^{40}Ar/^{39}Ar Geochronology Results from the Provo, Nephi, Salt Lake City, and Ogden 30' x 60' Quadrangles, Utah

by

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INTRODUCTION

This Open-File Report makes available raw analytical data from laboratory procedures completed to determine the age of rock samples collected during geologic investigations funded or partially supported by the Utah Geological Survey (UGS). Table 1 provides sample numbers, geologic units, locations, minerals dated, and ages for the samples. The references listed in table 1 generally provide additional information such as sample location, geologic setting, and significance or interpretation of the samples in the context of the area where they were collected. There are two reports (see appendix), the first (September 2001) was prepared by the New Mexico Geochronology Research Laboratory (NMGRL) and the University of Alaska, Fairbanks (UAF), under contract to the UGS and K.N. Constenius, and the second (January 2001) was prepared by NMGRL for UGS. Readers should note that the UAF data were recalculated to standardize results in Constenius and others (2003); the original UAF data are presented here and reported in Constenius and others (in prep.). Figures (plots) for samples 1 through 8, inadvertently omitted from the Constenius and others (2003) paper, are presented here. These data are highly technical in nature and proper interpretation requires considerable training in the applicable geochronologic techniques.

DISCLAIMER

ACKNOWLEDGMENTS

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Table 1. *Summary of $^{40}Ar/^{39}Ar$ samples and ages from the Provo, Nephi, Salt Lake City, and Ogden 30' x 60' quadrangle area.*

Sample Number	Geologic Unit	30'x60' quadrangle	7.5' quadrangle	UTM easting NAD27-12	UTM northing NAD27-12	Latitude (°N) WGS84	Longitude (°W) WGS84	Mineral Dated	Age (Ma)	Laboratory	Reference
KNC6901-1	Keetley volcanics	Salt Lake City	Kamas	470650	4509896	40.74133	111.34837	sanidine	38.20 ± 0.11	NMGRL	Constenius and others, 2003, 2011, in prep.
KNC52994-6	Felsic dike	Salt Lake City	Dromedary Peak	445517	4485904	40.52393	111.64395	hornblende	<36.1 ± 1.4	NMGRL	Constenius and others, 2003, 2011, in prep.
KNC61093-3T	Tibble Fm.	Provo	Timpanogos Cave	445956	4481372	40.48313	111.63838	biotite	>37.66 ± 0.90	NMGRL	Constenius and others, 2003, 2011, in prep.
KNC61093-2T	Tibble Fm.	Provo	Timpanogos Cave	445723	4481357	40.48298	111.64113	biotite	35.67 ± 0.17	UAF	Constenius and others, 2003, 2011, in prep.
KNC72393-1T	Tibble Fm.	Provo	Timpanogos Cave	445379	4481086	40.48052	111.64517	hornblende	28.81 ± 0.24	UAF	Constenius and others, 2003, 2011, in prep.
KNC72393-1T	Tibble Fm.	Provo	Timpanogos Cave	445379	4481086	40.48052	111.64517	biotite	31.69 ± 0.45	UAF	Constenius and others, 2003, 2011, in prep.
KNC81296-2	Duchesne River Fm.	Provo	Wolf Creek Summit	498716	4470470	40.38667	111.01585	biotite	<40.1 ± 2.4	NMGRL	Constenius and others, 2003, 2011, in prep.
*KNC92799-5	Keetley volcanics	Provo	Co-op Creek	485398	4468925	40.37262	111.17273	hornblende	40.43 ± 0.19	NMGRL	Constenius and others, 2003, 2011, in prep.
*KNC92799-6	Keetley volcanics	Provo	Co-op Creek	485381	4468801	40.37151	111.17292	hornblende	37.23 ± 0.12	NMGRL	Constenius and others, 2003, 2011, in prep.
*KNC9299-1	Stock?	Provo	Twin Peaks	472191	4462829	40.31737	111.32803	biotite	34.70 ± 0.14	NMGRL	Constenius and others, 2003, 2011, in prep.
*KNC92899-2	Keetley volcanics	Provo	Co-op Creek	482460	4456653	40.26201	111.20700	biotite	37.73 ± 0.22	NMGRL	Constenius and others, 2003, 2011, in prep.
*KNC71194-5	Moroni Fm.	Provo	Billies Mountain	463610	4441305	40.12312	111.42781	sanidine	34.68 ± 0.09	NMGRL	Constenius and others, 2003, 2011, in prep.
KNC61600-21	Green River Fm.	Provo	Strawberry Reservoir SW	479883	4434180	40.05948	111.23660	biotite	>45.03 ± 0.34	NMGRL	Constenius and others, 2003, 2011, in prep.
KNC7894-44	Moroni Fm.	Nephi	Birdseye	455887	4421878	39.94773	111.51713	sanidine	34.43 ± 0.10	NMGRL	Constenius and others, 2003, 2011, in prep.
KNC101701-7	Moroni Fm.	Nephi	Indianola	463207	4411684	39.85623	111.43087	sanidine	34.63 ± 0.09	NMGRL	Constenius and others, 2003, 2011, in prep.
^JC99-7	Lower Ankareh and Upper Thaynes Fms.	Provo	Co-op Creek	482450	4466445	40.35023	111.20738	biotite	97.2 ± 1.3	NMGRL	Constenius and others, 2003, 2011, in prep.
^KNC53094-3	Fowkes Fm.	Ogden	Castle Rock	488453	4543883	41.04795	111.13814	hornblende	38.78 ± 0.62	NMGRL	Coogan and King, 2016
^KNC53094-5	Fowkes Fm.	Ogden	Castle Rock	489260	4542870	41.03884	111.12852	biotite	40.41 ± 0.84	NMGRL	Coogan and King, 2016

Notes:
NMGRL is New Mexico Geochronology Research Laboratory.
UAF is University of Alaska, Fairbanks.
Age error is ±2σ
*NMGRL prepared a prior report in January 2001 (NMGRL-IR-114) for these 5 samples that is superceded by the September 2001 report.
^ Data for three samples from a prior NMGRL report in January 2001 (NMGRL-IR-114) included here.

APPENDIX

$^{40}Ar/^{39}Ar$ Geochronology Results from the Provo, Nephi, and Salt Lake City 30' x 60' Quadrangles, Utah

By

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September 2001

Prepared for

Utah Geological Survey and Kurt N. Constenius

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Table 1. $^{40}Ar/^{39}Ar$ analytical data.

	ID	Power/ Temp (°C)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
	KNC 6901-1, single crystal sanidine, J=0.0009738±0.10%, Discrimination=1.00623±0.00131										
†	01	1.8	22.27	1.938	4.435	0.345	0.26	94.8	N.A.	36.73	0.39
	10	1.8	22.00	0.0118	0.3878	8.031	43.3	99.5	N.A.	38.009	0.068
	03	1.8	22.07	0.0135	0.4688	9.758	37.8	99.4	N.A.	38.090	0.076
	06	1.8	22.07	0.0110	0.4390	11.804	46.2	99.4	N.A.	38.095	0.089
	08	1.8	22.01	0.0116	0.1558	7.204	43.9	99.8	N.A.	38.135	0.088
	14	1.8	22.05	0.0092	0.1817	9.190	55.4	99.8	N.A.	38.189	0.090
	13	1.8	22.11	0.0097	0.3679	4.179	52.7	99.5	N.A.	38.205	0.082
	09	1.8	22.10	0.0132	0.2584	11.849	38.8	99.7	N.A.	38.241	0.073
†	04	1.8	22.64	1.824	2.597	0.848	0.28	97.3	N.A.	38.28	0.22
	12	1.8	22.21	0.0082	0.5483	2.274	62.1	99.3	N.A.	38.28	0.12
†	07	1.8	22.47	1.932	2.011	0.847	0.26	98.0	N.A.	38.31	0.23
	02	1.8	22.07	0.0096	-0.0023	5.896	53.4	100.0	N.A.	38.322	0.073
	05	1.8	22.24	0.0103	0.3460	7.724	49.5	99.5	N.A.	38.447	0.073
†	15	1.8	23.30	2.224	1.676	0.261	0.23	98.6	N.A.	39.95	0.62
†	11	1.8	24.41	2.169	5.074	0.469	0.24	94.6	N.A.	40.13	0.38
	Mean age ± 2σ		n=10		MSWD=3.00	48.3	±15.5			38.20	0.11
	KNC-52994-6, 9.32 mg hornblende, J=0.0009741±0.10%, Discrimination=1.00623±0.00131										
†	A	800	223.4	11.21	566.0	0.289	0.046	25.5	9.0	98.2	2.1
†	B	900	49.35	3.883	77.90	0.118	0.13	54.0	12.7	46.30	0.98
†	C	1000	46.53	2.373	56.37	0.164	0.21	64.6	17.8	52.12	0.63
†	D	1030	29.66	2.867	24.36	0.128	0.18	76.5	21.7	39.49	0.70
	E	1060	26.52	3.620	22.74	0.137	0.14	75.7	26.0	35.02	0.62
	F	1090	24.10	5.699	15.03	0.345	0.090	83.5	36.7	35.11	0.27
	G	1120	24.39	6.164	15.45	0.473	0.083	83.3	51.5	35.47	0.26
	H	1170	26.45	6.326	18.11	0.746	0.081	81.7	74.7	37.71	0.24
†	I	1200	30.31	6.661	23.71	0.620	0.077	78.6	94.0	41.57	0.31
†	J	1250	31.89	6.489	16.79	0.186	0.079	86.1	99.8	47.79	0.46
†	K	1300	274.1	51.91	40.32	0.002	0.010	97.2	99.8	430.0	69.6
†	L	1730	476.5	198.8	1292.90	0.005	0.003	23.1	100.0	212.2	22.9
	Integrated age ± 2σ			n=12		3.21				45.51	0.63
	Plateau ± 2σ	steps E-H		n=4	MSWD=22.31	1.70	0.088		53.0	36.1	1.4

