Open File Report OF-AR-25

New Mexico Bureau of Geology and Mineral Resources
A division of
New Mexico Institute of Mining and Technology

$^{40}Ar/^{39}Ar$ Geochronology results from volcanic rocks from Grand Falls, Arizona

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Initially prepared as:

NM Geochronology Research Laboratory Internal Report

NMGRL-IR 227

Junw 15, 2002

SOCORRO 2005

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Introduction

Five volcanic rocks from the Grand Falls basalt flow were submitted for $^{40}Ar/^{39}Ar$ dating by Dr. Wendell Duffield. One sample of the Grand Falls basalt (GF-1) was previously dated by the $^{40}Ar/^{39}Ar$ technique, yielding an apparent age of 0.10±0.60 Ma (±2□). GF-1 and three other GF samples (2, 3 and 4) were re-submitted in an attempt to achieve a more precise age for the Grand Falls basalt flow. Groundmass concentrate was prepared from the four GF samples and an additional basalt flow, OLD-1, from the Grand Falls area.

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

The groundmass concentrate samples were analyzed by the furnace incremental heating age spectrum $^{40}Ar/^{39}Ar$ method. Abbreviated analytical methods for the furnace sample is given in Table 1. The analytical data for the five groundmass concentrates is given in Table 2. Figures 1-5 show the age spectrum and inverse isochron yielded by each of the groundmass concentrates. A summary plot of the ages yielded in this study is shown in Figure 6. Details of the overall operation of the New Mexico Geochronology Research Laboratory are provided in the Appendix.

Groundmass concentrate samples OLD-1, GF-1 and GF-2 each yield flat, well-behaved age spectra. The OLD-1 sample yields a flat age spectrum (Figure 1) for nearly 100% of the $^{39}Ar_K$ released. The radiogenic yields range from 0.5 to 11.2%. The K/Ca ratios from 0.03 to 0.47 but are highest for the intermediate temperature steps (875° & 975°C). A weighted mean or "plateau" assigned to the flattest portion of the age spectrum (steps B though H) yields an apparent age of 0.175±0.036 Ma with 92.7% of the cumulative $^{39}Ar_K$ released and a high (unacceptable) MSWD of 3.2. The high MSWD (denoted by a double asterisk (**) in Table 2) indicates that the data contains more uncertainties than can be solely attributed to analytical error. The inverse isochron for OLD-1 yields an apparent age (0.15±0.04 Ma) analytically indistinguishable from the plateau weighted mean age, a $^{40}Ar/^{36}Ar$ intercept of 300±3 and an unacceptable MSWD of 2.3.

The GF-1 age spectrum (Figure 2) is flat for ~90% of the $^{39}Ar_K$ released, but then increases in age for the two highest temperature steps. The radiogenic yields for GF-1 range from essentially zero to 9.3%, but generally remain below 4% for the majority of the spectrum. The K/Ca ratios are inversely proportional to the radiogenic yields, ranging from 0.42 at the lowest temperatures to less than 0.02 for the two highest temperature steps. Nearly 90% of the age spectrum (steps A through G) yields a weighted mean age of 0.011±0.030 Ma (MSWD=3.0). The inverse isochron for GF-1 yields an apparent age of –0.052±0.016 Ma (note the negative sign) and a $^{40}Ar/^{36}Ar$ intercept of 308±4 (MSWD=2.3).

The age spectrum for GF-2 (Figure 3) is similar to that yielded by the GF-1 groundmass concentrate. Radiogenic yields for GF-2 range from 0.4 to 10.5%, with the highest yield coming from

the fusion (1700°C) step. Like GF-1, the K/Ca ratios are inversely proportional to radiogenic yield and age, ranging from 0.30 (step A) to 0.02 (step I). Only the fusion step was excluded from the weighted mean age (-0.002±0.030 Ma), which incorporated 97.1% of the $^{39}Ar_K$ released (MSWD=4.0). The inverse isochron yielded a more negative apparent age (-0.013±0.018 Ma), a $^{40}Ar/^{36}Ar$ intercept of 298±4 and a MSWD of 4.4.

By comparison, the age spectra for GF-3 and GF-4 are more disturbed than those yielded by OLD-1, GF-1 or GF-2. The spectrum for GF-3 (Figure 4) is somewhat flat for approximately 60% of the argon released, but then ages increase steadily to the fusion step. Radiogenic yields for GF-3 are variable, ranging from essentially zero to 6.2 (fusion step). The K/Ca ratio pattern is similar to those of the previous three samples, where values are high (~0.40) for the initial temperature steps, but then steadily decrease to less than 0.04 for the highest temperature steps. The flattest portion of the age spectrum yields a weighted mean age of 0.054±0.075 Ma (55.5% of the $^{39}Ar_K$; MSWD=1.5). The inverse isochron yields an apparent age of –0.04±0.08 Ma, a $^{40}Ar/^{36}Ar$ intercept of 301±3 and a MSWD of 2.2.

The GF-4 groundmass concentrate yields the most disturbed and therefore, most imprecise age spectrum of all of the GF samples. The spectrum shape of GF-4 is not significantly dissimilar to those of GF-1, 2 or 3, but the individual steps are more scattered about the mean (0.016 Ma). The radiogenic yields range from zero to 16.2%, and are again highest for the fusion step. The K/Ca ratios are inversely proportional to age, ranging from 0.54 to 0.02. The steps greater than 300,000 years old were excluded from the weighted mean age (steps A through E; 0.016±0.117 Ma; 82.9% of the $^{39}Ar_K$ released; MSWD=5.2). The inverse isochron yields an unattainable age of –0.11±0.08 Ma. The $^{40}Ar/^{36}Ar$ intercept on the inverse isochron is 301±3 while the MSWD is 6.9.

