.81	37.00	0.5965	0.0510	0.0010	171.07	4.17	171.75	2.73	161.71	49.11	171.71	2.72	-0.4
40	611.4	188.7	0.31	36.76	0.8621	0.0499	0.0006	174.67	4.30	173.00	4.01	197.26	29.58	173.35	4.00	1.1
41	50.4	24.0	0.48	37.04	0.6726	0.0836	0.0048	241.89	13.28	171.75	3.08	993.20	120.00	170.49	3.08	37.9
42	92.4	60.8	0.66	36.41	0.6101	0.0507	0.0009	169.87	3.74	174.88	2.90	100.55	40.37	174.29	2.87	-3.2
43	113.0	51.2	0.45	37.09	0.6029	0.0503	0.0007	152.80	3.18	171.75	2.76	0.00	33.68	166.45	2.66	-12.8
44	166.5	69.3	0.42	35.84	0.5480	0.0509	0.0007	156.64	2.98	177.39	2.68	0.00	32.03	170.76	2.57	-13.8
45	149.2	46.5	0.31	36.37	0.5186	0.0516	0.0010	163.84	3.81	174.88	2.47	7.02	50.26	173.91	2.45	-7.1
46	142.9	36.8	0.26	20.56	0.3132	0.0554	0.0006	313.33	5.47	305.92	4.54	368.86	30.25	306.95	4.53	2.8
47	193.7	67.9	0.35	35.59	0.6212	0.0499	0.0006	176.80	3.57	178.65	3.08	152.19	31.60	178.33	3.06	-1.1
48	338.3	221.3	0.65	36.92	0.5466	0.0504	0.0008	173.90	3.53	172.37	2.52	194.65	38.14	172.45	2.52	1.0
49	188.2	88.2	0.47	36.61	0.7435	0.0505	0.0008	173.47	4.19	173.63	3.48	171.28	39.17	173.61	3.46	-0.1
50	495.8	187.6	0.38	36.80	0.8090	0.0521	0.0008	179.95	4.49	173.00	3.76	272.25	36.56	173.37	3.78	4.3
FC 1	442.7	223.9	0.51	5.24	0.1160	0.0752	0.0007	1108.94	16.32	1126.82	22.91	1074.09	19.43	1074.09	19.43	
FC 2	385.5	191.2	0.50	5.35	0.1453	0.0771	0.0008	1110.93	19.54	1104.54	27.57	1123.45	19.82	1123.45	19.82	
FC 3	362.7	240.4	0.66	5.22	0.0814	0.0750	0.0008	1109.15	12.75	1130.10	16.17	1068.33	21.42	1068.33	21.42	
FC 4	162.4	79.7	0.49	5.42	0.1068	0.0758	0.0008	1091.21	15.17	1092.35	19.81	1088.91	22.44	1088.91	22.44	
FC 5	99.1	47.8	0.48	5.28	0.0966	0.0766	0.0008	1115.68	14.28	1118.38	18.80	1110.40	20.91	1110.40	20.91	
FC 7	190.3	93.0	0.49	5.45	0.1475	0.0773	0.0010	1100.33	20.33	1086.46	27.08	1127.87	26.89	1127.87	26.89	
FC 8	29.2	9.7	0.33	5.38	0.0746	0.0755	0.0010	1092.76	12.71	1098.05	13.99	1082.26	26.00	1082.26	26.00	
FC 10	446.9	230.6	0.52	5.24	0.0927	0.0758	0.0009	1113.39	14.31	1125.70	18.28	1089.41	23.20	1089.41	23.20	
FC 11	123.3	66.4	0.54	5.23	0.1031	0.0756	0.0008	1112.23	15.07	1127.57	20.39	1082.39	20.89	1082.39	20.89	
FC 12	174.0	87.6	0.50	5.40	0.0988	0.0749	0.0009	1084.35	14.67	1094.61	18.40	1063.82	24.65	1063.82	24.65	
FC 13	28.9	9.5	0.33	5.48	0.1001	0.0781	0.0011	1104.04	15.51	1081.09	18.19	1149.53	27.88	1149.53	27.88	
FC 14	1019.3	659.8	0.65	5.15	0.0985	0.0749	0.0007	1117.91	14.44	1144.94	20.09	1065.77	18.78	1065.77	18.78	
FC 15	915.2	549.3	0.60	5.19	0.0955	0.0748	0.0008	1110.83	14.33	1135.83	19.16	1062.24	21.26	1062.24	21.26	
FC 16	28.9	9.3	0.32	5.48	0.0835	0.0786	0.0010	1108.24	13.33	1080.87	15.16	1162.33	24.95	1162.33	24.95	
FC 17	147.7	84.8	0.57	5.42	0.0801	0.0773	0.0008	1103.36	11.92	1091.15	14.83	1127.51	19.48	1127.51	19.48	
FC 18	1370.0	973.7	0.71	5.19	0.0821	0.0740	0.0006	1104.01	12.18	1136.37	16.49	1040.78	17.71	1040.78	17.71	
FC 19	521.0	285.8	0.55	5.38	0.0929	0.0760	0.0006	1097.79	12.61	1099.90	17.48	1093.62	14.72	1093.62	14.72	
R33 1	462.3	327.6	0.71	14.78	0.3715	0.0548	0.0006	419.17	9.43	421.94	10.26	403.91	24.71	421.94	10.26	
R33 2	564.3	302.2	0.54	15.02	0.2849	0.0545	0.0005	411.57	7.21	415.62	7.64	388.93	21.73	415.62	7.64	
R33 3	555.3	369.1	0.66	14.95	0.2752	0.0553	0.0006	418.58	7.38	417.36	7.44	425.27	24.82	417.36	7.44	
R33 4	104.2	56.6	0.54	14.69	0.2644	0.0556	0.0008	426.07	7.87	424.42	7.39	434.95	30.50	424.42	7.39	
R33 5	93.3	57.7	0.62	14.80	0.2521	0.0539	0.0016	413.17	11.58	421.59	6.95	366.37	66.57	421.59	6.95	
R33 6	60.2	35.5	0.59	14.84	0.2254	0.0563	0.0008	426.84	7.18	420.25	6.18	462.61	30.92	420.25	6.18	
R33 7	524.3	402.4	0.77	15.14	0.3097	0.0550	0.0006	412.48	7.76	412.38	8.17	413.01	22.97	412.38	8.17	
R33 8	139.4	98.5	0.71	14.96	0.2548	0.0556	0.0007	420.25	7.38	417.19	6.88	437.08	28.96	417.19	6.88	
R33 9	393.6	240.0	0.61	14.99	2.2321	0.0557	0.0007	419.67	8.85	416.36	9.00	437.88	28.51	416.36	9.00	

