GSA DR Item **2013139** accompanies Koning, D.J., Grauch, V.J.S., Connell, S.D., Ferguson, J., McIntosh, W., Slate, J.L., Wan, E., and Baldridge, W.S., 2013, Structure and tectonic evolution of the eastern Española Basin, Rio Grande rift, north-central New Mexico, in Hudson, M.R., and Grauch, V.J.S., eds., New Perspectives on Rio Grande Rift Basins: From Tectonics to Groundwater: Geological Society of America Special Paper 494, p. 185–219, https://doi.org/10.1130/2013.2494(08).

Appendix C. Summary of $^{40}Ar/^{39}Ar$ results for tephra biotite or sanidine

						Mean Age			
Sample	Unit	UTM coord zone 13; NAD 27) m	Lab #	Irradation	min	analysis	n	MSWD	K/Ca ± 2σ
SCV-946FU-251102-djk	Cejita Mbr (Chamita Fm)	3,987,345 ± 20 N 400,880 ±20 E	54283	NM-170	Biotite, single crystal	Mean	6	1.0	2.3 ± 1.7
SCV-948-251102-djk	Cejita Mbr (Chamita Fm),	3,987,440 ± 20 N 400,530 ± 20 E	54435	NM-172	Biotite, single crystal	Mean	8	2.5	0.5 ± 0.2
SCV-318-230702-djk	Cuarteles Mbr (Tesuque Fm)	3,988,340 ± 15 N 409,670 ± 15 E	54436	NM-172	Biotite, single crystal	Mean	14	3.9	0.3 ± 0.0
SCV-1014-051202-djk	Ojo Caliente Sandstone (Tesuque Fm)	3,986,170 ± 20 N 398,980 ± 20 E	54437	NM-172	Biotite, single crystal	Mean	12	2.7	0.6 ± 1.7
SCV-1154-160103-djk	Cuarteles Mbr (Tesuque Fm)	3,996,440 ± 20 N 411,160 ± 20 E	54445	NM-172	Biotite, single crystal	Mean	14	4.0	5.6 ± 13.7
Set-26-230807-djk	lower coarse unit (Tesuque Fm)	3,958,665 ± 8 N 419,464 ± 8 E	59156	NM-226	Sanidine, single crystal	Mean	12	4.0	38.4 ± 16.2

Sample preparation and irradiation:

Minerals separated with standard heavy liquid, Franz Magnetic and hand-picking techniques.

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.

Biotite and groundmass concentrates step-heated, using a Mo double-vacuum resistance furnace.

Sanidine, biotite and flux monitor fused or step-heated by a 50 watt Synrad CO2 laser.

Notes:

Fm = Formation; Mbr = Member

Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Reference:

Renne, P.R., C.C. Swisher, A.L. Deino, D.B. Karner, T.L. Owens and D.J. Depaolo, 1998, Intercalibration of standards: absolute ages and uncertainties in 40Ar/39Ar dating: Chemical Geology, v. 145, p.117-152.

Appendix C. Summary of $^{40}Ar/^{39}Ar$ results for groundmass concentrate from basalts

						Preferred Age				
Sample	Unit	UTM coord (zone 13; NAD 27) m	Lab #	Irradiation	min	analysis	n	$\%^{39}Ar$	MSWD	K/Ca ± 2σ
ML-767-190404-djk	2.5-3.0 m-wide basalt dike	390,330 E 3,998,450 N	55542-01	NM-187J	Groundmass Concentrate	Plateau	7	95.3	2.4	0.1 ± 0.1
V-63-061103-djk	Lower of two flows located on NE part of Black Mesa	412,130 E 4,007,050 N	55545-01	NM-187J	Groundmass Concentrate	Plateau	6	79.2	1.6	0.0 ± 0.0
120304cl-djk	Fm basalt flow interbedded in Vallito Mbr (Chamita Fm)	396,250 E 3,990,570 N	55546-01	NM-187J	Groundmass Concentrate	Plateau	4	77.4	2.3	0.2 ± 0.2
110604c-djk	Top of 18 m-thick Servilleta Basalt at south tip of Black Mesa	400,970 E 3,996,100 N	55547-01	NM-187J	Groundmass Concentrate	Plateau	7	96.1	1.2	0.1 ± 0.2
120304a-djk	Bomb found in silty sand of the Vallito Mbr, lowermost Chamita Fm	394,620 E 3,989,680 N	55548-01	NM-187K	Groundmass Concentrate	Plateau	5	62.2	3.9	0.2 ± 0.1
SCV-1584-040603-djk	Servilleta Basalt from footwall of La Mesita fault; upper flow.	414,595 E 4,004,755 N	55549-01	NM-187K	Groundmass Concentrate	Plateau	7	95.1	1.4	0.1 ± 0.2

Sample preparation and irradiation:

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.

Biotite and groundmass concentrates step-heated, using a Mo double-vacuum resistance furnace.

Sanidine, biotite and flux monitor fused or step-heated by a 50 watt Synrad CO2 laser.

Notes:

Fm = Formation; Mbr = Member

Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Reference:

Renne, P.R., C.C. Swisher, A.L. Deino, D.B. Karner, T.L. Owens and D.J. Depaolo, 1998, Intercalibration of standards: absolute ages and uncertainties in 40Ar/39Ar dating: Chemical Geology, v. 145, p.117-152.

$^{40}Ar/^{39}Ar$ Geochronology Results from Ojo Caliente, Chili and Las Tablas Quadrangles

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NOVEMBER 17 , 2009

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Introduction

Samples from the Ojo Cliente, Chili and Las Tablas quadrangles were submitted by Dan Koning as part of the STATEMAP program. A variety of material was separated from these samples, some were determined to be undatable. The separated phase and data is summarized below.

Table 1. Brief summary of results.

Sample	Phase	Age±2σ (Ma)	Comments
GTM-536-djk	Sanidine	25.05±0.06	Gaussian distribution
GTM-528-djk	Sanidine	22.48±0.07	nearly Gaussian distribution
GTM-439-djk	Sanidine	24.93±0.25	possible altered crystals removed
OC-188a0011004-djk	Sanidine/Plagioclase	No age assigned	younger than 16.7±2.6 Ma
GTM-627-djk	Biotite	22.88±0.07	concordant age spectrum
WRC-82	Biotite	29.98±0.09	somewhat concordant
WRC-37-111006	Biotite	11.72±0.62	somewhat disturbed
OC-808-180805-djk	Biotite	23.18±0.48	nearly Gaussian distribution
OC-759-300605-djk	Biotite	23.73±0.30	nearly Gaussian distribution
Unit-5c-NWchili-sect-djk	Biotite	10.97±0.47	somewhat Gaussian distribution
OC-379-111104-djk	Biotite	-	10 Ma spread in ages
GTM-625-djk	Groundmass Concentrate	24.92±0.34	nearly concordant
OC-740-130505	Groundmass Concentrate	10.55±0.45	concordant
GTM-260805	Groundmass Concentrate	4.59±0.12	somewhat discordant

TJ basalt	Groundmass Concentrate	4.79±0.15	somewhat discordant
J54B	Groundmass Concentrate	4.67±0.19	nearly concordant
ER-76	Groundmass Concentrate	21.5±1.1	nearly concordant, low precision
GSO602	Groundmass Concentrate	17.5±1.2	somewhat discordant
ER-43	Groundmass Concentrate	14.2±1.9	isochron age
091206-d	Groundmass Concentrate	9.0±1.0	isochron age
WRC-68	Groundmass Concentrate	No age assigned	highly discordant
GTM-490-djk	Groundmass Concentrate	No age assigned	highly discordant
OC-908-208805-djk	Groundmass Concentrate	No age assigned	highly discordant

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

Samples were initially prepared by crushing, sieving and then washing away clay-sized material. Sanidine was separated by cleaning in hydrofluoric acid, rinsing in distilled water and then separating with heavy liquid. Biotite was separated with a magnetic separator, heavy liquid and hand picking. The groundmass concentrates were prepared by crushing, sieving, cleaning with hydrochloric acid and removing of phenocryts with hand picking or by using a magnetic separator. The mineral separates and monitors (Fish Canyon tuff sanidine, 28.02, Renne et al., 1998) were loaded into aluminum discs and irradiated for 7 hours at the Nuclear Science Center in College Station, Texas.

The sanidine and monitors were analyzed by the single-crystal-laser-fusion method. Where xenocrystic contaminants were a possibility, biotite was step-heated as single crystals or small aliquots with a defocused CO_2 laser. The biotite and groundmass concentrate were analyzed with the incremental heating age spectrum method, heated with either the furnace or the CO2 laser equipped with a top hat lens. Abbreviated

analytical methods for the dated sample are given in Table 2, and details of the overall operation of the New Mexico Geochronology Research Laboratory is provided in the Appendix. The age results are summarized in Tables 1 and 2 and the argon isotopic data are given in Tables 3 -5.

Three of the four sanidine separates yielded Gaussian or near-Gaussin populations (GTM-536-djk, GTM-528-djk, GTM-439-djk, Figures 1-3 respectively). These samples also have high radiogenic yields and K/Ca values typical of sanidine. The fourth sample analyzed as single crystals (OC-188a-01104-djk, Figure 4) yielded apparent ages ranging from 7.6 Ma to 40.3 Ma, radiogenic yields from 25.3% to 109.2% and only three crystals with K/Ca values indicative of sanidine. The rest of the crystals have K/Ca values less than one which is indicative of plagioclase.

Of the three biotite samples analyzed by the furnace step-heating method, only one, GTM-627, yielded a concordant age spectrum with high radiogenic yields and typical K/Ca values (Figure 5). The other two (WRC-82 and WRC-37-111006, Figures 6 and 7, respectively) yielded somewhat disturbed age spectra. WRC-82 yielded slightly older apparent ages in the early heating steps, probably caused by slight excess Ar. The remaining portion of the age spectrum (65.9% of the ^{39}Ar released) is nearly concordant and this is the portion used to calculate the weighted mean age of 29.98±0.09 Ma. WRC-37-111006-djk has lower radiogenic yields (2.2% to 28.6%), lower K/Ca values (0.36-11.1) and a less concordant age spectrum than the other two but a weighted mean age of 11.72±0.62 Ma is calculated from all steps.

Eleven to eighteen aliquots containing one or two crystals of biotite from samples OC-808-180805-djk, OC-759-300605-djk, Unit-5c-NWchili-sect-djk and OC-379-111004-djk were step-heated with the CO2 laser. The low power A steps were used to drive off the atmospheric gas and increase the radiogenic yield and thus precision of the B steps. The more radiogenic B steps are shown plotted on Figures 8-11. The radiogenic yields of the OC-808-180805-djk and OC-759-300605-djk are all above 20%. All fifteen biotite crystals of OC-808-1808805-djk were used to calculate the weighted mean age of 23.18±0.47 Ma (Figure 8). Eleven of the fourteen OC-759-300605-djk crystals were used to calculate a weighted mean age of 23.73±0.30 Ma (Figure 9). Two analyses

with very little ^{39}Ar were excluded from the calculation and one small crystal with a low radiogenic yield were excluded. All but one analysis of Unit-5c-NWChili-Sect-djk, which was considered to be a xenocrystic, were used to calculate the weighted mean age of 10.97±0.47 Ma (Figure 10). The 10 Ma spread in ages of the analyzed OC-379-1104-djk crystals (9.93±0.84 Ma to 19.8±2.0 Ma,Figure 11) is approximately twice the spread of the other biotite samples analyzed as single crystals. A weighted mean age was not calculated for this sample.

The quality of the twelve groundmass concentrate analyses is highly variable, ranging from fairly well-behaved to highly disturbed. The age spectra for groundmass concentrates GTM-625-djk, OC-740-130505 and J-54B (Figures 12-14, respectively) are the most concordant with 98.1%, 100.0% and 100.0% (respectively) of the ^{39}Ar released being used to calculate a weighted mean age for the sample. It is noted that the radiogenic yields for OC-740-130505 are less than 20%, lower than expected for a sample of this age; which results in higher than normal errors on the individual steps. Groundmass concentrates GTM-260805-djk and TJ basalt (Figures 15 and 16) reveal young apparent ages in the early heating steps that are often indicative of alteration and accompanying ^{40}Ar loss; weighted mean ages for these samples are calculated from the more concordant later portions of the spectra (4.59±0.12 Ma and 4.79±0.15 Ma, respectively). Four of the groundmass concentrates yielded saddle-shaped age spectra (ER-76, GSO 602, 091206-d and ER-43-djk, Figures 17-20). This can often be indicative of excess ^{40}Ar (Zeitler, 1987). The inverse isochrons for ER-76 and GSO 602 do not have elevated $^{40}Ar/^{36}Ar$ ratios (>295.5). Weighted mean ages for these samples have therefore been calculated from the flatter mid-portion of the age spectra (21.5±1.1 Ma and 17.5±1.2 Ma, respectively). These portions contain 89.4% and 91.8% of the ^{39}Ar released. 091206-d and ER-43-djk have slightly elevated $^{40}Ar/^{36}Ar$ ratios (299.4±2.5 and 298.9±5.7, respectively) so we have assigned the isochron ages to these two samples (9.0±1.0 Ma and 14.2±1.9 Ma, respectively). It is noted that the radiogenic yields for both samples are less than 20%, the data is therefore highly affected by excess Ar. The remaining three groundmass analyses are so highly disturbed that no age is assigned to them (WRC-68, GTM-490-djk and OC-908-280805-djk, Figures 21-23, respectively).

Discussion

The data obtained from these samples varies greatly in quality, from precise, very reliable to data of such low quality that we were unable to assign an age to the sample. The sanidine from samples GTM-536-djk, GTM-528-djk and GTM-439-djk yielded precise and reliable ages for the flows and intrusions from which they were separated (25.05±0.06 Ma, 22.48±0.07 Ma, and 24.93±0.25 Ma, respectively). The crystals eliminated from the GTM-439-djk data are younger, less radiogenic and have smaller signals than the other crystals and have possibly undergone alteration and minor Ar loss. We are unable to assign an age to OC-188a-01104-djk. The large spread in ages (7.6 Ma to 40.3 Ma) without a clear main population implies significant xenocrystic contamination. The low radiogenic yields of many of the crystals (as low as 25.3%) implies that there may have been alteration and accompanying Ar loss, making the ages of those crystals suspect (youngest four crystals all have radiogenic yields below 80%). We are hesitant to assign the age of the youngest crystal as the maximum age of the unit.

The biotite samples analyzed by the furnace incremental heating age spectrum method (GTM-627-djk, WRC-82, and WRC-37-111006) provide reliable ages for the units from which they were sampled. GTM-627-djk provides an accurate eruption age (22.88±0.07 Ma) for the rhyodacite flow, biotite from WRC-82 (29.98±0.09 Ma) clast suggests that the clast came from the San Juan volcanic field rather than the Jemez, and that from WRC-37-111006-djk provides and eruption age (11.72±0.62 Ma) for the tephra rip-up clasts and therefore a maximum age for the unit containing the clasts.

Three of the four biotite samples that were analyzed as single or few crystal aliquots provided fairly precise eruption ages for the ash and tephra samples from which they were sampled. We point out that although the age of OC-808-180805-djk (23.18±0.48 Ma), from the stratigraphically lower Abiquiu Formation is younger age than

the age for the stratigraphically higher OC-759-300605-djk (23.73±0.30 Ma, sampled in the Tesuque Formation), these ages do agree within error. We are unable to assign an age to sample OC-379-1104-djk due to the 10 Ma spread in ages and low radiogenic yields (<25% radiogenic). The large spread in ages is suggestive of contaminants and we would therefore typically assign the age of the young crystals as an eruption age. In this case however, the low radiogenic yields are suggestive of alteration and accompanying Ar loss, making the youngest apparent ages suspect.

The basaltic dikes and flows analyzed as groundmass concentrates yielded reliable, if in some cases low precision, eruption dates (GTM-625-djk, OC-740-130505, GTM-260805-djk, J-54B, TJ basalt, ER-76, and 091206-d) with the exception of GTM-490-djk and OC-908-280805-djk, which yielded such highly disturbed age spectra that we were unable to assign an eruption age. The groundmass concentrate obtained from a basaltic bomb in the Chama-El Rito Member (ER-43) provides a fairly low precision (14.2±1.9 Ma) age for the Chama-El Rito member in the eastern half of the El Rito quadrangle. We are unable to assign an age to sample WRC-68, a basalt bomb, and thus constrain the age of the Vallito Member of the Chamita Formation.

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Table 2. Summary of $^{40}Ar/^{39}Ar$ results and analytical methods

Sample	Lab #	Irradiation	mineral	age analysis	steps/analyses	Age	±2σ	MSWD	
GTM-536-djk	57801	NM-217	sanidine	laser total fusion	15	25.05	0.06	0.98	
GTM-528-djk	57802	NM-217	sanidine	laser total fusion	15	22.48	0.08	2.35	
GTM-439-djk	57800	NM-217	sanidine	laser total fusion	12	24.93	0.25	1.53	
OC-188a-011004-djk	57174	NM-208	sanidine/plagioclase	laser total fusion	-	-	-	-	no age assigned
GTM-627	57852	NM-217	biotite	furnace step-heat	12	22.88	0.07	0.87	
WRC-82	57849	NM-217	biotite	furnace step-heat	9	29.98	0.09	0.09	
WRC-37-111006	57851	NM-217	biotite	furnace step-heat	10	11.72	0.62	4.87	
OC-808-180805-djk	57206	NM-208	biotite	laser step heat	16	23.18	0.48		
OC-759-300605-djk	57205	NM-208	biotite	laser step heat	12	23.73	0.30		
NW-unit5c-sect-djk	57850	NM-217	biotite	laser step heat	17	10.97	0.47		
OC-379-111104-djk	57207	NM-208	biotite	laser step heat	-	-	-		
GTM-625-djk	57808	NM-217	groundmass concentrate	furnace step-heat	6	24.92	0.34	2.31	
OC-740-130505	57143	NM-208	groundmass concentrate	furnace step-heat	9	10.55	0.45	0.36	
GTM-260805-djk	57183	NM-208	groundmass concentrate	furnace step-heat	6	4.59	0.12	6.67	
J54B	57452	NM-212	groundmass concentrate	furnace step-heat	9	4.67	0.19	1.89	
TJ basalt	57142	NM-208	groundmass concentrate	furnace step-heat	7	4.79	0.15	2.94	
ER-76	57814	NM-217	groundmass concentrate	furnace step-heat	7	21.5	1.1	1.14	
ER-43	57815	NM-217	groundmass concentrate	furnace step-heat	9	14.20	1.90	4.74	isochron
091206-d	57806	NM-217	groundmass concentrate	furnace step-heat	9	9.0	1.0	3.80	
GSO602	57805	NM-217	groundmass concentrate	furnace step-heat	8	17.5	1.2	5.62	
WRC-68	57807	NM-217	groundmass concentrate	furnace step-heat	-	-	-		
GTM-490-djk	57804	NM-217	groundmass concentrate	furnace step-heat	-	-	-		
OC-908-280805-djk	57453	NM-212	groundmass concentrate	furnace step-heat	-	-	-		

Sample preparation and irradiation:
Minerals separated with standard heavy liquid, Franz Magnetic and hand-picking techniques.
Samples in NM-208 and 217 irradiated in a machined Aluminum tray for 7 hours in D-3 position, Nuclear Science Center, College Station, TX.
Samples in NM-212 irradiated in a machined Aluminum tray for 10 hours in C.T. position at the USGS TRIGA reactor in Denver, Colorado.
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.
Biotite and groundmass concentrates step-heated, using a Mo double-vacuum resistance furnace.
Sanidine, biotite and flux monitor fused or step-heated by a 50 watt Synrad CO_2 laser.

Analytical parameters:
Electron multiplier sensitivity averaged 8.73e-17 x 10^{-17} moles/pA for NM-208 furnace analyses, 1.0x 10^{-16} moles/pA for NM-212 furnace analyses and 7e-17 for NM-217 furnace analyses. and 3.35 x 10^{-17} for the sanidine analysis and 4.68e-17e-17 for laser biotite analyses from NM-208 and 5.58e-17 for laser biotite analyses from NM-217.
Total system blank and background averaged 1430, 13.3, 5.5, 6.8, 27.4 x 10^{-18} moles at masses 40, 39, 38, 37 and 36, respectively for the furnace analyses.
Total system blank and background averaged 375, 8.6, 2.2, 2.8, 41.9 x x 10-18 moles at masses 40, 39, 38, 37 and 36 for the laser analyses.
J-factors determined by CO_2 laser-fusion of 6 single crystals from each of 10 radial positions around the irradiation tray.
Decay constants and isotopic abundances after Steiger and Jäger (1977).

