CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
416 W. Congress St., Suite 100
Tucson, Arizona 85701
520-770-3500
http://www.azgs.az.gov
inquiries@azgs.az.gov

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J.H.C.

JUN 20 1969

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

June 20, 1969

TO: J.H. Courtright

FROM: J.D. Sell

K-Ar Dates
Basin-and-Range Uplift
Catalina Mtns., Pima Co.

Attached is a copy of a reprint of Damon's article on the subject area. Although the paper was released in 1962 or 1963 (various references to the paper give conflicting years) he has pointed out some of the "atomic-clock resetting" problems in the area. Subsequent papers have enlarged on several of the problems.

In this paper Damon also talks about some of the Tertiary sediments along the flanks where Lance (1960) has shown the lower units to be involved in faulting in post-Lower Miocene time, but the Pliocene beds are not disturbed by faulting.

The discussion section contains numerous thoughts and words on correlating aspects.

James D. Sell

James D. Sell

JDS:lzb
Encl.

cc: WESaegart

5?-62

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National Academy of Sciences--National Research Council
Publication 1075
1963
Nuclear Geophysics Series No. 38.

D. SELL

K-Ar DATING OF BASIN AND RANGE UPLIFT CATALINA MOUNTAINS, ARIZONA

Paul E. Damon, Rolfe C. Erickson and Donald E. Livingston

Aldrich et al., (1957) reported the first K-Ar and Rb-Sr results for the Older Precambrian of Arizona. They dated micas from the Vishnu schist in the Grand Canyon, from the Lawler Peak granite near Bagdad and from a pegmatite near Wickenburg. Subsequently, Giletti and Damon (1961) reported a number of Rb-Sr dates for mineral separates from rocks which may be stratigraphically classified as Older Precambrian and Damon et al., (1962) reported the first Rb-Sr and K-Ar results for equivalent rocks in Sonora. These dates and a number of unpublished K-Ar dates from this laboratory are plotted as a histogram in Figure 1. The constants used throughout this paper are 0.0118 atom per cent for the relative abundance of K^{40}, $\lambda = 0.589 \times 10^{-10}$/yr. and $\lambda\beta = 4.76 \times 10^{-10}$/yr. for the decay constants of K^{40}, and $\lambda = 1.39 \times 10^{-11}$/yr.$^{-1}$ for Rb^{87} decay constant.

The concentration of dates between 1,300 and 1,400 m.y. for the Arizona-Sonor Older Precambrian is similar to that observed by Aldrich et al., (1957) for the western United States as a whole, including New Mexico, Colorado, and Wyoming as well as Arizona. The older peak at 1,600-1,700 m.y. would be considerably enhanced by inclusion of the unpublished results of Lanphere and Wasserburg (1962) for the Precambrian rocks of the Grand Wash cliffs south of Lake Mead, Arizona.

I have previously suggested that a significant but undetermined part of the spread of K-Ar ages within the block on the histogram from 1,100 to 1,700 m.y. is a result of depth of burial (Damon, 1961). If the diffusion curves of Evernden et al., (1960) for phlogopite are correct, and if this is any indication at all of diffusion in other micas, then burial to a depth of 7 km. will have a serious effect on K-Ar dates for micas.

However, in this paper, we would like to concentrate our attention on the obviously discordant results below 1,000 m.y. In each case, field examination has demonstrated the existence of a Cretaceous-Tertiary thermal event which has partially to completely "reset the atomic clock." For example, the Rb-Sr date falling in the 700-800 m.y. interval is for feldspar from the Granito Rojo Aibo (Damon et al., 1962) which has been intruded by a Cretaceous quartz monzonite pluton; the Rb-Sr date falling in

