$^{40}Ar/^{39}Ar$ Geochronology Results from the Cedar City, Hatch, and Haycock Mountain Quadrangles, Utah

by

Utah Geological Survey and Nevada Isotope Geochronology Laboratory

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INTRODUCTION

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

The data and methods are available at http://geology.utah.gov/online/analytical_data.htm:

Table 1. Sample numbers and locations.

Sample #	7.5' quadrangle	Longitude (NAD83)	Longitude (NAD83)	Reference
H101508-4	Hatch	-112.4030	37.6751	Biek and others (2012)
HM101408-1	Haycock Mountain	-112.6071	37.6879	Biek and others (2012)
CH2	Cedar City	4165419	320449	Knudsen (in preparation)

DISCLAIMER

This open-file release is intended as a data repository for information gathered in support of various UGS projects. The data are presented as received from Nevada Isotope Geochronology Laboratory and do not necessarily conform to UGS technical, editorial, or policy standards; this should be considered by an individual or group planning to take action based on the contents of this report. The Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding the suitability of this product for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

REFERENCE

Biek, R.F., Rowley, P.D., Anderson, J.J., Maldonado, F., Moore, D.W., Eaton, J.G., Hereford, R., and Matyjasik, B., 2012, Interim geologic map of the Panguitch 30' x 60' quadrangle, Garfield, Iron, and Kane Counties, Utah: Utah Geological Survey Open-File Report 599, 124 p., 3 plates, scale 1:62,500.

Knudsen, T.R., in preparation, Interim geologic map of the Cedar City quadrangle, Iron County, Utah: Utah Geological Survey Open-File Report, scale 1:24,000.

Nevada Isotope Geochronology Laboratory - Description and Procedures

Samples analyzed by the $^{40}Ar/^{39}Ar$ method at the University of Nevada Las Vegas were wrapped in Al foil and stacked in 6 mm inside diameter sealed fused silica tubes. Individual packets averaged 3 mm thick and neutron fluence monitors (FC-2, Fish Canyon Tuff sanidine) were placed every 5-10 mm along the tube. Synthetic K-glass and optical grade CaF_2 were included in the irradiation packages to monitor neutron induced argon interferences from K and Ca. Loaded tubes were packed in an Al container for irradiation. Samples irradiated at the U. S. Geological Survey TRIGA Reactor, Denver, CO were in-core for 7 hours in the In-Core Irradiation Tube (ICIT) of the 1 MW TRIGA type reactor. Correction factors for interfering neutron reactions on K and Ca were determined by repeated analysis of K-glass and CaF_2 fragments. Measured $(^{40}Ar/^{39}Ar)_K$ values were 1.04 (± 19.23%) x 10^{-2}. Ca correction factors were $(^{36}Ar/^{37}Ar)_{Ca}$ = 2.64 (± 4.93%) x 10^{-4} and $(^{39}Ar/^{37}Ar)_{Ca}$ = 6.60 (± 6.11%) x 10^{-4}. J factors were determined by fusion of 4-8 individual crystals of neutron fluence monitors which gave reproducibility's of 0.24% to 0.55 at each standard position. Variation in neutron fluence along the 100 mm length of the irradiation tubes was <4%. Matlab curve fit was used to determine J and uncertainty in J at each standard position. No significant neutron fluence gradients were present within individual packets of crystals as indicated by the excellent reproducibility of the single crystal fluence monitor fusions.

Irradiated FC-2 sanidine standards together with CaF_2 and K-glass fragments were placed in a Cu sample tray in a high vacuum extraction line and were fused using a 20 W CO_2 laser. Sample viewing during laser fusion was by a video camera system and positioning was via a motorized sample stage. Samples analyzed by the furnace step heating method utilized a double vacuum resistance furnace similar to the Staudacher et al. (1978) design. Reactive gases were removed by three GP-50 SAES getters prior to being admitted to a MAP 215-50 mass spectrometer by expansion. The relative volumes of the extraction line and mass spectrometer allow 80% of the gas to be admitted to the mass spectrometer for laser fusion analyses and 76% for furnace heating analyses. Peak intensities were measured using a Balzers electron multiplier by peak hopping through 7 cycles; initial peak heights were determined by linear regression to the time of gas admission. Mass spectrometer discrimination and sensitivity was monitored by repeated analysis of atmospheric argon aliquots from an on-line pipette system. Measured $^{40}Ar/^{36}Ar$ ratios were 278.21 ± 0.46% during this work, thus a discrimination correction of 1.0622 (4 AMU) was applied to measured isotope ratios. The sensitivity of the mass spectrometer was ~6 x 10^{-17} mol mV^{-1} with the multiplier operated at a gain of 36 over the Faraday. Line blanks averaged 6.58 mV for mass 40 and 0.03 mV for mass 36 for laser fusion analyses and 24.23 mV for mass 40 and 0.09 mV for mass 36 for furnace heating analyses. Discrimination, sensitivity, and blanks were relatively constant over the period of data collection. Computer automated operation of the sample stage, laser, extraction line and mass spectrometer as well as final data reduction and age calculations were done using LabSPEC software written by B. Idleman (Lehigh University). An age of 28.02 Ma (Renne et al., 1998) was used for the Fish Canyon Tuff sanidine fluence monitor in calculating ages for samples.