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)
GTM-439-djk, Sanidine, J=0.0008023±0.05%, D=1.004±0.001, NM-217C, Lab#=57800								
14	*17.84*	*0.0140*	*4.840*	*0.293*	*36.4*	*92.0*	*23.6*	*1.0*
07	*17.38*	*0.0267*	*2.510*	*0.180*	*19.1*	*95.7*	*23.9*	*1.6*
15	*17.60*	*0.0083*	*2.809*	*0.441*	*61.7*	*95.3*	*24.11*	*0.69*
02	17.62	0.0077	2.829	0.765	66.2	95.3	24.13	0.39
05	17.36	0.0017	0.6676	1.611	293.9	98.9	24.67	0.20
12	17.58	0.0040	1.376	0.786	127.8	97.7	24.69	0.41
09	17.59	0.0064	1.244	0.500	79.9	97.9	24.76	0.61
06	17.57	0.0009	1.130	1.172	563.0	98.1	24.78	0.27
04	17.58	0.0087	0.9847	0.500	58.3	98.3	24.85	0.61
11	17.46	0.0035	0.5549	0.717	146.4	99.1	24.86	0.43
13	17.64	0.0010	0.8796	1.007	534.6	98.5	24.98	0.30
08	17.97	0.0095	1.798	0.625	53.5	97.0	25.06	0.49
10	17.90	0.0012	0.9413	0.848	425.5	98.4	25.33	0.40
03	17.58	-0.0050	-0.5711	0.624	-	101.0	25.51	0.50
01	18.09	0.0059	0.7819	1.210	86.7	98.7	25.67	0.27
Mean age ± 2σ	n=12		MSWD=1.53		221.4 ±379.7		24.93	0.25
GTM-536-djk, Sanidine, J=0.0008007±0.05%, D=1.004±0.001, NM-217C, Lab#=57801								
06	18.73	0.0037	4.926	1.856	137.8	92.2	24.78	0.18
14	17.54	0.0044	0.6575	3.661	116.4	98.9	24.885	0.099
11	17.54	0.0045	0.5734	2.812	113.2	99.0	24.93	0.12
03	17.98	0.0017	2.004	2.285	304.9	96.7	24.94	0.14
01	17.61	0.0009	0.7394	3.019	545.9	98.8	24.95	0.11
08	17.76	0.0062	1.173	1.692	81.7	98.1	24.99	0.19
12	17.57	0.0052	0.5100	2.906	97.3	99.1	24.99	0.12
04	31.13	0.0041	46.35	4.866	124.1	56.0	25.01	0.19
05	17.68	0.0065	0.8120	4.411	78.5	98.6	25.022	0.082
10	17.57	0.0049	0.3305	2.172	103.2	99.4	25.07	0.15
02	17.82	0.0064	1.054	2.000	79.1	98.3	25.12	0.17
13	17.93	0.0019	1.379	2.576	274.4	97.7	25.13	0.13
09	17.67	0.0026	0.4646	7.782	192.9	99.2	25.151	0.056
07	18.24	0.0019	2.395	4.274	262.4	96.1	25.158	0.093
15	17.92	0.0058	1.216	1.768	87.7	98.0	25.20	0.19
Mean age ± 2σ	n=15		MSWD=0.98		173.3 ±256.1		25.050	0.063

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)
GTM-528-djk, Sanidine, J=0.0007997±0.06%, D=1.004±0.001, NM-217C, Lab#=57802								
04	22.30	0.0054	23.24	4.149	94.1	69.2	22.13	0.14
10	18.13	0.0065	8.732	8.180	78.6	85.8	22.294	0.074
09	16.73	0.0047	3.990	1.257	108.9	93.0	22.30	0.26
07	26.84	0.0071	38.17	7.027	72.3	58.0	22.32	0.14
03	18.23	0.0070	8.870	11.054	72.7	85.6	22.376	0.062
08	16.35	0.0072	2.514	1.377	70.9	95.5	22.38	0.23
02	16.96	0.0067	4.440	5.571	76.4	92.3	22.434	0.077
06	18.80	0.0087	10.61	8.695	58.6	83.3	22.461	0.074
12	19.68	0.0063	13.59	10.708	80.6	79.6	22.465	0.073
14	18.21	0.0090	8.452	4.368	56.8	86.3	22.528	0.098
05	27.91	0.0074	41.09	10.062	68.8	56.5	22.61	0.13
15	19.32	0.0081	12.02	2.184	63.2	81.6	22.61	0.19
01	16.42	0.0070	2.174	7.177	72.8	96.1	22.624	0.067
13	18.13	0.0108	7.953	4.119	47.2	87.0	22.63	0.11
11	19.36	0.0162	12.01	8.288	31.5	81.7	22.676	0.075
Mean age ± 2σ	n=14		MSWD=2.05		68.5 ±35.5		22.484	0.073
OC-188a, Sanidine, J=0.0007925±0.05%, D=1.004±0.001, NM-208J, Lab#=57174								
03	*12.17*	*-0.4941*	*84.97*	*0.001*	*-*	*-106.8*	*-18.7*	*146.1*
07	*21.17*	*1.921*	*54.07*	*0.013*	*0.27*	*25.3*	*7.6*	*12.1*
09	15.55	2.519	13.75	0.057	0.20	75.2	16.7	2.6
06	18.20	2.956	14.01	0.047	0.17	78.6	20.4	3.3
12	30.13	3.136	53.26	0.058	0.16	48.6	20.9	3.3
04	17.28	2.585	8.128	0.149	0.20	87.3	21.5	1.2
16	24.10	3.548	26.89	0.053	0.14	68.2	23.4	3.6
05	16.87	0.0069	1.292	1.372	73.4	97.7	23.43	0.14
01	20.68	2.465	12.84	0.289	0.21	82.6	24.31	0.63
14	20.18	0.0082	6.752	1.367	62.6	90.1	25.81	0.17
17	18.88	0.0126	1.781	1.087	40.4	97.2	26.06	0.18
10	24.74	2.617	13.41	0.058	0.19	84.9	29.8	3.8
08	22.04	2.155	3.010	0.071	0.24	96.8	30.3	2.3
15	25.37	4.184	14.44	0.039	0.12	84.5	30.5	5.0
13	20.19	2.301	-5.6090	0.084	0.22	109.2	31.3	2.9
11	40.33	0.0140	39.99	0.010	36.3	70.7	40.3	14.5

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
$(^{38}Ar/^{39}Ar)_K$ = 0.0125
$(^{40}Ar/^{39}Ar)_K$ = 0 ± 0.0004

Table 4. $^{40}Ar/^{39}Ar$ analytical data.

	ID	Power/Temp (Watts/°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)
	GTM-627, Biotite, 7.07 mg, J=0.0007997±0.06%, D=1.004±0.001, NM-217L, Lab#=57852-01										
	A	650	632.2	0.0478	2100.4	0.341	10.7	1.8	0.5	16.61	5.37
	B	750	74.61	0.0437	199.3	0.484	11.7	21.1	1.1	22.53	1.25
	C	850	42.31	0.0274	88.64	1.45	18.6	38.1	3.0	23.11	0.46
	D	920	27.88	0.0142	39.29	2.55	35.9	58.4	6.4	23.32	0.25
	E	1000	21.05	0.0102	17.19	6.23	50.3	75.9	14.7	22.90	0.10
	F	1075	20.11	0.0108	14.35	8.5	47.2	78.9	26.0	22.75	0.08
	G	1110	20.35	0.0080	14.88	10.9	63.5	78.4	40.5	22.87	0.08
	H	1180	19.24	0.0301	11.02	23.9	17.0	83.1	72.2	22.91	0.06
	I	1210	19.11	0.0410	10.66	15.1	12.5	83.5	92.2	22.89	0.06
	J	1250	20.19	0.0169	14.38	5.00	30.2	79.0	98.9	22.86	0.12
	K	1300	28.63	0.0175	44.28	0.67	29.2	54.3	99.8	22.29	0.60
	L	1680	507.0	0.1638	1675.3	0.186	3.1	2.4	100.0	17.16	5.78
	Integrated age ± 2σ			n=12		75.3	21.1		K2O=5.12	22.84	0.16
	Plateau ± 2σ		steps A-L	n=12	MSWD=0.87	75.3	30.5 ±37.3		100.0	22.88	0.07
	Isochron±2σ		steps A-L	n=12	MSWD=0.81		$^{40}Ar/^{36}Ar$= 294.1±2.6			22.90	0.08
	WRC-82, Biotite, 8.76 mg, J=0.000798±0.06%, D=1.004±0.001, NM-217L, Lab#=57849-01										
X	A	650	727.1	0.3915	2411.7	0.427	1.3	2.0	0.5	20.78	5.32
X	B	750	92.57	0.2107	248.6	0.627	2.4	20.6	1.3	27.32	1.13
X	C	850	45.75	0.1063	81.97	1.99	4.8	47.1	3.7	30.74	0.42
X	D	920	27.75	0.0444	22.02	3.67	11.5	76.6	8.1	30.34	0.16
X	E	1000	24.48	0.0248	11.05	8.2	20.5	86.7	18.0	30.30	0.09
X	F	1075	23.30	0.0253	7.162	8.1	20.2	90.9	27.8	30.25	0.07
X	G	1110	23.75	0.0404	8.843	5.25	12.6	89.0	34.1	30.19	0.10
	H	1180	24.46	0.1647	11.80	13.5	3.1	85.8	50.3	29.96	0.08
	I	1210	23.15	0.0316	7.467	18.3	16.1	90.5	72.4	29.91	0.07
	J	1250	22.63	0.0046	5.353	21.0	111.1	93.0	97.7	30.06	0.06
	K	1300	25.80	0.0047	16.69	1.51	108.5	80.9	99.5	29.80	0.24
	L	1680	274.4	0.2547	850.8	0.395	2.0	8.4	100.0	32.83	2.59
	Integrated age ± 2σ			n=12		82.9	9.8		K2O=4.56	30.03	0.17
	Plateau ± 2σ		steps H-L	n=5	MSWD=1.11	54.7	51.8 ±113.1		65.9	29.98	0.09
	Isochron±2σ		steps A-L	n=12	MSWD=3.53		$^{40}Ar/^{36}Ar$=294.6±4.3			30.10	0.15
	WRC-37-111006-djk, Biotite, 4.2 mg, J=0.000798±0.06%, D=1.004±0.001, NM-217L, Lab#=57851-14										
	A	650	528.9	0.0527	1750.4	4.53	9.7	2.2	13.9	16.72	3.13
	B	750	71.02	0.0461	216.8	5.76	11.1	9.8	31.7	9.97	0.45
	C	850	51.68	0.0470	146.9	3.19	10.9	16.0	41.5	11.87	0.46
	D	920	55.02	0.0525	163.1	2.21	9.7	12.4	48.3	9.82	0.52
	E	1000	64.12	0.0593	187.9	5.92	8.6	13.4	66.5	12.35	0.43
	F	1075	35.28	0.0590	90.57	6.7	8.6	24.2	87.1	12.24	0.26
	G	1110	29.73	0.0774	73.42	2.53	6.6	27.0	94.9	11.54	0.32
	H	1180	30.32	0.4098	73.47	1.20	1.2	28.5	98.6	12.41	0.40
	I	1210	33.08	1.415	80.29	0.354	0.36	28.6	99.7	13.60	1.14
	J	1250	44.07	0.6706	127.8	0.113	0.76	14.4	100.0	9.14	2.64
	Integrated age ± 2σ			n=10		32.5	6.0		K2O=3.72	12.24	1.32
	Plateau ± 2σ		steps A-J	n=10	MSWD=4.87	32.5	8.9 ±8.6		100.0	11.72	0.62
	Isochron±2σ		steps A-J	n=10	MSWD=5.35		$^{40}Ar/^{36}Ar$=294.9±2.2			11.83	1.11

	ID	Power/Temp (Watts/°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)
	GTM-625-djk, wr, 40.96 mg, J=0.0007669±0.10%, D=1.004±0.001, NM-217D, Lab#=57808-01										
Xi	B	625	362.0	3.967	1184.0	0.80	0.13	3.4	1.9	17.23	2.92
	C	700	81.98	3.681	213.5	1.77	0.14	23.4	6.3	26.44	0.66
	E	750	48.11	5.058	102.6	1.72	0.10	37.9	10.5	25.12	0.45
	F	800	42.02	3.996	81.33	3.63	0.13	43.6	19.3	25.23	0.27
	G	875	45.09	3.138	91.96	4.90	0.16	40.3	31.2	25.03	0.31
	H	975	41.25	2.442	78.76	7.8	0.21	44.1	50.2	25.02	0.21
	I	1075	44.11	1.250	89.76	10.3	0.41	40.1	75.4	24.33	0.24
	J	1250	51.96	7.235	118.2	4.46	0.071	34.0	86.2	24.37	0.36
	K	1700	81.55	10.99	217.1	5.67	0.046	22.5	100.0	25.35	0.52
	Integrated age ± 2σ			n=9		41.1	0.12		K2O=0.50	24.75	0.53
	Plateau ± 2σ		steps C-K	n=8	MSWD=2.31	40.3	0.20 ±0.23		98.1	24.92	0.34
	Isochron±2σ		steps C-K	n=8	MSWD=2.22		$^{40}Ar/^{36}Ar$=299.2±7.0			24.4	1.00
	OC-740-130505-djk, Groundmass Concentrate, 33.29 mg, J=0.0008033±0.09%, D=1.0068±0.0015, NM-208D, Lab#=57143-01										
	A	3	4636.9	3.919	15661.5	0.223	0.13	0.2	0.3	13.46	41.49
	B	3	2467.2	3.494	8289.9	0.448	0.15	0.7	0.8	25.66	22.20
	C	4	1214.9	5.707	4083.7	0.875	0.089	0.7	1.9	12.52	10.85
	D	4	746.8	4.382	2502.2	1.539	0.12	1.0	3.7	11.25	6.72
	E	5	464.9	3.193	1545.1	2.440	0.16	1.8	6.7	12.38	4.07
	F	6	441.3	3.453	1466.0	7.53	0.15	1.9	15.7	12.13	3.78
	G	8	130.8	3.147	415.8	31.97	0.16	6.3	54.3	11.92	1.10
	H	10	37.32	2.210	102.6	23.76	0.23	19.3	83.0	10.42	0.29
	I	25	46.61	14.40	137.2	14.10	0.035	15.6	100.0	10.58	0.39
	Integrated age ± 2σ			n=9		82.9	0.10		K2O=1.19	11.37	2.93
	Plateau ± 2σ		steps A-I	n=9	MSWD=0.33	82.9	0.16 ±0.11		100.0	10.55	0.45
	Isochron±2σ		steps A-I	n=9	MSWD=0.19		$^{40}Ar/^{36}Ar$= 296.4±1.5			10.38	0.55
	GTM-260805-djk, Groundmass Concentrate, 19.41 mg, J=0.0007819±0.09%, D=1.0068±0.0015, NM-208K, Lab#=57183-01										
Xi	A	3	8.694	0.5563	23.00	2.348	0.92	22.4	2.0	2.74	0.23
Xi	B	3	10.63	0.5990	27.17	3.738	0.85	24.9	5.2	3.73	0.16
	C	4	5.501	0.7002	7.685	4.58	0.73	59.8	9.1	4.63	0.10
	D	4	15.57	0.7518	43.37	5.19	0.68	18.1	13.5	3.98	0.19
	E	5	5.226	0.7982	7.053	5.26	0.64	61.4	18.0	4.52	0.09
	F	6	5.292	0.9196	7.446	16.94	0.55	59.9	32.5	4.47	0.04
	G	8	9.882	0.9434	23.13	22.04	0.54	31.6	51.3	4.41	0.08
	H	10	18.20	0.9869	50.82	19.61	0.52	17.9	68.0	4.60	0.15
	I	25	5.225	1.226	6.666	37.42	0.42	64.2	100.0	4.73	0.04
	Integrated age ± 2σ			n=9		117.1	0.51		K2O=2.96	4.49	0.12
	Plateau ± 2σ		steps C-I	n=7	MSWD=6.67	111.0	0.52 ±0.21		94.8	4.59	0.12
	Isochron±2σ		steps C-I	n=7	MSWD=6.58		$^{40}Ar/^{36}Ar$=290.4±9.5			4.67	0.18

	ID	Power/Temp (Watts/°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)
	TJ basalt, Groundmass Concentrate, 32.49 mg, J=0.0008005±0.06%, D=1.0068±0.0015, NM-208D, Lab#=57142-01										
X	A	3	62.49	1.235	206.9	8.81	0.41	2.3	9.3	2.08	0.57
X	B	3	30.79	1.673	96.28	14.78	0.30	8.0	25.0	3.58	0.28
	C	4	20.99	2.133	60.93	15.09	0.24	15.1	41.0	4.57	0.20
	D	4	11.95	2.942	30.52	21.70	0.17	26.5	64.0	4.58	0.11
	E	5	9.511	3.598	21.87	9.68	0.14	35.2	74.3	4.84	0.11
	F	6	7.919	4.104	16.63	13.09	0.12	42.2	88.1	4.84	0.08
	G	8	10.70	7.049	26.88	5.33	0.072	31.2	93.8	4.84	0.16
	H	10	15.36	10.22	41.38	2.241	0.050	25.9	96.1	5.78	0.33
	I	25	35.96	32.82	119.1	3.634	0.016	9.7	100.0	5.14	0.43
	Integrated age ± 2σ			n=9		94.4	0.12		K2O=1.39	4.32	0.34
	Plateau ± 2σ		steps C-I	n=7	MSWD=2.56	70.8	0.15 ±0.15		75.0	4.79	0.15
	Isochron±2σ		steps A-I	n=9	MSWD=4.43		$^{40}Ar/^{36}Ar$=288.7±5.5			5.02	0.29
	J54B, Groundmass Concentrate, 36.68 mg, J=0.0023±0.43%, D=1.0032±0.0012, NM-212F, Lab#=57452-01										
	A	550	38.07	0.3158	125.0	18.9	1.6	3.1	12.8	4.82	0.84
	B	625	7.116	0.6634	20.72	20.4	0.77	14.6	26.7	4.31	0.20
	C	700	5.523	1.565	15.38	21.9	0.33	19.9	41.6	4.56	0.15
	D	750	4.142	2.755	10.56	13.7	0.19	30.0	50.9	5.15	0.20
	E	800	2.660	4.157	6.182	15.3	0.12	44.1	61.3	4.85	0.17
	F	875	1.817	4.812	3.737	17.9	0.11	60.9	73.4	4.58	0.17
	G	975	1.709	5.509	3.401	17.8	0.093	67.7	85.6	4.78	0.17
	H	1075	2.415	6.407	6.424	8.9	0.080	43.1	91.6	4.32	0.23
	I	1250	5.302	16.57	18.23	6.72	0.031	24.1	96.2	5.35	0.57
Xi	J	1700	12.27	59.58	52.93	5.62	0.009	12.6	100.0	6.7	1.7
	Integrated age ± 2σ			n=10		147.3	0.088		K2O=0.67%	4.78	0.45
	Plateau ± 2σ		steps A-I	n=9	MSWD=1.89	141.6	0.44 ±1.04		96.2	4.67	0.19
	Isochron±2σ		steps A-I	n=9	MSWD=3.01		$^{40}Ar/^{36}Ar$= 295.0±4.7			4.70	0.24
	ER-76, wr, 42.82 mg, J=0.0007825±0.08%, D=1.0014±0.001, NM-217F, Lab#=57814-01										
Xi	B	625	1236.6	1.121	4087.1	2.24	0.46	2.3	7.3	40.48	7.35
	C	700	376.9	-0.1576	1216.6	2.19	-	4.6	14.5	24.33	2.59
	D	750	368.5	0.6771	1189.1	1.44	0.75	4.7	19.3	24.11	2.68
	E	800	995.4	0.8257	3301.9	1.75	0.62	2.0	25.0	27.69	5.97
	F	875	795.6	0.7307	2620.2	2.83	0.70	2.7	34.3	29.98	4.78
	G	975	344.2	0.7200	1115.1	5.80	0.71	4.3	53.3	20.71	2.04
	H	1075	229.4	2.116	725.7	3.22	0.24	6.6	63.9	21.25	1.48
	I	1250	97.84	19.48	286.2	10.0	0.026	15.2	96.8	21.19	0.59
Xi	J	1700	320.2	72.56	1032.9	0.99	0.007	6.6	100.0	30.91	2.96
	Integrated age ± 2σ			n=9		30.5	0.054		K2O=0.35	24.4	4.4
	Plateau ± 2σ		steps C-I	n=7	MSWD=1.14	27.3	0.37 ±0.56		89.4	21.5	1.1
	Isochron±2σ		steps C-I	n=7	MSWD=0.48		$^{40}Ar/^{36}Ar$= 297.2±1.6			20.4	1.5

