# $^{40}Ar/^{39}Ar$ Geochronology Results for the Black Ridge, Circleville Canyon, Government Point, Marysvale Canyon, and Shelly Baldy Peak Quadrangles, Marysvale Volcanic Field, Utah

*by*

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# INTRODUCTION

This Open-File Report makes available raw analytical data from laboratory procedures completed to determine the age of rock samples collected during geologic mapping funded or partially supported by the Utah Geological Survey (UGS). The references listed in table 1 provides additional information such as the geologic setting and significance or interpretation of the samples in the context of the area in which they were collected. This report was prepared by the New Mexico Geochronology Research Laboratory under contract to the UGS. These data are highly technical in nature and proper interpretation requires considerable training in the applicable geochronologic techniques.

***Table 1.*** *Sample numbers and locations.*

| Sample # | 7.5' quadrangle | Easting UTM NAD83 | Northing UTM NAD83 | Reference |
|---|---|---|---|---|
| GP101514-8 | Government Point | 369369 | 4195381 | Biek and others (2015) |
| 14-92 | Shelly Baldy Peak | 378273 | 4241815 | Rowley and others (2005) |
| 14-225 | Shelly Baldy Peak | 374808 | 4239411 | Rowley and others (2005) |
| 14-230B | Circleville Mountain | 372556 | 4233098 | Rowley and others (2005) |
| 14-234 | Circleville Mountain | 370529 | 4233315 | Rowley and others (2005) |
| 15-9 | Marysvale Canyon | 388237 | 4270971 | Rowley and others (2005) |
| 15-11 | Black Ridge | 366566 | 4235347 | Rowley and others (2005) |

# DISCLAIMER



# REFERENCES

Biek, R.F., Eaton, J.G., Rowley, P.D., and Mattox, S.R., 2015, Interim geologic map of the west half of the Loa 30′ x 60′ quadrangle, Garfield, Iron, and Kane Counties, Utah: Utah Geological Survey Open-File Report 648, 20 p., 2 plates, scale 1:62,500.

Rowley, P.D., Vice, G.S., McDonald, R.E., Anderson, J.J., Machette, M.N., Maxwell, D.J., Ekren, E.B., Cunningham, C.G., Steven, T.A., and Wardlaw, B.R., 2005, Interim geologic map of the Beaver 30′ x 60′ quadrangle, Beaver, Piute, Iron, and Garfield Counties, Utah: Utah Geological Survey Open-File Report 454, 27 p., 1 plate, scale 1:100,000.

# $^{40}Ar/^{39}Ar$ Geochronology Results From the Marysvale Volcanic Field

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## Introduction

Eight volcanic samples from the Marysvale volcanic field of southwest Utah were submitted for dating by Bob Biek of the Utah Geological Survey (GP101514-8, 14-92, 14-225, 14-230B, 14-233, 14-234, 14-329 and 14-285). Sample 15-11, the Delano Peak Tuff was sent to replace 14-329 and 15-9, the Joe Lott Tuff, was sent to replace 14-285. Sample 14-233 was to be replaced as well but a replacement has not been sent to date. Sanidine and/or plagioclase was analyzed from samples: GP101514-B, 14-92, 14-225, 14-230B and 15-9. Groundmass concentrate was analyzed from 14-234; while biotite and hornblende was analyzed from 15-11.

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

Sanidine and plagioclase separates were prepared by crushing, treating with dilute HF, density separation in lithium metatungstate heavy liquid, and hand-picking. The biotite and hornblende separates were prepared by using all of the previously mentioned procedures except dilute HF treatment. Groundmass concentrates were prepared by treating crushed material with dilute HCl and then removing the phenocrysts. The mineral separates and monitors (Fish Canyon tuff sanidine, 28.201, Kuiper et al., 2008) were loaded into aluminum discs and irradiated for 16 hours at the USGS TRIGA reactor in Denver Colorado.

Individual crystals of sanidine and plagioclase unknowns and sanidine monitors were fused with a Photon Machines $CO_2$ laser; the groundmass, hornblende and biotite were step-heated with a Photon Machines Diode laser and all were analyzed with a Thermo Argus VI mass spectrometer. Abbreviated analytical methods for the dated samples are given in Table 1, and details of the overall operation of the New Mexico Geochronology Research Laboratory is provided in the Appendix. The age results are summarized in Table 1 and the argon isotopic data are given in Tables 2 and 3.

Single crystals of sanidine from samples 14-92 and 14-225 were analyzed. Seventeen of the twenty analyzed crystals of 14-92 were used to calculate the weighted mean age of 18.81±0.02 Ma. Three slightly older crystals (possible xenocrysts) were eliminated before the calculation of the weighted mean. The analyzed crystals have uniformly high radiogenic yields (95.5% and greater) and K/Ca values between 9.3 and 18.5, all indicative of sanidine. For sample for 14-225, twelve of the fifteen analyzed crystals of sanidine were used to calculate the weighted mean age of 22.88±0.02 Ma. Two slightly older crystals (possible xenocrysts) were eliminated from the dataset before calculation of the weighted mean age. These sanidine also had uniformly high radiogenic yields (99.0%-99.9%) and fairly uniform K/Ca values (19.6-35.7).

Thirty-four crystals of 15-9 were analyzed. These crystals were much finer than those for 14-92 and 14-225, as can be seen by comparing the moles $^{39}Ar$ column in the data tables. The $^{39}Ar$ moles for 15-9 are one to two orders of magnitude smaller than for the other two samples. This combined with 4 months between irradiation and analysis resulted in $^{37}Ar$ signals too small to accurately measure. $^{37}Ar$ serves as our proxy for calcium (produced from $^{40}Ca$ during irradiation) therefore those crystals with no measurable $^{37}Ar$ have a undefined K/Ca value. For these crystals we were are also not able to make a correction for the $^{36}Ar$ produced from $^{40}Ca$, which results in over correction for atmospheric $^{40}Ar$ and therefore lower apparent ages. After the elimination of those crystals with no measurable $^{37}Ar$ from the weighted mean age calculation, sixteen crystals were used to calculate a weighted mean age of 19.12±0.10 Ma. Radiogenic yields for those crystals ranges from 91.3-99.1% and K/Ca values range from 8.0-79.9.

Single crystals of plagioclase from samples GP101514-B and 14-230B were analyzed (except for one sanidine crystal of GP101514-B). Only one very small crystal with a low radiogenic yield (52.1%) was eliminated from the fifteen analyzed crystals of GP101514-B before the calculation of the weighted mean of 25.41±0.12 Ma. The precision on the sanidine crystal (#13) is an order of magnitude better than the errors on the plagioclase crystals so the age of this crystal (25.43±0.07 Ma) is dominating the age calculation. The range in radiogenic yield is larger than we often see (64.4-91.5%) but there is no age correlation between radiogenic yield and age so there is no evidence that these crystals have lost radiogenic argon. The analyzed crystals of 14-230B plagioclase reveal an even larger spread in radiogenic yield (10.2-83.5%) and $^{40}Ar$ signal size from just 1.5 to 10 times blank level. There is a rough correlation between signal size, radiogenic yield and apparent age. After eliminating those crystals with $^{40}Ar$ signal sizes less than ~5 times blank level, the remaining 9 crystals yield a weighted mean age of 25.36±0.41 Ma.

Groundmass concentrate from 14-234 yielded a disturbed age spectrum with increasing radiogenic yields and apparent ages and decreasing K/Ca ratios over the initial 34.8% of the $^{39}Ar$ released. A weighted mean age of 23.51±0.06 Ma is calculated from the final 36.0% of the age spectrum. We note that the integrated age of 23.45±0.06 Ma agrees within error to the weighted mean age. The data was evaluated with an inverse isochron and found to be non-isochronous.

Single crystals of both hornblende and biotite were analyzed from sample 15-11. Four hornblende crystals were heated with two steps, the A steps are smaller in Ar signal size, less radiogenic, have a higher K/Ca and older apparent ages than the B steps. A weighted mean age of 26.80±0.16 Ma is calculated from the B steps. Five single biotite crystals were heated in three steps. The A steps for the most part have smaller signal sizes, lower radiogenic yields, lower K/Ca values and younger apparent ages than the B and C steps. A weighted mean of 5 of the B and C steps, excluding three apparently older steps with very small signal sizes, yields an age of 26.96±0.07 Ma. We note that this agrees within error to the age calculated from the single crystal hornblende analyses but that it has a very large MSWD value of 109.