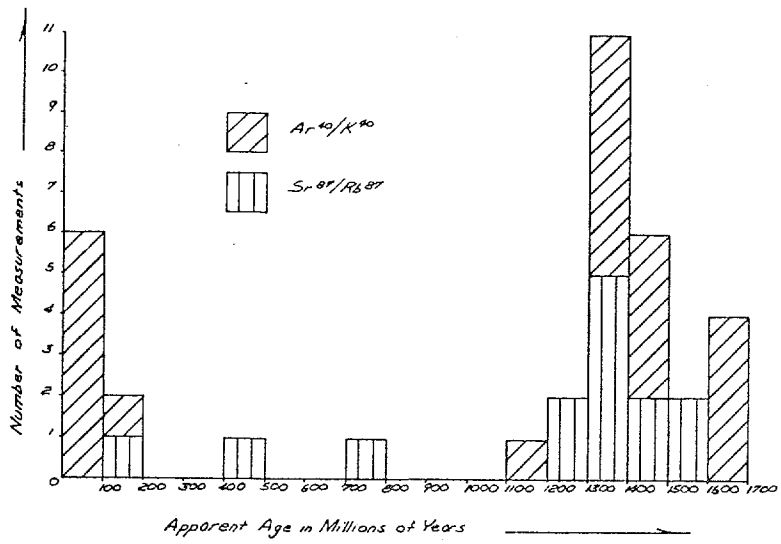

Figure 1. Histogram for Sr^{87}/Rb^{87} and Ar^{40}/K^{40} Apparent Ages for Mineral Separates from Arizona-Sonora rocks stratigraphically classified as Older Precambrian.

the 400-500 m.y. interval is for biotite from the Yavapai schist in the vicinity of a large basic Cretaceous-Tertiary dike.

The greatest discordancies have been observed in the Catalina-Rincon mountains. A schematic of this mountain block is shown in Figure 2. The major mass of the 50-mile long block is composed of Catalina gneiss which varies from schistose to augen and granitoid in texture and appears over wide areas to have undergone metamorphic differentiation. The crest is still capped by younger Precambrian and Paleozoic sediments and the range is flanked by Tertiary sediments and alluvium. According to Lance (1960), the Tertiary sedimentary-structural relationships indicate that block faulting continued into post-Lower Miocene time but major faulting bordering the mountain block did not continue into Pliocene time. A major NW-SE trending fault (the Mogul fault) separates the northernmost part of the Catalinas from the major part of the range to the south as a distinct block composed of about 50 square miles of coarsely porphyritic Precambrian Oracle granite. According to Voelger (1953), the Rillito beds, Cenozoic conglomerates which flank the range to the west, contain a preponderance of coarsely porphyritic granite cobbles in the lower part of the formation but much less in the upper part. Limestone also decreases towards the top but gneiss which is absent in the lower Rillito formation comprises 26 per cent of the upper Rillito beds and 75 per cent of the overlying alluvial fan deposits.

There is evidence that, at least, a large proportion of the Catalina gneiss has been derived from Older Precambrian rocks. First, the gneiss is overlain along its eastern margin by Younger Precambrian Apache