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1	1259.0	539.5	0.43	34.28	0.3761	0.0535	0.0011	197.70	4.28	185.35	2.0	347.8	47.8	185.37	2.01	7.1
2	1909.9	987.1	0.52	36.52	0.4269	0.0533	0.0013	186.17	4.57	174.13	2.01	341.8	54.8	174.12	2.01	7.3
3	1484.6	618.2	0.42	30.30	0.3581	0.1002	0.0021	381.36	7.65	209.3	2.43	1627.5	39	195.23	2.38	70.0
4	1274.3	722.2	0.57	35.45	0.3895	0.0572	0.0012	203.99	4.46	179.34	1.94	499.4	47.3	178.93	1.95	14.0
5	703.2	332.3	0.47	36.30	0.4216	0.0513	0.0015	180.64	5.3	175.2	2.01	252.4	68.6	175.23	2.01	3.3

6	1426.3	348.1	0.24	12.42	0.1295	0.0678	0.0010	569.73	7.82	499.29	5.01	861.8	30.3	500.39	5.09	17.0
7	635.6	329.6	0.52	36.27	0.4210	0.0563	0.0017	196.8	5.82	175.32	2.01	462.8	67.3	175.16	2.01	13.0
8	1099.3	462.7	0.42	34.54	0.3937	0.0580	0.0014	211.46	5.09	183.97	2.07	529.9	52.9	183.54	2.07	15.0
9	1067.0	427.2	0.40	37.44	0.4205	0.0556	0.0013	189.04	4.47	169.92	1.88	435	52.1	169.73	1.89	12.0
10	826.0	419.6	0.51	35.84	0.4111	0.0512	0.0014	182.54	4.95	177.39	2.01	249.7	62.9	177.43	2.01	3.1
11	956.5	476.8	0.50	35.09	0.3940	0.0517	0.0013	187.72	4.63	181.15	2.01	271.1	56.3	181.2	2.01	3.9
12	3783.0	4304.6	1.14	32.50	0.3380	0.1275	0.0018	438.82	6.16	195.37	2	2062.7	24.3	162.68	1.85	97.0
13	761.5	290.3	0.38	35.93	0.4132	0.0494	0.0014	176.31	5.04	176.95	2.01	167.7	67.6	176.94	2.01	-0.4
14	864.4	523.9	0.61	36.26	0.4075	0.0488	0.0013	172.68	4.71	175.38	1.94	135.7	64.6	175.34	1.94	-1.7
15	1698.1	678.1	0.40	34.83	0.3761	0.0519	0.0010	189.65	3.79	182.47	1.94	280	43.7	182.55	1.94	4.2
16	810.6	532.4	0.66	38.26	0.4683	0.0496	0.0016	167.02	5.31	166.34	2.01	176.7	75.2	166.35	2.01	0.4
17	1145.3	660.7	0.58	34.07	0.3715	0.1816	0.0029	559.18	8.24	186.48	2	2666.6	26.1	149.7	1.82	130.0
18	707.8	403.0	0.57	36.44	0.4250	0.0476	0.0015	168.04	5.08	174.51	2.01	77.9	72.9	174.38	2.00	-4.1
19	819.9	557.8	0.68	35.87	0.4117	0.0528	0.0014	187.43	4.83	177.27	2.01	317.5	58.6	177.29	2.01	6.1
20	804.5	485.7	0.60	35.71	0.4082	0.0551	0.0015	195.88	5.23	178.02	2.01	416.9	60.4	177.92	2.01	10.0
GJ1 3	329.0	10.9	0.03	9.94	0.1127	0.0610	0.0015	602.2	17.8	604	12.3	595.4	71	603.8	12.1	
GJ1 4	334.7	11.0	0.03	10.13	0.1066	0.0606	0.0010	655.6	17.5	615.6	12.1	795.9	62.5	619.4	12.1	

