^{40}Ar/^{39}Ar Geochronology Results for the Blind Lake, Deer Creek Lake, Flat Top, Henrie Knolls, Tabbys Peak, Tabbys Peak SW, Wig Mountain, and Wig Mountain NE Quadrangles, Utah

by

Utah Geological Survey and
New Mexico Geochronology Research Laboratory

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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 mapping funded or partially supported by the Utah Geological Survey (UGS). The references listed in table 1 report the age of the samples and 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. This report was prepared by the New Mexico Geochronology Research Laboratory (NMGRL) under contract to the UGS. These data are highly technical in nature and proper interpretation requires considerable training in the applicable geochronologic techniques.

Table 1. Sample numbers and locations.

Sample #	7.5' quadrangle	Latitude (N)	Longitude (W)	Reference
HK092106-1	Henrie Knolls	37° 35' 24.9"	112° 39' 36.9"	Biek and others (in prep.)
BT091106-1	Blind Lake	38° 09' 34.3"	111° 29' 57.4"	Doelling and Kuehne (in prep.)
HK092006-3	Henrie Knolls	37° 36' 56.9"	112° 43' 40.8"	Biek and others (in prep.)
HH091406-1	Flat Top	38° 29' 06.7"	111° 28' 15.3"	Doelling and Kuehne (in prep.)
HL091206-2	Deer Creek Lake	38° 05' 07.6"	111° 27' 39.7"	Doelling and Kuehne (in prep.)
D-17	Tabbys Peak SW	40° 18' 39.6"	112° 56' 36.3"	Clark and others (2008); Clark (2008)
D-4	Tabbys Peak SW	40° 19' 17.9"	112° 54' 01.1"	Clark and others (2008); Clark (2008)
D-6	Wig Mountain	40° 20' 03.3"	113° 01' 42.2"	Clark and others (2008); Clark (2008)
D-40	Tabbys Peak	40° 27' 47.7"	112° 59' 13.8"	Clark and others (2008); Clark (2008)
D-42	Wig Mountain NE	40° 26' 55.3"	113° 01' 57.8"	Clark and others (2008); Clark (2008)
D-7	Wig Mountain	40° 21' 37.8"	113° 00' 04.0"	Clark and others (2008); Clark (2008)
D-47	Tabbys Peak	40° 26' 18.0"	112° 56' 57.2"	Clark and others (2008); Clark (2008)

Location data based on NAD27.

DISCLAIMER

References to Reports that Cite or Explain Samples Analyzed in this Report

Biek, R.F., Rowley, P.D., Moore, D.W., Anderson, J.J., Sable, E.G., and Nealey, L.D., in preparation, Interim geologic map of the south-central part of the Panguitch 30' x 60' quadrangle, Garfield, Iron, and Kane Counties, Utah: Utah Geological Survey Open-File Report, scale 1:100,000.

Clark, D.L., 2008, Whole-rock geochemical data for the Granite Peak, Granite Peak SE, Dugway Proving Ground SW, Camels Back Ridge NE, Wig Mountain, Wig Mountain NE, Tabbys Peak, Tabbys Peak SE, Tabbys Peak SW, and Wildcat Mountain quadrangles, Utah: Utah Geological Survey Open-File Report 533, 4 pages, also available online, <http://geology.utah.gov/online/ofr/ofr-533.pdf>.

Clark, D.L., Oviatt, C.G., and Page, D., 2008, Interim geologic map of Dugway Proving Ground and adjacent areas, parts of the Wildcat Mountain, Rush Valley, and Fish Springs 30' x 60' quadrangles, Tooele County, Utah (year 2 of 2): Utah Geological Survey Open-File Report 532, 3 plates, scale 1:75,000.

Doelling, H.H., and Kuehne, P.A., in preparation, Geologic map of the east half of the Loa 30' x 60' quadrangle, Emery, Garfield, and Wayne Counties, Utah: Utah Geological Survey Map, scale 1:100,000.

$^{40}Ar/^{39}Ar$ Geochronology Results

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Introduction

Twelve volcanic rocks from various locations in Utah were submitted for dating by the Utah Geological Survey. The rocks vary in composition; therefore a variety of mineral phases or groundmass concentrates were separated and dated.

^{40}Ar/^{39}Ar Analytical Methods

Sample preparation
methods: crushing, sieving,
heavy liquid (Lithium Metatungstate), magnetic separator, handpicking
groundmass concentrates ultrasonically cleaned with dilute HCl
sanidine and plagioclase ultrasonically cleaned with dilute HF
biotite and hornblende cleaned with H2O

Irradiation
Drilled aluminum discs, 7 hours (NM-210) and 0.5 hours (NM-211), Nuclear Science Center in College Station, Texas
Monitors: Fish Canyon sanidine, 28.02 Ma (Renne et al, 1998)

Extraction methods
groundmass concentrates (7), hornblende (2), plagioclase (1) and biotite (1) separates analyzed by the furnace incremental heating
D-6, D-42, BT091106-1, D-17, HK092106-1, HK092006-3, HL091206-2, D-7, HH091406-1, D-47 and D-40
one sanidine separate was analyzed by single-crystal laser fusion
D-4
Analytical parameters are further detailed in Tables 1-3 footnotes and in Appendix 2

Results

Results from this study are summarized in Table 1 and detailed in Tables 2 and 3. Results from individual sample analyses are presented in Figures 1 to 12, and are summarized on a sample by sample basis below.

Sample	**Phase**	**Age±2σ**	**Method**
HK092106-1	Groundmass	0.058±0.036 Ma	Furnace step-heat
BT091106-1	Groundmass	3.38±0.19 Ma	Furnace step-heat
HK092006-3	Groundmass	5.27±0.14 Ma	Furnace step-heat

HH091406-1	Plagioclase	25.55±0.11 Ma	Furnace step-heat
HL091206-2	Hornblende	26.86±0.53 Ma	Furnace step-heat
D-17	Groundmass	38.17±0.47 Ma	Furnace step-heat
D-4	Sanidine	38.69±0.10 Ma	Laser total-fusion
D-6	Groundmass	39.16±0.23 Ma	Furnace step-heat
D-40	Groundmass	40.61±0.78 Ma	Furnace step-heat
D-42	Groundmass	40.66±0.45 Ma	Furnace step-heat
D-7	Hornblende	41.73±0.24 Ma	Furnace step-heat
D-47	Biotite	194.42±0.53 Ma	Furnace step-heat

HK092106-1 Groundmass (Figure 1)

Weighted mean age 0.058±0.036 Ma n/n_{total} 10/11 MSWD 1.18
Extraction method Furnace step-heat
Morphology of age spectrum Nearly concordant, over 85% nearly concordant, final step has anomalously old apparent age.
Radiogenic yields very low yields, -0.2% to 3.1% radiogenic
K/Ca 0.50 to 2.0
Isochron Age steps A-J, 0.057±0.027 Ma, atmospheric intercept
Interpretation imprecise eruption age due to low radiogenic yields

BT091106-1 Groundmass (Figure 2)

Weighted mean age 3.38±0.19 Ma n/n_{total} 8/10 MSWD 1.55
Extraction method Furnace step-heat
Morphology of age spectrum Somewhat disturbed age spectrum, young apparent ages in initial 38.9% of gas released
Radiogenic yields very low yields in initial and final two steps, other steps 9.4% to 26.9% radiogenic
K/Ca 0.024 to 2.6, decreasing consistently from initial to final heating step
Isochron Age steps C-J, 3.41±0.29 Ma, atmospheric intercept
Interpretation fairly reliable eruption age

HK092006-3 Groundmass (Figure 3)

Isochron age 5.27±0.13 Ma $^{40}Ar/^{36}Ar$= 299.3±3.1 n/n_{total} 7/10 MSWD 1.02
Extraction method Furnace step-heat
Morphology of age spectrum Nearly concordant age spectrum, young initial step and slightly old final step
Radiogenic yields increasing radiogenic yields (3-41%) over initial ~60% of age spectrum followed by decrease (34%-17.9%)
K/Ca 0.036 to 0.83, rise and fall correlated to change in radiogenic yields

Isochron Age steps D-J, 5.27±0.13 Ma, slightly above atmospheric intercept (299.3±3.1)
Interpretation reliable eruption age

HH091406-1 Plagioclase (Figure 4)

Weighted mean age 25.55±0.11 Ma n/n_{total} 10/10 MSWD 1.11
Extraction method Furnace step-heat
Morphology of age spectrum Well-behaved age spectrum, 100% used in weighted mean age calculation
Radiogenic yields Initial increase from 10.9% to 93.2% radiogenic over first 27.55% of gas released followed by oscillatory behavior
K/Ca 0.11 to 0.14, overall decreasing but somewhat oscillatory, inversely correlated with rise and fall in radiogenic yield
Isochron Age steps A-I, 25.60±0.12 Ma, atmospheric intercept
Interpretation reliable eruption age

HL091206-2 Hornblende (Figure 5)

Weighted mean age 26.86±0.53 Ma n/n_{total} 7/11 MSWD 1.41
Extraction method Furnace step-heat
Morphology of age spectrum Nearly concordant age spectrum, over initial ~74%, slightly older apparent ages over remainder of age spectrum
Radiogenic yields Increase from 2.2% to 68.9% over initial 48.2% of age spectrum followed by overall decrease to 18% radiogenic
K/Ca overall decrease from 1.9 to 0.011
Isochron Age steps A-G, 26.8±0.6 Ma, atmospheric intercept
Interpretation reliable eruption age

D-17 Groundmass Concentrate (Figure 6)

Weighted mean age 38.17±0.47 Ma n/n_{total} 5/10 MSWD 2.21
Extraction method Furnace step-heat
Morphology of age spectrum Somewhat disturbed age spectrum, saddle-shaped
Radiogenic yields Increase from -1.2% to 55.8% radiogenic over initial 4.9% of spectrum followed by decrease to 31.2%
K/Ca correlated to rise and fall in radiogenic yields, with values ranging from 0 to 1.8
Isochron Age steps F-J, 38.0±2.2 Ma, atmospheric intercept
Interpretation fairly reliable eruption age

D-4 sanidine (Figure 7)

Weighted mean age 38.69±0.10 Ma n/n_{total} 15/15 MSWD 2.18
Extraction method single-crystal laser fusion
Distribution of ages Somewhat Gaussian
Outliers none
Radiogenic yields 95.7% to 99.8%
K/Ca 34.1 to 1017.2
Interpretation accurate eruption age

D-6 Groundmass Concentrate (Figure 8)

Weighted Mean Age 39.16±0.23 Ma n/n_{total} 7/10 MSWD 3.74
Extraction method Furnace step-heat
Morphology of age spectrum Fairly well-behaved, rapidly increasing apparent ages over initial 7.95% of age spectrum
Radiogenic yields early increase in radiogenic yield (1.8%-80.6%) correlated to increase in apparent age, somewhat oscillatory over remainder of spectrum
K/Ca overall decreasing K/Ca values from 1.4 to 0.25
Isochron Age steps D-J, 39.55±0.22 Ma, less than atmospheric intercept (288.3±3.4)
Interpretation reliable eruption age

D-40 Groundmass Concentrate (Figure 9)

Integrated Age 40.61±0.78 Ma n/n_{total} 10/10
Extraction method Furnace step-heat
Morphology of age spectrum Disturbed saddle-shaped age spectrum
Radiogenic yields Initial increase (2.5% to 71.9%) over 5.8% of spectrum followed by overall decrease
K/Ca overall decreasing K/Ca values from 1.4 to 0.25
Isochron Age steps A-J, 40.1±1.9 Ma, less than atmospheric intercept (295.9±10.8)
Interpretation Spectrum disturbed by ^{39}Ar recoil, integrated age is best estimate of eruption age

D-42 Groundmass Concentrate (Figure 10)

Integrated Age 40.66±0.45 Ma n/n_{total} 10/10 MSWD 4.98
Extraction method Furnace step-heat
Morphology of age spectrum somewhat disturbed age spectrum, increasing apparent age over initial ~42%
Radiogenic yield initial increase correlated with rise in apparent age
K/Ca decrease in K/Ca (1.5- ~0.60) correlated with increase in radiogenic yield
Isochron Age steps D-I, 37.3±4.3 Ma, atmospheric intercept
Interpretation reliable eruption age