For $^{40}Ar/^{39}Ar$ analyses a plateau segment consists of 3 or more contiguous gas fractions having analytically indistinguishable ages (i.e. all plateau steps overlap in age at ± 2σ analytical error) and comprising a significant portion of the total gas released (typically >50%). Total gas (integrated) ages are calculated by weighting by the amount of ^{39}Ar released, whereas plateau ages are weighted by the inverse of the variance. For each sample inverse isochron diagrams are examined to check for the effects of excess argon. Reliable isochrons are based on the MSWD criteria of Wendt and Carl (1991) and, as for plateaus, must comprise contiguous steps and a significant fraction of the total gas released. All analytical data are reported at the confidence level of 1σ (standard deviation).

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

Staudacher, T.H., Jessberger, E.K., Dorflinger, D., and Kiko, J., A refined ultrahigh-vacuum furnace for rare gas analysis, *J. Phys. E: Sci. Instrum.*, *11*, 781-784, 1978.

Wendt, I., and Carl, C., 1991, The statistical distribution of the mean squared weighted deviation, *Chemical Geology*, v. 86, p. 275-285.

Note: Check your samples data sheets for the discrimination, and fluence monitor values used for each sample.

Nevada Isotope Geochronology Laboratory - Sample Descriptions – Biek UT DNR

General Comments: Your samples were run as conventional furnace step heating analyses on bulk basalt groundmass separates. All data are reported at the 1σ uncertainty level, unless noted otherwise.

Furnace step heating analyses produce what is referred to as an apparent age spectrum. The "apparent" derives from the fact that ages on an age spectrum plot are calculated assuming that the non-radiogenic argon (often referred to as trapped, or initial argon) is atmospheric in isotopic composition ($^{40}Ar/^{36}Ar = 295.5$). If there is excess argon in the sample ($^{40}Ar/^{36}Ar > 295.5$) then these apparent ages will be older than the actual age of the sample. U-shaped age spectra are commonly associated with excess argon (the first few and final few steps often have lower radiogenic yields, thus apparent ages calculated for these steps are effected more by any excess argon present). Excess argon can also produce generally discordant age spectra. This is often verified by isochron analysis, which utilizes the analytical data generated during the step heating run, but makes no assumption regarding the composition of the non-radiogenic argon. Thus, isochrons can verify (or rule out) excess argon, and isochron ages are usually preferred if a statistically valid regression is obtained (as evidenced by the MSWD, mean square of weighted deviates, a measure of the coherence of the population). If such a sample yields no reliable isochron, the best estimate of the age is that the minimum on the age spectrum is a maximum age for the sample (it could be affected by excess argon, the extent depending on the radiogenic yield). $^{40}Ar/^{39}Ar$ total gas ages are equivalent to K/Ar ages. Plateau ages are sometimes found, these are simply a segment of the age spectrum which consists of 3 or more steps, comprising >50% of the total gas released, which overlap in age at the ±2σ analytical error level (not including the J-factor error, which is common to all steps). However, in general an isochron age is the best estimate of the age of a sample, even if a plateau age is obtained.

