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Empirically Determined Uncertainty in Potassium-Argon Ages For Plio-Pleistocene Basalts From Crater Flat, Nye County, Nevada

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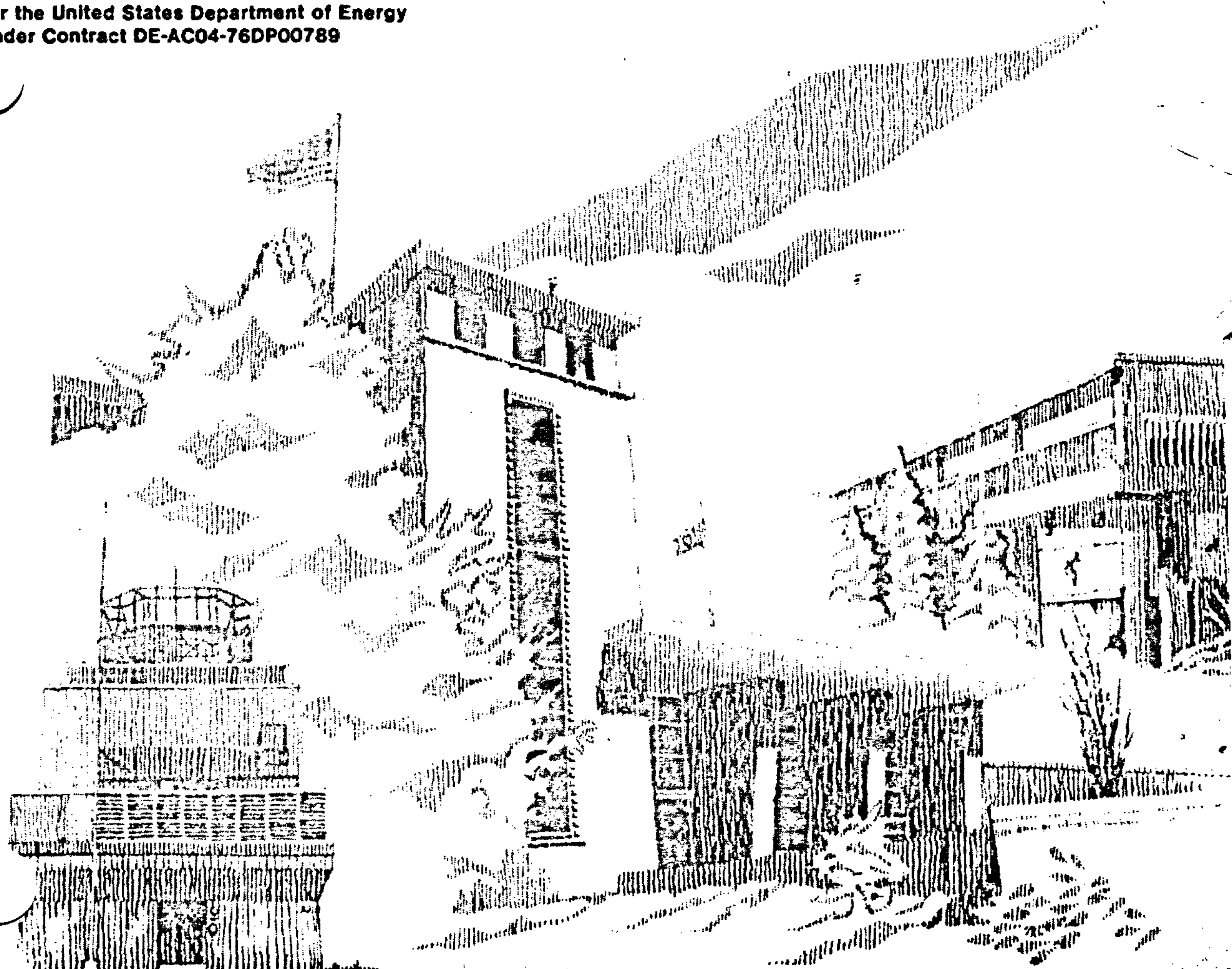

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Empirically Determined Uncertainty in Potassium-Argon Ages For Plio-Pleistocene Basalts From Crater Flat, Nye County, Nevada

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Abstract

Six samples of basalt from each of four sites in Crater Flat, Nye County, Nevada, were dated by potassium-argon isotopic methods, by each of three separate geochronology laboratories. The mean ages of the four sites range from about 0.4 my (million years) to 4.0 my. The standard error of an age is 0.16 my, regardless of age. Variation among the reported ages can be attributed to aliquot, sample, and interlaboratory differences, with the latter two being dominant. The standard deviation of an age for a single sample dated by one laboratory is estimated as 0.34 my. Overall, the results indicate that Quaternary basalts with approximately 1.5% potassium content can be assigned an age at 90% confidence to within an interval of about 1 my if multiple samples are dated by several laboratories. If only one sample is dated by a single laboratory, the interval increases to about 1.4 my.

