POTASSIUM-ARGON DATING OF POST-LARAMIDE PLUTONIC AND VOLCANIC ROCKS WITHIN THE BASIN AND RANGE PROVINCE OF SOUTHEASTERN ARIZONA AND ADJACENT AREAS

By

Paul E. Damon and Michael Bikerman

University of Arizona Geochronology Laboratories 1/

INTRODUCTION

In a previous paper (Damon and others, 1964) K-Ar dating evidence was presented that indicated that Laramide magmatism in the Basin and Range province was primarily confined to the time encompassed by the Laramie, Fort Union, and Wasatch Formations, i.e., a span of 20 m.y. from Maestrichtian through Wasatchian time. Furthermore, Laramide magmatism apparently occurred in a single rather violent pulse, which was most intense at the Mesozoic-Cenozoic boundary and did not appear to significantly overlap preceding Cretaceous orogenic events or the subsequent post-Laramide orogeny.

The present paper is concerned with K-Ar dating of post-Laramide magmatic rocks in southeastern Arizona and adjoining areas that are located in the region between 108°10' to 112°10' W. long from 31°25' to 33°45' N. lat. Results from this area will be compared with results for the entire Basin and Range province.

The rock types included in this study were restricted to andesitic through rhyolite volcanic extrusions and hypabyssal granitoid plutons, i.e., rocks formed from magmas that cooled quickly at or near the surface of the earth. An effort was made to collect fresh unweathered samples. In most cases, pure separates (> 95 percent pure) of minerals known to have a high retentivity for argon were obtained. In only a few cases were whole rock samples dated. The whole rock samples were from fresh potassic basaltic-andesites from which it was not feasible to separate pure potassium minerals within a suitable size range.

The sample selection and experimental techniques were designed to measure as accurately as possible the time of solidification of magmas associated with the post-Laramide Basin and Range orogeny. The criteria of rapid cooling, post-cooling chemical stability, and suitability for K-Ar dating were met as closely as possible. No effort has been made, as yet, to date the thin, flat-lying, post-orogenic Plio-Pleistocene basalts that are found here and there throughout the area under investigation. These are true basalts with

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normally low potassium content and are distinctly different from the older basaltic-andesites, which have been called basalts by some field geologists but which have an unusually high alkali metal content and are more silicic than true basalts (Taylor, 1959; Halva, 1961; Mielke, 1964).

TECHNIQUES

K analyses were made by flame photometry using a modified Perkin-Elmer instrument. The lithium internal standard technique, without chemical separations and with the addition of a sodium buffer, was used (Cooper, 1962). Analytical precision for 150 duplicate determinations was $\pm$ 0.56 percent s.d.

A Nier 6", 60° all metal mass spectrometer was used for the determination of argon by isotope dilution. The diluent consisted of very pure Ar^{38} (99.91 percent Ar^{38}) produced by thermal diffusion separation of atmospheric argon in the Laboratory of Professor Clusius, at the University of Zurich in Switzerland. Both the mass spectrometer and fusion system are equipped with bakeout ovens.

The samples were fused by R. F. induction heating in a molybdenum crucible surrounded by an alundum radiation shield. Purification was accomplished by titanium sponge gettering and the conversion of hydrogen to water over hot CuO. The sample was completely fused, equilibrated with the Ar^{38} spike, and purified before water was finally frozen out in a cold finger. This precaution was necessary to prevent the loss of argon by occlusion with ice. It was necessary to completely remove hydrogen and hydrocarbons to prevent the appearance of components other than Ar^{36} at the $M/e = 36$ position in the mass spectrum. With these precautions, a standard deviation of less than $\pm$ 5 percent was obtained for samples with less than 50 percent air correction.1/ When the atmospheric argon correction is greater than 50 percent, the error in this correction becomes the dominant source of error. The estimated precision for Ar^{40}/K^{40} analyses in this laboratory is plotted as a function of the atmospheric correction in figure 1.

