

1 APPENDIX: ANALYTICAL PROCEDURES

2 Single zircon U/Pb analyses were performed at the Berkeley Geochronology Center. After using
3 standard heavy mineral separation methods (crushing, sieving, heavy liquid, and magnetic
4 separations), zircon crystals were handpicked in ethanol under a binocular microscope.

5 Cathodoluminescence images of thermally annealed zircons from the northern Half Dome lobe
6 were taken with the JEOL JSM 5600 Scanning Electron Microscope and attached Hamamatsu
7 Cathodoluminescence Detector at the Stanford USGS Micro Analysis Center (SUMAC).

8 The complexity of the analyzed zircon populations (older unrecognized inheritance and
9 xenocrystic contamination as well as age lowering due to Pb loss) effectively rule out the use of
10 multi-crystal analyses (combining several zircon crystals into a single sample), which compound
11 the problem with age averaging and spuriously comforting agreement among analyses (Mundil et
12 al., 2001).

13 Only euhedral, clear grains devoid of optically recognizable cores were chosen for analysis.
14 Several techniques were employed on order to minimize the effects of secondary lead loss. All of
15 the zircons are treated using the method of thermal annealing at 850°C for 36 hrs (Mattinson,
16 2001; Mattinson, 2003), followed by chemical abrasion with conc. HF in pressurized dissolution
17 capsules at 220°C for 16 hrs. Diffusion of Pb out of the zircons during the annealing step is ruled
18 out by the studies of (Cherniak et al., 2001; Lee et al., 1997), as well as the striking statistical
19 coherence of the resulting U/Pb ages. Prior to dissolution the crystals were: (i) rinsed several
20 times in conc. HNO₃, (ii) cleaned in ultrasonically agitated aqua regia followed by clean HNO₃.
21 Zircons were then transferred to perforated miniature PTFE capsules and spiked with ²⁰⁵Pb-²³³U-
22 ²³⁵U tracer solution. The capsules were placed on an elevated rack in a 125 ml digestion vessel,
23 allowing vapor transfer dissolution in a mixture of 50% HF/conc. HNO₃ (30/1) at 220°C for 6

24 days. After dissolution, the dried sample/tracer mixture was taken up in 20 μl 3 M HCl+5 μl 0.25
25 M H₃PO₄, dried down, and loaded together with silica gel+H₃PO₄ on out-gassed Re filaments.
26 Isotope ratios were determined on a Micromass Sector 54 mass spectrometer using a Daly-type
27 ion counter positioned behind a WARP filter. Pb (as Pb+) and U (as UO₂+) were run sequentially
28 on the same filament. Significant systematic bias between results from our analyses and those
29 conducted in other labs due to tracer calibrations in excess of several permil seem unlikely, as
30 the ²⁰⁵Pb-²³³U-²³⁵U tracer solution was calibrated repeatedly against solutions derived from
31 certified standards of isotopically pure ²⁰⁶Pb and natural U (NIST SRM-991 and CRM-145,
32 respectively). To provide the highest level of confidence in the tracer calibration, the standard
33 solutions were themselves checked against solutions prepared from other NIST-certified
34 standards (NBLCRM111- A ²³³U, NBL-CRM135 ²³⁵U NIST SRM-981 and NIST SRM-982).
35 All of these calibrations (effectively three independent calibrations each for U and for Pb) agreed
36 within the precision of the measurements, so that we are confident of tracer Pb/U to within
37 0.15%. In addition our tracer solution was checked against the similarly-calibrated tracer solution
38 used at IGMR, ETH Zurich (itself checked against the tracer solution of the Royal Ontario
39 Museum, as well as several other laboratories, Wiedenbeck et al., 1995). No inter-laboratory bias
40 was detected by these cross-checks. In a cross check of the tracer (and entire procedure)
41 involving the comparison of zircon U/Pb ages for the same rock between BGC and the ROM,
42 agreement was at the 1 per mille level (Black et al., 2004). Repeat measurements of the total
43 procedural blank averaged 0.8 ± 0.3 pg Pb (U blanks were indistinguishable from zero), with
44 $^{206}\text{Pb}/^{204}\text{Pb} = 18.55 \pm 0.63$, $^{207}\text{Pb}/^{204}\text{Pb} = 15.50 \pm 0.55$, $^{208}\text{Pb}/^{204}\text{Pb} = 38.07 \pm 1.56$ (all 2σ of
45 population), and a $^{206}\text{Pb}/^{204}\text{Pb}$ - $^{207}\text{Pb}/^{204}\text{Pb}$ correlation of +0.9. The large ²⁰⁴Pb measurement error
46 of the blank leads to a geochemically unreasonable range for the ²⁰⁷Pb/²⁰⁴Pb ratio, consequently