## Discussion

We have confidence that the ages assigned to the samples analyzed by single crystal sanidine or plagioclase provide accurate eruption ages within the quoted error (14-92, 18.81±0.02 Ma; 15-9, 19.12±0.10 Ma; 14-225, 22.88±0.02 Ma; GP101514-B, 25.41±0.12 Ma; and 14-230B, 25.36±0.41 Ma). Although groundmass concentrate from

14-234 yielded a disturbed age spectrum and the increasing apparent ages correlated with increasing radiogenic yields is suggestive of recoil redistribution of $^{39}Ar$, because the integrated age (23.45±0.06 Ma) and the weighted mean age assigned to the steps I-K (23.51±0.06 Ma) agree within error we feel that the amount of recoil is probably minimal and the assigned age of 23.51±0.06 Ma provides an accurate eruption age for the mafic lava flows of Birch Creek. Likewise, because the ages calculated from the few single crystals of biotite (26.96±0.07 Ma) and hornblende (26.80±0.15 Ma) from 15-11 agree, we have more confidence than we might otherwise have that these are accurate ages for the eruption of the Delano Peak Tuff.

## References Cited

Kuiper, K. F., Deino, A., Hilgen, F. J., Krijgsman, W., Renne, P. R., and Wijbrans, J. R., 2008, Synchronizing rock clocks of earth history: Science, v. 320, p. 500-504.

Min, K., Mundil, R., Renne, P. L., and Ludwig, K.R., 2000, A test for systematic errors in $^{40}Ar/^{39}Ar$ geochronology through comparison with U/Pb analysis of a 1.1-Ga rhyolite: Geochimica et Cosmochimica Acta, v. 64, p. 73-98.

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

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

| Sample | Lab # | Irradiation | mineral | age analysis | steps/analyses | Age | ±2σ | MSWD | comments |
|---|---|---|---|---|---|---|---|---|---|
| 14-92 | 63805 | 277 | sanidine | laser fusion | 17 | 18.81 | 0.02 | 5.6 | |
| 15-9 | 64000 | 279 | sanidine | laser fusion | 16 | 19.12 | 0.10 | 9.9 | |
| 14-225 | 63807 | 277 | sanidine | laser fusion | 12 | 22.88 | 0.02 | 32 | |
| 14-234 | 63829 | 277 | groundmass concentrate | bulk step-heat | 3 | 23.51 | 0.06 | 0.04 | |
| GP101514-B | 63804 | 277 | plagioclase/sanidine | laser fusion | 14 | 25.41 | 0.12 | 1.44 | |
| 14-230B | 63809 | 277 | plagioclase | laser fusion | 9 | 25.36 | 0.41 | 4.5 | |
| 15-11 | 63770 | 277 | hornblende | single crystal step-heat | 4 | 26.80 | 0.15 | 4 | |
| 15-11 | 63769 | 277 | biotite | single crystal step-heat | 5 | 26.96 | 0.07 | 109.00 | |

**Sample preparation and irradiation:**

Minerals separated with standard heavy liquid, Franz Magnetic and hand-picking techniques.
Samples in NM-277 and 279 irradiated in a machined Aluminum tray for 16 hours in C.T. position, USGS TRIGA, Denver, Colorado.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-2). Assigned age = 28.201 Ma (Kuiper et al., 2008).

**Instrumentation:**

Total fusion analyses performed on a Argus VI mass spectrometer on line with automated all-metal extraction system. System = Jan
Step-heat analyses performed on a Argus VI mass spectrometer on line with automated all-metal extraction system. System = Obama
Multi-collector configuration: 40Ar-H1, 39Ar-Ax, 38Ar-L1, 37Ar-L2, 36Ar-CDD
Flux monitors fused with a Photon Machines Inc. $CO_2$ laser. Groundmass concentrate and glass step-heated with a Photon Machine Inc. Diode laser.

**Analytical parameters:**

Sensitivity for the Argus VI with the Diode laser (step-heated samples) is 9.84e-17 moles/fA.
Sensitivty for the Argus VI with the CO2 laser (fused monitors)is 4.62 e-17 moles/fA.
Typical system blank and background was 83.9, 1.32, 0.499, 0.382, 0.320 x $10^{-18}$ moles at masses 40, 39, 38, 37 and 36, respectively for the laser analyses.
J-factors determined by $CO_2$ laser-fusion of 6 single crystals from each of 8 radial positions around the irradiation tray.
Decay constants and isotopic abundances after Minn et al., (2000).

**Table 2. $^{40}Ar/^{39}Ar$ 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) |
|---|---|---|---|---|---|---|---|---|
| **GP101514-B,** plag and san, J=0.0038218±0.02%, IC=1.0258±0.0012, NM-277F, Lab#=63804 | | | | | | | | |
| *11* | *6.592* | *4.116* | *11.80* | *0.011* | *0.12* | *52.1* | *23.91* | *2.79* |
| 07 | 4.193 | 3.641 | 3.168 | 0.073 | 0.14 | 84.7 | 24.68 | 0.40 |
| 09 | 4.212 | 3.475 | 3.190 | 0.063 | 0.15 | 84.3 | 24.69 | 0.46 |
| 08 | 4.259 | 2.852 | 3.121 | 0.108 | 0.18 | 83.8 | 24.81 | 0.30 |
| 05 | 4.525 | 4.060 | 4.264 | 0.057 | 0.13 | 79.4 | 24.98 | 0.54 |
| 10 | 4.605 | 1.591 | 3.727 | 0.126 | 0.32 | 78.8 | 25.21 | 0.26 |
| 06 | 4.131 | 2.349 | 2.290 | 0.192 | 0.22 | 88.2 | 25.30 | 0.17 |
| 02 | 4.900 | 2.199 | 4.838 | 0.184 | 0.23 | 74.4 | 25.33 | 0.20 |
| 13 | 4.230 | 0.0296 | 1.908 | 0.602 | 17.3 | 86.7 | 25.43 | 0.07 |
| 03 | 4.009 | 3.834 | 2.194 | 0.101 | 0.13 | 91.5 | 25.51 | 0.31 |
| 15 | 4.497 | 3.023 | 3.600 | 0.141 | 0.17 | 81.7 | 25.55 | 0.24 |
| 01 | 4.297 | 2.665 | 2.819 | 0.216 | 0.19 | 85.6 | 25.55 | 0.16 |
| 04 | 4.069 | 3.434 | 2.160 | 0.076 | 0.15 | 91.1 | 25.76 | 0.39 |
| 12 | 5.797 | 5.473 | 8.468 | 0.072 | 0.093 | 64.4 | 26.00 | 0.48 |
| 14 | 4.670 | 3.367 | 4.034 | 0.095 | 0.15 | 80.3 | 26.05 | 0.34 |
| **Mean age ± 2σ** | | **n=14** | **MSWD=1.44** | | **1.4 ±9.1** | | **25.41** | **0.12** |
| **14-92,** san, J=0.0038243±0.02%, IC=1.0258±0.0012, NM-277F, Lab#=63805 | | | | | | | | |
| 15 | 2.718 | 0.0455 | 0.0834 | 1.526 | 11.2 | 99.2 | 18.73 | 0.02 |
| 09 | 2.828 | 0.0414 | 0.4375 | 2.906 | 12.3 | 95.5 | 18.76 | 0.01 |
| 19 | 2.715 | 0.0381 | 0.0519 | 2.888 | 13.4 | 99.5 | 18.77 | 0.01 |
| 16 | 2.712 | 0.0309 | 0.0392 | 1.324 | 16.5 | 99.7 | 18.77 | 0.02 |
| 03 | 2.711 | 0.0417 | 0.0285 | 3.859 | 12.2 | 99.8 | 18.79 | 0.01 |
| 17 | 2.729 | 0.0432 | 0.0866 | 2.880 | 11.8 | 99.2 | 18.79 | 0.01 |
| 11 | 2.739 | 0.0365 | 0.1204 | 2.692 | 14.0 | 98.8 | 18.79 | 0.01 |
| 14 | 2.719 | 0.0366 | 0.0474 | 2.123 | 14.0 | 99.6 | 18.80 | 0.01 |
| 13 | 2.732 | 0.0491 | 0.0926 | 2.220 | 10.4 | 99.1 | 18.81 | 0.01 |
| 18 | 2.740 | 0.0276 | 0.1097 | 0.775 | 18.5 | 98.9 | 18.81 | 0.04 |
| 21 | 2.788 | 0.0368 | 0.2743 | 1.612 | 13.9 | 97.2 | 18.82 | 0.02 |
| 10 | 2.720 | 0.0421 | 0.0431 | 2.727 | 12.1 | 99.7 | 18.82 | 0.01 |
| 04 | 2.727 | 0.0383 | 0.0632 | 2.766 | 13.3 | 99.4 | 18.83 | 0.01 |
| 05 | 2.745 | 0.0301 | 0.1159 | 2.582 | 16.9 | 98.8 | 18.84 | 0.01 |
| 07 | 2.805 | 0.0551 | 0.3234 | 4.525 | 9.3 | 96.7 | 18.84 | 0.01 |
| 12 | 2.726 | 0.0425 | 0.0505 | 2.593 | 12.0 | 99.6 | 18.85 | 0.01 |
| 06 | 2.740 | 0.0546 | 0.0955 | 1.002 | 9.3 | 99.1 | 18.86 | 0.03 |
| *08* | *2.712* | *0.0527* | *-0.0603* | *0.202* | *9.7* | *100.8* | *18.99* | *0.14* |
| *20* | *2.789* | *0.0231* | *0.0905* | *1.330* | *22.1* | *99.1* | *19.19* | *0.02* |
| *02* | *2.811* | *0.0385* | *0.1329* | *3.799* | *13.2* | *98.7* | *19.27* | *0.01* |
| **Mean age ± 2σ** | | **n=17** | **MSWD=5.56** | | **13.0 ±5.1** | | **18.81** | **0.02** |

