^{40}Ar-^{39}Ar methods

This document provides a description of the multi-collector instrument used to collect the data in this article and includes a detailed description of the multi-collector calibration and data evaluation.

Instrumentation

The Nu instruments Noblesse multi-collector mass spectrometer in the WiscAr laboratory at the University of Wisconsin-Madison (model NG022) is equipped with a 75° magnetic sector, Nier-type ion-source, two quadrupole lens arrays, and a fixed collector block (i.e., no moving parts). Volume of the WiscAr Noblesse is ~2300 cc. The collector configuration features an axial faraday detector and four discrete dynode ETP® ion-counting electron multipliers, two on the high mass side (IC0 and IC1) and two on the low mass side (IC2 and IC3), which allow for simultaneous measurement of all isotopes of Ar.

The ability of the instrument to resolve interferences is described by the mass resolving power (MRP), which is defined as m/Δm, where m is the mass of the peak and Δm is the mass difference between 5% and 95% of peak height on the side of the peak (Ireland, 2013). The MRP of the WiscAr Noblesse is ~3000, which is considerably higher than that determined in most Noblesse instruments installed prior to 2015 (more recent instruments exceed this MRP; Saxton, 2015). The MRP of the WiscAr Noblesse allows for resolution of hydrocarbons from Ar at m/e 37 to 40; at m/e 36, $^{36}Ar + H^{35}Cl$ can be substantially resolved from combined $^{36}Ar + H^{35}Cl + {}^{12}C_3$. To avoid any influence of $^{12}C_3$ at m/e 36 as well as other isobaric interferences at the other masses, measurements are taken on the low mass side of the argon peaks (see Fig. 1 Jicha et al., 2016). Peak position, width, and shape are optimized by first adjusting the source parameters and then changing the voltages of the quadrupole lenses. The same quadrupole settings are used for measurements of blanks, standard gas, and samples. All analyses in this study were conducted under similar high mass-resolution conditions.

The Noblesse is attached to a gas extraction line with a Photon Machines, Fusions 10.6 60 W CO_2 laser, two SAES GP-50 getters, an ARS cryotrap operating at -125 ºC, and two gas reservoir/pipette systems. The incremental heating analyses conducted in this study were performed on ~20 mg of volcanic groundmass. Gas released from the samples was cleaned with two SAES GP-50 getters, one at room temperature and one at 450 °C, for 6 minutes followed by exposure to a cryo trap for 2 more minutes. Procedural blanks averaged 6000 counts per second (cps) for ^{40}Ar and ~22 cps for ^{36}Ar, which correspond to ~3-4% of the ^{40}Ar and ^{36}Ar signals per heating step.

Multi-collector calibration

Our approach to multi-collector calibration is similar to that of Coble et al. (2011) in that we have developed an in-house standard gas to assess mass discrimination and differences in efficiencies of the IC detectors. However, because the collector configuration of the WiscAr Noblesse (4IC + 1 Faraday) is different than that at Stanford (3 IC + 1 Faraday; Coble et al., 2011), we do not need four reference gases. We can simply rely on one standard gas, which contains ^{39}Ar mixed with atmosphere. Our determination of the isotopic composition of the standard gas was done in single collector mode with measurements done on both the IC0 and IC1 detectors. Source mass bias was constrained via measurements of atmospheric Ar in a blank-air-standard routine. The Lee et al. (2006) value for atmospheric Ar was used for standard gas calibration.

Analyses of unknowns, blanks, and standard minerals are carried out in identical fashion with a routine involving one peak hop. This single routine works for experiments on samples of all ages. During initial measurement of the gas ^{40}Ar (IC0), ^{39}Ar (IC1), ^{37}Ar (IC2), and ^{36}Ar (IC3) are measured simultaneously, followed by a peak jump of one atomic mass unit where ^{39}Ar (IC0), ^{38}Ar (IC1), and ^{36}Ar (IC2) are measured. This two-step cycle, which takes 35 seconds, is repeated 15 times. The Faraday detector is not used. Beam switching is achieved by varying the field of the mass spectrometer magnet and with no adjustment to the quadrupole focusing lenses.

The peak hop is necessary to obtain $^{40}Ar/^{39}Ar$, $^{36}Ar/^{39}Ar$, and $^{37}Ar/^{39}Ar$ ratios, which are needed to calculate the age of a sample. Accurate and reproducible age determinations using a multi-collector mass spectrometer require that mass fractionation effects and the relative efficiencies of the different detectors be well known. This is achieved by repeating a standard bracketing routine. Analysis of bracketing standard gas aliquots allows the calculation of correction factors, which incorporate mass discrimination of the source and detector, and detector efficiency. The $^{39}Ar/^{36}Ar$ is corrected for instrument mass fractionation and detector efficiencies using the following equation:

true $^{39}Ar/^{36}Ar$ (unknown) = measured $^{39}Ar/^{36}Ar$ (unknown) / [measured $^{39}Ar/^{36}Ar$ (standard)/true $^{39}Ar/^{36}Ar$ (standard)].

The measured $^{39}Ar/^{36}Ar$ value for the standard represents the average of the two standard analyses that bracket the sample unknown. The decay of ^{39}Ar since creation of the standard gas and removal of sample from the reactor are taken into account in all of the calculations.

The measured $^{37}Ar/^{39}Ar$ ratio in sample unknowns, where ^{37}Ar is measured in IC2 and ^{39}Ar is measured in IC1, is corrected differently because there is no ^{37}Ar in the standard gas. In this case, ^{36}Ar is measured in IC2 and ^{38}Ar in IC1 in step 2 of the analytical routine so that:

true $^{37}Ar/^{39}Ar$ (unknown) = measured $^{37}Ar/^{39}Ar$ (unknown) / [measured $^{36}Ar/^{38}Ar$ (standard)/true $^{36}Ar/^{38}Ar$ (standard)].

