U–Pb zircon age of the Walloon Coal Measures in the Surat Basin, southeast Queensland: implications for paleogeography and basin subsidence

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Analytical Methods

Figure 1 Cathodoluminescence (CL) images of selected zircons extracted from the two tuff samples from Stratheden 4. Grains dated by CA-TIMS and spot analysed by LA-ICPMS are shown.

Table 1 CA-TIMS data from GA2180600 and GA 2180601 in Stratheden 4.

Table 2 U–Pb geochronologic analyses and trace element concentrations.

ANALYTICAL METHODS

LA-ICPMS methods

Zircon grains were separated from rocks using standard techniques and annealed at 900°C for 60 hours in a muffle furnace. They were mounted in epoxy and polished until their centres were exposed. Cathodoluminescence (CL) images were obtained with a JEOL JSM-1300 scanning electron microscope and Gatan MiniCL. Zircon was analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) using a ThermoElectron X-Series II quadrupole ICPMS and New Wave Research UP-213 Nd:YAG UV (213 nm) laser ablation system. In-house analytical protocols, standard materials, and data reduction software were used for acquisition and calibration of U-Pb dates and a suite of high field strength elements (HFSE) and rare earth elements (REE). Zircon was ablated with a laser spot of 25 µm wide using fluence and pulse rates of 5 J/cm² and 10 Hz, respectively, during a 45 second analysis (15 sec gas blank, 30 sec ablation) that excavated a pit ~25 µm deep. Ablated material was carried by a 1.2 L/min He gas stream to the nebuliser flow of the plasma. Dwell times were 5 ms for Si and Zr, 200 ms for ⁴⁹Ti and ²⁰⁷Pb, 80 ms for ²⁰⁶Pb, 40 ms for ²⁰²Hg, ²⁰⁴Pb, ²⁰⁸Pb, ²³²Th, and ²³⁸U and 10 ms for all other HFSE and REE. Background count rates for each analyte were obtained prior to each spot analysis and subtracted from the raw count rate for each analyte. Ablations pits that appear to have intersected glass or mineral inclusions were identified based on Ti and P. U-Pb dates from these analyses are considered valid if the U-Pb ratios appear to have been unaffected by the inclusions. Analyses that appear contaminated by common Pb were rejected based on mass 204 being above baseline. For concentration calculations, background-subtracted count rates for each analyte were internally normalised to ²⁹Si and calibrated with respect to NIST SRM-610 and -612 glasses as the primary standards. Temperature was calculated from the Ti-in-zircon thermometer (Watson *et al.* 2006). Because there are no constraints on the activity of TiO₂, an average value in crustal rocks of 0.8 was used.

Data were collected in one experiment in February 2015. For U-Pb and ²⁰⁷Pb/²⁰⁶Pb dates, instrumental fractionation of the background-subtracted ratios was corrected and dates were calibrated with respect to interspersed measurements of zircon standards and reference materials. The primary standard Plešovice zircon (Sláma *et al.* 2008) was used to monitor time-dependent instrumental fractionation based on two analyses for every 10 analyses of unknown zircon. A polynomial fit to the standard analyses yields each sample-specific fractionation factor.

Radiogenic isotope ratio and age error propagation for all analyses includes uncertainty contributions from counting statistics and background subtraction. For groups of analyses that are collectively interpreted from a weighted mean date (i.e., igneous zircon analyses), a weighted mean date is first calculated using Isoplot 3.0 (Ludwig 2003) using errors on individual dates that do not include a standard calibration uncertainty, and then a standard calibration uncertainty is propagated into the error on the weighted mean date. This uncertainty is the local standard deviation of the polynomial fit to the interspersed primary standard measurements versus time for the time-dependent, relatively larger U/Pb fractionation factor, and the standard error of the mean of the consistently time-invariant and smaller ²⁰⁷Pb/²⁰⁶Pb fractionation factor. This uncertainty is 2.24% (2σ) for ²⁰⁶Pb/²³⁸U. Age interpretations are based on ²⁰⁶Pb/²³⁸U dates. Errors on the dates from individual analyses are given at 2σ, as are the errors on the weighted mean dates.

Two zircon secondary reference materials were treated as unknowns to assess accuracy, interspersed as groups of two analyses for every 20 unknown analyses. Weighted mean dates are calculated using Isoplot 3.0 (Ludwig 2003) from errors on individual dates that do not include the standard calibration uncertainties. However, errors on weighted mean dates include the standard calibration uncertainties within each experiment and are given at 2σ . Zirconia zircon (327 Ma from unpublished chemical abrasion thermal ionisation mass spectrometry (CA-TIMS) data, Boise State University) yielded a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ date of 332 ± 9 Ma (MSWD=0.6, probability of fit = 0.80, $n = 12$). Seiland zircon (530 Ma from unpublished CA-TIMS data, Boise State University) yielded a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ date of 522 ± 15 Ma (MSWD = 0.7, probability of fit = 0.76, $n = 12$). These results show that accurate $^{206}\text{Pb}/^{238}\text{U}$ dates were obtained.

CA-TIMS methods

U–Pb dates were obtained by the chemical abrasion isotope dilution thermal ionisation mass spectrometry (CA-TIMS) method from analyses composed of single zircon grains (Table 1). Zircon grains were separated from the rock sample using standard techniques and mounted in epoxy and polished until the centres of the grains were exposed. Cathodoluminescence (CL) images were obtained with a JEOL JSM-1300 scanning electron microscope and Gatan MiniCL. Zircon was then removed from the epoxy mounts and subjected to a modified version of the chemical abrasion method of Mattinson (2005), reflecting analysis of single grains. Grains were selected for dating based on CL images that appear to lack inherited cores.

Grains were placed in a muffle furnace at 900°C for 60 hours in quartz beakers. Single grains were transferred to 3 mL Teflon PFA beakers and loaded into $300\ \mu\text{L}$ Teflon PFA microcapsules. Fifteen microcapsules were placed in a large-capacity Parr vessel, and the crystals partially dissolved in $120\ \mu\text{L}$ of 29 M HF for 12 hours at 180°C . Contents of each microcapsule were returned to 3 mL Teflon PFA beakers, HF removed and residual grains immersed in 3.5 M HNO_3 , ultrasonically cleaned for an hour, and fluxed on a hotplate at 80°C for an hour. The HNO_3 was removed and grains were rinsed twice in ultrapure H_2O before being reloaded into the same $300\ \mu\text{L}$ Teflon PFA microcapsules (rinsed and fluxed in 6 M HCl during crystal sonication and washing) and spiked with the EARTHTIME mixed ^{233}U – ^{235}U – ^{205}Pb tracer solution (ET535). These chemically abraded grains were dissolved in Parr vessels in $120\ \mu\text{L}$ of 29 M HF with a trace of 3.5 M HNO_3 at 220°C for 48 hours, dried to fluorides, and then redissolved in 6 M HCl at 180°C overnight. U and Pb were separated from the zircon matrix using an HCl-based anion-exchange chromatographic procedure (Krogh 1973), eluted together and dried with $2\ \mu\text{L}$ of 0.05 N H_3PO_4 .