Discussion

For each of the groundmass concentrate samples dated in this study, the weighted mean or plateau age is interpreted to represent the age of eruption of the rock in question. However, all of the GF age spectra exhibit increased apparent ages toward the highest temperatures of gas release. Specifically, the final 1 to 4 heating steps of each GF age spectrum yield apparent ages slightly to significantly older than those ages comprising the weighted mean or flat portion of the age spectrum. These anomalously old ages are likely caused by excess argon. Excess argon is non-atmospheric ^{40}Ar within a sample that is derived by a process other than the *in situ* radioactive decay of ^{40}K (McDougall and Harrison, 1999). Most commonly, excess argon refers to trapped $^{40}Ar/^{36}Ar$ compositions greater than 295.5 (the present day $^{40}Ar/^{36}Ar$ composition). In the case of the GF groundmass concentrates, small amounts of excess argon may have been incorporated into high temperature mafic mineral phases (e.g. pyroxene and/or olivine) at elevated argon partial pressures (i.e. at depth or in a magma

chamber). In many cases, an inverse isochron is employed to test for trapped $^{40}Ar/^{36}Ar$ compositions greater than 295.5. The inverse isochrons for the four GF groundmass concentrate samples yield trapped $^{40}Ar/^{36}Ar$ compositions only slightly greater than 295.5. However, for each GF inverse isochron, the final heating step (step I) was omitted because these data points resulted in more extreme negative ages and higher MSWD values. Therefore, given that the excess argon contamination appears limited to just the highest temperature steps, we can have confidence in the weighted mean of the lower temperature steps as the most accurate $^{40}Ar/^{39}Ar$ age of each sample.

The four GF groundmass concentrate samples were collected from the same (Grand Falls) basalt flow unit and must therefore be the same age. From Figure 6, it is apparent that the GF basalts are indeed the same age (i.e. overlap). However, it is also apparent that the uncertainties associated with each of the GF basalt ages are significantly different. For example, the uncertainty for GF-1 and GF-2 is only ±0.030 Ma, but the uncertainty for GF-3 and GF-4 are ±0.075 and ±0.117 Ma, respectively. While some of the age error can be attributed to the extremely young age of the GF basalt (Holocene basalts are difficult to date with the $^{40}Ar/^{39}Ar$ method due, in large part, to the $1.25 \square 10^9$ year half-life of ^{40}K), this cannot account for the very large errors (e.g. GF-3 and GF-4) and large variability between samples. The differences in uncertainty between the four GF ages undoubtedly result from variable alteration/hydration of the groundmass phases/glass. Indications of the alteration and/or hydration are the very low radiogenic yields (<3%). Electron microprobe results for the four GF samples also show greater alteration products for GF-3 and GF-4 (see attached electron probe report and figures). Therefore, to determine the most precise and accurate $^{40}Ar/^{39}Ar$ apparent age for the Grand Falls basalt flow, a weighted mean of the analyses with the lowest uncertainties was calculated. Samples GF-2 (-0.002±0.030 Ma) and GF-1 (0.011±0.030 Ma; this study) and GF-1 (0.10±0.06 Ma; previous study) were included in the weighted mean to yield an age of 0.008±0.019 Ma. The weighted mean age of 0.008±0.019 Ma is the preferred $^{40}Ar/^{39}Ar$ age for the Grand Falls basalt flow.

As mentioned above, the $^{40}Ar/^{39}Ar$ technique is not an ideal method for dating basalts less than approximately 50,000 years old. Many variables/uncertainties must be incorporated into the $^{40}Ar/^{39}Ar$ technique that are only magnified by extremely young samples. Among these are: the long half-life of 40K (the parent of ^{40}Ar), the uncertainty on the ^{40}K half-life, production of interfering isotopes during nuclear irradiation, extraction line backgrounds during sample heating, mass discrimination affects in the mass spectrometer and sample related affects such as alteration, excess argon and $^{39}Ar_K$ recoil. Several other techniques are available for Holocene-aged samples that are not as sensitive to external factors. Some of these include ^{14}C, ^{3}He, ^{36}Cl and thermoluminescence. In communications between Dr. Wendell Duffield and the NMGRL, it is reported that the Grand Falls basalt yielded a thermoluminescence (TL) age of 19,600±1,200 years (confidence value unknown) and ^{3}He age of 19,000±1,300 years (confidence value unknown). The TL and ^{3}He dating methods better their

precision by at least twenty-fold over the $^{40}Ar/^{39}Ar$ technique (see Figure 6). We are of course unable to speculate on the quality/accuracy of either TL or ^{3}He dates. However, we do note that the weighted mean age/error for the three preferred GF $^{40}Ar/^{39}Ar$ analyses (0.008±0.019 Ma) is analytically indistinguishable from the ages yielded by the TL and ^{3}He techniques.

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Table 1. 40Ar/39Ar analytical methods used for the groundmass concentrate samples.

Sample preparation and irradiation:

Geological samples provided by Dr. Wendell Duffield.
Groundmass concentrates were prepared using standard separation techniques (crushing, sieving, franzing and hand-picking).
Samples were packaged and irradiated in machined Al discs for 1 hour in the L67 position, Ford Research Reactor, University of Michigan.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-1). Assigned age = 27.84 Ma (Deino and Potts, 1990)
equivalent to Mmhb-1 at 520.4 Ma (Samson and Alexander, 1987).

Instrumentation:

Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.
Samples step-heated in Mo double-vacuum resistance furnace. Heating duration 9 minutes.
Reactive gases removed by reaction with 3 SAES GP-50 getters, 2 operated at ~450°C and
1 at 20°C, together with a W filiment operated at ~2000°C.

Analytical parameters:

Electron multiplier sensitivity averaged 1.76×10^{-16} moles/pA.
Total system blank and background for the furnace averaged 1740, 11.1, 3.7, 56.9, 7.6 x 10^{-18} moles
at masses 40, 39, 38, 37, and 36, respectively for temperatures <1300°C.
J-factors determined to a precision of ± 0.1% by CO_2 laser-fusion of 4 single crystals from each of 3 radial positions around the irradiation tray.
Correction factors for interfering nuclear reactions were determined using K-glass and CaF_2 and are as follows:
$(^{40}Ar/^{39}Ar)_K = 0.025 \pm 0.005$; $(^{36}Ar/^{37}Ar)_{Ca} = 0.00026 \pm 0.00002$; and $(^{39}Ar/^{37}Ar)_{Ca} = 0.0007 \pm 0.00005$.

Age calculations:

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

Table 2. 40Ar/39Ar analytical results for five Grand Falls lavas.