As a check on the accuracy of our analyses, the Lamont standard biotite was analyzed using two different preparations of the Zurich isotopic diluent. The results (table I) agree within experimental error with the Lamont analysis. Both this laboratory and Lamont have also intercalibrated with other laboratories. A further check on accuracy is evident from the analyses for samples 19a (table II) and 19b (table III). These samples are two different biotite separates from the Superior Dacite. The U. S. Geological Survey analysis, 19.4 m.y., is in close agreement with our argon analysis, 19.9 m.y. The internal consistency of the data provides a third check on the accuracy.

1/ All samples contain more or less air contamination. Atmospheric argon, which is chemically identical but isotopically different from radiogenic argon, must be subtracted from the total argon content to obtain the radiogenic argon-40.

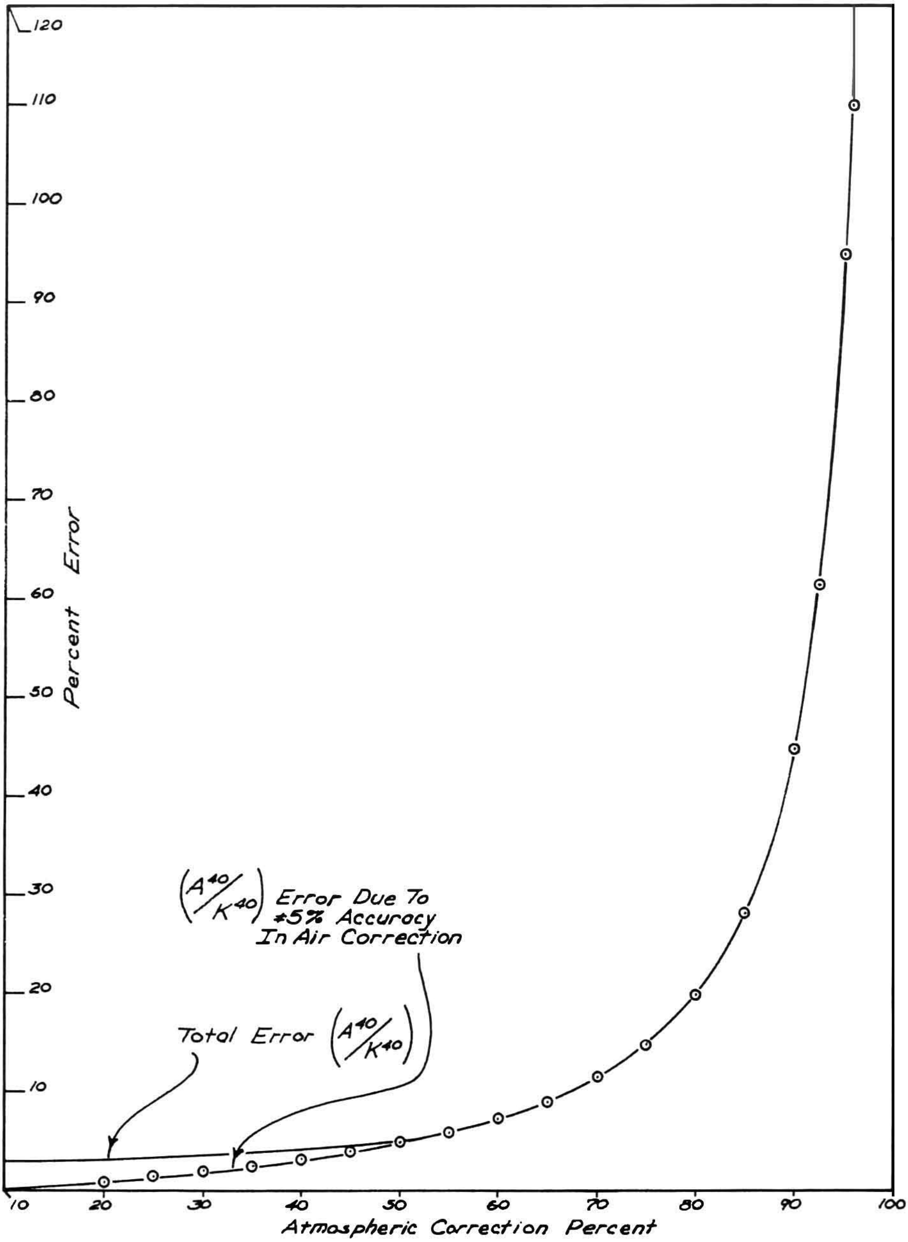

Figure 1.--Standard error in Ar^{40}/K^{40} as a function of the atmospheric Ar^{40} correction.