Pb and U were loaded on a single outgassed Re filament in $5\ \mu\text{L}$ of a silica-gel/phosphoric acid mixture (Gerstenberger & Haase 1997), and U and Pb isotopic measurements made on a GV Isoprobe-T multicollector thermal ionisation mass spectrometer equipped with an ion-counting Daly detector. Pb isotopes were measured by peak-jumping all isotopes on the Daly detector for 160 cycles. Pb mass fractionation was corrected using the known $^{202}\text{Pb}/^{205}\text{Pb}$ ratio of the ET2535 tracer solution that was recently measured on other samples. Transitory isobaric interferences due to high-molecular weight organics, particularly on ^{204}Pb and ^{207}Pb , disappeared within approximately 30 cycles, while ionisation efficiency averaged 104 cps/pg of each Pb isotope. Linearity (to $\geq 1.4 \times 10^6$ cps) and the associated deadtime

correction of the Daly detector were monitored by repeated analyses of NBS982, and have been constant since installation. Uranium was analysed as UO_2^+ ions in static Faraday mode on 1012 ohm resistors for 250 cycles, and corrected for isobaric interference of $^{233}\text{U}^{18}\text{O}^{16}\text{O}$ on $^{235}\text{U}^{16}\text{O}^{16}\text{O}$ with an $^{18}\text{O}/^{16}\text{O}$ of 0.00206. Ionisation efficiency averaged 200 mV/ng of each U isotope. U mass fractionation was corrected using the known $^{233}\text{U}/^{235}\text{U}$ ratio of the ET535 tracer solution.

CA-TIMS U–Pb dates and uncertainties were calculated using the algorithms of (Schmitz & Schoene 2007), ET535 tracer solution (Condon *et al.* in prep; McLean *et al.* in prep) with calibration of $^{235}\text{U}/^{205}\text{Pb} = 100.233$, $^{233}\text{U}/^{235}\text{U} = 0.99506$, and $^{205}\text{Pb}/^{204}\text{Pb} = 1196$, and U decay constants recommended by Jaffey *et al.* (1971). $^{206}\text{Pb}/^{238}\text{U}$ ratios and dates were corrected for initial ^{230}Th disequilibrium using a $\text{Th}/\text{U}[\text{magma}] = 3.0 \pm 0.3$ using the algorithms of Crowley *et al.* (2007), resulting in an increase in the $^{206}\text{Pb}/^{238}\text{U}$ dates of ca 0.09 Ma. Common Pb in analyses was assigned to the zircon with a composition determined by Stacey & Kramers (1975), except for 0.3 pg that was assigned to laboratory blank and subtracted based on the measured laboratory Pb isotopic composition and associated uncertainty. U blanks are difficult to precisely measure, but are estimated at 0.075 pg.

Weighted mean $^{206}\text{Pb}/^{238}\text{U}$ dates were calculated from equivalent dates using Isoplot 3.0 (Ludwig 2003). Errors given below are presented as $\pm x / y / z$. Error x is the 2σ internal error based on analytical uncertainties only, including counting statistics, subtraction of tracer solution, and blank and initial common Pb subtraction. It should be considered when comparing our dates with $^{206}\text{Pb}/^{238}\text{U}$ dates from other laboratories that used the same EARTHTIME tracer solution or a tracer solution that was cross calibrated using EARTHTIME gravimetric standards. Error y includes the tracer calibration uncertainty propagated in quadrature. It should be considered when comparing our dates with those derived from other geochronological methods using the U–Pb decay scheme (e.g. laser ablation ICPMS). Error z includes the ^{238}U decay constant uncertainty (Jaffey *et al.* 1971). It should be considered when comparing our dates with those derived from other decay schemes (e.g. $^{40}\text{Ar}/^{39}\text{Ar}$, ^{187}Re – ^{187}Os).

Results

Six zircon grains from a tuff at 182.84 to 183.04 m yielded equivalent CA-TIMS $^{206}\text{Pb}/^{238}\text{U}$ dates with a weighted mean of $158.86 \pm 0.04 / 0.09 / 0.19$ Ma (MSWD = 1.5, probability of fit = 0.18). This is the interpreted age of ash deposition. Thirty-one of thirty-two LA-ICPMS analyses yielded equivalent $^{206}\text{Pb}/^{238}\text{U}$ dates with a weighted mean of 163 ± 4 Ma (MSWD = 1.2, probability of fit = 0.20).

Seven zircon grains from a tuff at 396.41 to 396.46 m yielded equivalent CA-TIMS $^{206}\text{Pb}/^{238}\text{U}$ dates with a weighted mean of $162.55 \pm 0.05 / 0.09 / 0.20$ Ma (MSWD = 0.6, probability of fit = 0.74). This is the interpreted age of ash deposition. Three other grains yielded dates of 162.8 ± 0.1 , 169.9 ± 0.2 and 171.2 ± 0.2 Ma. Twenty-four of twenty-seven LA-ICPMS analyses yielded equivalent $^{206}\text{Pb}/^{238}\text{U}$ dates with a weighted mean of 166 ± 5 Ma (MSWD = 1.0, probability of fit = 0.43). Three other LA-ICPMS analyses yielded equivalent $^{206}\text{Pb}/^{238}\text{U}$ dates with a weighted mean of 184 ± 11 Ma (MSWD = 0.6, probability of fit = 0.83).

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Table 1 U-Pb isotopic CA-TIMS data.