| 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) |
|---|---|---|---|---|---|---|---|---|
| **14-225,** san, J=0.0038263±0.02%, IC=1.0258±0.0012, NM-277F, Lab#=63807 | | | | | | | | |
| 02 | 3.305 | 0.0167 | 0.0531 | 34.468 | 30.6 | 99.6 | 22.85 | 0.00 |
| 06 | 3.300 | 0.0210 | 0.0289 | 4.395 | 24.3 | 99.8 | 22.86 | 0.01 |
| 04 | 3.308 | 0.0172 | 0.0569 | 10.456 | 29.7 | 99.5 | 22.86 | 0.01 |
| 03 | 3.326 | 0.0260 | 0.1105 | 27.972 | 19.6 | 99.1 | 22.88 | 0.00 |
| 11 | 3.301 | 0.0191 | 0.0228 | 2.676 | 26.7 | 99.8 | 22.88 | 0.01 |
| 05 | 3.314 | 0.0154 | 0.0638 | 8.180 | 33.1 | 99.5 | 22.89 | 0.01 |
| 08 | 3.304 | 0.0143 | 0.0240 | 2.457 | 35.7 | 99.8 | 22.90 | 0.01 |
| 10 | 3.301 | 0.0208 | 0.0141 | 3.613 | 24.5 | 99.9 | 22.90 | 0.01 |
| 09 | 3.312 | 0.0222 | 0.0453 | 28.843 | 23.0 | 99.6 | 22.92 | 0.00 |
| 04 | 3.322 | 0.0197 | 0.1140 | 9.878 | 25.9 | 99.0 | 22.84 | 0.01 |
| 03 | 3.307 | 0.0199 | 0.0388 | 9.911 | 25.7 | 99.7 | 22.89 | 0.00 |
| *07* | *3.307* | *0.0178* | *0.0216* | *5.531* | *28.7* | *99.8* | *22.93* | *0.01* |
| 02 | 3.326 | 0.0182 | 0.0515 | 2.755 | 28.1 | 99.6 | 23.00 | 0.01 |
| *01* | *3.340* | *0.0184* | *0.0701* | *8.369* | *27.8* | *99.4* | *23.06* | *0.01* |
| **Mean age ± 2σ** | | **n=12** | **MSWD=32.23** | | **27.2 ±9.0** | | **22.88** | **0.02** |
| **14-230B,** plag, J=0.0038256±0.02%, IC=1.0258±0.0012, NM-277F, Lab#=63809 | | | | | | | | |
| *06* | *10.06* | *3.153* | *25.19* | *0.028* | *0.16* | *28.5* | *20.02* | *1.17* |
| *14* | *30.33* | *5.026* | *93.48* | *0.008* | *0.10* | *10.2* | *21.70* | *4.16* |
| *07* | *17.25* | *3.488* | *48.66* | *0.023* | *0.15* | *18.2* | *21.94* | *1.63* |
| *17* | *6.993* | *3.757* | *13.65* | *0.050* | *0.14* | *46.6* | *22.72* | *0.66* |
| *02* | *4.632* | *3.155* | *5.469* | *0.028* | *0.16* | *70.5* | *22.75* | *0.99* |
| *16* | *8.543* | *3.607* | *18.76* | *0.041* | *0.14* | *38.5* | *22.90* | *0.87* |
| *15* | *6.934* | *3.420* | *13.08* | *0.062* | *0.15* | *48.2* | *23.29* | *0.56* |
| 03 | 5.264 | 3.175 | 6.967 | 0.132 | 0.16 | 65.7 | 24.08 | 0.29 |
| 12 | 6.201 | 2.337 | 9.587 | 0.084 | 0.22 | 57.3 | 24.73 | 0.40 |
| *08* | *22.20* | *2.543* | *63.69* | *0.020* | *0.20* | *16.1* | *24.94* | *1.98* |
| 04 | 4.605 | 3.324 | 4.344 | 0.101 | 0.15 | 77.9 | 24.97 | 0.30 |
| 09 | 6.017 | 3.126 | 8.962 | 0.071 | 0.16 | 60.1 | 25.18 | 0.51 |
| 05 | 5.250 | 2.915 | 6.207 | 0.108 | 0.18 | 69.5 | 25.39 | 0.31 |
| 11 | 4.397 | 3.267 | 3.345 | 0.137 | 0.16 | 83.5 | 25.54 | 0.23 |
| 01 | 4.688 | 3.147 | 4.213 | 0.148 | 0.16 | 78.8 | 25.71 | 0.23 |
| 10 | 6.041 | 2.399 | 8.539 | 0.171 | 0.21 | 61.4 | 25.80 | 0.23 |
| 13 | 8.744 | 3.338 | 17.61 | 0.084 | 0.15 | 43.5 | 26.48 | 0.48 |
| **Mean age ± 2σ** | | **n=9** | **MSWD=4.50** | | **0.17 ±0.05** | | **25.36** | **0.41** |