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1	1002.6	550.2	0.55	36.10	0.4040	0.0494	0.0012	175.33	4.43	176.14	1.94	164.4	58.7	176.12	1.94	-0.5
2	3982.6	919.0	0.23	36.38	0.3838	0.0520	0.0008	182.59	3.14	174.82	1.82	284.4	35.6	174.91	1.82	4.7
3	803.0	280.3	0.35	36.08	0.4165	0.0512	0.0014	181.27	4.9	176.26	2.01	247	62.6	176.3	2.01	3.1
4	846.0	485.5	0.57	35.47	0.4027	0.0526	0.0014	188.94	4.93	179.21	2.01	312.3	59.7	179.24	2.01	5.8
5	664.8	350.3	0.53	37.16	0.4281	0.0485	0.0016	167.98	5.32	171.18	1.95	123.2	76.2	171.14	1.94	-2.0
6	801.4	427.3	0.53	27.08	0.3006	0.0587	0.0013	265.39	5.82	233.78	2.55	554.6	48.7	233.42	2.56	14.0
7	336.2	149.8	0.45	36.52	0.4802	0.0543	0.0026	189.17	8.7	174.13	2.26	381	109	174.11	2.26	9.0
8	784.5	454.1	0.58	36.01	0.4150	0.0503	0.0014	178.7	5.03	176.58	2.01	206.9	66	176.6	2.01	1.3
9	1636.6	1057.6	0.65	36.81	0.4199	0.0503	0.0012	175.25	4.17	172.81	1.95	208.3	53.9	172.85	1.95	1.5
10	1226.7	624.2	0.51	36.50	0.3996	0.0513	0.0011	179.73	4.05	174.26	1.88	252.4	50.7	174.31	1.88	3.4
11	858.2	445.2	0.52	36.50	0.4129	0.0529	0.0014	185.02	4.9	174.26	1.95	324.8	60.5	174.27	1.95	6.5
12	1317.3	749.7	0.57	36.64	0.4028	0.0492	0.0011	172.49	3.89	173.56	1.88	157.7	51.3	173.54	1.88	-0.7
13	1123.8	612.3	0.54	37.01	0.4109	0.0483	0.0012	168.04	4.1	171.87	1.88	114.4	56.6	171.78	1.88	-2.4
14	396.1	252.7	0.64	36.46	0.4652	0.0540	0.0023	188.72	7.78	174.44	2.2	371.3	97.5	174.43	2.20	8.6
15	687.8	451.7	0.66	36.83	0.4341	0.0528	0.0016	183.1	5.45	172.69	2.01	319.6	68.9	172.7	2.01	6.4
16	3125.9	1258.3	0.40	36.66	0.3897	0.0682	0.0011	231.77	4.05	173.5	1.82	873.7	34	169.22	1.81	32.0
17	555.8	282.3	0.51	37.05	0.4393	0.0492	0.0019	170.77	6.19	171.68	2.01	158.2	87.9	171.67	2.01	-0.6
18	4513.8	2138.3	0.47	37.58	0.3954	0.1518	0.0021	449.43	6.37	169.3	1.76	2365.8	23.9	135.56	1.59	120.0
19	488.2	270.0	0.55	36.79	0.4467	0.0518	0.0019	179.94	6.32	172.87	2.07	273.8	83.2	172.9	2.07	4.4
20	994.9	560.0	0.56	36.72	0.4046	0.0498	0.0012	173.81	4.29	173.19	1.88	182.3	57.1	173.2	1.88	0.4
GJ1 5	320.1	10.4	0.03	10.18	0.1108	0.0598	0.0010	622.3	24.7	617.9	13.1	638.3	103.7	618.2	13.00	
GJ1 6	325.2	10.7	0.03	9.98	0.1047	0.0657	0.0010	610.5	17.6	606.9	11.9	624.1	69.7	607.4	11.8	