H101508-4 Basalt Groundmass

This sample produced an age spectrum which has ages of ~5.3 Ma for the first ~70% ^{39}Ar released, followed by discordant ages which are both younger and older. The total gas age, which is equivalent to a conventional K/Ar age, is 5.26 ± 0.03 Ma. Steps 1-6 (69% of the ^{39}Ar released) define an indistinguishable plateau age of 5.25 ± 0.03 Ma. Steps 2-5 (53% of the ^{39}Ar released) define a statistically valid isochron age of 5.50 ± 0.03 Ma, and the initial $^{40}Ar/^{36}Ar$ = 391 ± 14, suggesting that some excess argon is present. However, the isochron is effectively a 3 point line fit, and the older age is anomalous given the indication of excess argon, thus this isochron is not considered reliable (i.e. it is likely this is a spurious line fit). Ca/K ratios are typical for basalt groundmass and radiogenic yields (%$^{40}Ar^*$) are high for this material, indicating a sample that has not undergone recent alteration. The plateau age should be considered the most reliable for this sample.

H101408-1 Basalt Groundmass

This sample produced a discordant age spectrum characterized by ages which decrease from ~1.6 Ma to ~0.9 Ma at step 5, followed by generally increasing ages with the remainder of the gas released. Note that the overall form of the age spectrum is distinctly U-shaped, which has been associated with the presence of excess argon. The total gas age is 1.30 ± 0.02 Ma. There are no plateau or isochron ages defined by these data. Ca/K ratios are typical for basalt groundmass and radiogenic yields (%^{40}Ar*) are reasonable for this material. Given the indication of excess argon from the age spectrum, the most conservative interpretation of these data is that the sample is less than or equal to the youngest age on the age spectrum, step 5 with an age of 0.92 Ma.

The interpretations given above are based simply on inspection of the laboratory data. Geologic relationships, which are unknown to us, are not considered. Please feel free to call or email (best way to contact me terry.spell@unlv.edu) if you have questions.

General Comments: Your sample was run as conventional furnace step heating analyses on a basalt groundmass separate. All data are reported at the 1σ uncertainty level, unless noted otherwise.

Furnace step heating analyses produce what is referred to as an apparent age spectrum. The "apparent" derives from the fact that ages on an age spectrum plot are calculated assuming that the non-radiogenic argon (often referred to as trapped, or initial argon) is atmospheric in isotopic composition ($^{40}Ar/^{36}Ar = 295.5$). If there is excess argon in the sample ($^{40}Ar/^{36}Ar > 295.5$) then these apparent ages will be older than the actual age of the sample. U-shaped age spectra are commonly associated with excess argon (the first few and final few steps often have lower radiogenic yields, thus apparent ages calculated for these steps are effected more by any excess argon present). Excess argon can also produce generally discordant age spectra. This is often verified by isochron analysis, which utilizes the analytical data generated during the step heating run, but makes no assumption regarding the composition of the non-radiogenic argon. Thus, isochrons can verify (or rule out) excess argon, and isochron ages are usually preferred if a statistically valid regression is obtained (as evidenced by the MSWD, mean square of weighted deviates, a measure of the coherence of the population). If such a sample yields no reliable isochron, the best estimate of the age is that the minimum on the age spectrum is a maximum age for the sample (it could be affected by excess argon, the extent depending on the radiogenic yield).

An ideal sample with a simple geologic history, with no excess argon, and that has remained undisturbed since initial cooling (e.g. no subsequent alteration or thermal disturbance), should produce a flat, concordant age spectrum in which all, or most, ages are identical within analytical uncertainty. $^{40}Ar/^{39}Ar$ total gas ages are equivalent to K/Ar ages. Plateau ages are sometimes found, these are simply a segment of the age spectrum which consists of 3 or more steps, comprising >50% of the total gas released, which overlap in age at the ±2σ analytical error level (not including the J-factor error, which is common to all steps). On occasion, a "pseudo-plateau" age is obtained. This satisfies all the criteria for a plateau age as outlined above, with the exception that the gas released comprises between 40-50%. However, in general an isochron age is the best estimate of the age of a sample, even if a plateau age is obtained.

CH2 Basalt Groundmass

This sample produced a discordant age spectrum characterized by ages which decrease from a first step at ~2.5 Ma to a minimum age at step 3 of ~1.3 Ma, followed by generally increasing ages with the remainder of the steps, ending at ~3.2 Ma for the final step. Note that overall the age spectrum has a distinct U-shape, suggesting the presence of excess argon. The total gas age (equivalent to a conventional K/Ar age) is 1.84 ± 0.07 Ma. Steps 4-13 (65% of the total ^{39}Ar released) define a younger plateau age of 1.51 ± 0.09 Ma. All 14 steps define a statistically valid isochron, which yields an age of 1.12 ± 0.08 Ma, and an initial $^{40}Ar/^{36}Ar$ of 305.2 ± 1.9, indicating that there is a small amount of excess argon in this sample. The Ca/K ratios are consistent with outgassing of a basalt groundmass separate. Radiogenic yields ($\%^{40}Ar^*$) are generally low, but this is typical of a relatively young basalt sample. The form of the age spectrum, and the >295.5 initial $^{40}Ar/^{36}Ar$ ratio, show that this sample contains excess argon. Thus the total gas and plateau ages are anomalously old. The isochron age should be considered the most accurate and reliable for this sample.