Acknowledgment

Sampling in 115°F heat in Crater Flat would have been less tolerable but for the assistance of Paul Damon and M. Shafiqullah (Shafi) from the University of Arizona; Bob Drake from the University of California Berkeley; Hal Krueger from Geochron; Bruce Crowe from Los Alamos National Laboratory; Will Carr from the United States Geological Survey (USGS); and Joe Fernandez of Sandia National Laboratories. Paul Damon, Shafiqullah, Bob Drake, Garniss Curtiss (Berkeley) and Hal Krueger performed the analytical work in support of this study. Field support was provided by Al Stephenson, Division 9764, and Adam Trujillo, Division 7135, of Sandia National Laboratories. The USGS graciously allowed use of its core library facility in Mercury, Nevada, for initial sample trimming and packaging during the June field expedition. Special appreciation is extended to Richard Marvin, USGS, and Bruce Crowe for their thoughtful reviews of a draft manuscript.

Contents

Figures

Tables

Empirically Determined Uncertainty in Potassium-Argon Ages For Plio-Pleistocene Basalts From Crater Flat, Nye County, Nevada

Introduction

This report presents results, conclusions, and recommendations from an experiment performed to assess uncertainty in potassium-argon (K-Ar) isotopic age determinations for late Cenozoic basalts. The purpose of this experiment is to statistically investigate the accuracy of K-Ar age determinations for relatively young basalts. Though many sources of variation affect such age determinations, it is often difficult to identify which ones are responsible for uncertainty in individual cases.

Users of isotopic dating methods commonly attempt to isolate causes of variation and compensate by rejecting anomalous samples, applying correction factors to calculated ages, and other means. However, a user of age dates who may not be associated with the isotopic laboratory commonly has no independent means by which to assess the confidence he can place in the accuracy of the reported ages. Isotopic laboratories as a matter of course report precision of calculated ages. Precision generally indicates only the reproducibility of a particular age given the sensitivity of laboratory instruments to conditions of a particular sample. This precision needs to be distinguished from the accuracy of the age determination, which depends on geological as well as laboratory sources of variation.

This experiment was designed to help an independent user estimate the accuracy of K-Ar age determinations for relatively young basalts. As such, the results and conclusions should be interpreted from the perspective of one who has sent a sample or set of samples to some independent isotopic laboratory for dating. When he receives a report on the ages determined by the laboratory, he may ask, "How accurate are the ages, and how do the true ages relate to the reported precision?" This experiment addresses these questions.

Because the purpose is to investigate confidence that a user can place in the age of a basalt sample determined by any of a number of isotope laboratories and not to compare or evaluate individual laboratories, the data provided by each of the three participating laboratories are not identified by source in this report. To further preserve anonymity, perhaps at the expense of weakening the conclusions, distinctions among analytical techniques employed by the different laboratories are also not treated, except in a general sense, as a source of variation among the reported ages.

The experiment was supported by radioactive waste disposal investigations at the Nevada Test Site, Nye County, Nevada. These studies are conducted by the Department of Energy, through contracts with various laboratories and agencies, including Sandia National Laboratories (SNL).

Experiment Design

The experiment design consists of a matrix of six redundant K-Ar age determinations for each of four sampling sites by each of three laboratories: the Department of Geology and Geophysics, Univeristy of California, Berkeley campus; the Laboratory of Isotope Geochemistry, Department of Geosciences, University of Arizona, Tucson; and Geochron Laboratories Division, Krueger Enterprises Incorporated, Cambridge, Massachusetts (Table 1). The four sample sites are located in Crater Flat, Nye County, Nevada (Figure 1). At each site, four sample sets of basaltic rocks were collected in June 1979 by a group composed of geochronologists from each of the participating isotope laboratories and geologists from SNL, USGS, and Los Alamos National Laboratory. Each sample set was performed by physically breaking a single piece of basalt into separate pieces. Each laboratory received one piece from each set. Separate sample sets at each site were collected from separate areas of the same outcrops, and all four sample sets from a single site were obtained within a general radius of about 20 to 30 m. The samples were cataloged, labeled, and sent to the three participating laboratories. Each laboratory was aware of the sampling location and known age constraints for each of the 16 samples so obtained.