Table S2. Analytical data for ^{10}Be measurements.

Altitude (m asl)	Shielding	Thickness (cm)	Aliquot	AMS ID §	Mass of quartz (g)	Mass of carrier ^ (mg)	Measured $^{10}\text{Be}/^9\text{Be}$		^{10}Be concentration *	
							ratio	$\pm 1\sigma$	(atoms g^{-1})	$\pm 1\sigma$
1	1	6.4	1	XBE1294	20.024	0.3390	4.42E-15	5.82E-16	2363	662
			2	XBE1231	10.040	0.3381	2.07E-15	2.38E-16	593	939

§ ratios measured at Centre for Accelerator Science, Australian Nuclear Science and Technology Organisation (ANSTO).

^ carrier Be concentration = $775.23 \pm 3.16 \mu\text{g Be g}^{-1}$; $^{10}\text{Be}/^9\text{Be} = 2.6 \times 10^{-16} \pm 6.9 \times 10^{-17}$.

* corrected with the mean Be-10 concentration of 14 procedural blanks from 8 batches of samples (30282 ± 8454 total ^{10}Be atoms); see Balco et al. (2023) for more information.

Table S3. Analytical data for in situ ^{14}C measurement.

TUCNL	AMS Lab	Quartz weight (g)	$\pm 1\sigma$ (μg)	Diluted Gas Mass (μg)	$\pm 1\sigma$ (μg)	$^{14}\text{C}/^{13}\text{C}$ corrected	$\pm 1\sigma$	$\delta^{13}\text{C}$ (‰)	$\pm 1\sigma$ (‰)	$^{14}\text{C}/\text{C}$ total	$\pm 1\sigma$	Total ^{14}C (atoms)	$\pm 1\sigma$ (atoms)	^{14}C conc. (atoms g^{-1})	$\pm 1\sigma$ (atoms g^{-1})
668	NOSAMS	4.9949	0.1	111.5	1.4	5.17E-12	6.95 E-14	-5.02	0.5	5.67 E-14	7.62 E-16	2.79 E+05	6.47 E+03	5.58 E+04	1.30 E+03

Table S4. SEM-derived mineral phases present in sample SIC.

Primary phases	Modal analysis (%)
Quartz	32.57
K Feldspar	29.37
Albite	19.60
Oligoclase	9.48
Andesine	3.39
Chlorite	0.76
Biotite	0.49
Muscovite	0.37
Smectite/Montmorillonite	0.36
Rutile	0.11
Magnetite	0.09
Labradorite	0.03
Apatite	0.03
Monazite	0.01
Other	0.86
Total	97.57

Table S5. Zircon (U-Th)He data for the Sif Island granite (grains 1-3) and the two Fish Canyon Tuff standards (FCT_1 and 10). Ft = the geometric correction factor for age calculation. Rs = the sphere equivalent radius of hexagonal crystal with the same surface/volume ratio. eU = the effective U concentration. Corrected age is the age corrected by the grain geometry and ejection factor Ft (Ketcham et al., 2011). The 1 σ errors represent the propagated analytical uncertainties from U, Th, Sm, and He measurements.