Sample	Radiogenic Isotope Ratios														Isotopic Dates					
	Th	²⁰⁶ Pb*	mol %	Pb*	Pb _c	²⁰⁶ Pb	²⁰⁸ Pb	²⁰⁷ Pb	% err	²⁰⁷ Pb	% err	²⁰⁶ Pb	% err	corr. coef.	²⁰⁷ Pb	±	²⁰⁷ Pb	±	²⁰⁶ Pb	±
	U	x10 ⁻¹³ mol	²⁰⁶ Pb*	Pb _c	(pg)	²⁰⁴ Pb	²⁰⁶ Pb	²⁰⁶ Pb		²³⁵ U		²³⁸ U			²⁰⁶ Pb		²³⁵ U		²³⁸ U	
(a)	(b)	(c)	(c)	(c)	(c)	(d)	(e)	(e)	(f)	(e)	(f)	(e)	(f)		(g)	(f)	(g)	(f)	(g)	(f)
Tuff from 182.84 to 183.04 m																				
z1	1.237	1.1036	97.91%	17	1.95	879	0.394	0.049358	0.186	0.169768	0.237	0.024946	0.071	0.791	164.88	4.36	159.22	0.35	158.84	0.11
z2	1.190	0.8969	99.25%	47	0.56	2415	0.379	0.049246	0.137	0.169421	0.186	0.024951	0.066	0.829	159.57	3.20	158.92	0.27	158.87	0.10
z4	0.956	1.3420	99.20%	42	0.90	2287	0.305	0.049370	0.153	0.169960	0.197	0.024968	0.068	0.755	165.44	3.56	159.38	0.29	158.98	0.11
z5	1.244	0.8305	97.04%	12	2.09	622	0.397	0.049110	0.249	0.168856	0.300	0.024937	0.075	0.752	153.10	5.82	158.43	0.44	158.78	0.12
z6	1.139	0.9162	97.96%	17	1.58	900	0.363	0.049258	0.198	0.169395	0.248	0.024941	0.070	0.787	160.15	4.63	158.89	0.36	158.81	0.11
z7	1.374	2.1786	99.05%	39	1.73	1934	0.438	0.049245	0.112	0.169403	0.168	0.024949	0.066	0.904	159.50	2.62	158.90	0.25	158.86	0.10
Tuff from 396.41 to 396.46 m																				
z2	1.017	0.3336	94.97%	6	1.46	365	0.324	0.049183	0.425	0.173075	0.477	0.025522	0.092	0.636	156.55	9.95	162.08	0.71	162.46	0.15
z3	0.622	0.2497	98.16%	17	0.39	987	0.198	0.049242	0.369	0.173394	0.419	0.025538	0.076	0.698	159.39	8.64	162.36	0.63	162.56	0.12
z4	0.518	0.2204	97.81%	14	0.41	830	0.165	0.049339	0.523	0.173997	0.572	0.025577	0.090	0.598	163.98	12.22	162.88	0.86	162.81	0.14
z5	0.609	0.0965	96.58%	9	0.28	527	0.194	0.049347	0.999	0.183093	1.072	0.026910	0.122	0.632	164.33	23.35	170.72	1.68	171.18	0.21
z6	0.467	0.1183	94.38%	5	0.58	324	0.149	0.050517	1.194	0.185966	1.258	0.026699	0.140	0.500	218.87	27.63	173.18	2.00	169.85	0.23
z7	0.565	0.2270	96.93%	10	0.59	594	0.180	0.049591	0.586	0.174566	0.642	0.025530	0.085	0.690	175.85	13.68	163.37	0.97	162.51	0.14
z8	0.536	0.1678	93.93%	5	0.90	302	0.171	0.049209	0.787	0.173315	0.856	0.025544	0.100	0.718	157.79	18.42	162.29	1.28	162.60	0.16
z9	0.580	0.1365	96.75%	9	0.38	558	0.185	0.049316	0.703	0.173736	0.765	0.025550	0.098	0.668	162.90	16.43	162.66	1.15	162.64	0.16
z10	0.505	0.1688	98.20%	16	0.26	1003	0.161	0.049219	0.436	0.173291	0.486	0.025535	0.078	0.689	158.30	10.20	162.27	0.73	162.54	0.13
z11	0.633	0.1880	98.13%	16	0.30	963	0.202	0.049372	0.459	0.173811	0.517	0.025533	0.069	0.867	165.53	10.72	162.72	0.78	162.53	0.11

(a) z1, z2, etc. are labels for analyses composed of single zircon grains that were annealed and chemically abraded (Mattinson 2005). Labels in bold denote those used in weighted mean calculations.

(b) Model Th/U ratio calculated from radiogenic ²⁰⁸Pb/²⁰⁶Pb ratio and ²⁰⁷Pb/²³⁵U date.

(c) Pb* and Pb_c are radiogenic and common Pb, respectively. mol % ²⁰⁶Pb* is with respect to radiogenic and blank Pb.

(d) Measured ratio corrected for spike and fractionation only. Fractionation correction is 0.16 ± 0.03 (1 sigma) %/amu (atomic mass unit) for single-collector Daly analyses, based on analysis of EARTHTIME ²⁰²Pb-²⁰⁵Pb tracer solution.

(e) Corrected for fractionation, spike, common Pb, and initial disequilibrium in ²³⁰Th/²³⁸U. Common Pb in analyses was assigned to the zircon with a composition determined by Stacey & Kramers (1975), except for 0.3 pg that was assigned to laboratory blank with a composition of ²⁰⁶Pb/²⁰⁴Pb = 18.04 ± 0.61%; ²⁰⁷Pb/²⁰⁴Pb = 15.54 ± 0.52%; ²⁰⁸Pb/²⁰⁴Pb = 37.69 ± 0.63% (1 sigma). ²⁰⁶Pb/²³⁸U and ²⁰⁷Pb/²⁰⁶Pb ratios corrected for initial disequilibrium in ²³⁰Th/²³⁸U using Th/U [magma] = 3.0 ± 0.3 (1 sigma).

(f) Errors are 2 sigma, propagated using algorithms of Schmitz & Schoene (2007) and Crowley *et al.* (2007).

(g) Calculations based on the decay constants of Jaffey *et al.* (1971). ²⁰⁶Pb/²³⁸U and ²⁰⁷Pb/²⁰⁶Pb dates corrected for initial disequilibrium in ²³⁰Th/²³⁸U using Th/U [magma] = 3.0 ± 0.3 (1 sigma).

Table 2 U-Pb geochronologic analyses and trace element concentrations.