	ID	Power/Temp (Watts/°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)
	GS0602, wr, 25.94 mg, J=0.0007696±0.07%, D=1.004±0.001, NM-217D, Lab#=57805-01										
Xi	A	550	6698.1	1.560	22262.7	0.85	0.33	1.8	4.2	158.95	36.89
	B	625	283.0	1.284	921.3	2.08	0.40	3.8	14.4	15.03	1.91
	C	700	149.2	1.460	469.8	1.64	0.35	7.0	22.5	14.48	1.22
	D	750	96.89	1.368	289.4	2.21	0.37	11.9	33.4	15.91	0.78
	E	800	111.6	1.167	336.8	1.85	0.44	10.9	42.5	16.86	0.92
	F	875	128.8	1.166	387.2	2.25	0.44	11.3	53.6	20.05	0.95
	G	975	159.6	1.383	486.4	2.32	0.37	10.0	65.0	22.09	1.13
	H	1075	54.93	2.256	141.5	1.60	0.23	24.2	72.9	18.39	0.61
	I	1250	52.14	16.81	139.8	4.70	0.030	23.5	96.0	17.09	0.40
Xi	J	1700	242.9	28.87	703.2	0.82	0.018	15.4	100.0	52.32	2.00
	Integrated age ± 2σ			n=10		20.3	0.083		K2O=0.39	25.1	4.5
	Plateau ± 2σ		steps B-I	n=8	MSWD=5.62	18.641	0.288±0.275		91.8	17.5	1.2
	Isochron±2σ		steps B-I	n=8	MSWD=6.39		$^{40}Ar/^{36}Ar$=298.2±4.5			17.3	1.90
	ER-43-djk, wr, 38.17 mg, J=0.0007841±0.07%, D=1.0014±0.001, NM-217F, Lab#=57815-01										
	B	625	440.0	0.9587	1442.0	2.74	0.53	3.2	8.0	19.69	2.83
	C	700	122.9	1.276	380.0	3.67	0.40	8.7	18.7	15.07	0.84
	D	750	65.44	1.626	190.8	3.57	0.31	14.1	29.2	12.99	0.50
	E	800	52.25	1.668	141.6	3.48	0.31	20.2	39.4	14.86	0.39
	F	875	69.11	1.402	199.5	4.45	0.36	14.9	52.4	14.50	0.54
	G	975	81.02	1.550	235.4	4.09	0.33	14.3	64.3	16.34	0.67
	H	1075	62.94	3.640	175.2	1.94	0.14	18.2	70.0	16.20	0.55
	I	1250	79.37	22.06	235.3	8.7	0.023	14.7	95.6	16.67	0.56
	J	1700	160.7	21.90	508.2	1.51	0.023	7.7	100.0	17.59	1.50
	Integrated age ± 2σ			n=9		34.2	0.065		K2O=0.44	15.86	1.22
	Plateau ± 2σ		steps B-J	n=9	MSWD=5.00	34.2	0.25 ±0.35		100.0	15.14	0.90
	Isochron±2σ		steps B-J	n=9	MSWD=4.74		$^{40}Ar/^{36}Ar$=298.9±5.7			14.2	1.9
	091206-d, wr, 38.34 mg, J=0.0007706±0.07%, D=1.004±0.001, NM-217D, Lab#=57806-01										
X	A	550	47793.3	2.056	158461.1	0.154	0.25	2.0	0.6	1006.65	177.21
X	B	625	1991.5	5.093	6660.5	0.434	0.10	1.2	2.4	32.77	13.51
X	C	700	619.1	3.802	2089.7	0.487	0.13	0.3	4.4	2.63	5.03
X	D	750	1279.0	3.154	4251.6	1.67	0.16	1.8	11.1	31.64	7.31
X	E	800	381.5	2.505	1240.9	2.19	0.20	3.9	20.0	20.80	2.32
	F	875	148.1	3.227	475.3	5.55	0.16	5.3	42.6	10.97	0.96
	G	975	43.19	5.272	124.9	5.07	0.097	15.6	63.2	9.37	0.37
	H	1075	55.71	4.865	167.2	4.17	0.10	12.0	80.1	9.32	0.44
	I	1250	39.06	7.796	109.3	2.10	0.065	19.0	88.7	10.34	0.40
Xi	J	1700	84.42	24.87	254.2	2.79	0.021	13.5	100.0	16.00	0.76
	Integrated age ± 2σ			n=10		24.6	0.075		K2O=0.32	21.7	5.8
	Plateau ± 2σ		steps F-I	n=4	MSWD=1.93	16.9	0.12 ±0.08		68.6	9.75	0.63
	Isochron±2σ		steps A-I	n=9	MSWD=3.80		$^{40}Ar/^{36}Ar$=299.4±2.5			9.0	1.0

	ID	Power/Temp (Watts/°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)
	WRC-68, wr, 39.73 mg, J=0.0007692±0.08%, D=1.004±0.001, NM-217D, Lab#=57807-01										
Xi	A	550	22736.0	1.782	75626.9	0.286	0.29	1.7	0.7	472.12	104.29
Xi	B	625	199.8	3.121	571.1	1.38	0.16	15.6	3.9	42.94	1.49
Xi	C	700	64.16	2.526	117.0	1.90	0.20	46.4	8.4	40.95	0.53
Xi	D	750	23.52	2.364	15.38	5.22	0.22	81.5	20.7	26.45	0.13
Xi	E	800	14.00	2.579	3.323	6.06	0.20	94.5	35.0	18.30	0.08
Xi	F	875	11.38	2.306	2.531	9.5	0.22	95.1	57.5	14.98	0.06
Xi	G	975	12.00	1.602	3.236	9.0	0.32	93.1	78.7	15.46	0.06
Xi	H	1075	22.40	1.587	15.31	4.22	0.32	80.4	88.7	24.84	0.15
Xi	I	1250	55.95	13.98	84.72	1.74	0.036	57.3	92.8	44.38	0.50
Xi	J	1700	82.13	19.06	240.8	3.04	0.027	15.3	100.0	17.58	0.78
	Integrated age ± 2σ			n=10		42.3	0.13		K2O=0.53	24.9	2.0
	GTM-490-djk, wr, 27.42 mg, J=0.0007673±0.09%, D=1.004±0.001, NM-217D, Lab#=57804-01										
X	A	550	18011.2	1.314	60081.3	0.240	0.39	1.4	4.0	325.24	88.83
X	B	625	88.65	2.352	275.6	0.87	0.22	8.4	18.5	10.25	1.13
X	C	700	50.27	4.163	125.6	0.91	0.12	26.8	33.7	18.63	0.77
X	D	750	41.36	8.271	89.35	1.00	0.062	37.8	50.2	21.64	0.57
X	E	800	48.27	12.57	103.7	0.70	0.041	38.6	61.8	25.86	0.77
X	F	875	39.94	14.80	77.03	0.67	0.034	46.1	72.9	25.55	0.87
X	G	975	72.02	17.55	185.9	0.523	0.029	25.7	81.6	25.79	1.18
X	H	1075	79.44	19.49	219.9	0.288	0.026	20.2	86.3	22.41	2.09
X	I	1250	143.3	95.23	441.9	0.148	0.005	14.3	88.8	30.16	3.95
X	J	1700	293.1	68.13	884.3	0.67	0.007	12.8	100.0	53.55	2.36
	Integrated age ± 2σ			n=10		6.03	0.028		K2O=0.11	37.8	9.0
	OC-908-280805-djk, Groundmass Concentrate, 39.87 mg, J=0.0023±0.43%, D=1.0032±0.0012, NM-212F, Lab#=57453-01										
X	A	550	95.60	2.447	300.0	8.9	0.21	7.5	11.8	29.5	2.0
X	B	625	11.32	2.978	23.64	4.55	0.17	40.4	17.8	18.90	0.49
X	C	700	7.204	4.206	8.754	9.1	0.12	68.9	29.9	20.51	0.23
X	D	750	6.614	5.538	5.194	7.5	0.092	83.7	39.9	22.88	0.26
X	E	800	6.426	7.472	4.469	12.0	0.068	89.1	55.8	23.68	0.24
X	F	875	6.368	8.966	3.915	13.3	0.057	93.5	73.4	24.65	0.26
X	G	975	6.700	9.543	4.950	11.3	0.053	89.9	88.3	24.96	0.30
X	H	1075	7.798	9.382	11.26	4.05	0.054	67.3	93.7	21.75	0.45
X	I	1250	11.98	47.25	44.82	2.10	0.011	22.0	96.5	11.3	1.6
X	J	1700	16.09	77.80	64.53	2.65	0.007	21.4	100.0	15.1	2.2
	Integrated age ± 2σ			n=10		75.5	0.049		K2O=0.32%	23.23	0.81

ID	Power/Temp (Watts/°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:

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 ± 2e-05
$(^{36}Ar/^{37}Ar)_{Ca}$ = 0.00028 ± 1e-05
$(^{38}Ar/^{39}Ar)_K$ = 0.0125
$(^{40}Ar/^{39}Ar)_K$ = 0 ± 0.0004

Table 6. $^{40}Ar/^{39}Ar$ 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)
OC-759-300605-djk, Biotite, 4 mg, J=0.0007753±0.10%, D=1.0068±0.0015, NM-208M, Lab#=57205								
11B	*62.11*	*0.0198*	*161.8*	*0.336*	*25.8*	*23.0*	*19.9*	*1.2*
05B	40.33	0.0792	81.33	0.376	6.4	40.4	22.66	0.83
14B	45.95	0.0578	98.85	1.692	8.8	36.4	23.27	0.36
13B	45.66	0.0969	97.78	2.604	5.3	36.7	23.31	0.29
12B	46.45	0.0836	100.3	1.385	6.1	36.2	23.37	0.37
07B	46.95	0.0929	101.2	1.581	5.5	36.3	23.71	0.36
10B	46.00	0.0510	97.78	1.611	10.0	37.2	23.78	0.31
06B	37.26	0.0584	67.85	1.182	8.7	46.2	23.92	0.36
08B	37.62	0.0917	68.98	1.897	5.6	45.8	23.96	0.33
09B	51.94	0.0668	117.2	1.038	7.6	33.3	24.04	0.49
04B	43.01	0.0325	86.04	0.694	15.7	40.9	24.42	0.55
03B	39.17	0.0636	71.41	0.569	8.0	46.1	25.11	0.50
02C	*53.69*	*-0.3131*	*61.92*	*0.005*	*-*	*65.9*	*48.8*	*36.9*
02B	*64.13*	*3.922*	*-206.1516*	*0.002*	*0.13*	*195.5*	*167.8*	*122.1*
Mean age ± 2σ	n=11	MSWD=1.68			8.0 ±6.0		23.73	0.30
OC-808-1808805-djk, Biotite, J=0.0007763±0.10%, D=1.0044±0.001, NM-208M, Lab#=57206								
08B	71.83	-0.0327	194.5	0.104	-	20.0	20.0	2.5
04B	50.25	0.1268	119.5	0.142	4.0	29.7	20.8	2.1
15B	45.21	0.0055	101.5	0.616	92.7	33.7	21.18	0.70
03B	40.86	0.1096	85.41	0.228	4.7	38.2	21.8	1.5
05B	55.10	0.0270	133.4	0.190	18.9	28.5	21.9	1.5
17B	48.13	0.0537	107.9	0.656	9.5	33.8	22.61	0.58
14B	55.23	0.0399	130.8	0.436	12.8	30.0	23.08	0.74
11B	58.45	0.0934	141.5	0.542	5.5	28.5	23.16	0.56
02B	30.64	0.0067	46.61	0.519	76.6	55.0	23.47	0.68
16B	47.05	0.0448	101.8	1.036	11.4	36.1	23.61	0.46
13B	47.82	0.0250	104.1	0.522	20.4	35.7	23.74	0.76
09B	43.66	-0.2811	89.33	0.108	-	39.5	24.0	2.3
06B	40.60	-0.0189	79.03	0.377	-	42.5	23.99	0.80
12B	50.75	0.0309	113.0	0.614	16.5	34.2	24.16	0.58
07B	71.87	-0.1255	183.6	0.170	-	24.5	24.5	1.8
Mean age ± 2σ	n=15	MSWD=1.43			24.8 ±51.9		23.18	0.48
OC-379-111104-djk, Biotite, J=0.0007771±0.09%, D=1.0044±0.001, NM-208M, Lab#=57207								
13B	75.26	0.2686	230.7	0.424	1.9	9.4	9.93	0.84
05B	89.89	0.0721	278.3	0.149	7.1	8.5	10.7	1.9
02B	33.59	0.0898	85.31	2.171	5.7	25.0	11.73	0.33
10B	113.3	0.1279	351.5	0.428	4.0	8.4	13.3	1.6
07B	46.75	0.0884	125.9	0.984	5.8	20.5	13.36	0.52
06B	99.70	0.1964	303.4	0.826	2.6	10.1	14.07	0.92
04B	178.3	0.1072	568.7	0.534	4.8	5.7	14.3	1.5
12B	156.6	0.0473	494.6	0.802	10.8	6.7	14.6	1.2
09B	71.89	0.1172	205.6	0.167	4.4	15.5	15.5	1.7
11B	171.2	0.0661	541.1	0.680	7.7	6.6	15.8	1.4
08B	109.8	0.1476	331.4	0.585	3.5	10.9	16.6	1.1
03B	167.2	0.0656	523.9	0.744	7.8	7.4	17.4	1.3
01B	267.2	0.1288	856.0	0.380	4.0	5.3	19.8	2.0
Mean age ± 2σ	n=13	MSWD=6.21			5.4 ±4.9		12.9	1.1

	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)
	unit-5c-NWchili-sect-djk, Biotite, J=0.0007974±0.06%, D=1.004±0.001, NM-217L, Lab#=57850								
	13B	174.9	0.0770	576.8	1.155	6.6	2.5	6.4	1.3
	05B	169.8	1.236	557.0	0.909	0.41	3.1	7.6	1.3
	09B	275.2	0.0911	910.4	0.597	5.6	2.2	8.8	2.2
	26B	56.50	0.1199	168.4	1.449	4.3	12.0	9.69	0.57
	11B	200.0	0.1073	653.4	1.141	4.8	3.4	9.9	1.5
	07B	264.6	0.1056	871.8	0.554	4.8	2.7	10.1	2.3
	18B	57.77	0.1551	171.2	5.168	3.3	12.4	10.30	0.37
	20B	54.35	0.0833	159.0	1.602	6.1	13.6	10.59	0.51
	03C	130.8	0.1184	417.5	0.780	4.3	5.7	10.6	1.2
	28B	54.45	0.4726	158.1	6.990	1.1	14.3	11.15	0.34
	15B	86.04	0.0803	264.8	2.807	6.4	9.1	11.18	0.63
	59B	61.01	0.0590	179.7	2.527	8.6	13.0	11.35	0.46
	57B	53.01	0.0769	152.2	5.236	6.6	15.2	11.52	0.35
	17B	160.7	0.1273	516.6	2.553	4.0	5.0	11.6	1.0
	22B	52.99	0.1055	150.8	2.998	4.8	15.9	12.10	0.42
	24B	167.1	0.0817	536.0	0.574	6.2	5.2	12.5	1.6
	03B	66.82	-0.0036	189.1	0.019	-	16.4	15.6	9.0
X	01B	119.9	0.1258	343.4	1.840	4.1	15.4	26.37	0.78
	Mean age ± 2σ	n=17		MSWD=2.67		4.9 ±4.0		10.97	0.47

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 27.84 Ma
Decay Constant (LambdaK (total)) = 5.543e-10/a
Correction factors:

$(^{39}Ar/^{37}Ar)_{Ca}$ = 0.00068 ± 2e-05
$(^{36}Ar/^{37}Ar)_{Ca}$ = 0.00028 ± 1e-05
$(^{38}Ar/^{39}Ar)_K$ = 0.0125
$(^{40}Ar/^{39}Ar)_K$ = 0 ± 0.0004

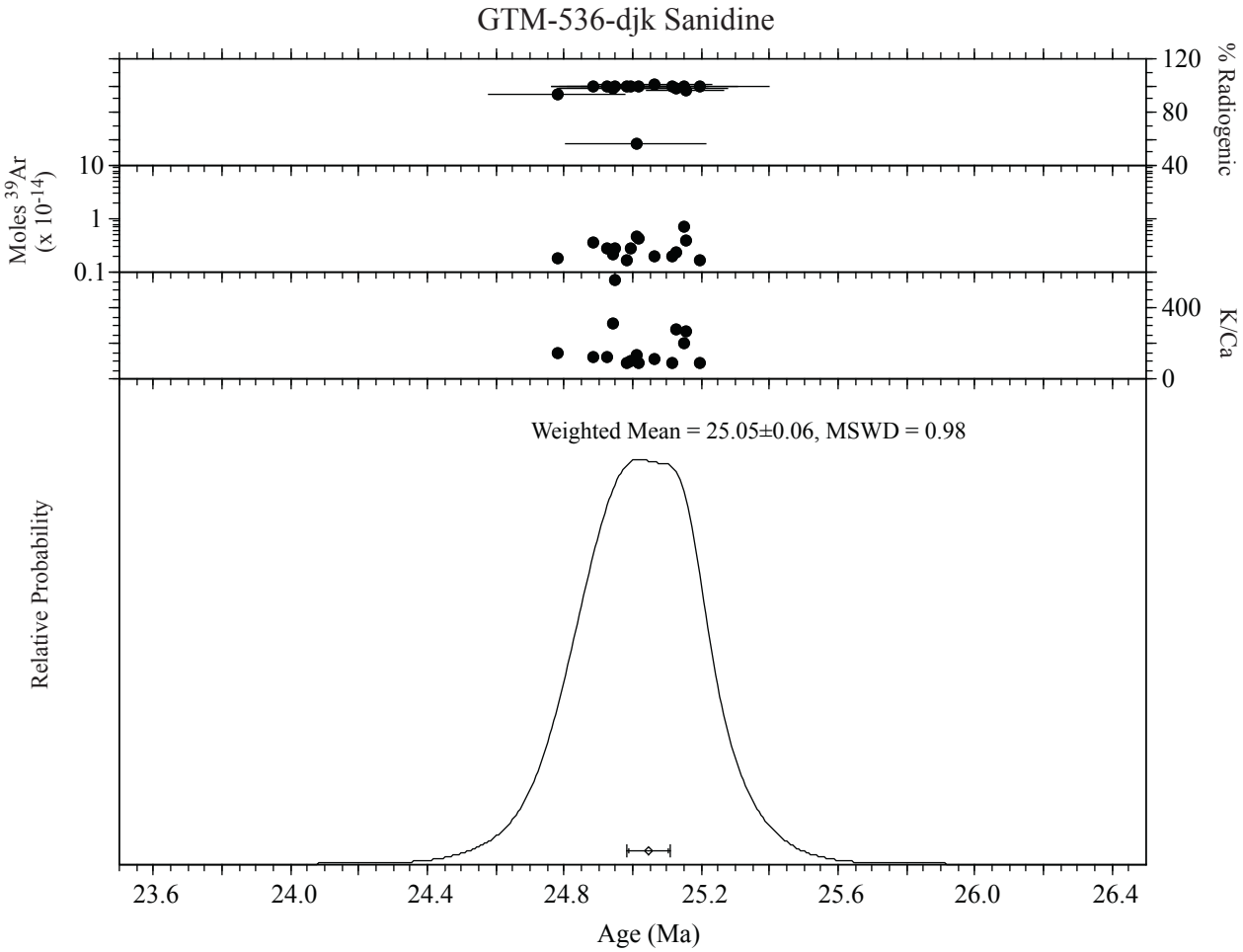


Figure 1. Age probability distribution diagram for GTM-536-djk sanidine. All errors quoted at 2 Sigma.

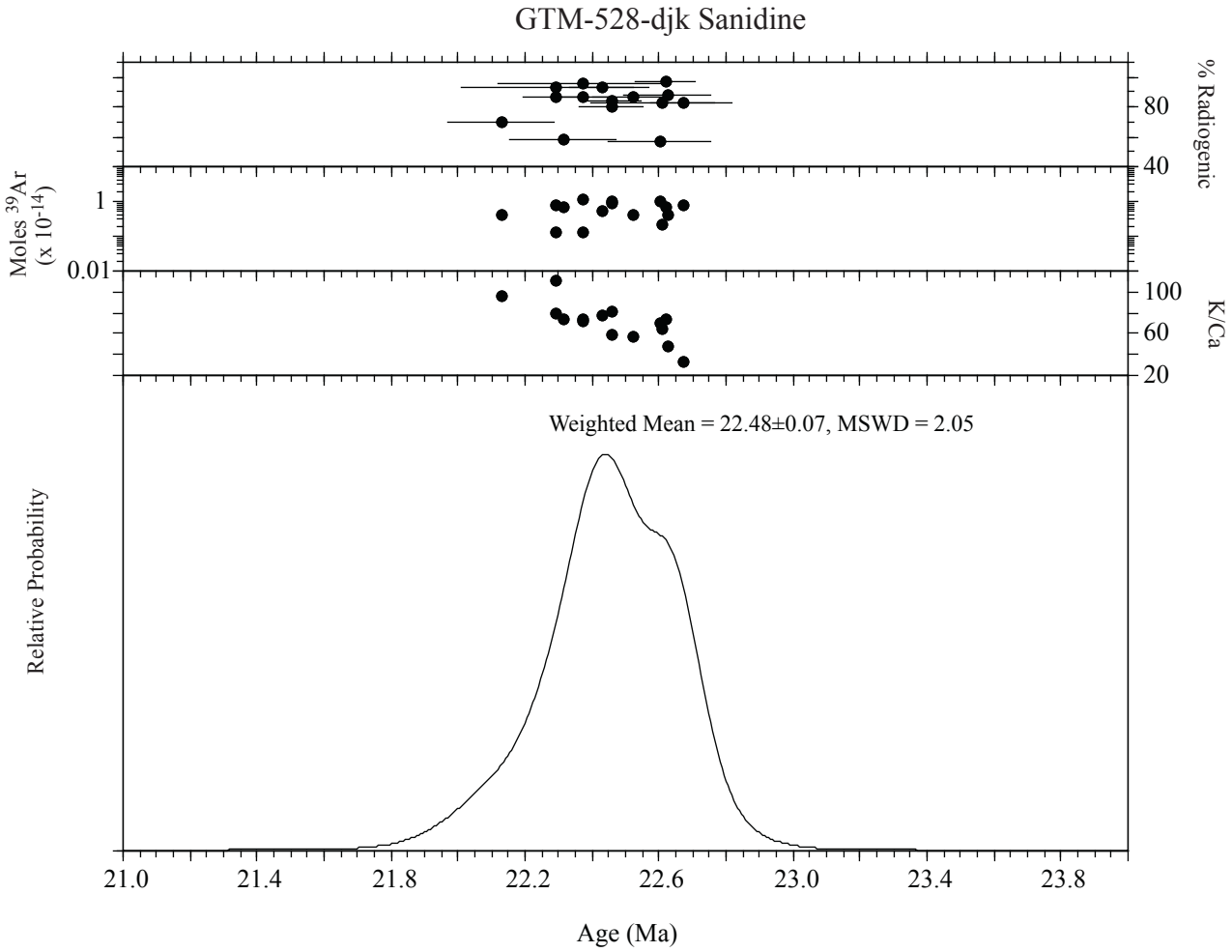


Figure 2. Age probability distribution diagram for GTM-528-djk sanidine. All errors quoted at 2 Sigma.