The measured $^{36}Ar/^{38}Ar$ value for the standard represents the average of the two standard analyses that bracket the sample unknown. The correction of $^{37}Ar_{IC2}/^{39}Ar_{IC1}$ using $^{36}Ar_{IC2}/^{38}Ar_{IC1}$ works even when $^{39}Ar_{IC1}$ signals are appreciably larger than the $^{38}Ar_{IC1}$ signals. We recognize that this correction assumes that the mass fractionation between ^{37}Ar and ^{39}Ar is the same as that between ^{36}Ar and ^{38}Ar. It should also be noted that a breakdown of the sources of analytical uncertainty assigned to each date in this study indicate that the uncertainty associated with $^{37}Ar_{IC2}/^{39}Ar_{IC1}$ only contributes on average about 0.6% to the analytical uncertainty versus ~9.3% for $^{40}Ar_{IC0}/^{39}Ar_{IC0}$ uncertainty and ~90.1% for $^{36}Ar_{IC3}/^{39}Ar_{IC1}$ uncertainty.

Because both ^{40}Ar and ^{39}Ar are measured in the same detector (IC0), the mass fractionation correction required to convert measured $(^{40}Ar/^{39}Ar)_{IC0}$ to the true $(^{40}Ar/^{39}Ar)_{IC0}$ is ignored following Brumm et al. (2010), who point out that the effect of this is a small systematic error, but because both monitor and unknown minerals are handled in the same way, the effect cancels out when the ages for the unknowns are calculated. It should be noted that because we measure $^{40}Ar_{IC0}/^{39}Ar_{IC1}$ in both the standard gas and the sample, we can also obtain the true $^{40}Ar/^{39}Ar$ in the sample by the same method that the true $^{39}Ar/^{36}Ar$ in the sample is determined. For this study, we calculated the ages in each incremental heating step two ways: using $(^{40}Ar/^{39}Ar)_{IC0}$ and the corrected $^{40}Ar_{IC0}/^{39}Ar_{IC1}$. The resulting plateau ages are virtually identical with the plateau ages determined using the corrected $^{40}Ar_{IC0}/^{39}Ar_{IC1}$ averaging ~1 ka younger.

All of the correction factors can vary by up to 2-3 per mil over a 24 hour period. However, the variation is typically gradual, and thus is accurately captured by the standard analyses which are done every 45 minutes. Apart from the dead time correction, which is applied within the Noblesse software, all data reduction (including signal vs. time fits) and corrections (e.g., IC dark noise, ^{37}Ar and ^{39}Ar decay, etc) are carried out offline using an in-house data reduction program, which represents a modified version of the ArArCalc freeware program.

Data evaluation

Because of the low ^{40}Ar radiogenic yields and thus imprecise ages obtained for these young SOH1 lavas, replicate experiments were performed on all of the samples to improve precision and evaluate accuracy. The age uncertainties reported in Table 1 reflect analytical uncertainties only at the 2σ level (plateau ages include J uncertainty); the decay constants used are those of Min et al. (2000). Our criteria for an acceptable plateau are similar to those outlined by Sharp and Renne (2005); a plateau must include: (1) three or more consecutive steps that contain $\geq$50% of the ^{39}Ar released, (2) have a probability of fit of at least 0.05, and (3) have no resolvable slope. We recognize that plateau ages are model dependent and assume an atmospheric Ar model. However, all of the isochrons have intercepts within error of the atmospheric $^{40}Ar/^{36}Ar$ value. We also recognize that the MSWD for the plateau ages are all <1. It is clear from DR Figure 1 that there are indeed heating steps in several of the experiments that are significantly older or younger than the plateau steps. If these steps were to be included in the plateau age calculations, the resulting MSWD would be significantly greater than unity (ie >3) and therefore these steps are not included in the plateau model age calculations. Lastly, one of the 9 incremental heating experiments ends on a step with a significant fraction (6.7%) of the ^{39}Ar released. A subsequent step was performed on this sample and it yielded virtually no ^{39}Ar, thereby indicating that all of the ^{39}Ar has been released from the sample.

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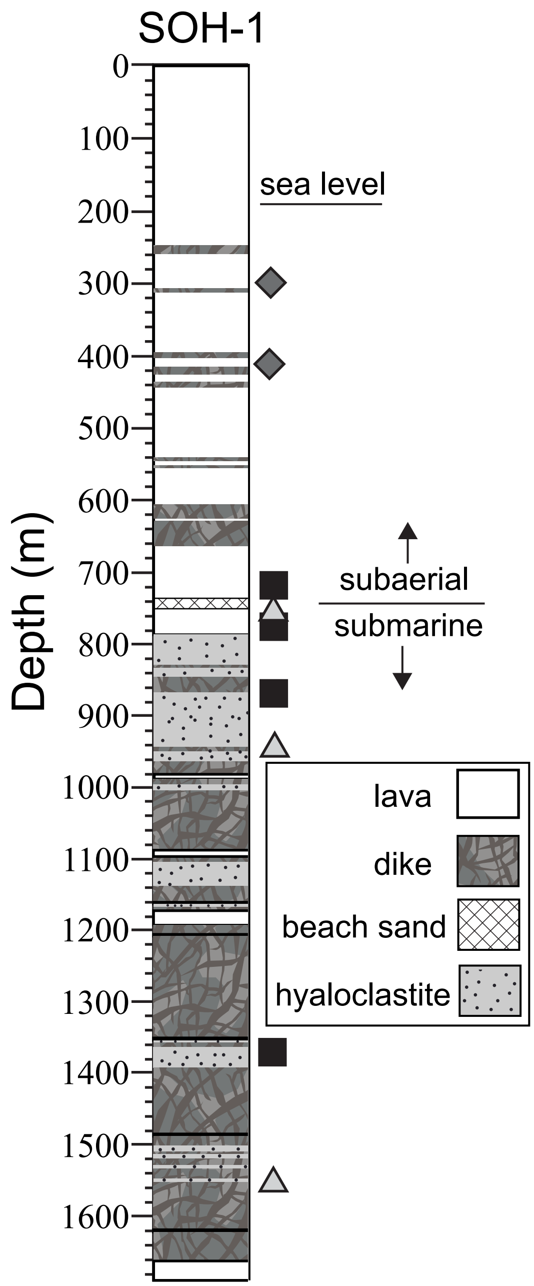

Figure DR1. Graphic log for SOH-1 scientific drill hole core (after Garcia et al., 2007). Three rock types are shown; lava (white), dikes (stripped gray pattern) and hyaloclastite (fragmental volcanic rocks; stippled gray pattern). Symbols on the side of the column show the location of dated samples (diamond, Teanby et al. (2002) reliable $^{40}Ar/^{39}Ar$ ages; triangle, duplicated unspiked K-Ar samples; square, new $^{40}Ar/^{39}Ar$ ages, Table 1). The subaerial and submarine contact (marked by a beach sand unit at ~740 m) and the current sea level depth for the SOH-1 section are shown. Depths are in meters.