Grain No.	pmol He	Th/U	Raw date (Ma)	1 σ \pm (Ma)	Ft 238U	Ft 235U	Ft 232Th	Ft 147Sm	Rs (um)	mass Zr. (g)	Corr. date (Ma)	1 σ \pm (Ma)	ppm eU (Zr)	ppm U (Zr)	ppm Th (Zr)	nmol 4He/g (Zr)
1	0.89147	0.31	70.0	1.0	0.760	0.726	0.726	0.924	50.23	2.78E-06	92.3	1.3	846	789	241	320.9816
2	0.38940	0.60	131.2	1.7	0.697	0.655	0.655	0.902	38.87	1.10E-06	189.1	2.5	493	433	255	352.5018
3	1.32293	0.61	133.4	1.7	0.726	0.688	0.688	0.912	43.51	2.23E-06	184.4	2.4	814	715	422	592.4261
FCT_1	0.13235	0.52	21.9	0.3	0.736	0.699	0.699	0.916	45.31	2.00E-06	29.9	0.4	560.8	501	255	66.3385
FCT_10	0.23255	0.51	22.0	0.3	0.771	0.738	0.738	0.927	52.86	3.55E-06	28.6	0.4	552.6	495	246	65.5684

Table S6. Apatite (U-Th)He data for the Sif Island granite (grains 1-10) and four Durango apatite standards (Dur_6, 7, 10 and 19). Ft = the geometric correction factor for age calculation. Rs = the sphere equivalent radius of hexagonal crystal with the same surface/volume ratio. eU = the effective U concentration. Corrected age is the age corrected by the grain geometry and ejection factor Ft (Ketcham et al., 2011). The 1 σ errors represent the propagated analytical uncertainties from U, Th, Sm, and He measurements.

Grain No.	pmol He	Th/U	Raw date (Ma)	1 σ \pm (Ma)	Ft 238U	Ft 235U	Ft 232Th	Ft 147Sm	Rs (um)	mass Ap. (g)	Corr. date (Ma)	\pm 1 σ (Ma)	ppm eU w/ Sm (Ca)	ppm U (Ca)	ppm Th (Ca)	ppm Sm (Ca)	nmol 4He/g (Ca)
1	0.02882	2.49	274.0	3.2	0.663	0.619	0.619	0.890	41.28	1.43E-06	411.8	4.8	15.5	8	20	620	20.1995
2	0.07114	6.79	637.2	7.6	0.604	0.554	0.554	0.869	34.39	8.54E-07	1068.0	12.9	25.5	9	58	650	83.3016
3	0.02019	4.19	189.5	2.1	0.624	0.576	0.576	0.877	36.53	9.48E-07	305.5	3.4	24.1	10	40	1028	21.2993
4	0.02290	4.09	122.4	1.4	0.612	0.562	0.562	0.872	35.15	1.16E-06	203.6	2.3	33.1	15	58	1020	19.7317
5	0.01634	3.88	120.6	1.4	0.698	0.658	0.658	0.902	46.70	2.53E-06	173.9	1.9	11.5	5	19	472	6.4567
6	0.05731	2.90	1132.2	47.2	0.592	0.541	0.541	0.865	33.24	9.33E-07	1823.4	76.6	11.0	5	15	506	61.4285
7	0.02982	3.17	115.8	1.3	0.610	0.561	0.561	0.872	35.04	7.80E-07	194.1	2.2	63.6	35	107	867	38.2571
8	0.04282	4.03	205.2	6.3	0.732	0.696	0.696	0.914	53.21	3.23E-06	281.1	8.8	14.0	6	23	632	13.2570
9	0.02773	1.30	110.9	1.5	0.600	0.549	0.549	0.868	33.99	7.76E-07	186.2	2.6	62.5	45	57	957	35.7293
10	0.03469	1.39	129.9	1.6	0.632	0.584	0.584	0.879	37.34	1.05E-06	206.6	2.6	50.2	35	47	969	33.1656
Dur_6	0.14798	19.55	30.5	0.4	1.000	1.000	1.000	1.000		1.41E-05	30.5	0.4	63.7	12	220	173	
Dur_7	0.08816	20.02	33.9	0.4	1.000	1.000	1.000	1.000		8.31E-06	33.9	0.4	57.9	10	200	176	
Dur_10	0.04046	17.81	30.0	0.4	1.000	1.000	1.000	1.000		4.87E-06	30.0	0.4	51.3	10	174	146	
Dur_19	0.04456	18.38	32.6	0.4	1.000	1.000	1.000	1.000		5.21E-06	32.6	0.4	48.5	9	165	140	

Table S7. Zircon hafnium isotope data for the 91500, FC52 (FC), Mud Tank (MT), Plešovice (PLES), R33, Sri Lanka (SL) and Temora (TEM) standards.