47 that uncertainty was reduced to a realistic ± 0.30 (thus encompassing a range of 15.2 to 15.8).
48 These ratios and uncertainties were propagated into the age and age-error calculations. Common
49 Pb in excess of the analytical blank was assumed to have the same composition as given above,
50 since whether blank Pb or average 250 Ma crustal Pb is used has essentially no effect on the final
51 result. Mass fractionation of U during analysis was controlled by the U double spike, whereas Pb
52 mass fractionation was corrected by $0.15 \pm 0.1\%/\text{AMU}$ (based on multiple analyses of NBS
53 981).

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- 1 Movie clip: Appendix
- 2 Instructions on how to step through individual frames of movie clip:
- 3 Quick Time Player:
 - 4 1. Click time display area
 - 5 2. Select frame number
 - 6 3. Use the forward cursor control key on your computer keyboard to forward each
 - 7 frame
- 8 Windows Media Player:
 - 9 1. Click arrow below “Now Playing” tab, point to “Enhancements” and then click “Play
 - 10 Speed Settings”
 - 11 2. To move the movie clip forward one frame, click the “Next Frame” button.

TABLE 1. U/Pb ZIRCON GEOCHRONOLOGY AGE DATA TABLE FOR ALL 8 SAMPLES FROM 4 LOBES

Sample	Longitude	Latitude	mg* zirc	ppm U	cm.Pb† (pg)	Th§ U	$\frac{^{207}\text{Pb}^{**}}{^{238}\text{U}}$	2s %er	diseq.corr.			$\frac{^{206}\text{Pb}^{**}}{^{238}\text{U}}$	$\frac{^{207}\text{Pb}^{**}}{^{206}\text{Pb}}$	2s %er	diseq.corr.		
									$\frac{^{206}\text{Pb}^{**}}{^{238}\text{U}}$	2s %er	r††				$\frac{^{206}\text{Pb}^*}{^{238}\text{U}}$	2s %er	$\frac{^{206}\text{Pb}^*}{^{238}\text{U}}$
KCL428Z4	-119.27842200	37.76491523	11.8	236	2.5	0.60	0.1002	1.80	0.014961	0.62	.46	1079	0.04857	1.61	95.73	0.60	
KCL428Z6	-119.27842200	37.76491523	15.6	172	2.0	0.60	0.0997	1.59	0.014869	0.34	.44	1279	0.04862	1.47	95.15	0.33	
KCL428Z1	-119.27842200	37.76491523	16.7	83	0.9	0.56	0.0979	0.87	0.014804	0.18	.43	1483	0.04798	0.81	94.73	0.17	
KCL428Z2	-119.27842200	37.76491523	7.3	377	0.8	0.46	0.0974	0.48	0.014768	0.24	.60	3036	0.04785	0.39	94.50	0.22	
KCL428Z3	-119.27842200	37.76491523	12.6	371	1.0	0.54	0.0972	0.73	0.014765	0.58	.82	4501	0.04773	0.41	94.48	0.55	
KCL428Z5	-119.27842200	37.76491523	6.4	358	0.9	0.57	0.0968	0.97	0.014748	0.23	.46	2476	0.04761	0.89	94.38	0.22	