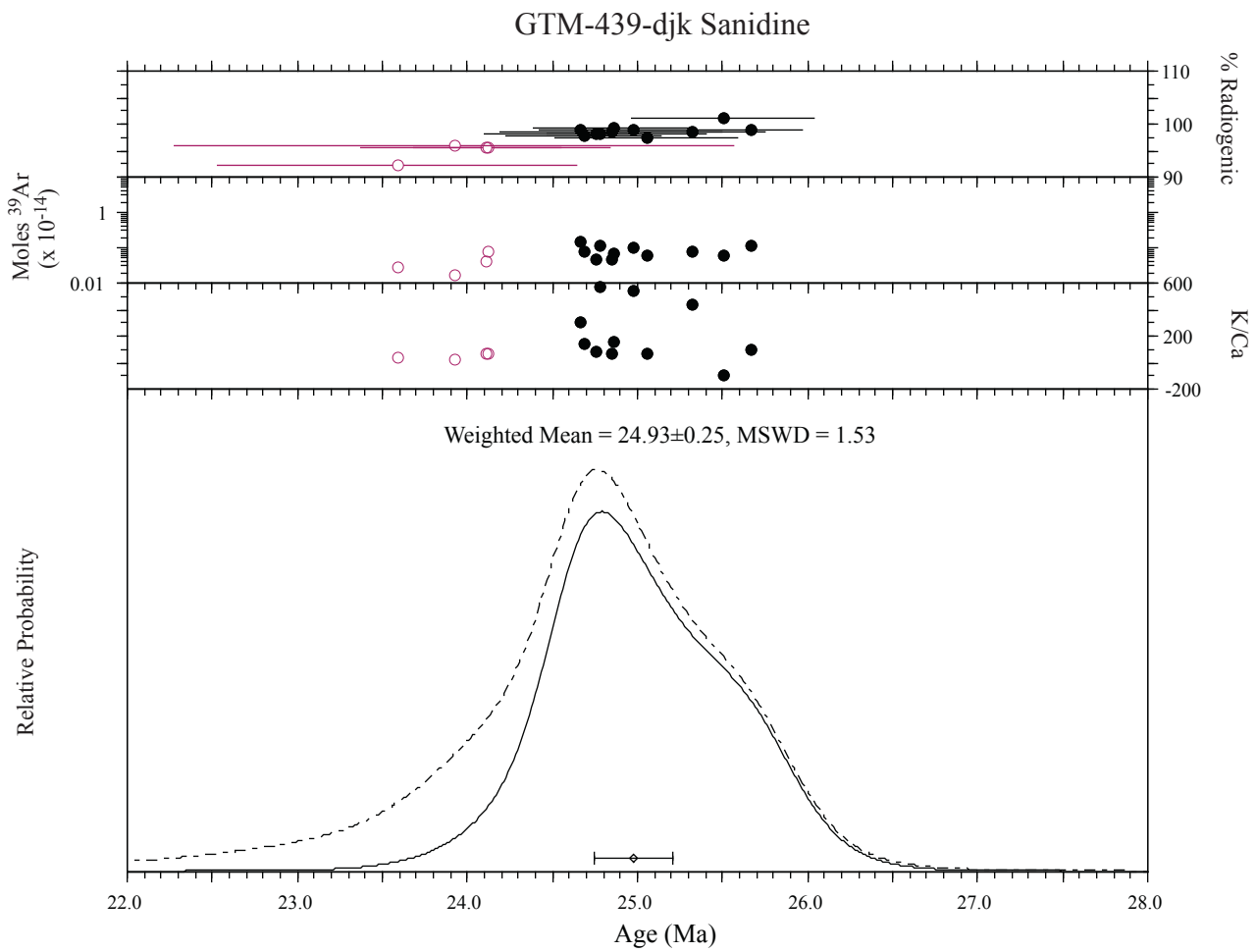


Figure 3. Age probability distribution diagram for GTM-439-djk sanidine. All errors quoted at 2 Sigma.

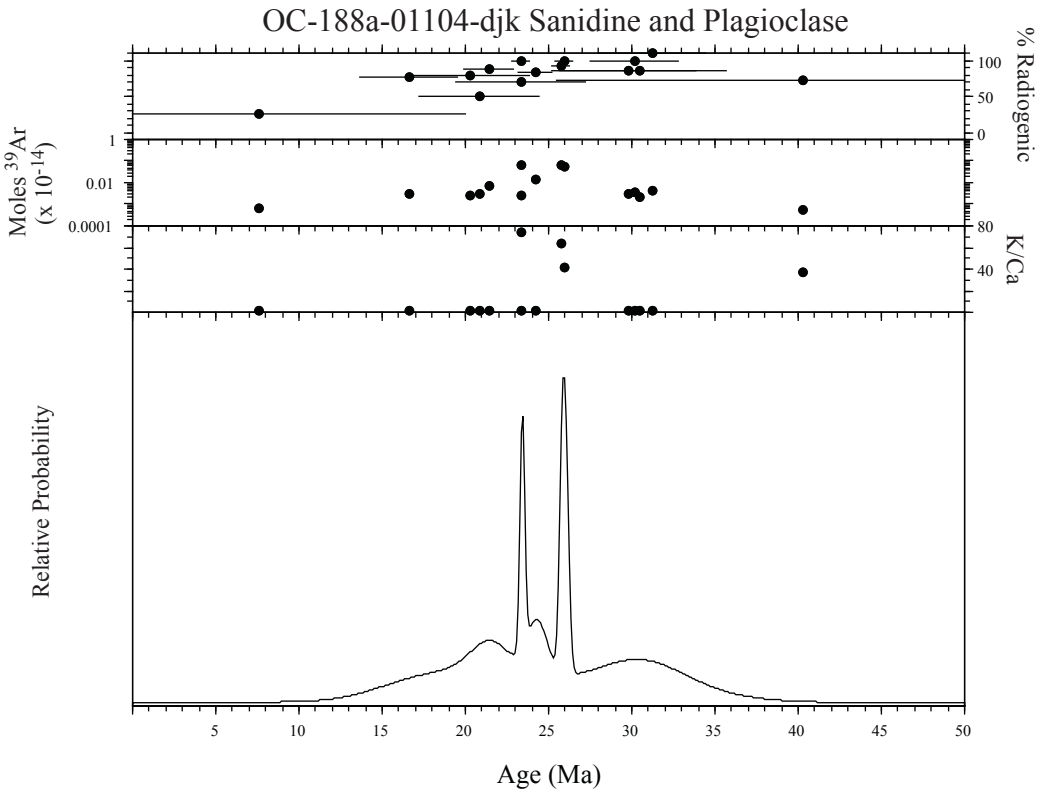


Figure 4. Age probability distribution diagram for OC-188a-01104-djk sanidine and plagioclase. All errors quoted at 2 Sigma.

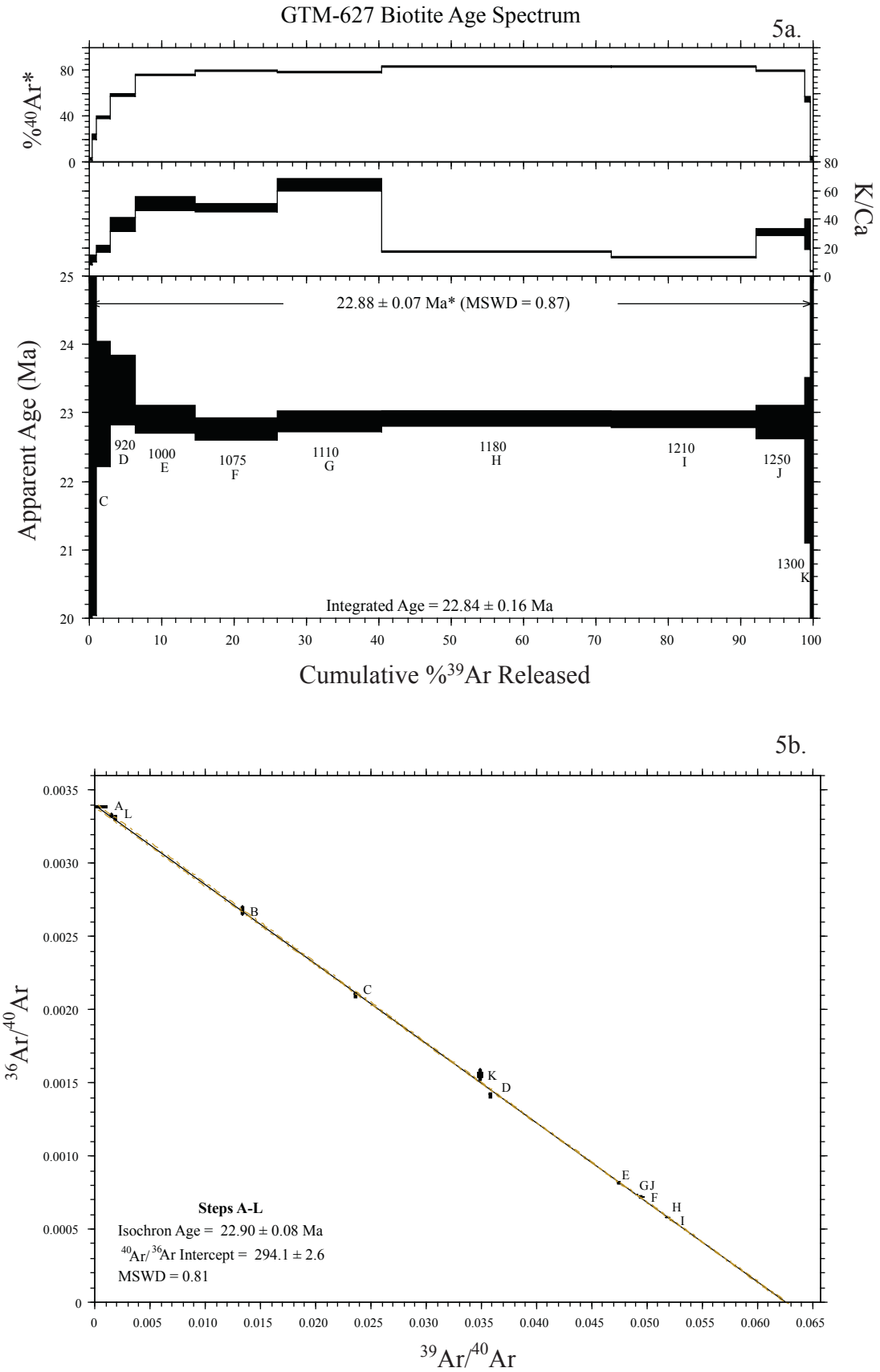


Figure 5. Age spectrum (5a) and isochron (5b) for GTM-627 biotite. All errors quoted at 2 sigma.

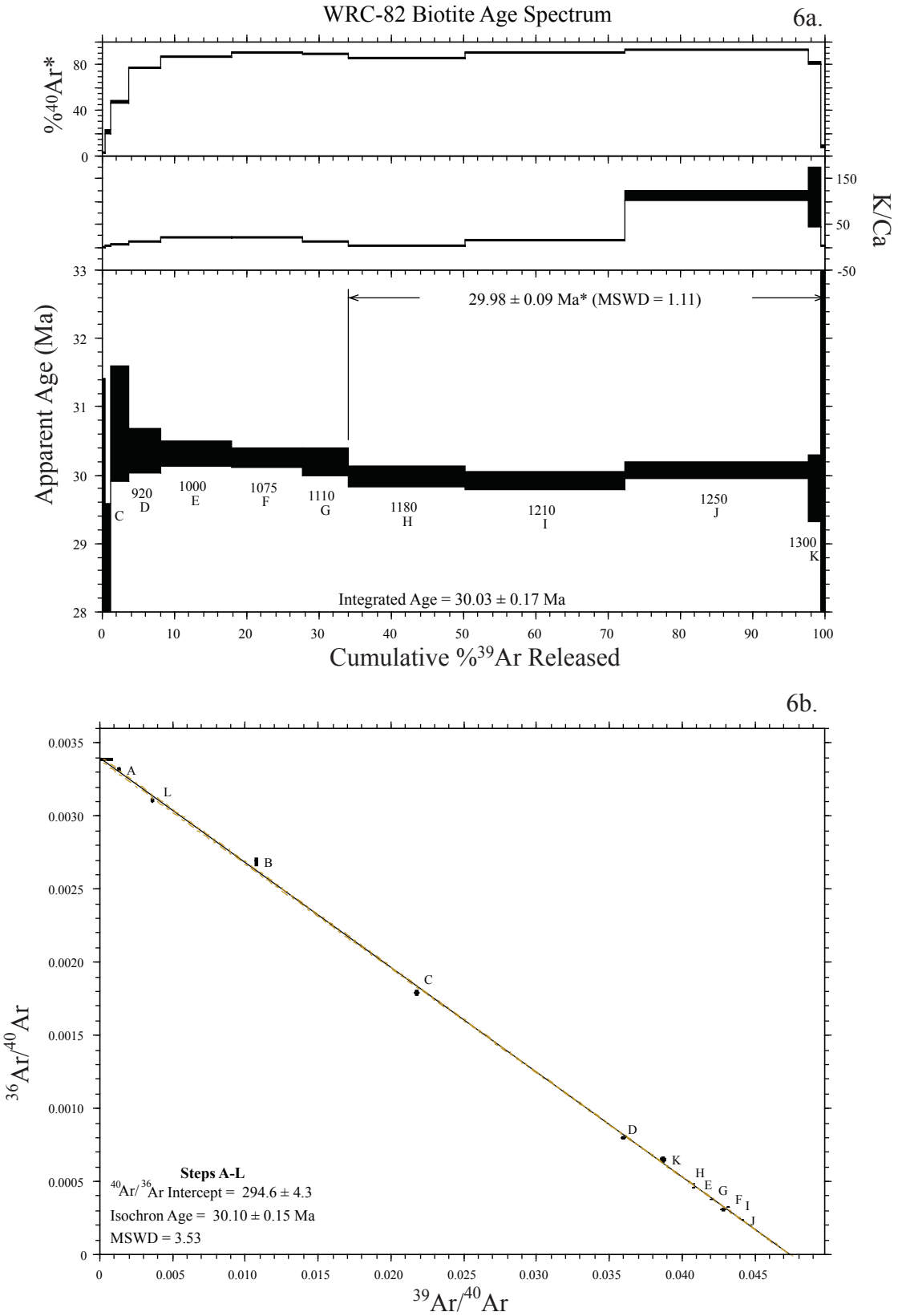


Figure 6. Age spectrum (6a) and isochron (6b) for WRC-82 biotite.

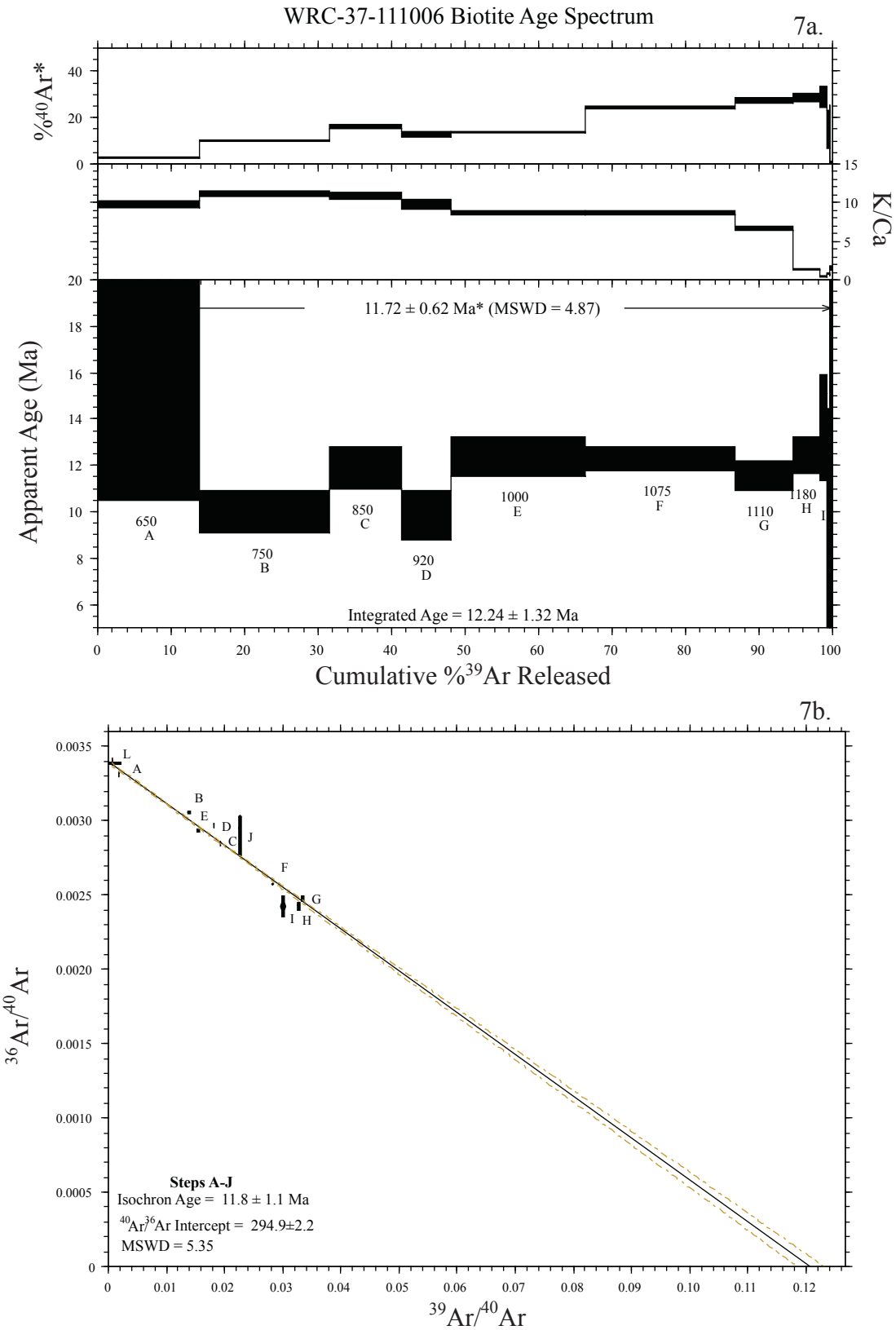


Figure 7. Age spectrum (7a) and isochron (7b) for WRC-37-111006-djk biotite.