Analysis			Notes	U ppm	Th ppm	Pb* ppm	Th/U	Corrected isotope ratios												error corr.	²³⁸ U ppm	±2s (%)	²⁰⁷ Pb* ppm	±2s (%)	error corr.	²⁰⁷ Pb* ppm	±2s (%)	error corr.	²⁰⁷ Pb* ppm	±2s (Ma)
								²⁰⁶ Pb/ ²⁰⁴ Pb	²⁰⁸ Pb/ ²³² Th	±2s (%)	²⁰⁶ Pb* ²⁰⁷ Pb*	±2s (%)	²⁰⁷ Pb* ²³⁵ U*	±2s (%)	²⁰⁶ Pb* ²³⁸ U*	±2s (%)														
tuff at 182.84 to 183.04 m L 25	2/12/2015 11:17:17 AM	(Run: 1)	high U signal variance	155.1	135.6	5.987	0.874	364.0676	0.00983	18.453	21.5229	12.525	0.18366	14.485	0.02867	7.2763	0.50	34.8814	7.2763	0.04646	12.525	-0	22	301						
tuff at 182.84 to 183.04 m L 29	2/12/2015 11:24:03 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	93.21	89.21	3.743	0.957	195.6194	0.01099	15.326	20.065	19.323	0.1940	21.127	0.02823	8.5419	0.40	35.4183	8.5419	0.04984	19.323	0	187	450						
tuff at 182.84 to 183.04 m L 34	2/12/2015 11:39:31 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	201.7	230.3	7.947	1.142	323.3393	0.00916	7.7205	24.9338	14.783	0.15387	18.339	0.02782	10.853	0.59	35.939	10.853	0.04011	14.783	0	-344	381						
tuff at 182.84 to 183.04 m L 36	2/12/2015 11:42:54 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	61.51	53.42	2.297	0.868	339.4688	0.00936	13.547	16.600	21.627	0.22889	23.052	0.02756	7.9791	0.35	36.2866	7.9791	0.06024	21.627	0	612	467						
tuff at 182.84 to 183.04 m L 16	2/12/2015 10:55:02 AM	(Run: 1)	high U signal variance	132.2	171.6	4.276	1.30	55.44812	0.00964	9.8207	19.8411	28.383	0.19118	29.124	0.02751	6.5256	0.22	36.3489	6.5256	0.05040	28.383	-0	213	658						
tuff at 182.84 to 183.04 m L 37	2/12/2015 11:44:36 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	160.2	181.2	6.085	1.131	141.0982	0.00863	8.5763	22.5445	12.157	0.16528	15.181	0.0270	9.0909	0.60	37.0041	9.0909	0.04436	12.157	-0	91	298						
tuff at 182.84 to 183.04 m L 32	2/12/2015 11:36:08 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	116.8	173.2	4.161	0.626	370.3813	0.01174	21.304	21.2257	17.961	0.17531	20.814	0.0270	10.518	0.51	37.0527	10.518	0.04711	17.961	0	55	428						
tuff at 182.84 to 183.04 m L 4	2/12/2015 10:27:42 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	80.1	72.42	3.01	0.904	101.5682	0.01032	18.464	20.9316	19.203	0.17758	21.618	0.0270	9.9273	0.46	37.0951	9.9273	0.04777	19.20	0	88	455						
tuff at 182.84 to 183.04 m L 11	2/12/2015 10:46:33 AM	(Run: 1)	high U signal variance	147.5	163.6	5.442	1.109	1298.924	0.00818	12.855	21.8167	10.369	0.16821	12.564	0.02662	7.094	0.56	37.571	7.094	0.04584	10.369	0	-11	250						
tuff at 182.84 to 183.04 m S 42	2/12/2015 12:00:09 PM	(Run: 1)	high U signal variance	242.2	259.9	10.06	0.703	421.7649	0.01207	16.4	12.9095	20.072	0.28323	21.447	0.02652	7.5549	0.35	37.710	7.5549	0.07746	20.072	0	1133	400						
tuff at 182.84 to 183.04 m L 1	2/12/2015 10:22:36 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	108	98.32	3.87	0.91	116.093	0.0090	14.875	20.1653	15.041	0.18031	17.10	0.02637	8.1353	0.48	37.9209	8.1353	0.04959	15.041	-0	176	351						
tuff at 182.84 to 183.04 m L 21	2/12/2015 11:10:30 AM	(Run: 1)	high U signal variance	474.1	762.1	19.06	1.607	1572.03	0.0080	5.0741	21.8215	16.8906	0.16558	9.35	0.02621	6.319	0.68	38.1593	6.319	0.04583	8.8906	0	-11	166						
tuff at 182.84 to 183.04 m L 24	2/12/2015 11:15:35 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	252.9	218.3	8.873	0.863	224.8517	0.00914	10.512	19.9894	9.1412	0.17864	12.688	0.0259	8.7991	0.69	38.6124	8.7991	0.0500	9.1412	0	196	212						
tuff at 182.84 to 183.04 m L 18	2/12/2015 10:58:25 AM	(Run: 1)	high U signal variance	244.1	336.9	9.55	1.38	154.014	0.00874	9.0349	21.4929	10.618	0.16593	12.767	0.02587	7.0884	0.56	38.6619	7.0884	0.04653	10.618	0	25	255						
tuff at 182.84 to 183.04 m L 3	2/12/2015 10:26:00 AM	(Run: 1)	high U signal variance	222.1	284.1	8.87	1.28	208.3422	0.01014	10.653	21.7772	11.844	0.16326	13.724	0.02579	6.9347	0.51	38.7815	6.9347	0.04592	11.844	0	-7	286						
tuff at 182.84 to 183.04 m L 22	2/12/2015 11:12:12 AM	(Run: 1)	high U signal variance	139.4	110.8	4.645	0.795	136.7282	0.0080	19.194	20.9705	19.855	0.16894	21.387	0.02569	7.947	0.37	38.9192	7.947	0.04769	19.855	0	84	471						
tuff at 182.84 to 183.04 m L 23	2/12/2015 11:13:53 AM	(Run: 1)	high U signal variance	247	371.8	9.682	1.505	148.670	0.00819	9.8495	20.232	10.279	0.17451	11.661	0.02561	5.5057	0.47	39.0515	5.5057	0.04943	10.279	0	168	240						
tuff at 182.84 to 183.04 m L 5	2/12/2015 10:29:23 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	124.1	99.81	4.376	0.80	496.1732	0.01086	22.00	23.5092	33.119	0.14925	34.067	0.02545	7.9815	0.23	39.2952	7.9815	0.04254	33.119	-0	-195	829						
tuff at 182.84 to 183.04 m L 15	2/12/2015 10:53:20 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	104.1	93.26	3.66	0.90	116.5455	0.00977	15.419	26.0662	25.872	0.13452	27.841	0.02543	10.285	0.37	39.3214	10.285	0.03836	25.872	0	-460	683						