Table 1. Experiment Design for Investigating the Uncertainty in K-Ar Isotopic Ages. Each set of six samples contained four identified and two unidentified samples.

	No. of Samples				
	Site 1	Site 2	Site 3	Site 4	Total
Berkeley	6	6	6	6	24
Arizona	6	6	6	6	24
Geochron	6	6	6	6	24
Total	18	18	18	18	72

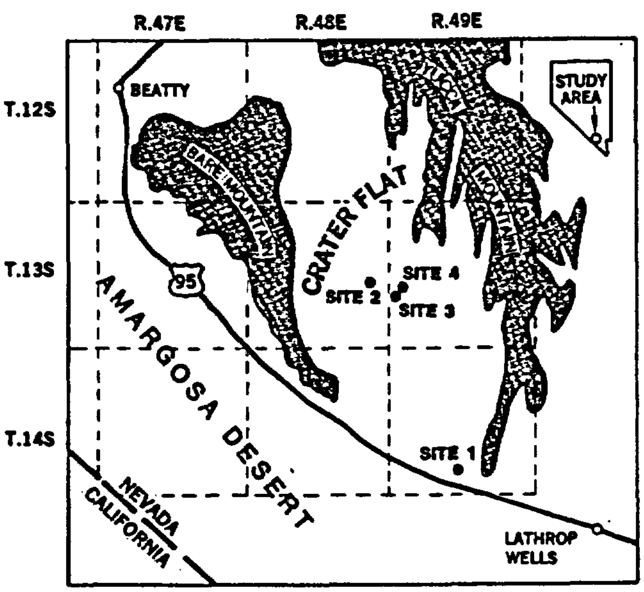

Figure 1. Location of Four Sampling Sites in Crater Flat, Nye County, Nevada

In August 1979, two additional sample sets were collected from each of the four sites without participation by the geochronologists. These were similarly subdivided, cataloged, and sent to the laboratories. However, samples from the second field expedition were labeled in a manner to prevent the geochronologists from knowing the sampling location or possible age constraints for individual samples. Thus, each laboratory received four identified samples and two unidentified samples for a total of six samples from each of the four sites. Eighteen samples were thus collected from each site, and each laboratory thus received 24 samples (Table 1).

Each isotope laboratory was provided orally with information regarding K-Ar age determinations by the USGS of basalt flows from the Crater Flat area. Lathrop Wells Cone, Site 1, had been dated previously as about 0.25 my. Red Cone, Site 2, is adjacent to and similar in terms of size and volume of flow material to Black Cone, previously dated as about 1.0 my.

Geomorphic characteristics show that Lathrop Wells Cone is essentially undissected, and the crater has not been breached by erosion. Black Cone is moderately dissected with small colluvial fans at the base of the cone. The remaining two sites, Sites 3 and 4, are dissected basalt outcrops protruding through the alluvial fill of east-central Crater Flat. Cone forms apparently have been removed by erosion, and only remnants of cone scoria remain in some places. Thus, geomorphic evidence indicates that Site 1, Lathrop Wells Cone, is the youngest; Site 2, Red Cone, is somewhat older (consistent with previous K-Ar age determinations); and Sites 3 and 4 are the oldest.

Results

Reported ages of the 72 samples and the average age for each site are given in Table 2 and Figure 2. The average of the individual precision brackets for each site reported by each laboratory also is included in Table 2. By inspection of the reported ages, it is clear that there are significant differences among the laboratories, as well as appreciable variation among samples from a given site. Laboratory A generally obtained older ages for most sites, and Laboratory B consistently obtained younger ages. For Site 1, Laboratory B reported two negative ages, an obviously impossible situation. This happened because the measured amount of radiogenic argon produced by potassium decay was less than that assumed to be present due to the atmospheric argon in the rock sample. Even for a single laboratory, it is apparent that variations among the reported ages for individual sites occur, though the standard deviation of the reported ages from a single laboratory agree quite well with the average of the reported precision. In some cases, e.g., Laboratories A and B, Site 1, the difference between identified and unidentified sample sites seems significant. When all reported ages from each site are considered, the standard deviation is generally much greater than reported precision. It is interesting to note that the standard deviations for each of the sites are about the same.