| 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) |
|---|---|---|---|---|---|---|---|---|
| **15-9,** Sanidine, J=0.0038163±0.03%, IC=1.0258±0.0012, NM-279B, Lab#=64000 | | | | | | | | |
| *34* | *30.36* | *7.333* | *97.86* | *0.025* | *0.070* | *6.8* | *14.36* | *6.28* |
| 07 | 2.772 | 0.0133 | 0.1811 | 0.611 | 38.5 | 98.1 | 18.84 | 0.10 |
| *13* | *2.839* | *-0.0083* | *0.3759* | *1.442* | - | *96.1* | *18.90* | *0.04* |
| *16* | *3.084* | *-0.0481* | *1.174* | *0.460* | - | *88.6* | *18.94* | *0.13* |
| 05 | 2.777 | 0.0064 | 0.1491 | 2.017 | 79.9 | 98.4 | 18.94 | 0.03 |
| 04 | 2.770 | 0.0088 | 0.0967 | 1.523 | 58.2 | 99.0 | 19.00 | 0.04 |
| *18* | *2.862* | *-0.0159* | *0.4001* | *0.856* | - | *95.8* | *19.01* | *0.07* |
| 32 | 2.874 | 0.0104 | 0.4425 | 0.408 | 48.9 | 95.5 | 19.01 | 0.12 |
| *12* | *2.850* | *-0.0066* | *0.3496* | *0.781* | - | *96.3* | *19.03* | *0.07* |
| 09 | 2.773 | 0.0227 | 0.0902 | 0.867 | 22.5 | 99.1 | 19.04 | 0.07 |
| 30 | 2.809 | 0.0133 | 0.2060 | 0.800 | 38.4 | 97.9 | 19.05 | 0.06 |
| *19* | *2.834* | *-0.0357* | *0.2768* | *0.528* | - | *97.0* | *19.05* | *0.11* |
| 23 | 2.826 | 0.0110 | 0.2600 | 0.485 | 46.6 | 97.3 | 19.06 | 0.10 |
| *15* | *2.873* | *-0.0231* | *0.4076* | *0.671* | - | *95.7* | *19.06* | *0.08* |
| *10* | *2.815* | *-0.0166* | *0.1854* | *0.595* | - | *98.0* | *19.12* | *0.09* |
| *28* | *2.855* | *-0.0029* | *0.3155* | *0.410* | - | *96.7* | *19.13* | *0.12* |
| *11* | *2.943* | *-0.0273* | *0.6048* | *0.450* | - | *93.8* | *19.14* | *0.13* |
| *21* | *2.937* | *-0.0486* | *0.5760* | *0.370* | - | *94.1* | *19.14* | *0.15* |
| 06 | 2.839 | 0.0168 | 0.2620 | 0.481 | 30.4 | 97.3 | 19.15 | 0.13 |
| 25 | 3.030 | 0.0262 | 0.8969 | 0.334 | 19.4 | 91.3 | 19.17 | 0.15 |
| *17* | *2.871* | *-0.0557* | *0.3347* | *0.409* | - | *96.4* | *19.17* | *0.14* |
| 29 | 2.886 | 0.0259 | 0.3981 | 0.492 | 19.7 | 96.0 | 19.19 | 0.10 |
| *20* | *2.910* | *-0.0097* | *0.4691* | *0.411* | - | *95.2* | *19.20* | *0.14* |
| 02 | 2.806 | 0.0089 | 0.0989 | 1.857 | 57.4 | 99.0 | 19.25 | 0.03 |
| *14* | *2.829* | *-0.0111* | *0.1666* | *0.781* | - | *98.2* | *19.26* | *0.07* |
| 31 | 2.851 | 0.0270 | 0.2392 | 0.345 | 18.9 | 97.6 | 19.28 | 0.14 |
| *24* | *2.883* | *-0.0020* | *0.3279* | *0.488* | - | *96.6* | *19.30* | *0.10* |
| 08 | 2.828 | 0.0641 | 0.1587 | 0.524 | 8.0 | 98.5 | 19.31 | 0.12 |
| 33 | 3.007 | 0.0616 | 0.7544 | 0.290 | 8.3 | 92.7 | 19.33 | 0.17 |
| 03 | 2.857 | 0.0421 | 0.1270 | 1.175 | 12.1 | 98.8 | 19.56 | 0.05 |
| 22 | 3.455 | 0.7470 | 2.296 | 0.132 | 0.68 | 82.1 | 19.67 | 0.38 |
| *27* | *4.137* | *2.979* | *4.922* | *0.070* | *0.17* | *70.6* | *20.29* | *0.73* |
| *01* | *6.692* | *4.587* | *10.40* | *0.163* | *0.11* | *59.6* | *27.69* | *0.46* |
| *26* | *313.7* | *0.3872* | *1042.2* | *0.007* | *1.3* | *1.8* | *39.80* | *43.61* |
| **Mean age ± 2σ** | | **n=16** | **MSWD=9.92** | | **31.7 ±44.1** | | **19.12** | **0.10** |

**Notes:**

Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interfering reactions.
Errors quoted for individual analyses include analytical error only, without interfering reaction or J uncertainties.
Mean age is weighted mean age of Taylor (1982). Mean age error is weighted error of the mean (Taylor, 1982), multiplied by the root of the MSWD where MSWD>1, and also incorporates uncertainty in J factors and irradiation correction uncertainties.
Decay constants and isotopic abundances after Minn et al., (2000).
# symbol preceding sample ID denotes analyses excluded from mean age calculations.
Ages calculated relative to FC-2 Fish Canyon Tuff sanidine interlaboratory standard at 28.201 Ma
Decay Constant (LambdaK (total)) = 5.463e-10/a
Correction factors:

$(^{39}Ar/^{37}Ar)_{Ca}$ = 0.0007064 ± 4e-06
$(^{36}Ar/^{37}Ar)_{Ca}$ = 0.0002731 ± 0
$(^{38}Ar/^{39}Ar)_K$ = 0.01261
$(^{40}Ar/^{39}Ar)_K$ = 0.00808 ± 0.00041

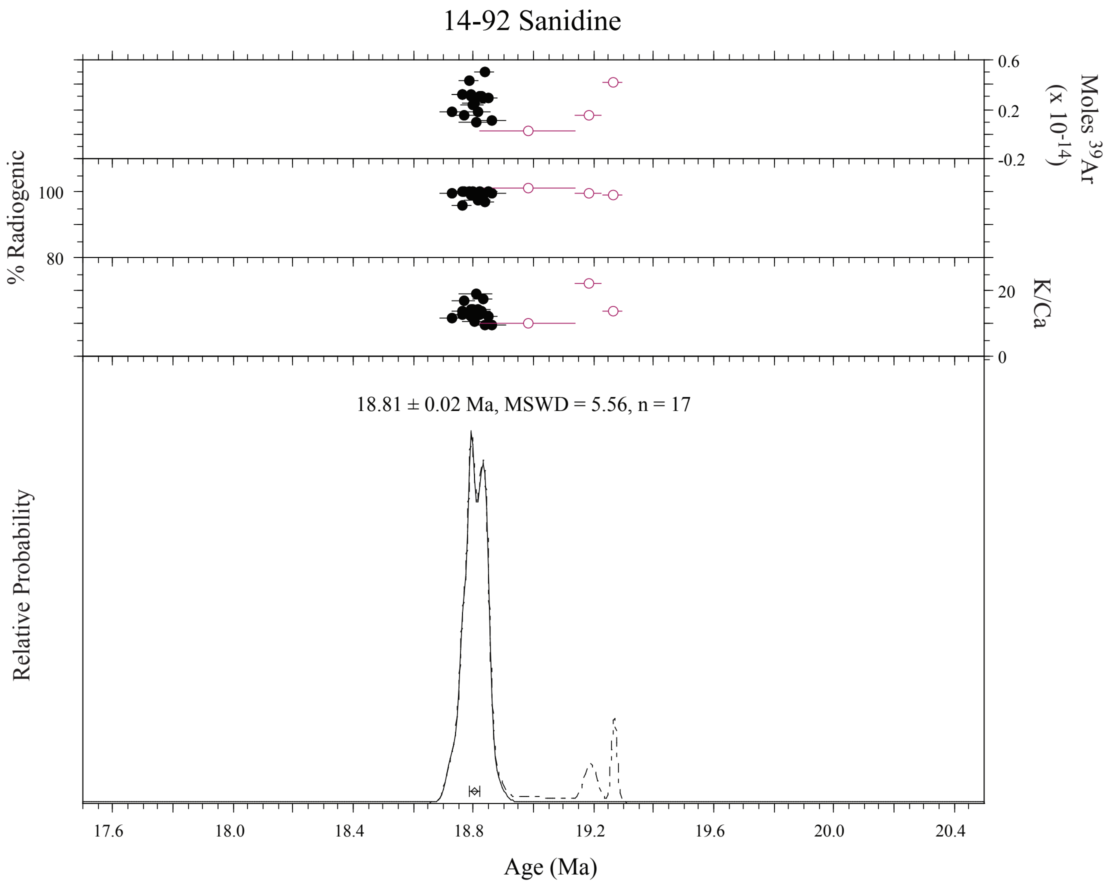
**Table 3. $^{40}Ar/^{39}Ar$ analytical data.**