D-7 Hornblende (Figure 11)

Integrated Age 41.73±0.24 Ma n/n_{total} 4/11 MSWD 1.76
Extraction method Furnace step-heat
Morphology of age spectrum somewhat disturbed age spectrum, initial 63.2% nearly flat, later steps some what discordant
Radiogenic yield fairly uniform after initial increase from 3.3% to 91.9% radiogenic
K/Ca fairly uniform until final heating step
Isochron Age steps A-K, 41.42±0.43 Ma, $^{40}Ar/^{36}Ar$ intercept slightly higher than atmosphere (301.9±4.6)
Interpretation reliable eruption age

D-47 Biotite (Figure 12)

Integrated Age   194.42±0.53 Ma
Extraction method   Furnace step-heat
Morphology of age spectrum   disturbed hump-shaped age spectrum
Radiogenic yield   increase and decrease roughly correlated to change in apparent age (31.4% to 99.6%)
K/Ca   increase and decrease (0.005 to 97.1) correlated to change in apparent age
Isochron Age   Non-isochronous
Interpretation   no age assigned, integrated age is best estimate but very low confidence

Discussion

Most the samples analyzed provide reliable age information. The sanidine separated from sample D-4 and analyzed as single crystal aliquots provides a reliable, precise eruption age for the rock from which it was sampled (38.69±0.10 Ma). HK092006-3 groundmass concentrate, HH091406-1 plagioclase and HL091206-2 hornblende that were step-heated as bulk separates in the furnace yielded well-behaved age spectra that are interpreted as providing reliable, precise eruption ages (5.39±0.07 Ma, 25.55±0.11 Ma, 26. 86±0.53 Ma, respectively). Sample HK092106-1 groundmass provided a well-behaved age spectrum but with very low radiogenic yields (-0.2% to 3.1%) which results in a fairly high error for the weighted mean age (0.058±0.036 Ma). We feel quite confident that the assigned weighted mean age provides an accurate, if somewhat low precision eruption age. Age spectra from groundmass samples BT091106-1, D-6 and D-42 yield young apparent ages and low radiogenic yields in the early heating steps that are suggestive of minor alteration and Ar loss. While our confidence in the assigned weighted mean ages (3.38±0.19 Ma, 39.16±0.23 Ma and 40.66±0.45 Ma, respectively) is not quite as high as with the previous samples, we still feel that the ages are reliable eruption ages. Hornblende from sample D-7 and groundmass concentrate from D-17 yielded somewhat disturbed age spectra that might be the result of alteration and related ^{39}Ar recoil or possibly (in the case of the hornblende), other phases that are poikilitically included within the hornblende grains. We still feel that the ages assigned to D-7 and D-17 (41.73±0.24 and 38.17±0.47 Ma, respectively) provide reasonably accurate eruption ages for the rocks from which they were sampled. Groundmass concentrate from D-40 and biotite from D-47 yielded disturbed age spectra.

Both the saddle-shaped age spectrum from D-40 and the hump-shaped one for D-47 are thought to be the result of ^{39}Ar recoil. Multi-phase samples, such as biotite containing chlorite alteration or fine grained altered groundmass concentrate are especially susceptible to recoil. Recoil shifts ^{39}Ar from high K sites to low K sites, thus increasing the apparent ages of the parts of the age spectra controlled by phases that have lost ^{39}Ar and decreasing the apparent ages of the parts of the age spectra controlled by phases that have gained ^{39}Ar. The integrated age can be considered the best estimate of a sample's age in cases where recoil is suspected, these are the ages we have assigned to samples D-40 (40.61±0.78 Ma) and D-47 (194.42±0.53 Ma). We caution however, that our confidence in these ages is not as high as our confidence in the other samples in this group.

References Cited

Renne, P.R., Owens, T.L., DePaolo, D.J., Swisher, C.C., Deino, A.L., and Darner, D.B., 1998. Intercalibration of standards, absolute ages and uncertainties in $^{40}Ar/^{39}Ar$ dating, Chemical Geology, 145, 117-152.

Steiger, R.H., and Jäger, E., 1977. Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology. Earth and Planet. Sci. Lett., 36, 359-362.

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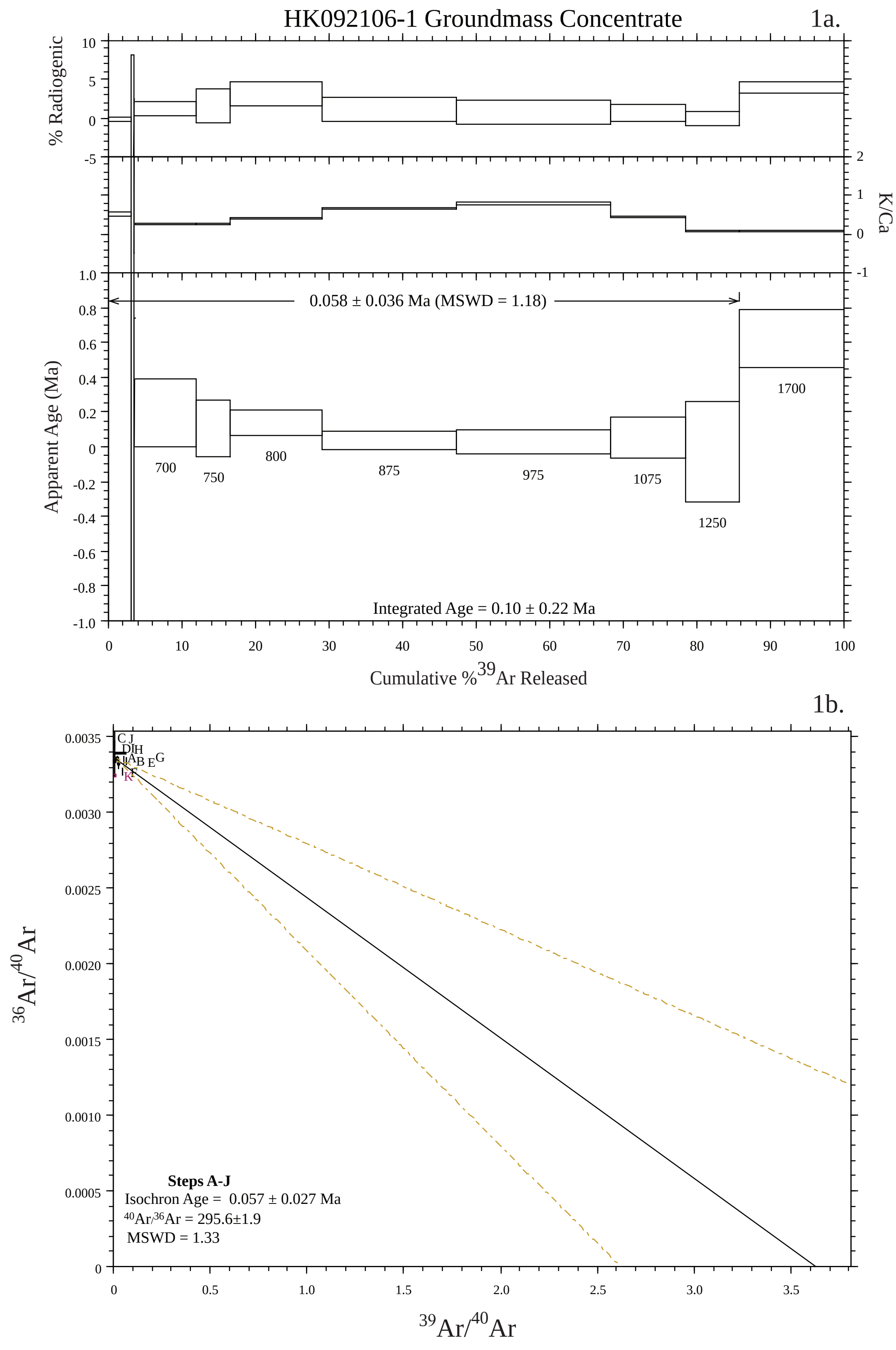


Figure 1. Age spectrum (1a) and isochron (1b) for groundmass concentrate HK092106-1. All errors quoted at 2 sigma.

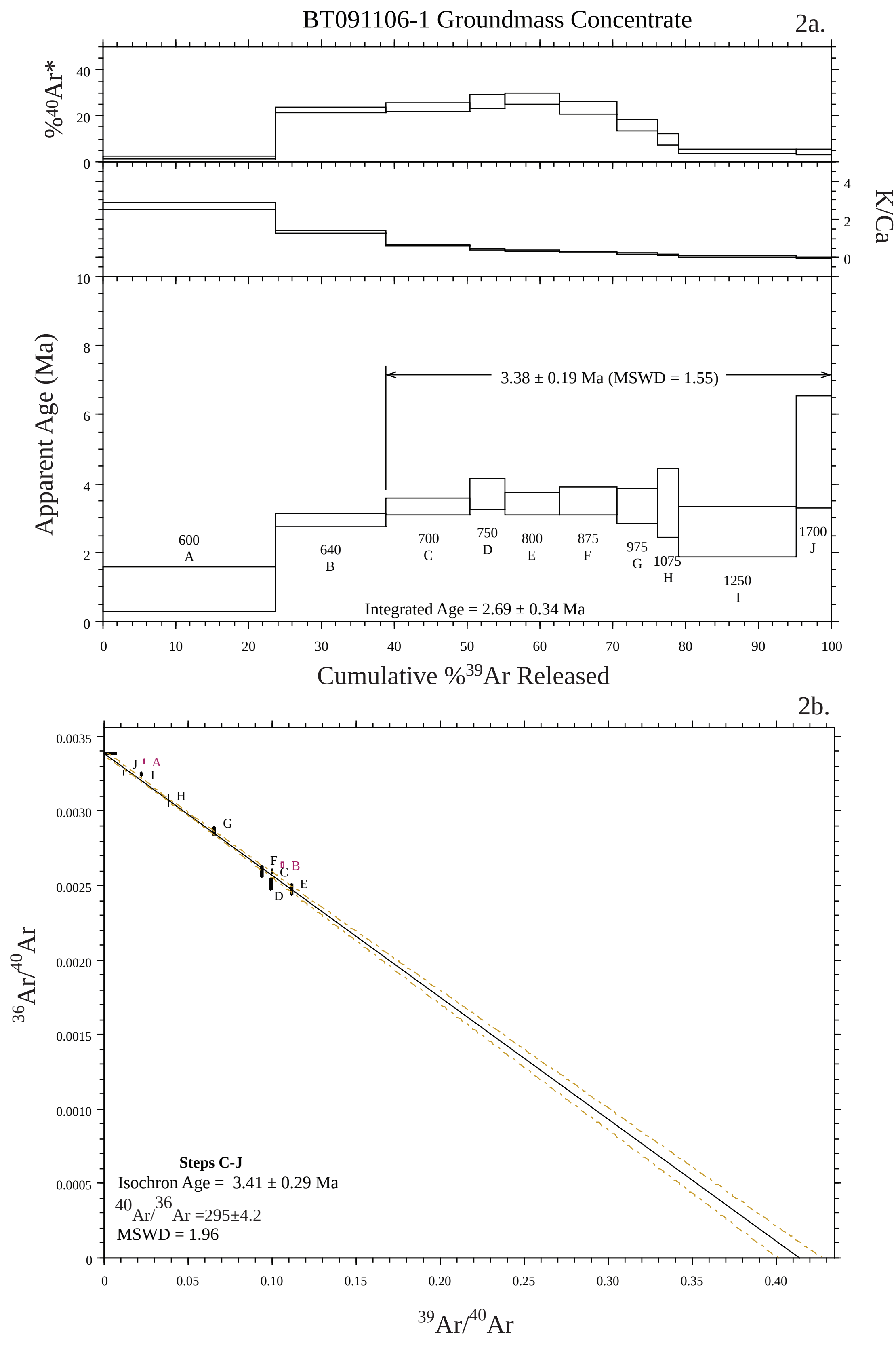
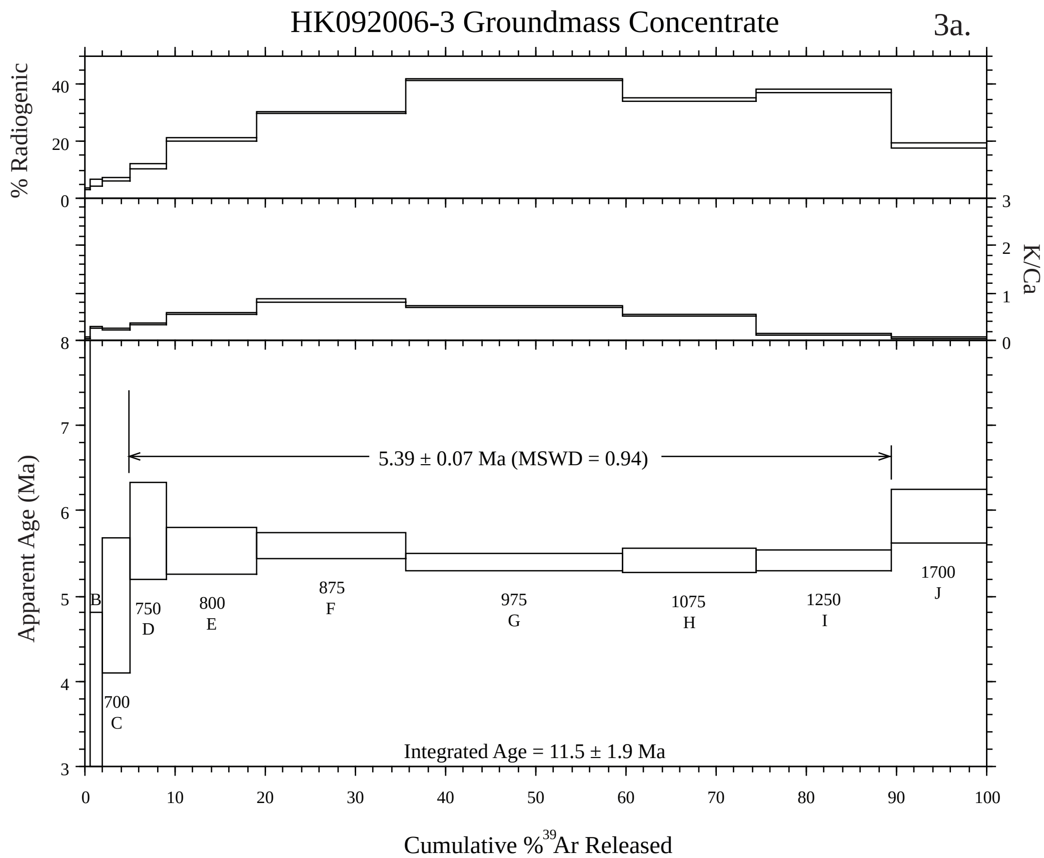