	ID	Power/ Temp (°C)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
	KNC61093-3T, 2.77 mg biotite, J=0.000975±0.10%, Discrimination=1.00623±0.00131										
†	A	650	78.3316	0.4070	251.2	0.088	1.3	5.3	1.3	7.2	1.7
†	B	750	21.1230	0.9742	48.8726	0.147	0.5	31.9	3.6	11.82	0.55
†	C	850	23.0522	0.3511	20.8184	0.184	1.5	73.4	6.4	29.50	0.33
†	D	920	24.0517	0.0301	11.9324	0.257	16.9	85.4	10.4	35.72	0.27
	E	1000	24.5011	0.0175	5.7191	0.381	29.1	93.1	16.2	39.65	0.19
	F	1075	23.8698	0.0103	4.7654	0.609	49.8	94.1	25.5	39.05	0.14
	G	1110	23.4870	0.0228	3.6619	0.435	22.4	95.4	32.2	38.96	0.14
	H	1180	22.6979	0.0628	3.2551	0.662	8.1	95.8	42.4	37.81	0.15
	I	1210	23.0600	0.1057	4.9345	0.476	4.8	93.7	49.7	37.59	0.15
	J	1250	21.9578	0.0720	2.3661	1.153	7.1	96.9	67.3	36.99	0.10
	K	1300	21.4620	0.0303	1.7797	2.014	16.9	97.6	98.2	36.43	0.10
†	L	1700	67.3595	0.0445	39.1564	0.117	11.5	82.8	100.0	95.53	0.86
	Integrated age ± 2σ		n=12			6.521				37.25	0.19
	Plateau ± 2σ	steps E-K	n=7		MSWD=84.6	5.728	17.6		87.8	37.66	0.90
	KNC61093-2T, Biotite, J=0.008611±0.42%										
†	A	150	20.165	0.069	0.068	N.A.	7.9	-0.1	0.2	-0.3	12.4
†	B	300	8.799	0.044	0.031	N.A.	12.3	-5.2	0.4	-7.1	6.5
†	C	450	5.490	0.035	0.016	N.A.	15.5	13.0	0.7	11.0	4.0
†	D	600	4.970	0.032	0.014	N.A.	17.2	17.4	1.2	13.3	2.9
†	E	800	3.474	0.015	0.006	N.A.	35.6	50.3	2.4	26.7	1.2
†	F	1000	3.113	0.014	0.004	N.A.	39.2	62.9	4.2	29.9	1.2
†	G	1200	2.792	0.011	0.002	N.A.	47.6	80.3	7.8	34.15	0.58
†	H	1500	2.725	0.010	0.002	N.A.	52.3	83.3	12.8	34.54	0.36
†	I	1800	2.642	0.012	0.001	N.A.	45.3	89.1	20.1	35.83	0.33
†	J	2150	2.585	0.011	0.001	N.A.	48.8	92.0	32.0	36.16	0.24
	K	2500	2.587	0.010	0.001	N.A.	55.3	92.3	42.8	36.31	0.24
	L	3500	2.538	0.010	0.000	N.A.	56.6	94.9	69.7	36.64	0.10
	M	4500	2.501	0.008	0.000	N.A.	66.8	96.1	91.2	36.56	0.10
	N	8500	2.526	0.006	0.000	N.A.	87.5	94.8	100.0	36.40	0.25
	Integrated age ± 2σ		n=14				38.5			35.66	0.17
	Plateau ± 2σ		n=4		MSWD=0.76		67.2		68.0	36.56	0.15
	KNC72393-1T, Biotite, J=0.008611±0.42%										
†	A	150	76.981	0.499	0.258	N.A.	1.1	0.8	0.7	9.5	29.9
†	B	300	16.514	0.796	0.049	N.A.	0.7	11.9	3.8	30.2	4.7
†	C	450	13.672	0.965	0.039	N.A.	0.6	16.4	7.9	34.4	2.7
†	D	600	10.459	1.143	0.029	N.A.	0.5	19.4	11.8	31.1	3.5
†	E	800	7.442	1.133	0.019	N.A.	0.5	26.7	19.8	30.5	1.3
†	F	1000	7.152	0.966	0.017	N.A.	0.6	30.6	26.2	33.5	1.6
†	G	1200	7.184	0.367	0.017	N.A.	1.5	30.2	33.4	33.2	1.4
†	H	1500	5.242	0.268	0.010	N.A.	2.0	42.1	43.1	33.82	0.75
†	I	1800	5.182	0.449	0.011	N.A.	1.2	35.8	51.8	28.44	0.90
†	J	2500	3.998	0.264	0.006	N.A.	2.1	53.3	66.1	32.60	0.73
†	K	3500	3.691	0.207	0.006	N.A.	2.6	51.4	76.2	29.0	1.0
†	L	8500	3.631	0.262	0.005	N.A.	2.1	58.2	100.0	32.27	0.75
	Integrated age ± 2σ		n=13				1.1			31.64	0.45
	Plateau ± 2σ		n=0		MSWD=N.A.					N.A.	N.A.

	ID	Power/ Temp (°C)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
	KNC82196-2, 4.77 mg biotite, J=0.0007596±0.10%, Discrimination=1.00623±0.00131										
†	A	650	5438.9356	0.4142	18092.2	0.099	1.2	1.7	1.8	122.8	38.5
	B	750	114.3514	0.3652	282.8944	1.187	1.4	26.9	23.1	41.71	0.75
	C	850	80.3805	0.1829	174.1177	0.779	2.8	36.0	37.1	39.24	0.55
†	D	920	98.4776	0.2107	196.9941	0.477	2.4	40.9	45.6	54.38	0.73
†	E	1000	86.9782	0.2388	149.0217	1.039	2.1	49.4	64.3	57.94	0.51
†	F	1075	70.1201	0.1812	130.9446	0.955	2.8	44.8	81.4	42.59	0.45
†	G	1110	64.0621	0.1003	109.4056	0.453	5.1	49.5	89.5	42.98	0.45
†	H	1180	54.6922	0.1080	60.5988	0.350	4.7	67.3	95.8	49.73	0.43
†	I	1210	42.0249	0.1039	25.9197	0.125	4.9	81.8	98.1	46.51	0.67
†	J	1250	49.5694	0.0916	40.9151	0.085	5.6	75.6	99.6	50.66	0.94
†	K	1300	100.1929	0.1126	137.1014	0.022	4.5	59.6	100.0	80.00	3.37
†	L	1685	3888.9079	-0.3532	10103.2	0.001	-	23.2	100.0	942.4	210.4
	Integrated age ± 2σ		n=12			5.573				48.4	2.2
	Plateau ± 2σ	steps B-C	n=2		MSWD=7.00	1.967	1.9		35.3	40.1	2.4
	KNC92799-5, 36.25 mg hbl, J=0.0014963±0.10%, Discrimination=1.00338±0.00158										
†	A	5	239.8598	0.3278	783.9571	0.666	1.6	3.4	0.8	22.1	4.7
†	B	10	47.2580	0.2841	121.7680	1.789	1.8	23.9	3.1	30.25	0.86
†	C	15	28.4202	2.0492	48.6874	1.962	0.2	50.0	5.5	38.00	0.42
†	D	20	19.1459	3.6321	15.7432	5.656	0.1	77.3	12.6	39.63	0.18
	E	25	17.9372	4.1187	10.7713	12.843	0.1	84.2	28.6	40.44	0.15
	F	30	17.8620	4.2606	10.5899	18.502	0.1	84.5	51.6	40.42	0.15
	G	35	16.8707	4.2834	7.2116	20.239	0.1	89.5	76.9	40.44	0.14
†	H	40	15.8083	4.3198	5.9059	12.785	0.1	91.2	92.8	38.66	0.11
†	I	45	15.4769	4.8298	5.8407	4.586	0.1	91.4	98.5	37.96	0.12
†	J	50	20.6555	5.6512	22.6964	0.926	0.1	69.8	99.7	38.69	0.39
†	K	50	58.5769	6.0834	157.1937	0.272	0.1	21.6	100.0	34.0	1.6
	Integrated age ± 2σ		n=11			80.227				39.48	0.34
	Plateau ± 2σ	steps E-G	n=3		MSWD=0.01	51.584	0.1		64.3	40.43	0.19
	KNC92799-6, 30.20 mg hbl, J=0.0014965±0.10%, Discrimination=1.00338±0.00158										
†	A	5	121.9337	2.1435	371.3646	0.137	0.2	10.1	0.2	33.2	4.2
†	B	10	37.0633	2.8524	80.0248	0.250	0.2	36.8	0.6	36.6	1.2
	C	15	18.8114	3.8652	17.2993	1.261	0.1	74.5	2.6	37.58	0.32
	D	20	15.0758	3.8945	5.0438	6.864	0.1	92.3	13.6	37.29	0.12
	E	25	14.5278	4.2128	3.5024	14.114	0.1	95.3	36.1	37.12	0.11
	F	30	14.7346	4.2650	4.0228	15.683	0.1	94.3	61.2	37.28	0.10
	G	35	14.7661	4.4760	4.4025	12.328	0.1	93.7	80.8	37.12	0.11
	H	40	14.4933	4.8473	3.3878	8.735	0.1	95.9	94.8	37.28	0.12
	I	45	14.6786	5.3228	4.1701	2.519	0.1	94.6	98.8	37.28	0.17
	J	50	15.3633	6.3092	7.1229	0.605	0.1	89.7	99.8	37.03	0.40
†	K	50	28.2197	6.9991	55.7533	0.138	0.1	43.7	100.0	33.2	1.7
	Integrated age ± 2σ		n=11			62.633				37.20	0.21
	Plateau ± 2σ	steps C-J	n=8		MSWD=0.61	62.108	0.1		99.2	37.23	0.12

	ID	Power/ Temp (°C)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
	KNC9299-1, 10.77mg biotite, J=0.0014954±0.10%, Discrimination=1.00338±0.00158										
†	A	10	404.2433	0.1586	1329.64	5.186	3.2	2.8	3.9	30.4	7.2
	B	14	22.0410	0.0499	30.6426	9.389	10.2	58.9	11.0	34.71	0.25
	C	18	17.0530	0.0316	13.3141	13.312	16.2	76.9	21.1	35.06	0.14
	D	22	15.5975	0.0308	8.7568	14.245	16.5	83.4	31.8	34.77	0.12
	E	26	15.3075	0.0502	7.7139	14.077	10.2	85.1	42.5	34.82	0.13
	F	30	15.3839	0.0860	7.9318	12.339	5.9	84.8	51.8	34.86	0.13
	G	35	15.1579	0.0548	7.4302	15.243	9.3	85.5	63.3	34.65	0.11
	H	40	14.9703	0.0364	6.8121	16.730	14.0	86.6	76.0	34.63	0.12
	I	45	15.1975	0.0264	7.7190	16.686	19.4	85.0	88.6	34.52	0.11
	J	50	16.4644	0.0355	12.0247	10.137	14.4	78.4	96.2	34.51	0.15
	K	50	16.3010	0.0363	11.5544	4.969	14.0	79.1	100.0	34.44	0.15
	Integrated age ± 2σ		n=11			132.314				34.54	0.76
	Plateau ± 2σ	steps B-K	n=10		MSWD=1.92	127.128	13.2		96.1	34.70	0.14
	KNC92899-2, 7.69 mg biotite, J=0.0014944±0.10%, Discrimination=1.00338±0.00158										
†	A	10	224.5429	0.2894	716.1019	12.971	1.8	5.8	11.6	34.6	4.2
	B	14	33.6994	0.0553	66.9720	17.480	9.2	41.3	27.1	37.13	0.44
	C	18	21.9719	0.0211	26.3536	13.987	24.2	64.6	39.6	37.85	0.22
	D	22	19.7519	0.0235	18.7181	13.102	21.7	72.0	51.3	37.94	0.19
	E	26	20.5445	0.0289	21.7593	11.626	17.7	68.7	61.7	37.66	0.20
	F	30	22.6179	0.0365	28.8924	9.691	14.0	62.3	70.3	37.58	0.23
†	G	35	23.8252	0.0482	31.8698	10.301	10.6	60.5	79.5	38.44	0.25
†	H	40	22.2466	0.0557	25.3965	10.243	9.2	66.3	88.6	39.33	0.24
†	I	45	27.2311	0.0455	42.8550	6.768	11.2	53.5	94.7	38.86	0.32
†	J	50	37.2572	0.0407	76.9250	4.055	12.5	39.0	98.3	38.75	0.57
†	K	50	50.4279	0.0388	124.4987	1.944	13.1	27.1	100.0	36.41	0.83
	Integrated age ± 2σ		n=11			112.168				37.6	1.4
	Plateau ± 2σ	steps B-F	n=5		MSWD=0.98	65.886	17.1		58.7	37.73	0.22
	KNC-71194-5, single crystal sanidine, J=0.001496±0.10%, Discrimination=1.00827±0.00148										
	04	1.6	12.9996	0.0145	0.4149	15.588	35.1	99.1	N.A.	34.425	0.079
	14	1.6	13.0825	0.0086	0.5110	8.671	59.4	98.9	N.A.	34.568	0.087
	07	1.6	13.1337	0.0082	0.5855	9.252	61.9	98.7	N.A.	34.645	0.082
	02	1.6	13.5207	0.0786	1.9158	15.369	6.5	95.9	N.A.	34.647	0.083
	10	1.6	13.1101	0.0079	0.4977	11.026	64.3	98.9	N.A.	34.652	0.083
	15	1.6	13.0584	0.0079	0.3052	10.092	64.5	99.3	N.A.	34.665	0.079
	05	1.6	13.0346	0.0086	0.2234	20.573	59.4	99.5	N.A.	34.666	0.073
	03	1.6	13.2400	0.0092	0.8872	20.270	55.8	98.0	N.A.	34.691	0.085
	09	1.6	13.0614	0.0117	0.2809	8.369	43.6	99.4	N.A.	34.693	0.074
	13	1.6	13.2636	0.0080	0.9633	13.468	63.5	97.9	N.A.	34.694	0.074
	11	1.6	13.1743	0.0117	0.6281	19.279	43.5	98.6	N.A.	34.721	0.079
	06	1.6	13.2041	0.0099	0.7073	9.218	51.4	98.4	N.A.	34.737	0.078
	08	1.6	13.1071	0.0089	0.3691	12.888	57.3	99.2	N.A.	34.745	0.081
	01	1.6	13.1117	0.0087	0.3237	9.875	58.6	99.3	N.A.	34.792	0.074
	12	1.6	13.2484	0.0162	0.7796	3.952	31.6	98.3	N.A.	34.799	0.085
	Mean age ± 2σ		n=15		MSWD=1.30	50.4	±32.1			34.678	0.087

