$^{40}Ar/^{39}Ar$ Geochronology Results for the Soldiers Pass, Granite Peak, Granite Peak SE, Camels Back Ridge NE, Flat Top, Blind Lake, and Deer Creek Lake 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 in which 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**
SP-3303	Soldiers Pass	40.17759°	111.97360°	Christiansen and others (2007); Biek and others (in prep.)
SP-4003	Soldiers Pass	40.15062°	111.98955°	Christiansen and others (2007); Biek and others (in prep.)
SP-3205	Soldiers Pass	40.15045°	111.99398°	Christiansen and others (2007); Biek and others (in prep.)
SP-4103	Soldiers Pass	40.15850°	111.97190°	Christiansen and others (2007); Biek and others (in prep.)
SP-603[A]	Soldiers Pass	40.20338°	111.97778°	Christiansen and others (2007); Biek and others (in prep.)
SP-1603B	Soldiers Pass	40.15518°	111.97959°	Christiansen and others (2007); Biek and others (in prep.)
AR-105	Soldiers Pass	40.06028°	112.02833°	Christiansen and others (2007); Biek and others (in prep.)
SP-1903	Soldiers Pass	40.15631°	111.97585°	Christiansen and others (2007); Biek and others (in prep.)
GP081605-6C	Granite Peak	40° 07' 44"	113° 17' 04"	Clark and others (2007); Clark and others (in prep.)
SM071405-11	Granite Peak SE	40° 03' 55.4"	113° 16' 18.5"	Clark and others (2007); Clark and others (in prep.)
FM083105-1	Camels Back Ridge NE	40° 12' 08"	112° 50' 16"	Clark and others (2007); Clark and others (in prep.)
GP102605-1	Granite Peak	40° 09' 58.2"	113° 15' 56.2"	Clark and others (2007); Clark and others (in prep.)
GP102605-3	Granite Peak SE	40° 05' 16.2"	113° 16' 45.9"	Clark and others (2007); Clark and others (in prep.)

FT081505-1	Flat Top	38° 26.462'*	111° 28.750'*	Doelling and Kuehne (2007)
FT081505-2	Flat Top	38° 26.312'*	111° 28.293'*	Doelling and Kuehne (2007)
BM081605-1	Blind Lake	38° 09.716'*	111° 23.866'*	Doelling and Kuehne (2007)
BM081605-2	Deer Creek Lake	38° 05.557'*	111° 24.766'*	Doelling and Kuehne (2007)

Location data based on NAD27, except where * indicates based on NAD83.

Disclaimer

This Open-File Report is intended as a data repository for technical analytical information gathered in support of various geologic mapping projects. The data are presented as received from the NMGRL and do not necessarily conform to UGS technical or editorial standards. Therefore, it may be premature for an individual or group to take actions based on the contents of this report.

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

Biek, R.F., Clark, D.L., and Christiansen, E.H., in preparation, Geologic map of the Soldiers Pass quadrangle, Utah County, Utah: Utah Geological Survey Map, scale 1:24,000.

Christiansen, E.H., Baxter, N., Ward, T.P., Zobell, E., Chandler, M.R., Dorais, M.J., Kowallis, B.J., and Clark, D.L., 2007, Cenozoic Soldiers Pass volcanic field, central Utah — implications for the transition to extension-related magmatism in the Basin and Range Province, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and

Chidsey, T.C., Jr., editors, Central Utah — diverse geology of a dynamic landscape: Utah Geological Association Publication 36.

Clark, D.L., Oviatt, G.C., and Page, D., 2007, Progress report 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 1 of 2): Utah Geological Survey Open-File Report 501, scale 1:62,500.

Clark, D.L., Biek, R.F., Willis, G.C., Brown, K.D., Kuehne, P.A., Ehler, J.B., and Ege, C.L., in preparation, Reconnaissance geologic map of the Granite Peak and Sapphire Mountain area, U.S. Army Dugway Proving Ground, Tooele County, Utah: Utah Geological Survey Open-File Report, scale 1:24,000.

Doelling, H.H., and Kuehne, P.A., 2007, Interim geologic map of the east half of the Loa 30' x 60' quadrangle, Wayne, Garfield, and Emery Counties, Utah: Utah Geological Survey Open-File Report 489, scale 1:62,500.

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

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Introduction

Fourteen 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 phases, including saindine, plagioclase, hornblende, biotite and 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 cleaned with dilute HCl
sanidine and plagioclase cleaned with dilute HF
biotite and hornblende cleaned with H2O

Irradiation
Drilled aluminum discs, 14 hours, Nuclear Science Center in College Station, Texas
Monitors: Fish Canyon sanidine, 28.02 Ma (Renne et al, 1998)

Extraction methods
groundmass concentrates analyzed with the furnace incremental heating
SP-3303, SP-4003, SP-3205 and SP-4103
hornblende separates analyzed with the furnace incremental heating
FT081505-2 and FT081505-1
sanidine separates were analyzed by the single-crystal laser fusion
GP081605-6c, SM071405-11, SP-603, SP-1603B and AR-105
biotite and plagioclase single-crystal separates heated in two steps by CO_2 laser
BM081605-01 and BM081605-2
Analytical parameters are further detailed in Table 1 footnotes and in Appendices 1 and 2

Results

Results from this study are summarized in Table 1. Analytical data are detailed in Appendix 1. Results from individual sample analyses are presented in Figures 1 to 14, and are summarized on a sample by sample basis below.

GP081605-6c sanidine (Figure 1)

Weighted mean age 7.78±0.05 Ma n/n_{total} 14/15 MSWD 2.66

Extraction method single-crystal laser fusion
Distribution of ages Gaussian
Outliers/excluded aliquots one crystal, small signal
Radiogenic yields 37.3% to 71.7%, abnormally low for typical 8 Ma sanidine
K/Ca 32.2 to 4364.4, poor measurement, analyzed too long after irradiation
Interpretation accurate eruption age

SM071405-11 sanidine (Figure 2)

Weighted mean age 8.20±0.05 Ma n/n_{total} 14/15 MSWD 1.62
Extraction method single-crystal laser fusion
Distribution of ages near Gaussian
Outliers/excluded aliquots one plagioclase crystal
Radiogenic yields 96.4% to 102.1%
K/Ca 20.3 to 38.1
Interpretation accurate eruption age

SP-603 sanidine (Figure 3)

Weighted mean age 34.70±0.07 Ma n/n_{total} 22/26 MSWD 1.52
Extraction method single-crystal laser fusion
Distribution of ages Gaussian
Outliers/excluded aliquots four plagioclase crystals
Radiogenic yields 98.5% to 99.8%
K/Ca 25.9 to 84.1
Interpretation accurate eruption age

SP-1603B sanidine (Figure 4)

Weighted mean age 34.70±0.07 Ma n/n_{total} 11/15 MSWD 1.68
Extraction method single-crystal laser fusion
Distribution of ages Gaussian
Outliers/excluded aliquots one xenocrystic sanidine, four plagioclase crystals
Radiogenic yields 99.0% to 99.8%
K/Ca 32.6 to 58.9
Interpretation accurate eruption age

AR-105 sanidine (Figure 5)

Weighted mean age 34.73±0.08 Ma n/n_{total} 9/9 MSWD 0.60
Extraction method single-crystal laser fusion
Distribution of ages Gaussian
Outliers/excluded aliquots none
Radiogenic yields 99.2% to 99.8%
K/Ca 50.8 to 72.8
Interpretation accurate eruption age

BM081605-1 plagioclase (Figure 6)

Weighted mean age 25.11±0.17 Ma n/n_{total} 11/11 MSWD 2.52
Extraction method four to five crystal aliquot two step laser analysis
Distribution of ages somewhat skewed
Outliers/excluded aliquots none
Radiogenic yields A steps 17.8% to 84.6%, B steps, 71.7% to 89.1%
K/Ca 0.16 to 0.20
Interpretation accurate eruption age

BM081605-2 plagioclase (Figure 7)

Weighted mean age 25.13±0.10 Ma n/n_{total} 6/10 MSWD 0.97
Extraction method four to five crystal aliquot two step laser analysis
Distribution of ages Gaussian
Outliers/excluded aliquots three young aliquots and one old
Radiogenic yields A steps 25.4% to 92.2%, B steps, 94.3% to 97.1%
K/Ca 0.13 to 0.17
Interpretation accurate eruption age

SP-1903 biotite (Figure 8)

Weighted mean age 34.79±0.10 Ma n/n_{total} 8/8 MSWD 1.72
Extraction method single crystal aliquot two step laser analysis
Distribution of ages Gaussian
Outliers/excluded aliquots none
Radiogenic yields A steps 19.9% to 60.7%, B steps, 93.2% to 98.0%
K/Ca 9.2 to 25.9
Interpretation accurate eruption age

SP-3303 groundmass concentrate (Figure 9)

Isochron age 19.47±0.14 Ma n/n_{total} 9/9 MSWD 1.4
$^{40}Ar/^{36}Ar$ intercept 299.6±1.2
Extraction method furnace incremental heating
Morphology of age spectrum somewhat disturbed, decreasing apparent ages
% of ^{39}Ar included in age calculation 100%
Radiogenic yields 1.0% to 59.3%, inversely correlated to decrease in apparent age
K/Ca 0.035 to 0.84, significant decrease over final two heating steps
Interpretation minor excess ^{40}Ar, accurate eruption age

SP-4003 groundmass concentrate (Figure 10)

Isochron age 19.65±0.17 Ma n/n_{total} 9/9 MSWD 3.6
$^{40}Ar/^{36}Ar$ intercept 298.3±3.1
Extraction method furnace incremental heating
Morphology of age spectrum somewhat disturbed, decreasing apparent ages
% of ^{39}Ar included in age calculation 100%
Radiogenic yields 1.7% to 81.1%, increase over 64.7% of spectrum, followed by decrease

K/Ca 0.14 to 0.65, increase over 22.9% of spectrum followed by decrease
Interpretation minor excess ^{40}Ar, accurate eruption age

SP-3205 groundmass concentrate (Figure 11)

Isochron age 33.73±0.65 Ma n/n_{total} 9/9 MSWD 3.1
$^{40}Ar/^{36}Ar$ intercept 304.4±3.0
Extraction method furnace incremental heating
Morphology of age spectrum disturbed, saddle-shaped
% of ^{39}Ar included in age calculation 100%
Radiogenic yields 1.7% to 81.1%, increase over 64.7% of spectrum, followed by decrease
K/Ca 0.14 to 0.65, increase over 22.9% of spectrum, followed by decrease
Interpretation minor excess ^{40}Ar, accurate eruption age

FT081505-1 hornblende (Figure 12)

Weighted mean age 25.95±0.97 Ma n/n_{total} 9/10 MSWD 1.15
Extraction method furnace incremental heating
Morphology of age spectrum nearly concordant, low precision
% of ^{39}Ar included in age calculation 90.4%
Radiogenic yields 5.9% to 81.1%, increase over 81.9% of spectrum, followed by decrease
K/Ca 0.002 to 0.18, increase over 81.9% of spectrum, followed by decrease
Interpretation accurate but low precision eruption age

FT081505-2 hornblende (Figure 13)

Weighted mean age 22.8±1.1 Ma n/n_{total} 4/4 MSWD 2.74
Extraction method furnace incremental heating, highest temperature gas fractions lost due to analytical problem, low temperature steps unaffected
Morphology of age spectrum dropping apparent ages
% of ^{39}Ar included in age calculation 100%
Radiogenic yields 2.6% to 61.2%, increase over 81.9% of spectrum, followed by decrease
K/Ca 0.78 to 1.8, increase over 54.2% of spectrum, followed by decrease
Interpretation accurate but low precision eruption age

SP-4103 groundmass concentrate (Figure 14)

Isochron age 34.9±4.2 Ma n/n_{total} 4/4 MSWD 107.7
$^{40}Ar/^{36}Ar$ intercept 288±62
Extraction method furnace incremental heating, highest temperature gas fractions lost due to analytical problem, low temperature steps unaffected
Morphology of age spectrum increase followed by dropping apparent ages
% of ^{39}Ar included in age calculation 100%
Radiogenic yields 2.6% to 61.2%, increase over 81.9% of spectrum, followed by decrease
K/Ca 0.78 to 1.8, increase over 54.2% of spectrum, followed by decrease
Interpretation minor excess ^{40}Ar accurate but very low precision eruption age

Discussion

Most of the samples analyzed provided reliable age information. The sanidine separated from samples SP-603, SP-603B, AR-105, GP081605-6c and SM071405-11 provided reliable, precise eruption ages for the rhyolites from which they were sampled (34.70±0.07 Ma, 34.70±0.07 Ma, 34.73±0.08 Ma, 7.78±0.05 Ma and 8.20±0.05 Ma, respectively). It is noted that the ages assigned to samples SP-603 and SP-603B are analytically indistinguishable. The K/Ca and radiogenic yield data are also indistinguishable. The single crystal data obtained for the plagioclase (BM081605-01 and BM081605-2) and biotite (SP-1903) samples provide reliable although less precise data than the sanidine ages. The groundmass concentrates (SP-3303, SP-4003 and SP-3205) and FT081505-1 hornblende provide fairly accurate but less straightforward age information. The old apparent ages revealed in the early heating steps of samples SP-3303, SP-4003 and FT081505-1 and the early and late heating steps of sample SP-3205 are strongly suggestive of excess Ar ($^{40}Ar/^{36}Ar > 295.5$; Harrison and McDougall, 1981; Zeitler and Fitzgerald, 1986). This is confirmed by the $^{40}Ar/^{36}Ar$ ratios determined by isochron analysis (299.6±1.4, 298.3±3.1, 298.7±1.9 and 304.4±3.0, respectively). We have therefore, assigned the isochron ages (19.47±0.17 Ma, 19.65±0.17 Ma, 25.95±0.97 Ma and 33.73±0.65 Ma, respectively) as the eruption ages. We have less confidence in the apparent age assigned to the FT081505-02 hornblende age spectra due to the analytical problems that affected the high temperature steps. We assign the weighted mean age calculated from the four lower temperature heating steps (22.8±1.1 Ma) as the eruption age, but will send more material to the reactor and reanalyze this sample. The disturbed age spectrum revealed by the groundmass concentrate from SP-4103 is probably the result of ^{39}Ar recoil (redistribution of ^{39}Ar created at the reactor from high K sites to low K sites) perhaps complicated by excess Ar and/or Ar loss. We have assigned the low precision isochron age (34.9±4.2 Ma) as the eruption age of this lava.