Figure 2. Age spectrum (2a) and isochron (2b) for groundmass concentrate BT091106-1. Points shown in purple are not included in age calculation. All errors quoted at 2 sigma.



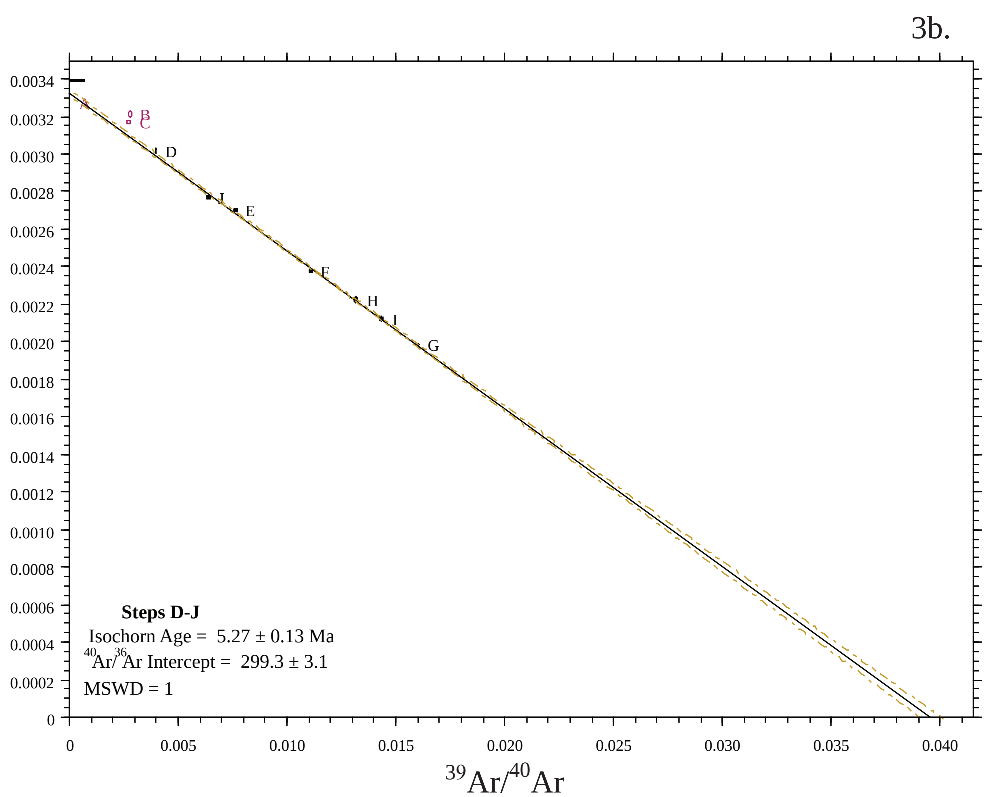


Figure 3. Age spectrum (3a) and isochron (3b) for groundmass concentrate HK092006-3. Points shown in purple not included in weighted mean age. All errors quoted at 2 sigma.

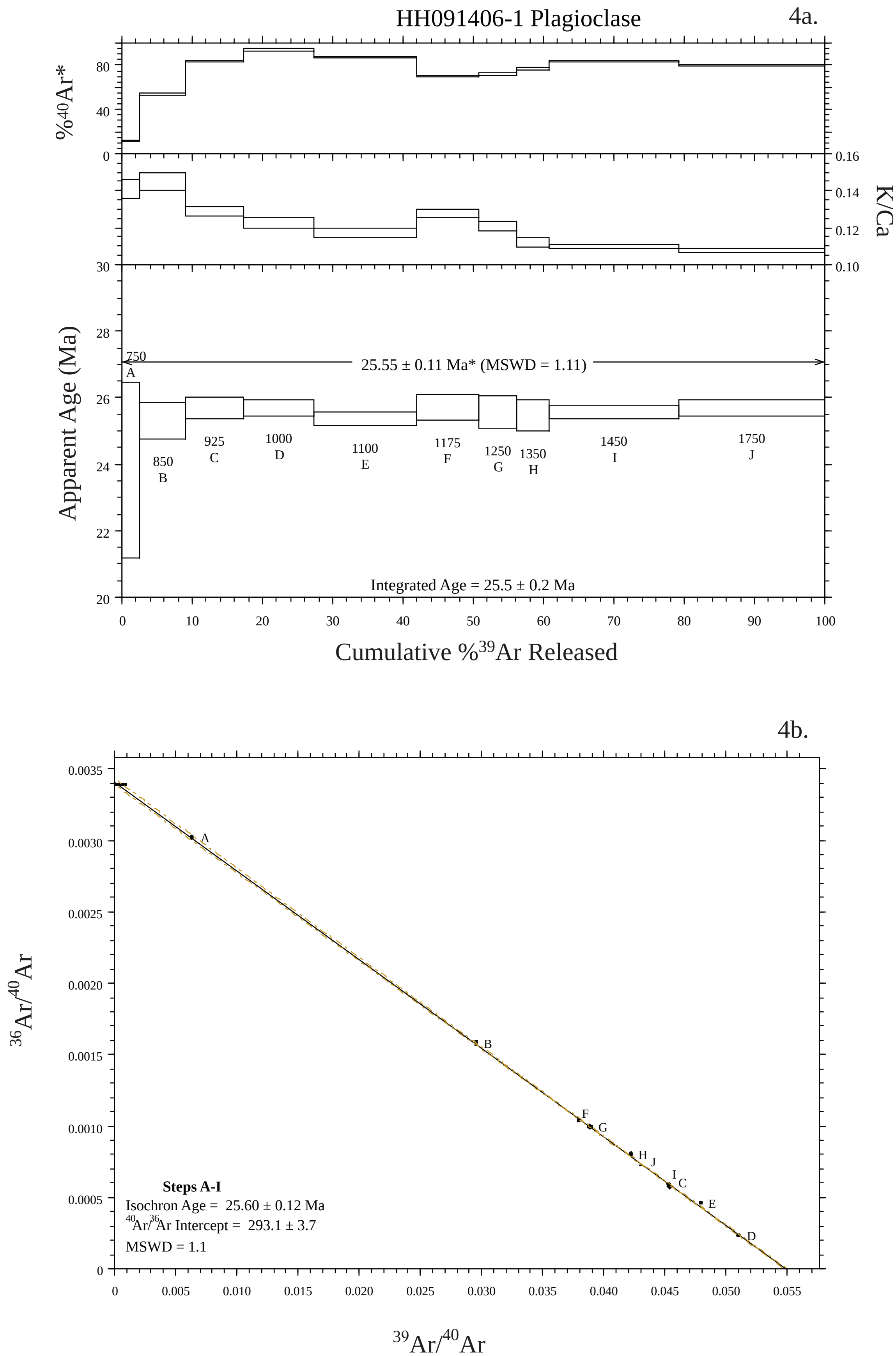


Figure 4. Age spectrum (4a) and isochron (4b) for plagioclase HH091406-1. All errors quoted at 2 sigma.