	ID	Power/ Temp (°C)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
	KNC61600-21, 3.12 mg biotite, J=0.0009728±0.10%, Discrimination=1.00623±0.00131										
†	A	650	100.2489	0.0308	293.9329	0.150	16.6	13.3	1.4	23.3	1.5
†	B	750	52.7908	0.0240	113.9698	0.195	21.3	36.2	3.3	33.20	0.99
†	C	850	34.0209	0.0124	29.7154	0.574	41.2	74.2	8.9	43.73	0.29
	D	920	30.2627	0.0127	14.0323	0.659	40.1	86.3	15.2	45.23	0.19
	E	1000	30.5585	0.0081	17.1749	0.665	63.0	83.4	21.6	44.14	0.22
	F	1075	32.6838	0.0116	24.7251	0.890	43.9	77.6	30.2	43.96	0.19
	G	1110	29.3088	0.0115	12.3648	0.648	44.5	87.5	36.5	44.44	0.19
	H	1180	28.3625	0.0116	7.6593	0.705	44.1	92.0	43.3	45.20	0.17
	I	1210	27.2130	0.0057	3.3190	1.091	89.6	96.4	53.8	45.42	0.13
	J	1250	26.6765	0.0029	1.9812	2.706	177.6	97.8	79.9	45.182	0.092
	K	1300	26.7463	0.0028	2.1873	1.780	184.3	97.6	97.1	45.20	0.11
†	L	1675	95.8731	0.0105	233.6631	0.302	48.6	28.0	100.0	46.4	1.2
	Integrated age ± 2σ			n=12		10.365				44.41	0.27
	Plateau ± 2σ		steps D-K	n=8	MSWD=10.5	9.143	117.4		88.2	45.03	0.34
	KNC 7894-44, single crystal sanidine, J=0.0009786±0.10%, Discrimination=1.00623±0.00131										
†	11	1.8	19.1782	3.9117	3.4142	0.112	0.1	96.4	N.A.	32.38	0.55
†	08	1.8	20.3759	2.2752	5.6093	0.507	0.2	92.8	N.A.	33.07	0.19
	13	1.8	19.6847	0.0109	0.4380	0.964	46.7	99.3	N.A.	34.158	0.089
	01	1.8	19.7296	0.0084	0.2450	3.401	60.9	99.6	N.A.	34.334	0.072
	02	1.8	19.7170	0.0096	0.1945	6.448	52.9	99.7	N.A.	34.338	0.081
	07	1.8	19.7310	0.0074	0.2356	3.292	69.3	99.6	N.A.	34.341	0.068
	04	1.8	19.7374	0.0097	0.1528	1.852	52.8	99.8	N.A.	34.395	0.074
	05	1.8	19.7546	0.0075	0.2020	3.791	67.8	99.7	N.A.	34.399	0.065
	06	1.8	19.7652	0.0092	0.2073	3.874	55.7	99.7	N.A.	34.415	0.065
	09	1.8	19.8298	0.0086	0.3289	2.261	59.5	99.5	N.A.	34.464	0.086
	03	1.8	19.8207	0.0072	0.2205	4.018	71.0	99.7	N.A.	34.504	0.072
	12	1.8	19.8711	0.0072	0.3658	3.105	71.1	99.5	N.A.	34.517	0.070
	14	1.8	19.9647	0.0101	0.5974	1.022	50.3	99.1	N.A.	34.561	0.088
	10	1.8	19.9190	0.0101	0.2834	2.058	50.6	99.6	N.A.	34.642	0.066
	Mean age ± 2σ			n=12	MSWD=2.74	59.1	±17.7			34.429	0.095

	ID	Power/ Temp (°C)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
	KNC101701-7, single crystal sanidine, J=0.0007659±0.10%, Discrimination=1.00623±0.00131										
	08	1.8	25.31	0.0091	0.2083	4.121	56.1	99.8	N.A.	34.552	0.072
	04	1.8	25.33	0.0070	0.2302	5.425	72.8	99.7	N.A.	34.569	0.068
	07	1.8	25.29	0.0087	0.0892	2.420	58.4	99.9	N.A.	34.57	0.12
	13	1.8	25.34	0.0067	0.1447	4.210	75.8	99.8	N.A.	34.619	0.075
	06	1.8	25.42	0.0242	0.3991	1.369	21.1	99.5	N.A.	34.63	0.16
	15	1.8	25.36	0.0087	0.0761	3.481	58.5	99.9	N.A.	34.681	0.083
	12	1.8	25.38	0.0321	0.1117	5.165	15.9	99.9	N.A.	34.686	0.069
	01	1.8	25.38	0.0073	0.1146	2.715	69.5	99.9	N.A.	34.692	0.083
	03	1.8	25.45	0.0095	0.3416	2.878	53.9	99.6	N.A.	34.698	0.078
†	14	1.8	25.48	0.0088	0.3078	1.811	58.3	99.6	N.A.	34.74	0.11
†	02	1.8	25.54	0.0093	0.5199	3.074	54.9	99.4	N.A.	34.745	0.076
†	16	1.8	25.84	4.146	2.869	0.209	0.12	98.0	N.A.	34.77	0.62
†	10	1.8	25.44	0.0076	-0.2776	2.898	67.1	100.3	N.A.	34.928	0.094
†	05	1.8	25.39	0.0091	-0.5354	1.173	55.9	100.6	N.A.	34.96	0.17
†	11	1.8	25.57	0.0069	-0.1412	4.293	74.0	100.2	N.A.	35.051	0.080
†	09	1.8	25.54	3.616	-0.4360	0.258	0.14	101.7	N.A.	35.62	0.59
	Mean age ± 2σ			n=9	MSWD=0.57	53.6	±42.7			34.63	0.09

Analytical Notes (for samples analyzed at NMGRL):

Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interferring reactions.

Ages calculated ralative to FC-1 Fish Canyon Tuff sanidine interlaboratory standard at 27.84 Ma.

Errors quoted for individual analyses include analytical error only, without interferring reaction or J uncertainties.

Mean age is weighted mean age of Taylor (1982). Mean age error is weighted error of the mean (Taylor, 1982), multiplied by the root of the MSWD where MSWD>1, and also incorporates uncertainty in J factors and irradiation correction uncertainties.

Decay constants and isotopic abundances after Steiger and Jaeger (1977).

Power/Temp (°C): samples KNC61093-2T and KNC72393-1T were heated using NdYag laser (mW); single-crystal sanidines were heated using CO_2 laser (W); all other samples heated using resistance furnace (°C).

† symbol preceding sample ID denotes analyses excluded from mean age calculations.

J = J Adjustment Factor

Discrimination = Mass Discrimination (a.m.u.)

Correction factors:

$(^{39}Ar/^{37}Ar)_{Ca} = 0.0007 \pm 2e\text{-}05$

$(^{36}Ar/^{37}Ar)_{Ca} = 0.00028 \pm 5e\text{-}06$

$(^{38}Ar/^{39}Ar)_K = 0.01077$

$(^{40}Ar/^{39}Ar)_K = 0.0002 \pm 0.0003$

Analytical Methods (for samples analyzed at NMGRL):

Sample preparation and irradiation:

Sanidine, hornblende and biotite separated using standard techniques (crushing, sieving, magnetics, heavy liquids and hand-picking).
Samples were packaged and irradiated in machined Al discs for 7 to 14 hours in D-3 position, Texas A&M University Research Reactor, or for 6 hours in L67 position, Ford Research Reactor, Univ. of Michigan.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-1). Assigned age = 27.84 Ma (Deino and Potts, 1990) relative to Mmhb-1 at 520.4 Ma (Samson and Alexander, 1987).

Instrumentation:

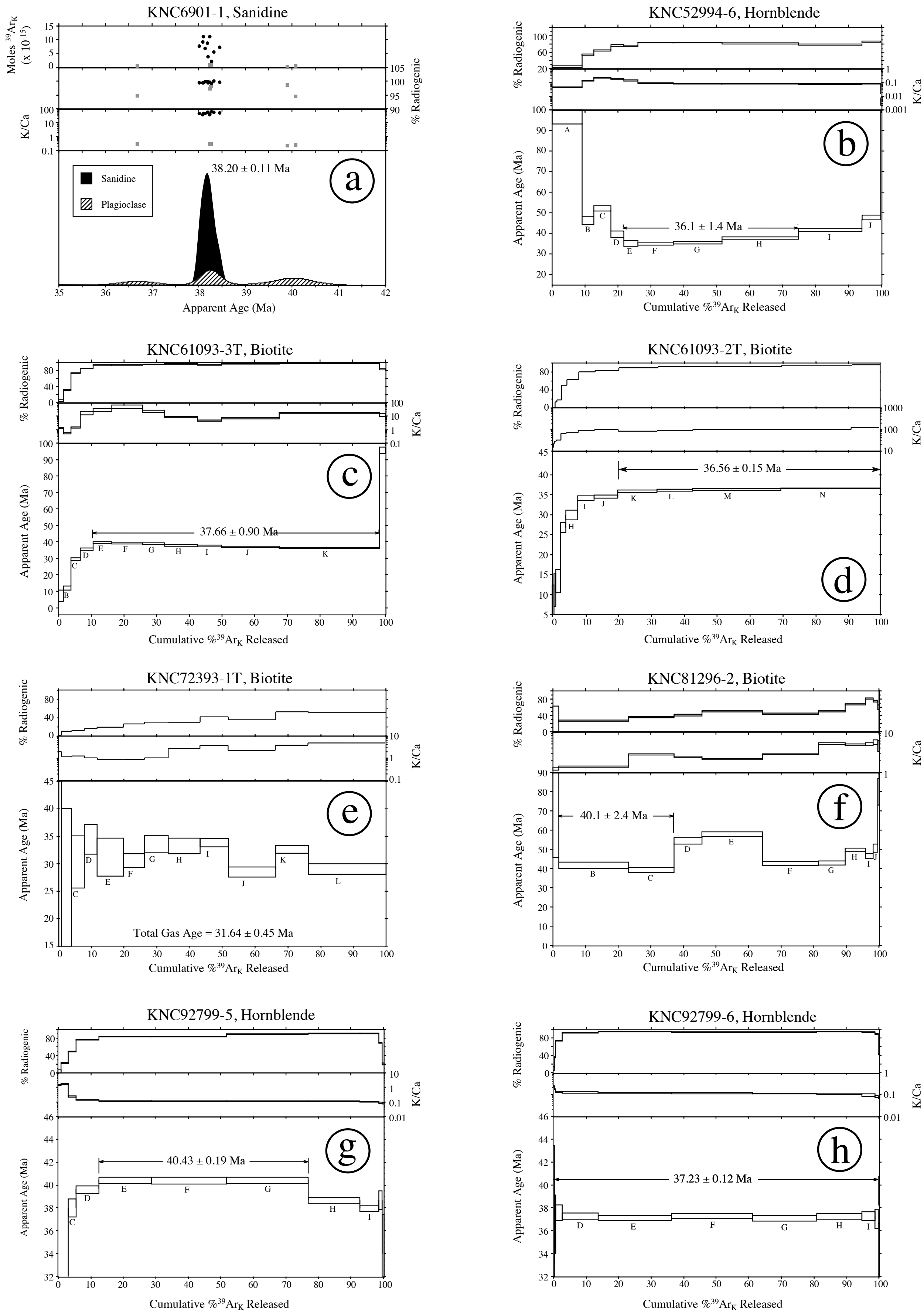
Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.
Single crystals of sanidine were fused by a 50-watt Synrad CO_2 laser.
Hornblende and biotite samples were step-heated in a Mo double-vacuum resistance furnace.
Reactive gases removed during a 2 minute (sanidine) or 13 minute (hornblendes and biotites) reaction with 2 SAES GP-50 getters, 1 operated at ~450°C and 1 at 20°C. Gas also exposed to a W filament operated at ~2000°C and a cold finger operated at -140°C.