TABLE I

Sample weight (grams)	Spike	Ar^{-40} radiogenic (moles/gm)	Atmospheric Ar^{-40} (percent)	K (percent)	Ar^{-40}/K^{-40}
0.6866	Zurich No. 1	5.29×10^{-9}	8.87	5.96 5.97	0.0295
1.2784	Zurich No. 2	5.15×10^{-9}	4.91	6.05 6.08	0.0283
Lamont analysis		5.24×10^{-9}	----	5.96	0.0292

$\lambda_\beta = 4.76 \times 10^{-10}$ yr.$^{-1}$, $\lambda_e = 0.589 \times 10^{-10}$ yr.$^{-1}$, $K^{40} = 1.21 \times 10^{-4}$ g. per g. K.

RESULTS

Data for samples of post-Laramide rocks, which have been dated by this laboratory, are presented in table II. A number of rock units sampled and dated by other laboratories fall within this area and are included on the location map (fig. 2). Data for these samples are given in table III.

It is significant that 13 of the 22 samples dated by this laboratory fall within the time interval of from 25 to 28 m. y. Twelve of the 13 samples lie within a circle of 50-mile radius with a center in the middle of the Sierrita Mountains. Most of the Rincon and Catalina Mountains also fall within this circle. The average for these 12 samples is 26.8 ± 1.0 m. y. The average for the K-Ar dates of four mica samples from Rincon and Catalina gneiss was previously determined at 26.8 ± 1.7 m. y. (Damon and others, 1963). Although the exact agreement is fortuitous, there appears to be nothing fortuitous about the occurrence of widespread volcanism, plutonism, and tectonic activity within this circle during a period of less than 3 m. y. When one considers that the experimental precision is about equal to the calculated standard deviation of these 12 results, one is forced to the conclusion that actual duration of time encompasses by these events was considerably less than 3 m. y. Only the closest attention to experimental precision has made possible the demonstration of this close coincidence in time. That a significant period of time did elapse between some of these events is evident at Sentinel Hill ("A" Mountain). The Turkey Track Andesite (No. 4) is separated from the "A" Mountain Tuff (No. 7) by an alluvial bed and considerable erosion took place between two ash flows that constitute separate members of the "A" Mountain Tuff.

The data for samples located between 108°10' to 112°10' W. long from 31°25' to 33°45' N. lat are plotted as a histogram in the upper part of figure 3. These data are added to those of the entire Basin and Range province and are plotted as the lower histogram in figure 3. In each case a block represents a single dated rock unit, and when more than one date was available for a unit, the values were averaged (e. g., 19a and 19b). The gaussian

