

Data Repository Appendix 1. Petrographic analysis of Birch Creek samples

Sample #	Location	LAT/LON	Elevation (m)	Rock Description	Major minerals (%)					Minor minerals	Accessories	Alteration - Disequilibrium textures	Paragenetic Sequence
					Q	K-spr	Plg	Bt	Musc				
BC-BS-1	W side of pluton, next to CS contact	37° 22' 53" N, 118° 07' 21" W	8290 ft	Border Suite Granite	30	20	20	5	5	Fluorite (in plag), Mt	Xenotime, Apatite, Zircon	Zoned plag, myrmekite	1 G plаг - musc along cleavage, Musc & Bt between grain boundaries
BC-BS-2	W side of pluton, next to EP contact	37° 22' 48" N, 118° 07' 38" W	8541 ft	Border Suite Granite	30	20	30		10	Garnet	Zircon		1 & 2 G Musc
BC-CS-1	E side of pluton	37° 22' 30" N, 118° 05' 58" W	8300 ft	Central Suite Granite	30	20	30		20	Bt, Chl, Fluorite	Zircon, Monazite, Apatite (inclusions in plag)	Radiating muscovite in k-spar	1, 2, & 3 G Musc (almost all plаг is ser, overprinting)
BC-CS-2	W side of pluton, next to BS contact	37° 22' 53" N, 118° 07' 21" W	8241 ft	Central Suite Granite	30	20	30	1	5	Fluorite	Zircon, Monazite, Apatite (inclusions in plag)	plаг/k-spar, myrmekite, fluorite-filled veins	1 G Musc & Bt overprinting
BC-Dma-1	E side of pluton contact	37° 22' 33" N, 118° 04' 56" W	7090 ft	Middle Deep Springs Qtzite	50		10	10	10	Py, Chl	Zircon; others hard to distinguish	Sutured Qtz (fine grained)	Hornfels; Musc overprinting, plаг alteration
BC-DU-1	South of camp hill along road, fault outcrop of DM and DU	37° 22.486' N, 118° 08.289' W	2608 ft	Upper Deep Springs Qtzite	70		10	10	10	Bt, Abundant Mt, Musc	Zircon; others hard to distinguish	Bt between angular qtz grains	Sedimentary layering; 1 & 2 G musc, small amount of ser, Bt replacing Mt + silicate

*Q = quartz, K-spr - Potassium feldspar, Plg = Plagioclase feldspar, Bt = Biotite, Musc = Muscovite, Mt = Magnetite, Chl = Chlorite, Py = Pyrite, Ser = Sericite

DATA REPOSITORY APPENDIX 2: MONAZITE OXYGEN ISOTOPE ANALYSIS

Elemental Composition of Standards

<i>Sample</i>	554	Brazil	Brazil	eBay
<i>Analyst</i>	<i>This study</i>	<i>This study</i>	<i>Nakamura</i>	<i>Pyle</i>
n	3	3	4	4
P₂O₅	29.85	27.96	27.97	30.31
SiO₂	0.44	1.27	1.28	0.34
ThO₂	3.73	6.97	6.75	0.39
Y₂O₃	1.40	0.54	0.43	0.72
La₂O₃	14.99	14.16	14.21	15.90
Ce₂O₃	30.47	30.29	30.97	31.73
Pr₂O₃	2.90	2.86	3.05	3.26
Nd₂O₃	11.35	10.31	10.22	12.49
Sm₂O₃	1.92	2.34	1.83	2.40
Gd₂O₃	2.68	2.09	n.d.	1.69
U₂O₃	0.02	0.39	0.24	0.12
CaO	0.87	0.47	0.52	0.05
Total	100.61	99.63	97.47	99.40

Conventional mass spectrometric oxygen isotope analysis of monazite standards was performed by Bruce Taylor of the Geological Survey of Canada using a conventional fluorination procedure (Clayton, R.N., and Mayeda, T., 1963, The use of bromine pentafluoride in the extraction of oxygen from oxides and silicates for isotopic analysis.: Geochimica et Cosmochimica Acta, v. 27, p. 47-52) followed by gas source mass spectrometric analysis. Measured conventional values of $\delta^{18}\text{O}$ for monazite standards were Brazil = $1.43 \pm 0.08\text{ ‰}$, 554 = $7.54 \pm 0.12\text{ ‰}$ and eBay = $9.34 \pm 0.31\text{ ‰}$ (all $\delta^{18}\text{O}$ values referenced to SMOW). Measurements of $^{18}\text{O}/^{16}\text{O}$ on the IMP were background-corrected. Periodic measurement of $^{18}\text{O}/^{16}\text{O}$ on a standard over the course of an analytical session showed no significant drift over time. However, measured values of $^{18}\text{O}/^{16}\text{O}$ changed after we changed mounts. Accurate measurements require that standards and samples be prepared in the same mount. We therefore used the average value of the correction factor CF determined by multiple measurements of standard 554 on the same mount during the same analytical session as the samples to correct the background-corrected $^{18}\text{O}/^{16}\text{O}$ measured ratios of the samples according to: $(^{18}\text{O}/^{16}\text{O})_{t,s} = (^{18}\text{O}/^{16}\text{O})_{m,s} * \text{CF}$, where $\text{CF} = (^{18}\text{O}/^{16}\text{O})_{t,\text{std}} / (^{18}\text{O}/^{16}\text{O})_{m,\text{std}}$ and t = true, m = measured, s = sample, and std = standard. In a given session standards 554 and Brazil have nearly identical correction factors even though their respective ThO₂ concentrations of ~3.7 % and ~6.8% are very different, suggesting that composition does not affect the value of $\delta^{18}\text{O}$ measured on the IMP. The average

CF value for eBay from session #2 is significantly different from the values for the other standards; however, we've discovered that eBay is not as homogeneous as was thought: the chemical analyses show that ThO₂ and Nd₂O₃ vary by several weight percent (Joe Pyle, pers. comm.). Likewise, the values of δ¹⁸O measured on eBay had a greater variance than for the other standards. Thus, the lower value of CF may result from a smaller number of analyses on a heterogeneous sample (biased sampling).

Correction Factors for Monazite Standards Measured on the IMP

Standard – session #	Corr. Factor	St. Dev.	n
554	1.0070	0.0003	26
Brazil	1.0074	0.0003	19
554-2	1.0066	0.0005	19
Brazil-2	1.0068	0.0009	17
eBay-2	1.0056	0.0009	15

Based on hundreds of analyses of presumably homogeneous candidate standards, we found that cycle-to-cycle variation during analyses of a single spot was much lower than spot-to-spot variation, and therefore the internal errors underestimated the true analytical error. We therefore used the error based on 17 analyses of monazite standard 554 contained in our sample mount and measured in the same analytical session as our samples (1σ on δ¹⁸O_{SMOW} = 0.73 ‰) to represent the analytical error for each sample analysis.

Data presented in this paper and in Loflin (2002) indicate that there is unlikely to be a significant matrix effect associated with oxygen isotope analysis of monazite on the ion microprobe. Evidence includes:

1. The IMP-measured oxygen isotope compositions of primary and secondary zones in monazites from the Ireteba granite are the same (Loflin, 2002), even though the compositions are greatly different (secondary zones enriched in huttonite component, see Townsend et al. 2000).
2. The matrix effect would have to be such that the differences in composition between the Brazil and 554 monazite standards would cause changes in matrix effects that fortuitously cancel out.
3. Although we don't have chemical analyses of magmatic BCP monazites, it seems unlikely that they have the same composition as the proximal DSF monazites which have typical metamorphic compositions, yet they both yield the same oxygen isotope composition.