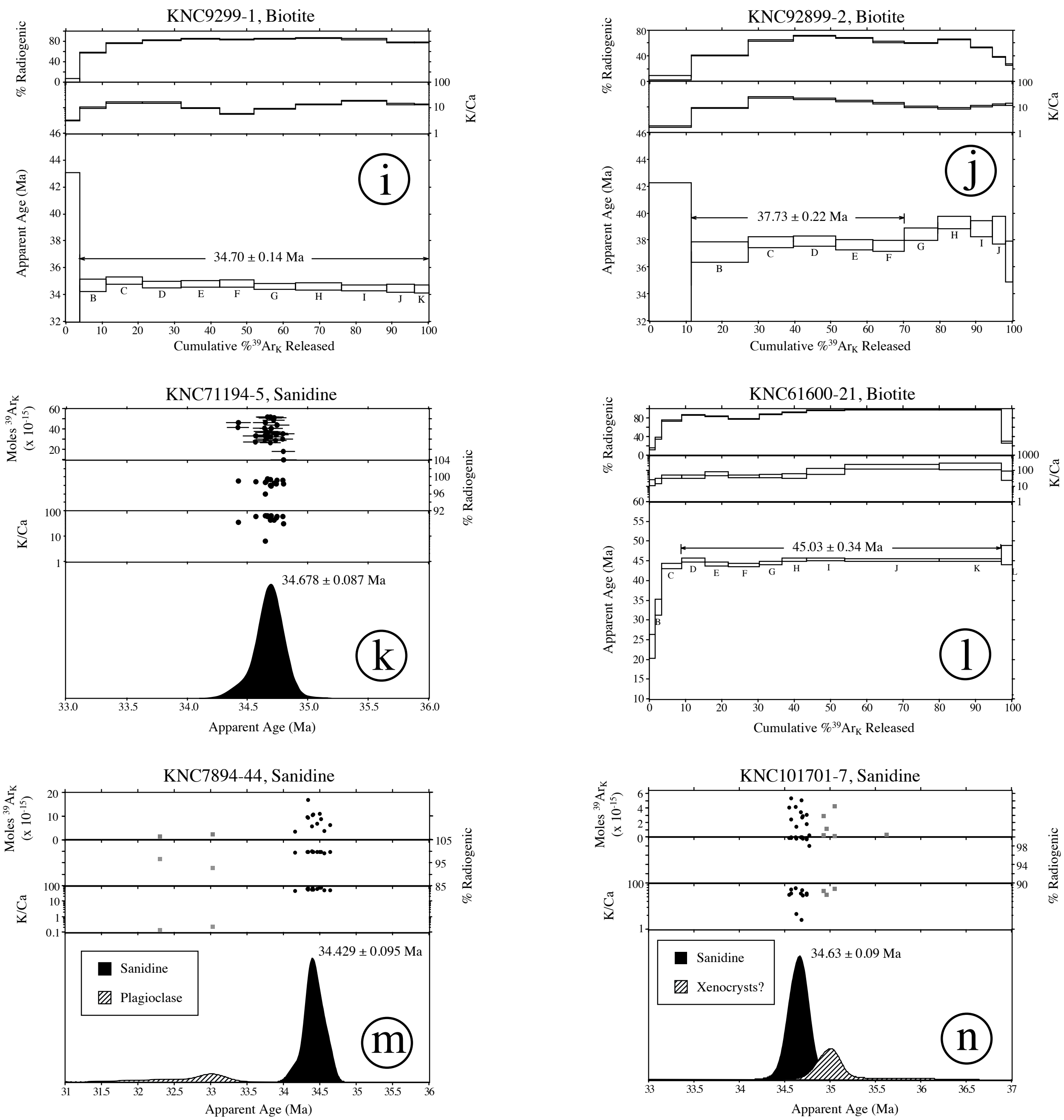
Analytical parameters:

Electron multiplier sensitivity averaged 1.45×10^{-16} moles/pA for those samples analyzed by the CO_2 laser.
Electron multiplier sensitivity averaged 1.45×10^{-16} moles/pA for those samples analyzed by the resistance furnace.
Total system blank and background for the laser fusion sample averaged 1110, 7.7, 11.6, 3.0, 8.1 x 10^{-18} moles
J-factors determined to a precision of ± 0.1% by CO_2 laser-fusion of 4 single crystals from each of 3, 4 or 6 radial positions around the irradiation tray.
Correction factors for interfering nuclear reactions were determined using K-glass and CaF_2 and are as follows:
$(^{40}Ar/^{39}Ar)_K = 0.0002 \pm 0.0003$; $(^{36}Ar/^{37}Ar)_{Ca} = 0.00028 \pm 0.000011$; and $(^{39}Ar/^{37}Ar)_{Ca} = 0.00089 \pm 0.00003$.

Age calculations:

Weighted mean age calculated by weighting each age analysis by the inverse of the variance.
Weighted mean error calculated using the method of (Taylor, 1982).
Total gas ages and errors calculated by weighting individual steps by the fraction of ^{39}Ar released.
MSWD values are calculated for n-1 degrees of freedom for plateau and preferred ages.
Isochron ages, $^{40}Ar/^{36}Ar_i$ and MSWD values calculated from regression results obtained by the methods of York (1969).
Decay constants and isotopic abundances following Steiger and Jäger (1977).
All final errors reported at ±2s, unless otherwise noted.


KNC6901-1, Sanidine
Moles $^{39}Ar_K$ (x 10^{-15})
% Radiogenic
K/Ca
Sanidine
Plagioclase
38.20 ± 0.11 Ma
a
Apparent Age (Ma)
KNC52994-6, Hornblende
% Radiogenic
K/Ca
Apparent Age (Ma)
36.1 ± 1.4 Ma
b
Cumulative %$^{39}Ar_K$ Released
KNC61093-3T, Biotite
37.66 ± 0.90 Ma
c
KNC61093-2T, Biotite
36.56 ± 0.15 Ma
d
KNC72393-1T, Biotite
Total Gas Age = 31.64 ± 0.45 Ma
e
KNC81296-2, Biotite
40.1 ± 2.4 Ma
f
KNC92799-5, Hornblende
40.43 ± 0.19 Ma
g
KNC92799-6, Hornblende
37.23 ± 0.12 Ma
h


KNC9299-1, Biotite
% Radiogenic
K/Ca
Apparent Age (Ma)
i
34.70 ± 0.14 Ma
B C D E F G H I J K
Cumulative %$^{39}Ar_K$ Released
KNC92899-2, Biotite
% Radiogenic
K/Ca
Apparent Age (Ma)
j
37.73 ± 0.22 Ma
B C D E F G H I J
Cumulative %$^{39}Ar_K$ Released
KNC71194-5, Sanidine
Moles $^{39}Ar_K$ (x 10^{-15})
% Radiogenic
K/Ca
34.678 ± 0.087 Ma
k
Apparent Age (Ma)
KNC61600-21, Biotite
% Radiogenic
K/Ca
Apparent Age (Ma)
45.03 ± 0.34 Ma
B C D E F G H I J K L
l
Cumulative %$^{39}Ar_K$ Released
KNC7894-44, Sanidine
Moles $^{39}Ar_K$ (x 10^{-15})
% Radiogenic
K/Ca
Sanidine
Plagioclase
34.429 ± 0.095 Ma
m
Apparent Age (Ma)
KNC101701-7, Sanidine
Moles $^{39}Ar_K$ (x 10^{-15})
% Radiogenic
K/Ca
Sanidine
Xenocrysts?
34.63 ± 0.09 Ma
n
Apparent Age (Ma)

UAF064-31 KNC72393-1T 4/2/97
Weighted average of J from standards = 0.008611 +/- 0.000036

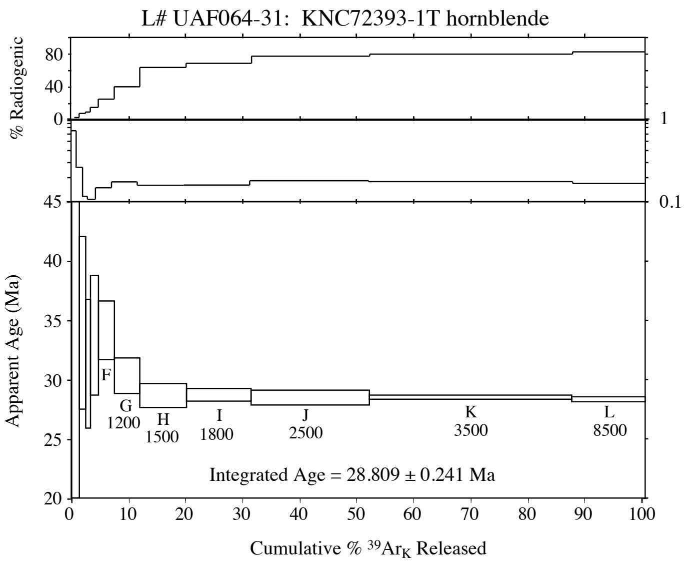
Laser Power (mW)	Cumulative 39Ar	40Ar/39Ar measured	+/-	37Ar/39Ar measured	+/-	36Ar/39Ar measured	+/-	% Atmospheri 40Ar	Ca/K	+/-	Cl/K	+/-	40*/39K	+/-	Age (Ma)	+/- (Ma)
150	0.005	80.710	1.070	1.334	0.027	0.265	0.006	96.8	2.449	0.049	0.0114	0.0008	2.624	1.379	40.3	21.0
300	0.015	27.223	0.163	3.717	0.020	0.085	0.002	91.7	6.837	0.036	0.0054	0.0003	2.258	0.475	34.8	7.2
450	0.024	20.218	0.252	8.412	0.101	0.064	0.001	90.0	15.520	0.188	0.0042	0.0003	2.033	0.353	31.3	5.4
600	0.033	13.932	0.109	9.119	0.070	0.042	0.001	84.3	16.832	0.130	0.0053	0.0004	2.191	0.331	33.7	5.1
800	0.048	8.692	0.084	6.594	0.070	0.024	0.001	74.5	12.151	0.130	0.0396	0.0007	2.220	0.161	34.2	2.5
1000	0.075	4.859	0.019	5.601	0.030	0.011	0.000	59.4	10.314	0.055	0.0846	0.0006	1.970	0.097	30.4	1.5
1200	0.120	2.930	0.012	6.179	0.034	0.005	0.000	36.1	11.384	0.062	0.1233	0.0010	1.861	0.065	28.7	1.0
1500	0.200	2.727	0.008	6.114	0.015	0.004	0.000	31.2	11.263	0.028	0.1320	0.0004	1.865	0.034	28.7	0.5
1800	0.315	2.412	0.009	5.442	0.020	0.003	0.000	22.6	10.020	0.037	0.1302	0.0006	1.852	0.040	28.6	0.6
2500	0.520	2.332	0.005	5.566	0.011	0.003	0.000	19.9	10.249	0.020	0.1331	0.0003	1.853	0.011	28.6	0.2
3500	0.871	2.242	0.003	5.840	0.007	0.003	0.000	17.1	10.757	0.013	0.1428	0.0002	1.841	0.014	28.4	0.2
8500	1.000	2.366	0.005	11.896	0.027	0.005	0.000	22.2	21.998	0.050	0.1491	0.0003	1.832	0.041	28.2	0.6
Integrated		3.412	0.003	6.577	0.006	0.007	0.000	45.0	12.119	0.011	0.1308	0.0001	1.869	0.014	28.8	0.2