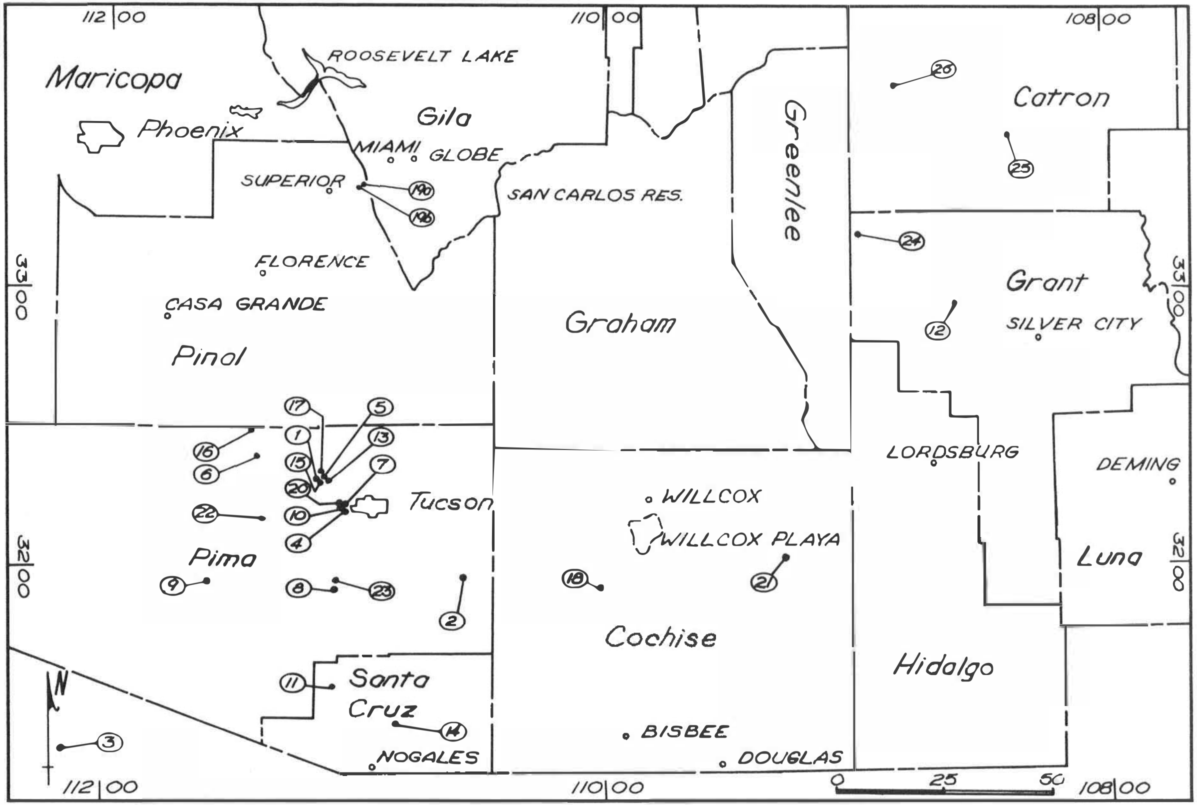

Figure 2. --Location map for samples located between 108°10' and 112°10' W. long from 31°25' to 33°45' N. lat.