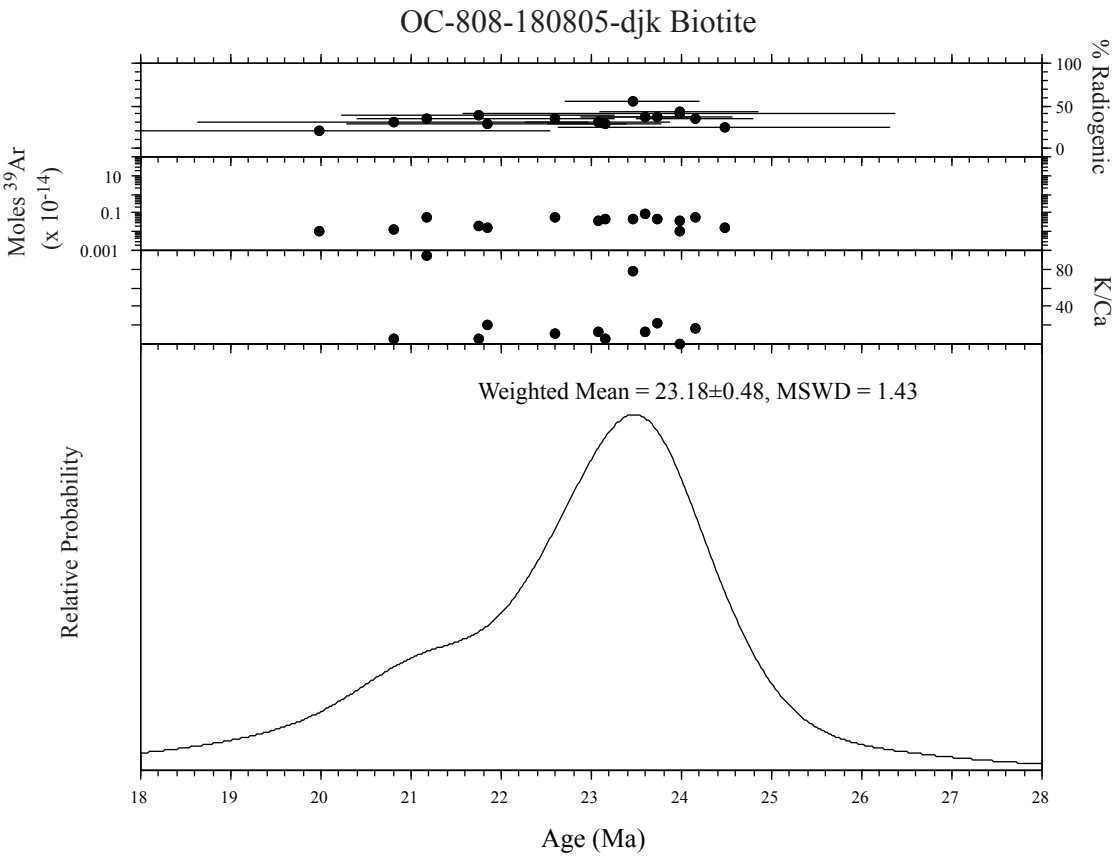


Figure 8. Age probability distribution diagram for OC-808-180805-djk biotite. All errors quoted at 2 Sigma.

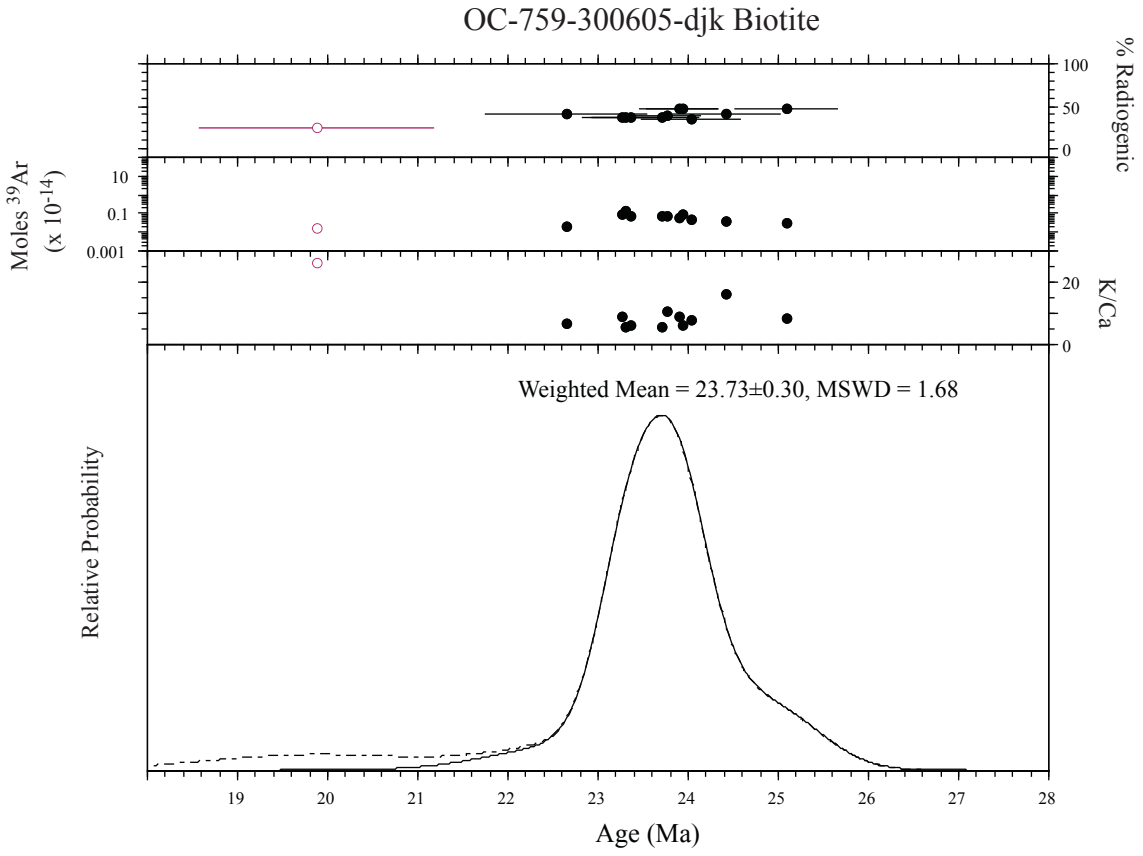


Figure 9. Age probability distribution diagram for OC-759-300605-djk biotite. All errors quoted at 2 Sigma.

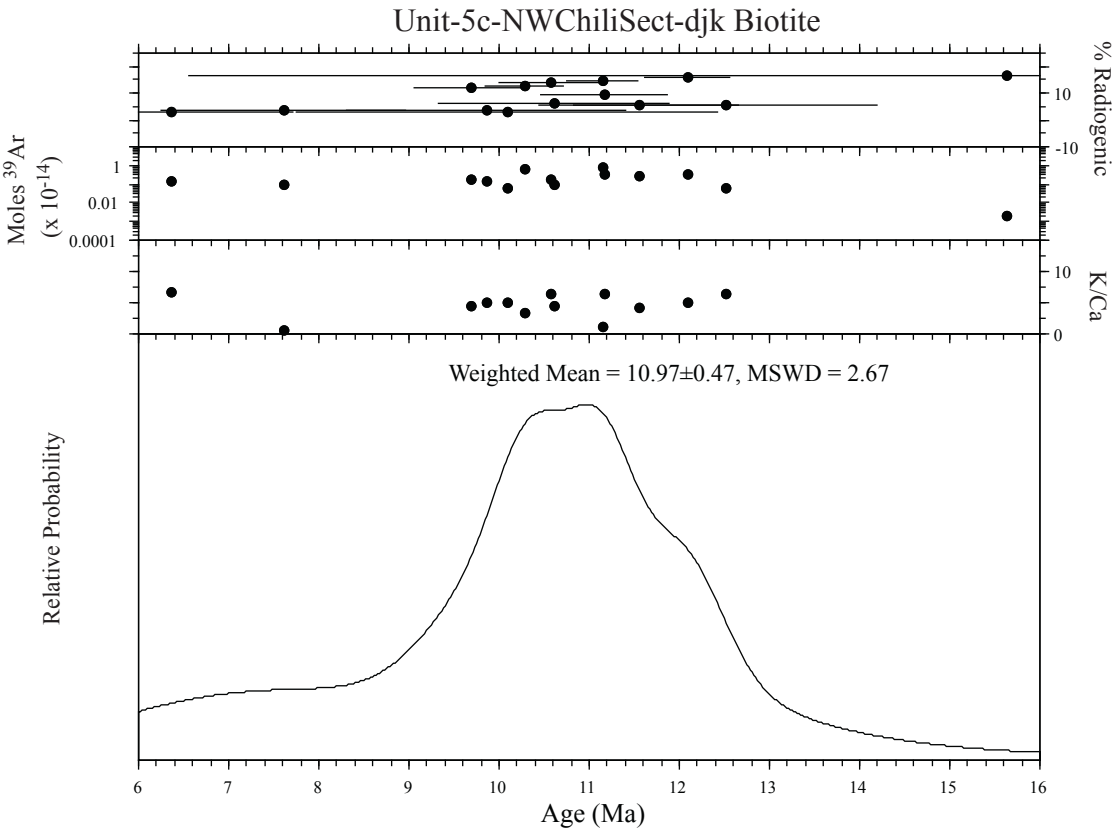


Figure 10. Age probability distribution diagram for Unit-5c-NWChiliSect-djk biotite. All errors quoted at 2 Sigma.

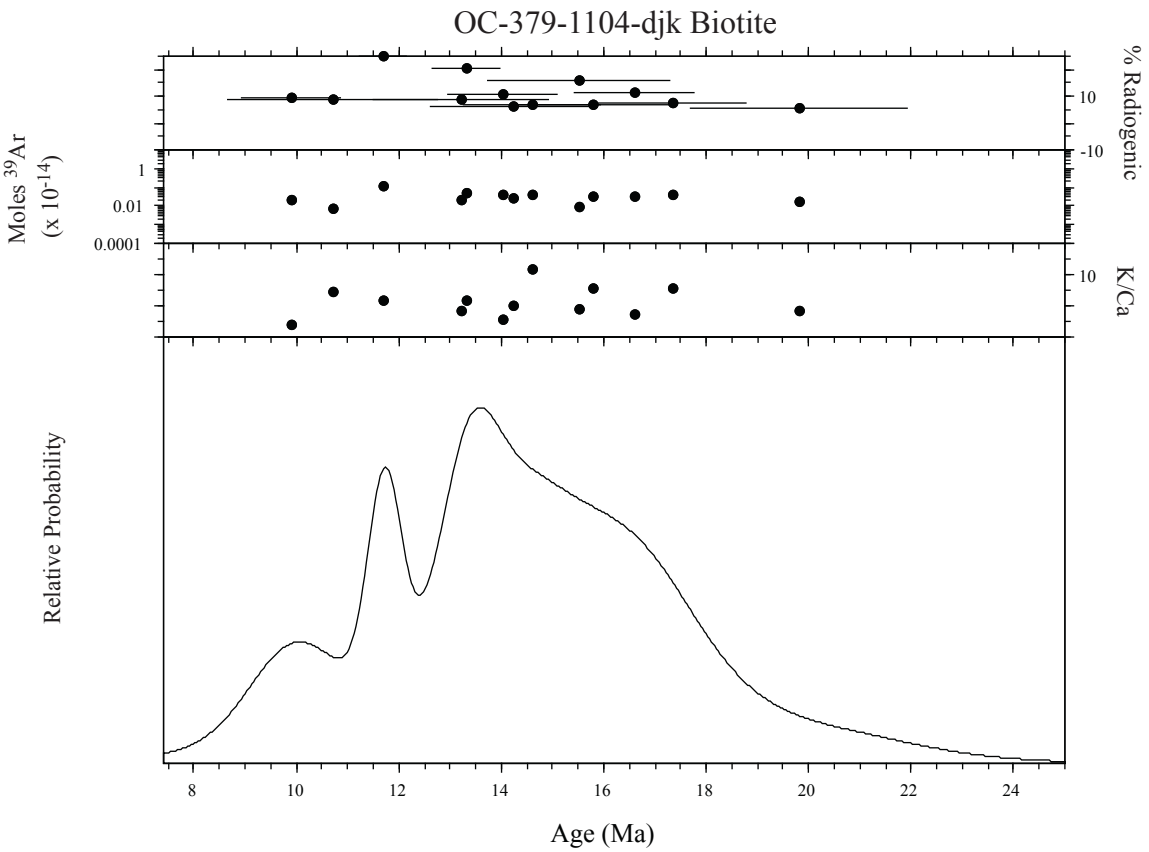
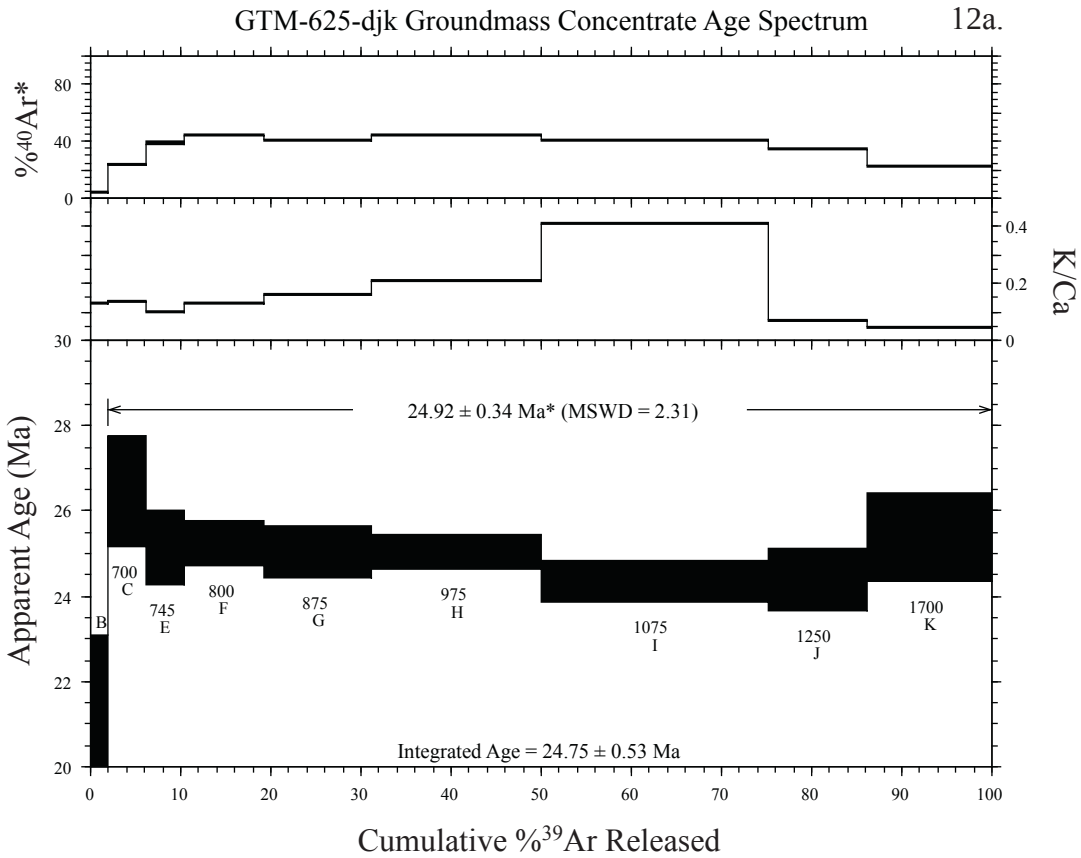


Figure 11. Age probability distribution diagram for Unit-5c-NWChiliSect-djk biotite. All errors quoted at 2 Sigma.



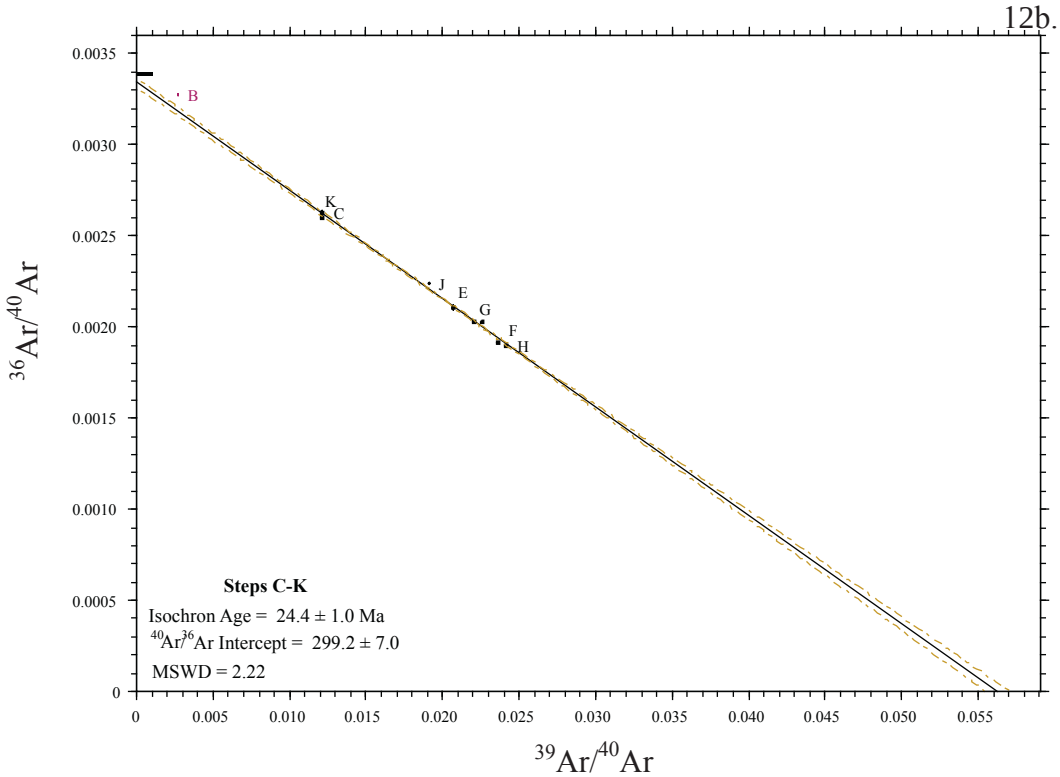
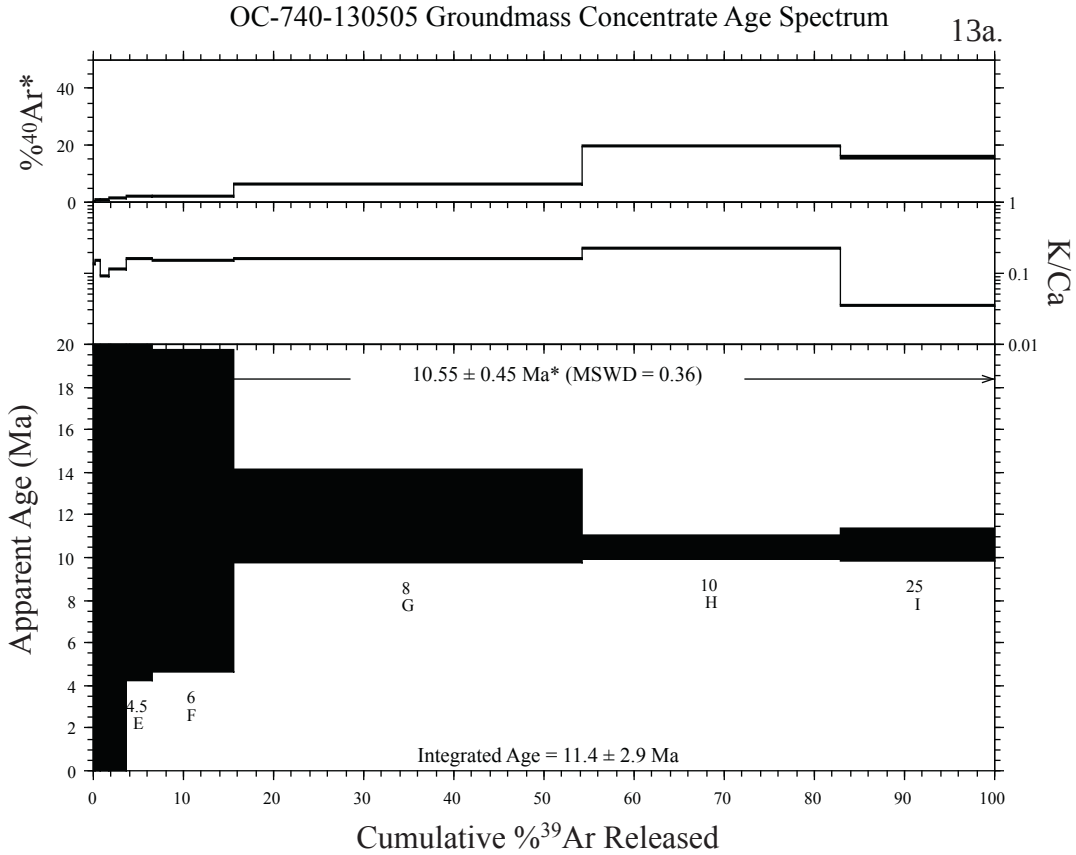


Figure 12. Age spectrum (12a) and isochron (12b) for GTM-625-djk groundmass concentrate.