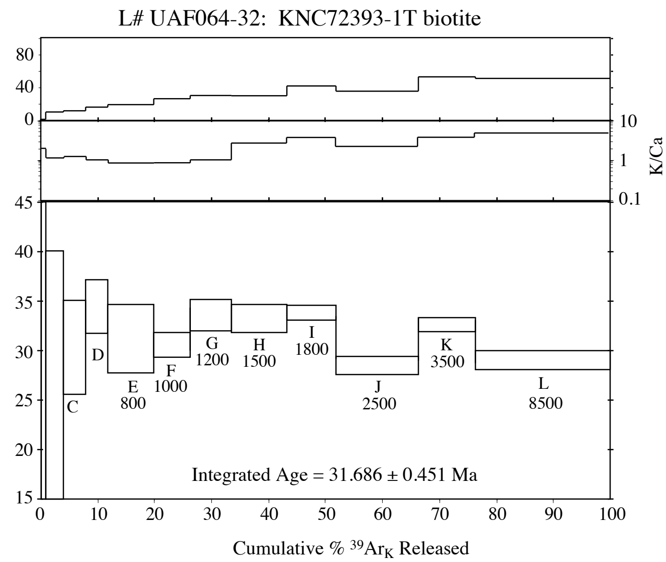
UAF064-32 KNC72393-1T BI 4/2/97
Weighted average of J from standards = 0.008611 +/- 0.000036

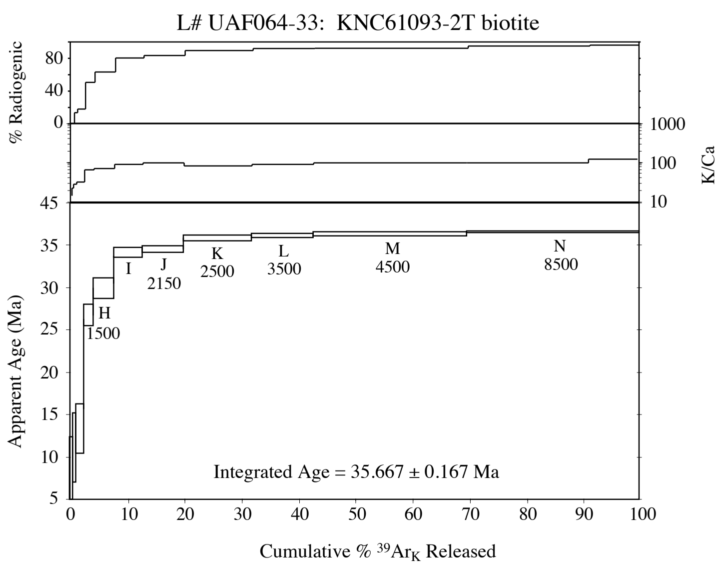
Laser Power (mW)	Cumulative 39Ar	40Ar/39Ar measured	+/-	37Ar/39Ar measured	+/-	36Ar/39Ar measured	+/-	% Atmospheri 40Ar	Ca/K	+/-	Cl/K	+/-	40*/39K	+/-	Age (Ma)	+/- (Ma)
150	0.007	76.981	0.805	0.499	0.015	0.258	0.007	99.2	0.916	0.028	0.0568	0.0026	0.612	1.933	9.5	29.9
300	0.038	16.514	0.066	0.796	0.008	0.049	0.001	88.1	1.461	0.015	0.0536	0.0007	1.962	0.310	30.2	4.7
450	0.079	13.672	0.056	0.965	0.005	0.039	0.001	83.6	1.771	0.010	0.0507	0.0007	2.233	0.176	34.4	2.7
600	0.118	10.459	0.072	1.143	0.010	0.029	0.001	80.6	2.099	0.019	0.0438	0.0004	2.021	0.227	31.1	3.5
800	0.198	7.442	0.036	1.133	0.008	0.019	0.000	73.3	2.080	0.014	0.0376	0.0003	1.982	0.082	30.5	1.3
1000	0.262	7.152	0.028	0.966	0.005	0.017	0.000	69.4	1.774	0.009	0.0388	0.0005	2.178	0.104	33.5	1.6
1200	0.334	7.184	0.033	0.367	0.003	0.017	0.000	69.8	0.673	0.006	0.0435	0.0004	2.158	0.093	33.2	1.4
1500	0.431	5.242	0.022	0.268	0.002	0.010	0.000	57.9	0.491	0.004	0.0417	0.0004	2.198	0.049	33.8	0.8
1800	0.518	5.182	0.029	0.449	0.003	0.011	0.000	64.2	0.824	0.006	0.0436	0.0004	1.845	0.059	28.4	0.9
2500	0.661	3.998	0.014	0.264	0.001	0.006	0.000	46.7	0.484	0.002	0.0419	0.0003	2.117	0.048	32.6	0.7
3500	0.762	3.691	0.013	0.207	0.001	0.006	0.000	48.6	0.380	0.003	0.0403	0.0003	1.881	0.062	29.0	1.0
8500	1.000	3.631	0.012	0.262	0.002	0.005	0.000	41.8	0.481	0.004	0.0373	0.0002	2.096	0.049	32.3	0.8
Integrated		6.336	0.008	0.477	0.001	0.015	0.000	67.4	0.876	0.002	0.0412	0.0001	2.055	0.028	31.6	0.5

UAF064-33 KNC61093-2T BI? 4/3/97 wasatch
Weighted average of J from standards = 0.008611 +/- 0.000036

Laser Power (mW)	Cumulative 39Ar	40Ar/39Ar measured	+/-	37Ar/39Ar measured	+/-	36Ar/39Ar measured	+/-	% Atmospheri 40Ar	Ca/K	+/-	Cl/K	+/-	40*/39K	+/-	Age (Ma)	+/- (Ma)
150	0.002	20.165	0.196	0.069	0.011	0.068	0.003	100.1	0.127	0.019	0.0131	0.0009	-0.021	0.801	-0.3	12.4
300	0.004	8.799	0.094	0.044	0.008	0.031	0.001	105.2	0.082	0.015	0.0098	0.0006	-0.455	0.419	-7.1	6.5
450	0.007	5.490	0.037	0.035	0.005	0.016	0.001	87.0	0.064	0.010	0.0104	0.0005	0.712	0.262	11.0	4.0
600	0.012	4.970	0.039	0.032	0.004	0.014	0.001	82.6	0.058	0.008	0.0137	0.0004	0.858	0.189	13.3	2.9
800	0.024	3.474	0.024	0.015	0.001	0.006	0.000	49.7	0.028	0.002	0.0196	0.0004	1.733	0.081	26.7	1.2
1000	0.042	3.113	0.018	0.014	0.001	0.004	0.000	37.1	0.026	0.002	0.0221	0.0003	1.940	0.081	29.9	1.2
1200	0.078	2.792	0.008	0.011	0.001	0.002	0.000	19.7	0.021	0.001	0.0242	0.0002	2.219	0.038	34.2	0.6
1500	0.128	2.725	0.006	0.010	0.000	0.002	0.000	16.7	0.019	0.001	0.0254	0.0002	2.245	0.024	34.5	0.4
1800	0.201	2.642	0.006	0.012	0.000	0.001	0.000	10.9	0.022	0.001	0.0258	0.0001	2.330	0.022	35.8	0.3
2150	0.320	2.585	0.006	0.011	0.000	0.001	0.000	8.0	0.020	0.000	0.0266	0.0001	2.351	0.016	36.2	0.2
2500	0.428	2.587	0.006	0.010	0.000	0.001	0.000	7.7	0.018	0.000	0.0259	0.0002	2.361	0.016	36.3	0.2
3500	0.697	2.538	0.003	0.010	0.000	0.000	0.000	5.1	0.018	0.000	0.0269	0.0001	2.383	0.007	36.6	0.1
4500	0.912	2.501	0.003	0.008	0.000	0.000	0.000	3.9	0.015	0.000	0.0266	0.0001	2.377	0.007	36.6	0.1
8500	1.000	2.526	0.006	0.006	0.000	0.000	0.000	5.2	0.011	0.000	0.0259	0.0001	2.367	0.016	36.4	0.3
Integrated		2.654	0.002	0.010	0.000	0.001	0.000	11.7	0.018	0.000	0.0260	0.0000	2.318	0.005	35.7	0.2


L# UAF064-31: KNC72393-1T hornblende
% Radiogenic
Apparent Age (Ma)
F
G 1200
H 1500
I 1800
J 2500
K 3500
L 8500
Integrated Age = 28.809 ± 0.241 Ma
Cumulative % $^{39}Ar_K$ Released


L# UAF064-32: KNC72393-1T biotite
K/Ca
C
D
E 800
F 1000
G 1200
H 1500
I 1800
J 2500
K 3500
L 8500
Integrated Age = 31.686 ± 0.451 Ma
Cumulative % $^{39}Ar_K$ Released


L# UAF064-33: KNC61093-2T biotite
% Radiogenic
K/Ca
Apparent Age (Ma)
H 1500
I
J 2150
K 2500
L 3500
M 4500
N 8500
Integrated Age = 35.667 ± 0.167 Ma
Cumulative % $^{39}Ar_K$ Released

$^{40}Ar/^{39}Ar$ Geochronology Results from the Provo Quadrangle, Utah

By

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JANUARY 10, 2001

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Introduction

Samples from Utah were submitted for $^{40}Ar/^{39}Ar$ dating by Jon King. Hornblende was prepared from KNC53094-3, and biotite from JC99-37 and KNC53094-5.

$^{40}Ar/^{39}Ar$ Analytical Methods and Results

The biotite and hornblende samples were analyzed by the CO_2 laser incremental heating age spectrum method. Abbreviated analytical methods for these samples are also given in Table 1. The argon isotopic results are listed in Table 2 (biotite and hornblende). Details of the overall operation of the New Mexico Geochronology Research Laboratory are provided in the Appendix. Figures show the probability distribution diagram yielded by the biotite and hornblende samples. A summary of the preferred sample ages is given in Table 1.

The age spectrum for sample KNC53094-3 (figure) is flat, yielding a plateau from steps D to H (90.3% of the $^{39}Ar_K$ released) with an age of 38.78±0.62 Ma. The radiogenic yields are initially low, but then increase to greater than 80% for the remainder of the age spectrum. The K/Ca ratios for nearly the entire age spectrum are consistent at about 0.10.

The age spectrum for sample JC99-37 is very discordant with ages increasing from an initial 60.7 Ma to greater than 190 Ma (figure). The radiogenic yield is somewhat correlated to the shape of the age spectrum. The maximum radiogenic yield for JC99-37 is less than 84%. The K/Ca ratios correlate well from steps A to C (0.7 to 8.0), but then are inversely correlated from steps C to K (8.0 to 2.2). The shape of the age spectrum for JC99-37 prevents a plateau from being assigned. The total gas or integrated age is 97.2±1.3 Ma (±2 σ). The isotope correlation diagram (inverse isochron) is highly non-isochronous; no age can be derived.

The age spectrum for biotite sample KNC53094-5 (figure) is also discordant, but to a lesser extent than JC99-37. KNC53094-5 yields an undulatory age spectrum where the youngest age achieved is essentially zero and the oldest age is 42 Ma. Both radiogenic yield and K/Ca values are correlated to the undulatory pattern of the age spectrum. Because of the discordance of the age spectrum, a plateau cannot be unambiguously assigned. The total gas or integrated age is 37.85±0.88 Ma. The inverse isochron for KNC53094-5 yields a high MSWD of 85.1 and an age of 40.41±0.84 Ma ($^{40}Ar/^{36}Ar$ = 283±19).

Discussion

For the hornblende sample, the plateau age is inferred to be the best estimate of the eruption age. The preferred age for hornblende KNC53094-3 is 38.78±0.62 Ma.

Biotite JC99-37 failed to yield a plateau age or a meaningful isochron age or total gas age. The steadily increasing ages together with the increasing radiogenic yields and K/Ca ratios are likely the result of alteration of the biotite. Alteration can cause ^{40}Ar loss, thereby resulting in anomalously young ages in the earliest portion of the $^{39}Ar_K$ release spectrum. Additional sample preparation and/or analytical manipulation are generally not effective for improving the quality of $^{40}Ar/^{39}Ar$ data from altered samples. An alternate (albeit, unlikely) explanation may be argon loss through a thermal/reheating event. However, a problem with a reheating scenario is the Jurassic apatite fission track and zircon fission track ages (152.0±11.5 Ma and 196.6±12.6 Ma, respectively). Closure/annealing temperatures for apatites and zircons range from 100°C to 250°C (Sharma et al., 1980), while the closure temperature for a biotite is approximately 350°C (Heizler et al., 1988). Assuming that there was a thermal event sufficiently hot enough to cause argon loss from the biotite, the fission tracks in the apatites/zircons would almost certainly be annealed. The fission track ages show no sign of a reheating event younger than approximately 150 Ma (Kurt Constenius, pers. comm.).