Data Repository Appendix 3: Chemical Compositions of Birch Creek Samples

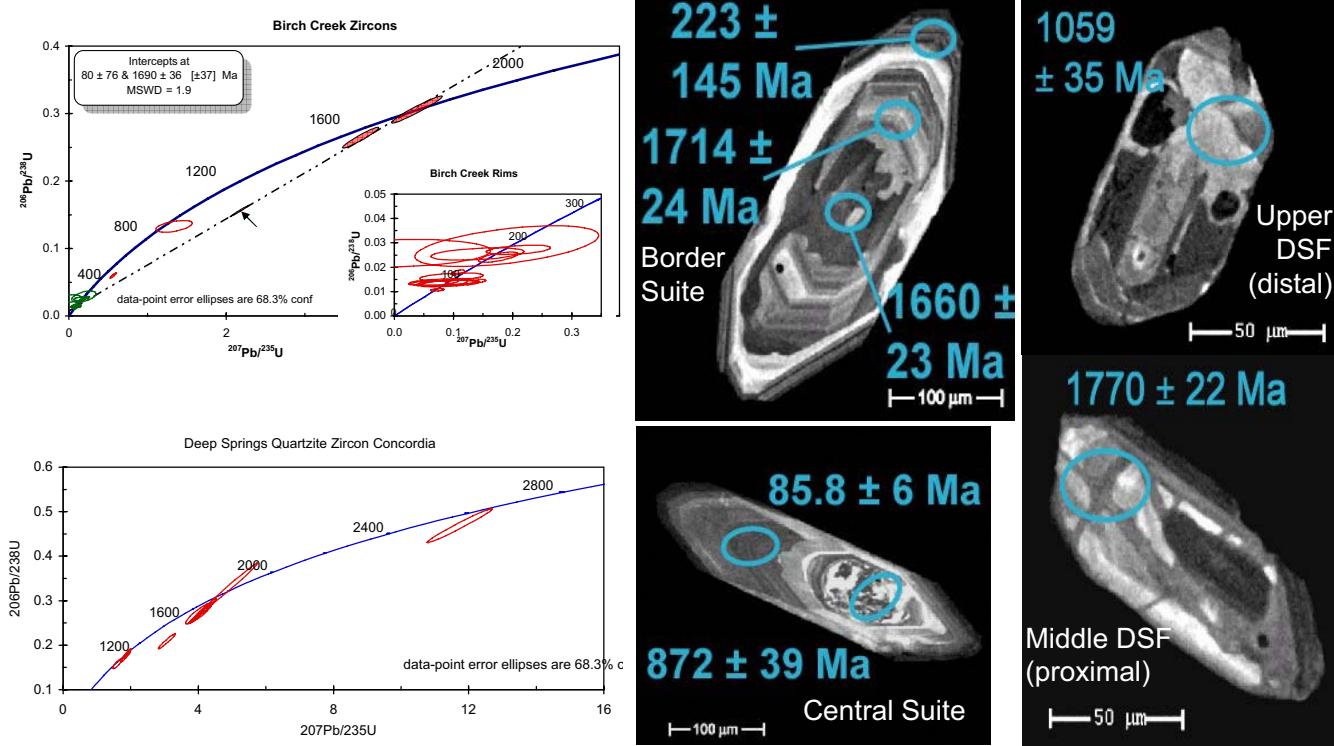
	BC-DU-1	BC-DMA-1	BC-BS-1	BC-BS-2	BC-CS-1	BC-CS-2
SiO ₂	61.80	79.31	74.13	69.96	70.71	70.51
Al ₂ O ₃	12.09	9.92	14.27	15.99	16.10	16.30
Fe ₂ O ₃	10.30	1.95	0.75	1.83	1.44	1.33
MnO	0.067	0.006	0.022	0.051	0.027	0.034
MgO	1.82	0.72	0.22	0.50	0.38	0.38
CaO	1.43	0.16	1.12	2.06	0.73	1.79
Na ₂ O	3.80	1.74	2.97	3.79	3.41	3.64
K ₂ O	2.98	4.53	5.57	3.35	4.71	4.73
TiO ₂	3.866	0.464	0.099	0.224	0.154	0.141
P ₂ O ₅	0.93	0.09	0.11	0.12	0.09	0.07
LOI	0.69	0.94	0.73	1.23	1.52	0.92
TOTAL	99.77	99.82	100.01	99.11	99.26	99.85
Ba	567	757	516	1266	1245	1720
Sr	81	81	270	561	288	484
Y	86	15	5	7	6	8
Zr	937	317	57	151	113	111
Be	2	1	3	3	4	3
V	192	14	b.d.	b.d.	b.d.	b.d.
Ga	20	10	24	26	28	25
Ge	1.6	1.0	2.2	1.4	1.7	1.3
Rb	79	101	174	119	181	140
Zr	937	323	66	151	122	113
Nb	42.0	11.9	24.3	13.7	11.2	9.9
Sn	3	b.d.	b.d.	2	1	b.d.
Cs	2.7	1.4	1.4	2.8	2.9	1.7
La	49.1	23.4	18.5	52.9	30.6	35.5
Ce	132	48.9	33.4	94.2	63.1	63.8
Pr	14.1	5.35	3.75	10.3	6.18	6.95
Nd	59.2	19.5	12.3	33.6	19.9	23.2
Sm	15.7	3.88	2.05	5.07	3.14	3.72
Eu	3.80	0.758	0.498	1.13	0.840	0.978
Gd	16.1	3.01	1.30	3.05	1.85	2.36
Tb	2.79	0.48	0.19	0.37	0.25	0.31
Dy	15.9	2.61	0.94	1.56	1.17	1.56
Ho	3.20	0.54	0.17	0.24	0.20	0.28
Er	10.1	1.69	0.49	0.65	0.59	0.81
Tm	1.49	0.251	0.073	0.090	0.084	0.110
Yb	9.41	1.67	0.47	0.56	0.53	0.65
Lu	1.39	0.246	0.066	0.077	0.075	0.086
Hf	23.9	8.2	2.6	4.2	3.3	3.1
Ta	2.28	0.48	6.21	0.71	0.57	0.52
Tl	0.47	0.70	1.13	0.85	1.32	1.01
Bi	1.5	1.3	0.7	1.0	6.7	0.6
Th	12.4	9.76	4.73	10.4	8.51	7.87
U	4.02	1.34	1.14	1.08	0.93	0.97
Cd	1.8	b.d.	b.d.	b.d.	0.3	b.d.
Cu	b.d.	30	b.d.	7	33	b.d.
Ni	14	11	2	b.d.	b.d.	1
Pb	8	23	32	21	17	32
Zn	70	27	28	85	95	55
S (%)	0.014	0.006	0.003	0.004	0.003	0.003

*Analyses performed by Actlabs. TE in ppm, others %

Data Repository Appendix 4: Ion Microprobe Zircon U-Pb Ages

Sample	Grain #	Spot #	Core/ Rim	$^{206}\text{Pb}/^{238}\text{U}$	1 σ	$^{207}\text{Pb}/^{235}\text{U}$	1 σ	$^{207}\text{Pb}/^{206}\text{Pb}$	1 σ	% Rad. ^{206}Pb	$^{207}\text{Pb}^*/^{235}\text{U}$	1 σ	$^{206}\text{Pb}^{*2}/^{238}\text{U}$	1 σ	Correlation of Concordia Ellipses (ρ)	$^{207}\text{Pb}^*/^{206}\text{Pb}^*$	1 σ	Pb corr.
bs2	10	1	Core	803.77	32.66	861.79	66.35	1014.12	201.02	78.9	1.34	0.15	0.13	0.006	0.51	0.07	0.007 (204Pb)	
bs2	3	1	Core	1509.48	51.76	1573.78	32.79	1661.09	22.82	99.6	3.71	0.15	0.26	0.010	0.95	0.10	0.001 (204Pb)	
bs2	3	2	Core	1719.48	64.74	1716.94	39.94	1713.85	24.09	99.7	4.42	0.21	0.31	0.013	0.97	0.10	0.001 (204Pb)	
bs2	9	2	Rim	89.49	5.75	87.94	39.52	46.15	1069.74	91.7	0.09	0.04	0.01	0.001	0.39	0.05	0.021 (206/8Pb)	
bs2	3	3	Rim	89.67	2.82	94.70	6.78	223.11	145.60	99.0	0.10	0.01	0.01	0.0004	0.56	0.05	0.003 (206/8Pb)	
bs2	1	2	Rim	153.77	8.66	164.19	18.96	317.32	220.94	95.7	0.18	0.02	0.02	0.001	0.66	0.05	0.005 (206/8Pb)	
bs2	9	1	Rim	161.89	10.38	133.47	46.37	-1.00	0.01	95.0	0.14	0.05	0.03	0.002	0.39	0.04	0.014 (206/8Pb)	
bs2	1	1	Rim	172.66	7.86	193.25	30.12	452.74	348.20	97.5	0.21	0.04	0.03	0.001	0.43	0.06	0.009 (206/8Pb)	
cs1	9	1	Core	374.36	16.09	452.62	16.96	872.55	38.88	99.4	0.56	0.03	0.06	0.003	0.92	0.07	0.001 (204Pb)	
cs1	4	1	Core	931.86	32.46	1172.96	26.43	1650.07	9.41	99.9	2.17	0.08	0.16	0.006	0.99	0.10	0.001 (204Pb)	
cs1	9	2	Rim	85.83	5.92	82.21	24.25	-1.00	0.01	96.4	0.08	0.03	0.01	0.001	0.52	0.05	0.013 (204Pb)	
cs1	10	1	Rim	102.48	6.62	93.43	32.94	-1.00	0.02	92.8	0.10	0.04	0.02	0.001	0.42	0.04	0.015 (206/8Pb)	
cs1	4	2	Rim	163.84	23.40	4.73	105.61	-1.00	0.03	81.5	0.00	0.10	0.03	0.004	0.18	0.00	0.029 (206/8Pb)	
dma1	1	1	Core	1223.97	59.86	1425.15	41.57	1739.95	25.25	99.8	3.07	0.17	0.21	0.011	0.97	0.11	0.001 (204Pb)	
dma1	25	1	Core	1562.61	81.53	1657.65	49.55	1780.27	14.54	99.9	4.12	0.25	0.27	0.016	0.99	0.11	0.001 (204Pb)	
dma1	16	1	Core	1598.48	76.43	1672.11	43.90	1765.81	21.06	99.7	4.19	0.22	0.28	0.015	0.98	0.11	0.001 (204Pb)	
dma1	18	1	Core	1856.90	163.00	1816.31	86.78	1770.06	22.13	99.7	4.98	0.51	0.33	0.034	0.99	0.11	0.001 (204Pb)	
dma1	8	1	Core	2476.71	110.87	2583.29	50.71	2667.99	16.66	99.7	11.73	0.64	0.47	0.025	0.98	0.18	0.002 (204Pb)	
du1	16	1	Core	1034.14	45.25	1059.58	35.29	1112.37	33.13	99.7	1.84	0.10	0.17	0.008	0.95	0.08	0.001 (204Pb)	

Zircon U-Pb ages were corrected for common Pb using the 204Pb correction unless two of the following three criteria were met, in which case 208Pb correction was used: 1) sample is relatively young, 2) sample has low amount of Th or, 3) $^{208}\text{Pb}/^{204}\text{Pb} < 400$. U-Pb dates are reported as $^{207}\text{Pb}/^{206}\text{Pb}$ ages for discordant analyses and $^{206}\text{Pb}/^{238}\text{U}$ for concordant ages.