Table 2. Reported K-Ar Ages, Precision Brackets, and Overall Site Means for Crater Flat Basalt Samples

Site			Laboratory A	Laboratory B	Laboratory C
SITE 1	Mean Age Reported		0.73	0.08	0.57
	Standard Deviation		0.19	0.08	0.09
	Average Precision Reported		±0.11	±0.13	±0.12
	Sample Set	1	0.70 ± 0.07	0.12 ± 0.03	0.60 ± 0.09
		2	0.65 ± 0.07	-0.01 ± 0.29	0.61 ± 0.16
		3	0.77 ± 0.08	-0.03 ± 0.14	0.66 ± 0.10
		4	0.59 ± 0.06	0.08 ± 0.03	0.56 ± 0.09
		5[1]	1.1 ± 0.3	0.125 ± 0.18	0.59 ± 0.21
		6[1]	0.58 ± 0.08	0.175 ± 0.09	0.39 ± 0.07
SITE 2	Mean Age Reported		1.53	1.12	1.55
	Standard Deviation		0.31	0.27	0.15
	Average Precision Reported		±0.19	±0.36	±0.20
	Sample Set	7	1.7 ± 0.2	0.965 ± 0.09	1.46 ± 0.11
		8	1.8 ± 0.2	0.95 ± 0.11	1.76 ± 0.19
		9	1.5 ± 0.2	0.975 ± 0.05	1.40 ± 0.13
		10	1.8 ± 0.2	1.66 ± 1.52	1.61 ± 0.24
		11[1]	0.99 ± 0.15	1.08 ± 0.24	1.64 ± 0.35
		12[1]	1.5 ± 0.2	1.11 ± 0.13	3.66 ± 0.14[2]
SITE 3	Mean Age Reported		4.27	3.73	3.89
	Standard Deviation		0.46	0.06	0.17
	Average Precision Reported		±0.45	~~±0.09~~	±0.32
	Sample Set	13	4.8 ± 0.5	3.637 ± 0.04	3.86 ± 0.11
		14	4.3 ± 0.5	3.815 ± 0.11	3.90 ± 0.92
		15	3.6 ± 0.4	3.78 ± 0.06	3.99 ± 0.12
		16	4.7 ± 0.5	3.745 ± 0.04	3.77 ± 0.32
		17[1]	4.3 ± 0.3	3.695 ± 0.22	4.14 ± 0.13
		18[1]	3.9 ± 0.5	3.73 ± 0.06	1.41 ± 0.38[2]
SITE 4	Mean Age Reported		4.22	3.69	4.00
	Standard Deviation		0.08	0.09	0.13
	Average Precision Reported		±0.32	±0.06	±0.12
	Sample Set	19	4.3 ± 0.3	3.79 ± 0.08	3.99 ± 0.10
		20	4.2 ± 0.3	3.795 ± 0.05	3.99 ± 0.12
		21	4.2 ± 0.3	3.555 ± 0.04	4.14 ± 0.11
		22	4.2 ± 0.3	3.64 ± ~~0.10~~	4.02 ± 0.12
		23[1]	4.3 ± 0.3	3.68 ± 0.06	3.76 ± 0.11
		24[1]	4.1 ± 0.4	3.705 ± 0.05	4.10 ± 0.15

	Overall Reported Ages from Each Site: Mean Reported Age	Standard Deviation
Site 1 – Lathrop Wells Cone	0.46	0.31
Site 2 – Red Cone	1.41	0.31
Site 3 – Along Wash in Central Crater Flat	3.96	0.35
Site 4 – Flow on Ridge Top in Central Crater Flat	3.97	0.24

[1]Unidentified samples

[2]Apparently labels of samples were interchanged, ages were switched between sample sets for the statistical analysis, including the calculation of means shown in this table. In the analysis all ages were rounded to two decimals.