tuff at 182.84 to 183.04 m L 30	2/12/2015 11:25:45 AM	(Run: 1)	high U signal variance	255.5	184.1	8.74	0.72	125.6363	0.01042	11.338	19.7072	9.2491	0.17781	10.784	0.02541	5.5458	0.51	39.3479	5.5458	0.05074	9.2491	0	229	214						
tuff at 182.84 to 183.04 m L 38	2/12/2015 11:46:18 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	123.3	230.3	5.296	1.74	189.8521	0.00776	14.634	20.929	15.306	0.16672	17.576	0.02531	8.640	0.49	39.5152	8.6401	0.04778	15.306	0	88	363						
tuff at 182.84 to 183.04 m L 33	2/12/2015 11:37:50 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	86.59	92.01	3.097	1.063	240.2158	0.00889	21.984	22.9025	24.071	0.1518	26.005	0.02521	9.8432	0.38	39.660	9.8432	0.04366	24.071	-0	-130	595						
tuff at 182.84 to 183.04 m L 28	2/12/2015 11:22:22 AM	(Run: 1)	high U signal variance	84.86	66.35	2.991	0.782	61.82654	0.01129	16.591	17.8892	18.404	0.19287	19.758	0.0250	7.1894	0.36	39.9626	7.1894	0.0559	18.40	0	448	409						
tuff at 182.84 to 183.04 m L 14	2/12/2015 10:51:39 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	125.1	120.6	4.471	0.993	395.730	0.01084	14.40	23.490	20.5	0.14653	23.32	0.0250	11.115	0.48	40.0594	11.115	0.04257	20.50	0	-193	513						
tuff at 182.84 to 183.04 m L 6	2/12/2015 10:31:05 AM	(Run: 1)	high U signal variance	456.9	603.6	17.81	1.321	545.5033	0.00974	7.1115	20.8499	11.562	0.16512	12.774	0.02492	5.4327	0.43	40.1362	5.4327	0.04807	11.562	0	102	273						
tuff at 182.84 to 183.04 m S 44	2/12/2015 12:03:33 PM	(Run: 1)	high U signal variance	121.2	91.11	3.923	0.752	47.91235	0.0083	22.321	19.8854	16.695	0.17255	18.20	0.02488	7.2585	0.40	40.1849	7.2585	0.05029	16.70	0	208	387						
tuff at 182.84 to 183.04 m S 40	2/12/2015 11:49:44 AM	(Run: 1)	high U signal variance	248.1	185.3	8.211	0.747	1823.067	0.0096	10.964	21.2647	10.505	0.16057	12.226	0.02476	6.2541	0.51	40.3809	6.2541	0.0470	10.505	0	51	251						
tuff at 182.84 to 183.04 m L 13	2/12/2015 10:49:56 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	98.42	87.8	3.554	0.892	503.7358	0.01082	22.371	14.6821	36.025	0.23169	37.044	0.02467	8.6287	0.23	40.5322	8.6287	0.06811	36.025	-0	872	746						
tuff at 182.84 to 183.04 m L 39	2/12/2015 11:47:59 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	125.9	116	4.095	0.921	356.460	0.00746	16.49	20.8531	26.182	0.16183	27.80	0.02448	9.3422	0.34	40.8565	9.3422	0.0480	26.182	-0	97	620						
tuff at 182.84 to 183.04 m L 7	2/12/2015 10:32:47 AM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	244	320.6	9.099	1.314	498.5179	0.0089	7.2416	21.700	10.288	0.15545	12.818	0.02446	7.6464	0.60	40.8763	7.6464	0.04608	10.288	-0	2	248						
tuff at 182.84 to 183.04 m L 12	2/12/2015 10:48:15 AM	(Run: 1)	high U signal variance	266.4	757.2	13.27	2.842	158.1462	0.00864	8.905	22.625	14.111	0.14738	15.679	0.02418	6.834	0.44	41.351	6.834	0.0442	14.111	-0	-100	347						
tuff at 182.84 to 183.04 m L 10	2/12/2015 10:37:52 AM	(Run: 1)	high U signal variance	98.74	97.2	3.275	0.984	61.70969	0.0080	12.432	19.6612	19.495	0.16856	20.315	0.0240	5.7127	0.28	41.603	5.7127	0.05086	19.495	-0	235	450						
tuff at 396.41 to 396.46 m S 68	2/12/2015 12:58:07 PM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	106.3	50.24	4.104	0.473	91.17414	0.01637	40.109	14.8553	23.082	0.26849	25.024	0.02893	9.6658	0.39	34.5695	9.6658	0.06732	23.082	0	848	480						
tuff at 396.41 to 396.46 m S 63	2/12/2015 12:49:40 PM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	145.8	68.68	5.23	0.471	456.3245	0.01181	17.086	19.860	16.275	0.20039	18.847	0.02886	9.5052	0.50	34.6461	9.5052	0.05035	16.275	0	211	377						
tuff at 396.41 to 396.46 m S 78	2/12/2015 1:22:03 PM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	84.38	52.21	2.973	0.619	100.1478	0.0084	14.819	22.8767	17.682	0.17346	20.284	0.02878	9.9040	0.49	34.7454	9.9041	0.04371	17.682	-0	-127	437						
tuff at 396.41 to 396.46 m S 80	2/12/2015 1:25:26 PM	(Run: 1)	high U signal variance	219	162.3	7.81	0.741	208.5178	0.0090	10.51	20.1244	10.311	0.18944	12.38	0.02765	6.851	0.55	36.1661	6.851	0.04969	10.311	-0	181	240						
tuff at 396.41 to 396.46 m S 62	2/12/2015 12:47:59 PM	(Run: 1)	high U signal variance	94.86	45.72	3.484	0.476	276.1638	0.01447	20.571	16.8273	16.52	0.22639	18.052	0.02763	7.2771	0.40	36.1937	7.2771	0.05943	16.52	-0	583	359						
tuff at 396.41 to 396.46 m S 59	2/12/2015 12:35:53 PM	(Run: 1)	high U signal variance	114.5	66.77	3.887	0.583	128.3906	0.00851	19.035	18.9036	17.655	0.20081	18.992	0.02753	7.0003	0.37	36.3222	7.0003	0.0529	17.655	-0	324	401						
tuff at 396.41 to 396.46 m S 55	2/12/2015 12:29:09 PM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	134.2	89.31	4.831	0.665	124.3061	0.01038	20.507	15.6392	32.329	0.2410	33.644	0.02734	8.644	0.26	36.5773	8.644	0.06394	32.329	-0	740	684						
tuff at 396.41 to 396.46 m S 60	2/12/2015 12:37:35 PM	(Run: 1)	high ²⁰⁶ Pb/ ²³⁸ U variance	198.1	127.6	6.887	0.644	244.7975	0.00972	19.80	23.3608</																			