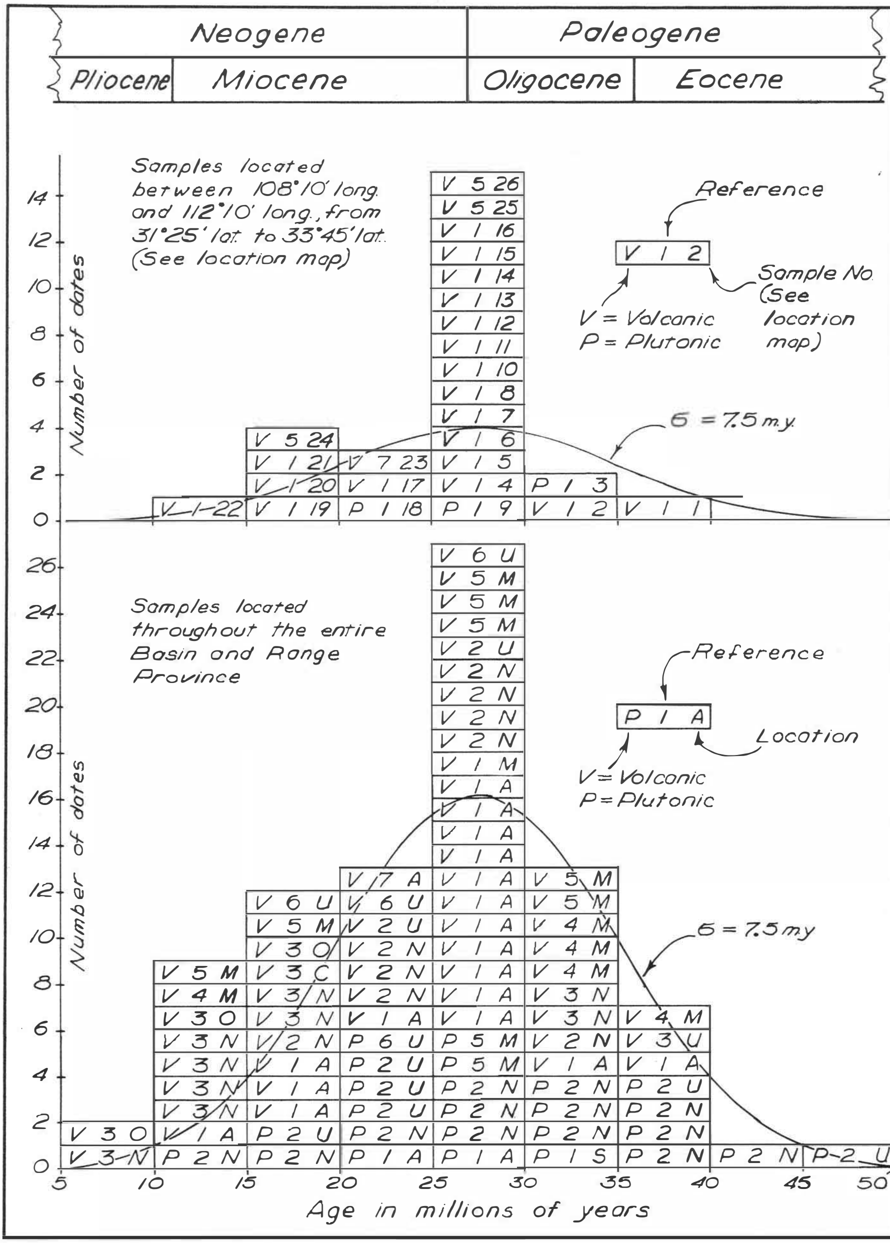

Figure 3. --Histograms for samples located on figure 2.

TABLE II
UNIVERSITY OF ARIZONA K-Ar DATES FOR MID-CENOZOIC PLUTONIC AND VOLCANIC ROCKS FROM SOUTHEASTERN ARIZONA AND A FEW ADJACENT LOCALITIES

No.	Rock unit, location, mineral, and catalog No.	K (percent)	Ar^{40} radiogenic x 10^{-10} (moles/g)	Ar^{40} atmospheric (percent)	Ar^{40}/K^{40} x 10^{-3}	Apparent age x 10^{-6} (year)	Geologic reference
1.	Rillito Andesite, northern Tucson Mts., Pima County (32°19'34" N. lat-111°08'22" W. long), biotite (PED-9-63)	6.46	4.46	29.0	2.29	38.5±1.3	Brown (1939) Imswiler (1959)
2.	Pantano Formation rhyolite ash flow, Highway 80, near Davidson's Canyon, Pima County (31°59'48" N. lat-110°38'36" W. long) (PED-13-62)						Brennan (1957) Metz (1963)
	Sanidine	8.26	5.44	17.1	2.18	36.7±1.1	
	Biotite	7.25	4.26	63.2	1.95	32.8±2.7	
3.	Granite, 11.1 miles south of Sonoyta on road to Caborca, Sonora, Mexico, biotite-muscovite mixture (31°39'36" N. lat-112°54'42" W. long) (PED-6-59)	6.53	3.90	48.0	1.98	33.2±1.1	Fries (1962)
4.	Turkey Track Andesite, Sentinel Peak ("A" Mt.), Pima County, plagioclase (32°12'28" N. lat-110°59'56" W. long) (PED-16-63)	0.69_5	0.348	65.0	1.66	28.0±2.6	Tolman (1909) Cooper (1961) Halva (1961)
5.	Upper andesite, northern Tucson Mts., Pima County, biotite (32°19'28" N. lat-111°07'37" W. long) (MB-2-62)	6.50_5	3.24	58.3	1.65	27.9±1.9	Brown (1939) Imswiler (1959)