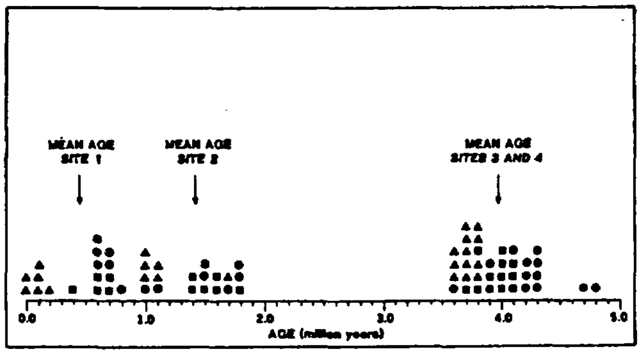

Figure 2. Histogram and Site Averages of Reported K-Ar Ages for Basalt Samples from Crater Flat, Nevada. Squares, circles and triangles represent ages of individual samples reported by different laboratories.

A statistical analysis of variance was performed to separate and identify sources of these apparent variations. Sources of variation considered were differences among sites, differences between sample collections, differences among samples, and differences among laboratories. The analysis of variance was done for each site separately and for the four sites combined. It shows that sample-to-sample and laboratory-to-laboratory variation dominate the total variation of the reported ages. Thus, the accuracy of a K-Ar age determination for the basalts of this experiment depends on both the number of laboratories and the number of samples analyzed by each laboratory.

Table 3 shows the average ages, standard errors,* computed confidence intervals, and sources of variance by category for specific sites and overall reported ages. Standard errors were calculated from the 18 reported ages for each site and did not consider the precision values reported by the laboratories. Estimated variances due to sampling and interlaboratory differences are similar for the four sites, suggesting that for basalts of this age range, the absolute uncertainty of K-Ar age determinations is constant, but relative dispersion is greater for younger rocks.

Confidence intervals for actual ages of the sites were calculated from the standard error of 0.16 my and indicate an uncertainty of about ± 0.5 my at 90% confidence and about ± 0.7 my at 95% confidence, independent of age. These uncertainty brackets pertain to age estimates obtained when 18 ages are reported by each of three laboratories for a single site. For a single sample dated by a randomly selected laboratory, the uncertainty is somewhat greater. In this case, the standard error is 0.34 my, and the 90% and 95% confidence intervals are about ± 0.7 or ± 0.9 my, respectively (Table 4).* Uncertainty in age estimates, when considering laboratory-to-laboratory variation is therefore somewhat greater than the precision reported by individual laboratories (Table 2).

The ages reported in Table 2 were calculated from measurements of potassium and radiogenic argon contained in the basalt samples. By inspection of Table 5, it is apparent that significant differences occur among the potassium and argon analyses of the individual laboratories.

Analysis of variance of the potassium and argon measurements (Table 4) shows differences among sample collections in that the two collections differ by more than the variation among individual samples can account for. This variability is attributed to "Experimental Factors" in Table 4.** When ages are calculated rom the potassium and argon measurements, the variation attributed to experimental factors disappears.

Table 4 separates the contribution of sampling and laboratory differences to the variances for potassium and argon measurements. Because variability within each of the four sites is similar, only overall estimates are shown. Included in Table 4 are the standard deviations and confidence intervals for potassium and argon measurements as well as age calculations.

Each laboratory performed at least two measurements of potassium and argon content of each rock sample. Table 5 lists the average of these subsample or aliquot measurements. The estimated contribution of subsample variance to overall sample-to-sample variance is shown in Table 6. Subsample variation contributes little to the total sampling variation of potassium measurements, but for two of the three laboratories, it contributes substantially to the variance among argon measurements.

*Standard error is a measure of how age estimates might vary if the experiment were repeated.

*Satterthwaite's approximation (Graybill, 1961, p 369) was used to obtain approximate degrees of freedom associated with the estimated σ's in Table 4. Note that the standard error in Table 4 is about twice the corresponding standard error in Table 3, but widths of confidence intervals are not increased by the same factor. This occurs because standard errors in Table 4 (estimated σ) are based on more degrees of freedom and hence are more precisely defined than those in Table 3.

**In the analysis of variance for potassium and argon data, variations associated with sample collections and with interactions among sites, laboratories, and collections were pooled to obtain the variation associated with "experimental factors." There are thus two levels of random variation in the data: variation among groups of samples and variation among samples within a group. For age calculations, though, the variation among sample groups was negligible.