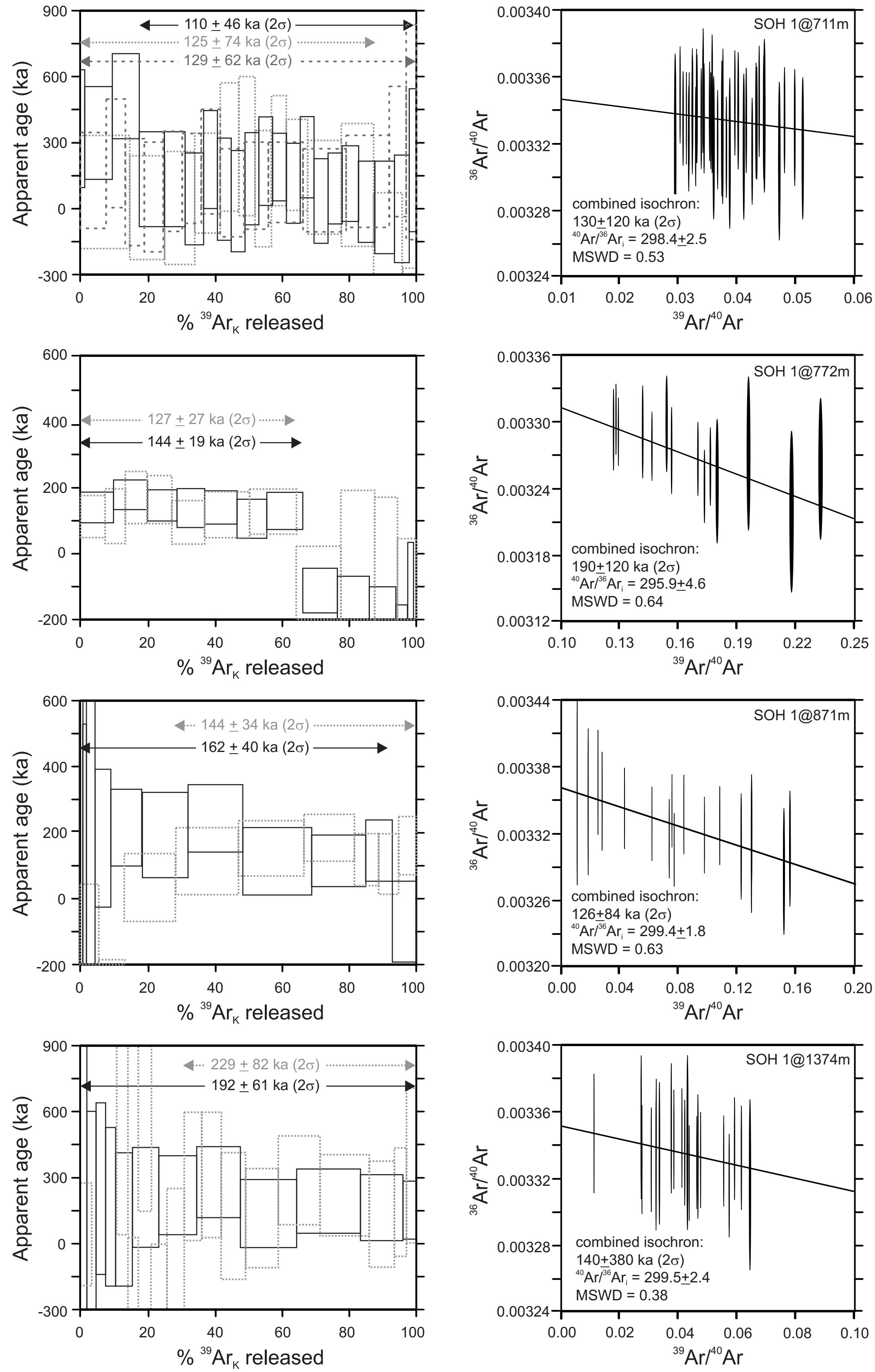

Figure DR2. Age spectra and isochrons

Table DR1. XRF major element analyses of SOH-1 drill core rocks for geochonology

Sample	Corrected Depth (m)	SiO_2	TiO_2	Al_2O_3	Fe_2O_3 *	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total	LOI	K_2O/P_2O_5
711	627	51.22	2.48	13.20	11.89	0.17	7.73	10.47	1.70	0.42	0.25	99.54	-0.11	1.69
772	688	50.85	2.72	13.23	12.71	0.19	6.40	10.51	2.25	0.42	0.26	99.54	0.13	1.61
871	754	50.22	2.32	13.07	12.05	0.18	8.54	10.54	2.16	0.35	0.23	99.66	0.11	1.55
1103	875	51.25	2.74	13.80	11.62	0.17	6.90	10.52	2.12	0.46	0.28	99.86	0.57	1.65
1374	840	48.66	2.59	13.48	12.48	0.18	8.39	11.19	2.16	0.49	0.24	99.86	1.15	2.05
1457	862	51.08	2.47	13.53	12.02	0.19	7.28	10.81	1.80	0.26	0.23	99.67	0.84	1.12

Samples analyzed at the University of Massachusetts using methods described by Rhodes and Vollinger (2004)