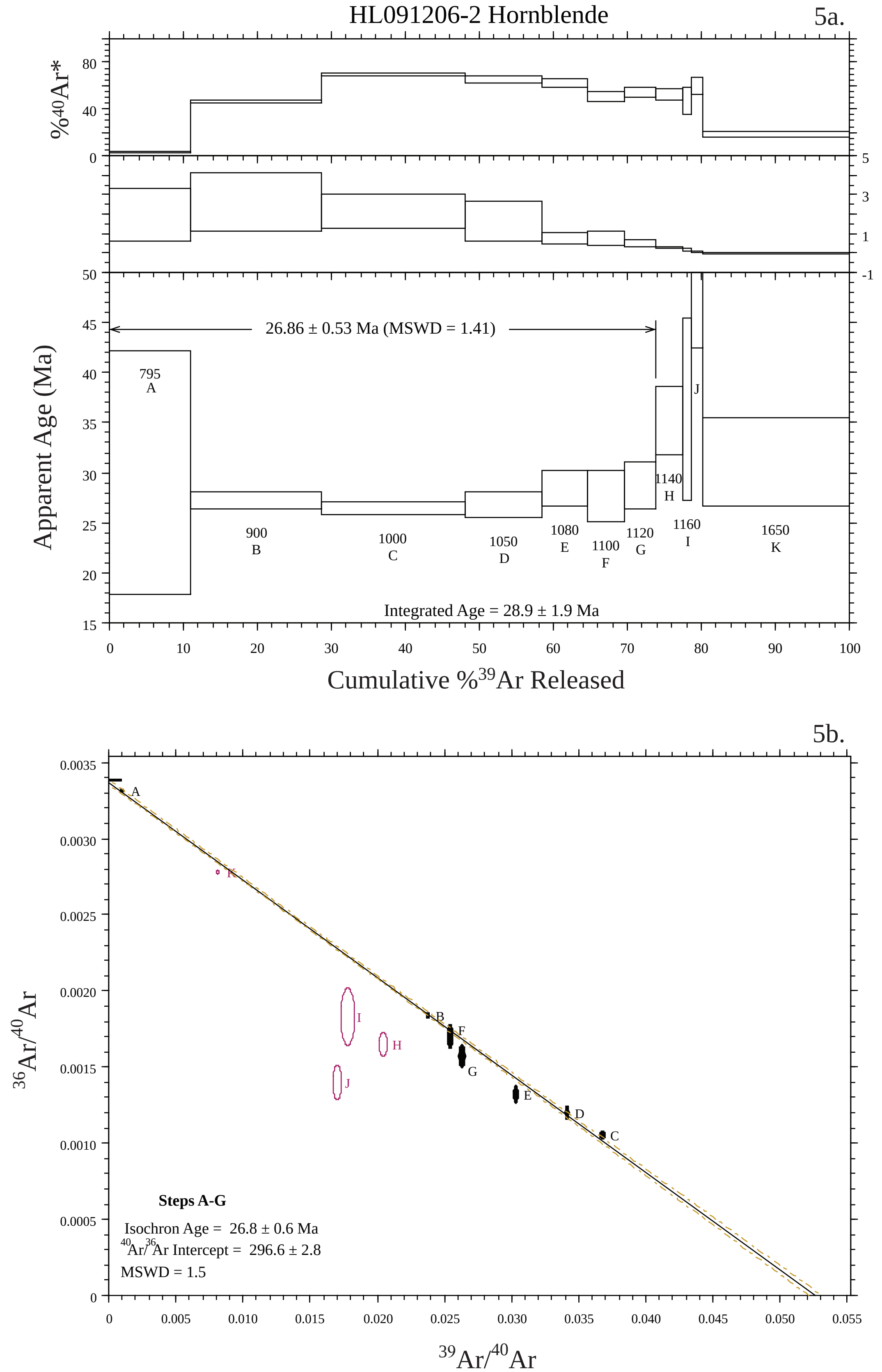
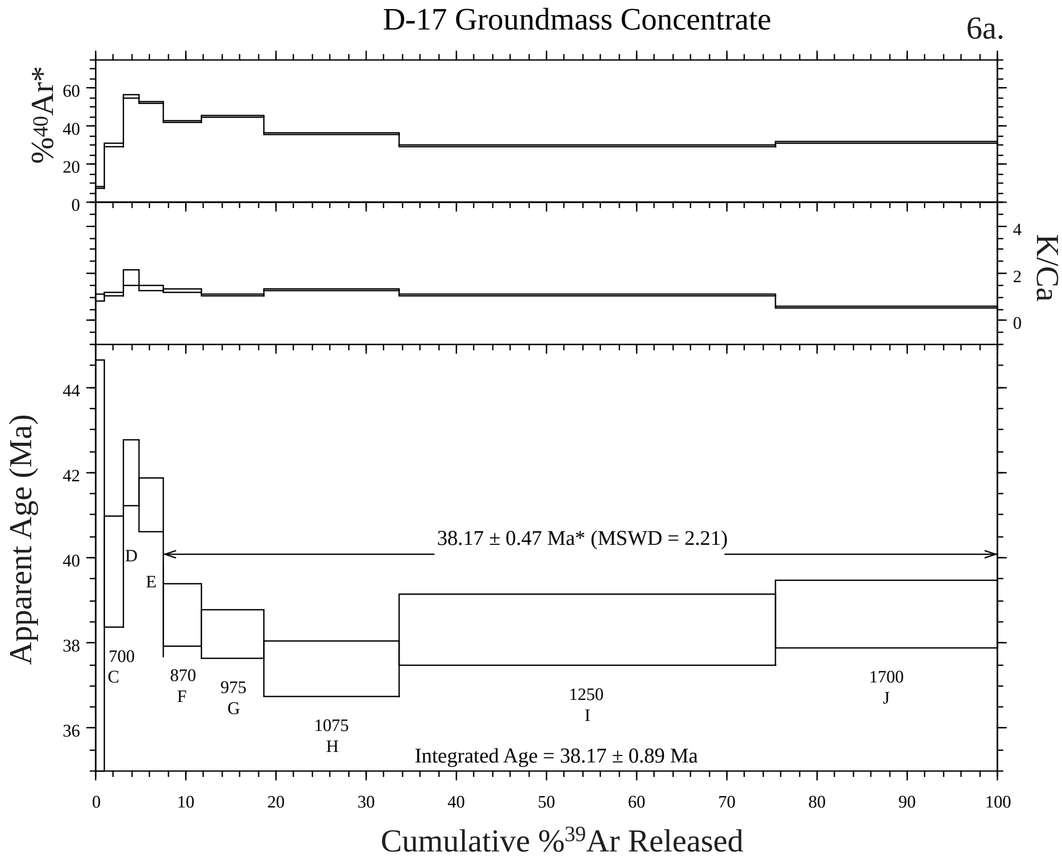


Figure 5. Age spectrum (5a) and isochron (5b) for hornblende HL091206-2. Points shown in purple not included in weighted mean age. All errors quoted at 2 sigma.



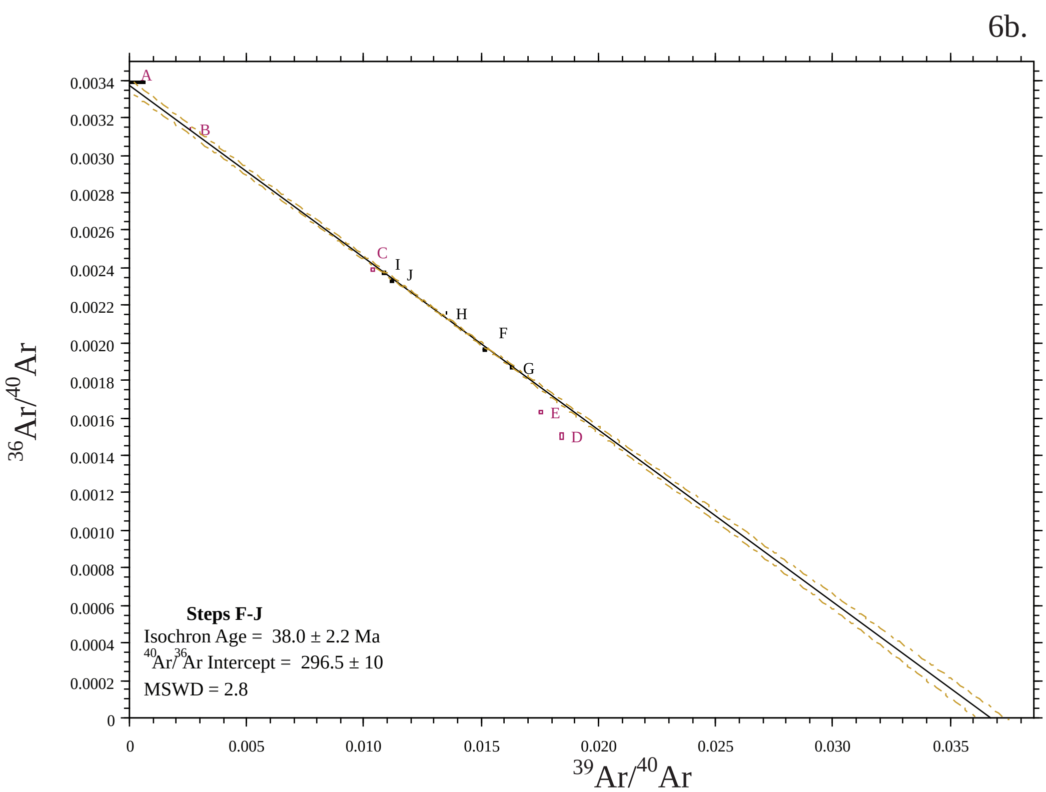


Figure 6. Age spectrum (6a) and isochron (6b) for groundmass concentrate D-17. Points in purple not included in weighted mean age.
All errors quoted at 2 sigma.

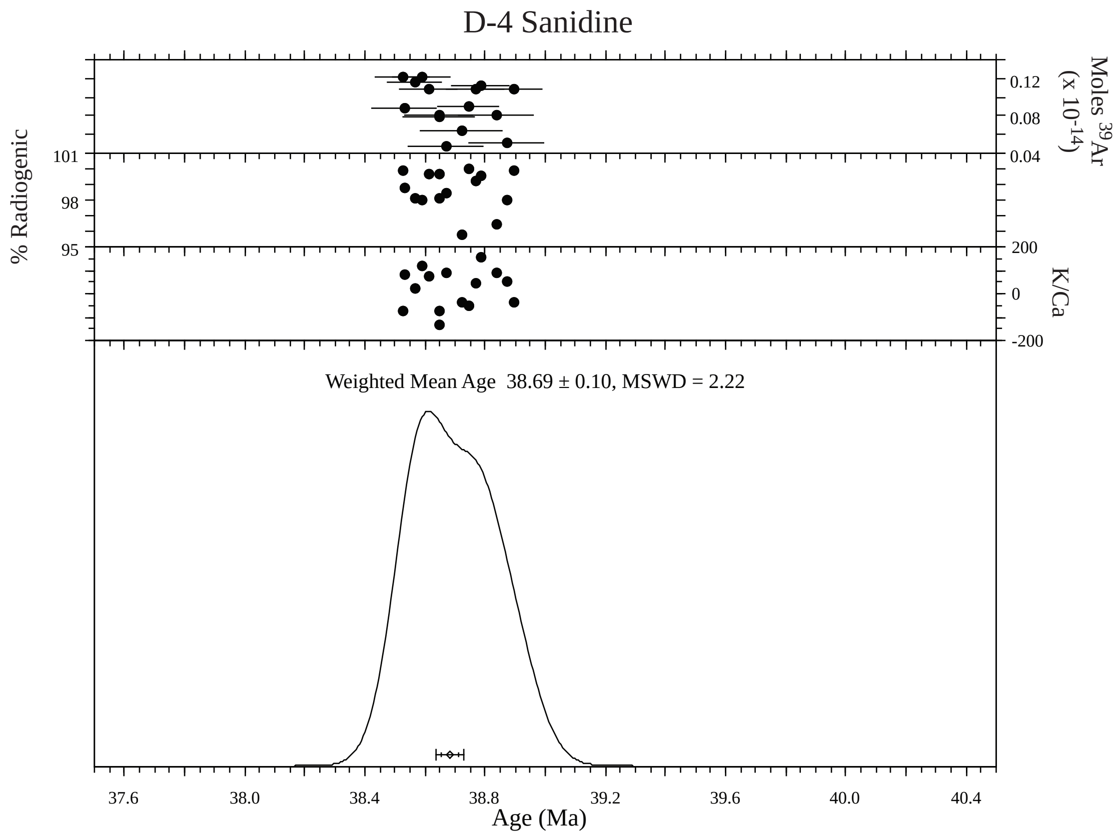
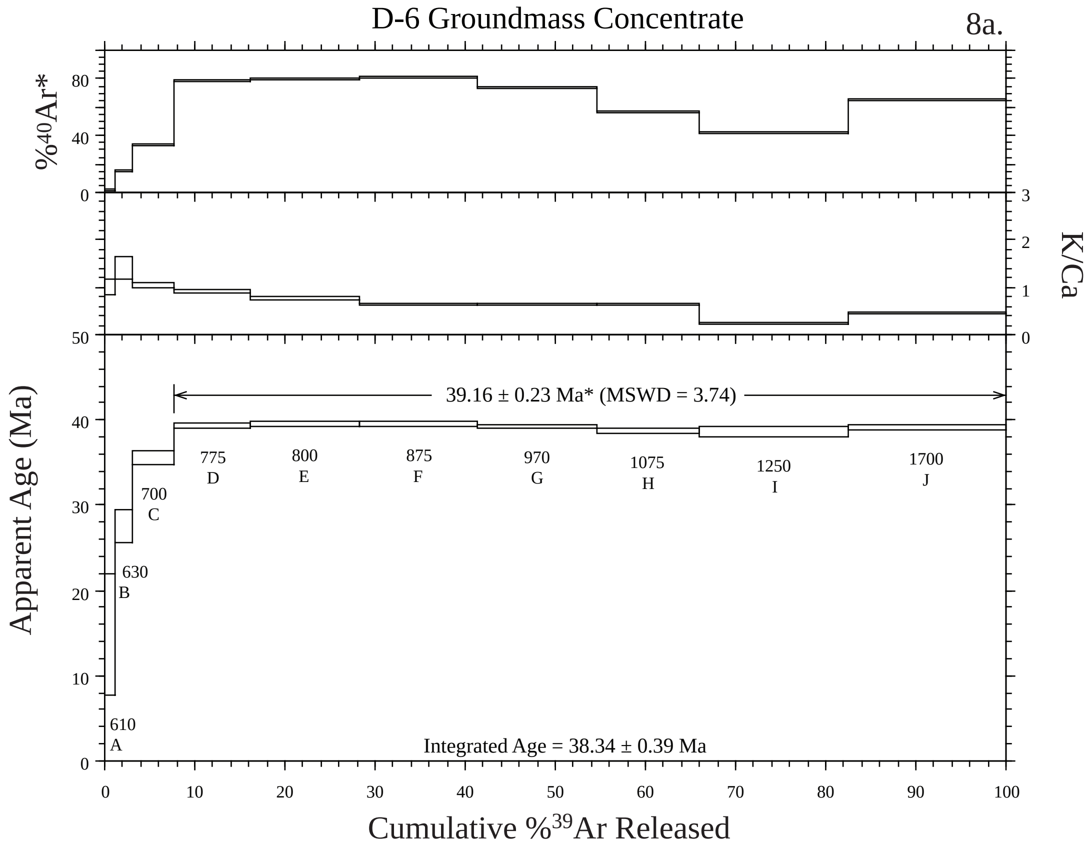


Figure 7. Age probability distribution diagram for D-4 sanidine.