05183Z05	-119.19370030	37.74876696	4.4	168	1.0	0.64	0.0992	2.24	0.015071	0.59	.39	703	0.04774	2.08	96.43	0.57	
05183Z01	-119.19370030	37.74876696	5.3	65	3.5	0.96	0.1464	11.48	0.014948	0.99	.91	111	0.07102	10.59	95.64	0.94	
05183Z04	-119.19370030	37.74876696	2.5	99	0.9	0.76	0.0991	4.71	0.014672	0.31	.78	268	0.04896	4.47	93.89	0.29	
05183Z03	-119.19370030	37.74876696	5.7	44	0.9	0.02	0.0981	5.42	0.014625	0.35	.82	267	0.04867	5.13	93.60	0.33	
05183Z02	-119.19370030	37.74876696	4.0	129	0.7	0.73	0.0971	2.10	0.014619	0.26	.43	648	0.04816	2.01	93.56	0.24	
05183Z06	-119.19370030	37.74876696	6.1	66	0.9	0.60	0.0975	3.02	0.014556	0.47	.45	419	0.04858	2.84	93.16	0.44	
NHDL889.Z3b	-119.58582260	38.09511868			0.8	0.50	0.0946	1.99	0.014268	0.24	.49	707	0.04806	1.88	91.33	0.22	
NHDL889.Z04	-119.58582260	38.09511868	1.3	221	2.2	0.64	0.0979	10.44	0.014233	0.67	.84	135	0.04990	9.89	91.10	0.61	
NHDL889.Z3a	-119.58582260	38.09511868			0.9	0.47	0.0936	2.28	0.014157	2.01	.89	2423	0.04796	1.05	90.62	1.82	
NHDL889.Z06	-119.58582260	38.09511868	1.7	126	2.3	0.64	0.0935	15.97	0.014118	0.93	.85	100	0.04800	15.19	90.37	0.84	
NHDL889.Z03	-119.58582260	38.09511868	3.1	356	2.4	0.50	0.0933	4.01	0.014110	0.32	.64	422	0.04794	3.81	90.32	0.29	
NHDL889.Z02	-119.58582260	38.09511868	6.4	477	2.8	0.54	0.0931	1.38	0.014068	0.27	.40	986	0.04802	1.30	90.06	0.24	
NHDL889.Z05	-119.58582260	38.09511868	1.1	317	2.0	0.63	0.0932	8.45	0.014030	0.54	.81	164	0.04817	8.03	89.82	0.48	
NHDL889.z1	-119.58582260	38.09511868			1.2	0.59	0.0923	1.95	0.014007	0.20	.56	617	0.04779	1.84	89.67	0.18	
NHDL889.Z01	-119.58582260	38.09511868	1.6	489	1.6	0.50	0.0925	2.80	0.014006	0.37	.48	446	0.04788	2.64	89.66	0.33	
NHDL889.Z2b	-119.58582260	38.09511868			0.9	0.55	0.0931	3.19	0.013995	2.55	.82	629	0.04823	1.83	89.59	2.28	
NHDL889.Z3c	-119.58582260	38.09511868			1.1	0.51	0.0935	5.33	0.013864	0.88	.42	405	0.04894	5.03	88.76	0.78	
NHDL922.z3b	-119.61632400	38.10203472			0.8	0.45	0.0944	0.68	0.014390	0.30	.55	2198	0.04759	0.57	92.10	0.28	
NHDL922.z3a	-119.61632400	38.10203472			0.7	0.45	0.0943	0.87	0.014343	0.50	.63	1677	0.04770	0.68	91.80	0.45	
NHDL922.Z03	-119.61632400	38.10203472	6.7	183	2.9	0.46	0.0947	3.10	0.014295	0.37	.50	409	0.04806	2.93	91.50	0.33	
NHDL922.Z02	-119.61632400	38.10203472	5.2	119	2.2	0.58	0.0954	5.97	0.014256	0.47	.71	268	0.04855	5.64	91.25	0.43	