The discordant age spectrum for biotite KNC53094-5 prevents a plateau age from being assigned to this sample. The most likely cause of the undulatory spectrum is alteration, but argon ($^{40}Ar_E$??) release from other mineral phases (hornblende, apatite, sphene) cannot be ruled out. Although the inverse isochron has a high MSWD (85.1), the age of 40.41±0.84 Ma is interpreted to be the age of eruption.

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Table 1. $^{40}Ar/^{39}Ar$ summary table and analytical procedures.

Sample	L#	Irrad	Mineral	age analysis	n	%^{39}Ar	MSWD	K/Ca	Age	±2
KNC53094-3	51474	NM-127	20.88 mg hornblende	plateau	5	90.3	20.3**	0.10	38.78	0.62*
JC99-37	51479	NM-127	2.56 mg biotite	N.A.	0	0.0	N.A.	N.A.	N.A.	N.A.
KNC53094-5	51488	NM-127	4.14 mg biotite	isochron	12	N.A.	85.1	24.0	40.41	0.84*

** MSWD outside 95% confidence interval
* two-sigma errors

Notes:

Sample preparation and irradiation:

Samples provided by Jon King of the Utah Geological Survey.
Sanidine, hornblende and biotite separated using standard techniques (crushing, sieving, magnetics, heavy liquids and hand-picking). Samples were packaged and irradiated in machined Al discs for 14 hours in D-3 position, Texas A&M University Research Reactor. Neutron flux monitor Fish Canyon Tuff sanidine (FC-1). Assigned age = 27.84 Ma (Deino and Potts, 1990) relative to Mmhb-1 at 520.4 Ma (Samson and Alexander, 1987).

Instrumentation:

Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system. Single crystals of sanidine were fused by a 50-watt Synrad CO_2 laser.
Hornblende and biotite samples were step-heated by 50-watt CO2 laser using a beam integrator lens. Reactive gases removed during a 2 minute (sanidine) or 13 minute (hornblendes and biotites) reaction with 2 SAES GP-50 getters, 1 operated at ~450°C and 1 at 20°C. Gas also exposed to a W filament operated at ~2000°C and a cold finger operated at -140°C.

Analytical parameters:

Electron multiplier sensitivity averaged 1.45×10^{-16} moles/pA for those samples analyzed by the laser.
Total system blank and background for the laser fusion sample averaged 1110, 7.7, 11.6, 3.0, 8.1×10^{-18} moles
Total system blank and background for the step-heated samples averaged 1028, 2.6, 1.2, 0.8, 3.9×10^{-17} moles
J-factors determined to a precision of ± 0.1% by CO_2 laser-fusion of 4 single crystals from each of 4 or 6 radial positions around the irradiation tray. Correction factors for interfering nuclear reactions were determined using K-glass and CaF_2 and are as follows:
$(^{40}Ar/^{39}Ar)_K = 0.0002 \pm 0.0003$; $(^{36}Ar/^{37}Ar)_{Ca} = 0.00028 \pm 0.000011$; and $(^{39}Ar/^{37}Ar)_{Ca} = 0.00089 \pm 0.00003$.

Age calculations:

Weighted mean age calculated by weighting each age analysis by the inverse of the variance. Weighted mean error calculated using the method of (Taylor, 1982).
Total gas ages and errors calculated by weighting individual steps by the fraction of ^{39}Ar released. MSWD values are calculated for n-1 degrees of freedom for plateau and preferred ages.
Isochron ages, $^{40}Ar/^{36}Ar_i$ and MSWD values calculated from regression results obtained by the methods of York (1969).
Decay constants and isotopic abundances following Steiger and Jäger (1977).
All final errors reported at ±2s, unless otherwise noted.

Table 2. $^{40}Ar/^{39}Ar$ analytical results for the samples step-heated in the CO2 laser.

KNC53094-3, 20.88 mg hornblende, J=0.00149654±0.10%, NM-127, Lab#=51474-01

ID		Laser Output (W)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ ($x 10^{-3}$)	$^{39}Ar_K$ ($x 10^{-16}$ mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1 σ (Ma)
A	†	*5*	*271*	*4.186*	*861.4*	*8.36*	*0.12*	*6.1*	*1.0*	*43.9*	*6.4*
B	†	*10*	*76.43*	*4.529*	*212.8*	*23.5*	*0.11*	*18.2*	*3.6*	*37.4*	*1.4*
C	†	*15*	*53.52*	*2.143*	*133.0*	*16.1*	*0.24*	*26.9*	*5.4*	*38.5*	*1.3*
D		20	25.35	4.164	38.63	39.1	0.12	56.3	9.9	38.30	0.44
E		25	18.04	4.981	13.57	122.3	0.10	80.1	23.8	38.75	0.15
F		30	16.91	4.965	9.513	220.9	0.10	85.8	48.9	38.93	0.13
G		35	16.62	5.010	7.673	274.1	0.10	88.8	80.1	39.60	0.13
H		40	15.40	5.422	5.739	137.4	0.094	91.9	95.7	38.00	0.12
I	†	*45*	*16.44*	*5.786*	*9.384*	*23.8*	*0.088*	*86.0*	*98.4*	*38.00*	*0.33*
J	†	*50*	*18.08*	*6.239*	*14.29*	*13.7*	*0.082*	*79.5*	*100.0*	*38.62*	*0.55*
total gas age				n=10		879.2	0.10			38.91	0.52*
plateau			MSWD=20.3**	n=5	steps D-H	793.8	0.10		90.3	38.78	0.62*
isochron			MSWD=17.9**	n=10		$^{40}Ar/^{36}Ar$=296±17*				38.65	0.59*

JC99-37, 2.56 mg biotite, J=0.001494995±0.10%, NM-127, Lab#=51479-01

ID		Laser Output (W)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ ($x 10^{-3}$)	$^{39}Ar_K$ ($x 10^{-16}$ mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1 σ (Ma)
A	†	*10*	*81.68*	*0.7229*	*199.2*	*165*	*0.71*	*28.0*	*24.5*	*60.7*	*1.0*
B	†	*14*	*61.93*	*0.2494*	*99.52*	*174*	*2.0*	*52.5*	*50.3*	*85.73*	*0.51*
C	†	*18*	*54.94*	*0.0636*	*53.72*	*100*	*8.0*	*71.1*	*65.2*	*102.42*	*0.43*
D	†	*22*	*57.50*	*0.0781*	*46.45*	*67.0*	*6.5*	*76.1*	*75.1*	*114.38*	*0.49*
E	†	*26*	*59.10*	*0.0890*	*43.62*	*45.9*	*5.7*	*78.2*	*81.9*	*120.55*	*0.53*
F	†	*30*	*61.66*	*0.0988*	*39.57*	*33.0*	*5.2*	*81.1*	*86.8*	*130.00*	*0.62*
G	†	*35*	*63.29*	*0.1020*	*38.75*	*26.4*	*5.0*	*81.9*	*90.7*	*134.70*	*0.60*
H	†	*40*	*63.64*	*0.1033*	*39.72*	*25.3*	*4.9*	*81.6*	*94.5*	*134.85*	*0.62*
I	†	*45*	*68.41*	*0.1098*	*39.86*	*22.9*	*4.6*	*82.8*	*97.9*	*146.65*	*0.70*
J	†	*50*	*75.81*	*0.1473*	*42.00*	*10.4*	*3.5*	*83.6*	*99.4*	*163.4*	*1.0*
K	†	*50*	*92.55*	*0.2270*	*52.22*	*4.14*	*2.2*	*83.3*	*100.0*	*196.9*	*2.2*
total gas age				n=11		674.7	3.8			97.2	1.3*
plateau			MSWD=N.A.	n=0		0.0	0.0		0.0	N.A.	N.A.
isochron			MSWD=1795.9*	n=11		$^{40}Ar/^{36}Ar$=145±85*				142.0*	23.7*

KNC53094-5, 4.14 mg biotite, J=0.001496146±0.10%, NM-127, Lab#=51488-01

ID		Laser Output (W)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ ($x 10^{-3}$)	$^{39}Ar_K$ ($x 10^{-16}$ mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1 σ (Ma)
A	†	*5*	*197.0*	*0.0263*	*666.9*	*45.3*	*19.4*	*0.0*	*3.1*	*-0.2*	*3.5*
B	†	*10*	*31.16*	*0.0175*	*62.61*	*166.0*	*29.1*	*40.6*	*14.4*	*33.86*	*0.39*
C	†	*14*	*21.13*	*0.0153*	*22.85*	*172.6*	*33.4*	*68.0*	*26.2*	*38.40*	*0.21*
D	†	*18*	*19.77*	*0.0161*	*16.37*	*169.7*	*31.6*	*75.5*	*37.7*	*39.88*	*0.16*
E	†	*22*	*20.33*	*0.0204*	*19.68*	*164.9*	*25.1*	*71.4*	*49.0*	*38.77*	*0.19*
F	†	*26*	*20.98*	*0.0267*	*23.89*	*161.6*	*19.1*	*66.4*	*60.0*	*37.19*	*0.19*
G	†	*30*	*20.32*	*0.0324*	*17.59*	*133.9*	*15.7*	*74.4*	*69.1*	*40.36*	*0.19*
H	†	*35*	*20.20*	*0.0292*	*15.00*	*161.5*	*17.5*	*78.1*	*80.2*	*42.08*	*0.18*
I	†	*40*	*23.64*	*0.0212*	*26.99*	*163.8*	*24.1*	*66.3*	*91.3*	*41.81*	*0.22*
J	†	*45*	*48.21*	*0.0361*	*111.6*	*76.1*	*14.1*	*31.6*	*96.5*	*40.69*	*0.68*
K	†	*50*	*54.56*	*0.0216*	*131.4*	*41.0*	*23.6*	*28.8*	*99.3*	*41.95*	*0.93*
L	†	*50*	*451.1*	*0.0252*	*1497.1*	*10.2*	*20.3*	*1.9*	*100.0*	*23.4*	*11.0*
total gas age				n=12		1466.6	24.0			37.85	0.88*
plateau			MSWD=N.A.	n=0		0.0	0.0		0.0	N.A.	N.A.
isochron			MSWD=85.1**	n=12		$^{40}Ar/^{36}Ar$=283±19*				40.41	0.84*