References Cited

Deino, A., and Potts, R., 1992. Age-probability spectra from examination of single-crystal $^{40}Ar/^{39}Ar$ dating results: Examples from Olorgesailie, Southern Kenya Rift, Quat. International, 13/14, 47-53.

Harrison, T.M., and McDougall, I. 1981. Excess ^{40}Ar in metamorphic rocks from Broken Hill, New South Wales: Implications for $^{40}Ar/^{39}Ar$ age spectra and the thermal history of the region. Earth Planet. Sci. Lett., 55, 123-149.

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.39AR dating, 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.

Taylor, J.R., 1982. An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements,. Univ. Sci. Books, Mill Valley, Calif., 270 p.

Zeitler, P.K. and Fitzgerald, J.D., 1986. Saddle-shaped $^{40}Ar/^{39}Ar$ age spectra from young, microstructurrally complex potassium feldspars. Geochem. et Cosmo. Acta., 50, pp.1185-1199.

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

Sample	Lab #	Irradiation	mineral	age analysis	steps	Age	±2σ	MSWD	40Ar/36Ar intercept	comments
GP081605-6c	56450	NM-197	sanidine	laser total fusion	14	7.78	0.05	2.66		
SM071405-11	56455	NM-197	sanidine	laser total fusion	14	8.20	0.05	1.62		
SP-3303	56430	NM-197	groundmass concentate	furnace step-heat	9	19.47	0.14	1.41	299.6±1.2	isochron age
SP-4003	56429	NM-197	groundmass concentrae	furnace step-heat	9	19.65	0.17	3.65	298.3±3.1	isochron age
FT081505-2	56451	NM-197	hornblende	furnace step-heat	4	22.8	1.1	2.74		analytical problems
FT081505-1	56452	NM-197	hornblende	furnace step-heat	9	25.95	0.97	1.15		
BM081605-01	56463	NM-197	plagioclase	laser step-heat	11	25.11	0.17	2.52		
BM081605-2	56462	NM-197	plagioclase	laser step-heat	6	25.13	0.10	0.97		
SP-3205	56461	NM-197	groundmass concentrate	furnace step-heat	9	33.73	0.65	3.13	304.4±3.0	isochron age
SP-603	56454	NM-197	sanidine	laser total fusion	22	34.70	0.07	1.52		
SP-1603B	56456	NM-197	sanidine	laser total fusion	11	34.70	0.07	1.68		
AR105	56453	NM-197	sanidine	laser total fusion	9	34.73	0.08	0.60		
SP-1903	56457	NM-197	biotite	laster step-heat	8	34.79	0.10	1.72		
SP-4103	56428	NM-197	groundmass concentate	furnace step-heat	6	34.90	4.20	107.72	288±62	highly disturbed, isochron age

Sample preparation and irradiation:
Minerals separated with standard heavy liquid, Franz Magnetic and hand-picking techniques.
Samples irradiated in a machined Aluminum tray for 14 hours in D-3 position, Nuclear Science Center, College Station, TX.
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 and hornblende step-heated for 9 minutes, using a Mo double-vacuum resistance furnace.
Plagioclase and biotite step-heated by a 50 watt Synrad CO2 laser.
Sanidine fused by a 50 watt Synrad CO_2 laser.

Analytical parameters:
J-factors determined to a precision of ± 0.1% 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 for single crystal sanidine analyses.

	ID	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ ($\times 10^{-3}$)	$^{39}Ar_K$ ($\times 10^{-15}$ mol)	K/Ca	$^{40}Ar^*$ (%)	Age (Ma)	±1σ (Ma)
	SP603, Sanidine, J=0.0013929±0.09%, D=1.002±0.001, NM-197K, Lab#=56454								
#	09	15.28	4.211	7.692	1.757	0.12	87.4	33.34	0.24
#	17	15.15	2.263	5.920	1.115	0.23	89.7	33.88	0.38
#	21	14.62	3.277	3.619	2.084	0.16	94.5	34.47	0.22
	12	13.93	0.0114	0.1799	17.682	44.7	99.6	34.54	0.06
	13	14.03	0.0108	0.4129	22.349	47.1	99.1	34.62	0.06
	18	13.95	0.0110	0.1234	29.228	46.2	99.7	34.63	0.05
	20	14.00	0.0131	0.2739	13.736	38.8	99.4	34.64	0.05
	25	13.98	0.0110	0.1916	10.371	46.5	99.6	34.65	0.06
	15	13.96	0.0116	0.1005	26.594	43.9	99.8	34.66	0.06
	01	13.97	0.0078	0.1349	36.036	65.2	99.7	34.66	0.05
	23	14.00	0.0197	0.2454	26.329	25.9	99.5	34.67	0.05
	08	13.97	0.0068	0.1121	7.051	74.8	99.8	34.68	0.08
	26	13.95	0.0104	0.0496	40.761	49.2	99.9	34.68	0.05
	04	14.04	0.0113	0.3498	28.968	45.0	99.3	34.68	0.05
	14	13.99	0.0130	0.1846	11.804	39.3	99.6	34.68	0.06
	19	14.01	0.0135	0.2220	30.696	37.8	99.5	34.71	0.05
	05	14.02	0.0061	0.2017	6.046	84.1	99.6	34.74	0.08
	16	14.01	0.0085	0.1758	21.597	60.2	99.6	34.74	0.06
	02	14.18	0.0074	0.7238	21.885	68.9	98.5	34.75	0.06
	22	14.01	0.0156	0.1402	27.045	32.6	99.7	34.76	0.06
	03	14.01	0.0083	0.1253	48.467	61.3	99.7	34.78	0.05
	07	14.03	0.0069	0.1744	22.918	73.4	99.6	34.80	0.06
	24	14.27	0.0136	0.9654	10.150	37.5	98.0	34.80	0.06
	06	14.03	0.0080	0.1714	11.149	63.4	99.6	34.80	0.06
	10	14.03	0.0081	0.1443	11.979	63.1	99.7	34.82	0.06
#	11	14.86	3.316	-0.0864	0.448	0.15	102.0	37.79	0.79
	Mean age ± 2σ		n=22	MSWD=1.52		52.2 ±30.7		34.70	0.07
	SP-1603B, Sanidine, J=0.0013907±0.08%, D=1.002±0.001, NM-197K, Lab#=56456								
	10	14.01	0.0087	0.3157	16.043	58.9	99.3	34.57	0.06
	04	13.97	0.0130	0.1749	25.251	39.3	99.6	34.60	0.05
	02	13.96	0.0112	0.0791	18.012	45.4	99.8	34.63	0.06
	12	14.01	0.0096	0.1925	33.718	52.9	99.6	34.67	0.05
	11	14.02	0.0090	0.2239	39.918	57.0	99.5	34.68	0.05
	15	13.99	0.0093	0.0903	54.866	54.7	99.8	34.71	0.04
	01	14.03	0.0098	0.1943	29.571	52.2	99.6	34.72	0.05
	13	14.02	0.0127	0.1390	17.507	40.1	99.7	34.73	0.07
	08	14.03	0.0099	0.1171	33.685	51.5	99.8	34.77	0.05
	03	14.05	0.0115	0.1909	34.916	44.2	99.6	34.79	0.05
	14	14.14	0.0157	0.4733	29.006	32.6	99.0	34.79	0.06
	09	*14.04*	*0.0071*	*-0.1561*	*8.380*	*72.1*	*100.3*	*35.01*	*0.08*
#	06	15.97	2.969	6.446	1.639	0.17	89.6	35.61	0.26
#	05	15.41	3.102	4.348	1.896	0.16	93.3	35.80	0.24
#	07	22.33	5.221	21.94	1.011	0.098	72.9	40.53	0.57
	Mean age ± 2σ		n=11	MSWD=1.68		48.1 ±16.7		34.70	0.07

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)
AR105, Sanidine, J=0.0013922±0.10%, D=1.002±0.001, NM-197K, Lab#=56453								
02	14.01	0.0086	0.2403	17.773	59.6	99.5	34.67	0.07
03	14.05	0.0087	0.3821	13.075	58.7	99.2	34.67	0.06
08	13.99	0.0083	0.1482	25.929	61.4	99.7	34.70	0.05
01	14.03	0.0070	0.2689	22.574	72.8	99.4	34.71	0.06
04	14.00	0.0070	0.1530	11.017	72.7	99.7	34.71	0.06
05	14.01	0.0100	0.1692	2.633	50.8	99.6	34.73	0.15
09	14.02	0.0085	0.1540	12.678	60.4	99.7	34.75	0.06
06	14.02	0.0074	0.1482	37.611	69.3	99.7	34.77	0.05
07	14.03	0.0094	0.0920	12.636	54.0	99.8	34.82	0.07
Mean age ± 2σ		n=9	MSWD=0.60		62.2 ±15.7		34.73	0.08
SM071405-11, Sanidine, J=0.0013923±0.08%, D=1.002±0.001, NM-197K, Lab#=56455								
09	5.432	2.315	8.174	0.494	0.22	59.1	8.05	1.20
10	3.285	0.0194	0.1549	15.062	26.4	98.7	8.12	0.04
05	3.330	0.0226	0.2919	13.108	22.6	97.5	8.13	0.05
15	3.354	0.0147	0.3314	13.962	34.8	97.1	8.16	0.05
11	3.312	0.0174	0.1602	5.865	29.3	98.6	8.19	0.10
01	3.390	0.0205	0.4171	18.928	24.8	96.4	8.19	0.04
13	3.296	0.0193	0.0780	3.874	26.4	99.3	8.21	0.16
08	3.288	0.0134	0.0386	8.906	38.1	99.7	8.21	0.07
06	3.355	0.0175	0.2030	15.415	29.2	98.3	8.26	0.04
03	3.290	0.0206	-0.0386	5.047	24.8	100.4	8.28	0.12
12	3.276	0.0181	-0.1947	3.786	28.1	101.8	8.36	0.15
04	3.375	0.0251	0.0817	4.353	20.3	99.3	8.40	0.13
02	3.310	0.0217	-0.1644	5.055	23.5	101.5	8.42	0.12
07	3.294	0.0178	-0.2273	6.224	28.7	102.1	8.43	0.09
Mean age ± 2σ		n=14	MSWD=1.62		25.5 ±17.3		8.20	0.05
GP081605-6c, Sanidine, J=0.0013819±0.05%, D=1.002±0.001, NM-197J, Lab#=56450								
03	8.249	0.0014	17.51	18.559	376.6	37.3	7.65	0.07
15	5.675	0.0033	8.789	18.407	156.9	54.2	7.66	0.05
01	5.618	0.0036	8.552	23.622	141.0	55.0	7.69	0.04
08	7.302	0.0015	14.24	11.429	347.3	42.4	7.70	0.07
13	5.740	0.0038	8.887	17.245	132.8	54.3	7.75	0.05
04	4.622	0.0037	5.104	15.758	138.4	67.4	7.75	0.04
02	6.315	0.0029	10.81	33.472	177.2	49.4	7.77	0.05
12	5.123	0.0007	6.736	12.563	747.9	61.1	7.79	0.05
11	5.435	0.0159	7.756	45.781	32.2	57.9	7.82	0.04
06	4.880	0.0008	5.838	14.182	668.4	64.7	7.85	0.05
14	4.401	0.0027	4.209	2.232	191.7	71.7	7.86	0.15
07	6.468	0.0002	11.18	12.965	3026.1	48.9	7.87	0.07
05	4.529	0.0057	4.569	13.291	88.8	70.2	7.91	0.04
10	6.804	0.0001	12.26	10.089	4364.4	46.7	7.91	0.07
# 09	16.36	-0.0339	42.98	0.793	-	22.3	9.08	0.51
Mean age ± 2σ		n=14	MSWD=2.66		756.4 ±2579.4		7.78	0.05

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)

Notes:

Age and error calculations:

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

Sample preparation and irradiation:

Minerals separated with standard heavy liquid, Franz Magnetic and hand-picking techniques.
Samples were irradiated in a machined Al disc for 14 hours in D-3 position, Nuclear Science Center, College Station, TX.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-2). Assigned age = 28.02 Ma (Renne et al, 1998).

Instrumentation and analytical procedures:

Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.
Sanidine fused by a 50 watt Synrad CO_2 laser.
Reactive gases removed during a 2 minute 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 7.29 x 10^{-17} moles/pA for laser analyses.
Total system blank and background averaged 297, 0.76, 0.65, 7.30, 1.74 x 10^{-18} moles at masses 40, 39, 38, 37 and 36, for laser analyses.
J-factors determined by CO_2 laser-fusion of 6 single crystals from each of 10 positions around the irradiation tray.
Correction factors for interfering nuclear reactions were determined using K-glass and CaF_2 and are as follows:

Table 3. $^{40}Ar/^{39}Ar$ analytical data for B steps of two-step laser analyses.