ID	Temp (°C)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-16} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
OLD-1, 189.68 mg groundmass concentrate, J=0.0001689±0.10%, NM-143, Lab#=52612-01										
A	*625*	*639.9*	*4.573*	*2154.9*	*1.92*	*0.11*	*0.5*	*1.4*	*1.1*	*1.1*
B	700	9.843	3.003	31.40	19.0	0.17	7.9	14.8	0.236	0.029
C	750	5.138	2.727	16.12	5.12	0.19	10.9	18.4	0.170	0.042
D	800	4.525	1.987	14.05	25.6	0.26	11.2	36.4	0.153	0.015
E	875	5.903	1.092	18.58	23.4	0.47	8.0	52.9	0.143	0.019
F	975	6.226	1.095	19.34	20.7	0.47	9.2	67.5	0.174	0.022
G	1075	11.18	1.904	35.23	11.3	0.27	8.0	75.4	0.272	0.038
H	1250	13.65	9.189	45.96	26.4	0.056	5.5	94.0	0.231	0.033
I	*1700*	*24.22*	*18.39*	*82.47*	*8.46*	*0.028*	*5.1*	*100.0*	*0.384*	*0.074*
total gas age			n=9		141.9	0.26			0.216	0.086*
plateau		MSWD=3.2**	n=7	steps B-H	131.5	0.27		92.7	0.175	0.036*
isochron		MSWD=2.3**	n=9		$^{40}Ar/^{36}Ar$=300±3*				0.15	0.04*
GF-1, 192.25 mg groundmass concentrate, J=0.0001697±0.10%, NM-143, Lab#=52614-01										
A	625	9.154	1.229	30.78	29.2	0.42	1.4	20.7	0.040	0.023
B	700	3.265	1.423	11.42	43.9	0.36	-0.7	51.7	-0.007	0.011
C	750	4.570	1.322	16.06	6.84	0.39	-2.1	56.5	-0.030	0.026
D	800	5.310	1.728	18.39	15.3	0.30	-0.3	67.3	-0.005	0.023
E	875	6.366	2.414	21.29	13.5	0.21	3.8	76.8	0.073	0.021
F	975	9.405	2.958	31.90	11.4	0.17	1.9	84.9	0.056	0.036
G	1075	16.65	3.308	56.65	6.11	0.15	0.8	89.2	0.043	0.060
H	*1250*	*28.02*	*26.59*	*97.25*	*11.0*	*0.019*	*4.7*	*97.0*	*0.407*	*0.078*
I	*1700*	*33.29*	*34.60*	*111.1*	*4.17*	*0.015*	*9.3*	*100.0*	*0.97*	*0.13*
total gas age			n=9		141.4	0.29			0.078	0.058*
plateau		MSWD=3.0**	n=7	steps A-G	126.2	0.32		89.2	0.011	0.030*
isochron		MSWD=2.3**	n=8		$^{40}Ar/^{36}Ar$=308±4*				-0.052	0.016*
GF-2, 193.83 mg groundmass concentrate, J=0.0001618±0.10%, NM-143, Lab#=52616-01										
A	625	15.62	1.691	52.52	16.0	0.30	1.3	12.5	0.061	0.047
B	700	2.414	1.440	8.360	41.7	0.35	1.3	45.2	0.009	0.009
C	750	3.553	1.539	12.86	8.30	0.33	-4.3	51.7	-0.044	0.022
D	800	4.329	1.753	15.35	15.0	0.29	-2.2	63.5	-0.028	0.018
E	875	4.781	2.382	17.72	6.85	0.21	-6.2	68.9	-0.087	0.027
FF	975	6.712	3.054	22.54	14.3	0.17	3.9	80.1	0.076	0.027
G	1075	11.94	3.032	40.97	7.50	0.17	0.4	86.0	0.013	0.051
H	1250	22.21	21.24	79.98	14.1	0.024	0.8	97.1	0.055	0.059
I	*1700*	*30.31*	*30.36*	*99.65*	*3.74*	*0.017*	*10.5*	*100.0*	*0.95*	*0.12*
total gas age			n=9		127.6	0.25			0.043	0.060*
plateau		MSWD=4.0**	n=8	steps A-H	123.9	0.26		97.1	-0.002	0.030*
isochron		MSWD=4.4**	n=8		$^{40}Ar/^{36}Ar$=298±4*				-0.013	0.018*
GF-3, 190.74 mg groundmass concentrate, J=0.0001699±0.10%, NM-143, Lab#=52618-01										
A	*625*	*64.48*	*1.315*	*216.1*	*5.57*	*0.39*	*1.1*	*5.0*	*0.22*	*0.15*
B	700	15.49	1.328	52.34	34.1	0.38	0.7	35.8	0.032	0.031
C	750	17.85	1.128	59.68	3.16	0.45	1.6	38.6	0.085	0.081
D	800	20.39	1.633	67.51	10.6	0.31	2.7	48.2	0.169	0.056
E	875	27.05	2.469	92.25	8.83	0.21	-0.2	56.2	-0.014	0.070
F	975	37.28	2.774	126.8	4.85	0.18	0.0	60.5	0.00	0.11
G	*1075*	*47.10*	*3.888*	*155.5*	*4.19*	*0.13*	*3.0*	*64.3*	*0.44*	*0.11*
H	*1250*	*54.13*	*12.27*	*183.2*	*36.1*	*0.042*	*1.7*	*96.9*	*0.283*	*0.087*
I	*1700*	*63.68*	*16.61*	*206.5*	*3.47*	*0.031*	*6.2*	*100.0*	*1.22*	*0.18*
total gas age			n=9		110.9	0.22			0.185	0.147*
plateau		MSWD=1.5	n=5	steps B-F	61.6	0.33		55.5	0.054	0.075*
isochron		MSWD=2.2	n=8		$^{40}Ar/^{36}Ar$=301±3*				-0.04	0.08*
GF-4, 189.58 mg groundmass concentrate, J=0.00017±0.10%, NM-143, Lab#=52620-01										
A	625	49.13	1.080	168.0	38.7	0.47	-0.9	28.4	-0.138	0.077
B	700	17.72	0.9503	59.74	40.5	0.54	0.7	58.1	0.036	0.034
C	750	21.25	1.086	72.97	15.6	0.47	-1.2	69.5	-0.077	0.047
D	800	27.39	1.892	90.21	11.1	0.27	3.1	77.7	0.263	0.070
E	875	43.10	3.179	146.4	7.08	0.16	0.1	82.9	0.02	0.10
F	*975*	*49.42*	*4.852*	*163.1*	*2.16*	*0.11*	*3.2*	*84.5*	*0.48*	*0.21*
G	*1075*	*82.70*	*5.672*	*274.3*	*2.75*	*0.090*	*2.5*	*86.5*	*0.63*	*0.22*
H	*1250*	*120.7*	*20.47*	*401.7*	*16.7*	*0.025*	*2.9*	*98.8*	*1.10*	*0.22*
I	*1700*	*97.49*	*28.18*	*283.8*	*1.70*	*0.018*	*16.2*	*100.0*	*4.93*	*0.28*
total gas age			n=9		136.3	0.38			0.202	0.173*
plateau		MSWD=5.2**	n=5	steps A-E	113.0	0.46		82.9	0.016	0.117*
isochron		MSWD=6.9**	n=8		$^{40}Ar/^{36}Ar$=301±3*				-0.11	0.08*

Notes:

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

Individual analyses show analytical error only; plateau and total gas age errors include error in J and irradiation parameters.