Experiment on February 12, 2015

Isotone ratio and date errors include systematic calibration errors of 1.02% ($^{207}\text{Pb}/^{206}\text{Pb}$) and 2.21% ($^{206}\text{Pb}/^{238}\text{U}$) (2 sigma).

Trace element concentrations were deleted from analyses known to have intersected inclusions of other minerals based on P and Ti.

Ablation used a laser spot size of 25 microns, and a laser firing repetition rate of 10 Hz.

Activity of TiO_2 for Ti-in-Zircon temperature calculation is 0.8.

Table 2 U-Pb geochronologic analyses and trace element concs

Analysis	Dates (Ma)				Concentrations (ppm)																
	²⁰⁷ Pb* ²³⁵ U	±2s (Ma)	²⁰⁶ Pb* ²³⁸ U*	±2s (Ma)	P	Ti	Y	Nb	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
tuff at 182.84 to 183.04 m L 25	2/12/2015 11:17:17 AM (Run: 1)	171	23	182	13	273	4.668	1041	0.567												
tuff at 182.84 to 183.04 m L 29	2/12/2015 11:24:03 AM (Run: 1)	180	35	179	15	223	10.493	659	0.405												
tuff at 182.84 to 183.04 m L 34	2/12/2015 11:39:31 AM (Run: 1)	145	25	177	19	192	5.864	1641	0.460	0.03778											
tuff at 182.84 to 183.04 m L 36	2/12/2015 11:42:54 AM (Run: 1)	209	44	175	14	130	6.684	519	0.113												
tuff at 182.84 to 183.04 m L 16	2/12/2015 10:55:02 AM (Run: 1)	178	47	175	11	195	5.990	1341	0.378												
tuff at 182.84 to 183.04 m L 37	2/12/2015 11:44:36 AM (Run: 1)	155	22	172	15	169	10.320	932	0.251												
tuff at 182.84 to 183.04 m L 32	2/12/2015 11:36:08 AM (Run: 1)	164	32	172	18	389	6.281	652	1.055	1.01954											
tuff at 182.84 to 183.04 m L 4	2/12/2015 10:27:42 AM (Run: 1)	166	33	171	17	200	9.210	845	0.411												
tuff at 182.84 to 183.04 m L 11	2/12/2015 10:46:33 AM (Run: 1)	158	18	169	12	167	6.887	1140	0.466												
tuff at 182.84 to 183.04 m S 42	2/12/2015 12:00:09 PM (Run: 1)	253	48	169	13	283	7.950	1108	1.054												
tuff at 182.84 to 183.04 m L 1	2/12/2015 10:22:36 AM (Run: 1)	168	27	168	13	157	4.202	812	0.337												
tuff at 182.84 to 183.04 m L 21	2/12/2015 11:10:30 AM (Run: 1)	156	13	167	10	610	10.345	4595	1.793	0.0323											
tuff at 182.84 to 183.04 m L 24	2/12/2015 11:15:35 AM (Run: 1)	167	20	165	14	200	3.842	690	0.602	0.01591											
tuff at 182.84 to 183.04 m L 18	2/12/2015 10:58:25 AM (Run: 1)	156	18	165	12	227	6.921	1909	0.556												
tuff at 182.84 to 183.04 m L 3	2/12/2015 10:26:00 AM (Run: 1)	154	20	164	11	222	16.193	1313	0.506												
tuff at 182.84 to 183.04 m L 22	2/12/2015 11:12:12 AM (Run: 1)	158	31	164	13	230	4.367	922	0.690												
tuff at 182.84 to 183.04 m L 23	2/12/2015 11:13:53 AM (Run: 1)	163	18	163	9	216	5.195	2298	0.516	0.05312											
tuff at 182.84 to 183.04 m L 5	2/12/2015 10:29:23 AM (Run: 1)	141	45	162	13	178	4.268	606	0.383	0.18645											
tuff at 182.84 to 183.04 m L 15	2/12/2015 10:53:20 AM (Run: 1)	128	34	162	16	128	9.686	486	0.253												
tuff at 182.84 to 183.04 m L 30	2/12/2015 11:25:45 AM (Run: 1)	166	17	162	9																
tuff at 182.84 to 183.04 m L 38	2/12/2015 11:46:18 AM (Run: 1)	157	26	161	14	331	8.026	1733	0.438												
tuff at 182.84 to 183.04 m L 33	2/12/2015 11:37:50 AM (Run: 1)	143	35	161	16	193	8.925	531	0.721												
tuff at 182.84 to 183.04 m L 28	2/12/2015 11:22:22 AM (Run: 1)	179	32	159	11	263	10.721	609	0.491												
tuff at 182.84 to 183.04 m L 14	2/12/2015 10:51:39 AM (Run: 1)	139	30	159	17	190	6.582	1210	0.539	0.03232											
tuff at 182.84 to 183.04 m L 6	2/12/2015 10:31:05 AM (Run: 1)	155	18	159	9	146	3.279	1268	0.720	0.07192											
tuff at 182.84 to 183.04 m S 44	2/12/2015 12:03:33 PM (Run: 1)	162	27	158	11	240	7.718	729	0.725												
tuff at 182.84 to 183.04 m S 40	2/12/2015 11:49:44 AM (Run: 1)	151	17	158	10	169	3.309	787	1.340	0.05411											
tuff at 182.84 to 183.04 m L 13	2/12/2015 10:49:56 AM (Run: 1)	212	71	157	13	142	8.089	807	0.418	0.0387											
tuff at 182.84 to 183.04 m L 39	2/12/2015 11:47:59 AM (Run: 1)	152	39	156	14	262	7.821	931	0.818												
tuff at 182.84 to 183.04 m L 7	2/12/2015 10:32:47 AM (Run: 1)	147	18	156	12	493	7.888	1339	0.526												
tuff at 182.84 to 183.04 m L 12	2/12/2015 10:48:15 AM (Run: 1)	140	20	154	10	616	10.193	5844	2.155	0.15647											
tuff at 182.84 to 183.04 m L 10	2/12/2015 10:37:52 AM (Run: 1)	158	30	153	9	258	10.866	925	0.611												
tuff at 396.41 to 396.46 m S 68	2/12/2015 12:58:07 PM (Run: 1)	241	54	184	18	246	5.403	917	1.127												
tuff at 396.41 to 396.46 m S 63	2/12/2015 12:49:40 PM (Run: 1)	185	32	183	17	235	6.619	1303	0.891	0.05351											
tuff at 396.41 to 396.46 m S 78	2/12/2015 1:22:03 PM (Run: 1)	162	30	183	18	277	6.494	1414	0.821												
tuff at 396.41 to 396.46 m S 80	2/12/2015 1:25:26 PM (Run: 1)	176	20	176	12	450	4.502	2266	4.633												
tuff at 396.41 to 396.46 m S 62	2/12/2015 12:47:59 PM (Run: 1)	207	34	176	13	228	6.098	1148	0.802												
tuff at 396.41 to 396.46 m S 59	2/12/2015 12:35:53 PM (Run: 1)	186	32	175	12																
tuff at 396.41 to 396.46 m S 55	2/12/2015 12:29:09 PM (Run: 1)	219	66	174	15	211	5.035	1194	1.878												
tuff at 396.41 to 396.46 m S 60	2/12/2015 12:37:35 PM (Run: 1)	152	24	174	15	515	2.354	2097	4.159	1.13838											
tuff at 396.41 to 396.46 m S 65	2/12/2015 12:53:03 PM (Run: 1)	316	58	173	14	241	5.993	1304	1.651												
tuff at 396.41 to 396.46 m S 70	2/12/2015 1:01:30 PM (Run: 1)	286	56	171	18	456	5.336	4008	9.649												
tuff at 396.41 to 396.46 m S 77	2/12/2015 1:20:22 PM (Run: 1)	217	40	170	14	618	2.421	3875	6.409	2.31131											
tuff at 396.41 to 396.46 m S 84	2/12/2015 1:39:14 PM (Run: 1)	255	56	169	16	425	4.611	2482	4.544												
tuff at 396.41 to 396.46 m S 64	2/12/2015 12:51:21 PM (Run: 1)	144	25	169	12	261	6.418	1421	2.606	1.19824											
tuff at 396.41 to 396.46 m S 61	2/12/2015 12:46:18 PM (Run: 1)	164	20	167	13	370	3.318	2036	4.545												
tuff at 396.41 to 396.46 m S 66	2/12/2015 12:54:45 PM (Run: 1)	150	28	167	13	434	5.304	1269	1.771	3.0569											
tuff at 396.41 to 396.46 m S 86	2/12/2015 1:42:37 PM (Run: 1)	153	17	166	11	496	3.847	3618	2.432	4.1246											
tuff at 396.41 to 396.46 m S 75	2/12/2015 1:17:00 PM (Run: 1)	156	25	166	19	223	5.789	1072	0.826	0.35672											
tuff at 396.41 to 396.46 m S 81	2/12/2015 1:34:10 PM (Run: 1)	185	28	164	14	221	6.329	1137	0.867												
tuff at 396.41 to 396.46 m S 85	2/12/2015 1:40:55 PM (Run: 1)	144	20	163	15	426	4.176	2638	1.895	0.98617											
tuff at 396.41 to 396.46 m S 67	2/12/2015 12:56:26 PM (Run: 1)	183	15	163	9																
tuff at 396.41 to 396.46 m S 48	2/12/2015 12:10:19 PM (Run: 1)	158	15	161	13	435	12.936	6964	10.504												
tuff at 396.41 to 396.46 m S 72	2/12/2015 1:11:55 PM (Run: 1)	184	32	160	14	270	4.599	1887	1.100	0.10345											
tuff at 396.41 to 396.46 m S 69	2/12/2015 12:59:49 PM (Run: 1)	150	19	160	15	364	2.817	2349	3.600												
tuff at 396.41 to 396.46 m S 82	2/12/2015 1:35:52 PM (Run: 1)	180	50	160	19	207	5.694	719	0.579												
tuff at 396.41 to 396.46 m S 83	2/12/2015 1:37:33 PM (Run: 1)	164	29	159	14	258	5.535	1000	1.460	0.01724											
tuff at 396.41 to 396.46 m S 71	2/12/2015 1:10:13 PM (Run: 1)	150	14	156	10	497	4.261	2841	5.710	0.19233											