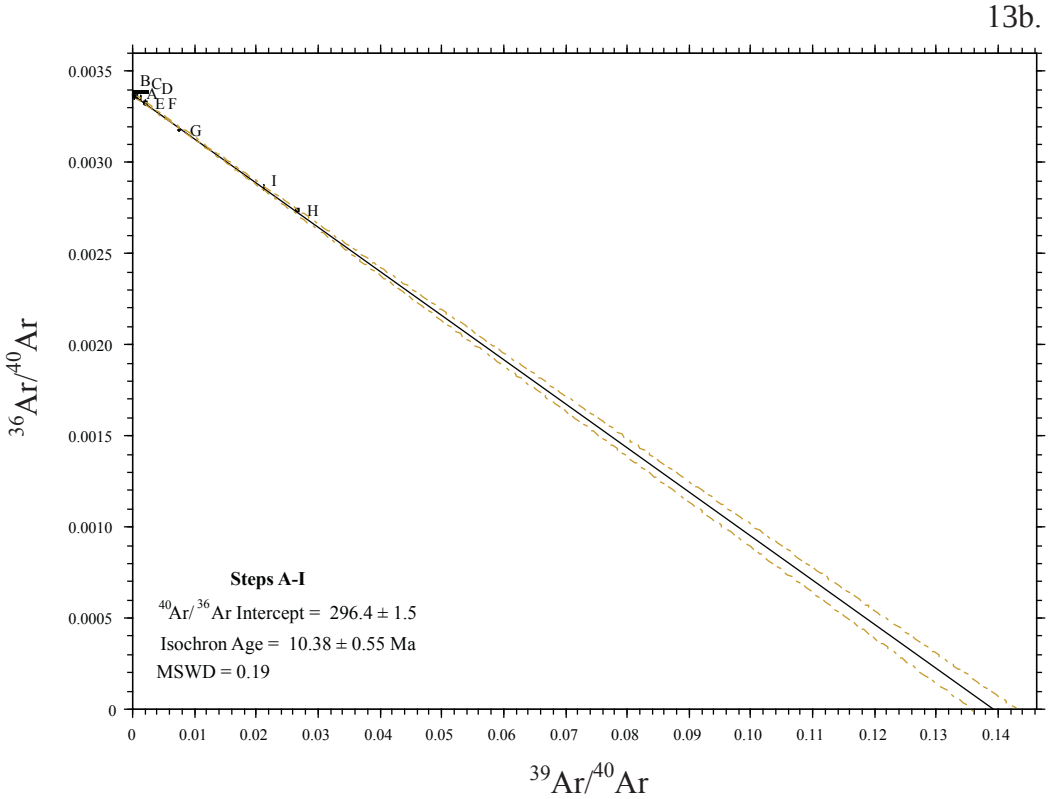


Figure 13. Age spectrum (13a) and isochron (13b) for OC-740-130505 groundmass concentrate.

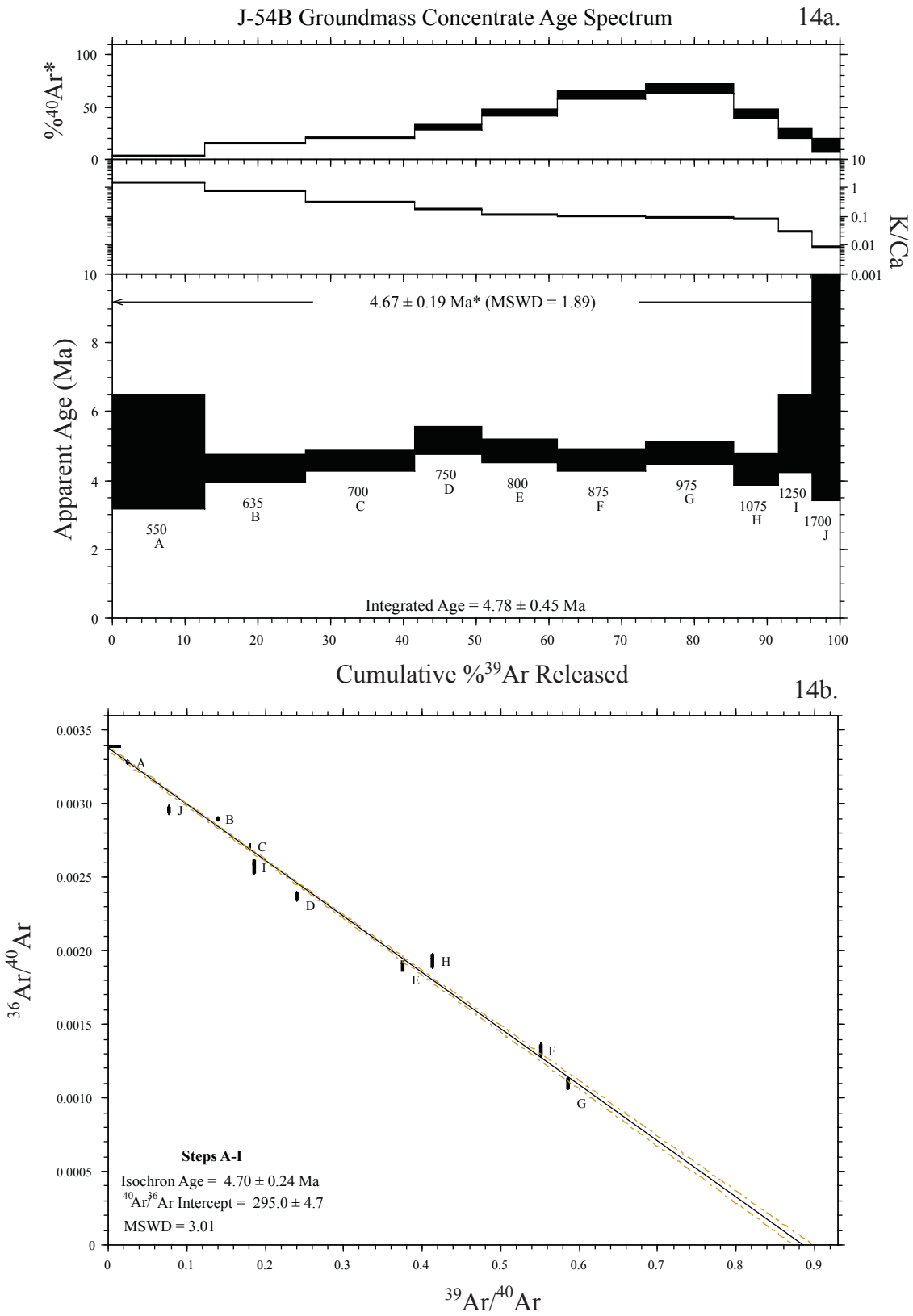
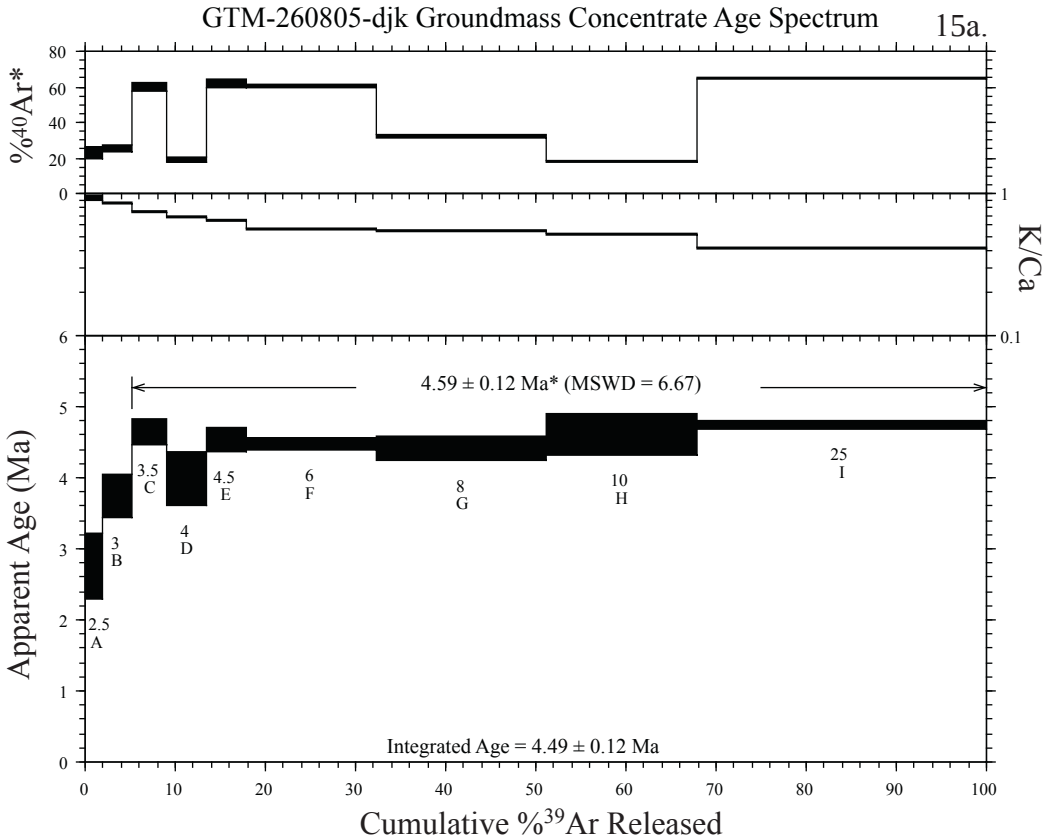


Figure 14. Age spectrum (14a) and isochron (14b) for J-54B groundmass concentrate.



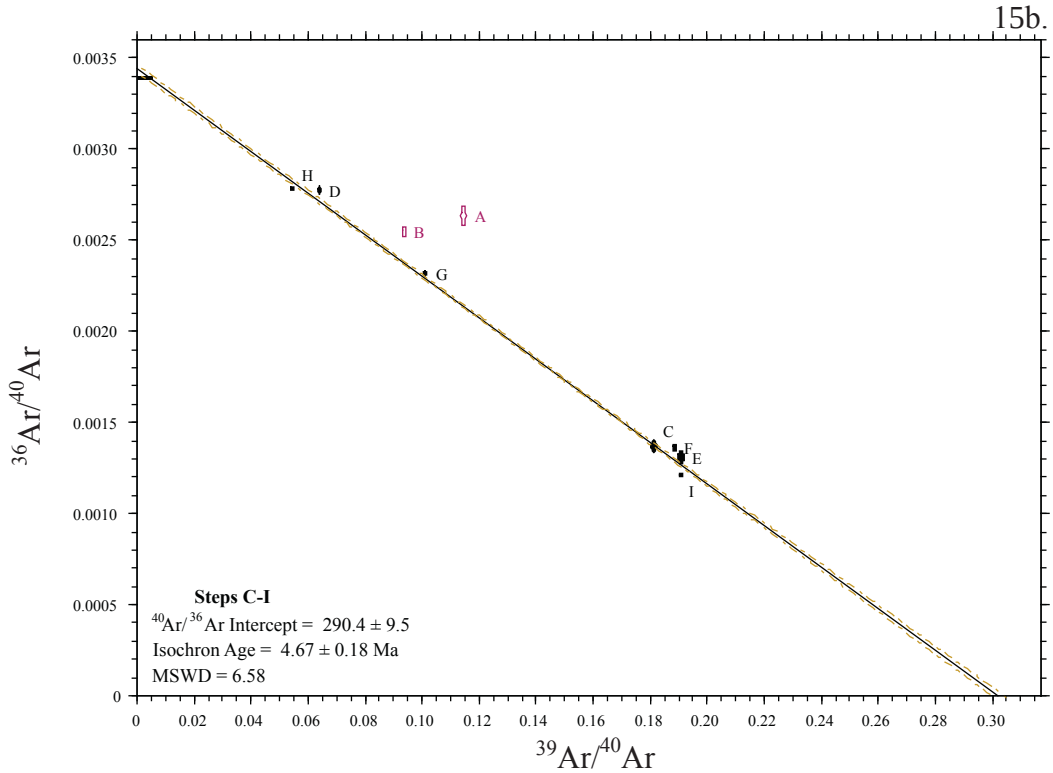
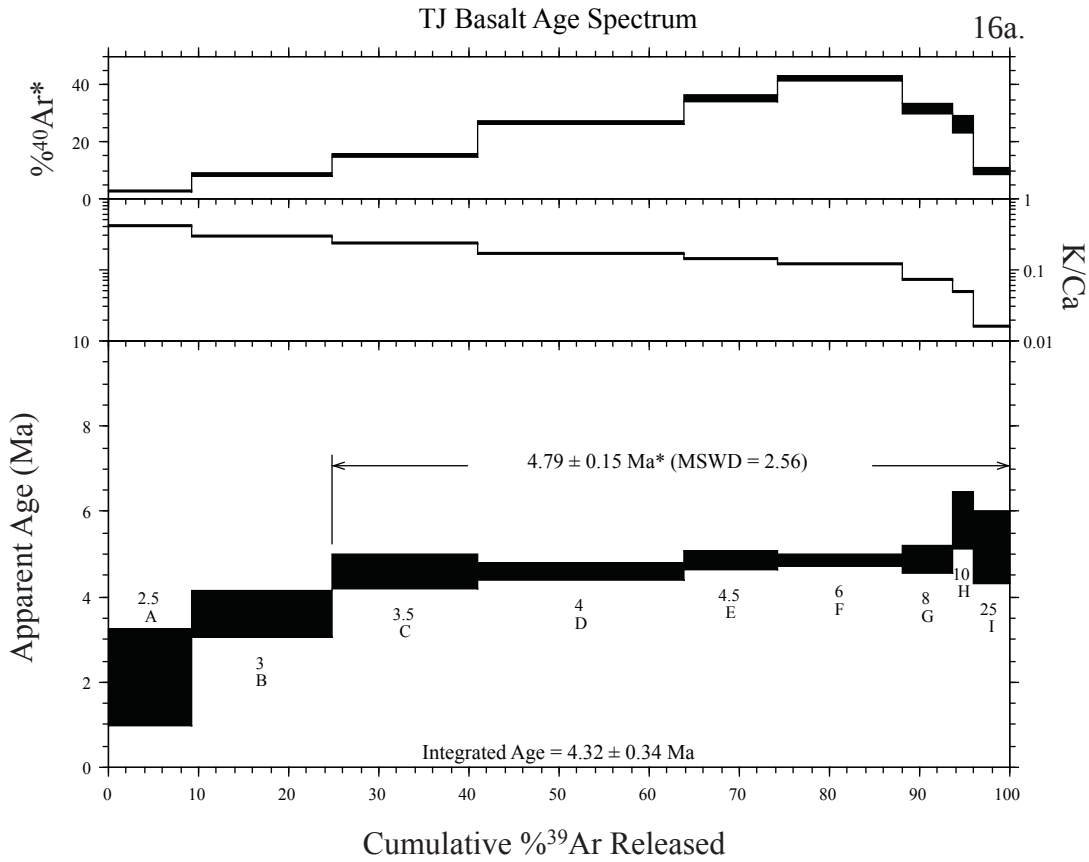


Figure 15. Age spectrum (15a) and isochron (15b) for GTM-260805-djk basalt.



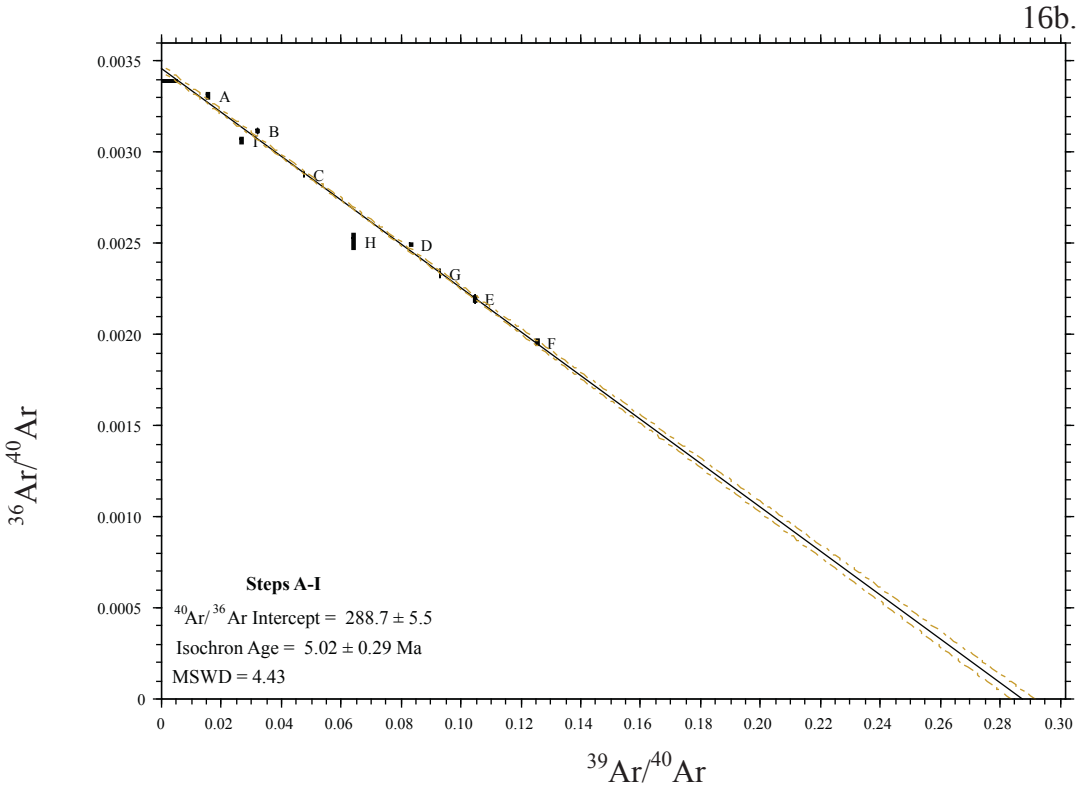
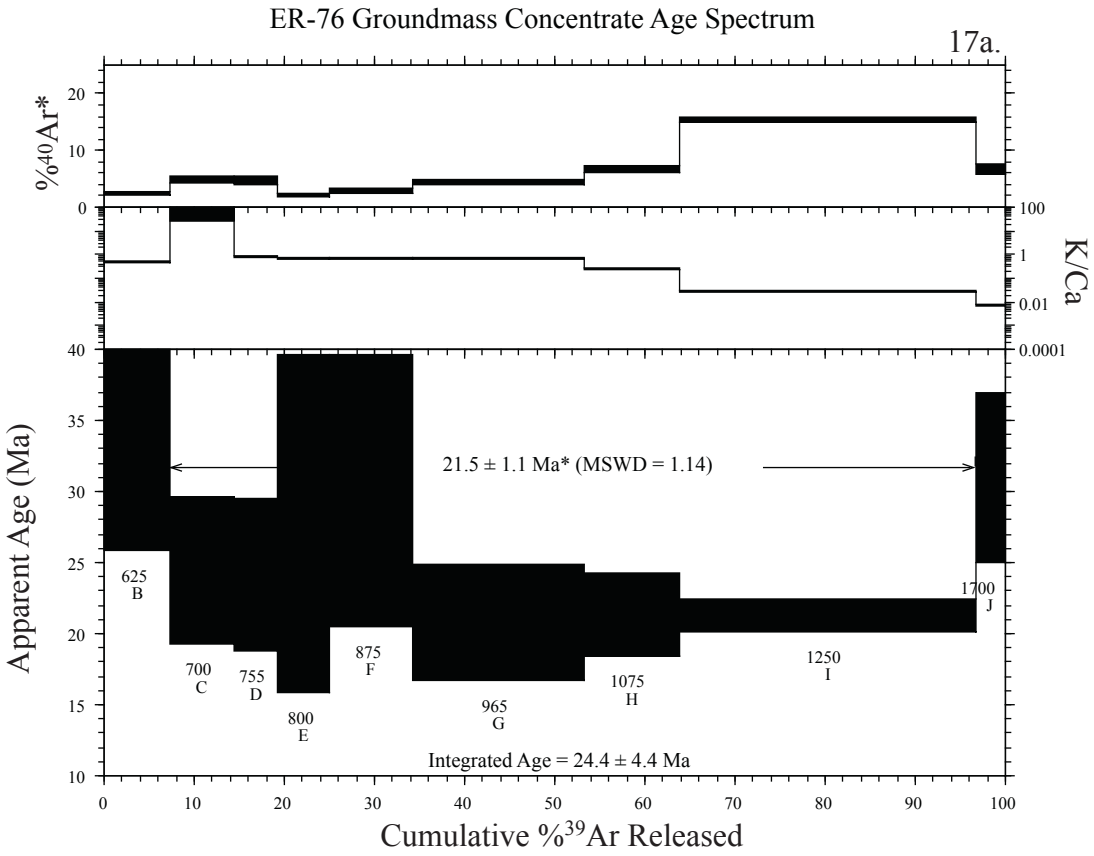


Figure 16. Age spectrum (16a) and isochron (16b) for TJ basalt.