	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)
	BM081605-2, Plagioclase, J=0.001397±0.07%, D=1.002±0.001, NM-197L, Lab#=56462								
#	07B	10.50	3.638	3.780	0.896	0.14	92.2	24.29	0.37
#	11B	10.27	3.602	2.675	2.218	0.14	95.2	24.54	0.20
#	06B	10.58	3.624	3.714	1.141	0.14	92.5	24.54	0.34
	10B	10.45	3.012	2.507	3.767	0.17	95.3	24.97	0.13
	08B	10.41	3.215	2.353	5.749	0.16	95.9	25.05	0.10
	09B	10.37	3.765	2.292	3.429	0.14	96.5	25.10	0.14
	04B	10.34	3.481	2.091	3.720	0.15	96.8	25.11	0.13
	05B	10.67	3.790	3.119	2.709	0.13	94.3	25.24	0.16
	02B	10.38	3.363	1.975	4.518	0.15	97.1	25.27	0.09
#	03B	10.44	3.125	1.300	1.995	0.16	98.8	25.86	0.21
	Mean age ± 2σ		n=6	MSWD=0.97		0.15 ±0.03		25.13	0.10
	BM081605-01, Plagioclase, J=0.0013986±0.09%, D=1.002±0.001, NM-197L, Lab#=56463								
	01B	11.66	3.116	7.607	3.651	0.16	82.9	24.28	0.25
	03B	12.06	3.017	8.287	2.495	0.17	81.8	24.75	0.25
	02B	11.16	3.143	4.997	3.036	0.16	89.1	24.96	0.18
	04B	11.39	3.050	5.767	3.623	0.17	87.3	24.96	0.17
	08B	12.38	3.210	9.141	9.096	0.16	80.3	24.97	0.12
	05B	11.59	3.247	6.173	3.761	0.16	86.6	25.19	0.18
	06B	12.62	2.567	9.437	4.719	0.20	79.6	25.22	0.15
	07B	11.67	3.253	6.402	7.633	0.16	86.1	25.23	0.12
	10B	11.87	2.884	6.910	4.134	0.18	84.8	25.27	0.18
	09B	14.17	3.008	14.43	5.194	0.17	71.7	25.48	0.24
	11B	12.03	3.017	7.171	3.236	0.17	84.5	25.51	0.19
	Mean age ± 2σ		n=11	MSWD=2.52		0.17 ±0.02		25.11	0.17
	SP-1903, Biotite, J=0.0013888±0.09%, D=1.002±0.001, NM-197K, Lab#=56457								
	06B	14.24	0.0294	0.9758	25.308	17.3	98.0	34.63	0.07
	01	15.01	0.0345	3.437	21.419	14.8	93.2	34.72	0.08
	07B	14.79	0.0552	2.636	16.917	9.2	94.8	34.77	0.08
	04B	14.96	0.0274	3.230	9.964	18.6	93.6	34.77	0.09
	08B	14.51	0.0197	1.670	17.100	25.9	96.6	34.77	0.08
	02B	14.48	0.0258	1.556	9.655	19.8	96.8	34.79	0.08
	09B	14.67	0.0205	2.073	12.245	24.9	95.8	34.90	0.08
	03B	14.44	0.0204	1.227	14.678	25.0	97.5	34.94	0.07
	Mean age ± 2σ		n=8	MSWD=1.72		19.5 ±11.6		34.79	0.10

Notes:

Age and error calculations:

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

Sample preparation and irradiation:

Minerals separated with standard heavy liquid, Franz Magnetic and hand-picking techniques.
Samples were irradiated in a machined Al disc for 14 hours in D-3 position, Nuclear Science Center, College Station, TX.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-2). Assigned age = 28.02 Ma (Renne et al, 1998).

Instrumentation and analytical procedures:

Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.
Plagioclase and biotite were step-heated by a 50 watt Synrad CO2 laser.
Reactive gases removed during a 3 minute 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 7.29 x 10^{-17} moles/pA for laser analyses.
Total system blank and background averaged 297, 0.76, 0.65, 7.30, 1.74 x 10^{-18} moles at masses 40, 39, 38, 37 and 36,
for laser analyses.
J-factors determined by CO_2 laser-fusion of 6 single crystals from each of 10 positions around the irradiation tray.
Correction factors for interfering nuclear reactions were determined using K-glass and CaF_2 and are as follows:

Table 4. ^{40}Ar/^{39}Ar analytical data for two-step laser analyses.

ID	Power (Watts)	^{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)
BM081605-2, Plagioclase, J=0.001397±0.07%, D=1.002±0.001, NM-197L, Lab#=56462-02										
A	1	9.054	3.122	5.586	0.836	0.16	84.6	15.6	19.25	0.90
B	4	10.38	3.363	1.975	4.52	0.15	97.1	100.0	25.27	0.09
Integrated age ± 2σ		n=2			5.35	0.15			24.33	0.33
BM081605-2, Plagioclase, J=0.001397±0.07%, D=1.002±0.001, NM-197L, Lab#=56462-03										
A	1	7.630	3.390	13.58	1.733	0.15	51.1	46.5	9.83	0.69
B	4	10.44	3.125	1.300	1.995	0.16	98.8	100.0	25.86	0.21
Integrated age ± 2σ		n=2			3.73	0.16			18.43	0.69
BM081605-2, Plagioclase, J=0.001397±0.07%, D=1.002±0.001, NM-197L, Lab#=56462-04										
A	1	6.479	3.536	13.19	1.915	0.14	44.4	34.0	7.25	1.18
B	4	10.34	3.481	2.091	3.72	0.15	96.8	100.0	25.11	0.13
Integrated age ± 2σ		n=2			5.64	0.15			19.06	0.83
BM081605-2, Plagioclase, J=0.001397±0.07%, D=1.002±0.001, NM-197L, Lab#=56462-05										
A	1	11.55	3.625	29.77	1.226	0.14	26.5	31.2	7.71	1.18
B	4	10.67	3.790	3.119	2.71	0.13	94.3	100.0	25.24	0.16
Integrated age ± 2σ		n=2			3.93	0.14			19.80	0.78
BM081605-2, Plagioclase, J=0.001397±0.07%, D=1.002±0.001, NM-197L, Lab#=56462-06										
A	1	11.16	3.567	21.77	1.151	0.14	45.0	50.2	12.64	0.82
B	4	10.58	3.624	3.714	1.141	0.14	92.5	100.0	24.54	0.34
Integrated age ± 2σ		n=2			2.292	0.14			18.58	0.90
BM081605-2, Plagioclase, J=0.001397±0.07%, D=1.002±0.001, NM-197L, Lab#=56462-07										
A	1	8.373	3.243	9.882	1.169	0.16	68.3	56.6	14.40	0.79
B	4	10.50	3.638	3.780	0.896	0.14	92.2	100.0	24.29	0.37
Integrated age ± 2σ		n=2			2.065	0.15			18.70	0.96
BM081605-2, Plagioclase, J=0.001397±0.07%, D=1.002±0.001, NM-197L, Lab#=56462-08										
A	1	9.225	3.468	24.25	2.32	0.15	25.4	28.8	5.92	1.21
B	4	10.41	3.215	2.353	5.75	0.16	95.9	100.0	25.05	0.10
Integrated age ± 2σ		n=2			8.07	0.16			19.56	0.73
BM081605-2, Plagioclase, J=0.001397±0.07%, D=1.002±0.001, NM-197L, Lab#=56462-09										
A	1	9.308	3.813	19.16	1.577	0.13	42.6	31.5	9.99	1.20
B	4	10.37	3.765	2.292	3.43	0.14	96.5	100.0	25.10	0.14
Integrated age ± 2σ		n=2			5.01	0.13			20.36	0.79
BM081605-2, Plagioclase, J=0.001397±0.07%, D=1.002±0.001, NM-197L, Lab#=56462-10										
A	1	9.708	3.050	17.10	1.372	0.17	50.6	26.7	12.36	0.76
B	4	10.45	3.012	2.507	3.77	0.17	95.3	100.0	24.97	0.13
Integrated age ± 2σ		n=2			5.14	0.17			21.61	0.46
BM081605-2, Plagioclase, J=0.001397±0.07%, D=1.002±0.001, NM-197L, Lab#=56462-11										
A	1	11.63	3.496	19.74	1.226	0.15	52.4	35.6	15.32	0.79
B	4	10.27	3.602	2.675	2.218	0.14	95.2	100.0	24.54	0.20
Integrated age ± 2σ		n=2			3.44	0.14			21.26	0.62

ID	Power (Watts)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
BM081605-01, Plagioclase, J=0.0013986±0.09%, D=1.002±0.001, NM-197L, Lab#=56463-01										
A	1	9.215	3.075	25.53	2.64	0.17	20.9	42.0	4.87	2.29
B	4	11.66	3.116	7.607	3.65	0.16	82.9	100.0	24.28	0.25
Integrated age ± 2σ		n=2			6.29	0.16			16.16	1.98
BM081605-01, Plagioclase, J=0.0013986±0.09%, D=1.002±0.001, NM-197L, Lab#=56463-02										
A	1	11.06	3.171	24.90	1.457	0.16	35.9	32.4	10.00	1.28
B	4	11.16	3.143	4.997	3.04	0.16	89.1	100.0	24.96	0.18
Integrated age ± 2σ		n=2			4.49	0.16			20.12	0.89
BM081605-01, Plagioclase, J=0.0013986±0.09%, D=1.002±0.001, NM-197L, Lab#=56463-03										
A	1	11.33	2.853	25.23	1.688	0.18	36.3	40.3	10.36	1.23
B	4	12.06	3.017	8.287	2.50	0.17	81.8	100.0	24.75	0.25
Integrated age ± 2σ		n=2			4.18	0.17			18.96	1.05
BM081605-01, Plagioclase, J=0.0013986±0.09%, D=1.002±0.001, NM-197L, Lab#=56463-04										
A	1	9.933	3.126	23.36	1.894	0.16	33.1	34.3	8.30	1.43
B	4	11.39	3.050	5.767	3.62	0.17	87.3	100.0	24.96	0.17
Integrated age ± 2σ		n=2			5.52	0.17			19.26	1.03
BM081605-01, Plagioclase, J=0.0013986±0.09%, D=1.002±0.001, NM-197L, Lab#=56463-05										
A	1	14.30	2.996	34.13	2.111	0.17	31.2	36.0	11.25	1.39
B	4	11.59	3.247	6.173	3.76	0.16	86.6	100.0	25.19	0.18
Integrated age ± 2σ		n=2			5.87	0.16			20.19	1.05
BM081605-01, Plagioclase, J=0.0013986±0.09%, D=1.002±0.001, NM-197L, Lab#=56463-06										
A	1	16.30	2.696	42.50	2.58	0.19	24.4	35.4	10.01	1.37
B	4	12.62	2.567	9.437	4.72	0.20	79.6	100.0	25.22	0.15
Integrated age ± 2σ		n=2			7.30	0.20			19.85	1.02
BM081605-01, Plagioclase, J=0.0013986±0.09%, D=1.002±0.001, NM-197L, Lab#=56463-07										
A	1	17.49	2.936	46.12	2.34	0.17	23.5	23.4	10.35	2.26
B	4	11.67	3.253	6.402	7.63	0.16	86.1	100.0	25.23	0.12
Integrated age ± 2σ		n=2			9.97	0.16			21.75	1.09
BM081605-01, Plagioclase, J=0.0013986±0.09%, D=1.002±0.001, NM-197L, Lab#=56463-08										
A	1	15.21	2.669	43.06	3.95	0.19	17.8	30.3	6.82	2.31
B	4	12.38	3.210	9.141	9.10	0.16	80.3	100.0	24.97	0.12
Integrated age ± 2σ		n=2			13.04	0.17			19.50	1.45
BM081605-01, Plagioclase, J=0.0013986±0.09%, D=1.002±0.001, NM-197L, Lab#=56463-09										
A	1	15.46	2.892	40.02	2.78	0.18	25.1	34.8	9.78	1.36
B	4	14.17	3.008	14.43	5.19	0.17	71.7	100.0	25.48	0.24
Integrated age ± 2σ		n=2			7.97	0.17			20.02	1.02
BM081605-01, Plagioclase, J=0.0013986±0.09%, D=1.002±0.001, NM-197L, Lab#=56463-10										
A	1	15.16	2.765	37.16	2.72	0.18	29.1	39.7	11.12	1.48
B	4	11.87	2.884	6.910	4.13	0.18	84.8	100.0	25.27	0.18
Integrated age ± 2σ		n=2			6.85	0.18			19.67	1.22