Analyses in italics are excluded from final age calculations.

Discrimination = 1.00567±0.00112 a.m.u.

n= number of heating steps

†=analyses excluded from plateau weighted mean age.

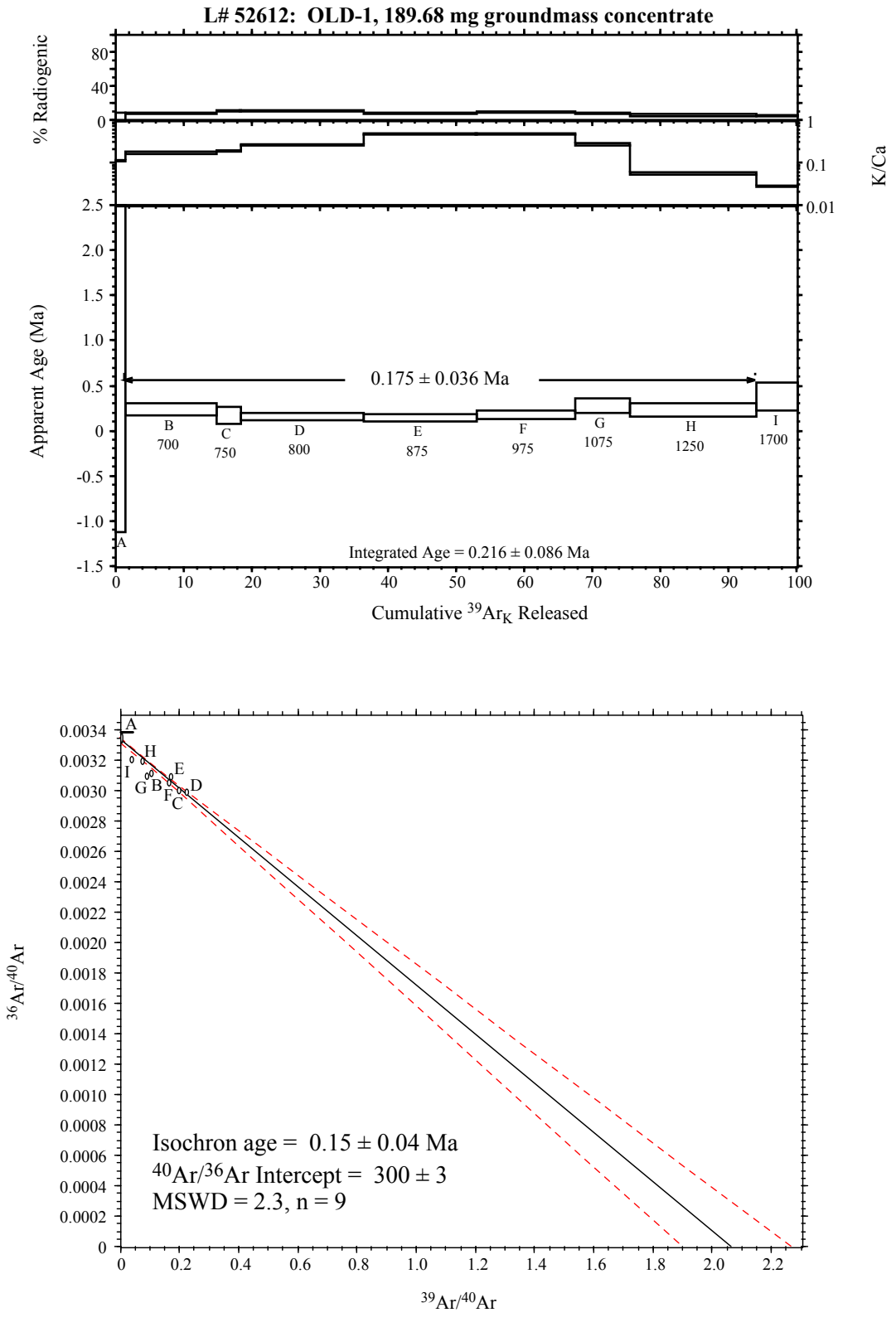

Figure 1. Age spectrum and inverse isochron for the OLD-1 groundmass concentrate. The weighted mean of steps B through H (0.175±0.036 Ma) is the preferred age for this sample. All errors are reported at two-sigma (2σ).