Table 2 U-Pb geochronologic analyses and trace element concs

Analysis	Lu	Hf	Ta	Th	U	Ti-in-zircon T(°C)	Ce/Ce*	Eu/Eu*	ΣREE	(Gd/Yb) _{cn}	Lu/Hf	Nb/Ta	Nb/U	Nb/Th	Th/U	Th/Y	Hf/Y
tuff at 182.84 to 183.04 m L 25	98.7	7514	0.150	135.6	155.1	698	355.29	0.80	985.83	0.02	0.01	3.78	0.004	0.004	0.87	0.13	7.22
tuff at 182.84 to 183.04 m L 29	35.7	7906	0.088	89.2	93.2	772	361.16	0.11	527.66	0.05	0.00	4.60	0.004	0.005	0.96	0.14	12.01
tuff at 182.84 to 183.04 m L 34	112.0	5655	0.252	230.3	201.7	718	34.20	0.71	1464.24	0.05	0.02	1.83	0.002	0.002	1.14	0.14	3.45
tuff at 182.84 to 183.04 m L 36	44.3	6562	0.157	53.4	61.5	729	95.86	0.93	490.97	0.02	0.01	0.72	0.002	0.002	0.87	0.10	12.65
tuff at 182.84 to 183.04 m L 16	85.6	6995	0.130	171.6	132.2	719	36.42	0.61	1200.19	0.06	0.01	2.90	0.003	0.002	1.30	0.13	5.22
tuff at 182.84 to 183.04 m L 37	50.7	9482	0.337	181.2	160.2	770	57.70	0.30	757.50	0.07	0.01	0.74	0.002	0.001	1.13	0.19	10.17
tuff at 182.84 to 183.04 m L 32	38.5	7872	0.345	73.1	116.9	724	5.61	0.15	566.91	0.03	0.00	3.05	0.009	0.014	0.63	0.11	12.08
tuff at 182.84 to 183.04 m L 4	42.3	7722	0.174	72.4	80.1	759	631.42	0.28	712.46	0.06	0.01	2.36	0.005	0.006	0.90	0.09	9.14
tuff at 182.84 to 183.04 m L 11	111.2	8357	0.314	163.6	147.5	732	325.91	0.68	1011.53	0.03	0.01	1.48	0.003	0.003	1.11	0.14	7.33
tuff at 182.84 to 183.04 m S 42	55.4	9322	0.473	259.9	242.2	745	220.28	0.26	856.22	0.05	0.01	2.23	0.004	0.004	1.07	0.23	8.42
tuff at 182.84 to 183.04 m L 1	87.2	7553	0.162	98.3	108.0	689	183.21	0.51	766.92	0.03	0.01	2.09	0.003	0.003	0.91	0.12	9.30
tuff at 182.84 to 183.04 m L 21	390.8	7600	0.651	762.1	474.1	771	147.72	0.57	3960.62	0.03	0.05	2.75	0.004	0.002	1.61	0.17	1.65
tuff at 182.84 to 183.04 m L 24	53.2	9542	0.448	218.3	252.9	681	83.91	0.14	618.09	0.03	0.01	1.34	0.002	0.003	0.86	0.32	13.82
tuff at 182.84 to 183.04 m L 18	133.9	7296	0.110	336.9	244.1	732	60.79	0.66	1694.79	0.04	0.02	5.07	0.002	0.002	1.38	0.18	3.82
tuff at 182.84 to 183.04 m L 3	73.3	7701	0.295	284.1	222.1	817	59.24	0.39	1077.62	0.05	0.01	1.72	0.002	0.002	1.28	0.22	5.87
tuff at 182.84 to 183.04 m L 22	59.8	12557	0.314	110.8	139.4	692	291.79	0.16	683.96	0.04	0.00	2.20	0.005	0.006	0.79	0.12	13.62
tuff at 182.84 to 183.04 m L 23	191.2	8478	0.228	371.8	247.0	707	45.29	0.71	1910.92	0.05	0.02	2.26	0.002	0.001	1.51	0.16	3.69
tuff at 182.84 to 183.04 m L 5	61.8	7191	0.074	99.8	124.1	690	15.00	0.61	653.29	0.03	0.01	5.21	0.003	0.004	0.80	0.16	11.88
tuff at 182.84 to 183.04 m L 15	27.5	8222	0.168	93.3	104.1	764	180.84	0.40	395.07	0.05	0.00	1.50	0.002	0.003	0.90	0.19	16.90
tuff at 182.84 to 183.04 m L 30																	
tuff at 182.84 to 183.04 m L 38	132.5	8006	0.199	230.3	132.3	746	66.94	0.83	1426.05	0.05	0.02	2.20	0.003	0.002	1.74	0.13	4.62
tuff at 182.84 to 183.04 m L 33	32.5	7506	0.248	92.0	86.6	756	2108.14	0.12	455.43	0.03	0.00	2.90	0.008	0.008	1.06	0.17	14.14
tuff at 182.84 to 183.04 m L 28	33.5	7075	0.136	66.4	84.9	774	313.22	0.33	533.30	0.04	0.00	3.62	0.006	0.007	0.78	0.11	11.63
tuff at 182.84 to 183.04 m L 14	89.7	6513	0.089	120.6	121.5	728	45.22	0.48	1178.40	0.04	0.01	6.06	0.004	0.004	0.99	0.10	5.38
tuff at 182.84 to 183.04 m L 6	97.3	5738	0.213	603.6	456.9	668	41.42	0.83	1203.38	0.03	0.02	3.37	0.002	0.001	1.32	0.48	4.53
tuff at 182.84 to 183.04 m S 44	42.4	9076	0.235	91.1	121.2	743	392.20	0.31	634.77	0.04	0.00	3.08	0.006	0.008	0.75	0.12	12.45
tuff at 182.84 to 183.04 m S 40	62.6	9061	0.456	185.3	248.1	669	116.32	0.19	723.97	0.02	0.01	2.94	0.005	0.007	0.75	0.24	11.51
tuff at 182.84 to 183.04 m L 13	59.1	6944	0.026	87.8	98.4	747	39.36	0.48	749.23	0.04	0.01	15.80	0.004	0.005	0.89	0.11	8.60
tuff at 182.84 to 183.04 m L 39	56.3	11708	0.389	116.0	125.9	744	1249.30	0.17	678.27	0.05	0.00	2.10	0.006	0.007	0.92	0.12	12.58