ID	Power (Watts)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
BM081605-01, Plagioclase, J=0.0013986±0.09%, D=1.002±0.001, NM-197L, Lab#=56463-11										
A	1	13.25	2.931	30.33	1.953	0.17	34.2	37.6	11.43	1.25
B	4	12.03	3.017	7.171	3.24	0.17	84.5	100.0	25.51	0.19
Integrated age ± 2σ		n=2			5.19	0.17			20.22	0.99
SP-1903, Biotite, J=0.0013888±0.09%, D=1.002±0.001, NM-197K, Lab#=56457-01										
	2	15.01	0.0345	3.437	22.12	14.8	93.2		34.72	0.08
SP-1903, Biotite, J=0.0013888±0.09%, D=1.002±0.001, NM-197K, Lab#=56457-02										
A	1	49.83	0.0727	127.7	0.500	7.0	24.3	4.8	30.03	1.50
B	2	14.48	0.0258	1.556	9.97	19.8	96.8	100.0	34.79	0.08
Integrated age ± 2σ		n=2			10.47	18.2			34.56	0.23
SP-1903, Biotite, J=0.0013888±0.09%, D=1.002±0.001, NM-197K, Lab#=56457-03										
A	1	21.95	0.1271	29.25	0.932	4.0	60.7	5.8	33.06	0.65
B	2	14.44	0.0204	1.227	15.16	25.0	97.5	100.0	34.94	0.07
Integrated age ± 2σ		n=2			16.09	19.2			34.83	0.17
SP-1903, Biotite, J=0.0013888±0.09%, D=1.002±0.001, NM-197K, Lab#=56457-04										
A	1	58.22	0.0196	152.7	0.347	26.1	22.5	3.3	32.57	2.00
B	2	14.96	0.0274	3.230	10.29	18.6	93.6	100.0	34.77	0.09
Integrated age ± 2σ		n=2			10.64	18.8			34.70	0.23
SP-1903, Biotite, J=0.0013888±0.09%, D=1.002±0.001, NM-197K, Lab#=56457-05										
A	1	39.83	0.1012	89.95	0.449	5.0	33.3		32.93	1.26
SP-1903, Biotite, J=0.0013888±0.09%, D=1.002±0.001, NM-197K, Lab#=56457-06										
A	1	39.09	0.4175	84.98	0.189	1.2	35.8	0.7	34.78	2.66
B	2	14.24	0.0294	0.9758	26.1	17.3	98.0	100.0	34.63	0.07
Integrated age ± 2σ		n=2			26.3	15.8			34.63	0.16
SP-1903, Biotite, J=0.0013888±0.09%, D=1.002±0.001, NM-197K, Lab#=56457-07										
A	1	55.14	0.1513	149.4	0.646	3.4	19.9	3.6	27.34	1.28
B	2	14.79	0.0552	2.636	17.47	9.2	94.8	100.0	34.77	0.08
Integrated age ± 2σ		n=2			18.11	8.7			34.50	0.20
SP-1903, Biotite, J=0.0013888±0.09%, D=1.002±0.001, NM-197K, Lab#=56457-08										
A	1	53.10	0.1921	138.3	0.889	2.7	23.1	4.8	30.42	1.03
B	2	14.51	0.0197	1.670	17.66	25.9	96.6	100.0	34.77	0.08
Integrated age ± 2σ		n=2			18.55	18.3			34.56	0.21
SP-1903, Biotite, J=0.0013888±0.09%, D=1.002±0.001, NM-197K, Lab#=56457-09										
A	1	38.02	0.0175	87.12	0.734	29.1	32.3	5.5	30.50	1.01
B	2	14.67	0.0205	2.073	12.64	24.9	95.8	100.0	34.90	0.08
Integrated age ± 2σ		n=2			13.38	25.1			34.66	0.21

ID	Power (Watts)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)

Notes:

Age and error calculations:
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.
symbol preceding sample ID denotes analyses excluded from mean age calculations.

Sample preparation and irradiation:
Minerals separated with standard heavy liquid, Franz Magnetic and hand-picking techniques.
Samples were irradiated in a machined Al disc for 14 hours in D-3 position, Nuclear Science Center, College Station, TX.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-2). Assigned age = 28.02 Ma (Renne et al, 1998).

Instrumentation and analytical procedures:
Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.
Plagioclase and biotite were step-heated by a 50 watt Synrad CO2 laser.
Reactive gases removed during a 3 minute 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 7.29 x 10^{-17} moles/pA for laser analyses.
Total system blank and background averaged 297, 0.76, 0.65, 7.30, 1.74 x 10^{-18} moles at masses 40, 39, 38, 37 and 36, for laser analyses.
J-factors determined by CO_2 laser-fusion of 6 single crystals from each of 10 positions around the irradiation tray.
Correction factors for interfering nuclear reactions were determined using K-glass and CaF_2 and are as follows:
$(^{36}Ar/^{37}Ar)_{Ca}$ = 0.00028±0.00001, $(^{39}Ar/^{37}Ar)_{Ca}$ = 0.00068±0.00005, $(^{40}Ar/^{39}Ar)_K$ = 0.0000±0.0004, $(^{38}Ar/^{39}Ar)_K$ = 0.013.

Table 5. $^{40}Ar/^{39}Ar$ analytical data for furnace incremental heating age spectrum data.

	ID	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)
	SP-3205, Groundmass Concentrate, 28.45 mg, J=0.0013936±0.10%, D=1.002±0.001, NM-197L, Lab#=56461-01										
X	A	625	2307.5	2.468	7557.4	5.71	0.21	3.2	1.5	178.46	21.54
X	B	700	97.41	0.9878	277.6	18.97	0.52	15.9	6.5	38.49	0.91
X	C	750	42.03	0.9662	93.51	20.94	0.53	34.4	12.0	36.06	0.38
X	D	800	43.99	1.129	100.0	22.2	0.45	33.0	17.9	36.18	0.40
X	E	875	39.24	0.7498	83.43	60.4	0.68	37.3	33.8	36.47	0.31
X	F	975	25.30	0.6211	38.86	90.5	0.82	54.8	57.7	34.56	0.17
X	G	1075	31.07	0.4046	58.59	70.0	1.3	44.4	76.1	34.36	0.24
X	H	1250	45.22	2.285	105.2	50.0	0.22	31.7	89.3	35.70	0.37
X	I	1700	57.55	4.015	144.9	40.5	0.13	26.2	100.0	37.58	0.48
	Integrated age ± 2σ			n=9		379.1	0.40		K2O=3.67	37.93	1.27
	Isochron±2σ	**steps A-I**		**n=9**	**MSWD=3.13**		**$^{40}Ar/^{36}Ar$=**	**304.4±3.0**		**33.73**	**0.65**
	SP-3303, Groundmass Concentrate, 51.14 mg, J=0.0013654±0.07%, D=1.002±0.001, NM-197G, Lab#=56430-01										
X	A	625	33792.4	14.56	113161.8	0.492	0.035	1.0	0.1	717.66	236.35
X	B	700	537.6	1.167	1758.6	15.78	0.44	3.4	2.7	44.01	5.32
X	C	750	270.3	0.7780	877.7	20.13	0.66	4.1	6.1	27.06	2.64
X	D	800	85.70	0.6096	262.0	11.04	0.84	9.7	7.9	20.37	0.88
X	E	875	53.10	0.7527	150.1	122.3	0.68	16.6	28.4	21.60	0.47
	F	975	21.50	0.8600	45.42	112.3	0.59	37.9	47.2	19.99	0.16
	G	1075	17.96	0.6810	33.42	111.7	0.75	45.3	65.9	19.94	0.13
	H	1250	13.69	2.703	20.04	167.7	0.19	58.4	94.0	19.62	0.09
	I	1700	13.45	3.181	19.40	35.7	0.16	59.3	100.0	19.59	0.11
	Integrated age ± 2σ			n=9		597.2	0.35		K2O=3.29	21.77	1.36
	Plateau ± 2σ	steps F-I		n=4	MSWD=2.83	427.4	0.44 ±0.59		71.6	19.72	0.19
	Isochron±2σ	**steps A-I**		**n=9**	**MSWD=1.41**		**$^{40}Ar/^{36}Ar$=**	**299.6±1.2**		**19.47**	**0.14**
	SP-4003, Groundmass Concentrate, 53.32 mg, J=0.0013673±0.06%, D=1.002±0.001, NM-197G, Lab#=56429-01										
X	A	625	2246.1	2.485	7471.2	2.123	0.21	1.7	0.4	92.87	21.45
X	B	700	56.30	1.250	161.8	15.83	0.41	15.3	3.1	21.11	0.58
X	C	750	22.49	0.9937	49.28	19.61	0.51	35.6	6.4	19.67	0.20
X	D	800	14.24	0.8932	21.56	11.13	0.57	55.8	*8.3*	19.49	0.17
X	E	875	16.65	0.7872	28.94	85.5	0.65	49.0	22.9	20.03	0.12
X	F	975	11.33	0.8453	11.14	142.3	0.60	71.6	47.1	19.90	0.06
	G	1075	9.886	0.8636	6.556	103.1	0.59	81.1	64.7	19.69	0.05
	H	1250	12.11	2.791	14.75	171.9	0.18	65.9	94.0	19.62	0.07
	I	1700	16.86	3.742	31.17	35.0	0.14	47.2	100.0	19.57	0.14
	Integrated age ± 2σ			n=9		586.5	0.32		K2O=3.09	20.07	0.32
	Plateau ± 2σ	steps G-I		n=3	MSWD=0.47	310.0	0.31 ±0.50		52.9	19.66	0.08
	Isochron±2σ	**steps A-I**		**n=9**	**MSWD=3.65**		**$^{40}Ar/^{36}Ar$=**	**298.3±3.1**		**19.65**	**0.17**

	ID	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)
	SP-4103, Groundmass Concentrate, 27.57 mg, J=0.00137±0.06%, D=1.002±0.001, NM-197G, Lab#=56428-01										
Xi	A	625	249.9	11.47	810.1	4.15	0.044	4.6	1.3	28.21	2.73
Xi	B	700	20.00	2.286	19.96	15.12	0.22	71.4	5.9	35.03	0.14
X	C	750	16.16	1.176	5.345	19.40	0.43	90.8	11.8	35.95	0.08
X	D	800	15.26	1.738	2.962	21.55	0.29	95.2	18.4	35.60	0.08
X	E	875	14.69	1.335	2.025	63.0	0.38	96.7	37.6	34.80	0.06
X	F	975	14.75	0.9546	2.616	91.5	0.53	95.3	65.5	34.44	0.05
	G	1075	15.92	0.9592	6.887	67.5	0.53	87.7	86.1	34.20	0.07
	H	1250	19.42	3.873	19.44	36.2	0.13	72.1	97.1	34.35	0.12
Xi	I	1700	22.98	11.30	28.56	9.35	0.045	67.3	100.0	38.14	0.21
	Integrated age ± 2σ			n=9		327.9	0.27		K2O=3.33	34.67	0.18
	Plateau ± 2σ	steps G-H		n=2	MSWD=1.21	103.696	0.392±0.566		31.6	34.24	0.13
	Isochron±2σ	**steps C-H**		**n=6**	**MSWD=107.72**		**^{40}Ar/^{36}Ar=**	**288±62**		**34.9**	**4.2**
	FT081505-2, Hornblende, 28.84 mg, J=0.0013885±0.09%, D=1.002±0.001, NM-197K, Lab#=56451-02										
	A	800	434.2	0.6580	1431.6	0.497	0.78	2.6	16.2	27.9	5.5
	B	950	40.46	0.2760	103.8	1.17	1.8	24.2	54.2	24.41	0.69
	C	1050	14.57	0.3321	19.23	0.869	1.5	61.2	82.6	22.21	0.45
	D	1120	19.30	0.8908	35.11	0.535	0.57	46.6	100.0	22.43	0.78
	Integrated age ± 2σ			n=4		3.07	1.107		K2O=0.03%	24.0	2.1
	Plateau ± 2σ	**steps A-D**		**n=4**	**MSWD=2.74**	**3.07**	**1.4 ±1.2**		**100.0**	**22.8**	**1.1**
	Isochron±2σ	steps A-D		n=4	MSWD=2.24		^{40}Ar/^{36}Ar=	298.3±4.5		22.46	1.15
	FT081505-1, Hornblende, 22.57 mg, J=0.0013904±0.10%, D=1.002±0.001, NM-197K, Lab#=56452-01										
	A	800	138.7	45.99	444.3	0.921	0.011	8.1	23.6	28.7	1.9
	B	950	25.50	8.859	53.01	0.807	0.058	41.5	44.2	26.49	0.78
	C	1050	25.53	39.43	63.44	0.662	0.013	39.3	61.2	25.71	0.89
	D	1120	17.67	16.30	30.98	0.550	0.031	55.8	75.3	24.84	0.88
	E	1140	20.52	23.66	45.53	0.171	0.022	44.0	79.7	22.9	2.6
	F	1160	14.38	2.846	9.988	0.089	0.18	81.1	81.9	29.1	4.3
	G	1180	23.88	5.823	35.32	0.065	0.088	58.3	83.6	34.7	5.3
	H	1220	28.82	36.78	73.98	0.076	0.014	34.7	85.5	25.6	5.1
	I	1300	59.17	192.8	222.7	0.190	0.003	15.7	90.4	26.7	3.2
Xi	J	1700	97.51	250.1	380.6	0.374	0.002	5.9	100.0	17.3	3.3
	Integrated age ± 2σ			n=10		3.91	0.008		K2O=0.05%	25.8	1.8
	Plateau ± 2σ	**steps A-I**		**n=9**	**MSWD=1.15**	**3.53**	**0.031±0.113**		**90.4**	**25.95**	**0.97**
	Isochron±2σ	steps A-I		n=9	MSWD=0.90		^{40}Ar/^{36}Ar=	298.7±3.9		25.4	1.1

ID	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)

Notes:

Age and error calculations:

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 is volume-weighted mean of all steps.
Integrated age calculated by recombining isotopic measurements of all steps.
Integrated age error calculated by recombining 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.
incorporates uncertainty in J factors and irradiation correction uncertainties.
X symbol preceding sample ID denotes analyses excluded from plateau age calculations.
i symbol preceding sample ID denotes analyses excluded from isochron age calculations.

Sample preparation and irradiation:

Minerals separated with standard heavy liquid, Franz Magnetic and hand-picking techniques.
Samples were irradiated in a machined Al disc for 14 hours in D-3 position, Nuclear Science Center, College Station, TX.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-2). Assigned age = 28.02 Ma (Renne et al, 1998).

Instrumentation and analytical procedures:

Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.
Groundmass concentrate and hornblende were step-heated for 9 minutes, using a Mo double-vacuum resistance furnace.
Reactive gases removed during furnace analysis by reaction with 3 SAES GP-50 getters, 2 operated at ~450°C and 1 at 20°C. Gas also exposed to a W filiment operated at ~2000°C.