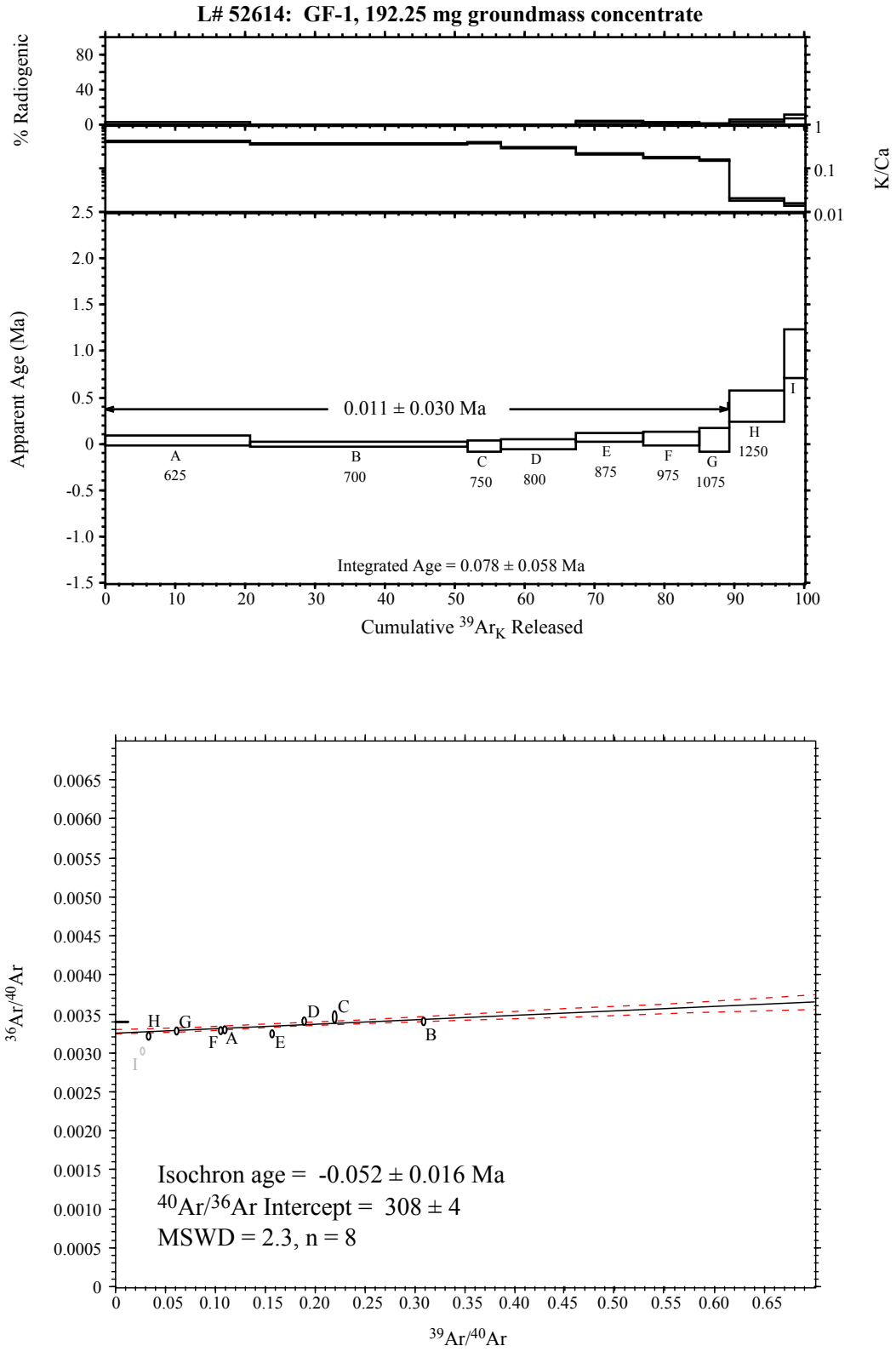

Figure 2. Age spectrum and inverse isochron for the GF-1 groundmass concentrate. The weighted mean of steps A through G (0.011±0.030 Ma) is the preferred age for this sample. All errors are reported at two-sigma (2σ).

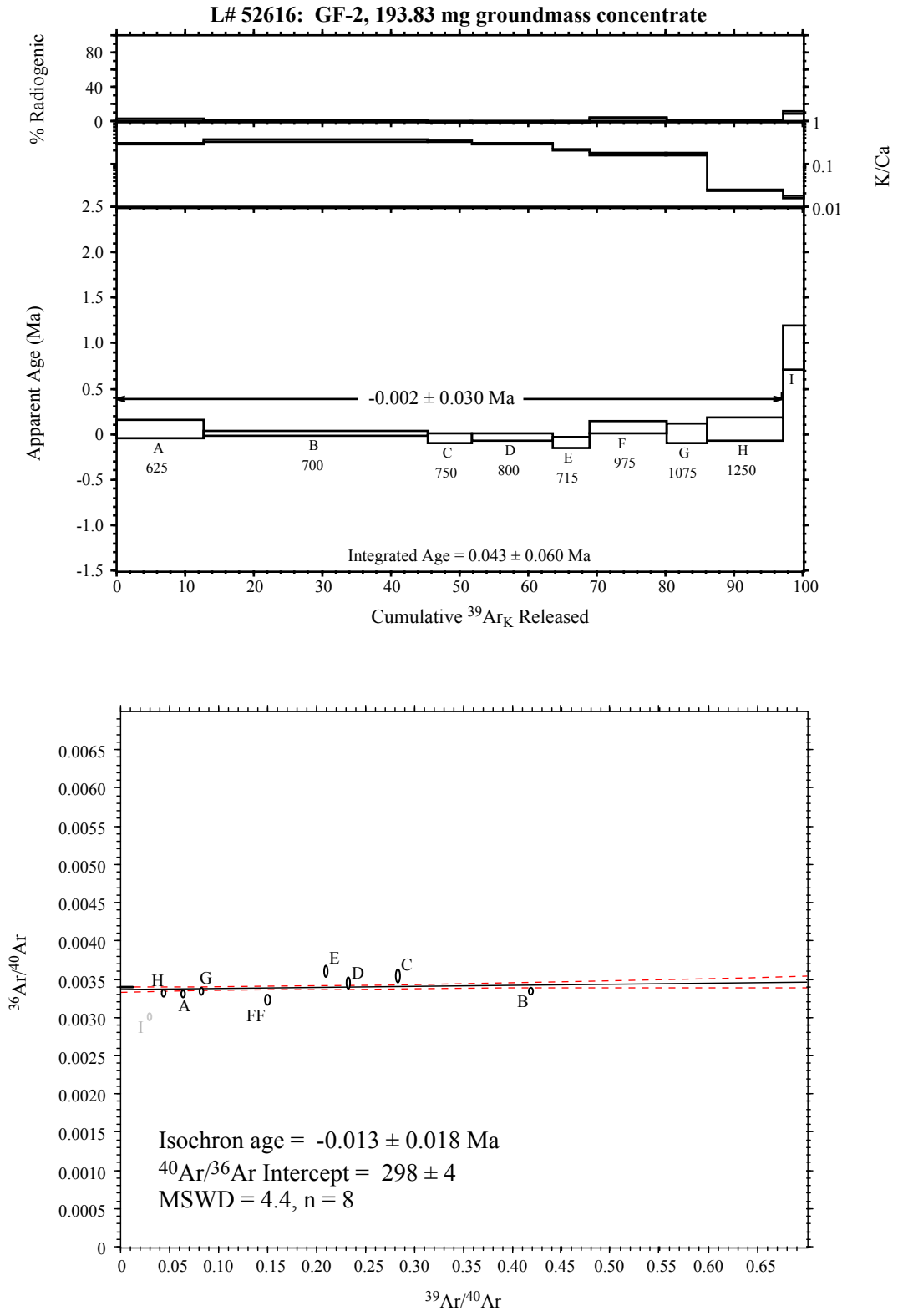

Figure 3. Age spectrum and inverse isochron for the GF-2 groundmass concentrate. The weighted mean of steps A through H (-0.002±0.030 Ma) is the preferred age for this sample. All errors are reported at two-sigma (2σ).