* total iron

Table DR2. Complete $^{40}Ar/^{39}Ar$ results

Laser - Incremental heating

Sample: SOH1-2333 J-value: 0.0005252 ± 0.0000008 (2σ)
Material: groundmass

File	Laser Power (%)	$^{40}Ar \pm 2\sigma_{40}$ (cps) (cps)	$^{39}Ar \pm 2\sigma_{39}$ (cps) (cps)	$^{37}Ar \pm 2\sigma_{37}$ (cps) (cps)	$^{36}Ar \pm 2\sigma_{36}$ (cps) (cps)	$^{40}Ar^*/^{39}Ar_K \pm 2\sigma$	$\%^{40}Ar^*$	Age (ka) ± 2σ (ka)	K/Ca	Included in plateau
NAE4620	2.48	199851 ± 69	5920 ± 12	8201 ± 187	663.99 ± 5.12	0.381291 ± 0.274730	1.13	367 ± 264	0.31	
NAE4623	2.58	589329 ± 211	17596 ± 19	27410 ± 337	1960.24 ± 11.86	0.354871 ± 0.208183	1.06	341 ± 200	0.28	
NAE4626	2.68	514394 ± 168	15901 ± 18	27930 ± 251	1702.15 ± 10.46	0.528923 ± 0.203411	1.63	508 ± 195	0.24	
NAE4629	2.76	410812 ± 139	12891 ± 16	26350 ± 245	1376.97 ± 9.26	0.138312 ± 0.221538	0.43	133 ± 213	0.21	✓
NAE4632	2.84	385968 ± 129	12294 ± 15	29651 ± 293	1294.80 ± 8.86	0.141124 ± 0.222363	0.45	136 ± 214	0.18	✓
NAE4635	2.92	327409 ± 112	10628 ± 15	28999 ± 277	1102.38 ± 7.52	0.053735 ± 0.220180	0.17	52 ± 212	0.16	✓
NAE4638	3	265843 ± 85	8768 ± 14	25452 ± 281	890.35 ± 6.48	0.231835 ± 0.230755	0.76	223 ± 222	0.15	✓
NAE4641	3.1	265015 ± 85	8796 ± 14	28164 ± 291	892.21 ± 6.59	0.097986 ± 0.233888	0.32	94 ± 225	0.13	✓
NAE4644	3.25	262701 ± 103	8991 ± 14	33114 ± 342	887.56 ± 6.67	0.036566 ± 0.231544	0.12	35 ± 223	0.12	✓
NAE4647	3.45	256951 ± 85	9147 ± 14	39104 ± 352	866.87 ± 6.09	0.134463 ± 0.208644	0.48	129 ± 201	0.10	✓
NAE4650	3.65	239537 ± 82	8811 ± 13	43450 ± 427	807.24 ± 5.81	0.223197 ± 0.205833	0.82	215 ± 198	0.09	✓
NAE4653	3.9	239388 ± 85	9169 ± 14	51655 ± 431	807.83 ± 5.93	0.250255 ± 0.201705	0.95	241 ± 194	0.08	✓
NAE4656	4.15	228213 ± 70	9076 ± 14	57067 ± 470	778.28 ± 5.87	0.039995 ± 0.200763	0.16	38 ± 193	0.07	✓
NAE4659	4.45	209625 ± 74	8750 ± 14	62922 ± 527	715.48 ± 5.40	0.113237 ± 0.192963	0.47	109 ± 185	0.06	✓
NAE4662	4.75	181011 ± 70	7744 ± 13	62591 ± 510	616.64 ± 4.74	0.241096 ± 0.191748	1.03	232 ± 184	0.05	✓
NAE4665	5.1	169446 ± 65	7614 ± 12	67672 ± 556	584.69 ± 4.80	0.030374 ± 0.194998	0.14	29 ± 187	0.05	✓
NAE4668	5.85	191438 ± 70	9263 ± 13	91294 ± 700	662.38 ± 4.96	0.097279 ± 0.165766	0.47	94 ± 159	0.04	✓
NAE4671	6.85	214924 ± 84	10779 ± 17	111897 ± 857	745.20 ± 6.16	0.120058 ± 0.176908	0.60	115 ± 170	0.04	✓
NAE4674	8	244955 ± 96	10803 ± 15	128037 ± 964	853.31 ± 6.67	0.029386 ± 0.190535	0.13	28 ± 183	0.04	✓
NAE4677	9.5	306044 ± 93	11625 ± 16	189505 ± 1394	1074.47 ± 7.48	0.020750 ± 0.199695	0.08	20 ± 192	0.03	✓
NAE4680	11.5	336167 ± 122	10322 ± 16	215297 ± 1583	1182.85 ± 7.98	0.004328 ± 0.242595	0.01	4 ± 233	0.02	✓
NAE4686	20	164869 ± 73	4987 ± 12	187745 ± 1479	598.38 ± 5.26	0.219707 ± 0.335323	0.65	211 ± 322	0.01	✓
						weighted mean age (19 of 22):		98 ± 46		

Sample: SOH1-2333 J-value: 0.0005252 ± 0.0000008 (2σ)
Material: groundmass

File	Laser Power (%)	$^{40}Ar \pm 2\sigma_{40}$ (cps) (cps)	$^{39}Ar \pm 2\sigma_{39}$ (cps) (cps)	$^{37}Ar \pm 2\sigma_{37}$ (cps) (cps)	$^{36}Ar \pm 2\sigma_{36}$ (cps) (cps)	$^{40}Ar^*/^{39}Ar_K \pm 2\sigma$	$\%^{40}Ar^*$	Age (ka) ± 2σ (ka)	K/Ca	Included in wtd. mean
NAE7685	2.45	330520 ± 143	10950 ± 18	31308 ± 594	1112.99 ± 9.24	0.063617 ± 0.261888	0.21	61 ± 252	0.15	✓
NAE7688	2.55	222188 ± 87	7617 ± 14	27247 ± 490	752.30 ± 6.44	-0.035219 ± 0.264077	-0.12	-34 ± 254	0.12	✓
NAE7691	2.68	175671 ± 70	6296 ± 12	29186 ± 589	595.71 ± 5.46	0.019384 ± 0.270095	0.07	19 ± 260	0.09	✓
NAE7694	2.85	142076 ± 56	5333 ± 11	30910 ± 519	481.13 ± 4.70	0.164278 ± 0.275319	0.61	158 ± 265	0.07	✓
NAE7697	3.05	110224 ± 57	4288 ± 10	28650 ± 596	372.85 ± 4.05	0.274394 ± 0.295385	1.06	264 ± 284	0.06	✓
NAE7700	3.35	98949 ± 54	4091 ± 10	32795 ± 533	336.98 ± 3.51	0.229474 ± 0.269039	0.94	221 ± 259	0.05	✓
NAE7703	3.75	93641 ± 47	4207 ± 10	40629 ± 594	323.19 ± 3.50	0.086464 ± 0.260886	0.39	83 ± 251	0.04	✓
NAE7706	4.2	89026 ± 47	4231 ± 10	45861 ± 656	306.74 ± 3.44	0.255045 ± 0.253413	1.20	245 ± 244	0.04	✓
NAE7709	5.2	105864 ± 51	5463 ± 11	68339 ± 826	369.23 ± 3.65	0.190319 ± 0.207976	0.97	183 ± 200	0.03	✓
NAE7712	7.5	175394 ± 71	7887 ± 12	116114 ± 1300	615.80 ± 5.31	0.092705 ± 0.207749	0.41	89 ± 200	0.03	✓
NAE7715	10.5	220305 ± 82	7248 ± 14	174948 ± 1880	781.98 ± 6.78	0.094749 ± 0.293756	0.31	91 ± 282	0.02	✓
NAE7718	15	186274 ± 74	4850 ± 12	170274 ± 1851	673.54 ± 6.22	-0.285310 ± 0.407629	-0.72	-274 ± 392	0.01	
NAE7721	20	81680 ± 48	2535 ± 8	107677 ± 1260	308.39 ± 3.62	-0.761630 ± 0.451790	-2.29	-732 ± 435	0.01	
						weighted mean age (11 of 13):		125 ± 74		