Analytical parameters:

Electron multiplier sensitivity averaged 1.25 x 10^{-16} moles/pA for furnance analyses.
Total system blank and background averaged 1110, 9.5, 2.3, 5.2, 3.5 x 10^{-18} moles at masses 40, 39, 38, 37 and 36, for furnace analyses.
J-factors determined by CO_2 laser-fusion of 6 single crystals from each of 6 positions around the irradiation tray.
Correction factors for interfering nuclear reactions were determined using K-glass and CaF_2 and are as follows:
$(^{36}Ar/^{37}Ar)_{Ca}$ = 0.00028±0.00001, $(^{39}Ar/^{37}Ar)_{Ca}$ = 0.00068±0.00005, $(^{40}Ar/^{39}Ar)_K$ = 0.0000±0.0004, $(^{38}Ar/^{39}Ar)_K$ = 0.013.

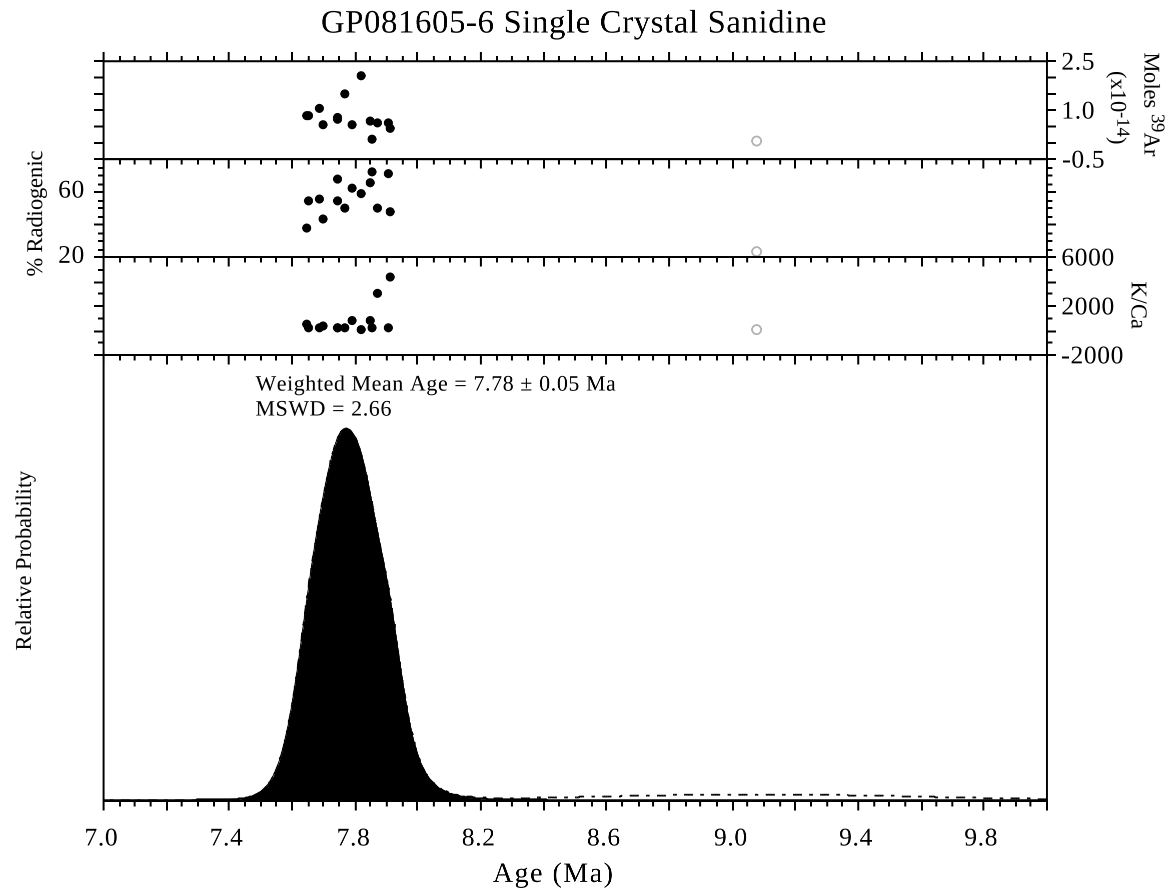


Figure 1. Age probability distribution diagram of GP081605-6c sanidine. All errors quoted at 2 sigma.

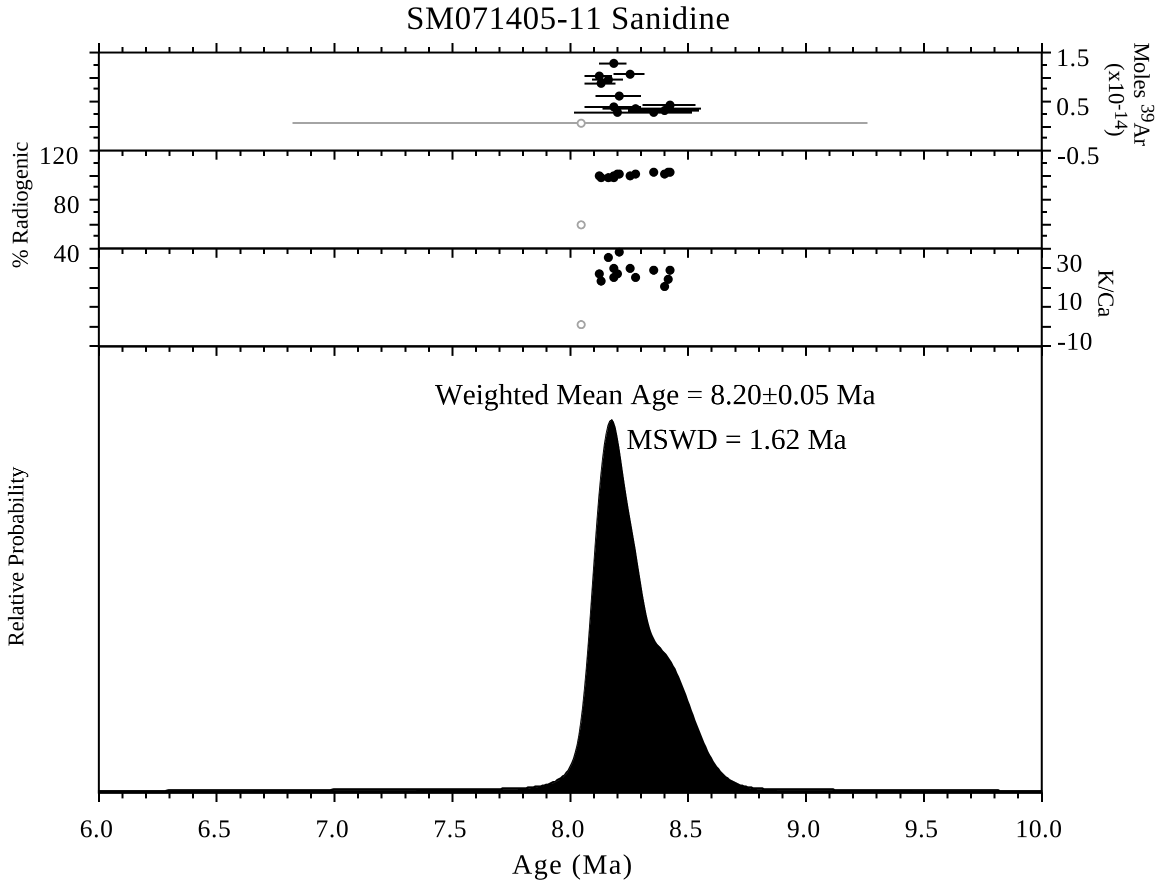


Figure 2. Age probability distribution diagram of SM071405-11 sanidine. All errors quoted at 2 sigma.

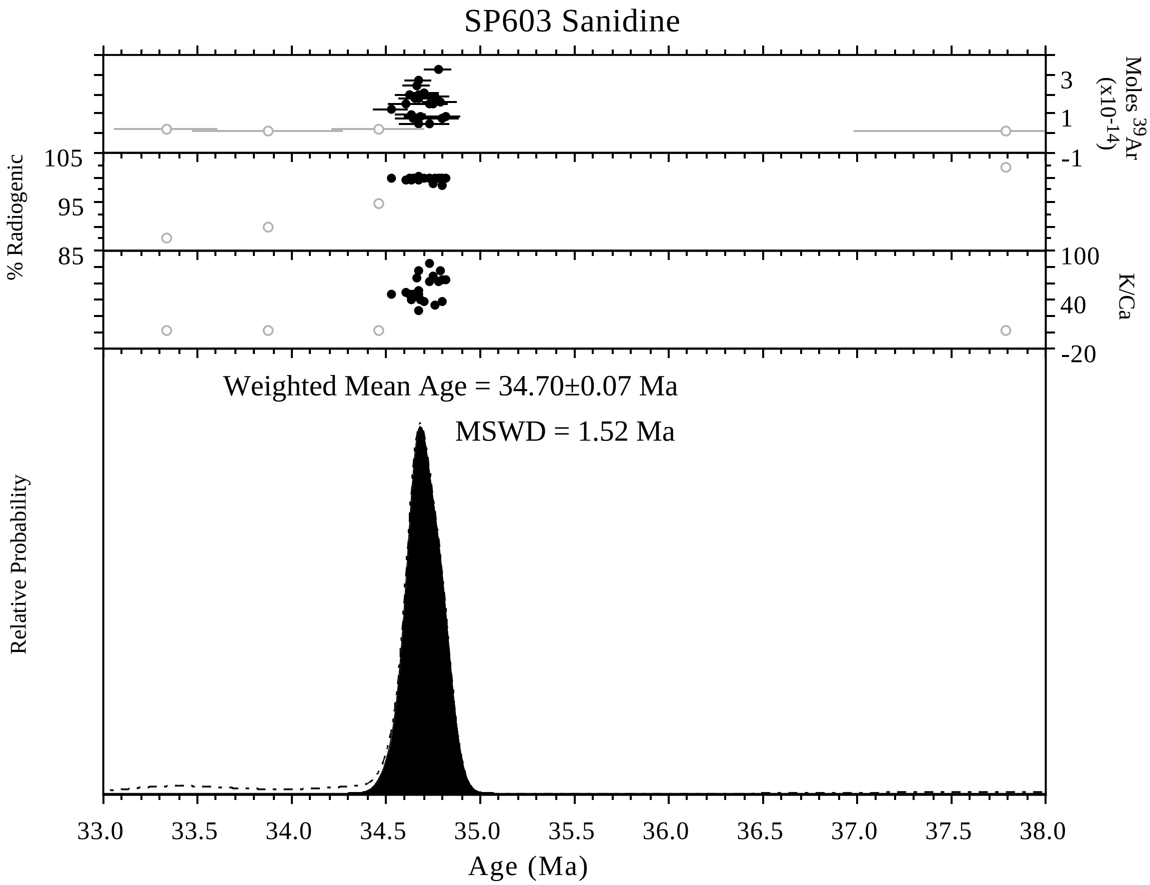


Figure 3. Age probability distribution diagram of SP603 sanidine. All errors quoted at 2 sigma.

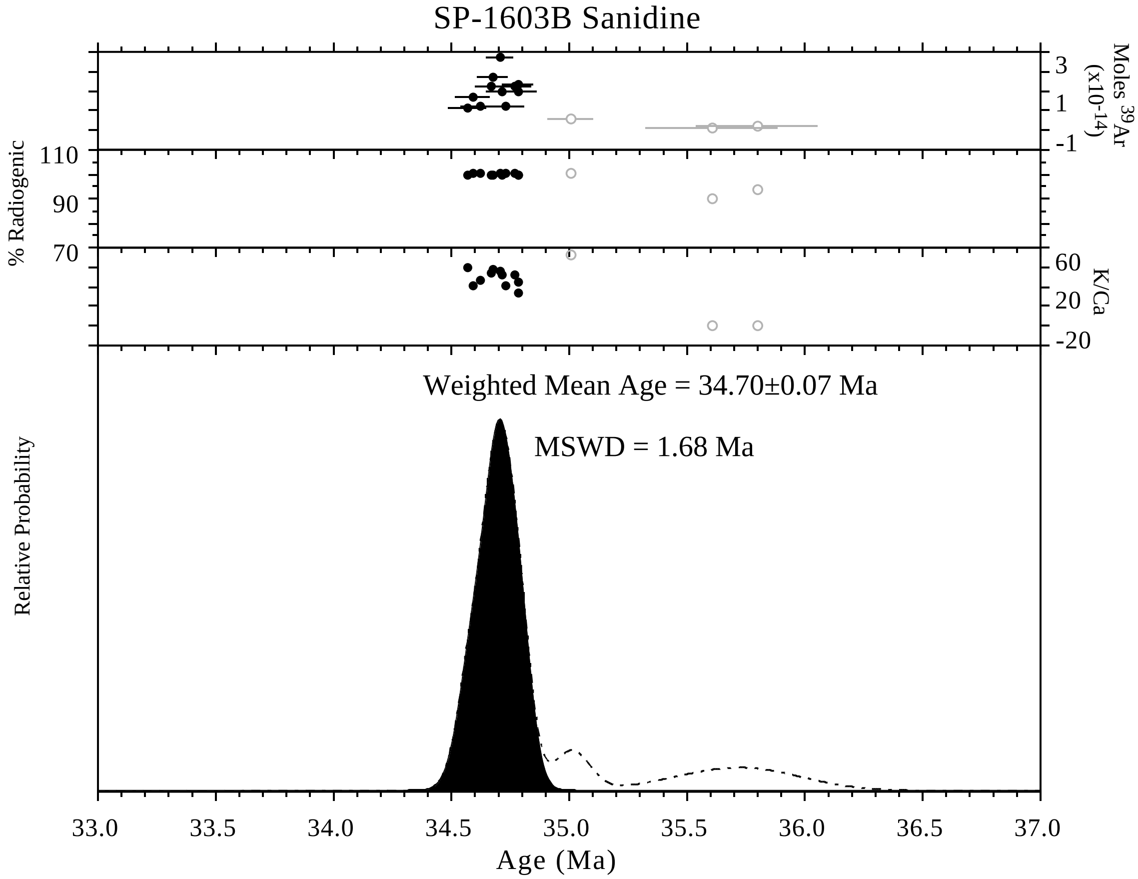


Figure 4. Age probability distribution diagram of SP-1603B sanidine. All errors quoted at 2 sigma.