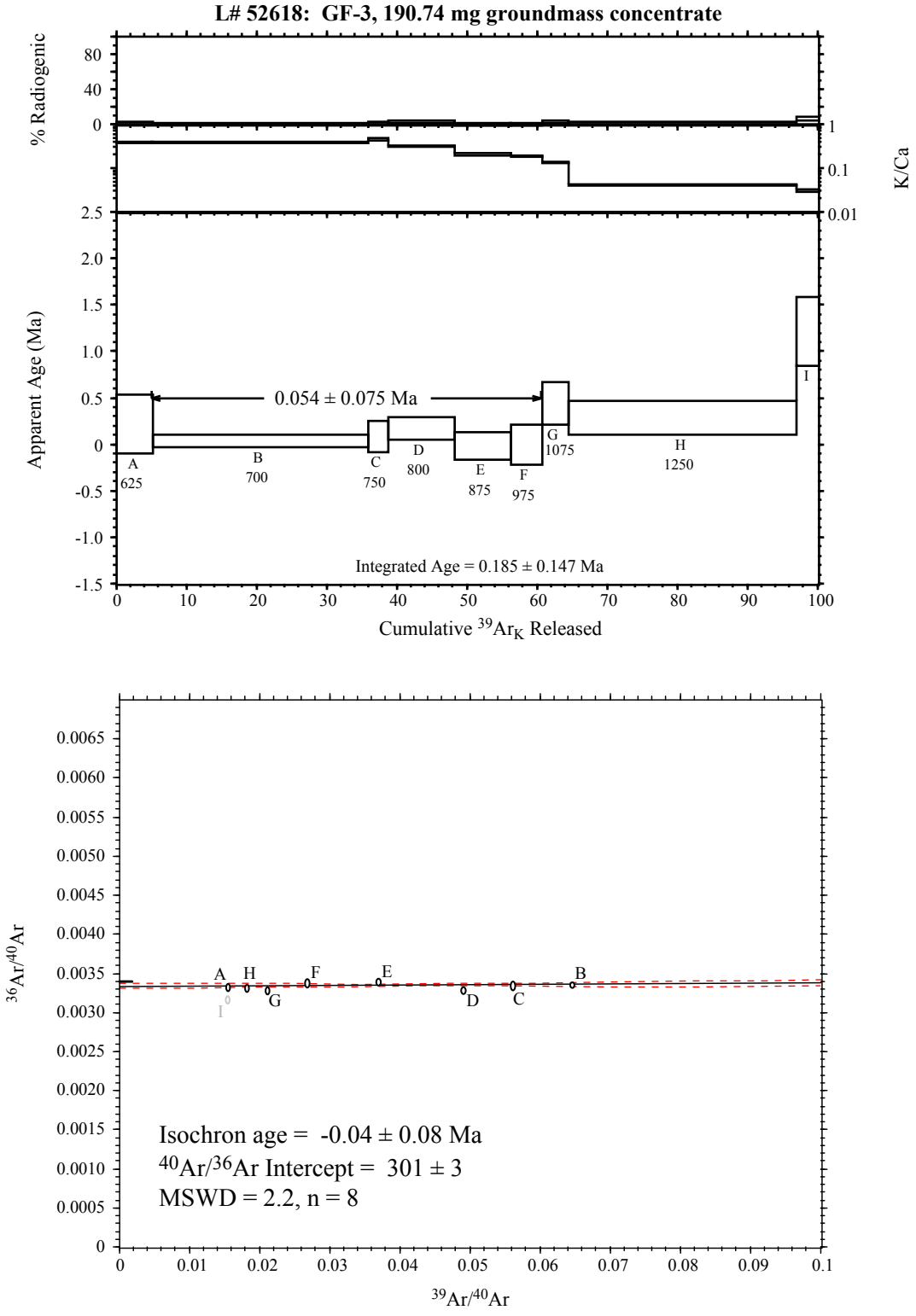

Figure 4. Age spectrum and inverse isochron for the GF-3 groundmass concentrate. The weighted mean of steps B through F (0.054±0.075 Ma) is the preferred age for this sample. All errors are reported at two-sigma (2σ).