Table 3. Average Reported Ages, Standard Errors, Confidence Intervals, and Sources of Variance for Each Site in Crater Flat

	Site 1	Site 2	Site 3	Site 4	Overall*
Average Age Est (my)	0.46	1.41	3.96	3.97	—
Std Error of Est (my)	0.20	0.14	0.16	0.15	0.16
90% Confidence Interval on "True Age"** (my)	±0.58	±0.41	±0.47	±0.44	±0.47
95% Confidence Interval on "True Age"** (my)	±0.86	±0.60	±0.69	±0.65	±0.69
Variance Estimates (my)					
Sampling	0.018	0.062	0.081	0.010	0.044
Laboratory	0.113	0.049	0.061	0.067	0.071
Total	0.131	0.112	0.142	0.078	0.115

*Apparent differences among site variance estimates could be "random" allowing data to be combined to provide overall values.
**Based on a set of 18 samples composed of six samples from each of the three laboratories.

Table 4. Variance, Standard Deviation (σ), and Confidence Intervals for Potassium and Radiogenic Argon Measurements and Age Calculations for All 72 Samples

	Potassium Analysis	Argon Analysis	Age Estimates
Source of Variation			
Sampling	0.0026 $(\%)^2$	0.325 $(\text{mol/g} \times 10^{-12})^2$	0.044 $(10^6\ \text{yr})^2$
Experimental Factors	0.0051 $(\%)^2$	0.249 $(\text{mol/g} \times 10^{-12})^2$	0.000 $(10^6\ \text{yr})^2$
Laboratory	0.0024 $(\%)^2$	0.204 $(\text{mol/g} \times 10^{-12})^2$	0.071 $(10^6\ \text{yr})^2$
Total*	0.0101 $(\%)^2$	0.778 $(\text{mol/g} \times 10^{-12})^2$	0.115 $(10^6\ \text{yr})^2$
Estimated σ	0.10%	0.88 mol/g x 10^{-12}	0.34 x 10^6 yr
Degrees of Freedom**	15	18	5
90% Confidence Interval on "True Value"†	±0.18%	±1.53 mol/g x 10^{-12}	±0.68 x 10^6 yr
95% Confidence Interval on "True Value"†	±0.21%	±1.85 mol/g x 10^{-12}	±0.87 x 10^6 yr

*Total variance is for a single sample measured by a single randomly selected laboratory.
**"Degrees of freedom" is a parameter used in calculating confidence limits on σ.
†For an age of one sample determined by a single laboratory; the "true" age is within the given interval relative to appropriate quantities reported in Tables 1 and 5.

able 5. Reported Potassium and Argon Analyses of Crater Flat Basalts

Sample Set		Potassium (%)			Radiogenic ^{40}Argon (mol/g x 10^{-12}) Parentheses Indicate % Atomospheric Argon					
		Laboratory A[1]	Laboratory B[1]	Laboratory C[1]	Laboratory A[4]		Laboratory B[4]		Laboratory C[4]	
Site 1	1	1.389	1.633	1.625[2]	1.75	(96.5)	0.23	(98.4)	1.69	(92.1)[5]
	2	1.528	1.606	1.643[2]	1.78	(98.5)	0.10	(99.9)	1.74	(96.0)[5]
	3	1.518	1.628	1.580[2]	2.10	(97.2)	−0.08	(100.0)	1.80	(93.5)[5]
	4	1.611	1.545	1.597[2]	1.70	(98.4)	0.21	(98.9)	1.54	(92.8)[5]
	5	1.586	1.577	1.607[2]	3.25	(97.6)	0.30	(99.6)	1.64	(96.6)[6]
	6	1.503	1.558	1.566	1.58	(97.7)[9]	0.48	(99.1)	1.05	(93.4)[5]
Site 2	7	1.493	1.472	1.473[2]	4.60	(94.1)	2.46	(94.6)	3.74	(83.6)
	8	1.446	1.380	1.459[2]	4.56	(95.6)	2.27	(96.4)	4.44	(90.8)[8]
	9	1.491	1.471	1.443	4.00	(98.0)	2.48	(91.6)	3.51	(87.6)[5]
	10	1.388	1.519	1.414	4.55	(97.1)	4.39	(98.5)	3.95	(92.0)[5]
	11	1.391	1.404	1.397[2]	2.48	(96.8)	2.63	(97.9)	3.98	(96.0)[6]
	12	1.367	1.408	1.437[2]	3.68	(96.7)	2.71	(96.2)	9.12	(69.9)[8,10]
Site 3	13	1.272[3]	1.710[3]	1.574	10.75	(90.8)	10.73[5]	(55.4)[5]	10.54	(50.7)[5]
	14	1.287[3]	1.555	1.460[2]	9.80	(88.3)	10.35	(52.0)	9.91	(94.8)[7]
	15	1.249	1.680	1.514[2]	8.08	(93.0)	10.95	(54.6)	10.49	(56.9)[5]
	16	1.309	1.632	1.572[2]	10.93	(91.9)	10.55	(45.5)	10.30	(87.1)[8]
	17	1.344	1.416	1.457[2]	10.43	(83.3)	8.95	(85.6)	10.48	(57.7)[5]
	18	1.342	1.465	1.409[2]	9.40	(89.5)	9.45	(60.3)	3.45	(95.4)[6,10]
Site 4	19	1.394	1.543	1.387	10.65	(77.7)	10.10	(74.3)	9.61	(33.5)[5]
	20	1.470	1.452	1.309[2]	10.93	(75.5)	9.55	(52.3)	9.08	(56.4)[5]
	21	1.399	1.591	1.421	10.40	(66.6)	9.75	(41.5)	10.22	(32.8)[5]
	22	1.530	1.436	1.431[2]	11.35	(75.5)	9.10	(68.2)	9.99	(52.9)
	23	1.269	1.434	1.437[2]	9.65	(81.8)	9.15	(64.4)	9.39	(47.9)[9]
	24	1.250	1.366	1.385[2]	9.08	(75.6)	8.75	(60.1)	9.85	(65.5)[5]