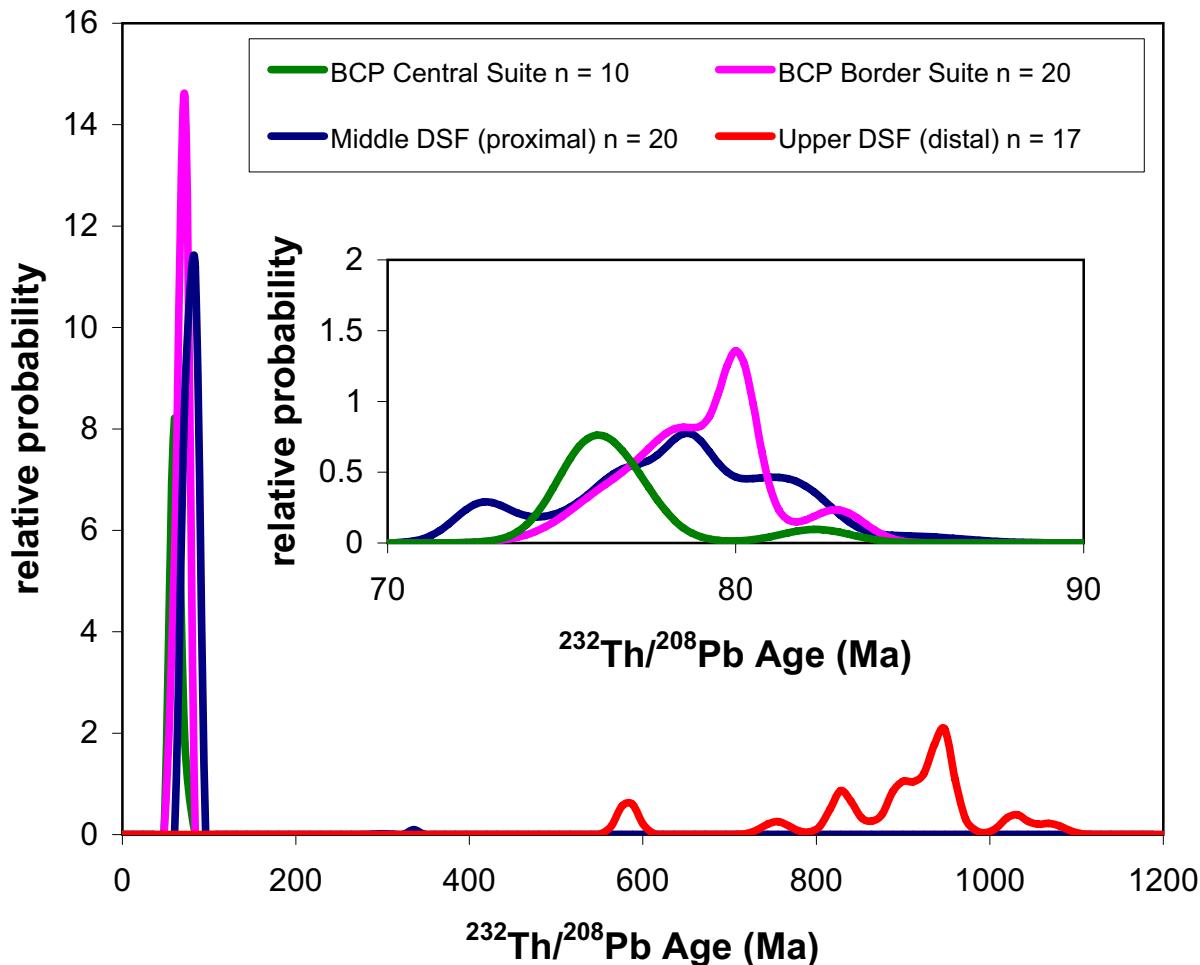


Data Repository Appendix 5: Ion Microprobe Th-Pb Monazite Ages

Sample	Grain #	Spot #	C/R	$^{208}\text{Pb}/^{232}\text{Th}$ (Ma)	1 s.e.	% Rad. Pb
Dma-1	1	1	Rim	77.0	1.0	99.4
Dma-1	1	2	Core	78.7	1.0	97.7
Dma-1	4	1		81.0	1.1	98.5
Dma-1	5	1		82.1	0.9	98.5
Dma-1	6	1		76.9	0.9	92.7
Dma-1	7	1	Core	74.6	1.3	99.5
Dma-1	8	1		80.6	0.9	98.3
Dma-1	9	1		79.4	1.5	99.2
Dma-1	13	1		76.7	1.1	95.2
Dma-1	14	1		75.1	1.2	79.8
Dma-1	14	2		77.8	1.7	95.4
Dma-1	15	1		80.8	1.4	98.5
Dma-1	15	2		72.7	0.8	98.3
Dma-1	16	1	Core	78.7	0.7	98.8
Dma-1	16	2	Rim	85.1	1.4	97.2
Dma-1	17	1		80.2	1.7	98.9
Dma-1	17	2		81.8	1.7	97.8
Dma-1	12	1		300.2	7.3	99.8
Dma-1	19	1		336.4	3.5	99.8
Dma-1	19	2		267.9	22.0	99.8
DU-1	1	1		945.2	9.9	99.9
DU-1	1	2		829.8	10.9	100.0
DU-1	2	1		1028.0	13.1	99.9
DU-1	4	1		939.2	24.2	99.9
DU-1	5	1		936.6	15.7	99.9
DU-1	19	1		754.0	15.1	95.5
DU-1	19	2		582.7	10.9	99.9
DU-1	20	1		917.6	13.4	99.9
DU-1	21	1		1069.0	16.0	99.9
DU-1	22	1		947.3	10.8	99.9
DU-1	23	1		919.1	13.2	99.9
DU-1	24	1		907.1	54.8	99.8
DU-1	24	2		822.4	16.7	100.0
DU-1	25	1		957.2	15.1	99.9
DU-1	26	1		861.5	16.1	99.9
DU-1	28	1		893.5	10.5	99.9
DU-1	29	1		906.0	23.5	99.9
BS1	9	3	Rim	76.2	1.5	99.0
BS1	9	1	Rim	76.4	1.3	99.1
BS2	7	1		76.4	1.0	99.5
BS1	9	2	Core	76.6	1.7	99.1
BS1	7	1	Rim	77.1	1.3	99.1
BS1	5	2	Rim	77.7	1.4	99.3
BS2	6	1		77.8	1.2	99.2
BS1	1	4	Core	77.9	1.9	98.9
BS1	5	1	Core	78.5	1.6	98.3
BS1	1	3	Rim	78.6	1.3	97.7
BS2	1	2		78.6	0.9	97.4
BS1	1	2	Core	78.6	1.0	98.7
BS1	16	2	Rim	79.0	1.3	99.3
BS1	1	1	Rim	79.1	1.3	99.0
BS1	16	1	Core	79.4	1.5	98.5
BS1	7	2	Core	79.4	1.2	99.0

Data Repository Appendix 5: Ion Microprobe Th-Pb Monazite Ages

Sample	Grain #	Spot #	C/R	$^{208}\text{Pb}/^{232}\text{Th}$ (Ma)	1 s.e.	% Rad. Pb
BS2	1	1		79.5	1.0	99.1
BS2	7	2		80.4	0.5	99.5
BS2	5	2 Rim		80.5	1.0	99.1
BS2	5	1 Core		83.2	0.8	99.0
CS2	5	1		75.7	0.8	99.4
CS2	9	1 Core		75.8	1.1	99.4
CS2	5	2		76.0	0.8	99.3
CS2	1	1		76.0	1.3	99.1
CS1	7	1 Core		76.5	1.3	99.4
CS1	4	1		76.8	0.9	97.4
CS1	9	2 Rim		76.9	1.0	99.2
CS2	9	2 Rim		77.2	0.9	99.4
CS1	3	1 Core		77.3	1.5	99.5
CS1	7	2 Rim		82.5	1.0	99.5
CS1	9	3 Core		398.3	38.9	99.9
CS1	9	6 Core		1372.3	36.7	100.0
CS1	9	4 Core		1496.0	15.0	100.0
CS1	9	1 Core		1612.8	19.2	100.0
CS1	9	5 Core		1686.2	38.6	100.0

Birch Creek Monazite Ages


	BC-DU1-sp2	BC-DU1-sp3	DU1-10-sp1	DU1-10-sp2	DU-1-11-sp1 core	DU-1-11-sp2	DU1-12-sp1	DU1-16-sp1 core	DU1-16-sp2 rim
P ₂ O ₅	27.86	27.08	27.99	25.20	28.18	27.88	26.19	27.86	27.39
SiO ₂	1.22	1.79	1.46	2.97	0.89	1.10	2.31	0.88	1.48
ThO ₂	6.04	8.60	6.27	13.98	5.12	5.84	10.89	5.17	7.25
UO ₂	0.14	0.26	1.90	0.44	0.33	0.15	0.43	0.38	0.27
Y ₂ O ₃	0.20	0.92	2.11	0.60	0.97	0.59	0.65	0.79	0.62
La ₂ O ₃	11.47	11.81	12.59	10.91	13.89	13.93	10.52	12.99	10.84
Ce ₂ O ₃	31.18	29.07	27.76	26.18	30.04	30.96	28.14	30.09	29.15
Pr ₂ O ₃	4.11	3.31	3.13	3.07	3.32	3.30	3.55	3.37	3.67
Nd ₂ O ₃	15.20	13.25	11.64	12.84	12.38	12.22	13.59	12.70	14.67
Sm ₂ O ₃	1.62	1.60	1.88	1.80	1.76	1.68	1.88	2.00	1.90
Gd ₂ O ₃	0.62	0.91	1.57	0.83	1.26	0.86	0.90	1.29	0.93
Dy ₂ O ₃	0.12	0.32	0.72	0.16	0.33	0.27	0.26	0.35	0.29
CaO	0.37	0.48	0.75	0.56	0.62	0.52	0.48	0.70	0.49
PbO	0.23	0.35	0.57	0.73	0.18	0.24	0.66	0.46	0.35
Total	100.35	99.74	100.29	100.27	99.23	99.52	100.43	99.00	99.27
P	5.67	5.55	5.66	5.25	5.75	5.69	5.41	5.72	5.63
Si	0.29	0.43	0.35	0.73	0.21	0.27	0.56	0.21	0.36
Th	0.33	0.47	0.34	0.78	0.28	0.32	0.60	0.29	0.40
Y	0.03	0.12	0.27	0.08	0.12	0.08	0.09	0.10	0.08
La	1.02	1.06	1.11	0.99	1.23	1.24	0.95	1.16	0.97
Ce	2.74	2.58	2.43	2.36	2.65	2.74	2.51	2.67	2.59
Pr	0.36	0.29	0.27	0.28	0.29	0.29	0.32	0.30	0.33
Nd	1.30	1.15	0.99	1.13	1.07	1.05	1.18	1.10	1.27
Sm	0.13	0.13	0.16	0.15	0.15	0.14	0.16	0.17	0.16
Gd	0.05	0.07	0.13	0.07	0.10	0.07	0.07	0.10	0.07
Dy	0.01	0.03	0.06	0.01	0.03	0.02	0.02	0.03	0.02
U	0.01	0.01	0.10	0.02	0.02	0.01	0.02	0.02	0.02
Ca	0.10	0.12	0.19	0.15	0.16	0.13	0.12	0.18	0.13
Pb	0.02	0.02	0.04	0.05	0.01	0.02	0.04	0.03	0.02
Total	12.05	12.04	12.08	12.06	12.06	12.06	12.06	12.09	12.04
	DU1-17-sp1	DU1-17-sp2	DU1-18-sp1 core	DU1-18-sp2 rim	DU1-19-sp1	DU1-19-sp2	DU1-19-sp3	DU1-20-sp1	DU1-20-sp2
P ₂ O ₅	28.54	27.86	27.16	27.30	27.16	26.04	27.32	26.31	24.81
SiO ₂	0.79	0.91	0.66	1.86	1.67	1.51	1.43	1.98	2.50
ThO ₂	5.68	5.56	4.91	9.94	8.06	8.39	8.04	9.44	11.57
UO ₂	0.16	0.25	0.25	0.23	0.27	0.24	0.09	0.14	0.31
Y ₂ O ₃	0.48	0.27	1.33	0.32	0.63	0.38	0.36	0.33	0.65
La ₂ O ₃	11.44	12.22	11.84	12.29	10.86	11.11	10.35	16.36	12.63
Ce ₂ O ₃	30.48	31.20	29.80	29.22	29.25	29.71	29.30	30.72	28.40
Pr ₂ O ₃	3.76	3.63	3.34	3.39	3.65	3.74	3.83	2.88	3.17
Nd ₂ O ₃	14.60	13.86	13.09	12.71	13.86	14.51	15.22	9.41	11.53
Sm ₂ O ₃	2.15	2.04	2.08	1.51	2.02	1.76	1.94	0.83	1.33
Gd ₂ O ₃	0.95	0.75	1.37	0.72	1.15	0.89	0.79	0.45	0.68
Dy ₂ O ₃	0.20	0.13	0.46	0.09	0.23	0.17	0.17	0.11	0.24
CaO	0.55	0.47	0.71	0.66	0.49	0.46	0.55	0.43	0.48
PbO	0.16	0.17	0.37	0.51	0.37	0.24	0.27	0.47	0.49
Total	99.92	99.30	97.36	100.72	99.65	99.14	99.67	99.83	98.76
P	5.78	5.72	5.70	5.55	5.58	5.48	5.61	5.45	5.27
Si	0.19	0.22	0.16	0.45	0.41	0.37	0.35	0.48	0.63
Th	0.31	0.31	0.28	0.54	0.45	0.47	0.44	0.53	0.66
Y	0.06	0.03	0.18	0.04	0.08	0.05	0.05	0.04	0.09
La	1.01	1.09	1.08	1.09	0.97	1.02	0.93	1.48	1.17
Ce	2.67	2.77	2.71	2.57	2.60	2.70	2.60	2.75	2.61
Pr	0.33	0.32	0.30	0.30	0.32	0.34	0.34	0.26	0.29
Nd	1.25	1.20	1.16	1.09	1.20	1.29	1.32	0.82	1.03
Sm	0.18	0.17	0.18	0.13	0.17	0.15	0.16	0.07	0.12
Gd	0.08	0.06	0.11	0.06	0.09	0.07	0.06	0.04	0.06
Dy	0.02	0.01	0.04	0.01	0.02	0.01	0.01	0.01	0.02
U	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Ca	0.14	0.12	0.19	0.17	0.13	0.12	0.14	0.11	0.13
Pb	0.01	0.01	0.03	0.03	0.02	0.02	0.02	0.03	0.03
Total	12.03	12.06	12.12	12.04	12.05	12.11	12.05	12.08	12.11