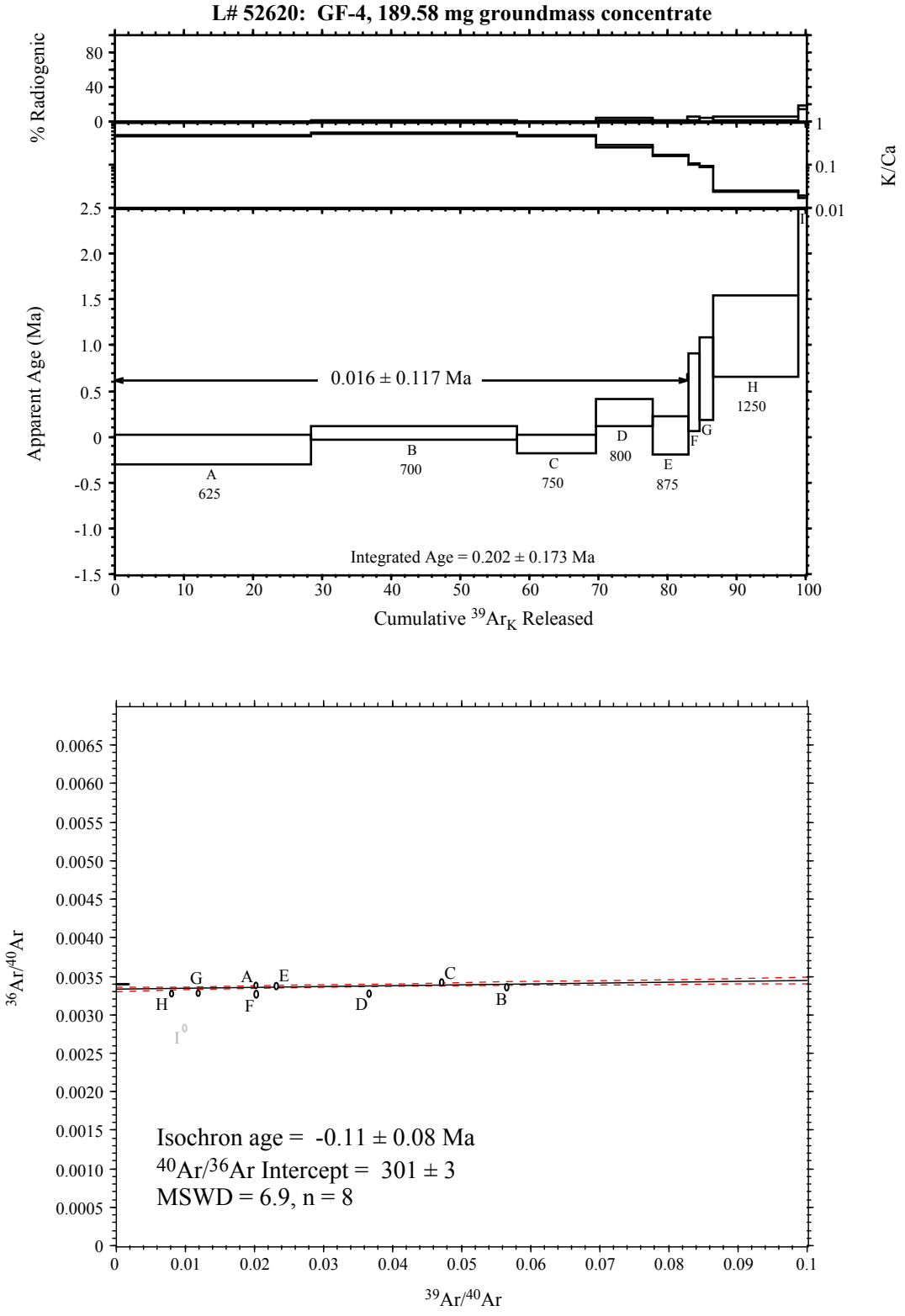

Figure 5. Age spectrum and inverse isochron for the GF-4 groundmass concentrate. The weighted mean of steps A through E (0.016±0.117 Ma) is the preferred age for this sample. All errors are reported at two-sigma (2σ).

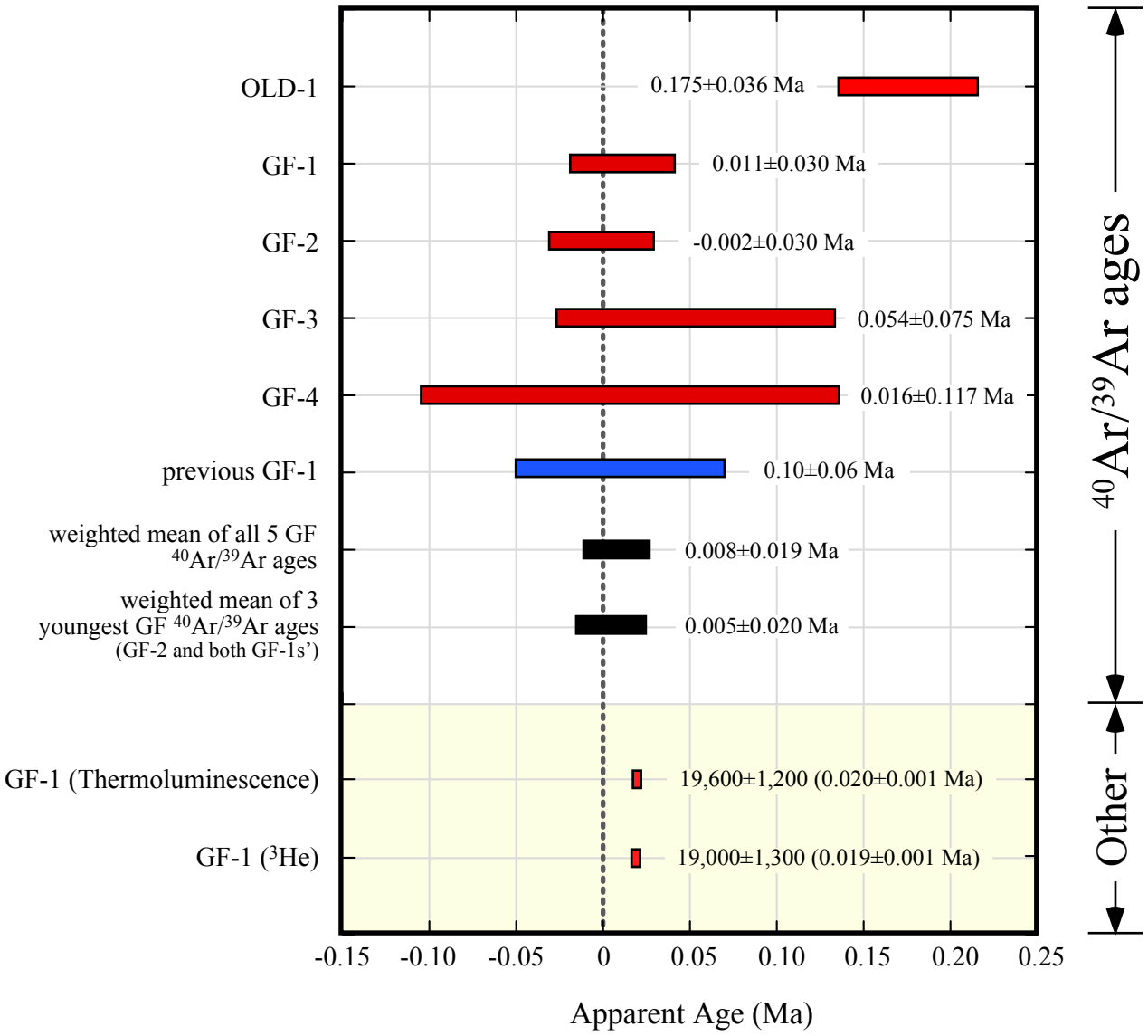

Figure 6. $^{40}Ar/^{39}Ar$ summary plot for the five groundmass concentrate samples dated in this study. Also shown is the previous $^{40}Ar/^{39}Ar$ age for GF-1, the weighted mean age of all the $^{40}Ar/^{39}Ar$ GF ages, the 3 youngest $^{40}Ar/^{39}Ar$ GF ages and the GF-1 ages by thermoluminescence and ^{3}He. The preferred $^{40}Ar/^{39}Ar$ age of eruption for the Grand Falls basalt is the weighted mean of the 3 youngest $^{40}Ar/^{39}Ar$ ages (0.005±0.020 Ma). All $^{40}Ar/^{39}Ar$ errors are reported at two-sigma (2σ).