Sample: SOH1-2333 J-value: 0.0005252 ± 0.0000008 (2σ)
Material: groundmass

File	Laser Power (%)	$^{40}Ar \pm 2\sigma_{40}$ (cps) (cps)	$^{39}Ar \pm 2\sigma_{39}$ (cps) (cps)	$^{37}Ar \pm 2\sigma_{37}$ (cps) (cps)	$^{36}Ar \pm 2\sigma_{36}$ (cps) (cps)	$^{40}Ar^*/^{39}Ar_K \pm 2\sigma$	$\%^{40}Ar^*$	Age (ka) ± 2σ (ka)	K/Ca	Included in wtd. mean
NAF0436	2.4	264697 ± 127	8156 ± 15	13328 ± 2100	886.26 ± 6.07	0.140719 ± 0.240084	0.43	135 ± 231	0.26	✓
NAF0439	2.45	201864 ± 88	6414 ± 12	11588 ± 2689	673.78 ± 5.15	0.251854 ± 0.256888	0.80	242 ± 247	0.24	✓
NAF0442	2.55	186593 ± 80	6045 ± 12	13196 ± 2258	626.84 ± 4.58	0.080329 ± 0.245463	0.26	77 ± 236	0.20	✓
NAF0445	2.7	182837 ± 78	6072 ± 11	16290 ± 2963	615.28 ± 4.63	0.069840 ± 0.244234	0.23	67 ± 235	0.16	✓
NAF0448	2.9	159174 ± 73	5481 ± 10	19160 ± 2746	535.90 ± 4.21	0.126174 ± 0.245012	0.43	121 ± 236	0.12	✓
NAF0451	3.2	169126 ± 66	6058 ± 12	24143 ± 2180	570.25 ± 4.33	0.129026 ± 0.228719	0.46	124 ± 220	0.11	✓
NAF0454	3.7	160769 ± 77	6051 ± 13	28105 ± 1903	541.34 ± 4.86	0.226788 ± 0.254221	0.85	218 ± 244	0.09	✓
NAF0457	4.4	189762 ± 86	7654 ± 15	46207 ± 2136	645.94 ± 5.41	0.073801 ± 0.223174	0.30	71 ± 215	0.07	✓
NAF0460	5.4	182395 ± 89	7922 ± 14	58123 ± 1937	623.42 ± 5.13	0.109262 ± 0.203546	0.47	105 ± 196	0.06	✓
NAF0463	7	206230 ± 78	8995 ± 14	83473 ± 2596	709.26 ± 5.63	0.120052 ± 0.194919	0.52	115 ± 187	0.05	✓
NAF0466	9.5	318979 ± 143	11358 ± 17	148386 ± 3548	1104.46 ± 7.70	0.085744 ± 0.212620	0.30	82 ± 204	0.03	✓
NAF0469	13	339924 ± 152	11719 ± 21	298074 ± 5049	1212.55 ± 8.29	0.128694 ± 0.227140	0.44	124 ± 218	0.02	✓
NAF0472	16.5	97945 ± 50	3593 ± 10	98894 ± 2509	351.10 ± 3.34	0.267263 ± 0.301854	0.96	257 ± 290	0.02	✓
NAF0475	20	66104 ± 44	1982 ± 7	52850 ± 2257	233.04 ± 3.16	0.364293 ± 0.512759	1.07	350 ± 493	0.02	✓
						weighted mean age (14 of 14):		129 ± 62		