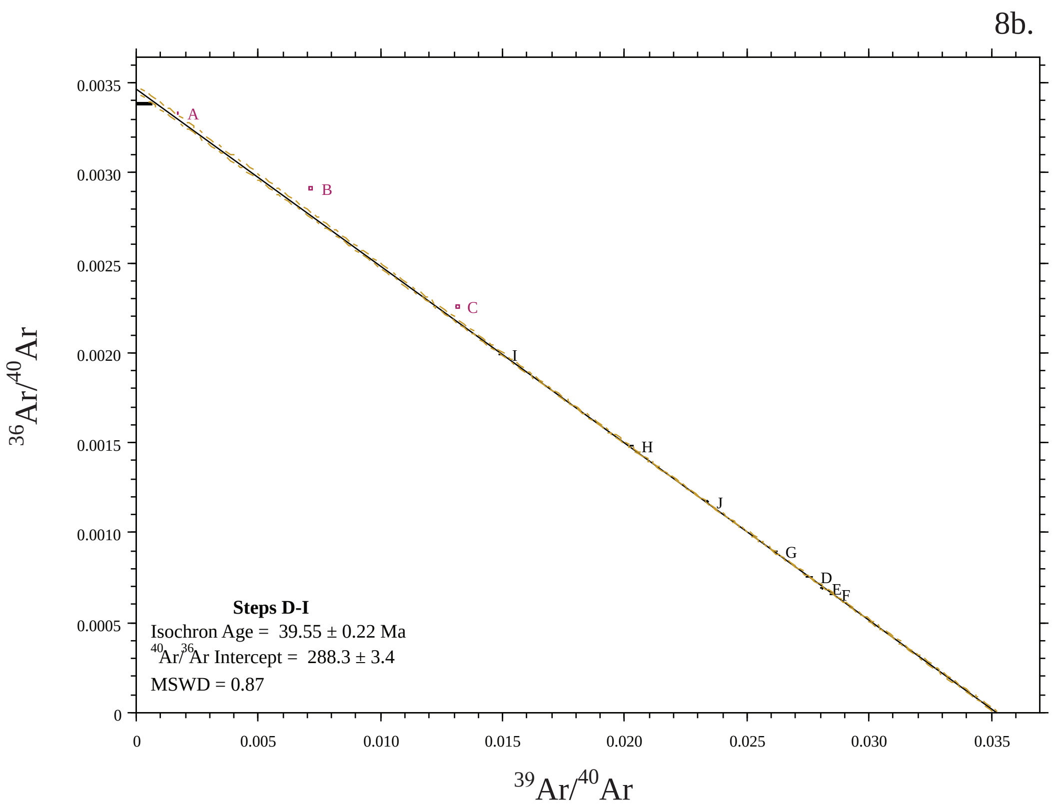
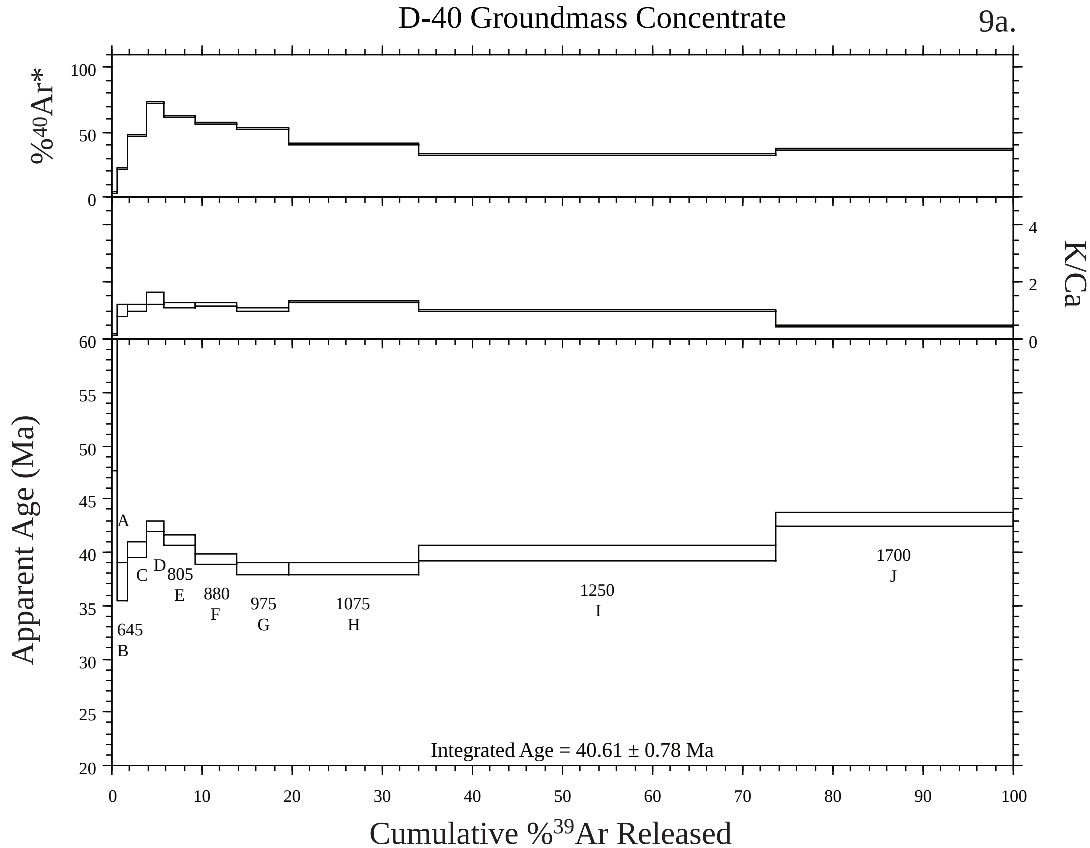


Figure 8. Age spectrum (8a) and isochron (8b) for groundmass concentrate D-6. Points shown in purple not included in weighted mean age calculation. All errors quoted at 2 sigma.



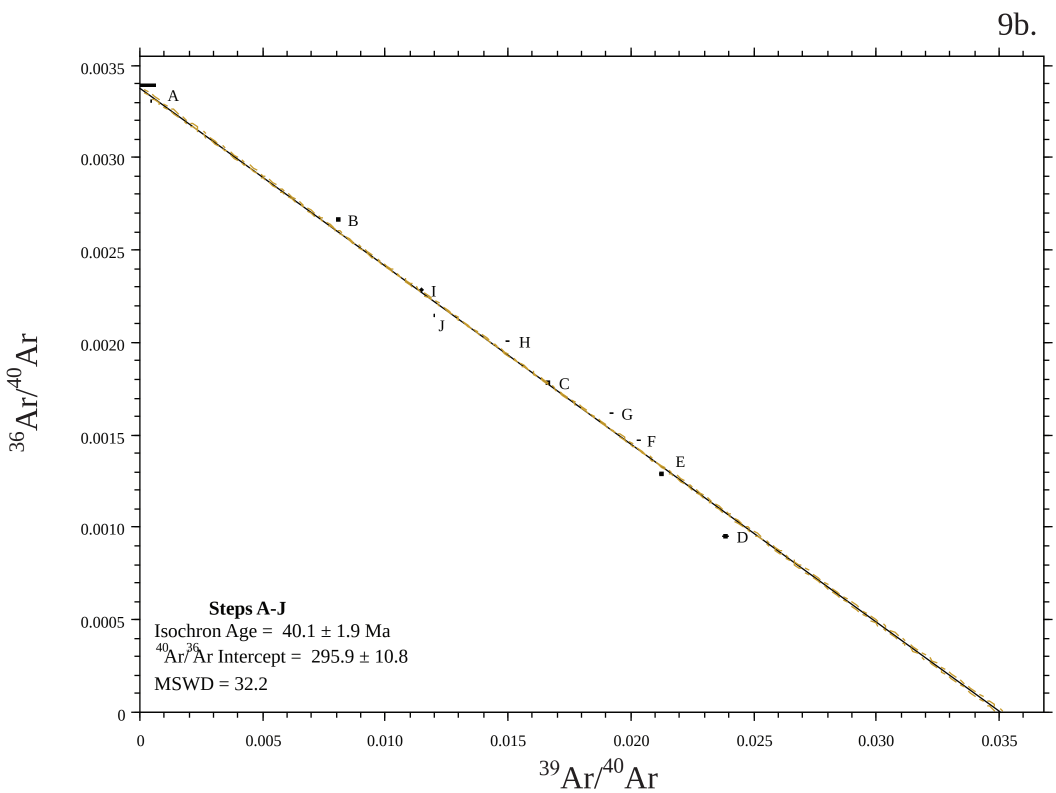
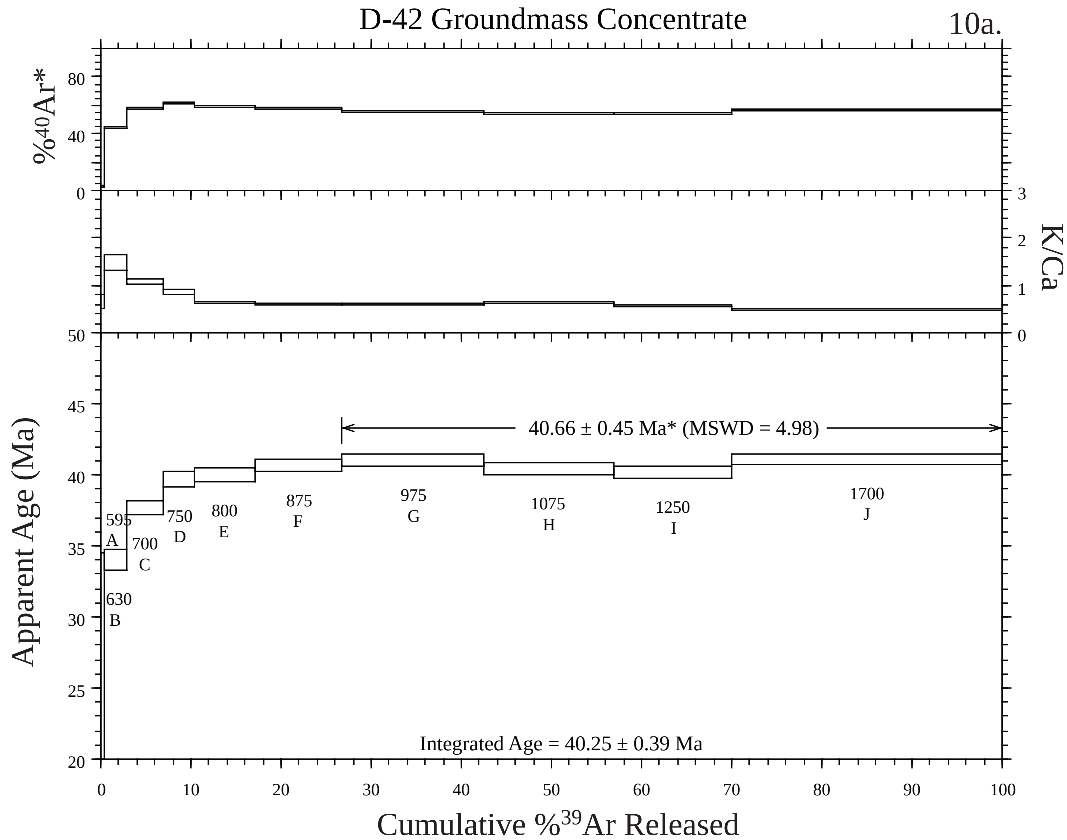


Figure 9. Age spectrum (9a) and isochron (9b) for groundmass concentrate D-40. All errors quoted at 2 sigma.