| | ID | Power (Watts) | $^{40}Ar/^{39}Ar$ | $^{37}Ar/^{39}Ar$ | $^{36}Ar/^{39}Ar$ (x $10^{-3}$) | $^{39}Ar_K$ (x $10^{-15}$ mol) | K/Ca | $^{40}Ar^*$ (%) | $^{39}Ar$ (%) | Age (Ma) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **14-234,** gm, 12.23 mg, J=0.0038372±0.12%, D=1±0, NM-277H, Lab#=63829-01 | | | | | | | | | |
| X | A | 1 | 13.19 | 0.4716 | 36.42 | 0.869 | 1.1 | 18.6 | 0.4 | 17.18 |
| X | B | 1 | 9.376 | 0.4715 | 21.43 | 3.19 | 1.1 | 32.8 | 1.8 | 21.47 |
| X | C | 1 | 6.232 | 0.5441 | 10.24 | 9.14 | 0.94 | 52.1 | 5.7 | 22.64 |
| X | D | 2 | 4.685 | 0.6794 | 4.826 | 12.17 | 0.75 | 70.7 | 11.0 | 23.09 |
| X | E | 2 | 4.094 | 0.6842 | 2.689 | 13.65 | 0.75 | 81.9 | 16.9 | 23.37 |
| X | F | 2 | 3.835 | 0.6349 | 1.696 | 14.44 | 0.80 | 88.3 | 23.1 | 23.58 |
| X | G | 3 | 3.658 | 0.5574 | 1.004 | 27.0 | 0.92 | 93.1 | 34.8 | 23.72 |
| X | H | 5 | 3.540 | 0.5707 | 0.6625 | 67.8 | 0.89 | 95.8 | 64.0 | 23.61 |
| | I | 7 | 3.546 | 0.9294 | 0.8385 | 56.5 | 0.55 | 95.1 | 88.4 | 23.50 |
| | J | 10 | 3.585 | 1.460 | 1.118 | 19.35 | 0.35 | 94.1 | 96.8 | 23.51 |
| | K | 15 | 3.602 | 1.534 | 1.194 | 7.41 | 0.33 | 93.6 | 100.0 | 23.51 |
| | **Integrated age ± 2σ** | | n=11 | | | 231.5 | 0.66 | | K2O=1.90 | 23.45 |
| | **Plateau ± 2σ** | **steps I-K** | **n=3** | | **MSWD=0.04** | **83.262** | **0.483±0.241** | | **36.0** | **23.51** |
| | **Isochron±2σ** | steps A-K | n=11 | | MSWD=118.02 | | $^{40}Ar/^{36}Ar$= | 280.2±0.7 | | 23.65 |
| | **15-11,** biotite, J=0.0037745±0.03%, D=1±0, NM-277E, Lab#=63769 | | | | | | | | | |
| | 02C | 10 | 4.102 | 0.0178 | 0.6131 | 9.786 | 28.7 | 95.6 | 26.85 | 0.01 |
| | 01B | 10 | 4.113 | 0.0183 | 0.6201 | 14.575 | 27.9 | 95.6 | 26.91 | 0.01 |
| | 03C | 10 | 4.087 | 0.0099 | 0.5200 | 11.028 | 51.4 | 96.3 | 26.93 | 0.01 |
| | 05C | 10 | 4.179 | 0.0110 | 0.7986 | 3.768 | 46.2 | 94.4 | 27.00 | 0.01 |
| | 04C | 10 | 4.003 | 0.0074 | 0.1841 | 14.962 | 69.2 | 98.7 | 27.03 | 0.01 |
| | *02B* | *1* | *4.237* | *0.0361* | *0.7742* | *1.223* | *14.1* | *94.7* | *27.46* | *0.03* |
| | *04B* | *1* | *4.218* | *0.0739* | *0.5913* | *0.969* | *6.9* | *96.0* | *27.72* | *0.04* |
| | *03B* | *1* | *4.321* | *0.0704* | *0.8591* | *0.497* | *7.3* | *94.3* | *27.88* | *0.07* |
| | **Mean age ± 2σ** | | | **n=5** | **MSWD=108.66** | | **44.7 ±34.4** | | **26.96** | **0.07** |
| | **15-11,** hbl, J=0.0037732±0.03%, D=1±0, NM-277E, Lab#=63770 | | | | | | | | | |
| | 03B | 10 | 5.287 | 3.645 | 5.704 | 1.026 | 0.14 | 73.7 | 26.75 | 0.07 |
| | 04B | 10 | 4.609 | 3.914 | 3.483 | 1.024 | 0.13 | 84.6 | 26.75 | 0.05 |
| | 02B | 10 | 7.854 | 4.328 | 14.53 | 0.441 | 0.12 | 49.8 | 26.85 | 0.16 |
| | 01B | 10 | 7.312 | 4.606 | 12.60 | 0.689 | 0.11 | 54.2 | 27.21 | 0.13 |
| | **Mean age ± 2σ** | | | **n=4** | **MSWD=4.00** | | **0.12 ±0.03** | | **26.80** | **0.16** |

**Notes:**

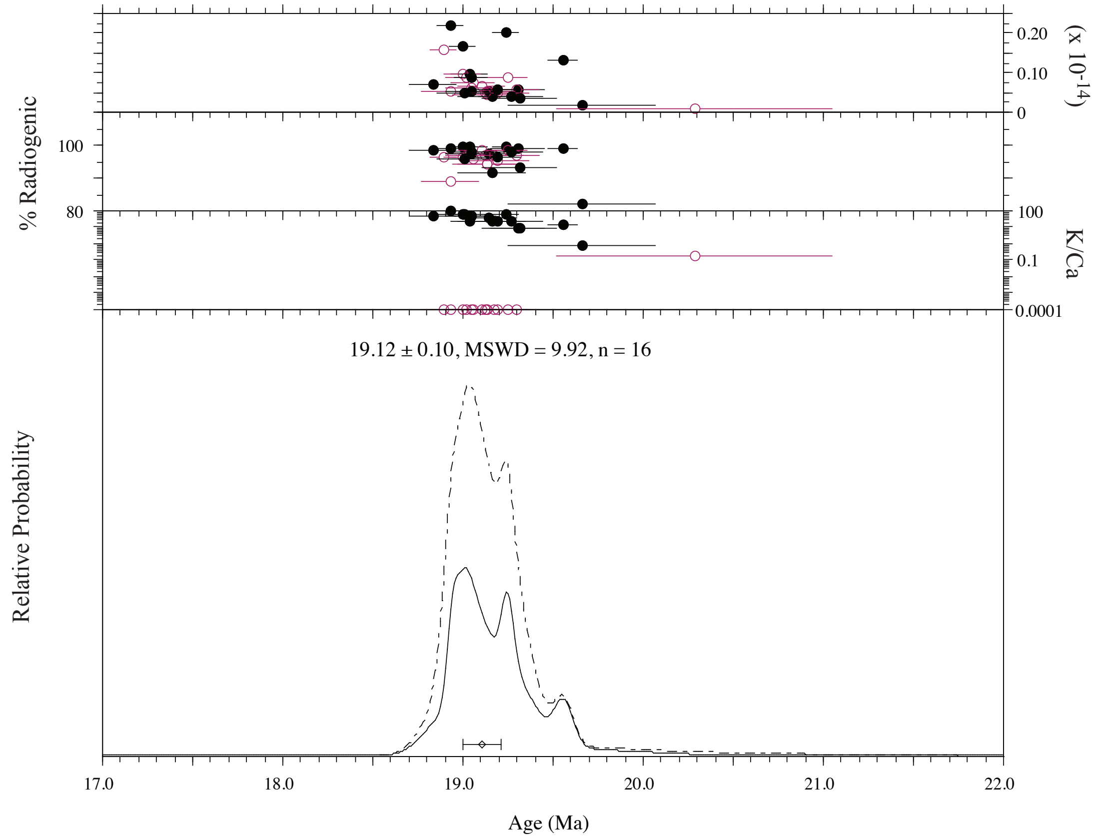
Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interfering reactions.
Errors quoted for individual analyses include analytical error only, without interfering reaction or J uncertainties.
Integrated age calculated by summing isotopic measurements of 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 Minn et al., (2000).
# 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 28.201 Ma
Decay Constant (LambdaK (total)) = 5.463e-10/a
Correction factors:

$(^{39}Ar/^{37}Ar)_{Ca}$ = 0.0007064 ± 4e-06
$(^{36}Ar/^{37}Ar)_{Ca}$ = 0.0002731 ± 0
$(^{38}Ar/^{39}Ar)_K$ = 0.01261