tuff at 182.84 to 183.04 m L 7	114.5	6787	0.290	320.6	244.0	745	254.86	0.68	1291.28	0.03	0.02	1.81	0.002	0.002	1.31	0.24	5.07
tuff at 182.84 to 183.04 m L 12	305.1	7206	0.336	757.2	266.4	769	34.20	0.62	4537.87	0.08	0.04	6.41	0.008	0.003	2.84	0.13	1.23
tuff at 182.84 to 183.04 m L 10	53.8	11064	0.304	97.2	98.7	775	377.06	0.26	693.52	0.05	0.00	2.01	0.006	0.006	0.98	0.11	11.96
tuff at 396.41 to 396.46 m S 68	54.7	7535	0.310	50.2	106.3	710	101.41	0.29	714.55	0.04	0.01	3.64	0.011	0.022	0.47	0.05	8.22
tuff at 396.41 to 396.46 m S 63	65.8	7163	0.424	68.7	145.8	728	9.21	0.22	1023.95	0.05	0.01	2.10	0.006	0.013	0.47	0.05	5.50
tuff at 396.41 to 396.46 m S 78	67.3	8307	0.474	52.2	84.4	727	26.57	0.20	1035.32	0.05	0.01	1.73	0.010	0.016	0.62	0.04	5.87
tuff at 396.41 to 396.46 m S 80	113.5	8445	1.404	162.3	219.0	695	256.16	0.18	1748.49	0.04	0.01	3.30	0.021	0.029	0.74	0.07	3.73
tuff at 396.41 to 396.46 m S 62	62.7	7547	0.304	45.7	94.9	721	23.71	0.29	895.84	0.04	0.01	2.64	0.008	0.018	0.48	0.04	6.57
tuff at 396.41 to 396.46 m S 59																	
tuff at 396.41 to 396.46 m S 55	63.6	8960	0.642	89.3	134.2	704	261.53	0.15	906.38	0.05	0.01	2.92	0.014	0.021	0.67	0.07	7.50
tuff at 396.41 to 396.46 m S 60	103.3	9151	1.395	127.6	198.1	643	7.25	0.14	1639.95	0.05	0.01	2.98	0.021	0.033	0.64	0.06	4.36
tuff at 396.41 to 396.46 m S 65	64.1	8763	0.976	183.6	227.4	719	193.50	0.16	1026.35	0.04	0.01	1.69	0.007	0.009	0.81	0.14	6.72
tuff at 396.41 to 396.46 m S 70	148.4	6631	1.931	608.9	482.4	709	220.01	0.34	2982.36	0.09	0.02	5.00	0.020	0.016	1.26	0.15	1.65
tuff at 396.41 to 396.46 m S 77	172.7	8560	1.733	287.4	335.3	645	5.24	0.19	2764.37	0.06	0.02	3.70	0.019	0.022	0.86	0.07	2.21
tuff at 396.41 to 396.46 m S 84	117.3	7444	1.141	236.1	280.0	697	118.22	0.27	1926.09	0.06	0.02	3.98	0.016	0.019	0.84	0.10	3.00
tuff at 396.41 to 396.46 m S 64	65.1	7523	0.804	90.0	153.9	726	2.64	0.19	1062.39	0.05	0.01	3.24	0.017	0.029	0.58	0.06	5.30
tuff at 396.41 to 396.46 m S 61	92.4	7751	1.540	159.7	236.5	669	361.12	0.10	1534.02	0.05	0.01	2.95	0.019	0.028	0.68	0.08	3.81
tuff at 396.41 to 396.46 m S 66	65.4	8495	0.618	82.9	136.8	709	1.98	0.15	998.09	0.04	0.01	2.86	0.013	0.021	0.61	0.07	6.69
tuff at 396.41 to 396.46 m S 86	169.3	8143	0.696	173.2	232.5	681	2.35	0.31	2866.36	0.07	0.02	3.50	0.010	0.014	0.74	0.05	2.25
tuff at 396.41 to 396.46 m S 75	58.1	8405	0.524	63.1	110.5	716	3.50	0.20	832.49	0.05	0.01	1.57	0.007	0.013	0.57	0.06	7.84
tuff at 396.41 to 396.46 m S 81	71.6	8111	0.457	76.8	153.1	724		0.15	948.98	0.03	0.01	1.90	0.006	0.011	0.50	0.07	7.14
tuff at 396.41 to 396.46 m S 85	123.0	7937	0.567	104.0	161.5	688	4.23	0.31	2016.46	0.06	0.02	3.34	0.012	0.018	0.64	0.04	3.01
tuff at 396.41 to 396.46 m S 67																	
tuff at 396.41 to 396.46 m S 48	223.9	4683	1.080	911.6	530.6	793	172.04	0.63	5052.22	0.14	0.05	9.73	0.020	0.012	1.72	0.13	0.67
tuff at 396.41 to 396.46 m S 72	95.1	7172	0.483	91.0	147.2	696	14.72	0.17	1392.49	0.05	0.01	2.28	0.007	0.012	0.62	0.05	3.80
tuff at 396.41 to 396.46 m S 69	108.1	8075	1.012	143.2	209.3	656	130.58	0.31	1755.81	0.05	0.01	3.56	0.017	0.025	0.68	0.06	3.44
tuff at 396.41 to 396.46 m S 82	45.2	7813	0.364	33.4	80.1	715		0.24	596.85	0.04	0.01	1.59	0.007	0.017	0.42	0.05	10.87
tuff at 396.41 to 396.46 m S 83	53.8	8871	1.000	79.5	149.5	710	58.24	0.14	801.84	0.04	0.01	1.46	0.010	0.018	0.53	0.08	8.87
tuff at 396.41 to 396.46 m S 71	125.8	7637	1.666	278.0	288.8	690	35.60	0.38	2128.14	0.06	0.02	3.43	0.020	0.021	0.96	0.10	2.69
tuff at 396.41 to 396.46 m S 46	106.8	8127	1.742	126.1	227.1	660	474.22	0.14	1752.31	0.05	0.01	3.69	0.028	0.051	0.56	0.06	3.59

Figure 1 Cathodoluminescence (CL) images of selected zircons extracted from the two tuff samples from Stratheden 4. Grains dated by CA-TIMS and spot analysed by LA-ICPMS are shown.