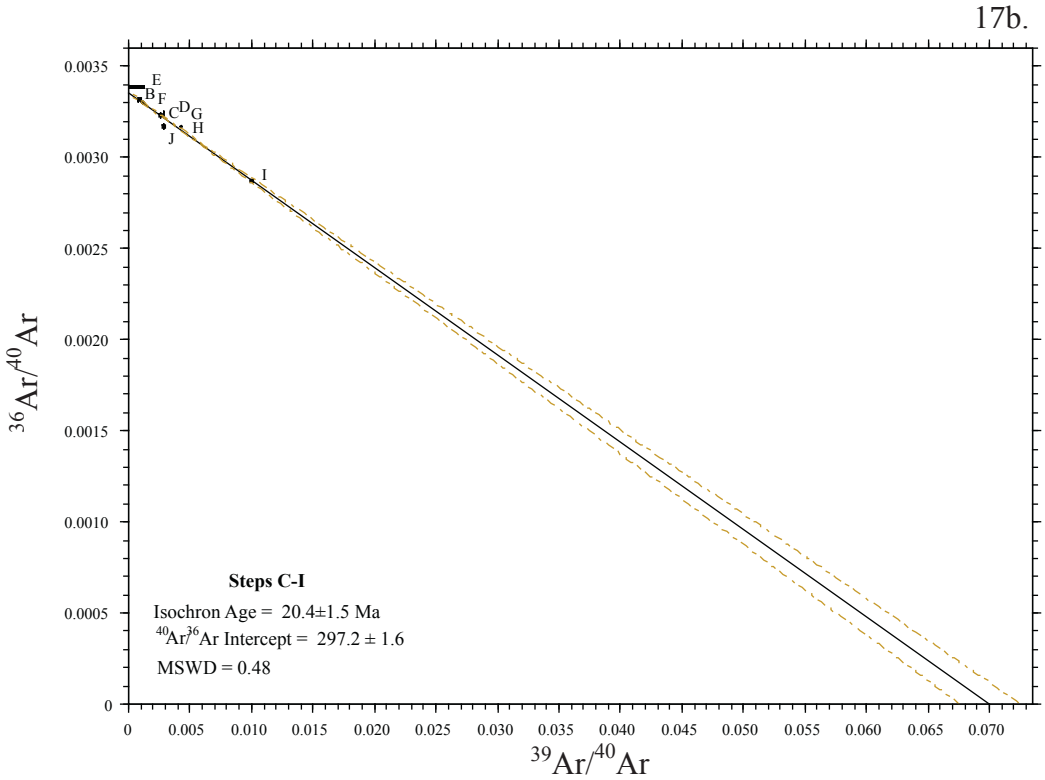
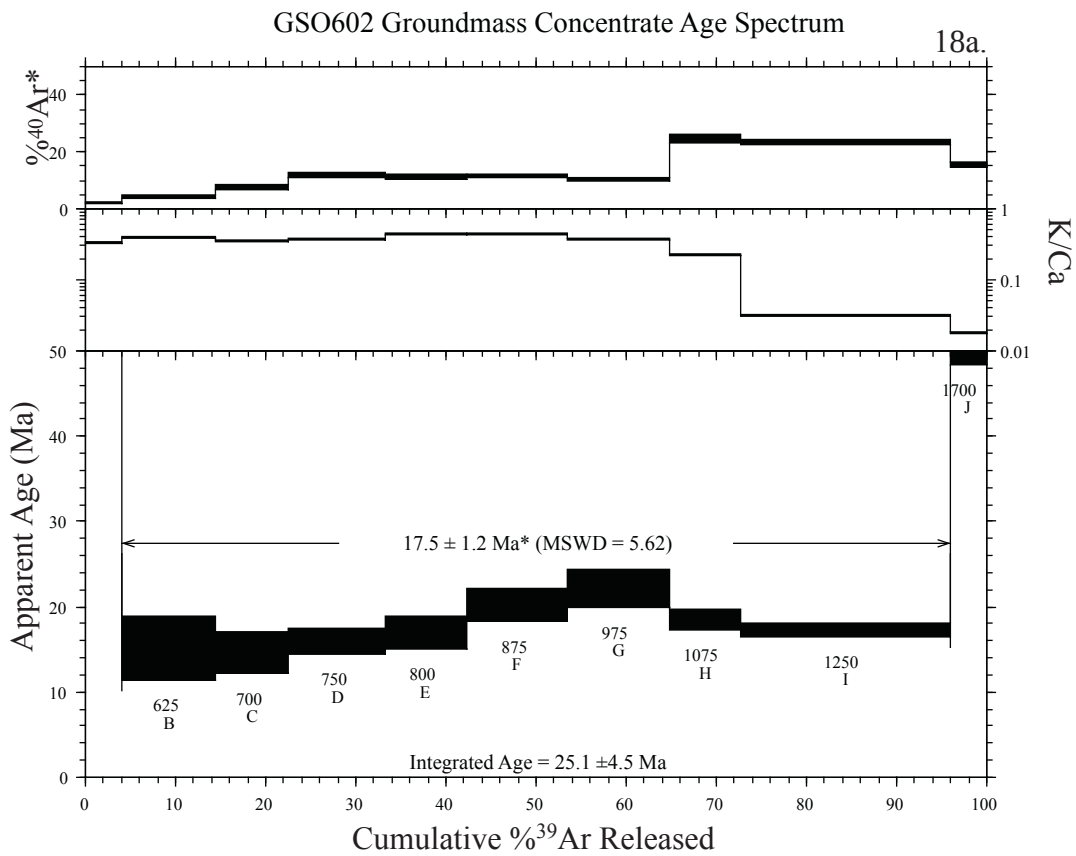


Figure 17. Age spectrum (17a) and isochron (17b) for ER-76 groundmass concentrate.



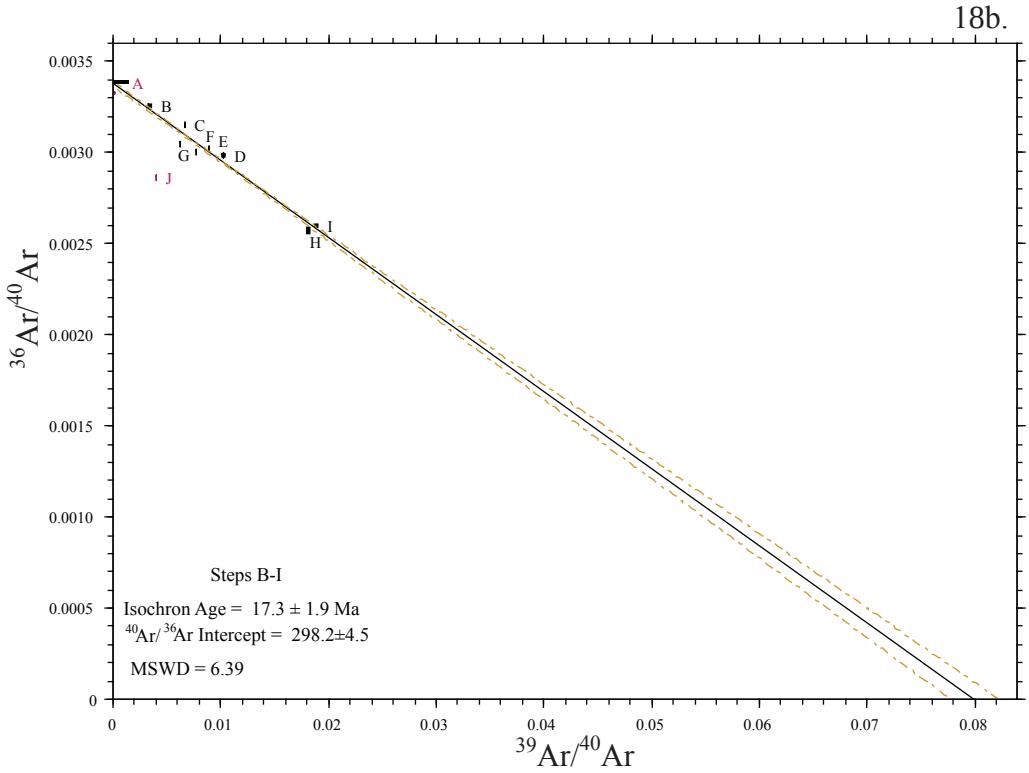


Figure 18. Age spectrum (18a) and isochron (8b) for GSO 602 groundmass concentrate. All errors quoted at 2 sigma.

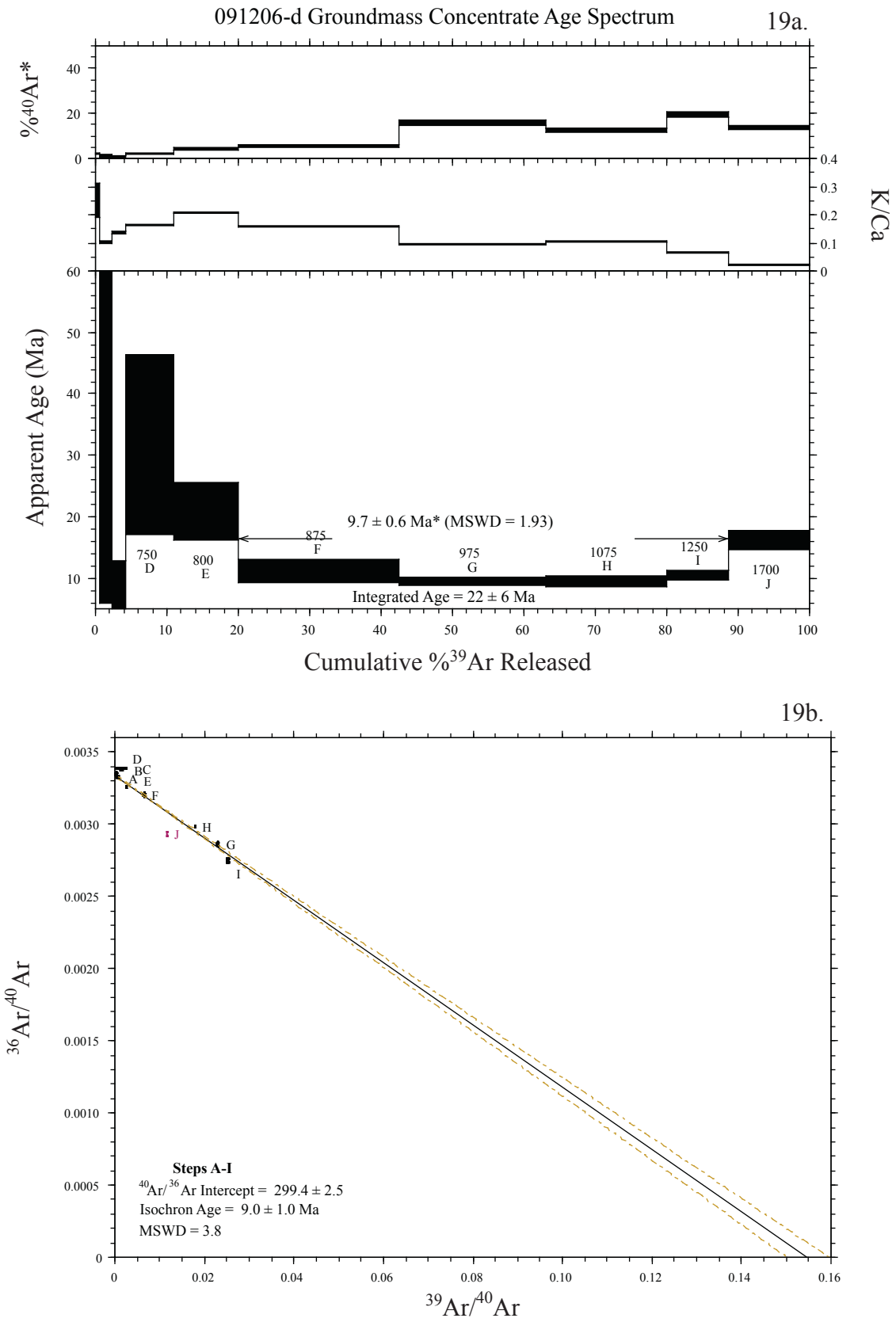


Figure 19. Age spectrum (19a) and isochron (19b) for 091206-d groundmass concentrate.

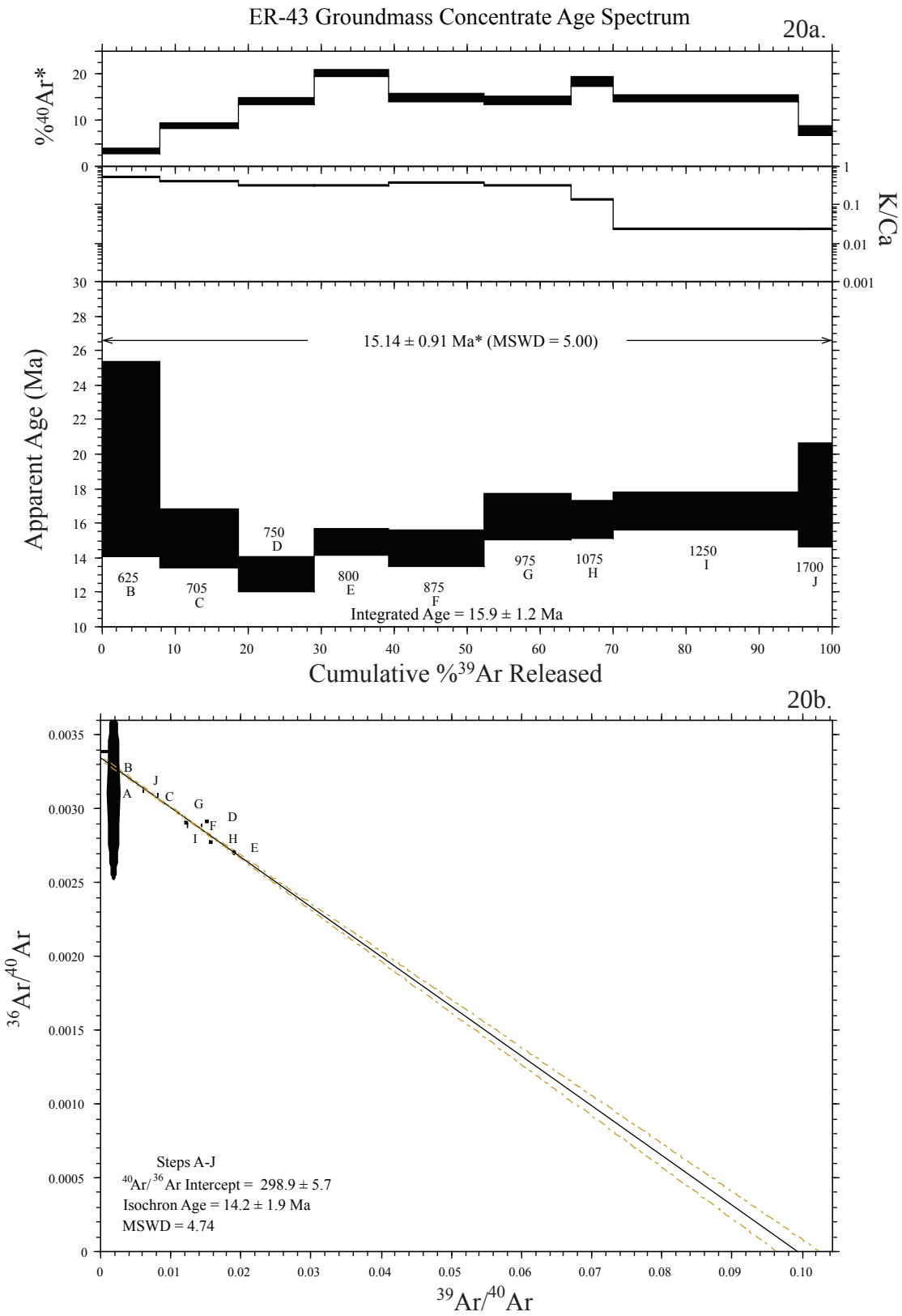
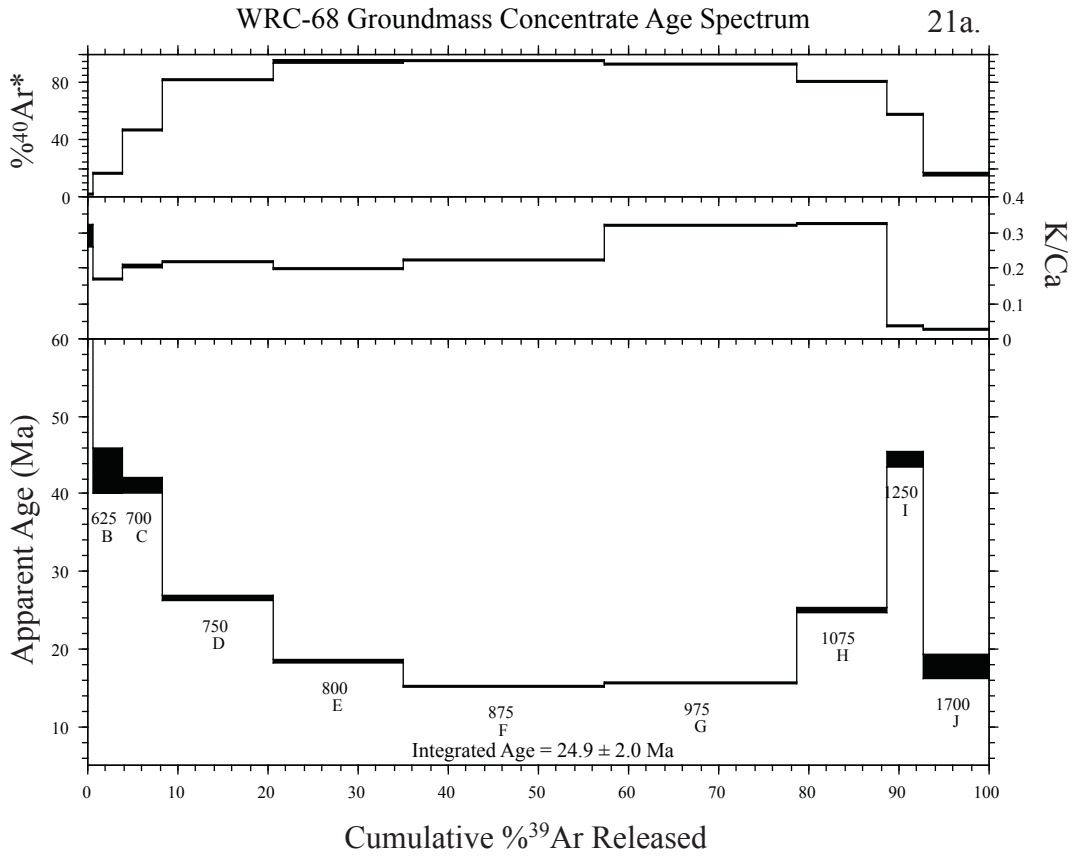


Figure 20. Age spectrum (20a) and isochron (20b) for ER-43-djk groundmass concentrate.



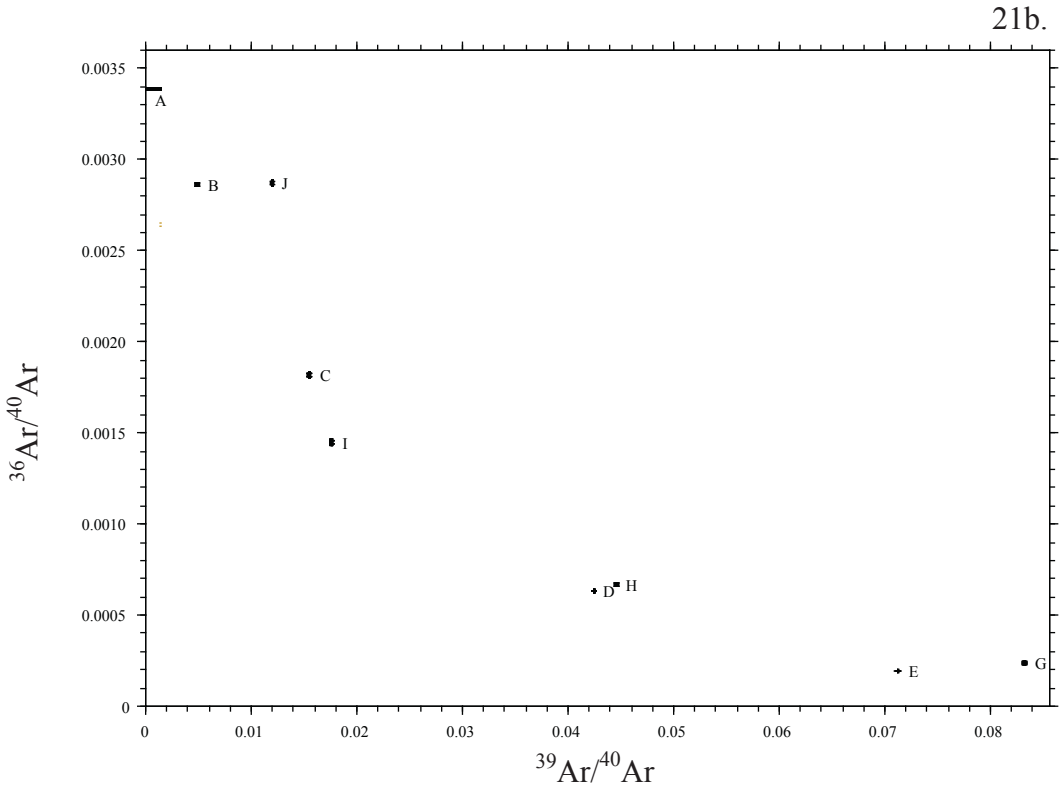


Figure 21. Age spectrum (21a) and isochron (21b) for WRC-68 groundmass concentrate.

