$^{40}\text{Ar}/^{39}\text{Ar}$ Geochronology results from three Quaternary basalts

By

Richard P. Esser

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Prepared for

Dr. Roy Breckenridge
Idaho Geological Survey
University of Idaho
PO Box 443014
Moscow, ID 83844-3014

NEW MEXICO
GEOCHRONOLOGICAL RESEARCH LABORATORY (NMGRL)

CO-DIRECTORS

DR. MATTHEW T. HEIZLER
DR. WILLIAM C. McINTOSH

LABORATORY TECHNICIANS

LISA PETERS
RICHARD P. ESSER

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Introduction

Three basaltic rocks were submitted to the New Mexico Geochronology Research Laboratory for $^{40}$Ar/$^{39}$Ar dating by Dr. Roy Breckenridge of the Idaho Geological Survey.

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

Groundmass concentrate was prepared from the three basalt samples (RB-02-HA, RB-02-MA and RB-02-WR).

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 three groundmass concentrates is given in Table 2. Figures 1-3 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 4. Details of the overall operation of the New Mexico Geochronology Research Laboratory are provided in the Appendix.

Groundmass concentrate samples RB-02-WR and RB-02-MA yield age spectra that are very similar in appearance to one another. The age spectra for RB-02-WR (Figure 1) and RB-02-MA (Figure 2) are predominately flat for the majority of the $^{39}$Ar_K released. However, both spectra exhibit a minor increase in age at the 750°-825°C temperature steps and then another increase in age at the 1200°C temperature steps. The radiogenic yields and K/Ca ratios for these two samples are very similar as well, ranging from 0% to about 12% radiogenic yield and from 0.005 to 0.5 for the K/Ca values. For both samples, radiogenic yields are generally highest for the intermediate temperature steps (~750°-825°C). K/Ca ratio decreases with increasing temperature. A weighted mean or “plateau” age assigned to the flattest portion of each spectrum (steps D through G for both samples) yields apparent ages of 1.17±0.21 Ma (45.4% of the cumulative $^{39}$Ar_K released; MSWD=3.30) for RB-02-WR and 1.45±0.16 Ma (49.8% of the cumulative $^{39}$Ar_K released; MSWD=1.53). In each case, the MSWD values were greater than 1, so that the uncertainties were multiplied by the square root of the MSWD according to the procedures set forth by Mahon (1996). The inverse isochron results for RB-02-WR (age=1.06±0.19 Ma; $^{40}$Ar/$^{36}$Ar=296±4; MSWD=3.8) and RB-02-MA (age=1.25±0.36 Ma; $^{40}$Ar/$^{36}$Ar=298±4; MSWD=3.3) are analytically indistinguishable from their respective plateau weighted mean ages and also yield trapped $^{40}$Ar/$^{36}$Ar compositions equivalent to modern day atmosphere (295.5).

The age spectrum for RB-02-HA (Figure 3) is more precise than the spectra for RB-02-WR and RB-02-MA and does not exhibit the same increase in apparent age at the 750°-825°C temperature steps. However, there is an increase in age at the highest temperature steps. The radiogenic yields are not as high as those for the previous two samples, but are more consistent at about 9%. The K/Ca ratios vary from 0.009 to 0.69 and also trend to lower values as the heating temperatures increase. The
weighted mean of steps B through G yields an apparent age of 0.515±0.063 Ma (89.3% of the cumulative 39ArK released; MSWD=1.29). The inverse isochron yields an apparent age of 0.45±0.08 Ma with a 40Ar/36Ar ratio of 298±4 and a MSWD of 2.

Discussion

All three of the RB age spectra exhibit small increases in apparent ages at the highest temperatures of gas release. Specifically, the final 1 to 2 heating steps of each RB age spectrum yield apparent ages slightly older than those ages comprising the weighted mean or flattest portion of the age spectrum. In addition, the RB-02-WR and RB-02-MA age spectra exhibit an increase in age at intermediate temperature steps. The anomalously old ages at the highest temperatures are likely caused by excess argon. The increase in age at the 750°C temperature steps for RB-02-WR and RB-02-MA may be caused by excess argon. Excess argon is non-atmospheric 40Ar within a sample that is derived by a process other than the in situ radioactive decay of 40K (McDougall and Harrison, 1999). Most commonly, excess argon refers to trapped 40Ar/36Ar compositions greater than 295.5 (the present day 40Ar/36Ar composition). In the case of the RB groundmass concentrates, small amounts of excess argon may have been incorporated into high temperature mafic mineral phases (e.g. pyroxene and/or olivine; the cover letter that accompanied the samples indicates “an ophitic texture and consist of 1 mm augite grains enclosing 0.1 to 0.2 mm labradorite laths”) at elevated argon partial pressures (i.e. at depth or in a magma chamber). In some cases, an inverse isochron can be employed to test for trapped 40Ar/36Ar compositions greater than 295.5. However, the inverse isochrons for the three RB groundmass concentrate samples yield trapped 40Ar/36Ar compositions statistically indistinguishable from 295.5.