New Mexico Tech Electron microprobe lab analysis report

Analyses: Standard basalt analysis for Duffield
Date: Dec. 3, 2001
Analysts: L. Heizler and N. Dunbar

Objective of analyses:

Samples were evaluated to determine their suitability for 40-Ar/39-Ar analysis. Evaluation of the samples for dating is based on: 1) presence of potassic feldspar suitable for Ar analysis as a groundmass phase or as rims on plagioclase, 2) presence of glassy groundmass that may contain excess Ar, 3) presence of secondary alteration phases that may adversely affect the Ar analysis.

Analytical Methods:

The analyses were performed using a Cameca SX-100 electron microprobe with 3 wavelength-dispersive spectrometers. An accelerating voltage of 15 kV, and a 20 nA beam current were used. A backscatter electron (BSE) image was generated for a selected area of the sample surface. A potassium K-alpha x-ray map (K-map) of this area was also collected to determine the location and distribution of potassium within the sample and to investigate the character (crystalline or glassy) of groundmass material. Quantitative analyses were performed in order to determine the composition of major phases, groundmass crystals or glass, and any alteration phases (see attachments).

Summary of Data for each sample:

Old-1: This is a very coarse crystalline sample consisting primarily of plagioclase laths (up to 300□), pyroxene, and olivine, with minor magnetite. Plagioclase laths have low z slightly albitic rims. Mg-rich olivine crystals have Fe-rich rims. Feathery skeletal magnetite is mainly associated with pyroxene and olivine in the matrix. There is a moderate amount of crystalline interstitial material that is relatively K-rich and appears to be dominantly composed of intergrown albite and potassic feldspar, with some pyroxene, olivine and magnetite. The K-content of the matrix appears variable, representing slightly mixed compositions due to this fine intergrowth. The potassium in the sample occurs mainly within matrix potassium feldspar. Plagioclase rims are also slightly enriched in potassium. No alteration phases are apparent within the sample, although minor void areas may have previously contained alteration clay. *Rating: glassiness 10/10; alteration 9/10; presence of datable primary phases 9/10

GF-1: This is a coarse crystalline sample consisting primarily of plagioclase laths (to 150□) and pyroxene, with lesser amounts of olivine and ilmenite (or hi Ti magnetite). The sample contains some large Mg-rich olivine phenocrysts (to 300□). There is a moderate amount of crystalline interstitial material that is relatively K-rich and appears to be dominantly composed of intergrown potassium feldspar and albite. The matrix appears as a mix of lighter (potassium feldspar) and darker gray (albite) patches on the BSE image, with some higher z inclusions. The potassium in the sample is primarily contained within the lighter matrix phase (6.5-9wt% K_2O). Analyses within this phase are variable and appear to represent slightly mixed compositions due to feldspar intergrowth and the presence of inclusions (apatite, ferromags). Albitic feldspars within the matrix contain ~2.5wt% K_2O. Albitic rims on plagioclase are also slightly enriched in

potassium (0.65wt% K_2O). No alteration phases are apparent within the sample, although minor void areas may have previously contained alteration clay. *Rating: glassiness 10/10; alteration 9/10; presence of datable primary phases 10/10

GF-2: This is a coarse crystalline sample similar to GF-1 consisting primarily of plagioclase laths (to 100□) and zoned pyroxene, with some olivine and ilmenite (or hi Ti magnetite). Plagioclase laths have low z albitic rims. There is a moderate amount of crystalline interstitial material that is relatively K-rich and appears to be dominantly composed of intergrown potassium feldspar and albite with some void areas. The matrix appears as a mix of lighter (potassium feldspar) and darker gray (albite) patches on the BSE image, with some higher z inclusions. The potassium in the sample is primarily contained within the lighter matrix phase (6.5-9wt% K_2O). Analyses within this phase are variable and appear to represent slightly mixed compositions due to feldspar intergrowth and the presence of inclusions (apatite, ferromags). Matrix albite contains ~2wt% K_2O. Albitic rims on plagioclase are also slightly enriched in potassium (~0.75wt% K_2O). No alteration phases are apparent within the sample, although minor void areas may have previously contained alteration clay. *Rating: glassiness 10/10; alteration 9/10; presence of datable primary phases 10/10

GF-3: This sample is overall finer crystalline than GF-1 and GF-2, consisting primarily of plagioclase laths (to 100□), zoned pyroxene (typically 50□ or less) and ferromags, with some olivine phenocrysts (to 100□). Plagioclase laths have low z albitic rims. There is a moderate amount of K-rich interstitial material that appears to be dominantly composed of finely intergrown alkali feldspars. Chemical analyses within the matrix are variable and appear to represent slightly mixed compositions due to feldspar intergrowth and the presence of inclusions. The potassium in the sample is primarily contained within matrix feldspars. Albitic rims on plagioclase are also slightly enriched in potassium. The sample contains a minor amount of alteration clay. *Rating: glassiness 10/10; alteration 8/10; presence of datable primary phases 9/10

GF-4: This is a fine crystalline sample similar to GF-3 consisting primarily of plagioclase laths (to 100□), zoned pyroxene (typically 50□ or less) and ferromags. The sample also contains some olivine phenocrysts (to 100□). Plagioclase laths have low z albitic rims. There is a moderate amount of K-rich interstitial material that appears to be dominantly composed of finely intergrown alkali feldspars. The presence of Fe and Ti in chemical analyses within the matrix is likely due to fine inclusions. The potassium in the sample is primarily contained within matrix alkali feldspars (~4wt% K_2O). Albitic rims on plagioclase are also slightly enriched in potassium (up to ~1wt% K_2O). The sample contains a minor amount of alteration clay. *Rating: glassiness 10/10; alteration 8/10; presence of datable primary phases 9/10

* The higher the number the more desirable for dating purposes.

Attachments:

Data sheets for unknowns

Data sheets of reference material
K-maps and BSE images