Cation totals calculated on a 24 oxygen basis

	DU1-21-sp1 core	DU1-21-sp2 rim	DU1-22-sp1	DU1-22-sp2	DU1-23-sp1 rim	DU1-23-sp2 core	DU1-24-sp1 core	DU1-24-sp2 rim	DU1-25-sp1
P ₂ O ₅	28.36	26.60	27.58	26.64	27.14	25.31	28.21	26.33	26.02
SiO ₂	0.77	1.61	1.34	1.25	1.54	1.42	0.92	1.86	1.83
ThO ₂	4.91	7.79	7.64	7.60	8.34	7.60	5.16	9.78	8.80
UO ₂	0.23	0.29	0.16	0.21	0.29	0.14	0.36	0.33	0.26
Y ₂ O ₃	0.58	0.61	0.47	0.43	0.14	0.44	1.00	0.36	0.71
La ₂ O ₃	11.88	11.33	10.99	10.85	10.62	9.83	13.44	11.91	10.95
Ce ₂ O ₃	30.70	29.90	29.98	29.67	30.23	28.90	30.11	29.50	29.32
Pr ₂ O ₃	3.80	3.69	3.74	3.91	3.92	3.95	3.57	3.39	3.79
Nd ₂ O ₃	14.13	14.37	14.06	14.64	14.71	16.25	12.53	13.03	14.34
Sm ₂ O ₃	1.90	1.47	1.89	1.82	1.56	2.54	1.89	1.71	1.53
Gd ₂ O ₃	1.02	0.62	0.92	0.87	0.43	0.96	1.20	0.79	0.75
Dy ₂ O ₃	0.24	0.15	0.19	0.24	0.03	0.24	0.40	0.22	0.22
CaO	0.57	0.39	0.53	0.58	0.52	0.36	0.58	0.50	0.42
PbO	0.25	0.48	0.34	0.36	0.32	0.18	0.29	0.30	0.40
Total	99.33	99.29	99.80	99.06	99.77	98.12	99.66	99.98	99.32
P	5.78	5.53	5.65	5.57	5.59	5.43	5.74	5.46	5.44
Si	0.19	0.40	0.32	0.31	0.38	0.36	0.22	0.46	0.45
Th	0.27	0.44	0.42	0.43	0.46	0.44	0.28	0.55	0.50
Y	0.08	0.08	0.06	0.06	0.02	0.06	0.13	0.05	0.09
La	1.06	1.03	0.98	0.99	0.95	0.92	1.19	1.08	1.00
Ce	2.71	2.69	2.65	2.68	2.69	2.68	2.65	2.65	2.65
Pr	0.33	0.33	0.33	0.35	0.35	0.36	0.31	0.30	0.34
Nd	1.22	1.26	1.21	1.29	1.28	1.47	1.08	1.14	1.27
Sm	0.16	0.13	0.16	0.16	0.13	0.22	0.16	0.14	0.13
Gd	0.08	0.05	0.07	0.07	0.03	0.08	0.10	0.06	0.06
Dy	0.02	0.01	0.02	0.02	0.00	0.02	0.03	0.02	0.02
U	0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02
Ca	0.15	0.10	0.14	0.15	0.14	0.10	0.15	0.13	0.11
Pb	0.02	0.03	0.02	0.02	0.02	0.01	0.02	0.02	0.03
Total	12.05	12.08	12.04	12.10	12.05	12.16	12.06	12.07	12.10
	DU1-25-sp2	DU1-26-sp1 core	DU1-26-sp2 rim	DU1-26-sp3 rim	DU1-26-sp4 core	DU1-27-sp1 rim	DU1-27-sp2	DU1-27-sp3	DU1-28-sp1
P ₂ O ₅	27.21	27.22	25.81	25.91	27.78	24.13	24.98	24.92	27.05
SiO ₂	1.82	0.78	2.42	2.42	0.87	3.55	2.69	3.04	1.29
ThO ₂	8.51	4.96	11.53	11.54	4.40	16.57	13.20	14.44	7.56
UO ₂	0.36	0.42	0.42	0.33	0.08	0.44	0.34	0.50	0.14
Y ₂ O ₃	0.69	0.87	0.46	0.50	0.33	0.32	0.49	0.38	0.48
La ₂ O ₃	10.98	13.99	10.45	10.24	11.25	9.07	10.63	9.60	13.22
Ce ₂ O ₃	29.69	29.73	27.55	27.46	31.52	25.19	27.62	26.45	30.01
Pr ₂ O ₃	3.61	3.24	3.55	3.40	4.05	3.40	3.29	3.36	3.35
Nd ₂ O ₃	14.33	12.48	13.67	14.04	15.58	13.34	12.64	13.62	12.75
Sm ₂ O ₃	1.58	2.05	1.78	1.91	1.80	2.05	1.68	2.03	1.59
Gd ₂ O ₃	0.71	1.59	0.77	0.83	0.78	0.75	0.81	0.76	0.85
Dy ₂ O ₃	0.19	0.43	0.21	0.19	0.14	0.14	0.20	0.15	0.26
CaO	0.45	0.72	0.53	0.52	0.38	0.51	0.57	0.52	0.61
PbO	0.37	0.38	0.49	0.44	0.16	0.68	0.41	0.66	0.50
Total	100.48	98.84	99.62	99.70	99.11	100.13	99.52	100.41	99.66
P	5.55	5.66	5.38	5.39	5.72	5.10	5.26	5.22	5.59
Si	0.44	0.19	0.60	0.59	0.21	0.89	0.67	0.75	0.32
Th	0.47	0.28	0.65	0.65	0.24	0.94	0.75	0.81	0.42
Y	0.09	0.11	0.06	0.07	0.04	0.04	0.06	0.05	0.06
La	0.98	1.27	0.95	0.93	1.01	0.84	0.98	0.88	1.19
Ce	2.62	2.67	2.48	2.47	2.80	2.30	2.52	2.39	2.68
Pr	0.32	0.29	0.32	0.30	0.36	0.31	0.30	0.30	0.30
Nd	1.23	1.10	1.20	1.23	1.35	1.19	1.12	1.20	1.11
Sm	0.13	0.17	0.15	0.16	0.15	0.18	0.14	0.17	0.13
Gd	0.06	0.13	0.06	0.07	0.06	0.06	0.07	0.06	0.07
Dy	0.02	0.03	0.02	0.02	0.01	0.01	0.02	0.01	0.02
U	0.02	0.02	0.02	0.02	0.00	0.02	0.02	0.03	0.01
Ca	0.12	0.19	0.14	0.14	0.10	0.14	0.15	0.14	0.16
Pb	0.02	0.03	0.03	0.03	0.01	0.05	0.03	0.04	0.03
Total	12.05	12.14	12.06	12.05	12.07	12.05	12.08	12.06	12.09