An alternative explanation to excess argon for the increase in age at the 750°C temperature steps (RB-02-WR and RB-02-MA) is alteration and argon loss causing anomalously young ages for the 700°C and, to a lesser extent, the 750°C temperature steps. The low radiogenic yields (<<12%) for RB-02-WR and RB-02-MA (and RB-02-HA) are indicative of alteration and/or hydration of groundmass phases, particularly glass. Hydration and/or alteration can increase the quantity of atmospheric argon within a sample, partially or completely overwhelming the radiogenic argon. Hydration and/or alteration may also cause potassium bearing phases to lose any in situ produced 40Ar* relative to the parent 40K, thereby lowering the 40Ar/39Ar ratio and apparent age. The 700°C heating steps may have lost comparatively more 40Ar*, thus decreasing their apparent ages. Generally, additional sample preparation and/or analytical manipulation are not effective for improving the quality of data from low radiogenic yield basalts. There does not appear to be any argon loss for the low temperature heating steps for the RB-02-HA groundmass concentrate, despite its low radiogenic yields.
Given the apparent combination of argon loss and excess argon for the RB-02-WR and RB-02MA groundmass concentrate samples, the weighted mean of the flattest portion of each age spectra yields the most accurate age of each sample. For RB-02-WR, the preferred age is the weighted mean of steps D through G at 1.17±0.21 Ma. For RB-02-MA, the preferred age is the weighted mean of steps D through G at 1.45±0.16 Ma. Because sample RB-02-HA yields a spectrum that is less disturbed than the other two samples (i.e. no low temperature argon loss), its preferred age of 0.515±0.063 Ma is more precise.

Figure 4 shows a summary of the $^{40}$Ar/$^{39}$Ar ages produced by this study plotted against the geomagnetic polarity time scale (GPTS) of Izett and Obradovich (1994). According to personal communications with Dr. Roy Breckenridge, the stratigraphic relationships among the three RB samples are unknown. However, Dr. Breckenridge does state that RB-02-WR and RB-02-MA have opposite magnetic polarities. Based on the $^{40}$Ar/$^{39}$Ar apparent ages, it appears that RB-02-MA should have yielded a reversed magnetic polarity as its age and error are entirely contained within the Matuyama reversed Subchron. In order to have normal polarity, RB-02-WR must have been erupted during the Jaramillo Normal Subchron. The $^{40}$Ar/$^{39}$Ar apparent age of RB-02-HA indicates that the sample was erupted during the Brunhes Normal Chron.
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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. Roy Breckenridge.
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 D-3 position, Texas A&M University Research Reactor.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-1). Assigned age = 27.84 Ma (Deino and Potts, 1990)
relative 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 7 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 filament operated at ~2000°C.

Analytical parameters:
Electron multiplier sensitivity averaged 2.2x10^{-19} moles/pA.
Total system blank and background for the furnace averaged 3520, 16.5, 4.0, 4.4, 15.4 x 10^{-16} moles
at masses 40, 39, 38, 37, and 36, respectively for temperatures <1300°C.
J-factors determined to a precision of ± 0.1% by CO2 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 CaF2 and are as follows:
\(^{40}\text{Ar}/^{39}\text{Ar}\), _k_ = 0.0002±0.0003; \(^{40}\text{Ar}/^{36}\text{Ar}\), _k_ = 0.00028±0.00001; and \(^{39}\text{Ar}/^{37}\text{Ar}\), _k_ = 0.00089±0.00003.

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 \(^{39}\text{Ar}\) released.
Isochron ages, \(^{40}\text{Ar}/^{36}\text{Ar}\), 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 ±2σ, unless otherwise noted.
### Table 2. $^{40}\text{Ar}^{39}\text{Ar}$ analytical data.