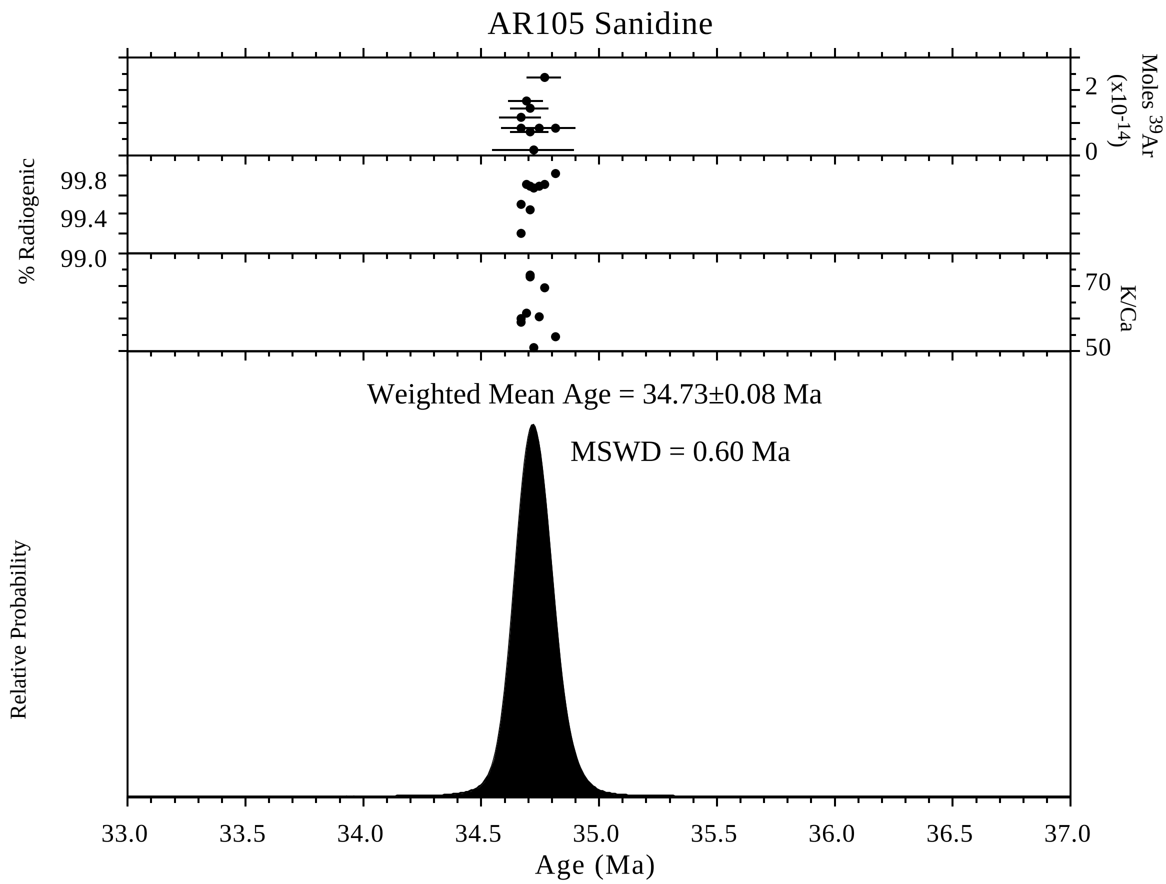


Figure 5. Age probability distribution diagram of AR105 sanidine. All errors quoted at 2 sigma.

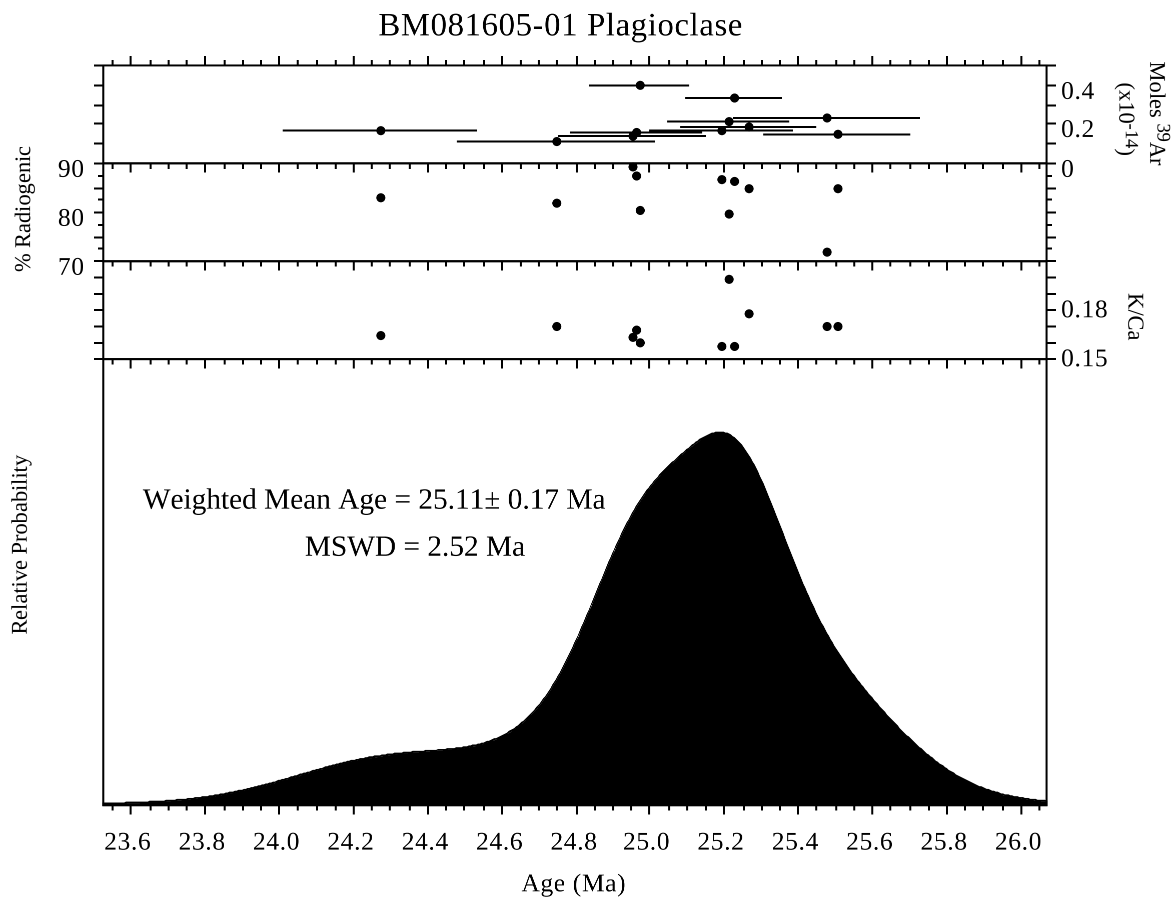


Figure 6. Age probability distribution diagram of BM081605-01 plagioclase, B steps. All errors quoted at 2 sigma.

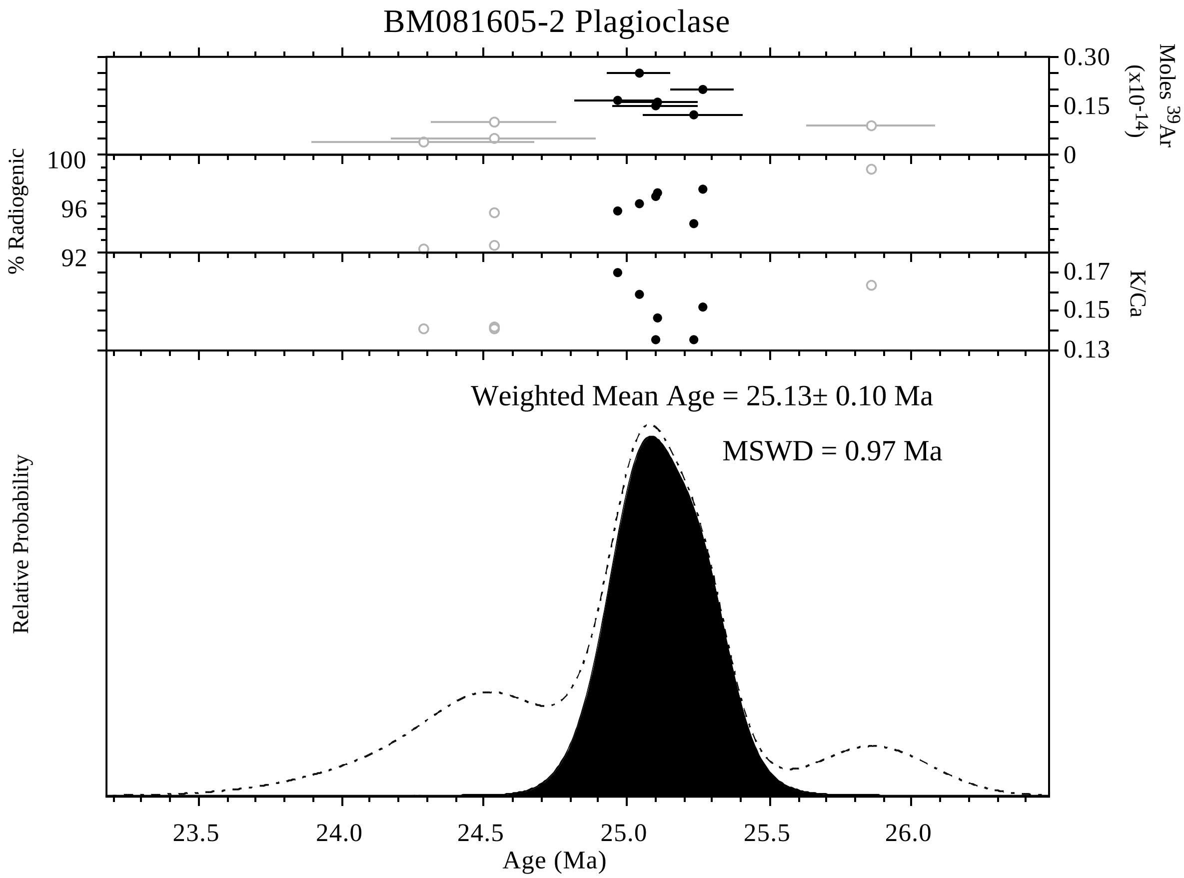


Figure 7. Age probability distribution diagram of BM081605-02 plagioclase, B steps. All errors quoted at 2 sigma.

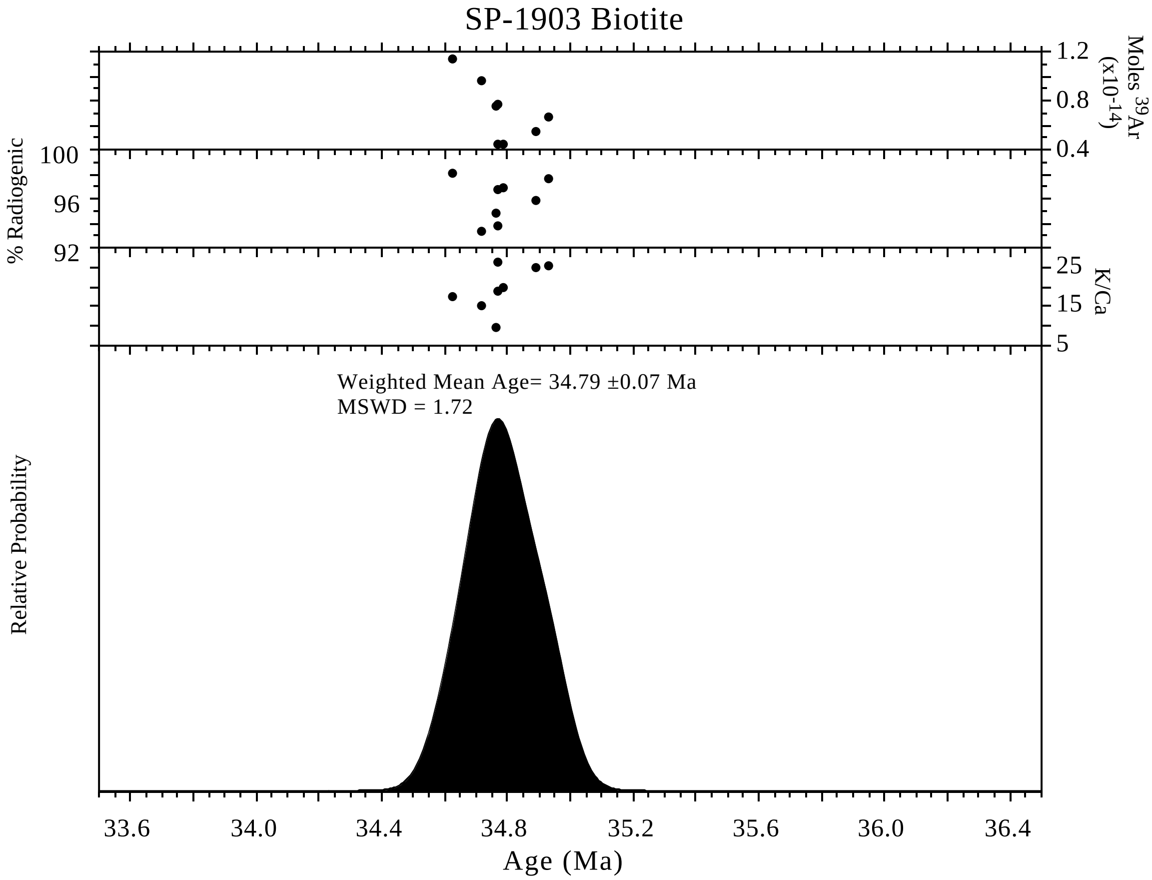


Figure 8. Age probability distribution diagram of SP-1903 biotite, B steps. All errors quoted at 2 sigma.