Cation totals calculated on a 24 oxygen basis

	DU1-28sp2	DU1-29-sp1	DU1-29-sp2	DU1-29-sp3	DU1-29-sp4	DU1-5-sp1	DU1-5-sp2	DU1-5-sp3	DU1-5-sp4
	core	rim	core	core	rim	core	rim	core	rim
P ₂ O ₅	26.82	26.91	22.11	27.26	21.94	27.00	24.69	26.44	25.53
SiO ₂	1.43	1.30	4.53	1.49	4.51	1.47	3.03	1.60	2.76
ThO ₂	8.42	6.49	20.26	8.04	19.94	7.43	14.77	8.34	12.66
UO ₂	0.18	0.42	0.46	0.46	0.55	0.23	0.39	0.17	0.31
Y ₂ O ₃	0.31	0.60	0.60	0.32	0.60	0.31	0.20	0.34	0.24
La ₂ O ₃	13.71	13.63	8.18	13.48	8.25	10.49	8.74	10.39	8.87
Ce ₂ O ₃	30.03	29.75	23.49	29.57	23.68	29.68	26.57	29.33	27.16
Pr ₂ O ₃	3.21	3.39	3.17	3.18	3.13	3.86	3.72	3.98	3.73
Nd ₂ O ₃	12.30	12.27	12.88	12.04	13.06	15.57	14.58	15.55	14.95
Sm ₂ O ₃	1.48	1.90	1.98	1.77	1.81	1.83	1.63	1.94	1.92
Gd ₂ O ₃	0.68	1.18	0.76	1.13	0.77	0.59	0.57	0.68	0.64
Dy ₂ O ₃	0.16	0.26	0.22	0.20	0.27	0.11	0.09	0.14	0.14
CaO	0.62	0.51	0.47	0.74	0.46	0.44	0.58	0.47	0.46
PbO	0.22	0.60	1.10	0.33	0.98	0.27	0.56	0.48	0.66
Total	99.57	99.19	100.20	99.98	99.91	99.27	100.09	99.84	100.02
P	5.56	5.59	4.78	5.59	4.76	5.59	5.20	5.50	5.32
Si	0.35	0.32	1.16	0.36	1.16	0.36	0.75	0.39	0.68
Th	0.47	0.36	1.18	0.44	1.16	0.41	0.84	0.47	0.71
Y	0.04	0.08	0.08	0.04	0.08	0.04	0.03	0.04	0.03
La	1.24	1.23	0.77	1.21	0.78	0.95	0.80	0.94	0.81
Ce	2.69	2.67	2.19	2.62	2.22	2.66	2.42	2.64	2.45
Pr	0.29	0.30	0.30	0.28	0.29	0.34	0.34	0.36	0.33
Nd	1.08	1.08	1.17	1.04	1.20	1.36	1.29	1.37	1.31
Sm	0.13	0.16	0.17	0.15	0.16	0.15	0.14	0.16	0.16
Gd	0.06	0.10	0.06	0.09	0.07	0.05	0.05	0.06	0.05
Dy	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
U	0.01	0.02	0.03	0.03	0.03	0.01	0.02	0.01	0.02
Ca	0.16	0.13	0.13	0.19	0.13	0.11	0.15	0.13	0.12
Pb	0.01	0.04	0.08	0.02	0.07	0.02	0.04	0.03	0.04
Total	12.08	12.11	12.11	12.08	12.12	12.06	12.07	12.10	12.05
	DU1-4-sp1	DU1-4-sp2	DU1-4-sp3	DU1-3-sp1	DU1-2-sp1	DU1-2-sp2	Dma-1-1-sp1	Dma-1-20-sp2	Dma-1-20-sp3
	core	rim	core	core	rim	core	core	rim	rim
P ₂ O ₅	24.65	24.18	26.30	28.29	28.84	27.74	27.36	27.64	30.25
SiO ₂	2.59	3.21	2.39	1.15	0.84	0.79	1.48	1.39	0.08
ThO ₂	12.85	15.80	11.90	6.24	5.68	5.80	7.48	7.15	0.87
UO ₂	0.33	0.35	0.29	0.24	0.27	0.49	0.10	0.12	0.02
Y ₂ O ₃	0.76	0.52	0.79	0.86	1.01	2.28	0.53	0.45	0.26
La ₂ O ₃	12.52	11.95	12.57	11.44	14.04	13.49	16.14	17.03	10.73
Ce ₂ O ₃	27.09	26.20	27.71	30.26	30.47	28.46	30.41	30.86	33.45
Pr ₂ O ₃	3.02	2.88	3.18	3.80	3.24	3.18	3.11	3.09	3.94
Nd ₂ O ₃	11.58	11.27	11.65	14.47	11.80	11.36	10.50	10.20	14.99
Sm ₂ O ₃	1.67	1.46	1.50	1.84	1.70	1.79	1.11	0.91	2.66
Gd ₂ O ₃	0.79	0.71	0.86	0.99	1.13	1.62	0.48	0.46	1.65
Dy ₂ O ₃	0.28	0.22	0.27	0.25	0.41	0.83	0.16	0.16	0.24
CaO	0.58	0.56	0.56	0.46	0.71	0.87	0.45	0.42	0.41
PbO	0.50	0.72	0.65	0.23	0.34	0.41	0.66	0.62	0.00
Total	99.20	100.02	100.59	100.52	100.46	99.09	99.97	100.50	99.54
P	5.23	5.12	5.41	5.71	5.79	5.69	5.60	5.62	6.02
Si	0.65	0.80	0.58	0.28	0.20	0.19	0.36	0.34	0.02
Th	0.73	0.90	0.66	0.34	0.31	0.32	0.41	0.39	0.05
Y	0.10	0.07	0.10	0.11	0.13	0.29	0.07	0.06	0.03
La	1.16	1.10	1.13	1.01	1.23	1.21	1.44	1.51	0.93
Ce	2.49	2.40	2.46	2.64	2.64	2.53	2.69	2.72	2.88
Pr	0.28	0.26	0.28	0.33	0.28	0.28	0.27	0.27	0.34
Nd	1.04	1.01	1.01	1.23	1.00	0.98	0.91	0.88	1.26
Sm	0.15	0.13	0.13	0.15	0.14	0.15	0.09	0.08	0.22
Gd	0.07	0.06	0.07	0.08	0.09	0.13	0.04	0.04	0.13
Dy	0.02	0.02	0.02	0.02	0.03	0.07	0.01	0.01	0.02
U	0.02	0.02	0.02	0.01	0.01	0.03	0.01	0.01	0.00
Ca	0.16	0.15	0.15	0.12	0.18	0.23	0.12	0.11	0.10
Pb	0.03	0.05	0.04	0.02	0.02	0.03	0.04	0.04	0.00
Total	12.12	12.09	12.04	12.03	12.04	12.12	12.06	12.06	12.00

Cation totals calculated on a 24 oxygen basis

	Dma-1-21-sp1	Dma-1-21-sp2	Dma-1-19-sp1	Dma-1-19-sp2	Dma-1-19-sp3	Dma-1-19-sp4	Dma-1-18-sp1	Dma-1-18-sp2	Dma-1-18-sp3
	core		rim		rim				
P ₂ O ₅	29.70	29.89	29.10	29.29	29.97	28.34	28.67	29.40	29.05
SiO ₂	0.23	0.13	0.33	0.56	0.39	0.27	0.50	0.30	0.42
ThO ₂	2.92	4.47	7.83	9.73	7.25	7.58	6.46	5.64	3.62
UO ₂	0.97	0.49	1.34	0.66	1.02	1.17	0.15	0.21	0.04
Y ₂ O ₃	1.84	2.68	2.45	2.71	2.21	2.56	0.55	0.99	0.38
La ₂ O ₃	15.00	14.09	10.91	10.04	11.94	11.84	13.99	13.57	11.76
Ce ₂ O ₃	30.15	28.52	25.84	25.50	27.10	26.50	29.95	30.15	33.01
Pr ₂ O ₃	3.36	3.17	3.20	2.97	2.97	3.09	3.28	3.23	3.46
Nd ₂ O ₃	11.19	10.97	11.71	11.32	11.22	10.65	11.69	12.00	13.43
Sm ₂ O ₃	1.35	1.51	2.49	2.32	1.98	2.09	1.75	1.82	2.13
Gd ₂ O ₃	1.04	1.35	2.06	1.97	1.66	1.84	1.09	1.13	1.28
Dy ₂ O ₃	0.48	0.74	0.81	0.83	0.75	0.86	0.30	0.33	0.22
CaO	0.84	1.11	1.58	1.64	1.38	1.54	0.89	1.05	0.50
PbO	0.28	0.40	0.31	0.20	0.05	0.19	0.16	0.39	0.14
Total	99.39	99.49	99.92	99.72	99.86	98.49	99.41	100.22	99.45
P	5.94	5.95	5.86	5.86	5.94	5.82	5.83	5.89	5.88
Si	0.06	0.03	0.08	0.13	0.09	0.07	0.12	0.07	0.10
Th	0.16	0.24	0.42	0.52	0.39	0.42	0.35	0.30	0.20
Y	0.23	0.34	0.31	0.34	0.28	0.33	0.07	0.13	0.05
La	1.31	1.22	0.96	0.88	1.03	1.06	1.24	1.18	1.04
Ce	2.61	2.46	2.25	2.21	2.33	2.35	2.63	2.61	2.89
Pr	0.29	0.27	0.28	0.26	0.25	0.27	0.29	0.28	0.30
Nd	0.94	0.92	1.00	0.96	0.94	0.92	1.00	1.01	1.15
Sm	0.11	0.12	0.20	0.19	0.16	0.18	0.15	0.15	0.18
Gd	0.08	0.11	0.16	0.15	0.13	0.15	0.09	0.09	0.10
Dy	0.04	0.06	0.06	0.06	0.06	0.07	0.02	0.03	0.02
U	0.05	0.03	0.07	0.04	0.05	0.06	0.01	0.01	0.00
Ca	0.21	0.28	0.40	0.42	0.35	0.40	0.23	0.27	0.13
Pb	0.02	0.03	0.02	0.01	0.00	0.01	0.01	0.03	0.01
Total	12.06	12.04	12.07	12.02	12.00	12.10	12.04	12.05	12.03
	Dma-1-17-sp1	Dma-1-17-sp2	Dma-1-17-sp3	Dma-1-16-sp1	Dma-1-16-sp2	Dma-1-16-sp3	Dma-1-16-sp4	Dma-1-15-sp1	Dma-1-15-sp2
	core		rim		rim				
P ₂ O ₅	29.56	29.22	28.92	29.49	29.47	29.74	28.89	29.50	28.71
SiO ₂	0.29	0.23	0.46	0.32	0.46	0.42	0.58	0.34	0.38
ThO ₂	1.73	1.45	3.00	1.98	2.55	2.29	2.89	2.09	1.97
UO ₂	0.08	0.12	0.22	0.14	0.11	0.08	0.19	0.08	0.12
Y ₂ O ₃	1.34	1.71	1.69	2.12	1.59	1.53	1.24	2.37	1.93
La ₂ O ₃	15.97	16.11	15.58	12.16	15.07	15.20	15.84	11.69	10.52
Ce ₂ O ₃	33.80	33.45	33.36	31.20	33.35	33.32	33.47	30.69	30.33
Pr ₂ O ₃	3.07	3.26	2.81	3.58	3.23	3.31	3.23	3.83	3.98
Nd ₂ O ₃	10.91	10.83	10.32	13.94	11.12	11.25	10.71	13.89	16.17
Sm ₂ O ₃	1.45	1.46	1.32	2.27	1.52	1.47	1.44	2.17	2.66
Gd ₂ O ₃	0.91	0.99	0.96	1.58	0.98	1.06	0.92	1.41	1.70
Dy ₂ O ₃	0.40	0.40	0.38	0.62	0.41	0.36	0.43	0.63	0.57
CaO	0.35	0.37	0.30	0.27	0.27	0.24	0.41	0.47	0.22
PbO	0.07	0.00	0.00	0.00	0.06	0.03	0.23	0.05	0.11
Total	99.94	99.60	99.30	99.68	100.17	100.28	100.43	99.19	99.36
P	5.90	5.87	5.84	5.90	5.88	5.91	5.80	5.91	5.83
Si	0.07	0.06	0.11	0.08	0.11	0.10	0.14	0.08	0.09
Th	0.09	0.08	0.16	0.11	0.14	0.12	0.16	0.11	0.11
Y	0.17	0.22	0.22	0.27	0.20	0.19	0.16	0.30	0.25
La	1.39	1.41	1.37	1.06	1.31	1.32	1.39	1.02	0.93
Ce	2.92	2.91	2.92	2.70	2.88	2.86	2.91	2.66	2.66
Pr	0.26	0.28	0.24	0.31	0.28	0.28	0.28	0.33	0.35
Nd	0.92	0.92	0.88	1.18	0.94	0.94	0.91	1.17	1.39
Sm	0.12	0.12	0.11	0.19	0.12	0.12	0.12	0.18	0.22
Gd	0.07	0.08	0.08	0.12	0.08	0.08	0.07	0.11	0.14
Dy	0.03	0.03	0.03	0.05	0.03	0.03	0.03	0.05	0.04
U	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01
Ca	0.09	0.09	0.08	0.07	0.07	0.06	0.10	0.12	0.06
Pb	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Total	12.04	12.07	12.04	12.03	12.03	12.01	12.08	12.04	12.07