Sample: SOH1-2533 J-value: 0.0005280 ± 0.0000008 (2σ)
Material: groundmass

File	Laser Power (%)	$^{40}Ar \pm 2\sigma_{40}$ (cps) (cps)	$^{39}Ar \pm 2\sigma_{39}$ (cps) (cps)	$^{37}Ar \pm 2\sigma_{37}$ (cps) (cps)	$^{36}Ar \pm 2\sigma_{36}$ (cps) (cps)	$^{40}Ar^*/^{39}Ar_K \pm 2\sigma$	$\%^{40}Ar^*$	Age (ka) ± 2σ (ka)	K/Ca	Included in wtd. mean
NAE4689	2.4	164751 ± 64	28070 ± 26	19548 ± 249	543.29 ± 4.46	0.145338 ± 0.048104	2.48	140 ± 46	0.62	✓
NAE4692	2.5	165888 ± 60	28826 ± 25	26499 ± 310	544.74 ± 4.44	0.185125 ± 0.046524	3.21	179 ± 45	0.47	✓
NAE4695	2.65	140759 ± 54	24889 ± 23	27466 ± 268	466.04 ± 4.03	0.151878 ± 0.048944	2.68	147 ± 47	0.39	✓
NAE4698	2.9	148935 ± 59	23368 ± 22	29353 ± 325	495.36 ± 4.73	0.143539 ± 0.061136	2.25	139 ± 59	0.34	✓
NAE4701	3.2	186228 ± 67	27343 ± 25	44615 ± 379	622.22 ± 4.71	0.145493 ± 0.052196	2.13	141 ± 50	0.26	✓
NAE4704	3.6	195874 ± 70	25144 ± 22	50820 ± 421	660.24 ± 5.08	0.109900 ± 0.061177	1.41	106 ± 59	0.21	✓
NAE4707	4.3	234357 ± 81	30384 ± 26	82162 ± 628	793.00 ± 5.85	0.134574 ± 0.058276	1.74	130 ± 56	0.16	✓
NAE4710	5.1	243621 ± 93	29643 ± 33	102992 ± 797	854.31 ± 6.61	-0.111895 ± 0.068026	-1.36	-108 ± 66	0.12	
NAE4713	6.1	279211 ± 89	27955 ± 24	128692 ± 954	982.80 ± 6.55	-0.145261 ± 0.071247	-1.45	-140 ± 69	0.09	
NAE4716	7.5	392927 ± 127	24564 ± 25	158481 ± 1146	1385.25 ± 8.52	-0.332377 ± 0.106383	-2.07	-321 ± 103	0.07	
NAE4719	9.3	285472 ± 93	5760 ± 11	66830 ± 540	984.17 ± 6.91	-0.538684 ± 0.384374	-1.08	-521 ± 372	0.04	
NAE4722	11.5	488721 ± 160	4159 ± 10	94298 ± 755	1673.75 ± 11.15	-0.863858 ± 0.893524	-0.72	-835 ± 864	0.02	
NAE4725	15	382491 ± 129	2573 ± 8	73817 ± 666	1279.54 ± 9.72	2.502098 ± 1.303820	1.65	2417 ± 1259	0.01	
NAE4728	20	203275 ± 65	1667 ± 6	53960 ± 536	681.14 ± 6.05	2.566590 ± 1.266091	2.06	2479 ± 1222	0.01	
						weighted mean age (7 of 14):		144 ± 19		

Sample: SOH1-2533 J-value: 0.0005280 ± 0.0000008 (2σ)

Material: groundmass

File	Laser Power (%)	$^{40}Ar \pm 2\sigma_{40}$ (cps) (cps)	$^{39}Ar \pm 2\sigma_{39}$ (cps) (cps)	$^{37}Ar \pm 2\sigma_{37}$ (cps) (cps)	$^{36}Ar \pm 2\sigma_{36}$ (cps) (cps)	$^{40}Ar^*/^{39}Ar_K \pm 2\sigma$	$\%^{40}Ar^*$	Age (ka) ± 2σ (ka)	K/Ca	Included in wtd. mean
NAF0478	2.4	43744 ± 35	10214 ± 15	8999 ± 2123	144.89 ± 2.16	0.116954 ± 0.066030	2.73	113 ± 64	0.49	✓
NAF0481	2.5	42695 ± 35	8389 ± 15	10207 ± 1983	142.38 ± 2.32	0.118139 ± 0.085758	2.32	114 ± 83	0.35	✓
NAF0484	2.7	40881 ± 37	8938 ± 15	11890 ± 2252	134.74 ± 2.32	0.177740 ± 0.080659	3.88	172 ± 78	0.32	✓
NAF0487	3	57182 ± 35	10317 ± 15	19042 ± 2708	190.69 ± 2.46	0.170020 ± 0.075232	3.06	164 ± 73	0.23	✓
NAF0490	3.7	87909 ± 47	13577 ± 18	28925 ± 2640	297.60 ± 2.97	0.098686 ± 0.068298	1.52	95 ± 66	0.20	✓
NAF0493	4.7	131039 ± 63	18633 ± 22	58176 ± 3116	446.66 ± 4.36	0.122516 ± 0.072160	1.74	118 ± 70	0.14	✓
NAF0496	5.9	152603 ± 68	19426 ± 19	82709 ± 2511	524.43 ± 4.49	0.132352 ± 0.070751	1.68	128 ± 68	0.10	✓
NAF0499	7.2	210219 ± 85	16716 ± 22	90541 ± 3261	733.52 ± 6.55	-0.097557 ± 0.120515	-0.77	-94 ± 116	0.08	
NAF0502	8.5	380084 ± 173	12884 ± 19	97804 ± 2785	1301.07 ± 10.17	-0.049364 ± 0.244284	-0.17	-48 ± 236	0.06	
NAF0505	9.5	536957 ± 254	10854 ± 17	116410 ± 2994	1837.07 ± 13.71	-0.214668 ± 0.395177	-0.43	-208 ± 382	0.04	
NAF0508	10.5	531286 ± 254	9367 ± 17	137149 ± 4129	1829.45 ± 14.48	-0.438843 ± 0.486871	-0.77	-424 ± 471	0.03	
						weighted mean age (7 of 11):		127 ± 27		

Sample: SOH1-2856 J-value: 0.0005277 ± 0.0000009 (2σ)
Material: groundmass

File	Laser Power (%)	$^{40}Ar \pm 2\sigma_{40}$ (cps) (cps)	$^{39}Ar \pm 2\sigma_{39}$ (cps) (cps)	$^{37}Ar \pm 2\sigma_{37}$ (cps) (cps)	$^{36}Ar \pm 2\sigma_{36}$ (cps) (cps)	$^{40}Ar^*/^{39}Ar_K \pm 2\sigma$	$\%^{40}Ar^*$	Age (ka) ± 2σ (ka)	K/Ca	Included in wtd. mean
NAE5330	2.5	36148 ± 28	397 ± 4	4195 ± 282	122.12 ± 2.77	0.048580 ± 2.500176	0.05	47 ± 2415	0.04	✓
NAE5333	2.8	51371 ± 31	951 ± 6	10027 ± 258	173.62 ± 2.74	0.348758 ± 0.986259	0.64	337 ± 953	0.04	✓
NAE5336	3.2	89563 ± 41	2261 ± 7	21583 ± 319	305.35 ± 3.44	0.046017 ± 0.490633	0.12	44 ± 474	0.04	✓
NAE5339	3.7	154098 ± 76	4330 ± 13	43542 ± 461	524.44 ± 5.60	0.224284 ± 0.417643	0.63	217 ± 403	0.04	✓
NAE5342	4.5	186730 ± 75	8104 ± 17	80002 ± 720	641.51 ± 5.57	0.189646 ± 0.216638	0.82	183 ± 209	0.04	✓
NAE5345	5.5	214290 ± 89	15853 ± 20	158565 ± 1279	747.98 ± 6.24	0.222861 ± 0.120528	1.64	215 ± 116	0.04	✓
NAE5348	6.8	383447 ± 130	23848 ± 27	241460 ± 1902	1332.43 ± 10.49	0.199627 ± 0.134100	1.23	193 ± 130	0.04	✓
NAE5351	8.1	363985 ± 129	28157 ± 28	272982 ± 2138	1267.83 ± 9.81	0.251893 ± 0.105905	1.94	243 ± 102	0.04	✓
NAE5354	9.6	466881 ± 176	35419 ± 33	343023 ± 2665	1640.81 ± 12.53	0.117137 ± 0.107436	0.88	113 ± 104	0.04	✓
NAE5357	11.1	256010 ± 82	27793 ± 27	267913 ± 2100	917.44 ± 7.38	0.118866 ± 0.080652	1.28	115 ± 78	0.04	✓
NAE5360	12.8	110772 ± 55	13651 ± 20	132965 ± 1102	399.39 ± 4.32	0.150674 ± 0.096378	1.84	146 ± 93	0.04	✓
NAE5364	14.8	101235 ± 44	12635 ± 17	120936 ± 970	375.93 ± 3.51	-0.114860 ± 0.084650	-1.42	-111 ± 82	0.04	
						weighted mean age (11 of 12):		162 ± 40		