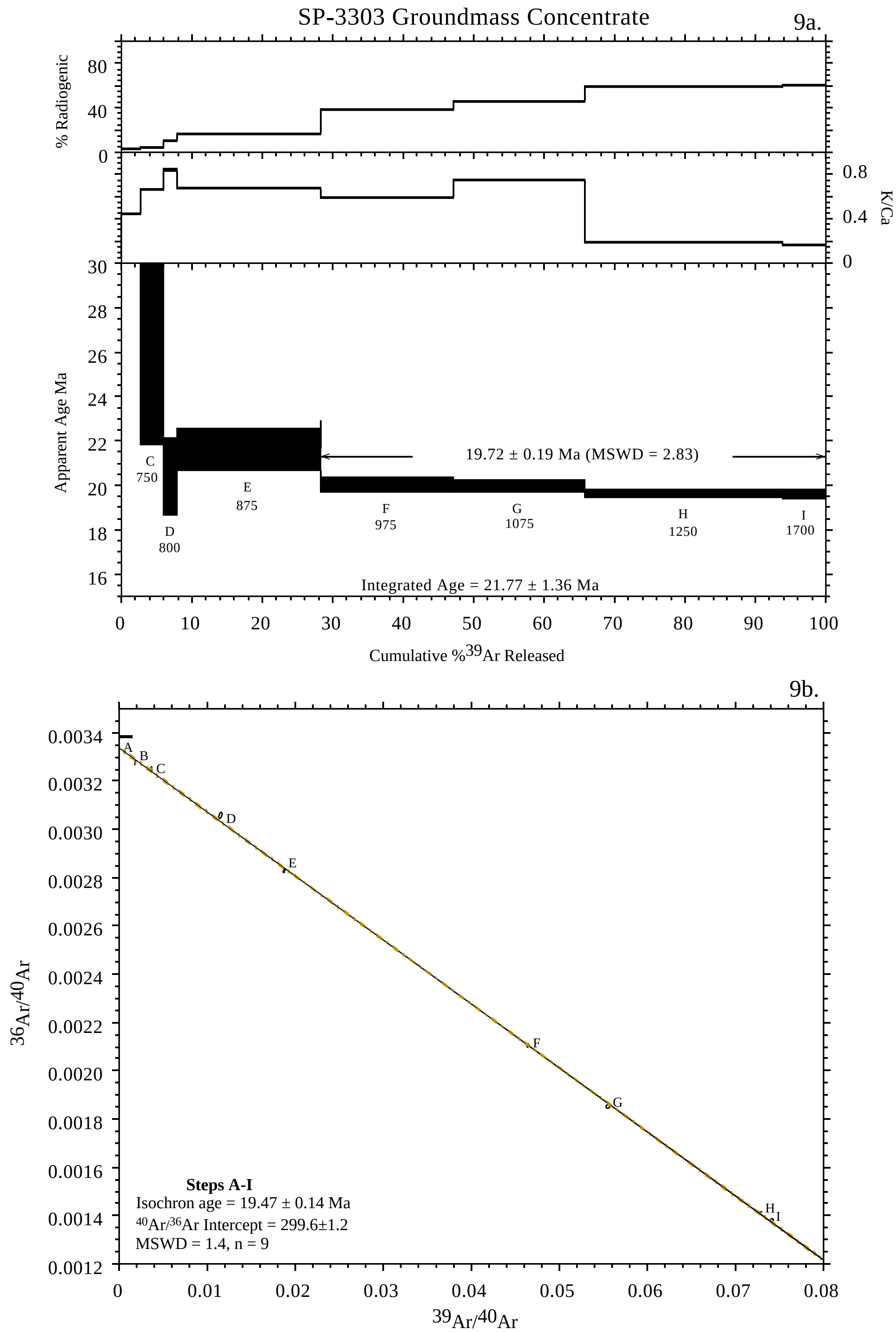


Figure 9. Age spectrum (9a) and isochron (9b) for SP-3303 groundmass concentrate. All errors quoted at two sigma.

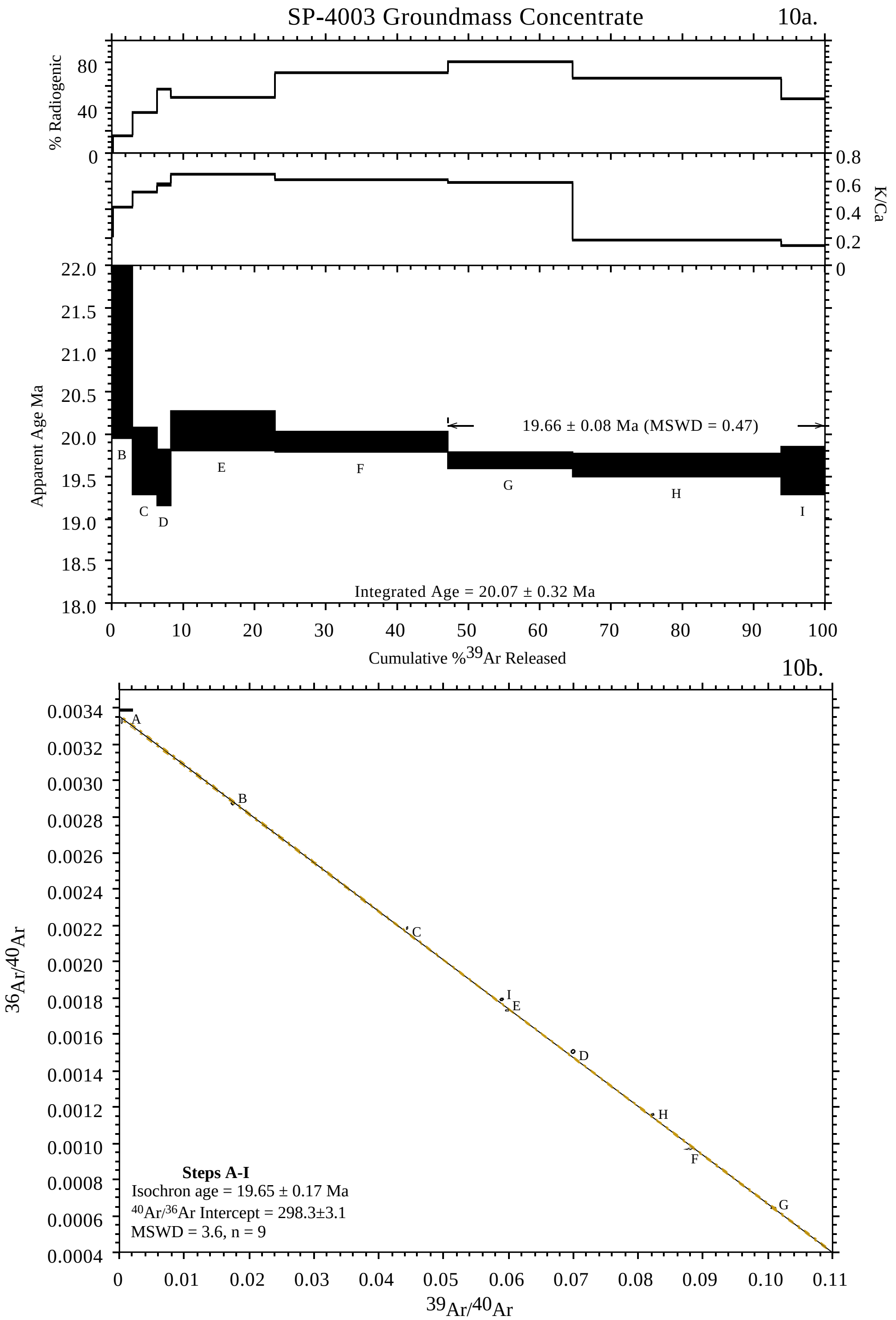


Figure 10. Age spectrum (10a) and isochron (10b) for SP-4003 groundmass concentrate. All errors quoted at two sigma.

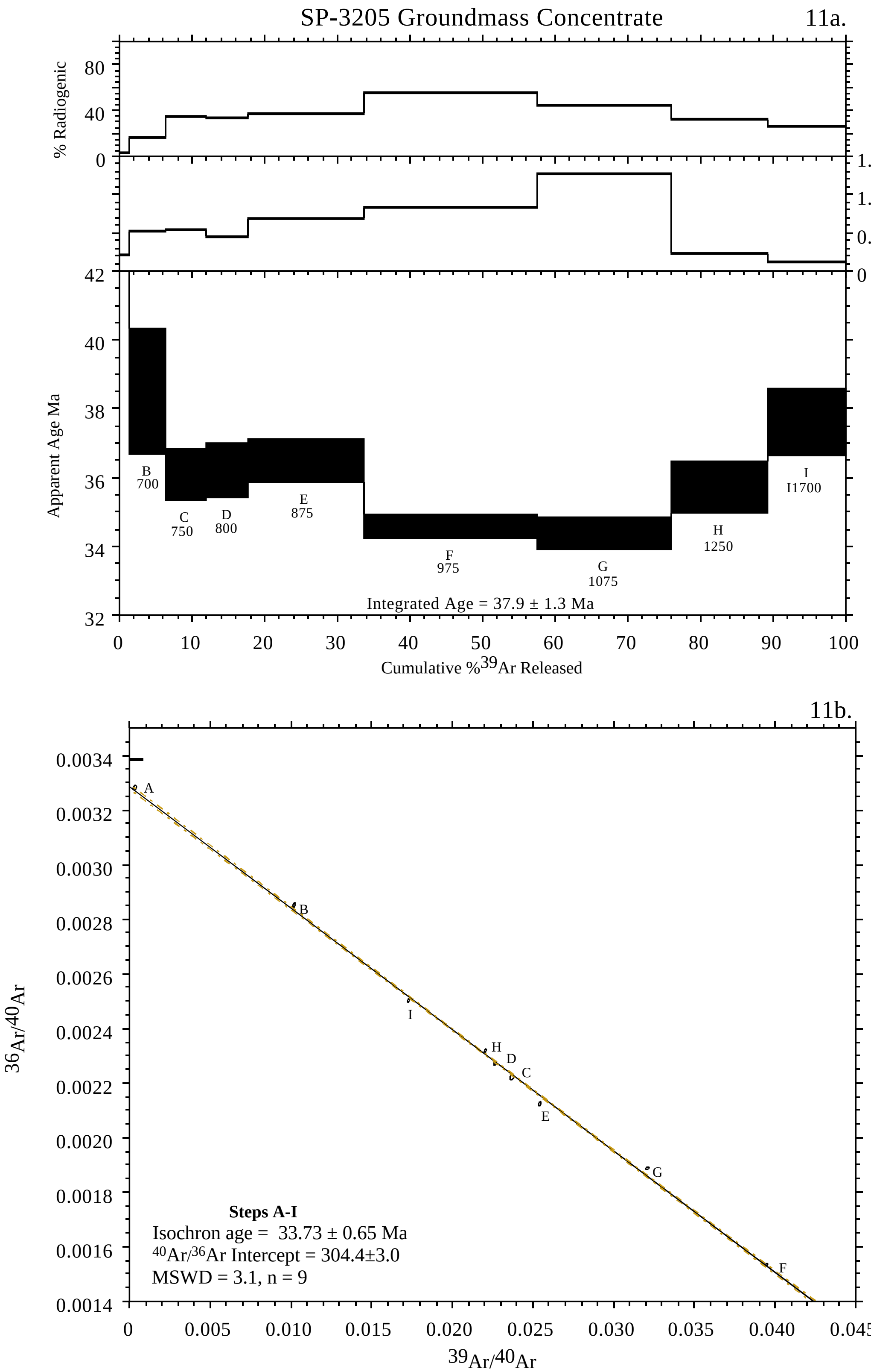
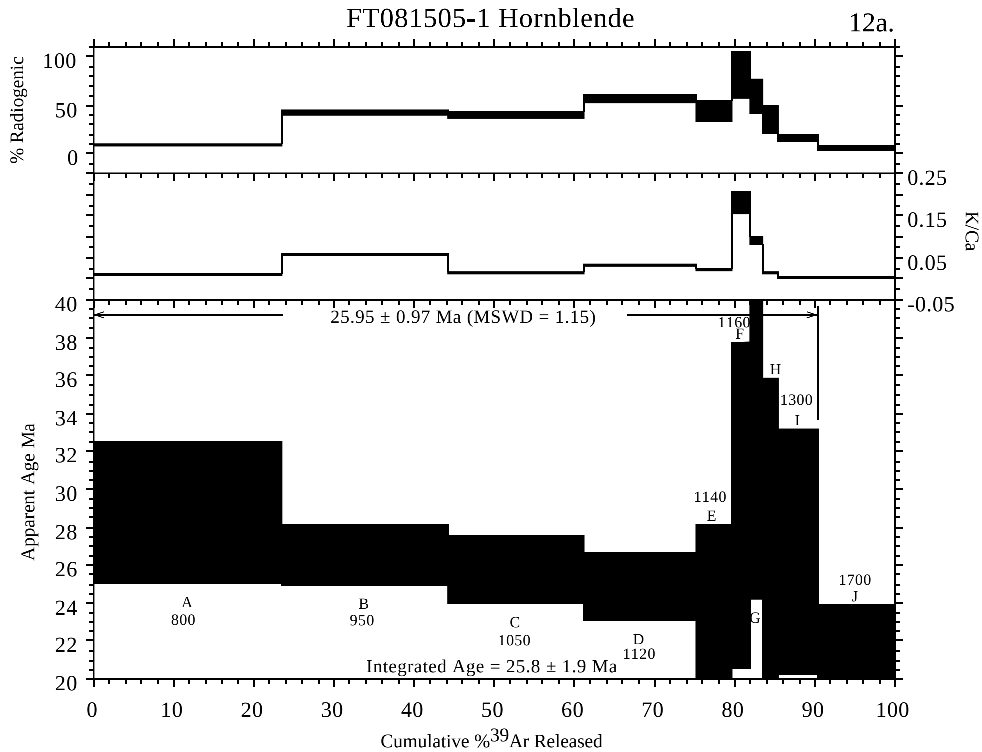


Figure 11. Age spectrum (11a) and isochron (11b) for SP-3205 groundmass concentrate. All errors quoted at two sigma.