[1]Average of 2 separate analyses, rounded upward from 5 unless indicated by other footnote
[2]Average of 3 separate analyses, rounded upward from 5
[3]Average of 4 separate analyses, rounded upward from 5
[4]Average of 2 analyses, rounded upward from 5 unless indicated by other footnote
[5]Average of 3 analyses, rounded upward from 5
[6]Average of 4 analyses, rounded upward from 5
[7]Average of 5 analyses, rounded upward from 5
[8]Average of 6 analyses, rounded upward from 5
[9]Only 1 analysis reported or legible on report sheets
[10]Apparently labels for samples 12(c) and 18(c) were interchanged.

Table 6. Variance Estimates of Potassium and Argon Measurements for Subsamples and Samples

Variance	Laboratory A	Laboratory B	Laboratory C
Potassium			
Sample	.0032	.0030	.0017
Subsample	.00041	.00016	.00004
Contribution of Subsample*	6.4%	2.7%	1.2%
Argon			
Sample	.547	.250	.178
Subsample	.494	.119	.025
Contribution of Subsample*	45%	24%	7%

*Divide subsample variance by two to obtain its approximate contribution to total sample variance, because generally two subsamples were analyzed for each rock sample.

The results of this experiment support the contention of others that ^{40}K-^{40}Ar age determinations must be carefully interpreted in terms of their relation to true ages (Holmes, 1962; Damon, 1970; Dalrymple and Lanphere, 1969, 1974; Berger and York, 1970; Noble and Naughton, 1968; Giletti, 1971; McDougall, 1971, among others).

Possible Sources of Uncertainty

It is generally accepted in the geological sciences that uncertainty associated with the "true" age of a rock is commonly greater than the uncertainty associated with analytical precision, as reported by geochronologists. In pursuing the sources of this larger uncertainty, much attention has focused on leakage or assimilation of radiogenic argon from or into rock systems before or after the start of the radiometric clocks (Damon et al, 1967; Baksi, 1973; Krummenacher, 1970; Shafiqullah and Damon, 1974; Brewer, 1969; McDougall et al, 1979; Dalrymple and Lanphere, 1974; Dalrymple, 1969; and York et al, 1969, among others). Generally, such discussions are concerned with lithologic heterogeneity on scales ranging from intracrystalline to the entire rock mass. Differential preservation of either potassium or argon in the crystallized rock as well as the evolution and character of the initial rockforming magma can contribute to real differences among K-Ar ratios from even a single lava flow. This, in turn, can lead to variations in age determinations of a crystallizing event.