TABLE II—Continued

No.	Rock unit, location, mineral, and catalog No.	K (percent)	Ar^{40} radiogenic x 10^{-10} (moles /g)	Ar^{40} atmospheric (percent)	Ar^{40}/K^{40} x 10^{-3}	Apparent age x 10^{-6} (year)	Geologic reference
6.	Petroglyph Hill Andesite, Silver Bell mining district, Pima County, biotite (32°23'07" N. lat-111°24'42" W. long) (PED-1-63)	5.86	2.92	49.9	1.66	27.9 ± 1.4	Richard and Courtright (1954) Watson (1964) Mauger et al. (in press)
7.	"A" Mt. gray tuff, Sentinel Hill ("A" Mt.), Pima County, sanidine (32°12'32" N. lat-110°59'22" W. long)						
	(PED-17-62)	5.36	2.86	7.9	1.77	29.7 ± 0.9	Tolman (1909)
	(PED-7b-63)	5.31_5	2.45	25.6	1.53	25.8 ± 0.9	Halva (1961)
8.	Fine tuff from Helmet Fanglomerate 3 miles southwest of Helmet Peak, Pima County, biotite (31°55'49" N. lat-111°06'49" W. long) (RM-1-64)	6.01	3.00	66.1	1.66	27.9 ± 2.6	Mauger (in preparation)
9.	Kitt Peak sphene-bearing granite, Quinlan Mts., Pima County, biotite (31° 58'12" N. lat-111° 35'30" W. long) (PED-2-62)	6.64	3.26	23.5	1.63	27.4 ± 0.9	Wilson et al. (1960) Galbraith et al. (1959)
10.	"A" Mt. basaltic-andesite, Sentinel Peak ("A" Mt.), Pima County, whole-rock (32°12'56" N. lat-110°59'22" W. long) (PED-17-63)	1.56_5	0.756	43.7	1.60	27.0 ± 1.2	Tolman (1909) Taylor (1960) Halva (1961)

TABLE II—Continued

No.	Rock unit, location, mineral, and catalog No.	K (percent)	Ar^{40} radiogenic x 10^{-10} (moles/g)	Ar^{40} atmospheric (percent)	Ar^{40}/K^{40} x 10^{-3}	Apparent age x 10^{-6} (year)	Geologic reference
11.	Corral de Piedras welded tuff, Tumacacori Mts., Santa Cruz County, biotite with hornblende (32°34'06" N. lat-111°05'30" W. long) (PED-9-62)	4.98	2.36	44.3	1.57	26.5±1.2	Wilson et al. (1960)
12.	Moonstone Tuff, Schoolhouse quadrangle, Grant County, New Mexico, sanidine (32°51'50" N. lat-108°37'30" W. long) (JGW-1-59)	5.53	2.62	25.9	1.57	26.5±0.9	Wargo (1959)
13.	Contzen Pass Sill, northern Tucson Mts., Pima County, biotite (32°19'43" N. lat-111°08'06" W. long) (5A-2)	6.70	3.11	44.4	1.54	26.0±1.2	Imswiler (1959)
14.	Patagonia Tuff, near Patagonia Water Gap, Santa Cruz County, biotite (31°28'48" N. lat-110°48'00" W. long) (PED-10-62)	4.90	2.21	80.0	1.49	25.3±5.1	Wilson et al. (1960)
15.	Safford Tuff, northern Tucson Mts., Pima County, biotite (32°19'43" N. lat-111°08'21" W. long) (PED-10-63)	6.96_5	3.06	51.7	1.46	25.2±1.4	Brown (1939) Imswiler (1959) Bikerman (1963)
16.	Rhyolite from Ragged Top Peak, Silver Bell mining district, Pima County, biotite (32°26'36" N. lat-111°29'30" W. long) (RM-4-63)	6.50	2.91	39.3	1.48	25.3±1.0	Watson (1964) Mauger et al. (in press)