10a.



10b.

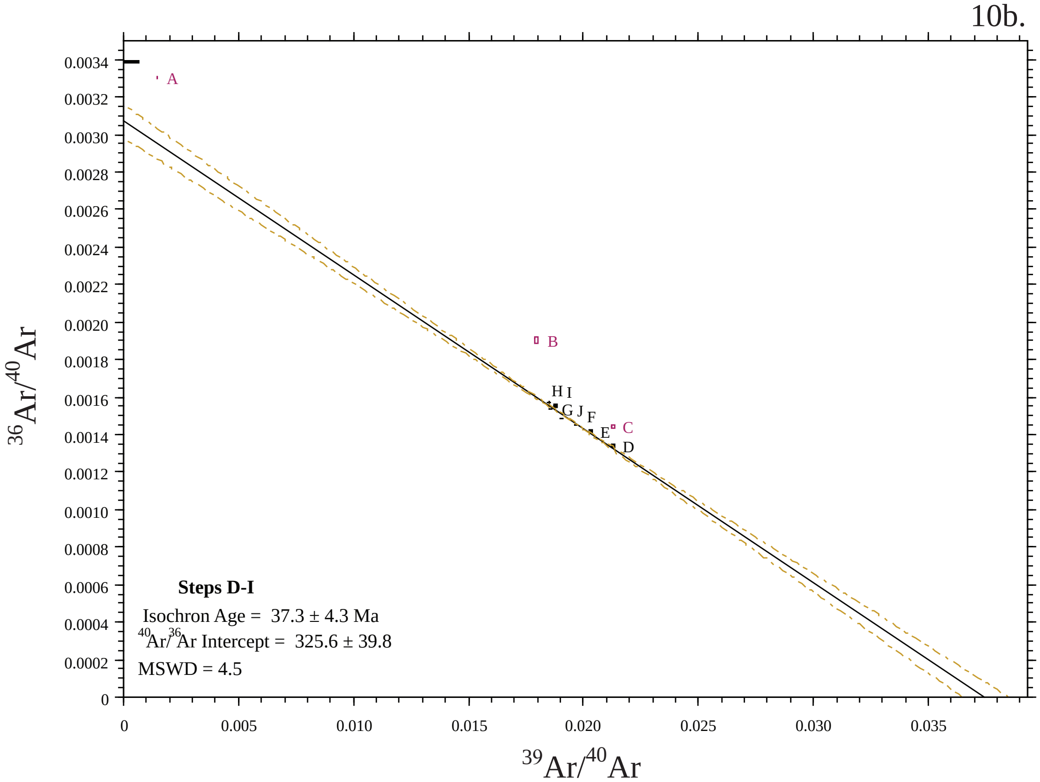


Figure 10. Age spectrum (10a) and isochron (10b) for groundmass concentrate D-42. All errors quoted at 2 sigma.

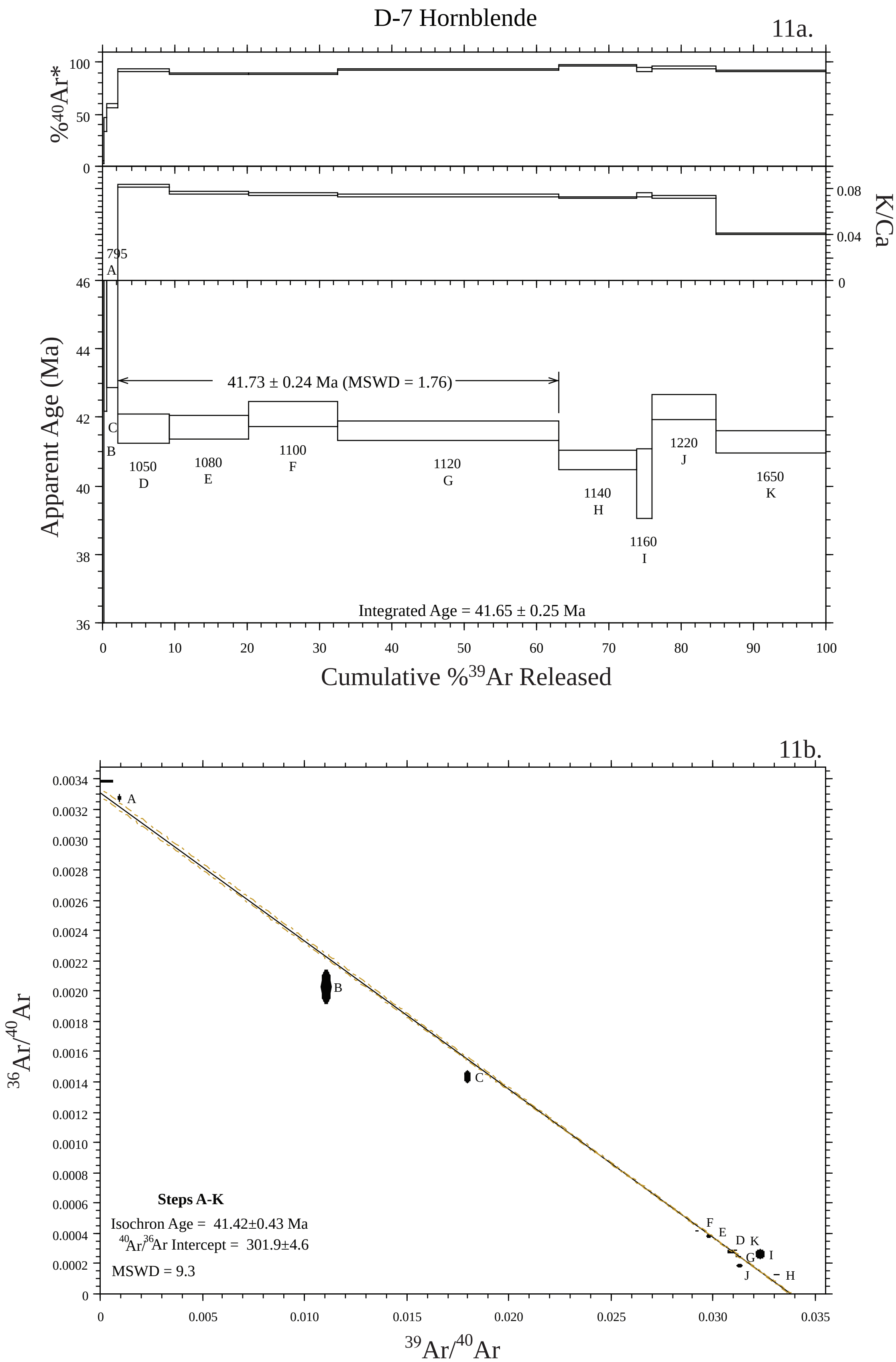


Figure 11. Age spectrum (11a) and isochron (11b) for hornblende D-7. All errors quoted at 2 sigma.

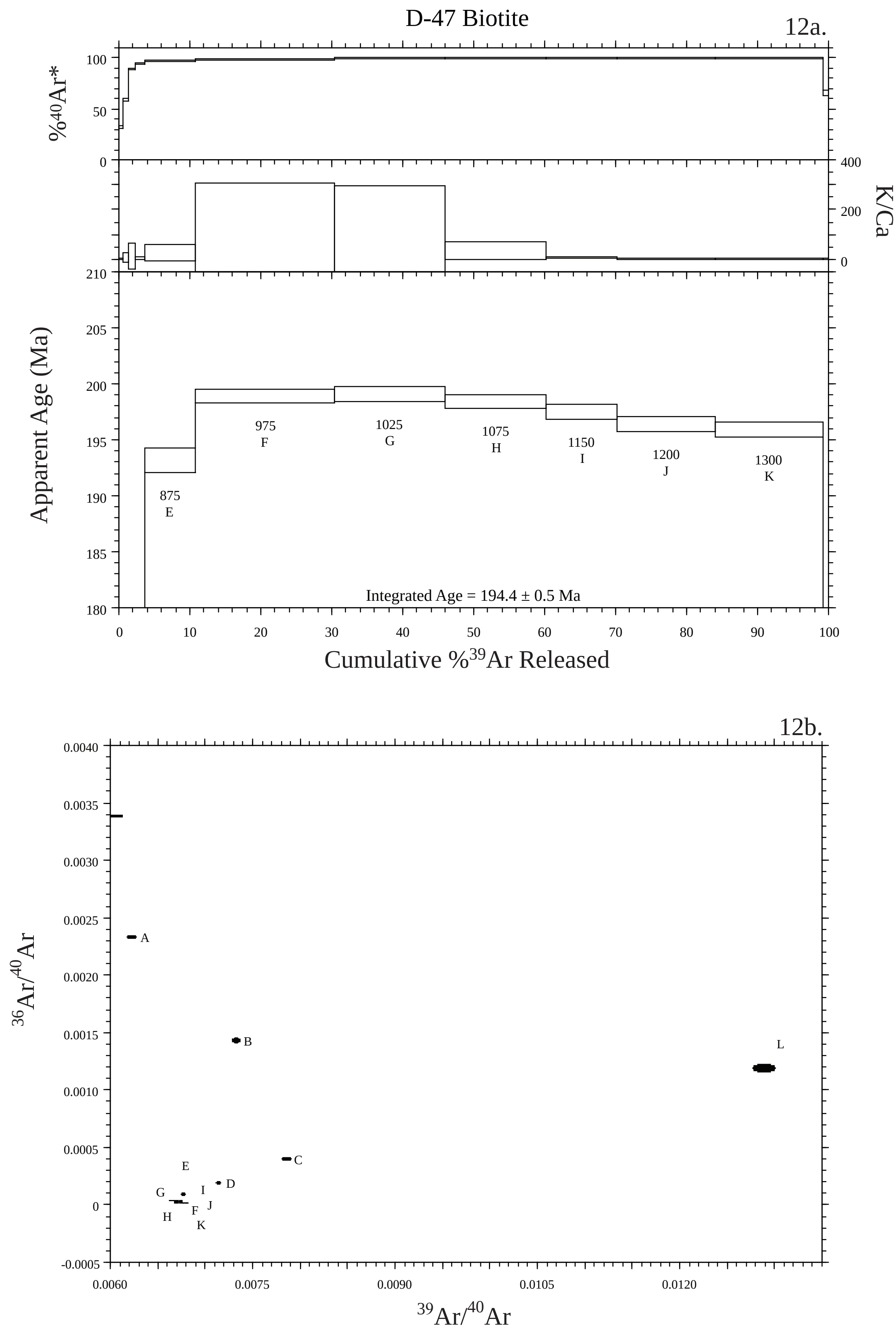


Figure 12. Age spectrum (12a) and isochron (12b) for biotite D-47. All errors quoted at 2 sigma.