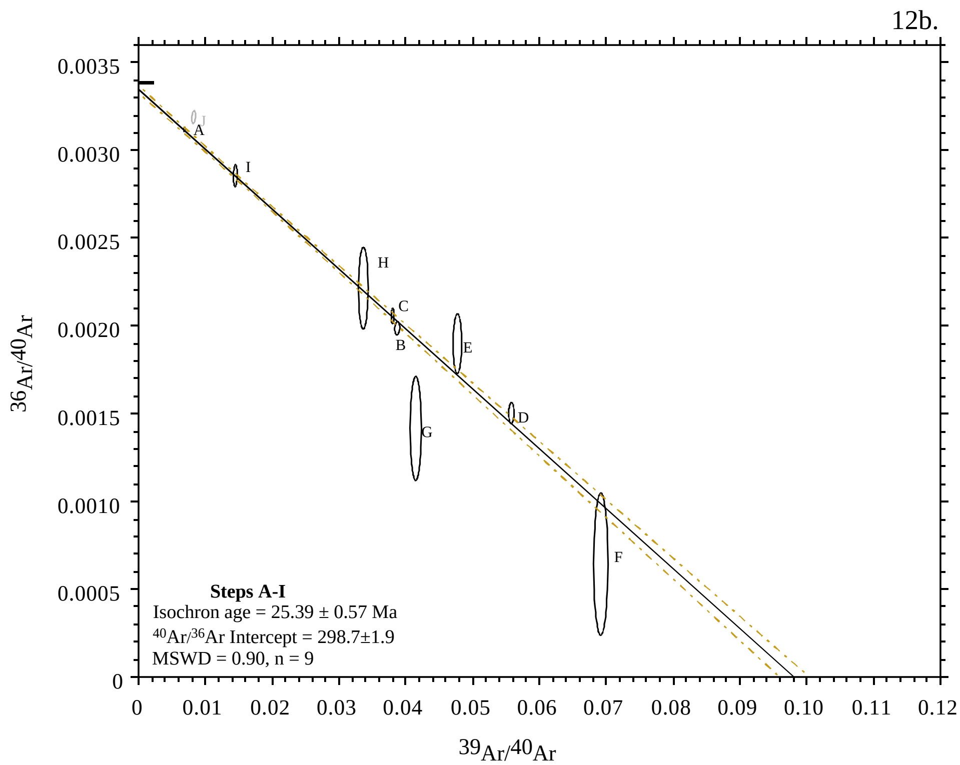


Figure 12. Age spectrum (12a) and isochron (12b) for FT081505-1 hornblende. All errors quoted at two sigma.

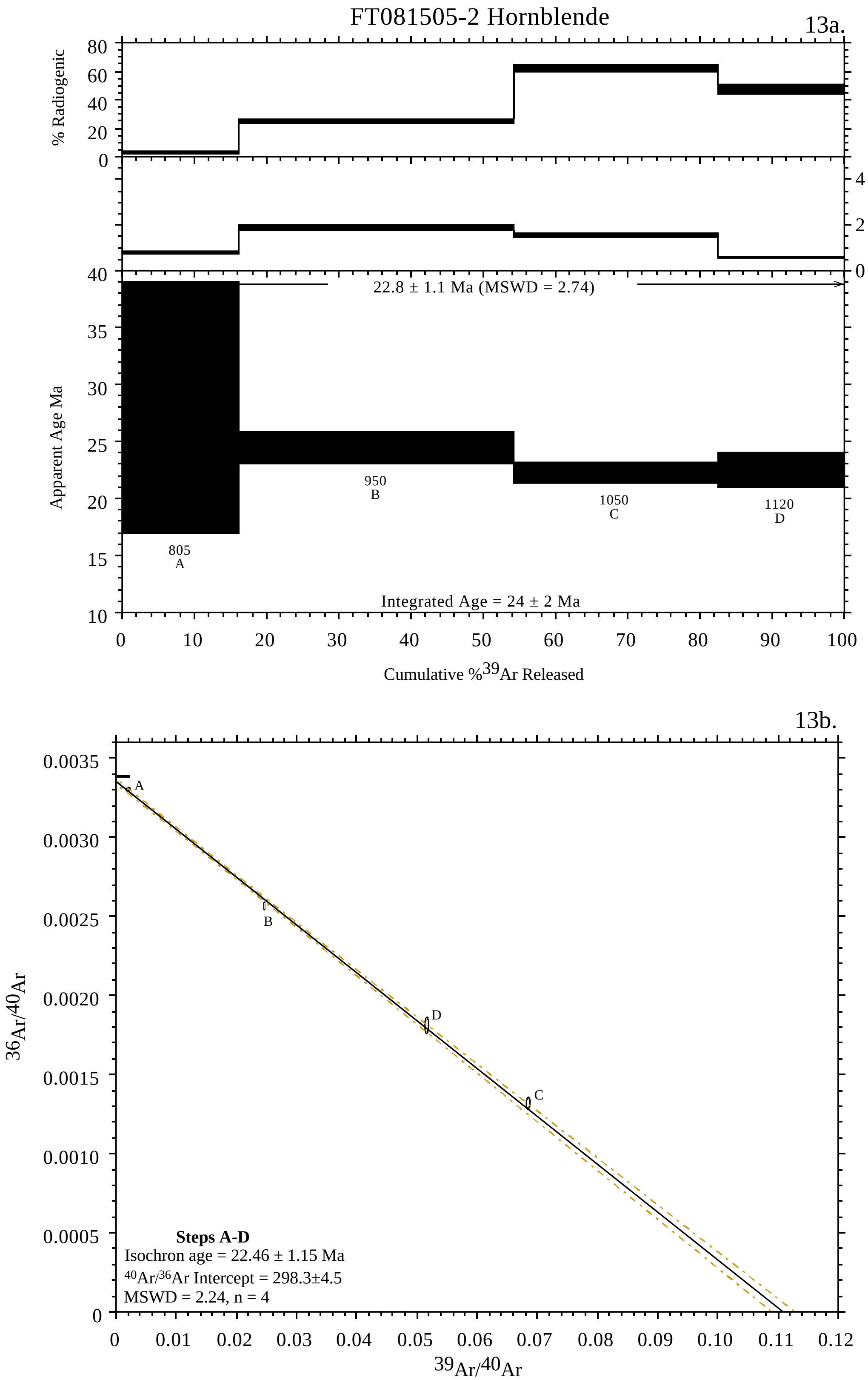


Figure 13. Age spectrum (13a) and isochron (13b) for FT081505-2 hornblende. All errors quoted at two sigma.

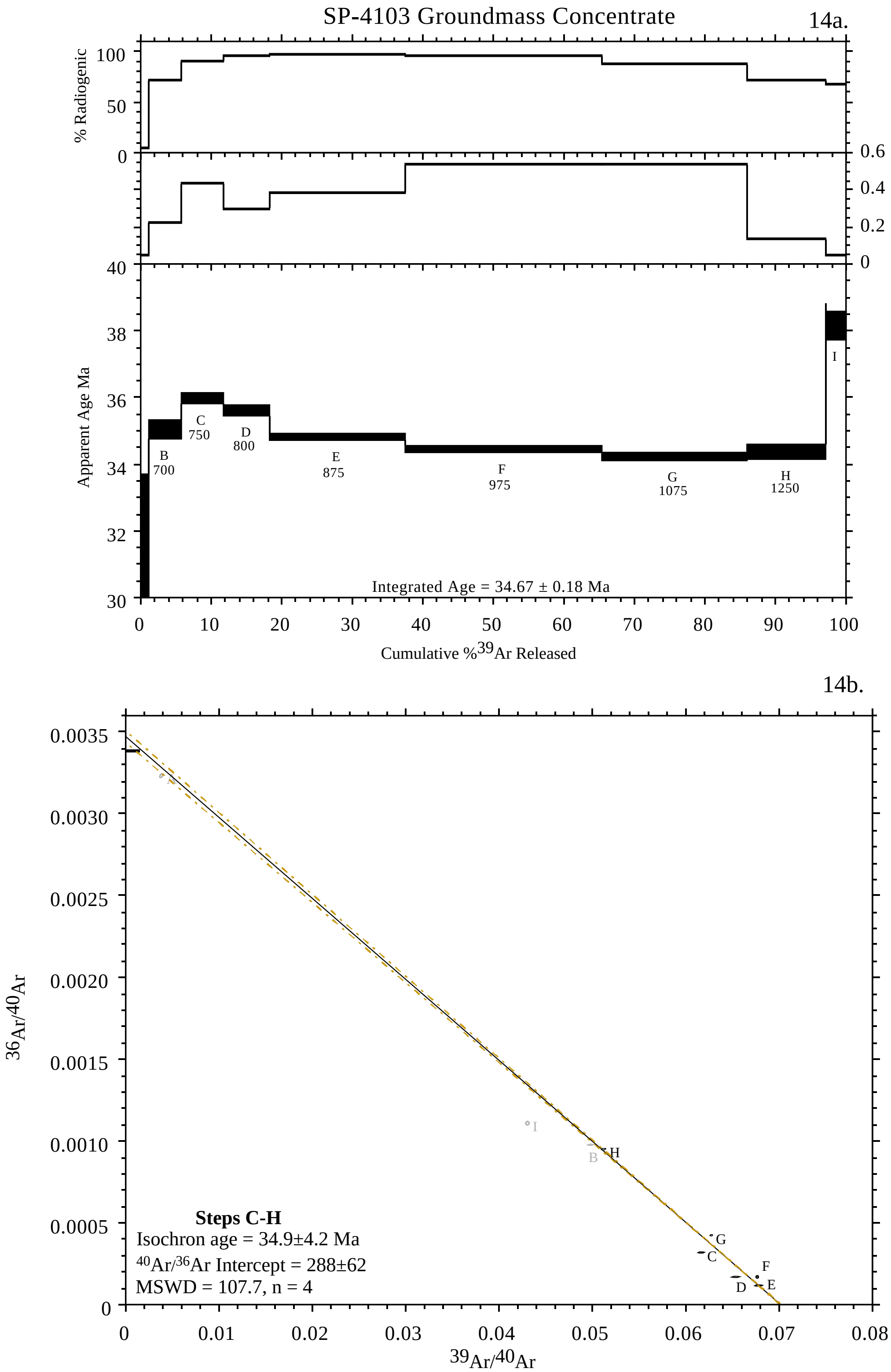


Figure 14. Age spectrum (14a) and isochron (14b) for SP-4103 groundmass concentrate. All errors quoted at two sigma.

New Mexico Bureau of Mines and Mineral Resources

Procedures of the New Mexico Geochronology Research Laboratory

For the Period June 1998 – present

Matthew Heizler
William C. McIntosh
Richard Esser
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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.

References cited

Dalrymple, G.B., Alexander, E.C., Jr., Lanphere, M.A., and Kraker, G.P., 1981. Irradiation of samples for $^{40}Ar/^{39}Ar$ dating using the Geological Survey TRIGA reactor. U.S.G.S., Prof. Paper, 1176.

Deino, A., and Potts, R., 1990. Single-Crystal $^{40}Ar/^{39}Ar$ dating of the Olorgesailie Formation, Southern Kenya Rift, J. Geophys. Res., 95, 8453-8470.

Deino, A., and Potts, R., 1992. Age-probability spectra from examination of single-crystal $^{40}Ar/^{39}Ar$ dating results: Examples from Olorgesailie, Southern Kenya Rift, Quat. International, 13/14, 47-53.

Fleck, R.J., Sutter, J.F., and Elliot, D.H., 1977. Interpretation of discordant $^{40}Ar/^{39}Ar$ age-spectra of Mesozoic tholieiites from Antarctica, Geochim. Cosmochim. Acta, 41, 15-32.

Heizler, M. T., and Harrison, T. M., 1988. Multiple trapped argon components revealed by $^{40}Ar/^{39}Ar$ analysis, Geochim. Cosmochim. Acta, 52, 295-1303.

Mahon, K.I., 1996. The New “York” regression: Application of an improved statistical method to geochemistry, International Geology Review, 38, 293-303.

McDougall, I., and Harrison, T.M., 1988. Geochronology and thermochronology by the ^{40}Ar-^{39}Ar method. Oxford University Press.

Samson, S.D., and, Alexander, E.C., Jr., 1987. Calibration of the interlaboratory $^{40}Ar/^{39}Ar$ dating standard, Mmhb-1, Chem. Geol., 66, 27-34.

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.

Taylor, J.R., 1982. An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements,. Univ. Sci. Books, Mill Valley, Calif., 270 p.

York, D., 1969. Least squares fitting of a straight line with correlated errors, Earth and Planet. Sci. Lett.., 5, 320-324.