These interpretations are based primarily on inspection of the laboratory data. Geologic relationships, which we generally do not know, have not been taken into account in the comments presented above. Please feel free email (best way to contact me terry.spell@unlv.edu) if you have questions.

Terry Spell
UNLV Geoscience

Biek-UT DNR, HM101408-1, Basalt Groundmass, 114.03 mg, J = 0.001735 ± 0.007%
4 amu discrimination = 1.0622 ± 0.46%, 40/39K = 0.0104 ± 19.23%, 36/37Ca = 0.000264 ± 4.93%, 39/37Ca = 0.0006595 ± 6.11%

step	T (C)	t (min.)	36Ar	37Ar	38Ar	39Ar	40Ar	%40Ar*	% 39Ar rlsd	Ca/K	40Ar*/39ArK	Age (Ma)	1s.d.
1	550	12	4.132	84.203	11.063	129.262	1202.91	5.6	4.0	11.517088	0.524507	1.64	0.14
2	600	12	1.237	110.788	6.221	154.162	388.345	17.0	4.8	12.71011354	0.411319	1.29	0.05
3	650	12	1.082	172.107	6.318	251.091	353.819	24.5	7.8	12.12071655	0.330119	1.03	0.03
4	700	12	1.017	229.053	7.165	354.477	360.093	34.0	11.0	11.42410994	0.331078	1.04	0.03
5	750	12	1.035	232.690	7.656	398.310	363.032	33.6	12.3	10.32510621	0.293358	0.92	0.02
6	800	12	1.079	180.761	6.976	364.548	392.666	31.1	11.3	8.759788848	0.342905	1.07	0.02
7	850	12	1.160	128.361	6.362	301.888	407.485	27.5	9.4	7.508884989	0.356971	1.12	0.03
8	900	12	1.182	83.437	5.416	205.842	378.939	17.9	6.4	7.157630068	0.315734	0.99	0.03
9	970	12	1.603	96.498	7.607	232.553	517.210	17.4	7.2	7.327604995	0.374554	1.17	0.05
10	1060	12	7.861	183.961	12.466	339.176	2390.01	9.8	10.5	9.58399633	0.696570	2.18	0.10
11	1160	12	6.385	1440.38	16.688	448.489	1739.08	13.4	13.9	57.52875729	0.526106	1.65	0.11
12	1400	12	1.045	435.097	1.159	47.385	239.630	14.0	1.5	169.6803537	0.649872	2.03	0.30
							Cumulative %39Ar rlsd =		100.0		Total gas age =	1.30	0.02

note: isotope beams in mV, rlsd = released, error in age includes J error, all errors 1 sigma
(36Ar through 40Ar are measured beam intensities, corrected for decay for the age calculations)

No plateau
No isochron

Biek-UT DNR, H101508-4, Basalt Groundmass, 41.21 mg, J = 0.001709 ± 0.01%

4 amu discrimination = 1.0622 ± 0.46%, 40/39K = 0.0104 ± 19.23%, 36/37Ca = 0.000264 ± 4.93%, 39/37Ca = 0.0006595 ± 6.11%