Table 1. Summary of $^{40}Ar/^{39}Ar$ results and analytical methods

Sample	Lab #	Irradiation	mineral	age analysis	steps/analyses	Age	±2σ	MSWD	40Ar/36Ar intercept	comments
HK092106-1	57364	NM-211	groundmass concentrate	furnace step-heat	10	0.058	0.036	1.18		
BT091106-1	57308	NM-210	groundmass concentrate	furnace step-heat	8	3.38	0.19	1.55		
HK092006-3	57366	NM-211	groundmass concentrate	furnace step-heat	7	5.27	0.14	1.02	299.3±3.1	isochron age
HH091406-1	57314	NM-210	plagioclase	furnace step-heat	10	25.55	0.11	1.11		
HL091206-2	57324	NM-210	hornblende	furnace step-heat	7	26.86	0.53	1.41		
D-17	57310	NM-210	groundmass concentrate	furnace step-heat	5	38.17	0.47	2.21		
D-4	57320	NM210	sanidine	laser total fusion	15	38.69	0.10	2.22		
D-6	57306	NM-210	groundmass concentrate	furnace step-heat	7	39.55	0.22	0.87		
D-40	57334	NM-210	groundmass concentrate	furnace step-heat	10	40.61	0.78			sample possibly affected by recoil, integrated age best estimate of sample's age
D-42	57307	NM-210	groundmass concentrate	furnace step-heat	11	40.66	0.45	4.98		
D-7	57330	NM-210	hornblende	furnace step-heat	4	41.73	0.24	1.76		
D-47	57332	NM-210	biotite	furnace step-heat	-	194.42	0.53	-		hump-shaped age spectra, very low confidence

Sample preparation and irradiation:
Minerals separated with standard heavy liquid, Franz Magnetic and hand-picking techniques.
Samples in NM-210 irradiated in a machined Aluminum tray for 14 hours in D-3 position, Nuclear Science Center, College Station, TX.
Samples in NM-211 irradiated in a machined Aluminum tray for 0.5 hours at the USGS Triga reactor, Denver CO.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-2). Assigned age = 28.02 Ma (Renne et al, 1998).

Instrumentation:
Analyses performed on a Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.
Groundmass concentrate,hornblende and plagioclase step-heated, using a Mo double-vacuum resistance furnace.
Sanidine fused by a 50 watt Synrad CO_2 laser.

Analytical parameters:
Electron multiplier sensitivity averaged 1.08 x 10^{-16} moles/pA for furance analyses and 5.61e-17 for laser analyses.
Total system blank and background averaged 7330, 45.8, 21.8, 34.8, 71.5 x 10^{-18} moles at masses 40, 39, 38, 37 and 36, respectively for the furnace analyses.
Total system blank and background averaged 516, 9.75, 5.88, 4.92, 40.8 x 10^{-18} moles at masses 40, 39, 38, 37 and 36, respectively for the laser analyses.
J-factors determined by CO_2 laser-fusion of 6 single crystals from each of 6 or 10 radial positions around the irradiation tray.
Decay constants and isotopic abundances after Steiger and Jäger (1977).

Table 2. $^{40}Ar/^{39}Ar$ analytical data.

	ID	Power (°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)
	HK092106-1, wr, 84.23 mg, J=0.0001156±0.36%, D=1.001±0.001, NM-211C, Lab#=57364-01										
	A	600	2612.9	1.030	8858.3	0.969	0.50	-0.2	3.2	-1.0	2.3
	B	625	123.3	0.2544	414.9	0.072	2.0	0.6	3.5	0.15	0.96
	C	625	146.0	0.4636	516.8	0.084	1.1	-4.6	3.8	-1.4	1.1
	D	700	79.59	2.055	266.8	2.485	0.25	1.1	12.1	0.191	0.099
	E	750	32.80	2.088	109.9	1.353	0.24	1.5	16.6	0.102	0.081
	F	800	20.24	1.282	66.70	3.752	0.40	3.1	29.2	0.132	0.036
	G	875	14.33	0.7729	48.18	5.453	0.66	1.1	47.5	0.032	0.026
	H	975	17.87	0.6615	60.22	6.227	0.77	0.7	68.4	0.026	0.033
	I	1075	40.93	1.148	138.0	3.019	0.44	0.6	78.5	0.049	0.059
	J	1250	107.4	7.043	365.9	2.189	0.072	-0.2	85.8	-0.03	0.14
Xi	K	1700	74.96	6.638	245.6	4.228	0.077	3.9	100.0	0.616	0.084
	Integrated age ± 2σ			n=11		29.83	0.22	K2O=1.18%		0.10	0.22
	Plateau ± 2σ		steps A-J	n=10	MSWD=1.18	25.60	0.51 ±1.12		85.8	0.058	0.036
	Isochron±2σ		steps A-J	n=10	MSWD=1.33		$^{40}Ar/^{36}Ar$=	295.6±1.9		0.057	0.027
	BT091106-1, Groundmass Concentrate, 27.48 mg, J=0.0007823±0.07%, D=1.002±0.001, NM-210K, Lab#=57308-01										
Xi	A	600	41.41	0.1926	138.0	12.90	2.6	1.6	23.7	0.93	0.32
Xi	B	640	9.358	0.3933	24.75	8.26	1.3	22.2	38.9	2.928	0.099
	C	700	9.991	0.8038	26.08	6.322	0.63	23.5	50.5	3.32	0.12
	D	750	10.04	1.201	25.44	2.624	0.42	26.1	55.3	3.69	0.22
	E	800	8.909	1.367	22.41	4.079	0.37	26.9	62.8	3.39	0.16
	F	875	10.60	1.867	28.04	4.263	0.27	23.3	70.6	3.49	0.20
	G	975	15.15	2.797	44.12	3.076	0.18	15.5	76.3	3.32	0.25
	H	1075	25.89	3.424	80.38	1.566	0.15	9.4	79.2	3.42	0.49
	I	1250	43.42	17.91	145.8	8.81	0.028	4.2	95.3	2.59	0.37
	J	1700	84.98	21.59	282.0	2.538	0.024	4.0	100.0	4.90	0.81
	Integrated age ± 2σ			n=10		54.44	0.11	K2O=0.97%		2.69	0.34
	Plateau ± 2σ		steps C-J	n=8	MSWD=1.55	33.28	0.27 ±0.42		61.1	3.38	0.19
	Isochron±2σ		steps C-J	n=8	MSWD=1.96		$^{40}Ar/^{36}Ar$=	295±4.2		3.41	0.29
	HK092006-3, wr, 74.82 mg, J=0.0001157±0.31%, D=1.001±0.001, NM-211C, Lab#=57366-01										
Xi	A	600	140629	14.07	461797.5	0.216	0.036	3.0	0.7	716.2	127.9
Xi	B	625	357.1	1.956	1151.0	0.400	0.26	4.8	2.0	3.59	0.47
I	C	700	360.0	2.089	1144.5	0.934	0.24	6.1	5.1	4.59	0.40
	D	750	250.6	1.580	758.3	1.22	0.32	10.6	9.1	5.56	0.28
	E	800	129.6	0.9390	350.7	3.06	0.54	20.1	19.1	5.43	0.14
	F	875	89.74	0.6128	214.1	5.05	0.83	29.5	35.6	5.529	0.075
	G	975	62.32	0.7282	124.2	7.38	0.70	41.2	59.8	5.355	0.048
	H	1075	75.48	1.015	168.8	4.48	0.50	34.0	74.4	5.359	0.074
	I	1250	69.28	4.333	148.8	4.59	0.12	37.0	89.5	5.367	0.062
X	J	1700	154.2	12.67	431.9	3.22	0.040	17.9	100.0	5.81	0.16
	Integrated age ± 2σ			n=10		30.6	0.18	K2O=1.36%		11.5	1.9
	Plateau ± 2σ		steps D-I	n=6	MSWD=0.94	25.8	0.55 ±0.51		84.4	5.39	0.07
	Isochron±2σ		steps D-J	n=7	MSWD=1.02		$^{40}Ar/^{36}Ar$=	299.3±3.1		5.27	0.13

	ID	Power (°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)
	HH091406-1, Plagioclase, 28.63 mg, J=0.0007841±0.07%, D=1.002±0.001, NM-210M, Lab#=57314-01										
	A	750	155.3	3.634	469.6	1.414	0.14	10.9	2.6	23.8	1.3
	B	850	33.68	3.534	54.20	3.494	0.14	53.3	9.0	25.28	0.27
	C	925	21.96	3.979	13.75	4.513	0.13	83.0	17.4	25.67	0.16
	D	1000	19.54	4.180	5.645	5.487	0.12	93.2	27.5	25.66	0.12
	E	1100	20.80	4.363	10.77	7.936	0.12	86.4	42.1	25.34	0.11
	F	1175	26.26	3.999	28.26	4.729	0.13	69.5	50.8	25.69	0.19
	G	1250	25.61	4.237	26.50	3.018	0.12	70.8	56.3	25.54	0.24
	H	1350	23.61	4.574	20.07	2.470	0.11	76.5	60.9	25.44	0.24
	I	1450	21.98	4.663	14.33	10.03	0.11	82.5	79.4	25.55	0.10
	J	1750	23.13	4.766	17.95	11.20	0.11	78.8	100.0	25.67	0.11
	Integrated age ± 2σ			n=10		54.30	0.12	K2O=0.93%		25.51	0.20
	Plateau ± 2σ		steps A-J	n=10	MSWD=1.11	54.30	0.12 ±0.03		100.0	25.55	0.11
	Isochron±2σ		steps A-J	n=10	MSWD=1.10		$^{40}Ar/^{36}Ar$=	293.1±3.7		25.60	0.12
	HL091206-2, Hornblende, 30.83 mg, J=0.0007875±0.09%, D=1.002±0.001, NM-210N, Lab#=57324-01										
	A	800	962.0	0.2639	3183.6	0.924	1.9	2.2	11.1	29.9	6.1
	B	900	42.03	0.1953	77.09	1.465	2.6	45.8	28.7	27.17	0.46
	C	1000	27.16	0.2398	28.62	1.617	2.1	68.9	48.2	26.41	0.31
	D	1050	29.28	0.3227	35.09	0.856	1.6	64.7	58.5	26.70	0.62
	E	1080	32.97	0.7329	43.59	0.515	0.70	61.1	64.7	28.41	0.89
	F	1100	39.26	0.7222	66.90	0.411	0.71	49.8	69.6	27.6	1.3
	G	1120	37.92	1.065	59.87	0.361	0.48	53.6	74.0	28.7	1.2
Xi	H	1140	48.63	2.154	80.65	0.295	0.24	51.4	77.5	35.2	1.7
Xi	I	1160	55.82	3.960	103.0	0.099	0.13	46.1	78.7	36.2	4.5
Xi	J	1220	57.70	22.12	86.45	0.138	0.023	58.9	80.4	48.4	3.0
Xi	K	1650	105.5	203.3	349.8	1.631	0.003	18.0	100.0	31.0	2.2
	Integrated age ± 2σ			n=11		8.31	0.011	K2O=0.13%		28.9	1.9
	Plateau ± 2σ		steps A-G	n=7	MSWD=1.41	6.149	1.8 ±1.7		74.0	26.86	0.53
	Isochron±2σ		steps A-G	n=7	MSWD=1.54		$^{40}Ar/^{36}Ar$=	296.6±2.8		26.80	0.49
	D-17, Groundmass Concentrate, 24.28 mg, J=0.0007811±0.06%, D=1.002±0.001, NM-210K, Lab#=57310-01										
Xi	A	600	20693	-4.1542	70850.1	0.098	-	-1.2	0.1	-379.4	167.1
Xi	B	625	382.7	0.5386	1199.3	1.549	0.95	7.4	1.0	39.5	2.6
Xi	C	700	96.25	0.4692	229.6	3.806	1.1	29.6	3.2	39.66	0.65
Xi	D	750	54.17	0.2866	81.42	2.753	1.8	55.6	4.9	41.98	0.39
Xi	E	800	56.86	0.3852	92.45	4.677	1.3	52.0	7.6	41.21	0.31
	F	875	65.74	0.4179	128.8	7.155	1.2	42.1	11.9	38.63	0.37
	G	975	61.07	0.4721	114.2	11.71	1.1	44.8	18.8	38.18	0.28
	H	1075	73.92	0.3942	159.6	25.10	1.3	36.2	33.7	37.37	0.33
	I	1250	91.79	0.4631	217.9	70.38	1.1	29.9	75.5	38.28	0.41
	J	1700	88.93	0.9259	207.5	41.35	0.55	31.2	100.0	38.65	0.40
	Integrated age ± 2σ			n=10		168.6	0.91	K2O=3.41%		38.21	0.87
	Plateau ± 2σ		steps F-J	n=5	MSWD=2.21	155.7	0.99 ±0.58		92.4	38.17	0.47
	Isochron±2σ		steps F-J	n=5	MSWD=2.79		$^{40}Ar/^{36}Ar$=	296±10		38.0	2.2