Cation totals calculated on a 24 oxygen basis

	Dma-1-15-sp3	Dma-1-14-sp1	Dma-1-14-sp2	Dma-1-14-sp3	Dma-1-13-sp1	Dma-1-13-sp2	Dma-1-13-sp3	Dma-1-13-sp4	Dma-1-12-sp1
P ₂ O ₅	28.71	28.72	29.46	29.43	29.53	28.89	28.08	29.65	28.50
SiO ₂	0.31	0.33	0.35	0.38	0.24	0.21	0.48	0.28	1.08
ThO ₂	1.79	2.79	2.51	2.74	1.39	1.30	3.27	1.78	8.77
UO ₂	0.27	0.21	0.22	0.12	0.11	0.14	0.10	0.07	0.43
Y ₂ O ₃	2.28	1.65	1.69	1.52	1.37	1.41	1.50	1.37	1.60
La ₂ O ₃	11.89	18.41	18.12	18.59	18.00	17.81	15.08	15.60	12.06
Ce ₂ O ₃	31.18	34.25	34.78	34.65	34.94	35.07	33.34	33.96	27.98
Pr ₂ O ₃	3.66	2.62	2.81	2.73	3.02	3.01	3.17	3.22	3.18
Nd ₂ O ₃	14.24	7.64	8.00	7.66	9.21	9.44	11.11	11.05	11.22
Sm ₂ O ₃	2.16	0.83	0.76	0.71	0.96	1.09	1.38	1.42	2.10
Gd ₂ O ₃	1.46	0.65	0.71	0.65	0.79	0.78	0.98	0.84	1.38
Dy ₂ O ₃	0.59	0.37	0.38	0.40	0.35	0.36	0.38	0.36	0.53
CaO	0.27	0.47	0.29	0.31	0.31	0.26	0.26	0.19	1.12
PbO	0.00	0.08	0.03	0.00	0.00	0.00	0.00	0.10	0.00
Total	98.78	99.01	100.11	99.90	100.19	99.75	99.12	99.90	99.94
P	5.84	5.83	5.88	5.88	5.89	5.84	5.76	5.92	5.74
Si	0.07	0.08	0.08	0.09	0.06	0.05	0.12	0.07	0.26
Th	0.10	0.15	0.14	0.15	0.08	0.07	0.18	0.10	0.48
Y	0.29	0.21	0.21	0.19	0.17	0.18	0.19	0.17	0.20
La	1.05	1.63	1.58	1.62	1.57	1.57	1.35	1.36	1.06
Ce	2.74	3.01	3.00	2.99	3.01	3.07	2.96	2.93	2.44
Pr	0.32	0.23	0.24	0.24	0.26	0.26	0.28	0.28	0.28
Nd	1.22	0.65	0.67	0.65	0.78	0.81	0.96	0.93	0.95
Sm	0.18	0.07	0.06	0.06	0.08	0.09	0.12	0.12	0.17
Gd	0.12	0.05	0.06	0.05	0.06	0.06	0.08	0.07	0.11
Dy	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04
U	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.02
Ca	0.07	0.12	0.07	0.08	0.08	0.07	0.07	0.05	0.29
Pb	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Total	12.07	12.08	12.03	12.03	12.06	12.09	12.09	12.02	12.03

	Dma-1-12-sp2	Dma-1-12-sp3	Dma-1-11-sp1	Dma-1-11-sp2	Dma-1-10-sp1	Dma-1-10-sp2	Dma-1-10-sp3	Dma-1-9-sp1	Dma-1-9-sp2
P ₂ O ₅	28.36	27.34	29.16	28.85	29.04	29.13	29.10	28.22	28.41
SiO ₂	0.83	1.66	0.53	0.66	0.55	0.48	0.52	0.98	0.77
ThO ₂	8.92	8.50	3.52	4.26	2.84	3.04	3.07	6.84	5.73
UO ₂	0.60	0.36	0.19	0.20	0.08	0.10	0.12	0.20	0.21
Y ₂ O ₃	1.21	0.52	1.86	1.26	1.06	1.21	1.23	1.60	2.24
La ₂ O ₃	14.12	13.49	15.66	17.10	18.13	18.15	17.60	16.65	15.90
Ce ₂ O ₃	28.95	30.12	32.62	33.34	34.49	33.97	33.95	31.73	31.45
Pr ₂ O ₃	3.07	3.34	3.10	2.88	2.78	2.80	2.97	2.57	2.80
Nd ₂ O ₃	9.93	11.14	10.11	8.96	8.60	8.64	9.14	7.89	8.76
Sm ₂ O ₃	1.28	1.55	1.28	1.03	0.92	0.86	0.95	0.84	1.09
Gd ₂ O ₃	0.80	0.70	1.00	0.80	0.65	0.79	0.66	0.77	0.99
Dy ₂ O ₃	0.34	0.25	0.54	0.31	0.30	0.33	0.30	0.37	0.48
CaO	1.23	0.72	0.38	0.49	0.38	0.38	0.40	0.82	0.63
PbO	0.25	0.10	0.05	0.14	0.00	0.06	0.08	0.13	0.10
Total	99.87	99.76	99.98	100.28	99.81	99.91	100.09	99.60	99.56
P	5.75	5.59	5.84	5.79	5.83	5.84	5.83	5.72	5.75
Si	0.20	0.40	0.13	0.16	0.13	0.12	0.12	0.24	0.18
Th	0.49	0.47	0.19	0.23	0.15	0.16	0.17	0.37	0.31
Y	0.16	0.07	0.23	0.16	0.13	0.15	0.16	0.20	0.29
La	1.25	1.20	1.37	1.50	1.59	1.59	1.54	1.47	1.40
Ce	2.54	2.66	2.83	2.90	3.00	2.95	2.94	2.78	2.75
Pr	0.27	0.29	0.27	0.25	0.24	0.24	0.26	0.22	0.24
Nd	0.85	0.96	0.85	0.76	0.73	0.73	0.77	0.67	0.75
Sm	0.11	0.13	0.10	0.08	0.08	0.07	0.08	0.07	0.09
Gd	0.06	0.06	0.08	0.06	0.05	0.06	0.05	0.06	0.08
Dy	0.03	0.02	0.04	0.02	0.02	0.03	0.02	0.03	0.04
U	0.03	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.01
Ca	0.32	0.19	0.10	0.12	0.10	0.10	0.10	0.21	0.16
Pb	0.02	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.01
Total	12.05	12.05	12.03	12.05	12.05	12.05	12.05	12.06	12.06

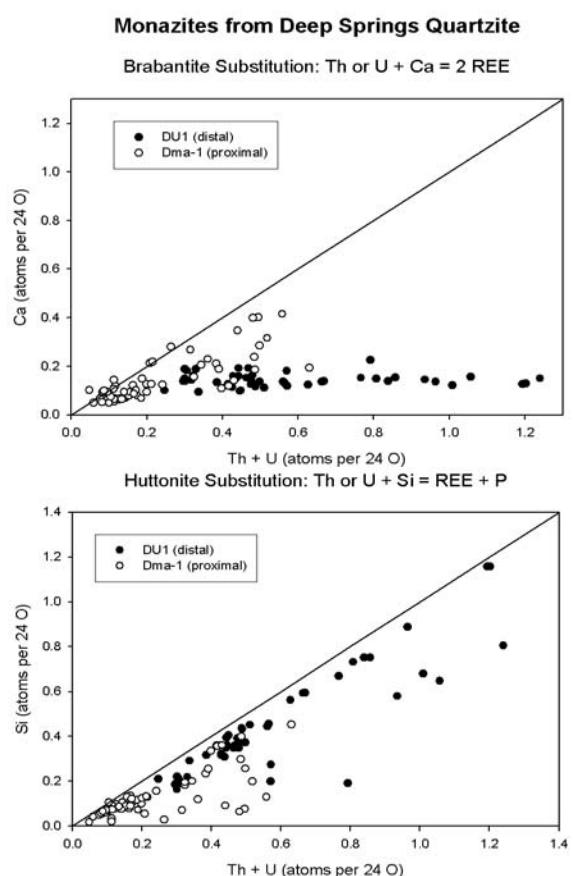
Cation totals calculated on a 24 oxygen basis