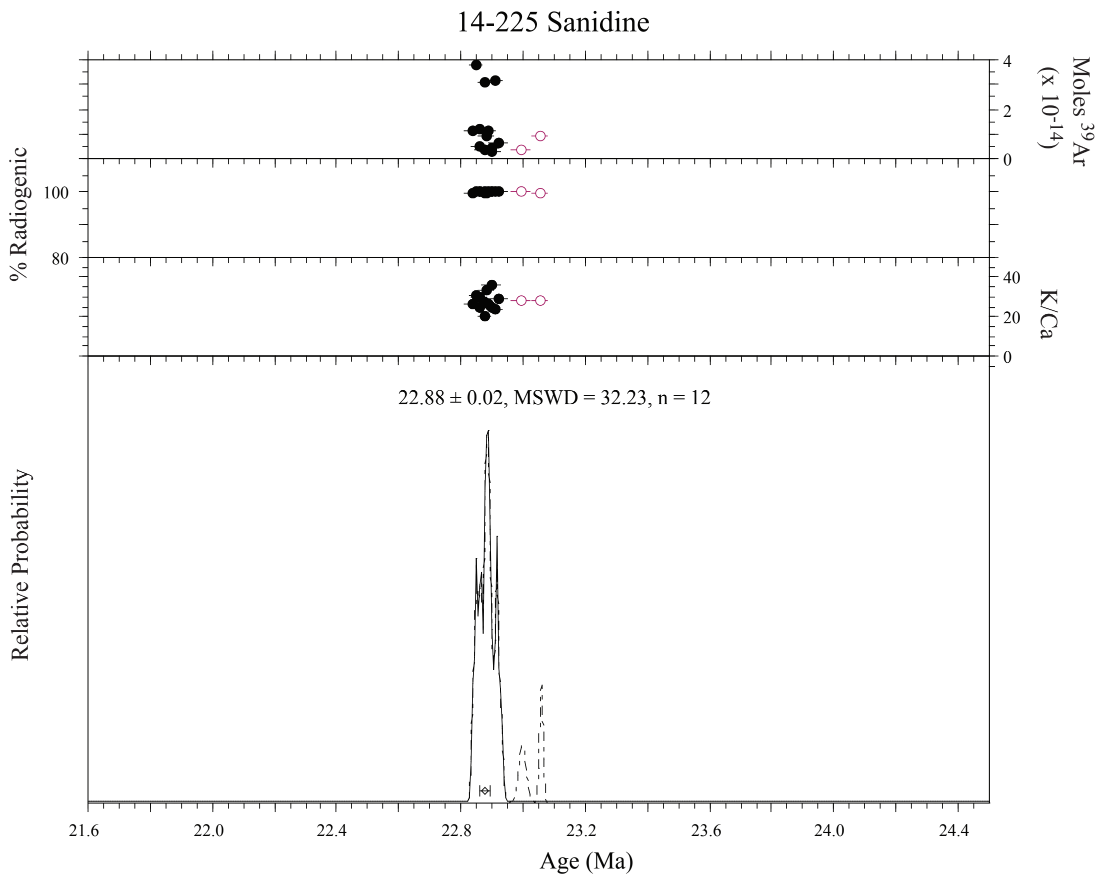


14-92 Sanidine
Moles $^{39}$Ar (x $10^{-14}$)
0.6
0.2
-0.2
% Radiogenic
100
80
K/Ca
20
0
18.81 ± 0.02 Ma, MSWD = 5.56, n = 17
Relative Probability
17.6
18.0
18.4
18.8
19.2
19.6
20.0
20.4
Age (Ma)

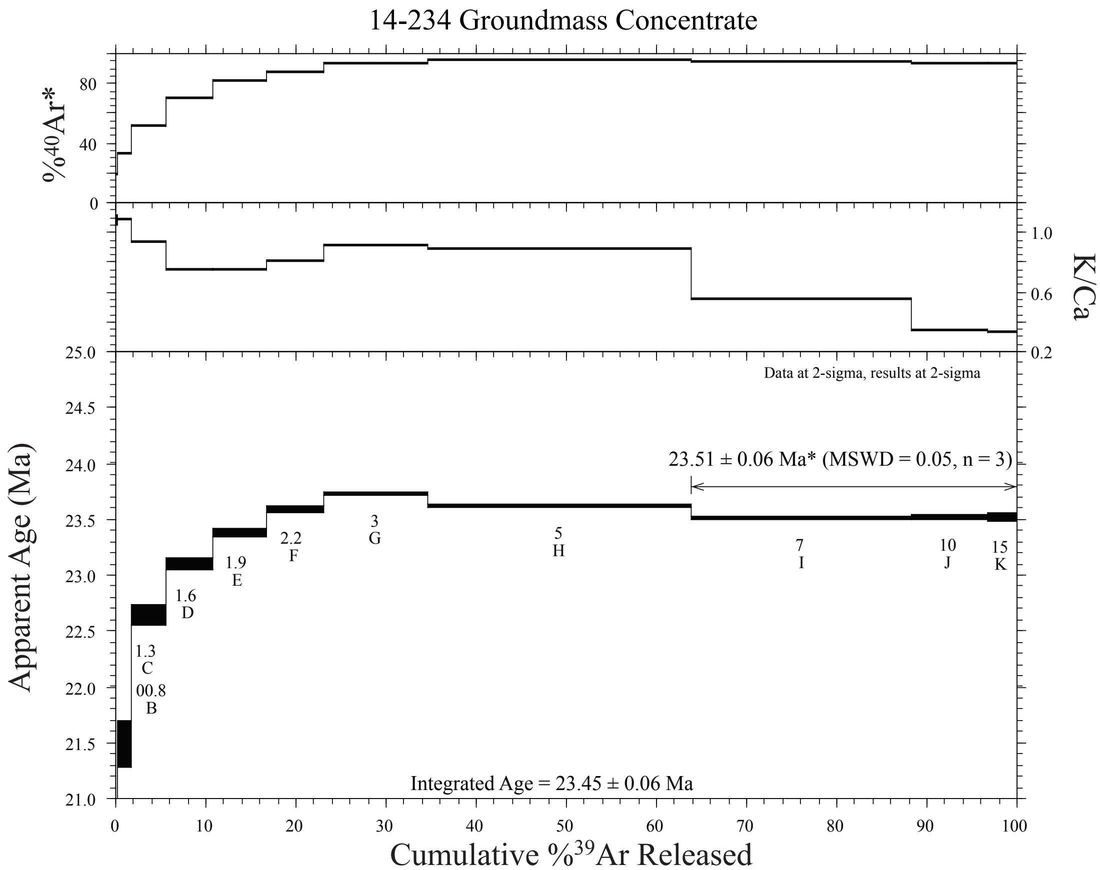
15-9 Sanidine



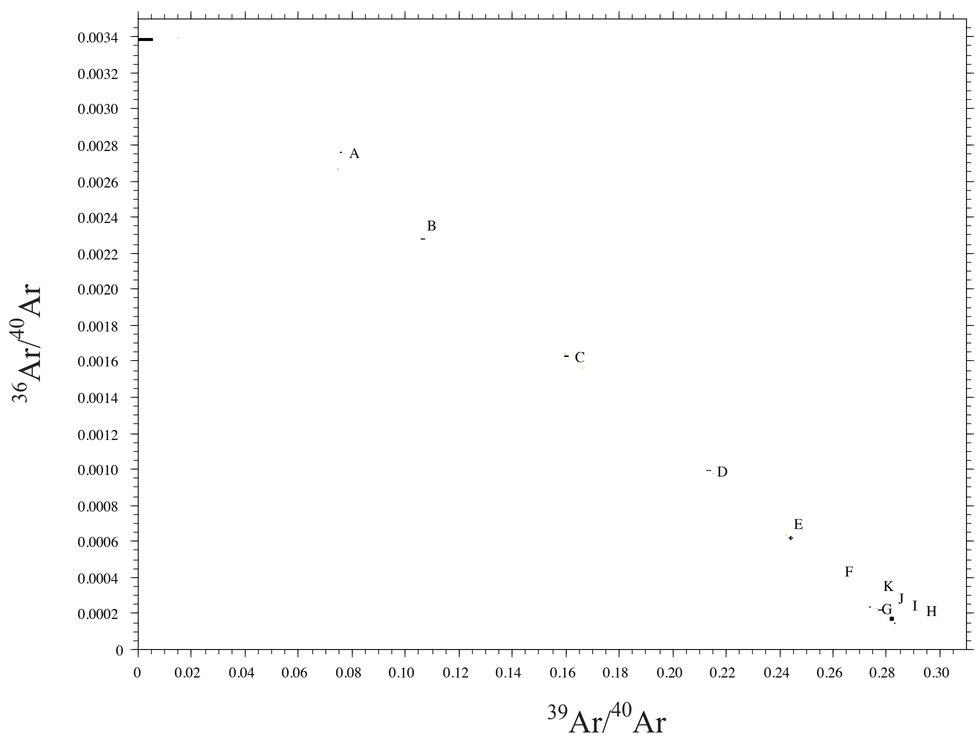

Age (Ma)



14-225 Sanidine
Moles $^{39}$Ar (x 10$^{-14}$)
% Radiogenic
K/Ca
22.88 ± 0.02, MSWD = 32.23, n = 12
Relative Probability
Age (Ma)