Another source of variation in radiometric age determinations is the difference in analytical methods and instruments used by various geochronology laboratories. Kuntz et al (1980) discuss these sources of age discrepancies for young basalts in detail. Variance among and within the subsamples and the overall laboratory-to-laboratory differences observed in this study supports previous conclusions that laboratory techniques contribute significantly to limits on the reproducibility for measurements of potassium and especially argon contents of young basalts.

A small source of variation may be attributed to the use of different numerical values for electron and beta potassium decay constants. One laboratory in this study used 4.72×10^{-10} per year for $\lambda\beta$ and 0.585×10^{-10} per year for $\lambda\epsilon$, whereas the other two laboratories used 4.96×10^{-10} per year and 0.581×10^{-10} per year for $g\beta$ and $\lambda\epsilon$, respectively. However, these differences caused negiligible variation among the reported ages.

Isochron plots (Hayatsu and Carmichael, 1970; Shafiqullah and Damon, 1974) provide a method for estimating corrections for extraneous argon. This method must still rely on measured values for potassium and argon and does not explain the variance in these values.

From the perspective of an independent user of K-Ar ages, any of the possible lithologic or analytical sources of variance could be responsible for introducing error to age determinations. It is beyond the scope of this study to evaluate which factor or combination of factors can be applied to obtain corrections for the reported ages. Therefore, equal credibility is assumed for each reported analysis. The variability among reported ages is treated statistically as a normally distributed population about a true mean. The statistical analysis leads to a set of age brackets that can be assigned with specified confidence levels to each site. The standard deviation of ages reported for each site and the corresponding confidence intervals are appropriate measures of the uncertainty associated with K-Ar ages of these young basalts.

Conclusions

The following conclusions are based on the results of this study:

1. Quaternary basalts with about 1.5% potassium content can be assigned, at 90% confidence, an age within an interval of about 1 my if six

samples from a single site are radiometrically dated by ^{40}K-^{40}Ar methods by each of three laboratories.

2. Wider intervals are required for the same degree of confidence for an age determined by a single laboratory for a single sample.
3. Standard precision brackets that commonly accompany reported K-Ar ages for young basalts do not adequately represent the uncertainty inherent in the ages.
4. Geomorphic and stratigraphic methods are better than K-Ar dating techniques for determining the relative age of Quaternary basalts because the accuracy of K-Ar methods prohibits its confident resolution within the past million or so years.

Recommendations

The following recommendations reflect user concerns and are offered for consideration by the community of geochronologists.

1. Statistical means and standard deviations for potassium, radiogenic argon, and atmospheric argon contents and radiometric ages of numerous basalt deposits whose mean radiometric ages span the Quaternary period should be established as standards for K-Ar age determinations of Quaternary basalts. Statistical parameters for standard deposits should be determined by combining results from several independent laboratories that perform redundant analyses on multiple samples. The standards should be determined and the results published by some central organization, preferably the National Bureau of Standards. Current standards for radiometric dating of rocks, if available at all, are commonly specific minerals with very narrow ranges in composition. This type of standard is well suited for calibrating instruments and determining precision but not well suited for assessing the accuracy of the age of a rock that is of a class with a wide range in composition. This recommendation addresses a means of establishing accuracy standards to compliment existing precision standards. Similar standards for other time periods and rock types may also be desirable, but the results of this study are restricted to Plio-Pleistocene basalts.

   Samples from the deposits upon which the standards are based should be available to individual analysts for calibration of their results during study of the radiometric ages of young basalts. Results of individual analyses on the calibration samples should be reported to the organizing insitution for incorporation in the evolving statistical standards for the deposits.
2. The practice of reporting precision of radiometric ages for young basalts to the nearest tens of thousands of years should be abandoned because the precision, as reported, is misleading. Rather, precision should be reported for individual potassium and argon measurements, and confidence intervals based on statistical standards as recommended above should be reported for ages.
3. Stratigraphic and geomorphic interpretations of relative ages of Quaternary basalts should not be modified to fit radiometric age distributions without careful consideration of the real uncertainty in the radiometric ages.
4. A set of experiments should be designed to assess the dependence of K-Ar age uncertainties for young basalts on each of the components of lithologic and analytical variations. Data from the study reported here could be analyzed in this manner as a step in solving the problem of accuracy for K-Ar ages of Quaternary basalts. Time and budgets have precluded carring this study to its fullest extent; therefore, the results were presented at a stage of development thought sufficient to illustrate the distinction between precision and accuracy.

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