NHDL922.Z04	-119.61632400	38.10203472	5.5	108	4.3	0.50	0.0931	9.94	0.014206	0.80	.63	145	0.04754	9.46	90.93	0.73	
NHDL922.Z01	-119.61632400	38.10203472	3.5	102	2.0	0.60	0.0935	7.45	0.014167	0.51	.73	178	0.04787	7.09	90.68	0.46	
NHDL922.Z22	-119.61632400	38.10203472			0.6	0.63	0.0961	7.50	0.014151	0.45	.86	175	0.04927	7.12	90.58	0.40	
NHDL922.Z06	-119.61632400	38.10203472	0.9	95	1.5	0.56	0.1065	21.28	0.014150	1.38	.88	67	0.05455	20.08	90.58	1.25	
NHDL922.Z05	-119.61632400	38.10203472	0.9	430	2.1	0.70	0.0940	8.13	0.014146	0.51	.79	188	0.04821	7.73	90.55	0.46	
CPL76.Z12	-119.49235120	38.19528725	0.3	45	1.4	1.08	0.2077	71.29	0.021805	5.72	.90	31	0.06902	66.20	139.05	7.95	
CPL76.Z04	-119.49235120	38.19528725	0.7	30	2.3	1.11	0.2049	62.96	0.021426	5.07	.89	32	0.06930	58.48	136.66	6.93	
CPL76.Z02	-119.49235120	38.19528725	5.7	46	1.9	0.94	0.1462	6.20	0.020685	0.44	.77	200	0.05126	5.86	131.98	0.59	
CPL76.Z16	-119.49235120	38.19528725	0.2	220	2.6	0.41	0.0907	84.98	0.013877	4.72	.92	35	0.04735	80.65	88.84	4.19	
CPL76.Z15	-119.49235120	38.19528725	0.2	163	1.2	0.55	0.1284	42.71	0.013802	3.30	.92	48	0.06740	39.71	88.37	2.91	
CPL76.Z11	-119.49235120	38.19528725	0.7	106	1.2	0.38	0.0936	23.41	0.013706	1.36	.89	68	0.04952	22.22	87.75	1.19	
CPL76.Z14	-119.49235120	38.19528725	0.3	129	1.7	0.32	0.0884	57.82	0.013696	3.16	.90	40	0.04677	55.00	87.69	2.77	
CPL76.Z01	-119.49235120	38.19528725	0.1	701	2.6	0.48	0.1019	47.66	0.013678	2.97	.90	40	0.05396	45.01	87.58	2.60	
CPL76.Z05	-119.49235120	38.19528725	2.1	119	1.8	0.43	0.0920	9.15	0.013633	0.59	.80	142	0.04893	8.69	87.29	0.51	
CPL76.Z06	-119.49235120	38.19528725	0.5	187	1.8	0.39	0.0947	26.15	0.013619	1.54	.90	67	0.05039	24.77	87.20	1.35	
CPL76.Z03	-119.49235120	38.19528725	0.5	194	2.9	0.37	0.0998	39.14	0.013518	2.43	.90	45	0.05348	36.97	86.56	2.10	
CPL89.Z05	-119.49436030	38.16235911	2.5	146	2.5	0.48	0.1090	8.77	0.015921	0.60	.79	165	0.04966	8.30	101.83	0.61	
CPL89.Z14	-119.49436030	38.16235911	1.5	204	3.4	0.51	0.1063	19.44	0.015691	1.14	.90	107	0.04914	18.43	100.36	1.14	
CPL89.Z04	-119.49436030	38.16235911	1.7	175	2.7	0.47	0.1040	10.66	0.015285	0.66	.82	125	0.04934	10.13	97.79	0.65	
CPL89.Z12	-119.49436030	38.16235911	0.9	80	1.9	0.73	0.1081	55.20	0.014408	3.52	.88	53	0.05440	52.12	92.22	3.24	