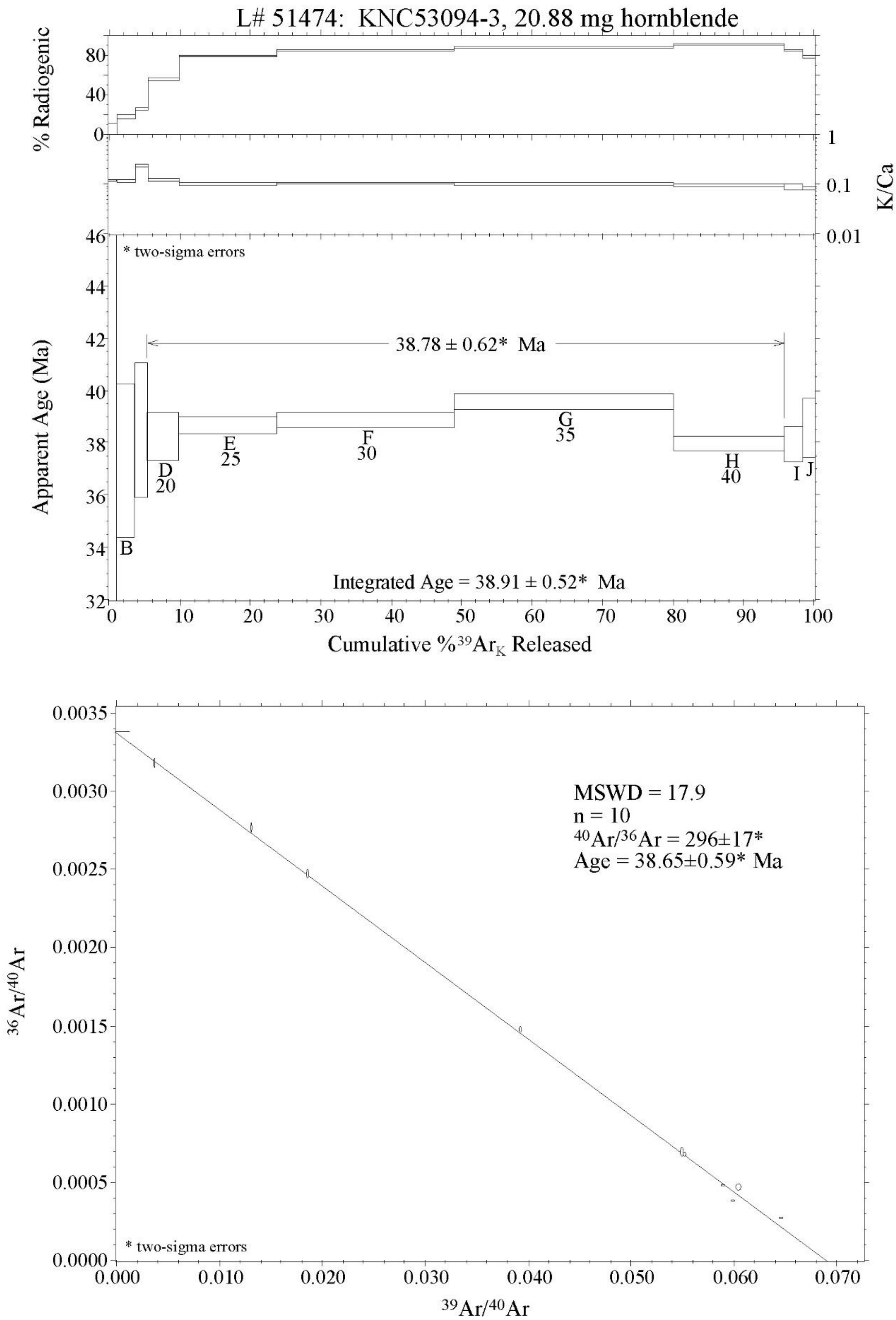


Figure 1. Age spectrum and inverse isochron for hornblende KNC53094-3. The plateau age of 38.78±0.62 Ma is the preferred age of this sample.

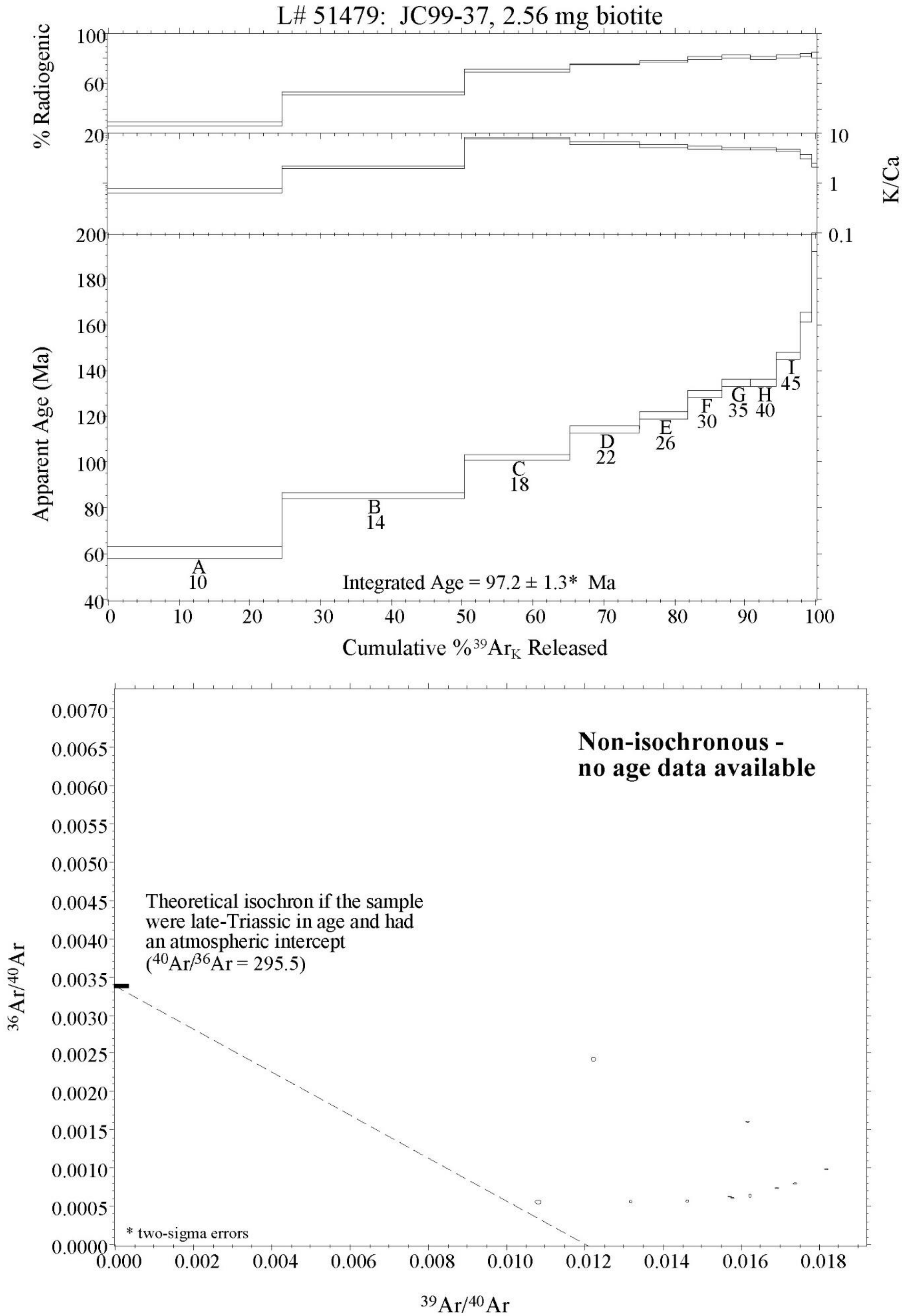
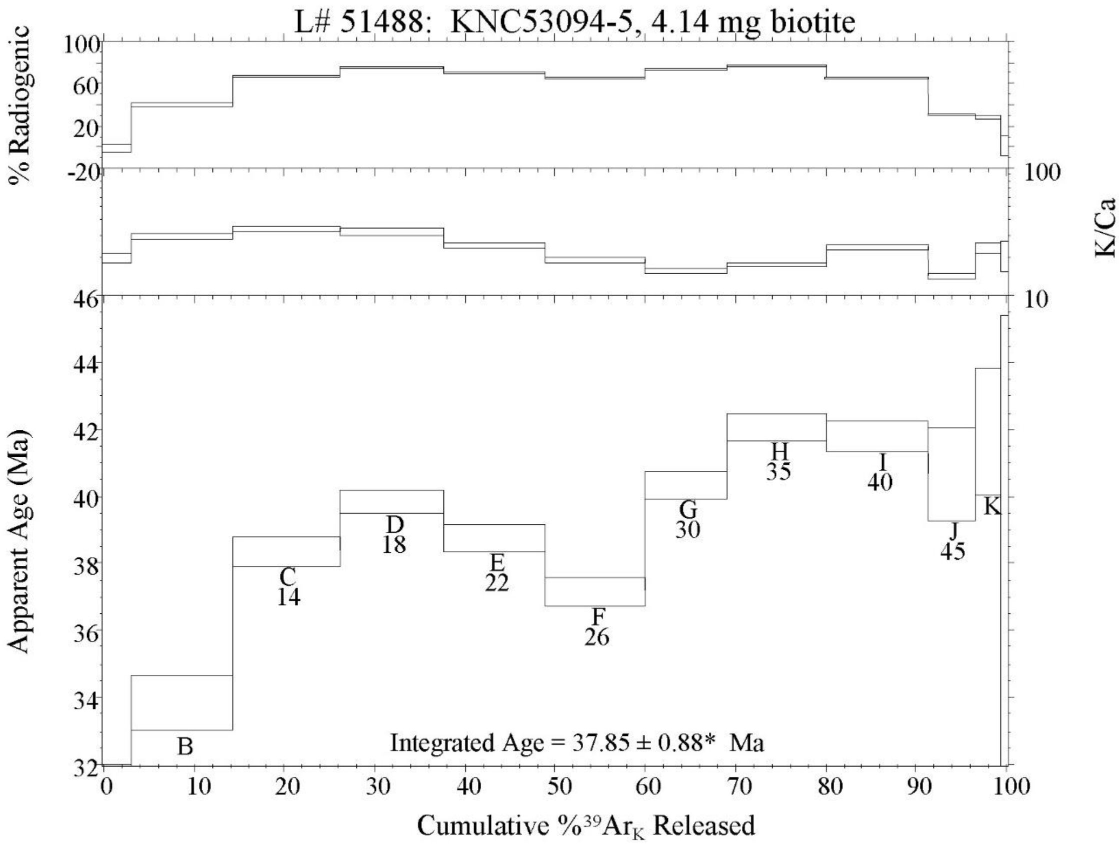


Figure 2. Age spectrum and inverse isochron for biotite JC99-37. We cannot assign an age to this sample.



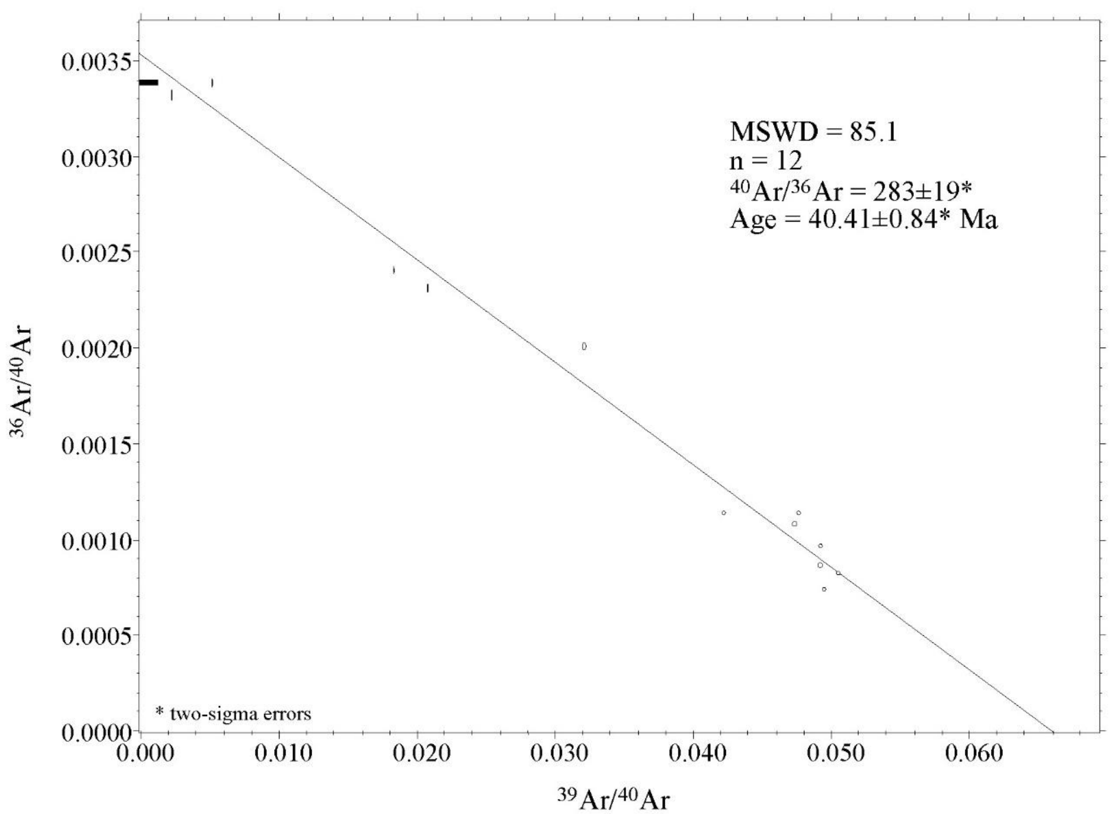


Figure 3. Age spectrum and inverse isochron for biotite KNC53094-5. The inverse isochron age of 40.41±0.84 Ma is the preferred age of this sample.