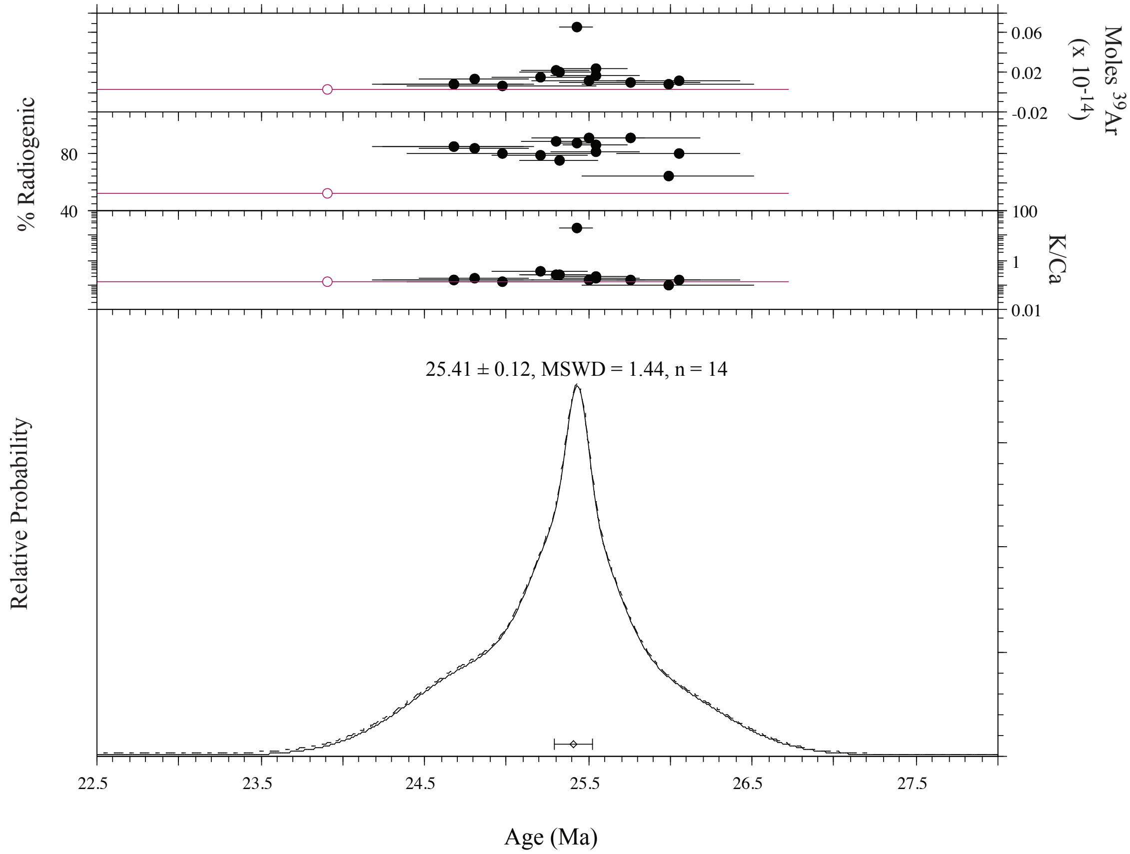


14-234 Groundmass Concentrate
%40Ar*
K/Ca
Apparent Age (Ma)
Data at 2-sigma, results at 2-sigma
23.51 ± 0.06 Ma* (MSWD = 0.05, n = 3)
Integrated Age = 23.45 ± 0.06 Ma
Cumulative %39Ar Released