CPL89.Z03	-119.49436030	38.16235911	2.4	29	2.1	1.21	0.0914	43.25	0.013406	2.49	.90	46	0.04941	41.03	85.85	2.14
CPL89.Z06	-119.49436030	38.16235911	1.9	212	2.5	0.72	0.0902	8.54	0.013389	0.84	.58	160	0.04887	8.09	85.74	0.72
CPL89.Z15	-119.49436030	38.16235911	1.1	89	1.8	0.86	0.0774	45.17	0.013341	2.35	.87	63	0.04207	43.14	85.44	2.01
CPL89.Z02	-119.49436030	38.16235911	3.7	211	1.5	0.35	0.0858	3.47	0.013306	1.13	.46	452	0.04678	3.12	85.21	0.96
CPL89.Z13	-119.49436030	38.16235911	1.3	34	2.0	0.83	0.1006	56.97	0.013291	3.75	.86	37	0.05482	53.77	85.11	3.19
CPL89.Z01	-119.49436030	38.16235911	6.4	75	2.0	0.95	0.0835	12.42	0.013100	0.98	.72	221	0.04624	11.74	83.90	0.82
RE007.Z05	-119.3285814	37.67126894	1.1	455	1.5	0.61	0.0942	3.91	0.014115	0.27	.76	316	0.04839	3.72	90.36	0.24
RE007.Z01	-119.3285814	37.67126894	7.2	408	1.4	0.52	0.0927	0.71	0.014082	0.26	.49	1872	0.04776	0.63	90.15	0.23
RE007.Z03	-119.3285814	37.67126894	3.4	764	1.4	0.50	0.0930	1.14	0.014078	0.19	.31	1606	0.04793	1.10	90.12	0.17
RE007.Z06	-119.3285814	37.67126894	3.1	1323	1.6	0.51	0.0925	0.55	0.014068	0.19	.51	2365	0.04768	0.48	90.05	0.17
RE007.Z04	-119.3285814	37.67126894	10.4	199	1.4	0.61	0.0927	1.15	0.014054	0.26	.43	1375	0.04784	1.07	89.97	0.23
RE007.Z02	-119.3285814	37.67126894	8.6	793	1.4	0.56	0.0917	0.82	0.014045	0.43	.60	4265	0.04734	0.65	89.91	0.39
T684Z.Z01	-119.32530284	37.67908826	4.5	524	1.6	0.55	0.0930	1.06	0.014049	0.36	.47	1308	0.04799	0.95	89.93	0.33
T684Z.Z06	-119.32530284	37.67908826	2.1	186	1.4	0.41	0.0945	4.74	0.014037	0.30	.81	261	0.04883	4.50	89.86	0.27
T684Z.Z05	-119.32530284	37.67908826	4.0	384	1.3	0.54	0.0926	1.27	0.014011	0.28	.42	1098	0.04791	1.18	89.70	0.25
T684Z.Z03	-119.32530284	37.67908826	2.3	443	1.3	0.52	0.0929	1.78	0.014003	0.24	.47	712	0.04812	1.68	89.64	0.21
T684Z.Z04	-119.32530284	37.67908826	3.3	452	1.6	0.56	0.0932	1.47	0.013999	0.29	.42	861	0.04828	1.38	89.62	0.26
T684Z.Z02	-119.32530284	37.67908826	2.7	470	1.4	0.48	0.0921	1.63	0.013978	0.33	.43	815	0.04778	1.52	89.48	0.30