step	T (C)	t (min.)	36Ar	37Ar	38Ar	39Ar	40Ar	%40Ar*	% 39Ar rlsd	Ca/K	40Ar*/39ArK	Age (Ma)	1s.d.
1	550	12	0.316	23.944	4.971	54.913	177.917	58.9	3.1	7.700759957	1.714707	5.28	0.07
2	600	12	0.246	33.258	6.906	88.432	215.508	77.4	5.0	6.639982088	1.728695	5.32	0.04
3	650	12	0.293	57.167	10.145	194.239	402.141	85.9	11.1	5.194089679	1.712756	5.27	0.04
4	700	12	0.296	75.903	10.573	308.168	588.454	90.7	17.6	4.345766422	1.697467	5.23	0.03
5	760	12	0.305	72.980	8.648	339.960	649.176	91.4	19.4	3.787054211	1.713732	5.28	0.05
6	820	12	0.283	49.366	4.631	214.418	427.906	87.5	12.2	4.06187324	1.685432	5.19	0.03
7	880	12	0.257	38.543	2.634	123.810	257.424	81.2	7.1	5.494492923	1.572897	4.84	0.04
8	940	12	0.249	31.816	1.843	81.249	205.638	76.6	4.6	6.914198784	1.749515	5.39	0.06
9	1000	12	0.293	33.740	1.758	74.458	202.057	69.5	4.3	8.003563367	1.699094	5.23	0.06
10	1060	12	0.397	48.557	1.935	80.820	236.952	62.2	4.6	10.61958586	1.673072	5.15	0.05
11	1120	12	0.483	60.722	1.201	48.373	207.301	44.5	2.8	22.26181769	1.724141	5.31	0.07
12	1180	12	0.665	205.028	1.206	36.729	217.383	35.5	2.1	101.2241421	1.891042	5.82	0.19
13	1250	12	1.109	433.743	2.464	79.508	376.026	40.9	4.5	98.85880208	1.841260	5.67	0.18
14	1400	12	0.696	159.806	0.837	26.429	213.798	26.0	1.5	109.9113157	1.843863	5.68	0.20
								Cumulative %39Ar rlsd =	100.0		Total gas age =	5.26	0.03
											Plateau age = (steps 1-6)	5.25	0.03
											Isochron age = (steps 2-5)	5.50	0.03

note: isotope beams in mV, rlsd = released, error in age includes J error, all errors 1 sigma

(36Ar through 40Ar are measured beam intensities, corrected for decay for the age calculations)

Knudsen-UT DNR, CH2, Basalt Groundmass, 100.50 mg, J = 0.00167 ± 0.25%
4 amu discrimination = 1.0381 ± 0.93%, 40/39K = 0.0313 ± 27.39%, 36/37Ca = 0.000278 ± 2.43%, 39/37Ca = 0.000667 ± 0.99%

step	T (C)	t (min.)	36Ar	37Ar	38Ar	39Ar	40Ar	%40Ar*	% 39Ar rlsd	Ca/K	40Ar*/39ArK	Age (Ma)	1s.d.
1	600	12	8.265	90.681	5.547	167.883	2476.99	5.5	6.6	2.898281205	0.817071	2.46	0.42
2	650	12	3.266	92.258	4.247	215.458	1013.74	9.4	8.5	2.297188876	0.442608	1.33	0.14
3	700	12	1.983	98.533	4.475	270.060	669.088	17.3	10.6	1.957194296	0.428325	1.29	0.08
4	750	12	2.328	99.710	4.892	298.045	787.506	17.4	11.7	1.794522459	0.459216	1.38	0.08
5	800	12	1.963	73.693	3.737	217.084	652.220	15.8	8.5	1.820932168	0.473500	1.43	0.09
6	850	12	1.899	55.883	2.518	125.843	600.561	11.4	4.9	2.382410908	0.543926	1.64	0.14
7	900	12	1.698	48.833	2.098	94.086	522.161	9.0	3.7	2.784870916	0.496088	1.49	0.16
8	950	12	2.110	54.968	2.319	96.077	642.802	7.8	3.8	3.070033083	0.516020	1.55	0.20
9	1000	12	1.894	52.423	2.141	81.870	575.436	7.6	3.2	3.436336813	0.525986	1.58	0.20
10	1050	12	2.820	69.700	3.044	105.392	859.840	7.8	4.1	3.549261388	0.632634	1.91	0.23
11	1100	12	3.225	80.559	3.109	107.419	974.584	7.0	4.2	4.02536913	0.634296	1.91	0.26
12	1150	12	7.824	192.896	6.031	194.086	2329.65	5.7	7.6	5.336624988	0.685799	2.07	0.34
13	1220	12	13.607	782.348	107.912	329.577	3969.47	5.9	13.0	12.77364845	0.716039	2.16	0.34
14	1400	12	9.973	815.154	78.436	239.869	2945.43	8.7	9.4	18.31607143	1.071387	3.23	0.35
							Cumulative %39Ar rlsd =		100.0		Total gas age =	1.84	0.07
											Plateau age = (steps 4-13)	1.51	0.09
											Isochron age = (steps 1-14)	1.12	0.08

note: isotope beams in mV, rlsd = released, error in age includes J error, all errors 1 sigma
(36Ar through 40Ar are measured beam intensities, corrected for decay for the age calculations)