TABLE II—Continued

No.	Rock unit, location, mineral, and catalog No.	K (percent)	Ar^{40} radiogenic x 10^{-10} (moles/g)	Ar^{40} atmospheric (percent)	Ar^{40}/K^{40} x 10^{-3}	Apparent age x 10^{-6} (year)	Geologic reference
17.	Safford Peak dacite plug, northern Tucson Mts., Pima County, biotite (32°20'44" N. lat-111°08'55" W. long) (PED-1-64)	7.07_5	3.10	32.9	1.45	24.5±0.9	Brown (1939) Imswiler (1959)
18.	Stronghold Granite, Little Dragoon Mts., Cochise County, biotite (31°55'24" N. lat-109°58'00" W. long) (CMB-1-62)	6.52	2.54	57.0	1.29	22 ±3 1/	Peterson (1954) Bock (1962)
19a	Superior Dacite ash flow, old abandoned tunnel, east of Superior on Highway 60-70, Pinal County, biotite (33°18'36" N. lat-111°05'00" W. long) (PED-4-62)	6.83	2.43	45.9	1.18	19.9±0.9	Peterson (1954, 1962) Ransome (1903)
20.	Uppermost basaltic andesite, Tumamoc Hill, Pima County, whole-rock (32°12' 47" N. lat-111°00' 20" W. long) (PED-8-63)	2.67	0.945	74.9	1.17	19.8±3.0	Tolman (1909) Taylor (1960) Halva (1961)
21.	Rhyolite Canyon Formation ash flow, unit 6, Massai Point, Chiricahua National Monument, Cochise County, sanidine (32°00'24" N. lat-109°18'42" W. long) (PED-12-62)	5.75	1.66	40.8	0.954	16.2±0.7	Enlows (1955)

1/ K and Ar aliquots for sample 18 are from separate vials and may not be exactly equivalent.

TABLE II—Continued

No.	Rock unit, location, mineral, and catalog No.	K (percent)	Ar^{40} radiogenic x 10^{-10} (moles/g)	Ar^{40} atmospheric (percent)	Ar^{40}/K^{40} x 10^{-3}	Apparent age x 10^{-6} (year)	Geologic reference
22.	Recortado Mt. vitrophyre, Roskruge Mts., Pima County, feldspar (32°10'44" N. lat-111°21'24" W. long) (MB-3-64)	5.20	1.29	12.8	0.82	14.0±0.5	Galbraith et al. (1959) Bikerman (in preparation)

TABLE III
K-Ar DATES FROM OTHER LABORATORIES FOR MID-CENOZOIC PLUTONIC AND VOLCANIC ROCKS LOCATED WITHIN 108°10' TO 112°10' W. LONG, 31°25' TO 33°45' N. LAT

No.	Rock unit, location, and mineral	K (percent)	Ar^{40} radiogenic x 10^{-10} (moles/g)	Ar^{40} atmospheric (percent)	Ar^{40}/K^{40} x 10^{-3}	Apparent age x 10^{-6} (year)	Geologic reference
19b	Superior Dacite ash flow, vitrophyre unit, Globe-Miami district, Pinal County, biotite	5.67	2.04	n.d.	1.15	19.4	Creasey et al. (1962) (sample No. 10)
23.	Andesite dikes, Pima district, intruding Helmet Fanglomerate, Pima County, biotite	3.87	1.69	n.d.	1.40	23.6	Creasey et al. (1962) (sample No. 7)
24.	Obsidian nodules, post-Datil, west of Mule Creek, Grant County, New Mexico, whole rock	4.13	1.36	40	1.09	18.5	Weber and Bassett (1963) (sample No. 2)

TABLE III—Continued

No.	Rock unit, location, and mineral	K (percent)	Ar^{40} radiogenic x 10^{-10} (moles/g)	Ar^{40} atmospheric (percent)	Ar^{40}/K^{40} x 10^{-3}	Apparent age x 10^{-6} (year)	Geologic reference
25.	Obsidian nodules, Datil Formation flow-banded rhyolite from Ewe Canyon, 17-1/2 miles east-northeast of Mogollon, Catron County, New Mexico, whole-rock	4.02	1.92	21	1.59	26.8	Weber and Bassett (1963) (sample No. 4)
26.	Vitrophyre, Datil Formation from east face of Saliz Mts., 5-1/2 miles southwest of Reserve, Catron County, New Mexico, whole-rock	3.18	1.58	36	1.65	27.9	Weber and Bassett (1963) (sample No. 5)

distribution ($\sigma = \pm 7.5$ m. y.) was derived as a best fit to the equivalent data for the Laramide orogeny (Damon et al., 1964). Except for the high peak perhaps caused by excessive sampling in the Pima County area, the gaussian distribution curve also provides a fairly good fit to the data for the Basin and Range orogeny (lower histogram, fig. 3). The curve is skewed toward upper Miocene. This may be the result of a real increase in the tempo of magmatism at that time or may possibly be the result of a higher probability for preservation of the younger volcanics from the ravages of erosion.