New Mexico Bureau of Mines and Mineral Resources

Open file report #

Procedures of the New Mexico Geochronology Research Laboratory

For the Period June 1998 – present

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$^{40}Ar/^{39}Ar$ and K-Ar dating

Often, large bulk samples (either minerals or whole rocks) are required for K-Ar dating and even small amounts of xenocrystic, authigenic, or other non-ideal behavior can lead to inaccuracy. The K-Ar technique is susceptible to sample inhomogeneity as separate aliquots are required for the potassium and argon determinations. The need to determine absolute quantities (i.e. moles of $^{40}Ar^*$ and ^{40}K) limits the precision of the K-Ar method to approximately 1% and also, the technique provides limited potential to evaluate underlying assumptions. In the $^{40}Ar/^{39}Ar$ variant of the K-Ar technique, a sample is irradiated with fast neutrons thereby converting ^{39}K to ^{39}Ar through a (n,p) reaction. Following irradiation, the sample is either fused or incrementally heated and the gas analyzed in the same manner as in the conventional K-Ar procedure, with one exception, no argon spike need be added.

Some of the advantages of the $^{40}Ar/^{39}Ar$ method over the conventional K-Ar technique are:

1. A single analysis is conducted on one aliquot of sample thereby reducing the sample size and eliminating sample inhomogeneity.
2. Analytical error incurred in determining absolute abundances is reduced by measuring only isotopic ratios. This also eliminates the need to know the exact weight of the sample.
3. The addition of an argon spike is not necessary.
4. The sample does not need to be completely fused, but rather can be incrementally heated. The $^{40}Ar/^{39}Ar$ ratio (age) can be measured for each fraction of argon released and this allows for the generation of an age spectrum.

The age of a sample as determined with the $^{40}Ar/^{39}Ar$ method requires comparison of the measured $^{40}Ar/^{39}Ar$ ratio with that of a standard of known age. Also, several isotopes of other elements (Ca, K, Cl, Ar) produce argon during the irradiation procedure and must be corrected for. Far more in-depth details of the determination of an apparent age via the $^{40}Ar/^{39}Ar$ method are given in Dalrymple et al. (1981) and McDougall and Harrison (1988).

Analytical techniques

Sample Preparation and irradiation details

Mineral separates are obtained in various fashions depending upon the mineral of interest, rock type and grain size. In almost all cases the sample is crushed in a jaw crusher and ground in a disc grinder and then sized. The size fraction used generally corresponds to the largest size possible which will permit obtaining a pure mineral separate. Following sizing, the sample is washed and dried. For plutonic and metamorphic rocks and lavas, crystals are separated using standard heavy liquid, Franz magnetic and hand-picking techniques. For volcanic sanidine and plagioclase, the sized sample is reacted with 15% HF acid to remove glass and/or matrix and then thoroughly washed prior to heavy liquid and magnetic separation. For groundmass concentrates, rock fragments are selected which do not contain any visible phenocrysts.

The NMGRL uses either the Ford reactor at the University of Michigan or the Nuclear Science Center reactor at Texas A&M University. At the Ford reactor, the L67 position is used (unless otherwise noted) and the D-3 position is always used at the Texas A&M reactor. All of the Michigan irradiations are carried out underwater without any shielding for thermal neutrons, whereas the Texas irradiations are in a dry location which is shielded with B and Cd. Depending upon the reactor used, the mineral separates are loaded into either holes drilled into Al discs or into 6 mm I.D. quartz tubes. Various Al discs are used. For Michigan, either six hole or twelve hole, 1 cm diameter discs are used and all holes are of equal size. Samples are placed in the 0, 120 and 240° locations and standards in the 60, 180 and 300° locations for the six hole disc. For the twelve hole disc, samples are located at 30, 60, 120, 150, 210, 240, 300, and 330° and standards at 0, 90, 180 and 270 degrees. If samples are loaded into the quartz tubes, they are wrapped in Cu foil with standards interleaved at ~0.5 cm intervals. For Texas, 2.4 cm diameter discs contain either sixteen or six sample holes with smaller holes used to hold the standards. For the six hole disc, sample locations are 30, 90, 150, 210, 270 and 330° and standards are at 0, 60, 120, 180, 240 and 300°. Samples are located at 18, 36, 54, 72, 108, 126, 144, 162, 198, 216, 234, 252, 288, 306, 324, 342 degrees and standards at 0, 90, 180 and 270 degrees in the sixteen hole disc. Following sample loading into the discs, the discs are stacked, screwed together and sealed in vacuo in either quartz (Michigan) or Pyrex (Texas) tubes.

Extraction Line and Mass Spectrometer details

The NMGRL argon extraction line has both a double vacuum Mo resistance furnace and a CO_2 laser to heat samples. The Mo furnace crucible is heated with a W heating element and the temperature is monitored with a W-Re thermocouple placed in a hole drilled into the bottom of the crucible. A one inch long Mo liner is placed in the bottom of the crucible to collect the melted samples. The furnace temperature is calibrated by either/or melting Cu foil or with an additional thermocouple inserted in the top of the furnace down to the liner. The CO_2 laser is a Synrad 10W laser equipped with a He-Ne pointing laser. The laser chamber is constructed from a 3 3/8" stainless steel conflat and the window material is ZnS. The extraction line is a two stage design. The first stage is equipped with a SAES GP-50 getter, whereas the second stage houses two SAES GP-50 getters and a tungsten filament. The first stage getter is operated at 450°C as is one of the second stage getters. The other second stage getter is operated at room temperature and the tungsten filament is operated at ~2000°C. Gases evolved from samples heated in the furnace are reacted with the first stage getter during heating. Following heating, the gas is expanded into the second stage for two minutes and then isolated from the first stage. During second stage cleaning, the first stage and furnace are pumped out. After gettering in the second stage, the gas is expanded into the mass spectrometer. Gases evolved from samples heated in the laser are expanded through a cold finger operated at -140°C and directly into the second stage. Following cleanup, the gas in the second stage and laser chamber is expanded into the mass spectrometer for analysis.

The NMGRL employs a MAP-215-50 mass spectrometer which is operated in static mode. The mass spectrometer is operated with a resolution ranging between 450 to 600 at mass 40 and isotopes are detected on a Johnston electron multiplier operated at

~2.1 kV with an overall gain of about 10,000 over the Faraday collector. Final isotopic intensities are determined by linear regression to time zero of the peak height versus time following gas introduction for each mass. Each mass intensity is corrected for mass spectrometer baseline and background and the extraction system blank.

Blanks for the furnace are generally determined at the beginning of a run while the furnace is cold and then between heating steps while the furnace is cooling. Typically, a blank is run every three to six heating steps. Periodic furnace hot blank analysis reveals that the cold blank is equivalent to the hot blank for temperatures less than about 1300°C. Laser system blanks are generally determined between every four analyses. Mass discrimination is measured using atmospheric argon which has been dried using a Ti-sublimation pump. Typically, 10 to 15 replicate air analyses are measured to determine a mean mass discrimination value. Air pipette analyses are generally conducted 2-3 times per month, but more often when samples sensitive to the mass discrimination value are analyzed. Correction factors for interfering nuclear reactions on K and Ca are determined using K-glass and CaF_2, respectively. Typically, 3-5 individual pieces of the salt or glass are fused with the CO_2 laser and the correction factors are calculated from the weighted mean of the individual determinations.

Data acquisition, presentation and age calculation

Samples are either step-heated or fused in a single increment (total fusion). Bulk samples are often step-heated and the data are generally displayed on an age spectrum or isochron diagram. Single crystals are often analyzed by the total fusion method and the results are typically displayed on probability distribution diagrams or isochron diagrams.

The Age Spectrum Diagram

Age spectra plot apparent age of each incrementally heated gas fraction versus the cumulative % $^{39}Ar_K$ released, with steps increasing in temperature from left to right. Each apparent age is calculated assuming that the trapped argon (argon not produced by *in situ* decay of ^{40}K) has the modern day atmospheric $^{40}Ar/^{36}Ar$ value of 295.5. Additional parameters for each heating step are often plotted versus the cumulative $\%^{39}Ar_K$ released. These auxiliary parameters can aid age spectra interpretation and may include radiogenic yield (percent of ^{40}Ar which is not atmospheric), K/Ca (determined from measured Ca-derived ^{37}Ar and K-derived ^{39}Ar) and/or K/Cl (determined from measured Cl-derived ^{38}Ar and K-derived ^{39}Ar). Incremental heating analysis is often effective at revealing complex argon systematics related to excess argon, alteration, contamination, ^{39}Ar recoil, argon loss, etc. Often low-temperature heating steps have low radiogenic yields and apparent ages with relatively high errors due mainly to loosely held, non-radiogenic argon residing on grain surfaces or along grain boundaries. An entirely or partially flat spectrum, in which apparent ages are the same within analytical error, may indicate that the sample is homogeneous with respect to K and Ar and has had a simple thermal and geological history. A drawback to the age spectrum technique is encountered when hydrous minerals such as micas and amphiboles are analyzed. These minerals are not stable in the ultra-high vacuum extraction system and thus step-heating can homogenize important details of the true ^{40}Ar distribution. In other words, a flat age spectrum may result even if a hydrous sample has a complex argon distribution.

The Isochron Diagram

Argon data can be plotted on isotope correlation diagrams to help assess the isotopic composition of Ar trapped at the time of argon closure, thereby testing the assumption that trapped argon isotopes have the composition of modern atmosphere which is implicit in age spectra. To construct an "inverse isochron" the $^{36}Ar/^{40}Ar$ ratio is plotted versus the $^{39}Ar/^{40}Ar$ ratio. A best fit line can be calculated for the data array which yields the value for the trapped argon (Y-axis intercept) and the $^{40}Ar^*/^{39}Ar_K$ value (age) from the X-axis intercept. Isochron analysis is most useful for step-heated or total fusion data which have a significant spread in radiogenic yield. For young or low K samples, the calculated apparent age can be very sensitive to the composition of the trapped argon and therefore isochron analysis should be preformed routinely on these samples (cf. Heizler and Harrison, 1988). For very old (>Mesozoic) samples or relatively old sanidines (>mid-Cenozoic) the data are often highly radiogenic and cluster near the X-axis thereby making isochron analysis of little value.

The Probability Distribution Diagram

The probability distribution diagram, which is sometimes referred to as an ideogram, is a plot of apparent age versus the summation of the normal distribution of each individual analysis (Deino and Potts, 1992). This diagram is most effective at displaying single crystal laser fusion data to assess the distribution of the population. The K/Ca, radiogenic yield, and the moles of ^{39}Ar for each analysis are also often displayed for each sample as this allows for visual ease in identifying apparent age correlations between, for instance, plagioclase contamination, signal size and/or radiogenic concentrations. The error (1σ) for each age analysis is generally shown by the horizontal lines in the moles of ^{39}Ar section. Solid symbols represent the analyses used for the weighted mean age calculation and the generation of the solid line on the ideogram, whereas open symbols represent data omitted from the age calculation. If shown, a dashed line represents the probability distribution of all of the displayed data. The diagram is most effective for displaying the form of the age distribution (i.e. gaussian, skewed, etc.) and for identifying xenocrystic or other grains which fall outside of the main population.

Error Calculations

For step-heated samples, a plateau for the age spectrum is defined by the steps indicated. The plateau age is calculated by weighting each step on the plateau by the inverse of the variance and the error is calculated by either the method of Samson and Alexander (1987) or Taylor (1982). A mean sum weighted deviates (MSWD) value is determined by dividing the Chi-squared value by n-1 degrees of freedom for the plateau ages. If the MSWD value is outside the 95% confidence window (cf. Mahon, 1996; Table 1), the plateau or preferred age error is multiplied by the square root of the MSWD.

For single crystal fusion data, a weighted mean is calculated using the inverse of the variance to weight each age determination (Taylor, 1982). Errors are calculated as described for the plateau ages above.

Isochron ages, $^{40}Ar/^{36}Ar_i$ values and MSWD values are calculated from the regression results obtained by the York (1969) method.

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