<table>
<thead>
<tr>
<th>ID</th>
<th>Power (Watts)</th>
<th>$^{40}\text{Ar}^{39}\text{Ar}$ (x 10$^{-5}$)</th>
<th>$^{36}\text{Ar}^{39}\text{Ar}$ (x 10$^{-5}$)</th>
<th>$^{39}\text{Ar}^{39}\text{Ar}$ K/Ca</th>
<th>$^{40}\text{Ar}^{*}$</th>
<th>$^{39}\text{Ar}$</th>
<th>Age ±1σ (Ma)</th>
<th>±1σ (Watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RB-02-WR</td>
<td>189.88 mg groundmass concentrate, J=0.0001109±0.10%, D=1.00623±0.00131, NM-153, Lab#=53247-01</td>
<td>A 625 7619.2 0.9390 25699.4 0.075 0.54 0.3 2.6 5.0 8.5</td>
<td>B 700 102.8 1.919 336.4 1.17 0.27 3.5 42.2 0.71 0.12</td>
<td>C 750 87.77 3.785 280.7 0.180 0.13 5.9 48.3 1.03 0.21</td>
<td>D 800 62.44 6.831 190.1 0.451 0.075 10.9 63.6 1.374 0.090</td>
<td>E 875 52.39 9.027 162.4 0.398 0.057 9.8 77.1 1.032 0.100</td>
<td>F 975 64.47 11.79 203.4 0.341 0.043 8.3 88.6 1.08 0.12</td>
<td>G 1075 171.9 13.23 573.9 0.149 0.039 2.0 93.7 0.70 0.32</td>
</tr>
<tr>
<td>RB-02-MA</td>
<td>183.96 mg groundmass concentrate, J=0.0001111±0.10%, D=1.00623±0.00131, NM-153, Lab#=53248-01</td>
<td>A 625 6854.8 1.075 23025.1 0.132 0.47 0.7 4.9 10.2 7.5</td>
<td>B 700 119.8 2.230 391.2 0.931 0.23 3.6 39.0 0.87 0.15</td>
<td>C 750 109.0 3.952 350.1 0.143 0.13 5.4 44.3 1.18 0.25</td>
<td>D 800 67.53 6.498 203.1 0.471 0.079 11.9 61.6 1.62 0.12</td>
<td>E 875 56.09 8.719 170.2 0.419 0.059 11.6 77.0 1.316 0.099</td>
<td>F 975 73.83 11.81 229.1 0.339 0.043 9.6 89.4 1.44 0.15</td>
<td>G 1075 235.2 13.59 769.9 0.128 0.038 3.8 94.1 1.79 0.41</td>
</tr>
<tr>
<td>RB-02-HA</td>
<td>187.53 mg groundmass concentrate, J=0.0001117±0.10%, D=1.00623±0.00131, NM-153, Lab#=53250-01</td>
<td>A 625 8667.4 0.7430 29473.3 0.047 0.69 -0.5 1.0 -8.5 10.3</td>
<td>B 700 116.4 1.721 382.5 0.788 0.30 3.0 17.9 0.71 0.14</td>
<td>C 750 70.39 2.702 226.2 0.152 0.19 5.4 21.2 0.76 0.18</td>
<td>D 800 42.34 3.178 134.3 0.774 0.16 6.9 37.8 0.586 0.070</td>
<td>E 875 28.36 3.144 88.33 1.02 0.16 8.9 59.7 0.509 0.047</td>
<td>F 975 28.40 3.873 82.55 1.00 0.13 8.8 81.2 0.471 0.046</td>
<td>G 1075 61.36 5.114 202.1 0.424 0.100 3.3 90.3 0.42 0.11</td>
</tr>
</tbody>
</table>

**Notes:**
- Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interfering reactions.
- Ages calculated relative to FC-1 Fish Canyon Tuff sanidine interlaboratory standard at 27.84 Ma.
- Errors quoted for individual analyses include analytical error only, without interfering reaction or J uncertainties.
- Integrated age calculated by recombing isotopic measurements of all steps.
- Integrated age error calculated by recombining errors of isotopic measurements of all steps.
- Plateau age is inverse-variance-weighted mean of selected steps.
- Plateau age error is inverse-variance-weighted mean error (Taylor, 1982) times root MSWD where MSWD>1.
- Plateau and integrated ages incorporate uncertainties in interfering reaction corrections and J factors.
- Decay constants and isotopic abundances after Steiger and Jaeger (1977).
- Decay constants and isotopic abundances after Steiger and Jaeger (1977).

**Correction factors:**
- ($^{36}\text{Ar}^{39}\text{Ar})_b$ = 0.00072 ± 2e-05
- ($^{38}\text{Ar}^{39}\text{Ar})_b$ = 0.00028 ± 5e-06
- ($^{40}\text{Ar}^{39}\text{Ar})_b$ = 0.01077
- ($^{40}\text{Ar}^{39}\text{Ar})_b$ = 0.0002 ± 0.0003
Figure 1. $^{40}$Ar/$^{39}$Ar age spectrum and inverse isochron for the RB-02-WR groundmass concentrate. The preferred age of this sample is the weighted mean of steps D through G ($1.17 \pm 0.21$ Ma). All errors are two-sigma.
Figure 2. $^{40}$Ar/$^{39}$Ar age spectrum and inverse isochron for the RB-02-MA groundmass concentrate. The preferred age of this sample is the weighted mean of steps D through G (1.45 ± 0.16 Ma). All errors are two-sigma.
Figure 3. $^{40}$Ar/$^{39}$Ar age spectrum and inverse isochron for the RB-02-HA groundmass concentrate. The preferred age of this sample is the weighted mean of steps B through G ($0.515 \pm 0.063$ Ma). All errors are two-sigma.
Figure 4. Summary plot of the $^{40}$Ar/$^{39}$Ar ages yielded by this study. The age of RB-02-WR indicates that this sample yield a normal or reversed polarity. Sample RB-02-MA should yield a reversed polarity, while RB-02-HA should yield a normal polarity. All errors are reported at two-sigma.