	ID	Power (°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)
	D-6, Groundmass Concentrate, 28.98 mg, J=0.0007808±0.08%, D=1.002±0.001, NM-210K, Lab#=57306-01										
Xi	A	600	582.2	0.5166	1934.7	1.497	0.99	1.8	1.2	14.8	3.6
Xi	B	625	139.0	0.3693	404.1	2.384	1.4	14.1	3.1	27.43	0.94
Xi	C	700	75.80	0.5052	170.7	5.990	1.0	33.5	7.9	35.44	0.44
	D	750	36.18	0.5644	27.37	10.48	0.90	77.8	16.3	39.22	0.15
	E	800	35.56	0.6833	24.78	15.26	0.75	79.6	28.4	39.45	0.16
	F	875	35.05	0.8125	23.18	16.20	0.63	80.6	41.4	39.40	0.12
	G	975	38.13	0.8332	34.18	16.64	0.61	73.7	54.7	39.17	0.12
	H	1075	49.22	0.8066	73.06	14.19	0.63	56.3	66.0	38.62	0.20
	I	1250	66.73	2.049	132.9	20.74	0.25	41.4	82.6	38.54	0.29
	J	1700	42.71	1.125	50.35	21.84	0.45	65.4	100.0	38.94	0.15
	Integrated age ± 2σ			n=10		125.2	0.50	K2O=2.13%		38.34	0.39
	Plateau ± 2σ		steps D-J	n=7	MSWD=3.74	115.35	0.57 ±0.42		92.1	39.16	0.23
	Isochron±2σ		steps D-J	n=7	MSWD=0.87		$^{40}Ar/^{36}Ar$=	288.3±3.4		39.55	0.22
	D-40, Groundmass Concentrate, 21.97 mg, J=0.0007893±0.06%, D=1.002±0.001, NM-210O, Lab#=57334-01										
X	A	600	2055.9	3.019	6787.0	1.218	0.17	2.5	0.7	70.8	11.6
X	B	625	123.3	0.5196	328.0	2.206	0.98	21.4	1.9	37.18	0.91
X	C	700	59.98	0.4769	106.7	3.854	1.1	47.5	4.0	40.13	0.37
X	D	750	41.83	0.3678	39.84	3.337	1.4	71.9	5.8	42.35	0.27
X	E	800	46.99	0.4404	60.57	6.456	1.2	62.0	9.4		0.23
X	F	875	49.14	0.4252	72.13	8.12	1.2	56.7	13.9	39.26	0.25
X	G	975	51.97	0.5048	83.83	10.73	1.0	52.4	19.8	38.39	0.25
X	H	1075	66.55	0.4043	133.3	26.07	1.3	40.8	34.2	38.31	0.29
X	I	1250	87.00	0.5265	198.9	71.92	0.97	32.5	73.8	39.81	0.39
X	J	1700	83.25	1.205	178.7	47.59	0.42	36.7	100.0	43.02	0.36
	Integrated age ± 2σ			n=10		181.5	0.74	K2O=4.02%		40.61	0.78
	Isochron±2σ		steps A-J	n=10	MSWD=32.15		$^{40}Ar/^{36}Ar$=	295.9±10.8		40.1	1.9
	D-42, Groundmass Concentrate, 28.5 mg, J=0.0007817±0.06%, D=1.002±0.001, NM-210K, Lab#=57307-01										
Xi	A	600	675.2	0.7902	2225.7	0.767	0.65	2.6	0.6	24.6	4.9
Xi	B	625	55.51	0.3503	105.7	3.392	1.5	43.8	3.0	33.96	0.37
Xi	C	700	46.94	0.4831	67.78	5.723	1.1	57.4	7.1	37.63	0.25
X	D	750	46.94	0.6006	62.89	4.736	0.85	60.5	10.5	39.64	0.25
X	E	800	49.08	0.8004	69.59	9.18	0.64	58.2	17.1	39.88	0.24
X	F	875	50.73	0.8646	73.46	13.43	0.59	57.4	26.8	40.60	0.20
	G	975	53.67	0.8452	82.46	22.06	0.60	54.7	42.6	40.98	0.21
	H	1075	53.93	0.8062	84.82	19.90	0.63	53.7	57.0	40.37	0.21
	I	1250	53.09	0.9283	82.61	18.27	0.55	54.2	70.1	40.13	0.21
	J	1700	52.32	1.022	77.79	41.56	0.50	56.2	100.0	41.05	0.19
	Integrated age ± 2σ			n=10		139.0	0.59	K2O=2.40%		40.25	0.39
	Plateau ± 2σ		steps G-J	n=4	MSWD=4.98	101.802	0.557±0.118		73.2	40.66	0.45
	Isochron±2σ		steps D-J	n=7	MSWD=4.54		$^{40}Ar/^{36}Ar$=	325.6±39.8		37.3	2.0

	ID	Power (°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)
	D-7, Hornblende, 26.41 mg, J=0.0007854±0.08%, D=1.002±0.001, NM-210N, Lab#=57330-01										
X	A	800	1067.8	-42.5443	3481.2	0.139	-	3.3	0.4	48.3	10.9
X	B	900	93.92	-58.2553	173.9	0.105	-	40.2	0.6	50.7	4.3
X	C	1000	55.77	-6.3638	77.89	0.600	-	57.8	2.2	44.9	1.0
	D	1050	32.23	6.200	10.60	2.693	0.082	91.9	9.3	41.65	0.22
	E	1080	33.38	6.672	14.58	4.215	0.076	88.7	20.3	41.69	0.18
	F	1100	34.03	6.806	15.85	4.680	0.075	87.9	32.6	42.09	0.18
	G	1120	31.85	6.922	9.755	11.69	0.074	92.7	63.2	41.57	0.14
X	H	1140	30.01	7.095	5.608	4.083	0.072	96.4	74.0	0.31	0.15
X	I	1160	30.77	6.856	9.782	0.835	0.074	92.4	76.1	40.04	0.52
X	J	1220	31.75	7.057	7.770	3.339	0.072	94.6	84.9	42.27	0.18
X	K	1650	31.84	12.51	12.44	5.759	0.041	91.7	100.0	41.26	0.17
	Integrated age ± 2σ			n=11		38.13	0.071	K2O=0.71%		41.65	0.25
	Plateau ± 2σ		steps D-G	n=4	MSWD=1.76	23.27	0.075±0.008		61.0	41.73	0.24
	Isochron±2σ		steps A-K	n=11	MSWD=9.31		$^{40}Ar/^{36}Ar$= 302±14			41.42	0.43
	D-47, Biotite, 5.41 mg, J=0.0007846±0.08%, D=1.002±0.001, NM-210N, Lab#=57332-01										
X	A	625	160.3	0.6153	372.3	0.552	0.83	31.4	0.7	69.9	1.6
X	B	700	136.4	0.0775	194.9	0.560	6.6	57.8	1.4	108.3	1.3
X	C	750	127.1	0.0417	50.50	0.826	12.2	88.3	2.4	152.2	1.0
X	D	800	140.0	0.1141	26.79	1.176	4.5	94.4	3.8	177.90	0.73
X	E	875	147.7	0.0207	12.52	5.753	24.7	97.5	10.9	193.11	0.55
X	F	975	150.1	0.0053	5.250	15.85	97.1	99.0	30.5	198.88	0.29
X	G	1025	149.4	0.0056	2.712	12.60	91.2	99.5	46.0	199.02	0.35
X	H	1075	149.0	0.0160	2.897	11.53	31.9	99.4	60.2	198.36	0.33
X	I	1150	148.2	0.1005	2.776	8.10	5.1	99.5	70.2	197.44	0.34
X	J	1200	147.2	0.1897	2.273	11.27	2.7	99.6	84.1	196.39	0.34
X	K	1300	146.7	0.2683	2.085	12.36	1.9	99.6	99.3	195.90	0.33
X	L	1700	72.52	94.51	112.6	0.530	0.005	64.9	100.0	69.8	1.6
	Integrated age ± 2σ			n=12		81.1	0.68	K2O=7.34%		194.42	0.53

Notes:

Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interfering reactions.
Errors quoted for individual analyses include analytical error only, without interfering reaction or J uncertainties.
Integrated age calculated by summing isotopic measurements of all steps.
Integrated age error calculated by quadratically combining errors of isotopic measurements of all steps.
Plateau age is inverse-variance-weighted mean of selected steps.
Plateau age error is inverse-variance-weighted mean error (Taylor, 1982) times root MSWD where MSWD>1.
Plateau error is weighted error of Taylor (1982).
Decay constants and isotopic abundances after Steiger and Jäger (1977).
symbol preceding sample ID denotes analyses excluded from plateau age calculations.
Weight percent K_2O calculated from ^{39}Ar signal, sample weight, and instrument sensitivity.
Ages calculated relative to FC-2 Fish Canyon Tuff sanidine interlaboratory standard at 28.02 Ma
Decay Constant (LambdaK (total)) = 5.543e-10/a
Correction factors:
$(^{39}Ar/^{37}Ar)_{Ca}$ = 0.00068 ± 5e-05
$(^{36}Ar/^{37}Ar)_{Ca}$ = 0.00028 ± 2e-05
$(^{38}Ar/^{39}Ar)_K$ = 0.01077
$(^{40}Ar/^{39}Ar)_K$ = 0 ± 0.0004

Table 3. $^{40}Ar/^{39}Ar$ analytical data.

ID	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$^{40}Ar^*$ (%)	Age (Ma)	±1σ (Ma)
D-4, Sanidine, J=0.0007852±0.10%, D=1.002±0.001, NM-210N, Lab#=57320								
06	27.55	-0.0065	0.2058	11.411	-	99.8	38.53	0.07
04	27.85	0.0066	1.213	8.224	77.5	98.7	38.53	0.09
13	28.08	0.0337	1.894	10.978	15.2	98.0	38.57	0.07
03	28.10	0.0045	1.907	11.437	114.3	98.0	38.59	0.07
15	27.67	0.0076	0.3881	10.262	66.9	99.6	38.62	0.07
01	28.13	-0.0037	1.881	7.342	-	98.0	38.65	0.10
10	27.68	-0.0064	0.3329	7.648	-	99.6	38.65	0.09
09	28.04	0.0062	1.500	4.395	82.3	98.4	38.67	0.11
07	28.87	-0.0130	4.182	6.027	-	95.7	38.72	0.12
05	27.68	-0.0088	0.0955	8.494	-	99.9	38.75	0.08
11	27.89	0.0131	0.7542	10.116	38.8	99.2	38.77	0.08
12	27.81	0.0033	0.4348	10.578	153.2	99.5	38.79	0.08
02	28.75	0.0059	3.492	7.511	86.9	96.4	38.84	0.10
14	28.31	0.0102	1.941	4.728	49.9	98.0	38.88	0.10
08	27.80	-0.0117	0.1317	10.244	-	99.9	38.90	0.08
Mean age ± 2σ		n=15	MSWD=2.18		76.1 ±63.5		38.68	0.10

Notes:

Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interfering reactions.
Errors quoted for individual analyses include analytical error only, without interfering 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 Jäger (1977).
symbol preceding sample ID denotes analyses excluded from mean age calculations.
Ages calculated relative to FC-2 Fish Canyon Tuff sanidine interlaboratory standard at 28.02 Ma
Decay Constant (LambdaK (total)) = 5.543e-10/a
Correction factors:

$(^{39}Ar/^{37}Ar)_{Ca}$ = 0.00068 ± 5e-05
$(^{36}Ar/^{37}Ar)_{Ca}$ = 0.00028 ± 2e-05
$(^{38}Ar/^{39}Ar)_K$ = 0.01077
$(^{40}Ar/^{39}Ar)_K$ = 0 ± 0.0004

New Mexico Bureau of Mines and Mineral Resources

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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