Sample: SOH1-2856 J-value: 0.0005277 ± 0.0000009 (2σ)
Material: groundmass

File	Laser Power (%)	$^{40}Ar \pm 2\sigma_{40}$ (cps) (cps)	$^{39}Ar \pm 2\sigma_{39}$ (cps) (cps)	$^{37}Ar \pm 2\sigma_{37}$ (cps) (cps)	$^{36}Ar \pm 2\sigma_{36}$ (cps) (cps)	$^{40}Ar^*/^{39}Ar_K \pm 2\sigma$	$\%^{40}Ar^*$	Age (ka) ± 2σ (ka)	K/Ca	Included in wtd. mean
NAE7658	4	255363 ± 102	6939 ± 13	77416 ± 946	882.90 ± 7.90	-0.306891 ± 0.354421	-0.83	-296 ± 342	0.04	
NAE7661	5.5	297183 ± 111	15829 ± 21	173720 ± 1845	1062.08 ± 9.14	-0.393135 ± 0.176457	-2.08	-380 ± 170	0.04	
NAE7664	7	308846 ± 144	29009 ± 31	307604 ± 3148	1113.76 ± 9.74	0.022319 ± 0.102073	0.21	22 ± 99	0.04	
NAE7667	8.5	404033 ± 169	33953 ± 32	364731 ± 3703	1436.59 ± 11.79	0.117590 ± 0.105423	0.98	114 ± 102	0.04	✓
NAE7670	10	361432 ± 144	35495 ± 32	390751 ± 3969	1295.45 ± 10.14	0.157819 ± 0.086951	1.54	152 ± 84	0.04	✓
NAE7673	11.5	209749 ± 85	27350 ± 28	304692 ± 3109	765.86 ± 6.60	0.191024 ± 0.073661	2.47	185 ± 71	0.04	✓
NAE7676	13	83839 ± 51	13143 ± 18	146663 ± 1551	314.32 ± 3.53	0.122093 ± 0.081821	1.90	118 ± 79	0.04	✓
NAE7679	15	82913 ± 42	10819 ± 16	121468 ± 1303	305.98 ± 3.37	0.108588 ± 0.095103	1.41	105 ± 92	0.04	✓
NAE7682	18	62868 ± 41	9598 ± 14	110487 ± 1191	234.53 ± 2.88	0.166340 ± 0.091245	2.52	161 ± 88	0.04	✓
						weighted mean age (6 of 9):		144 ± 34		

Sample: SOH1-4508 J-value: 0.0005282 ± 0.0000010 (2σ)
Material: groundmass

File	Laser Power (%)	$^{40}Ar \pm 2\sigma_{40}$ (cps) (cps)	$^{39}Ar \pm 2\sigma_{39}$ (cps) (cps)	$^{37}Ar \pm 2\sigma_{37}$ (cps) (cps)	$^{36}Ar \pm 2\sigma_{36}$ (cps) (cps)	$^{40}Ar^*/^{39}Ar_K \pm 2\sigma$	$\%^{40}Ar^*$	Age (ka) ± 2σ (ka)	K/Ca	Included in wtd. mean
NAE7724	2.45	282032 ± 123	2984 ± 11	17763 ± 543	941.13 ± 9.96	0.824629 ± 1.112624	0.87	797 ± 1075	0.07	
NAE7727	2.55	374511 ± 143	4527 ± 14	28860 ± 585	1282.26 ± 12.76	-1.339728 ± 0.916194	-1.61	-1296 ± 886	0.07	
NAE7730	2.7	303779 ± 163	4762 ± 17	30702 ± 701	1045.23 ± 10.87	-1.235678 ± 0.755194	-1.93	-1195 ± 731	0.07	
NAE7734	2.85	244065 ± 113	4525 ± 16	30354 ± 677	814.87 ± 8.89	0.704980 ± 0.647886	1.30	681 ± 626	0.06	
NAE7737	3.05	244082 ± 126	5010 ± 16	35971 ± 617	836.00 ± 8.65	-0.535876 ± 0.561826	-1.09	-518 ± 543	0.06	
NAE7740	3.3	281718 ± 134	5632 ± 17	39483 ± 668	940.33 ± 9.89	0.730251 ± 0.567058	1.45	706 ± 548	0.06	
NAE7743	3.65	291920 ± 135	6625 ± 19	52361 ± 761	1001.90 ± 9.64	-0.465769 ± 0.472976	-1.05	-450 ± 457	0.05	
NAE7746	4	334945 ± 162	7757 ± 19	64927 ± 904	1144.66 ± 11.45	-0.216707 ± 0.467407	-0.50	-210 ± 452	0.05	
NAE7749	4.4	291704 ± 141	8078 ± 21	68704 ± 881	984.94 ± 9.70	0.382386 ± 0.382155	1.05	370 ± 369	0.05	✓
NAE7752	5	308973 ± 145	9548 ± 23	84490 ± 1058	1046.29 ± 9.86	0.344738 ± 0.327867	1.06	333 ± 317	0.05	✓
NAE7755	5.7	331566 ± 157	10808 ± 23	96300 ± 1231	1131.54 ± 10.49	0.125506 ± 0.305558	0.41	121 ± 295	0.05	✓
NAE7758	6.7	333186 ± 155	13799 ± 22	124513 ± 1445	1142.60 ± 10.09	0.138261 ± 0.225931	0.57	134 ± 218	0.05	✓
NAE7761	8	403326 ± 155	17725 ± 23	170378 ± 1855	1377.70 ± 11.74	0.310698 ± 0.202570	1.36	300 ± 196	0.04	✓
NAE7767	12	446832 ± 157	20875 ± 25	330768 ± 3452	1567.45 ± 12.64	0.242734 ± 0.185198	1.12	235 ± 179	0.03	✓
NAE7770	15	274369 ± 116	10684 ± 19	208229 ± 2250	968.61 ± 8.31	0.156583 ± 0.241935	0.60	151 ± 234	0.02	✓
NAE7815	18	108956 ± 57	5150 ± 10	103675 ± 1258	388.81 ± 4.12	0.211499 ± 0.247309	0.99	204 ± 239	0.02	✓
NAE7818	21	131831 ± 61	4330 ± 11	95490 ± 1154	461.54 ± 5.15	0.371783 ± 0.372466	1.20	359 ± 360	0.02	✓
						weighted mean age (7 of 17):		229 ± 82		