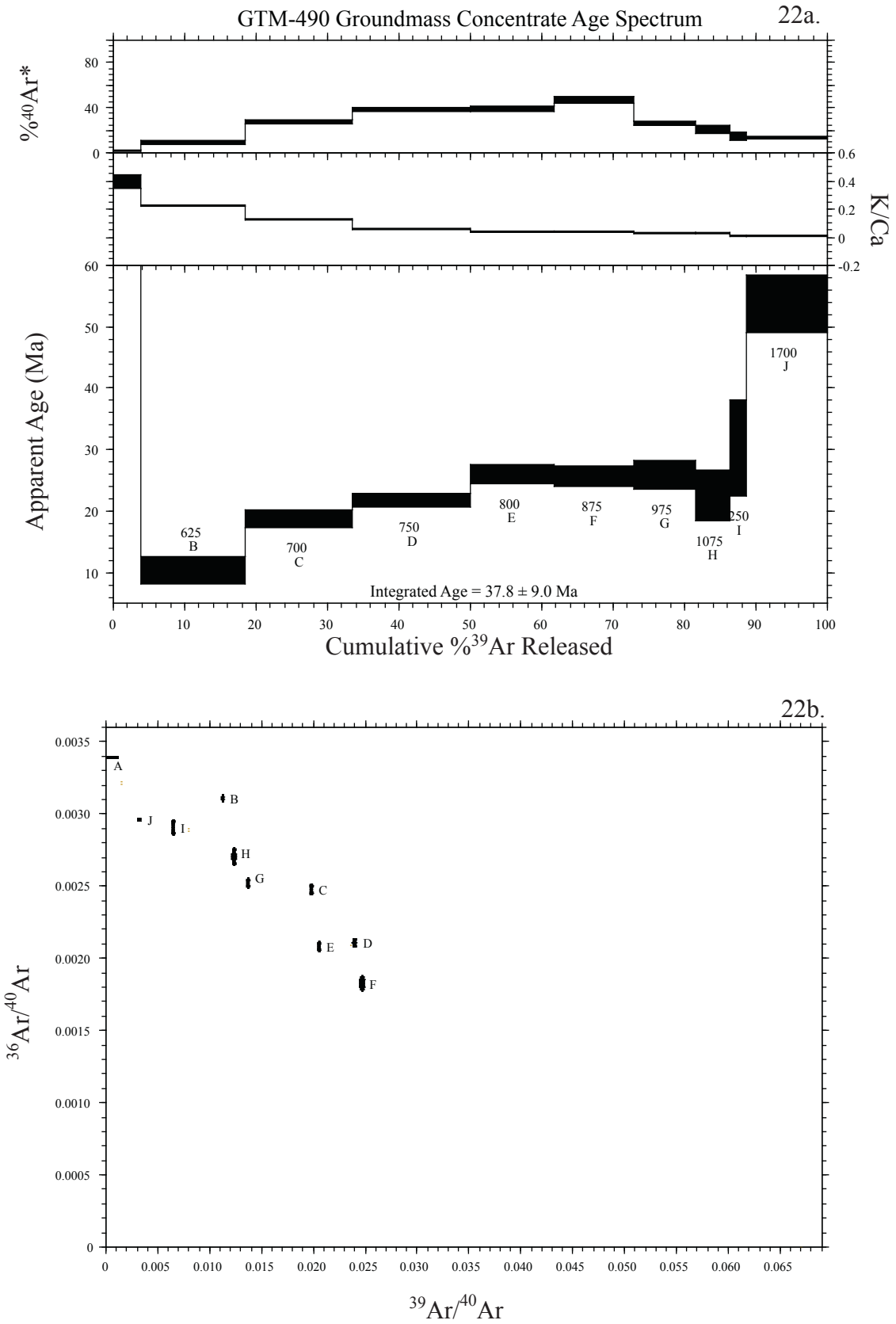


Figure 22. Age spectrum (22a) and isochron (22b) for GTM-490 groundmass concentrate.

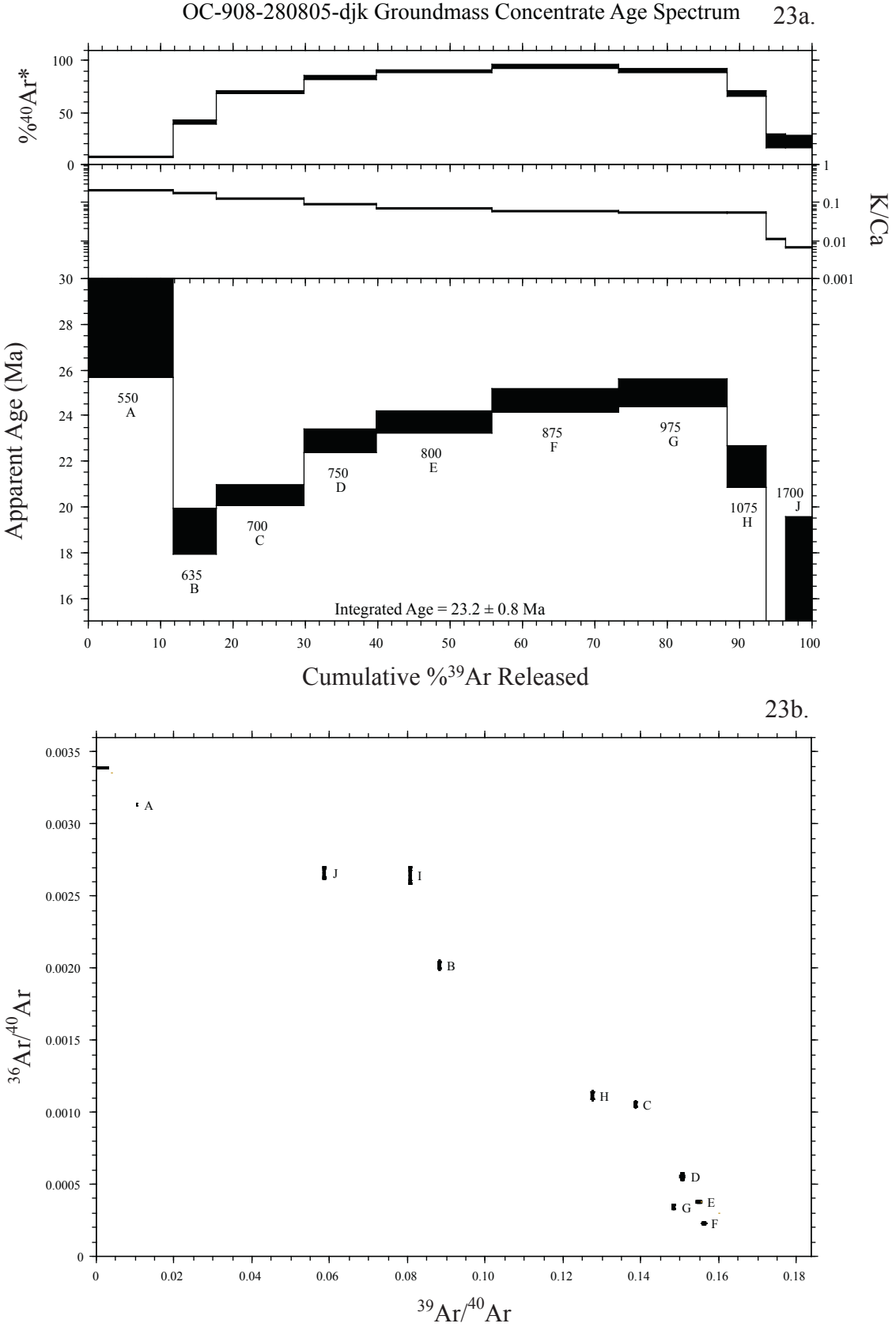


Figure 23. Age spectrum (23a) and isochron (23b) for OC-908-280805-djk groundmass concentrate.

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
Lisa Peters

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

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Internal Report #: NMGRL-IR-633

Introduction

Two tephra samples were submitted by Dan Koning as part of the STATEMAP program. Sanidine was separated from VG-63-250907-djk and Set-26-230807-djk. The age data is summarized below in Table 1.

Table 1. Brief summary of results.

Sample	Phase	Age±2s (Ma)	Comments
VG-63-250907-djk	Sanidine	21.12±0.06 Ma	near gaussian
Set-26-230807-djk	Sanidine	25.52±0.07 Ma	near gaussian

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

Samples were prepared by crushing, sieving and then treating with dilute HF acid. Sanidine was then separated with Franz magnetic separator, heavy liquids and hand-picking. The mineral separates and monitors (Fish Canyon tuff sanidine, 28.02, Renne et al., 1998) were loaded into aluminum discs and irradiated for 7 hours at the USGS TRIGA, Denver, Colorado.

The monitors and samples were analyzed by the single crystal laser fusion method. Abbreviated analytical methods for the dated samples are given in Tables 1 and 2, complete data in Table 3 and details of the overall operation of the New Mexico Geochronology Research Laboratory is provided in the Appendix.

The sanidine from both samples yield near Gaussian populations (Figures 1 and 2). All fifteen analyzed crystals were used to calculate the weighted mean age of 21.12±0.06 Ma for VG-63-250907-djk. Three plagioclase crystals were eliminated from the data set before a weighted mean age of 25.52±0.07 Ma was calculated Set-26-230807-djk using all the sanidine crystals.

Discussion

We assign the weighted mean ages calculated for samples VG-63-250907-djk and SET-26-230807-djk (21.120.06 MA and 25.52±0.07 Ma) as our preferred ages for these samples and the eruption ages of the units from which they were sampled.

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

Sample	Lab #	Irradiation	mineral	age analysis	crystals	Age	±2σ	MSWD
VG-63-250907-djk	59157	226	sanidine	laser total fusion	15	21.12	0.06	2.97
Set-26-230807-djk	59156	226	sanidine	laser total fusion	12	25.52	0.07	4.04

Sample preparation and irradiation:
Minerals separated with standard heavy liquid, Franz Magnetic and hand-picking techniques.
Samples in NM-226 irradiated in a machined Aluminum tray for 7 hours in C.T. position, USGS TRIGA, Denver, Colorado.
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.
Flux monitors and sanidine fused by a 50 watt Synrad CO_2 laser.

Analytical parameters:
Electron multiplier sensitivity averaged 4.70e-17 moles/pA for laser analyses.
Total system blank and background averaged 383, 1.5 0.69, 4.1, 8.4 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 5 single crystals from each of 6 radial positions around the irradiation tray.
Decay constants and isotopic abundances after Steiger and Jäger (1977).

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)
Set-26-230807-djk, Sanidine, J=0.0015776±0.06%, D=1.005±0.001, NM-226E, Lab#=59156								
11A	9.233	0.0200	1.092	5.284	25.5	96.5	25.16	0.10
08A	9.417	0.0136	1.532	7.563	37.5	95.2	25.31	0.07
09A	9.164	0.0165	0.5403	6.310	31.0	98.3	25.42	0.06
07A	9.110	0.0137	0.3501	13.692	37.3	98.9	25.43	0.05
05A	9.150	0.0115	0.4129	12.331	44.5	98.7	25.49	0.05
06A	9.344	0.0113	1.046	6.095	45.2	96.7	25.51	0.08
02A	9.175	0.0126	0.4586	12.487	40.6	98.5	25.52	0.05
13A	9.925	0.0164	2.984	19.225	31.1	91.1	25.53	0.06
01A	9.100	0.0155	0.1301	16.094	32.8	99.6	25.58	0.05
15A	9.122	0.0131	0.1775	10.144	39.1	99.4	25.61	0.05
04A	9.171	0.0091	0.3112	14.727	56.2	99.0	25.63	0.05
03A	9.148	0.0128	0.2079	16.247	39.8	99.3	25.65	0.05
Mean age ± 2σ	n=12	MSWD=4.04			38.4 ±16.2		25.52	0.07
VG-63-250907-djk, Sanidine, J=0.001577±0.06%, D=1.005±0.001, NM-226E, Lab#=59157								
01A	9.496	0.0089	7.089	7.846	57.4	77.9	20.91	0.09
16A	7.664	0.0088	0.7811	14.164	57.8	97.0	21.00	0.05
06A	10.91	0.0221	11.73	9.272	23.0	68.2	21.03	0.11
11A	7.522	0.0076	0.2556	12.525	67.4	99.0	21.04	0.05
09A	7.851	0.0107	1.351	7.355	47.6	94.9	21.05	0.07
04A	7.625	0.0094	0.5547	9.955	54.2	97.9	21.08	0.05
05A	7.608	0.0073	0.4749	5.777	69.6	98.2	21.10	0.07
12A	7.676	0.0080	0.7008	12.223	63.8	97.3	21.10	0.05
14A	7.643	0.0132	0.5718	13.374	38.8	97.8	21.12	0.05
10A	7.672	0.0103	0.6392	14.916	49.5	97.5	21.14	0.05
13A	7.639	0.0095	0.4949	9.268	53.9	98.1	21.17	0.06
08A	7.728	0.0073	0.7728	4.628	69.8	97.0	21.18	0.08
02A	7.938	0.0256	1.485	4.912	19.9	94.5	21.19	0.09
03A	7.612	0.0094	0.2850	10.378	54.5	98.9	21.27	0.05
15A	7.790	0.0085	0.7926	9.252	60.0	97.0	21.34	0.06
Mean age ± 2σ	n=15	MSWD=2.97			52.5 ±30.3		21.12	0.06

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).
X 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:

$(^{39}Ar/^{37}Ar)_{Ca}$ = 0.0007 ± 5e-05
$(^{36}Ar/^{37}Ar)_{Ca}$ = 0.00028 ± 2e-05
$(^{38}Ar/^{39}Ar)_K$ = 0.013
$(^{40}Ar/^{39}Ar)_K$ = 0.01 ± 0.002

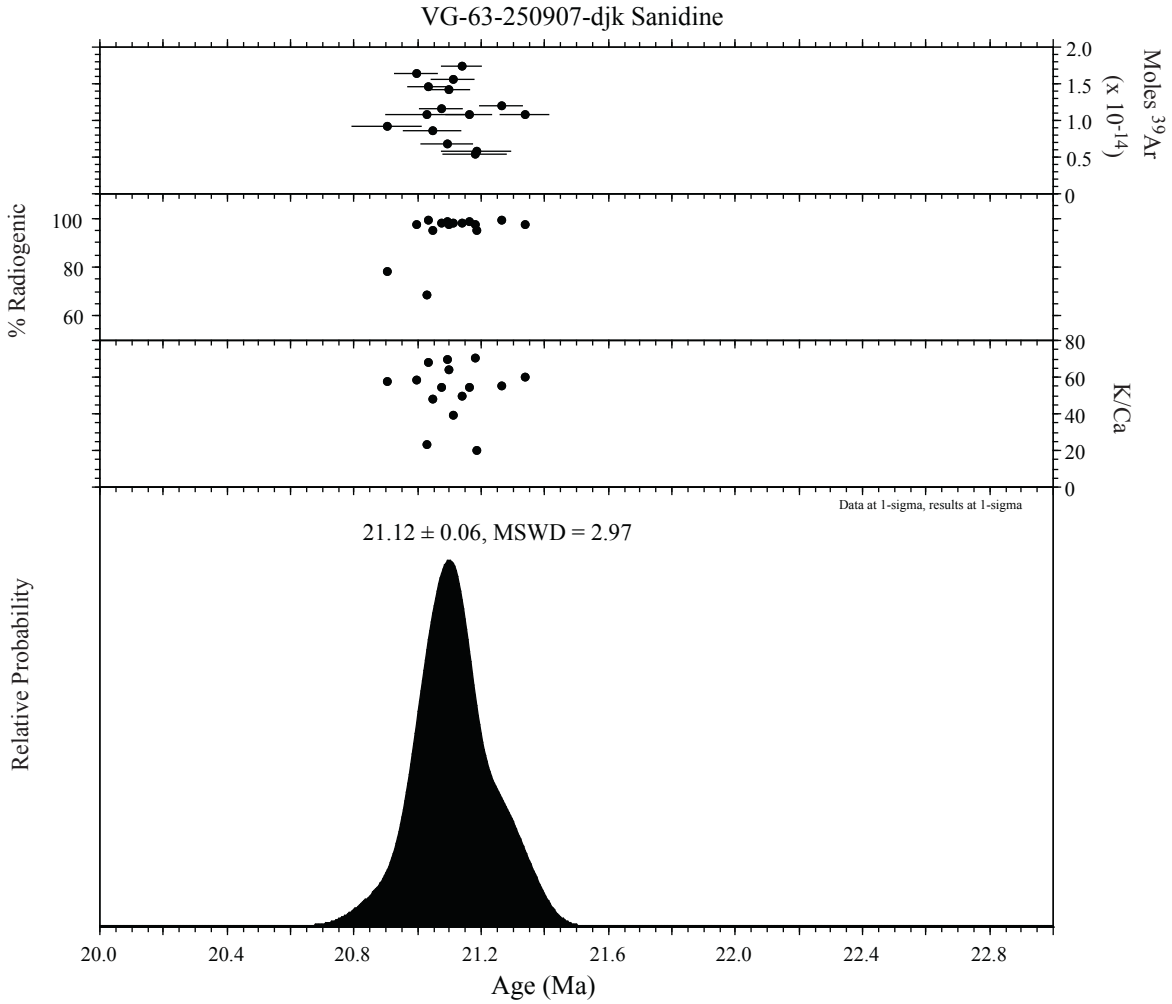

Figure 1. Age probability distribution diagram for VG-63-250907-djk sanidine. All errors quoted at 2 Sigma.

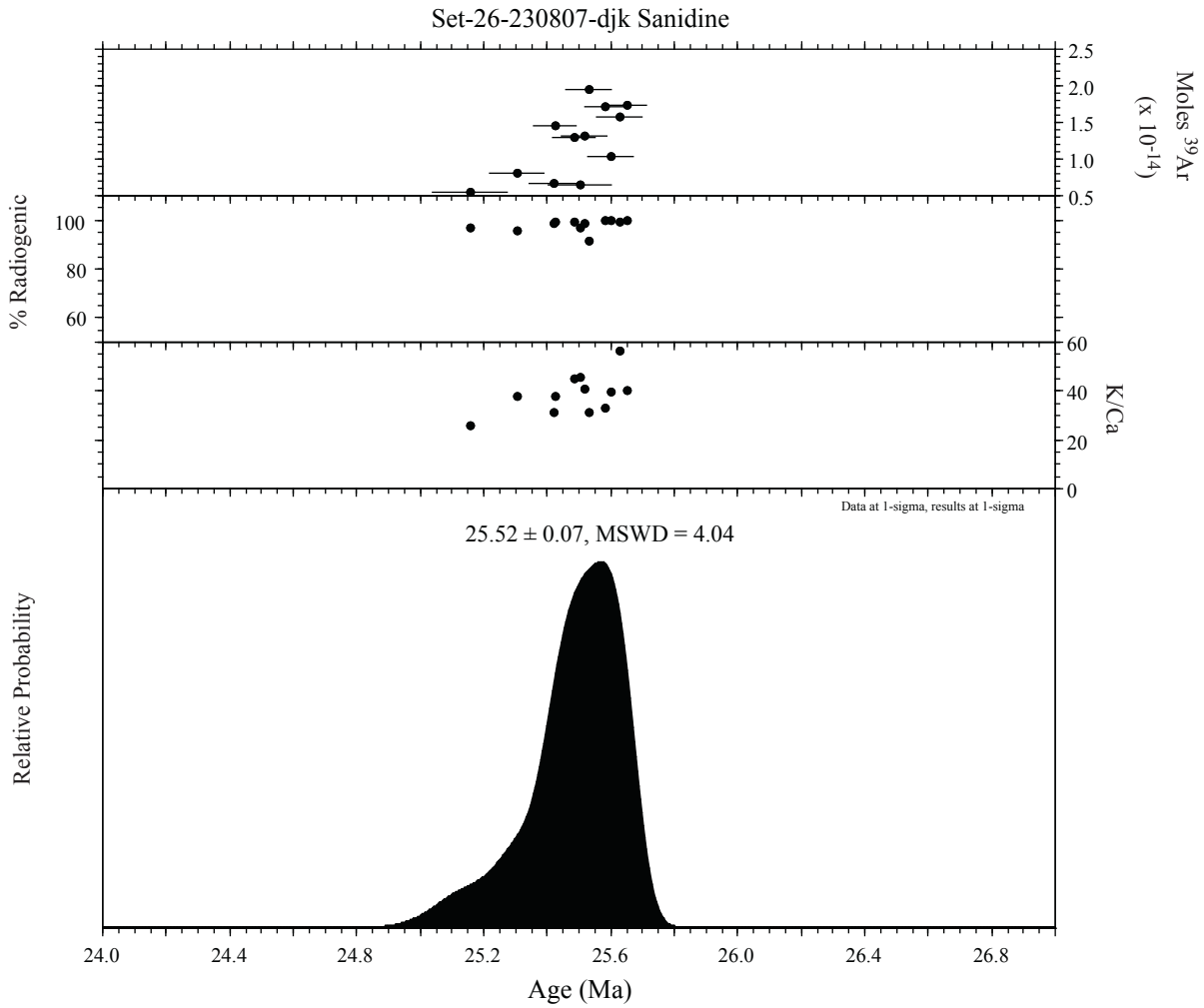

Figure 2. Age probability distribution diagram for Set-26-230807-djk sanidine. All errors quoted at 2 Sigma.

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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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