	Dma-1-9-sp3	Dma-1-8-sp1	Dma-1-8-sp2	Dma-1-8-sp3	Dma-1-7-sp1	Dma-1-7-sp2	Dma-1-7-sp3	Dma-1-6-sp1	Dma-1-6-sp2
P ₂ O ₅	28.57	29.19	29.27	29.32	27.14	28.65	28.13	29.01	29.00
SiO ₂	1.08	0.34	0.31	0.26	1.89	0.54	0.81	0.57	0.31
ThO ₂	7.08	2.24	1.99	1.63	11.07	3.76	5.76	3.88	3.27
UO ₂	0.18	0.15	0.13	0.11	0.42	0.20	0.17	0.05	0.21
Y ₂ O ₃	1.67	1.62	1.84	1.87	1.81	2.23	2.16	1.48	1.59
La ₂ O ₃	15.53	15.31	14.08	14.75	14.96	15.18	16.10	17.31	18.30
Ce ₂ O ₃	31.29	33.26	32.89	32.92	29.30	31.53	31.63	33.45	33.37
Pr ₂ O ₃	2.79	3.11	3.24	3.25	2.51	2.85	2.75	2.79	2.81
Nd ₂ O ₃	8.96	11.11	12.44	11.95	7.79	9.64	8.38	8.57	8.16
Sm ₂ O ₃	1.08	1.30	1.78	1.52	0.82	1.19	0.87	0.95	0.98
Gd ₂ O ₃	0.89	0.94	1.18	1.03	0.78	0.98	0.92	0.70	0.73
Dy ₂ O ₃	0.48	0.42	0.47	0.46	0.54	0.56	0.56	0.39	0.43
CaO	0.74	0.27	0.25	0.36	0.75	0.84	0.60	0.50	0.58
PbO	0.15	0.10	0.11	0.06	0.15	0.00	0.13	0.11	0.10
Total	100.48	99.35	99.98	99.48	99.90	98.14	98.98	99.75	99.83
P	5.72	5.88	5.87	5.89	5.53	5.82	5.73	5.83	5.84
Si	0.26	0.08	0.07	0.06	0.45	0.13	0.20	0.13	0.07
Th	0.38	0.12	0.11	0.09	0.61	0.21	0.32	0.21	0.18
Y	0.21	0.21	0.23	0.24	0.23	0.29	0.28	0.19	0.20
La	1.36	1.34	1.23	1.29	1.33	1.34	1.43	1.52	1.61
Ce	2.71	2.90	2.85	2.86	2.58	2.77	2.79	2.91	2.91
Pr	0.24	0.27	0.28	0.28	0.22	0.25	0.24	0.24	0.24
Nd	0.76	0.94	1.05	1.01	0.67	0.83	0.72	0.73	0.69
Sm	0.09	0.11	0.15	0.13	0.07	0.10	0.07	0.08	0.08
Gd	0.07	0.07	0.09	0.08	0.06	0.08	0.07	0.06	0.06
Dy	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.03	0.03
U	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.01
Ca	0.19	0.07	0.06	0.09	0.19	0.22	0.16	0.13	0.15
Pb	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01
Total	12.04	12.03	12.05	12.06	12.03	12.08	12.06	12.04	12.08

	Dma-1-6-sp3	Dma-1-5-sp1	Dma-1-5-sp2	Dma-1-5-sp3	Dma-1-4-sp1	Dma-1-4-sp2	Dma-1-4-sp3	Dma-1-3-sp1	Dma-1-3-sp2
P ₂ O ₅	28.53	29.44	28.81	29.55	28.72	28.92	29.28	29.20	29.65
SiO ₂	0.84	0.24	0.17	0.45	0.38	0.32	0.37	0.30	0.28
ThO ₂	6.12	1.46	0.88	1.88	2.95	2.43	2.34	1.70	1.53
UO ₂	0.24	0.05	0.20	0.06	0.10	0.15	0.15	0.06	0.10
Y ₂ O ₃	1.74	1.88	1.63	1.24	1.44	1.66	1.75	1.90	1.98
La ₂ O ₃	16.08	12.60	14.23	13.26	17.92	17.16	15.02	15.22	12.97
Ce ₂ O ₃	31.78	31.72	33.07	32.34	33.90	34.11	33.05	32.46	31.46
Pr ₂ O ₃	2.78	3.71	3.40	3.63	2.80	3.02	3.35	3.16	3.55
Nd ₂ O ₃	8.67	14.04	12.70	13.40	8.74	9.29	11.10	11.38	13.41
Sm ₂ O ₃	0.94	2.14	1.77	2.11	0.89	1.11	1.54	1.61	2.14
Gd ₂ O ₃	0.87	1.52	1.14	1.16	0.76	0.78	1.08	1.27	1.46
Dy ₂ O ₃	0.43	0.54	0.47	0.39	0.39	0.42	0.46	0.59	0.56
CaO	0.81	0.20	0.19	0.29	0.34	0.37	0.26	0.37	0.39
PbO	0.11	0.00	0.16	0.08	0.00	0.16	0.00	0.00	0.10
Total	99.93	99.55	98.84	99.83	99.32	99.91	99.73	99.20	99.58
P	5.75	5.91	5.87	5.90	5.82	5.83	5.87	5.88	5.92
Si	0.20	0.06	0.04	0.11	0.09	0.08	0.09	0.07	0.07
Th	0.33	0.08	0.05	0.10	0.16	0.13	0.13	0.09	0.08
Y	0.22	0.24	0.21	0.16	0.18	0.21	0.22	0.24	0.25
La	1.41	1.10	1.26	1.15	1.58	1.51	1.31	1.34	1.13
Ce	2.77	2.75	2.91	2.79	2.97	2.97	2.87	2.83	2.72
Pr	0.24	0.32	0.30	0.31	0.24	0.26	0.29	0.27	0.31
Nd	0.74	1.19	1.09	1.13	0.75	0.79	0.94	0.97	1.13
Sm	0.08	0.18	0.15	0.17	0.07	0.09	0.13	0.13	0.17
Gd	0.07	0.12	0.09	0.09	0.06	0.06	0.09	0.10	0.11
Dy	0.03	0.04	0.04	0.03	0.03	0.03	0.04	0.05	0.04
U	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.01
Ca	0.21	0.05	0.05	0.07	0.09	0.10	0.07	0.09	0.10
Pb	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.01
Total	12.06	12.03	12.08	12.03	12.06	12.08	12.04	12.06	12.04

Cation totals calculated on a 24 oxygen basis

	Dma-1-2-sp1	Dma-1-2-sp2	Dma-1-1-sp1	Dma-1-1-sp2	
P ₂ O ₅	29.37	29.13	28.07	27.46	
SiO ₂	0.14	0.09	1.25	1.50	
ThO ₂	2.00	2.00	8.33	7.63	
UO ₂	0.08	0.05	0.56	0.20	
Y ₂ O ₃	0.23	0.20	1.53	0.26	
La ₂ O ₃	14.51	10.87	13.66	15.42	
Ce ₂ O ₃	33.48	32.14	28.53	31.23	
Pr ₂ O ₃	3.32	3.69	3.25	3.32	
Nd ₂ O ₃	12.21	14.93	10.34	10.58	
Sm ₂ O ₃	2.11	2.73	1.55	1.18	
Gd ₂ O ₃	1.14	1.66	0.96	0.49	
Dy ₂ O ₃	0.09	0.21	0.39	0.06	
CaO	0.41	0.56	0.93	0.55	
PbO	0.00	0.14	0.22	0.02	
Total	99.09	98.39	99.54	99.88	
P	5.94	5.94	5.70	5.61	
Si	0.03	0.02	0.30	0.36	
Th	0.11	0.11	0.45	0.42	
Y	0.03	0.03	0.20	0.03	
La	1.28	0.97	1.21	1.37	
Ce	2.93	2.84	2.50	2.76	
Pr	0.29	0.32	0.28	0.29	
Nd	1.04	1.29	0.89	0.91	
Sm	0.17	0.23	0.13	0.10	
Gd	0.09	0.13	0.08	0.04	
Dy	0.01	0.02	0.03	0.01	
U	0.00	0.00	0.03	0.01	
Ca	0.11	0.14	0.24	0.14	
Pb	0.00	0.01	0.01	0.00	
Total	12.03	12.04	12.04	12.05	