Sample: SOH1-4508 J-value: 0.0005282 ± 0.0000010 (2σ)
Material: groundmass

File	Laser Power (%)	$^{40}Ar \pm 2\sigma_{40}$ (cps) (cps)	$^{39}Ar \pm 2\sigma_{39}$ (cps) (cps)	$^{37}Ar \pm 2\sigma_{37}$ (cps) (cps)	$^{36}Ar \pm 2\sigma_{36}$ (cps) (cps)	$^{40}Ar^*/^{39}Ar_K \pm 2\sigma$	$\%^{40}Ar^*$	Age (ka) ± 2σ (ka)	K/Ca	Included in wtd. mean
NAF0511	2.4	221202 ± 105	2493 ± 10	16183 ± 3334	741.71 ± 8.02	0.417742 ± 1.093584	0.47	404 ± 1057	0.07	✓
NAF0514	2.45	89616 ± 49	2456 ± 8	17101 ± 3133	303.70 ± 3.82	0.120830 ± 0.506933	0.33	117 ± 490	0.06	✓
NAF0517	2.55	69029 ± 39	2323 ± 8	16217 ± 2693	233.39 ± 2.88	0.272438 ± 0.405757	0.91	263 ± 392	0.06	✓
NAF0520	2.8	51402 ± 35	2224 ± 8	15618 ± 2537	175.14 ± 2.62	0.156195 ± 0.380864	0.67	151 ± 368	0.06	✓
NAF0523	3.3	111277 ± 51	4198 ± 10	32387 ± 2318	379.97 ± 4.36	0.094175 ± 0.325658	0.35	91 ± 315	0.06	✓
NAF0526	4	163242 ± 72	6913 ± 14	53734 ± 3410	556.08 ± 5.18	0.213320 ± 0.236730	0.90	206 ± 229	0.06	✓
NAF0529	5	207801 ± 78	9933 ± 13	83912 ± 3093	710.83 ± 6.02	0.223827 ± 0.187183	1.06	216 ± 181	0.05	✓
NAF0532	6.3	198825 ± 78	11451 ± 18	96833 ± 2932	680.69 ± 6.22	0.285750 ± 0.168328	1.64	276 ± 163	0.05	✓
NAF0535	8	248217 ± 103	14760 ± 21	137669 ± 3463	861.13 ± 7.73	0.136670 ± 0.161281	0.81	132 ± 156	0.05	✓
NAF0538	10.5	299948 ± 113	16750 ± 21	201083 ± 3849	1047.01 ± 8.27	0.195766 ± 0.152250	1.08	189 ± 147	0.04	✓
NAF0541	13.5	179197 ± 68	11143 ± 16	199764 ± 4460	647.05 ± 5.57	0.164772 ± 0.156250	1.01	159 ± 151	0.02	✓
NAF0544	17	55375 ± 38	3603 ± 10	58758 ± 3245	198.04 ± 2.73	0.251643 ± 0.244828	1.62	243 ± 237	0.03	✓
						weighted mean age (12 of 12):		192 ± 61		

The values in this table have been corrected for instrument background, source mass bias, detector efficiency, and decay of ^{37}Ar and ^{39}Ar

Instrument:	Noblesse 5-collector mass spectrometer	
Standard:	Alder Creek rhyolite sanidine	
Standard age (Ma):	1.1864 ± 0.0012	Rivera et al. (2013); Jicha et al. (2016)

Atmospheric argon ratios		
$^{40}Ar/^{36}Ar$	298.56 ± 0.31	Lee et al. (2006)
$^{38}Ar/^{36}Ar$	0.1885 ± 0.0003	Lee et al. (2006)

Interfering isotope production ratios		
$(^{40}Ar/^{39}Ar)_K$	0.00054 ± 0.00014	Jicha & Brown (2014)
$(^{38}Ar/^{39}Ar)_K$	0.01210 ± 0.00002	Jicha & Brown (2014)
$(^{39}Ar/^{37}Ar)_{Ca}$	0.000695 ± 0.00001	Renne et al. (2013)
$(^{38}Ar/^{37}Ar)_{Ca}$	0.0000196 ########	Renne et al. (2013)
$(^{36}Ar/^{37}Ar)_{Ca}$	0.000265 ± 0.00002	Renne et al. (2013)

Decay constants		
λ_{40Ar}	$(0.580 \pm 0.014) \times 10^{-10}\ a^{-1}$	Min et al. (2000)
λ_{B^-}	$(4.884 \pm 0.099) \times 10^{-10}\ a^{-1}$	Min et al. (2000)
^{39}Ar	$(2.58 \pm 0.03) \times 10^{-3}\ a^{-1}$	Stoenner et al. (1965)
^{37}Ar	$(8.23 \pm 0.042) \times 10^{-4}\ h^{-1}$	Stoenner et al. (1965)
^{36}Cl	$(2.303 \pm 0.046) \times 10^{-6}\ a^{-1}$	