Note: Uncertainties of individual ratios and ages are given at the 2s level and do not include decay constant errors. Ratios involving ^{208}Pb are corrected for initial disequilibrium in $^{230}\text{Th}/^{238}\text{U}$ adopting Th/U=4 for the crystallization environment (Schaerer, 1984).

*Sample weight is calculated from crystal dimensions and is associated with as much as 50% uncertainty (estimated).

[†]Total common Pb including analytical blank (analytical Pb blank is 0.8 ± 0.3 pg per analysis). Blank composition is $^{206}\text{Pb}/^{204}\text{Pb} = 18.55 \pm 0.63$, $^{207}\text{Pb}/^{204}\text{Pb} = 15.50 \pm 0.55$, $^{208}\text{Pb}/^{204}\text{Pb} = 38.07 \pm 1.56$ (all 2σ of population), and a $^{206}\text{Pb}/^{204}\text{Pb}$ - $^{207}\text{Pb}/^{204}\text{Pb}$ correlation of +0.9.

[§]Present day Th/U ratio calculated from radiogenic $^{208}\text{Pb}/^{206}\text{Pb}$ and age.

^{*}Measured value corrected for tracer contribution and mass fractionation (0.15 ± 0.09 %/amu).

^{**}Ratios of radiogenic Pb versus U; data corrected for mass fractionation, tracer contribution and common Pb contribution.

^{††}Correlation coefficient of radiogenic $^{207}\text{Pb}/^{205}\text{U}$ versus $^{206}\text{Pb}/^{208}\text{U}$.

TABLE 2. ZIRCON SATURATION TEMPERATURES FOR OLDEST AND YOUNGEST UNITS IN ALL 4 LOBES

sample	unit	Zr	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	total mol	M	T, K	T, C	Total
KCL-428	KC lobe old	190.1	60.2	0.9	16.9	6.4	0.1	3.1	5.8	3.6	2.8	0.2	1.8	2.1	1,030	757	100
05-183	KC lobe young	143.2	59.8	0.8	17.6	6.5	0.1	2.7	6.2	3.8	2.2	0.3	1.8	2.0	1,010	737	100
RE007	S HD lobe old	115.1	61.7	0.8	16.2	5.6	0.1	2.0	4.9	3.7	2.8	0.3	1.7	1.9	1,000	727	98
T684	S HD lobe young	56.8	76.2	0.1	12.9	1.1	0.0	0.1	0.9	3.6	4.5	0.0	1.8	1.3	983	710	99
NHDL-922	N HD lobe old	175.7	60.9	0.8	17.9	5.4	0.1	2.3	5.6	4.2	2.4	0.3	1.8	1.9	1,032	759	100
NHDL-889	N HD lobe young	105.7	72.8	0.3	14.3	1.9	0.0	0.6	2.2	3.8	4.0	0.1	1.8	1.5	1,021	748	100
CPL-76	CP lobe old	119.0	71.2	0.4	15.3	2.0	0.0	0.6	2.6	4.5	3.2	0.1	1.8	1.5	1,028	755	100
CPL-89	CP lobe young	99.8	74.2	0.2	14.3	1.2	0.0	0.3	1.3	3.9	4.4	0.1	1.8	1.4	1,025	752	100

TABLE 3. 2-D FINITE DIFFERENCE MODELING PARAMETERS FOR FIG. 11 AND MOVIE CLIP

Parameter	Units	Background	Pluton 1	Pluton 2	Pluton 3	Overall
Geologic Age		Host Rock	Kuna Crest (KC)	Half Dome (HD)	Cathedral Peak (CP)	
age	Ma		92-95	88-92	85-88	
Rock Material						
type		granodiorite	diorite	diorite	granodiorite	
Initial Temperature	°C	300	2800	2700	2700	
density	kg/m^3	2700				
thermal conductivity	W/m^K	2.65	2.65	2.65	2.65	
specific heat	J/kg^K	1140	1142	1142	1142	
latent heat of fusion	J/mole	150,000	150,000	150,000	150,000	
latent temperature	°C	725	725	725	675	
Intrusion Process			----- map shape -----			
shape			0.0	1.0	4.0	
Relative time duration	Ma		----- instantaneous -----			
Intrusion Temperature	°C	900	850	850		
Modeling Size						
length (X)	km				165 (E-W)	
depth (Z)	km				165 (N-S)	
grid spacing	km				0.2063	
Modeling Time						
total duration	my				10.0	
calculation step	years				250	
" "	sec				1.58 x 10^13	
Model Setup						
Initial conditions					constant (300C)	
Boundary conditions					constant (300C)	
Computation						
#time steps					44,000	
Computer memory	Mbytes				26	