Data Repository Appendix 7: Oxygen Isotope Compositions of Monazites

Sample	Grain#	Spot#	18O	16O	18O/16O bkg corr	18O/16O corr	δ 18OSMOW
BS1		1	7.085E+06	3.527E+09	0.002008	0.002023	8.696
BS1		1	7.080E+06	3.525E+09	0.002008	0.002022	8.596
BS1		1	7.099E+06	3.537E+09	0.002007	0.002021	7.943
BS1	3	1	7.081E+06	3.525E+09	0.002009	0.002023	8.820
BS1	7	1	7.109E+06	3.536E+09	0.002010	0.002024	9.535
BS1	5	1	7.220E+06	3.596E+09	0.002008	0.002022	8.481
BS1	9	1	6.943E+06	3.454E+09	0.002010	0.002024	9.614
BS1	9	2	6.949E+06	3.459E+09	0.002009	0.002023	9.097
BS1	9	3	6.855E+06	3.413E+09	0.002008	0.002023	8.644
BS1	15	1	6.977E+06	3.468E+09	0.002012	0.002026	10.372
BS1	15	2	7.007E+06	3.489E+09	0.002008	0.002022	8.595
BS1	16	1	7.094E+06	3.530E+09	0.002010	0.002024	9.385
BS1	16	2	6.990E+06	3.482E+09	0.002008	0.002022	8.240
BS1	19	1	7.028E+06	3.499E+09	0.002008	0.002022	8.554
BS1	20	1	7.150E+06	3.557E+09	0.002010	0.002024	9.410
BS1	20	2	7.093E+06	3.529E+09	0.002010	0.002024	9.428
BS2	1	1	7.043E+06	3.506E+09	0.002009	0.002023	8.835
BS2	1	2	6.958E+06	3.464E+09	0.002009	0.002023	8.838
BS2	2	1	7.070E+06	3.519E+09	0.002009	0.002023	8.887
BS2	2	2	7.097E+06	3.535E+09	0.002008	0.002022	8.255
BS2	3	1	7.064E+06	3.516E+09	0.002009	0.002023	9.056
BS2	4	1	7.043E+06	3.504E+09	0.002010	0.002024	9.354
BS2	5	1	7.052E+06	3.512E+09	0.002008	0.002022	8.571
BS2	7	1	7.017E+06	3.492E+09	0.002010	0.002024	9.271
BS2	7	2	7.004E+06	3.488E+09	0.002008	0.002022	8.325
BS2	7	3	6.966E+06	3.471E+09	0.002007	0.002021	8.037
BS2	8	1	7.027E+06	3.500E+09	0.002008	0.002022	8.376
BS2	9	1	7.023E+06	3.496E+09	0.002009	0.002023	8.779
CS1	1	1	7.060E+06	3.514E+09	0.002009	0.002023	9.103
CS1	1	2	7.126E+06	3.549E+09	0.002008	0.002022	8.292
CS1	2	1	7.020E+06	3.499E+09	0.002006	0.002020	7.622
CS1	2	2	6.983E+06	3.476E+09	0.002009	0.002023	8.745
CS1	3	1	6.955E+06	3.471E+09	0.002004	0.002018	6.234
CS1	4	1	6.917E+06	3.444E+09	0.002008	0.002022	8.593
CS1	4	2	6.976E+06	3.474E+09	0.002008	0.002022	8.434
CS1	6	1	6.931E+06	3.452E+09	0.002008	0.002022	8.408
CS1	7	1	7.057E+06	3.507E+09	0.002012	0.002026	10.405
CS1	7	2	6.983E+06	3.473E+09	0.002011	0.002025	9.743
CS1	8	1	7.058E+06	3.514E+09	0.002008	0.002022	8.623
CS1	8	2	7.018E+06	3.493E+09	0.002009	0.002024	9.182
CS1	9	1	6.962E+06	3.467E+09	0.002008	0.002022	8.592
CS1	9	2	6.963E+06	3.467E+09	0.002009	0.002023	8.775
CS1	10	1	7.004E+06	3.488E+09	0.002008	0.002022	8.400
CS1	14a	1	6.849E+06	3.414E+09	0.002006	0.002021	7.642
CS1	14a	2	6.862E+06	3.418E+09	0.002008	0.002022	8.257
CS1	14	1	6.942E+06	3.456E+09	0.002009	0.002023	8.767
CS1	14	2	6.930E+06	3.452E+09	0.002007	0.002021	8.096
CS2	1	1	6.991E+06	3.481E+09	0.002008	0.002023	8.704
CS2	2	1	6.993E+06	3.484E+09	0.002007	0.002021	8.044

Data Repository Appendix 7: Oxygen Isotope Compositions of Monazites

Sample	Grain#	Spot#	18O	16O	18O/16O bkg corr	18O/16O corr	δ 18OSMOW
CS2		2	7.006E+06	3.488E+09	0.002008	0.002022	8.606
CS2		3	1 6.962E+06	3.466E+09	0.002008	0.002023	8.630
CS2		4	1 6.966E+06	3.467E+09	0.002009	0.002023	9.074
CS2		4	2 6.958E+06	3.463E+09	0.002009	0.002023	9.125
CS2		5	1 6.968E+06	3.470E+09	0.002008	0.002022	8.500
CS2		5	2 6.942E+06	3.455E+09	0.002009	0.002023	9.022
CS2		6	1 6.983E+06	3.478E+09	0.002008	0.002022	8.427
CS2		6	2 6.992E+06	3.483E+09	0.002007	0.002021	7.952
CS2		8	1 7.025E+06	3.497E+09	0.002009	0.002023	8.842
CS2		8	2 7.025E+06	3.499E+09	0.002008	0.002022	8.322
CS2		9	1 7.011E+06	3.491E+09	0.002008	0.002023	8.671
CS2		9	2 6.979E+06	3.476E+09	0.002008	0.002022	8.324
CS2		10	1 6.972E+06	3.471E+09	0.002008	0.002023	8.707
CS2		10	2 6.952E+06	3.462E+09	0.002008	0.002022	8.529
CS2		12	1 6.876E+06	3.423E+09	0.002008	0.002023	8.709
CS2		13	1 6.999E+06	3.484E+09	0.002009	0.002023	8.843
CS2		14	1 6.872E+06	3.420E+09	0.002009	0.002023	9.115
CS2		14	2 6.996E+06	3.484E+09	0.002008	0.002022	8.391
CS2		15	1 6.947E+06	3.458E+09	0.002009	0.002023	8.885
CS2		16	1 6.966E+06	3.466E+09	0.002010	0.002024	9.497
Dma1		1	1 7.060E+06	3.515E+09	0.002008	0.002023	8.680
Dma1		6	1 7.126E+06	3.551E+09	0.002007	0.002021	7.958
Dma1		7	1 6.989E+06	3.478E+09	0.002009	0.002023	9.061
Dma1		16	1 7.121E+06	3.542E+09	0.002010	0.002024	9.577
Dma1		4	1 7.018E+06	3.485E+09	0.002014	0.002026	10.532
Dma1		5	1 7.046E+06	3.504E+09	0.002011	0.002023	9.020
Dma1		5	2 7.009E+06	3.481E+09	0.002013	0.002026	10.397
Dma1		6	1 7.002E+06	3.479E+09	0.002012	0.002025	9.985
Dma1		6	2 6.992E+06	3.479E+09	0.002010	0.002022	8.576
Dma1		7	1 6.914E+06	3.440E+09	0.002010	0.002022	8.600
Dma1		7	2 6.959E+06	3.460E+09	0.002011	0.002024	9.209
Dma1		8	1 7.070E+06	3.515E+09	0.002011	0.002024	9.296
Dma1		8	2 7.170E+06	3.565E+09	0.002011	0.002024	9.285
Dma1		9	1 6.976E+06	3.473E+09	0.002008	0.002021	7.920
Dma1		9	2 7.030E+06	3.500E+09	0.002008	0.002021	7.841
Dma1		12	1 6.854E+06	3.415E+09	0.002007	0.002020	7.169
Dma1		12	2 6.910E+06	3.444E+09	0.002006	0.002019	6.903
Dma1		12	3 6.888E+06	3.438E+09	0.002003	0.002016	5.474
Dma1		13	1 7.072E+06	3.517E+09	0.002011	0.002023	9.025
Dma1		13	2 6.991E+06	3.471E+09	0.002014	0.002026	10.576
Dma1		14	1 6.927E+06	3.449E+09	0.002008	0.002021	7.830
Dma1		15	1 7.111E+06	3.537E+09	0.002010	0.002023	8.922
Dma1		16	1 7.148E+06	3.556E+09	0.002010	0.002023	8.647
Dma1		16	2 7.162E+06	3.564E+09	0.002010	0.002022	8.514
Dma1		16	3 7.011E+06	3.485E+09	0.002012	0.002025	9.721
Dma1		17	1 7.071E+06	3.518E+09	0.002010	0.002023	8.761
Dma1		17	2 7.170E+06	3.568E+09	0.002009	0.002022	8.385
Dma1		17	3 7.011E+06	3.485E+09	0.002011	0.002024	9.445
Dma1		19	1 6.971E+06	3.473E+09	0.002007	0.002020	7.303

Data Repository Appendix 7: Oxygen Isotope Compositions of Monazites

Sample	Grain#	Spot#	18O	16O	18O/16O bkg corr	18O/16O corr	δ 18OSMOW
Dma1	19	2	6.970E+06	3.475E+09	0.002005	0.002018	6.453
Dma1	19	3	7.006E+06	3.495E+09	0.002004	0.002017	5.931
Dma1	20	1	6.957E+06	3.462E+09	0.002009	0.002022	8.371
DU1	1	1	6.898E+06	3.443E+09	0.002004	0.002016	5.549
DU1	1	2	6.782E+06	3.385E+09	0.002004	0.002016	5.532
DU1	1	3	6.947E+06	3.468E+09	0.002003	0.002016	5.350
DU1	2	1	6.800E+06	3.394E+09	0.002003	0.002016	5.347
DU1	3	1	6.613E+06	3.302E+09	0.002003	0.002016	5.155
DU1	4	1	6.628E+06	3.311E+09	0.002002	0.002014	4.620
DU1	4	2	6.640E+06	3.319E+09	0.002001	0.002013	4.085
DU1	5	1	6.828E+06	3.410E+09	0.002002	0.002015	4.861
DU1	10	1	6.665E+06	3.323E+09	0.002005	0.002018	6.419
DU1	11	1	6.862E+06	3.421E+09	0.002006	0.002019	6.738
DU1	12	1	6.676E+06	3.334E+09	0.002002	0.002015	4.854
DU1	12	2	6.667E+06	3.332E+09	0.002000	0.002013	3.948
DU1	16	1	6.872E+06	3.428E+09	0.002005	0.002017	6.070
DU1	17	1	6.884E+06	3.435E+09	0.002004	0.002017	5.773
DU1	17	2	6.923E+06	3.456E+09	0.002003	0.002016	5.228
DU1	18	1	6.820E+06	3.404E+09	0.002004	0.002016	5.499
DU1	19	1	6.833E+06	3.411E+09	0.002003	0.002016	5.282
DU1	19	2	6.570E+06	3.283E+09	0.002001	0.002014	4.258
DU1	20	1	6.801E+06	3.394E+09	0.002003	0.002016	5.404
DU1	21	1	6.825E+06	3.403E+09	0.002005	0.002018	6.468
DU1	21	2	6.893E+06	3.438E+09	0.002004	0.002017	5.980
DU1	22	1	6.888E+06	3.438E+09	0.002003	0.002016	5.464
DU1	23	1	6.591E+06	3.289E+09	0.002004	0.002017	5.770
DU1	24	1	6.963E+06	3.479E+09	0.002001	0.002014	4.435
DU1	24	2	6.634E+06	3.311E+09	0.002004	0.002017	5.666
DU1	25	1	6.820E+06	3.405E+09	0.002003	0.002015	5.112
DU1	26	1	6.750E+06	3.368E+09	0.002004	0.002016	5.574
DU1	27	1	6.230E+06	3.114E+09	0.002000	0.002013	3.867
DU1	28	1	6.745E+06	3.370E+09	0.002001	0.002014	4.441
DU1	29	1	6.681E+06	3.341E+09	0.002000	0.002012	3.524