Standard Name	$(^{176}\text{Yb} + ^{176}\text{Lu}) / ^{176}\text{Hf}$ (%)	Volts Hf	$^{176}\text{Hf} / ^{177}\text{Hf}$	$\pm 1\sigma$	$^{176}\text{Lu} / ^{177}\text{Hf}$
91500	5.097283	3.90	0.282298	0.000024	0.000329
91500	5.479697	3.19	0.282328	0.000022	0.000369
91500	5.305471	3.71	0.282274	0.000018	0.000336
91500	5.495535	2.58	0.282280	0.000032	0.000384
91500	5.208993	3.80	0.282303	0.000028	0.000336
91500	5.141215	3.76	0.282330	0.000022	0.000328
FC	9.912616	6.40	0.282128	0.000016	0.000585
FC	19.052846	6.53	0.282121	0.000020	0.001071
FC	10.023903	6.45	0.282164	0.000021	0.000592
FC	18.052486	5.89	0.282180	0.000020	0.001039
FC	8.319504	5.52	0.282187	0.000025	0.000478
FC	15.585770	6.40	0.282164	0.000017	0.000886
FC	11.324315	6.59	0.282171	0.000016	0.000664
FC	17.325099	6.69	0.282173	0.000018	0.000968
MT	0.124530	4.30	0.282518	0.000017	0.000007
MT	0.161946	4.25	0.282483	0.000024	0.000009
MT	5.094476	2.50	0.282289	0.000027	0.000333
MT	5.162817	2.51	0.282292	0.000034	0.000337
MT	0.125911	6.53	0.282511	0.000014	0.000008
MT	0.123790	6.50	0.282496	0.000014	0.000007
MT	5.231028	3.82	0.282290	0.000026	0.000333
MT	0.129909	6.32	0.282477	0.000015	0.000008
MT	0.136615	6.31	0.282504	0.000012	0.000008
MT	0.128478	6.37	0.282519	0.000011	0.000008
MT	0.120716	6.47	0.282503	0.000016	0.000007
PLES	2.465361	7.92	0.282435	0.000017	0.000110
PLES	1.232292	8.00	0.282505	0.000017	0.000055
PLES	1.821537	7.50	0.282517	0.000018	0.000081
PLES	4.404970	7.41	0.282489	0.000015	0.000196
PLES	2.317073	7.33	0.282483	0.000021	0.000101
PLES	1.378770	7.46	0.282491	0.000020	0.000060
PLES	1.599745	7.43	0.282464	0.000017	0.000071
R33	40.672065	7.82	0.282681	0.000020	0.002530
R33	34.105614	7.31	0.282697	0.000020	0.002245
R33	31.964525	6.42	0.282744	0.000019	0.001878
R33	20.031031	6.71	0.282731	0.000021	0.001231
R33	34.279085	6.59	0.282741	0.000017	0.002061
R33	58.720237	7.36	0.282680	0.000022	0.003716
R33	18.217018	6.48	0.282733	0.000017	0.001101
R33	35.337465	6.80	0.282701	0.000018	0.002196

SL	37.698477	6.67	0.282610	0.000018	0.002234
SL	2.192154	6.27	0.281643	0.000015	0.000131
SL	2.128581	6.27	0.281650	0.000019	0.000128
SL	2.137116	6.07	0.281656	0.000020	0.000127
SL	2.322788	6.03	0.281675	0.000021	0.000138
SL	2.345916	5.94	0.281659	0.000019	0.000139
SL	1.935535	6.13	0.281665	0.000020	0.000116
SL	2.351082	5.89	0.281658	0.000020	0.000140
SL	2.136327	5.95	0.281644	0.000017	0.000127
SL	1.373498	7.54	0.282479	0.000016	0.000060
TEM	26.638004	3.75	0.282657	0.000023	0.001719
TEM	9.893999	6.36	0.282639	0.000021	0.000658
TEM	13.202114	5.89	0.282663	0.000020	0.000850
TEM	14.986972	6.11	0.282651	0.000015	0.000955
TEM	11.826550	6.06	0.282650	0.000024	0.000727
TEM	25.909344	5.89	0.282638	0.000023	0.001650
TEM	28.527244	6.10	0.282684	0.000020	0.001777
TEM	10.131978	6.23	0.282709	0.000017	0.000687

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