The distribution of dates for plutons is very similar to the distribution for volcanic rocks. Seventy percent of the dates are for volcanic rocks, whereas this was reversed for the Laramide study (74 percent plutons). This is probably the result of the difference in the time available for erosion of volcanics and uncovering of plutons. It is interesting that none of the three mid-Cenozoic plutons dated by this laboratory are associated with a major ore deposit.

Ever since Gilluly's masterful Presidential address to the Geological Society of America in 1948, serious doubt has been cast on the theory of periodic diastrophism (Gilluly, 1949). It should be remembered that Gilluly was apparently reacting to the excesses of geologists like Stille who, according to Gilluly, had constructed a list of 40 worldwide orogenic episodes, each lasting an average of only 300,000 years. So corrosive was the doubt aroused by such excesses that, following Gilluly, many geologists began to doubt the existence of discrete and widespread orogenic episodes within the western States during Cretaceous and Tertiary time. Although not generally found in print, it has become common place to hear statements to the effect that orogeny was quasi-continuous during this entire span of time, although active within only a very limited area at any one time. However, this may be, the authors believe that at least one aspect of orogeny, magmatism, did occur in periodic and widespread pulses throughout the Basin and Range province during this time. However, the duration of these pulses is very long ($\sigma = \pm 7.5$ m. y.) compared to the supposed duration of diastrophic episodes postulated by Stille.

Although the magmatic pulses in the Basin and Range province may be separated into discrete Laramide and mid-Cenozoic episodes, the major provincewide magmatic pulse is composed of local magmatic events, which may be much more intense during a restricted period of time in any one area, for example, the Tucson area, when compared to other areas in the province. This local more catastrophic event in the Tucson area happens to coincide with the most intense mid-Cenozoic magmatism throughout the province, but magmatism in other local areas was probably more active before or after this intense episode in the Tucson area. For example, only one magmatic event was dated in the Tucson area during the 5-million year period from 30 to 35 m. y., but the fact that this was not a magmatically dormant time is evident from the considerable number of events that have been recorded in this interval in Nevada (six events) and New Mexico (five events).

The apparent duration of diastrophism can be deceptive. If, for example, the Catalina-Rincon Mountain block were raised in a relatively short period of time, say about 1 m. y., the block would nevertheless continue to rebound as a result of erosion and isostatic adjustment for a much longer period of time until it was wasted away. The erosion and isostatic readjustment of such a large block, 1,000 square miles in area, might well be interpreted as quasi-continuous diastrophism during the entire Neogene period. This would be especially true on a grander scale, if other ranges—for example the Coyote-Quinlan Range (50 miles distant)—were active at the same time, as suggested by the datum for the Kitt Peak granite (sample No. 9).

CONCLUSIONS

The following conclusions appear to be warranted by present data:

(1) During post-Laramide orogeny time, the Basin and Range province was subjected to a pulse of magmatism. The magmatism began in upper Eocene-lower Oligocene time, reached a peak of intensity at the Oligocene-Miocene boundary, and continued into Pliocene time at a diminishing rate.

(2) The composite of Basin and Range magmatic events both during the mid-Tertiary and Laramide orogenies appear to approximately follow a gaussian distribution with a standard deviation of $\pm$ 7.5 m. y. The two discrete magmatic episodes are separated by a period of magmatic quiescence during middle Eocene time.

(3) In the Pima County area, at least within a circle of 50-mile radius centered in the Sierrita Mountains, magmatism was extremely intense during a span of 3 m. y. or less from 25-28 m. y. ago. The intense magmatism was contemporaneous with the updoming and cooling of the Catalina-Rincon Mountain block (Damon et al., 1963).

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