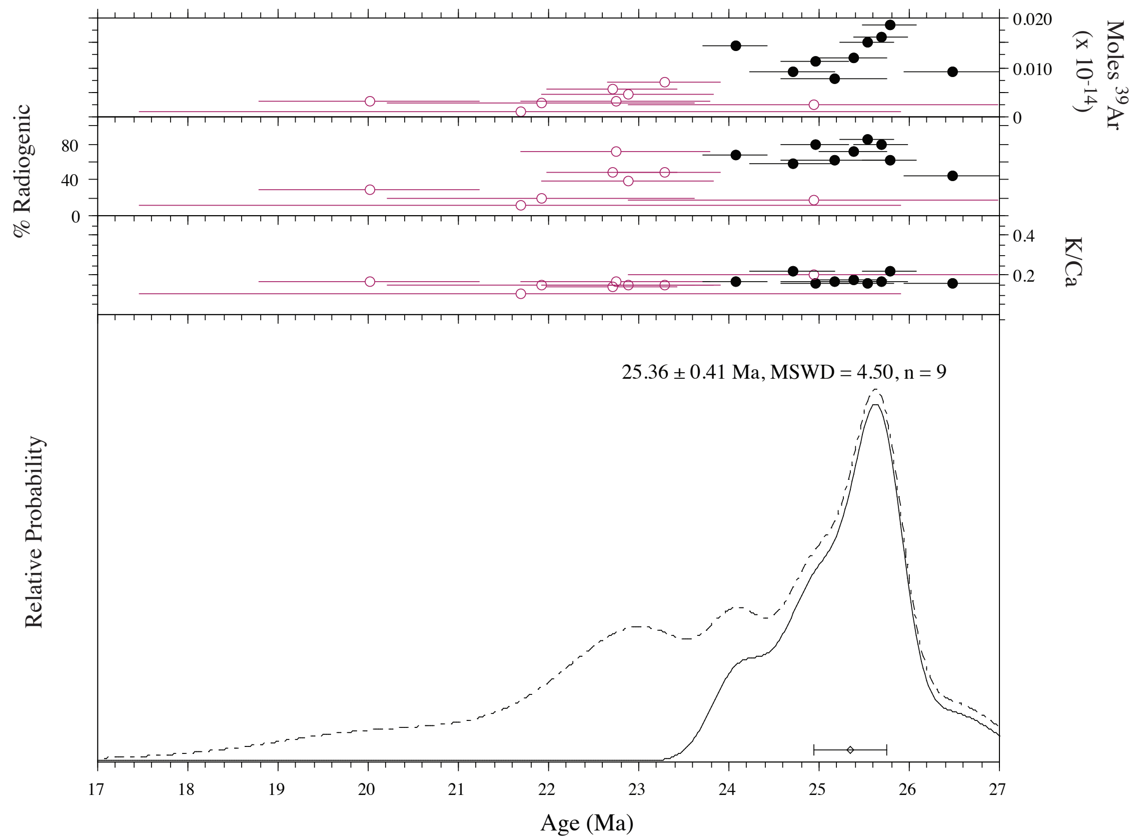



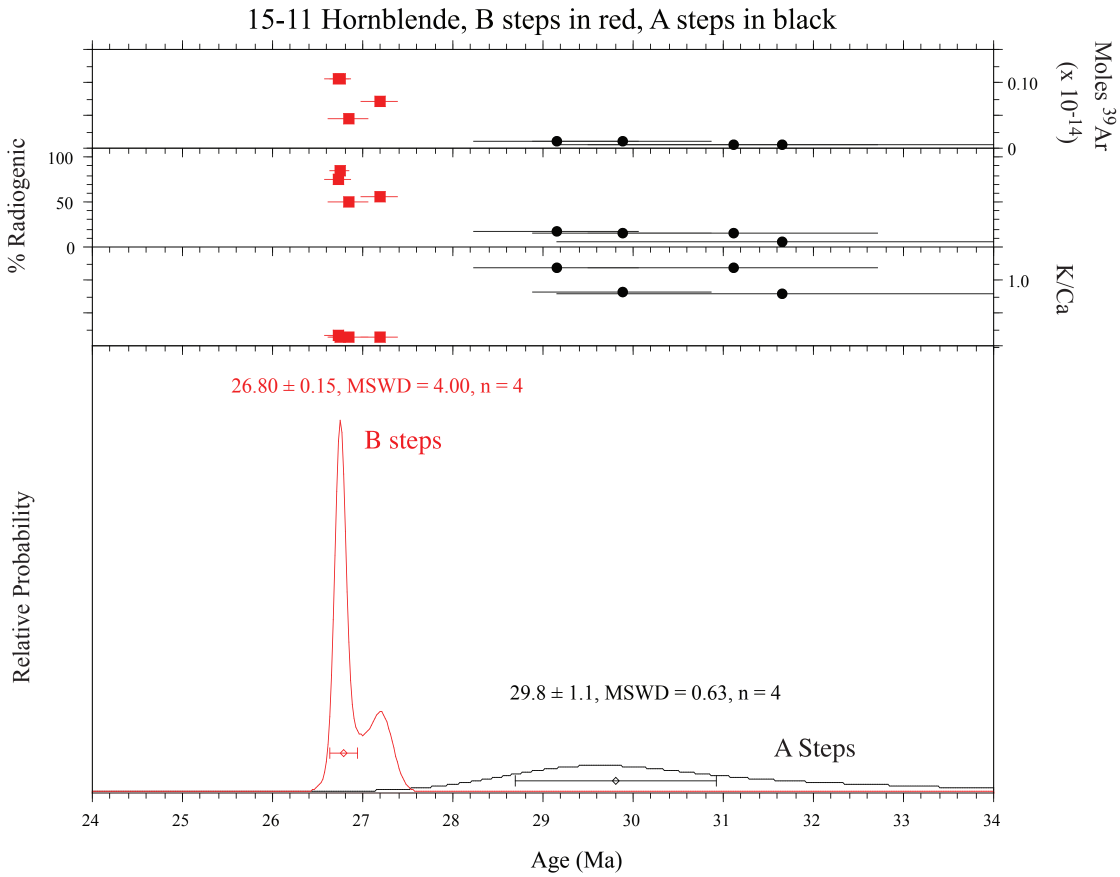
36Ar/40Ar
39Ar/40Ar

GP101514-B Plagioclase and Sanidine

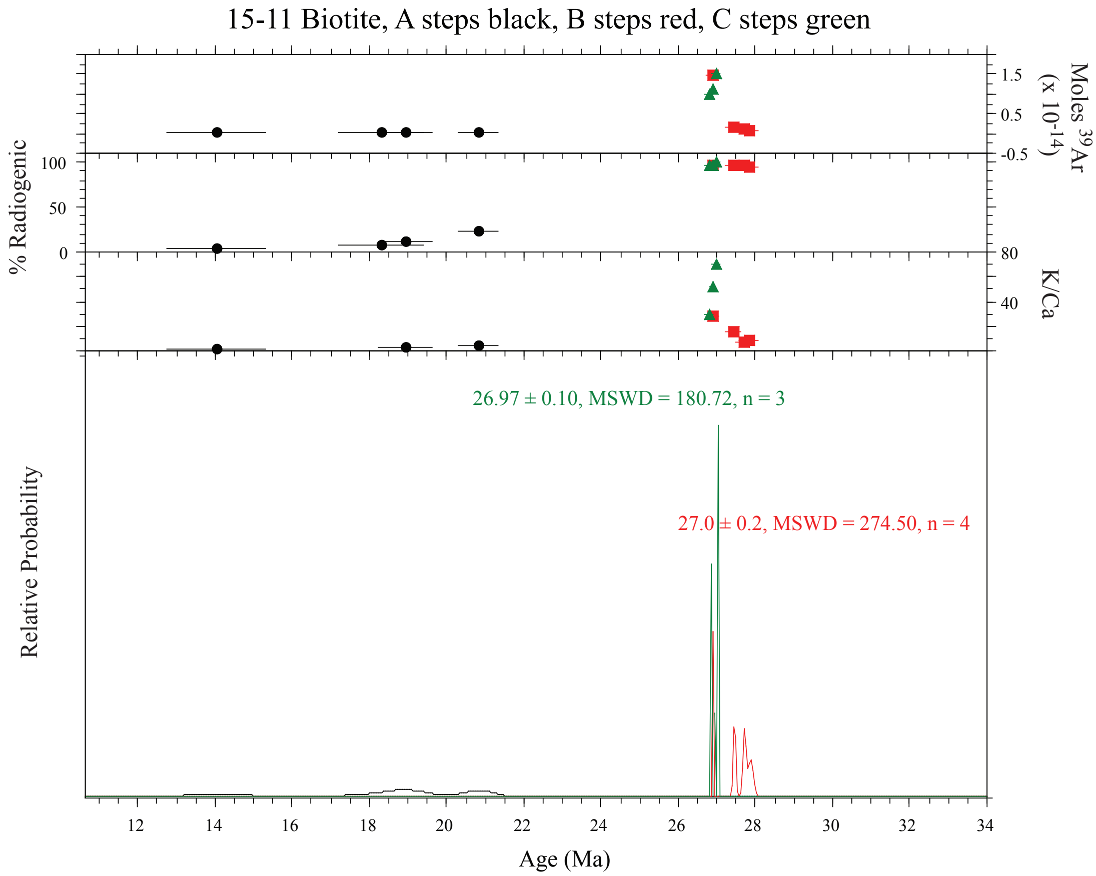


14-230B Plagioclase

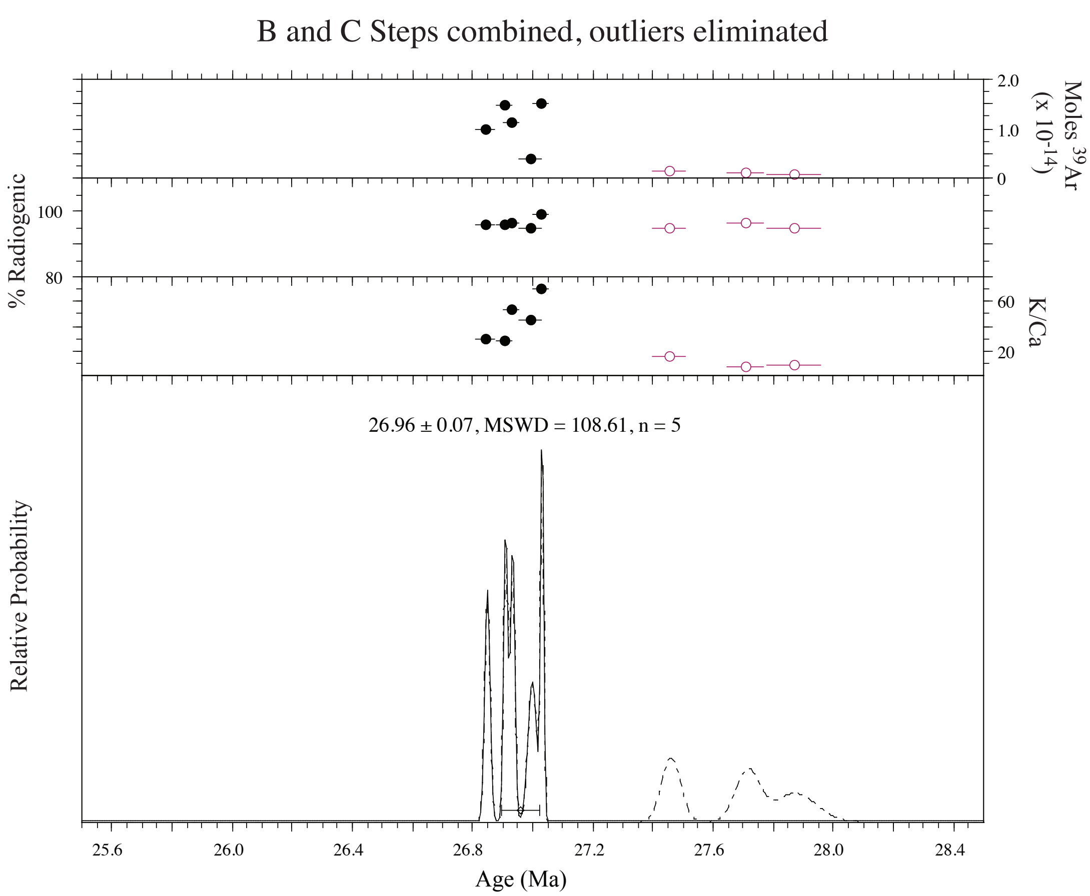




15-11 Hornblende, B steps in red, A steps in black
Moles $^{39}$Ar
(x 10$^{-14}$)
0.10
0
% Radiogenic
100
50
0
K/Ca
1.0
26.80 ± 0.15, MSWD = 4.00, n = 4
B steps
Relative Probability
29.8 ± 1.1, MSWD = 0.63, n = 4
A Steps
24
25
26
27
28
29
30
31
32
33
34
Age (Ma)



15-11 Biotite, A steps black, B steps red, C steps green
Moles $^{39}$Ar (x $10^{-14}$)
% Radiogenic
K/Ca
Relative Probability
26.97 ± 0.10, MSWD = 180.72, n = 3
27.0 ± 0.2, MSWD = 274.50, n = 4
Age (Ma)

B and C Steps combined, outliers eliminated
Moles $^{39}$Ar (x $10^{-14}$)
% Radiogenic
K/Ca
Relative Probability
26.96 ± 0.07, MSWD = 108.61, n = 5
Age (Ma)