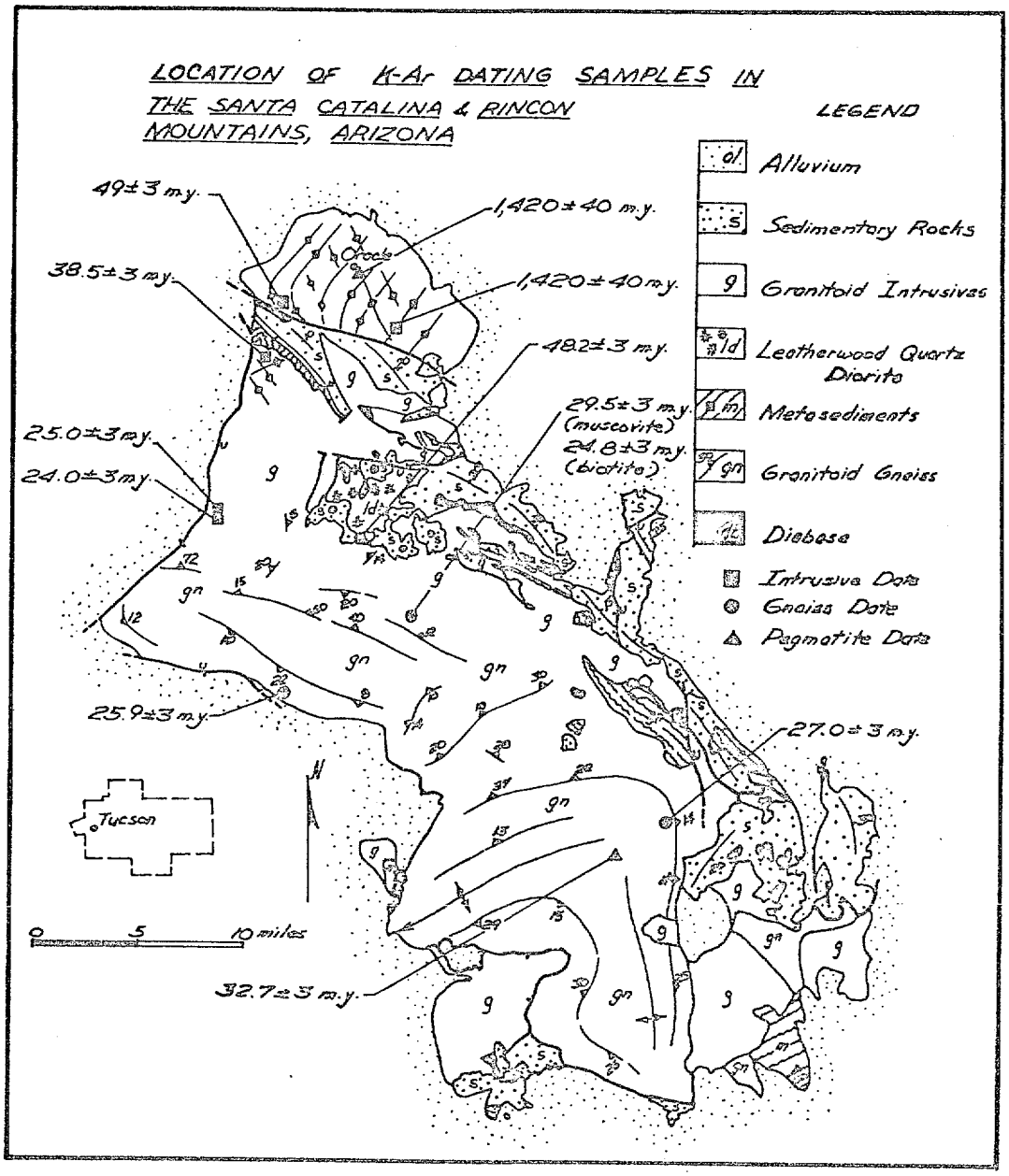

Figure 2

sediments and secondly, E. Catanzaro (personal communication, 1961) has determined the lead isotopic content of zircons extracted from the gneiss which was collected at the Hitchcock Memorial. His results, although highly discordant, when plotted on a Wetherill concordia plot, fall exactly on the chord determined by Silver and Deutsch (1961) for the Johnny Lyon granodiorite which intersects the concordia at 1,660 m.y.

By contrast the Rb-Sr date for muscovite separated from this gneiss (collected at the same point) is approximately 150 m.y. (Giletti and Damon, 1961). Furthermore, a consistent K-Ar age of 26.8 ±1.7 m.y. has been obtained on micas from the gneiss collected at this and other points (Table 1 and Fig. 2).

TABLE 1

K-Ar Dates for Mica from Catalina Gneiss, Santa Catalina and Rincon Mountains, Arizona

Location and Mineral	K %	Radiogenic $Ar^{40} \times 10^{-10}$ moles/gm.	Atmospheric Ar^{40} %	Apparent Age m.y.
Sabino Canyon, muscovite, (PED-4-58)	7.98	3.69	53.6	25.9
Hitchcock Memorial, muscovite, (PED-4a-58)	8.35	4.41	26.5	29.5
Hitchcock Memorial, biotite (PED-4a-58)	7.08	3.14	51.8	24.8
N.E. Rincon Mtns., schist lens in gneiss, muscovite, (PED-29-60)	8.58	4.15	46.1	27.0
			Average:	26.8 ± 1.7 (s.d.)

The two granites from Cargadero Canyon yield K-Ar dates which are not significantly less than the gneiss which they intrude (Table 2). In the unsheared zone north of the Mogul fault, biotite from the Oracle granite yields a K-Ar age of 1,420 m.y. as compared to the age of 1,450 m.y. obtained by the Rb-Sr method (Giletti and Damon, 1961). Muscovite from a pegmatite in the Oracle granite near Oracle also yields an age of 1,420 m.y. (Table 3). However, in the shear zone adjacent to the Mogul fault, biotite from the Oracle granite has suffered severe argon loss and yields an apparent age of only 49.2 m.y. The Samaniego granite immediately south of the Mogul fault, which Wallace (1954) considered to be Precambrian in age, gave a K-Ar date of 38.5 m.y.

TABLE 2

K-Ar Dates for Biotite from Granitic Rocks, Santa Catalina Mountains, Arizona

Location	K %	Radiogenic $Ar^{40} \times 10^{-10}$ moles/gm.	Atmospheric Ar^{40} %	Apparent Age m.y.
Oracle granite, north of Mogul fault, (PED-2-58)	6.83	258	3.2	1,420
Oracle granite, shear zone along Mogul fault, (PED-1-58)	5.86	5.04	27.1	49.2
Samaniego granite, south of Mogul fault, (PED-27-57)	6.22	4.30	32.8	38.5
Coarse-grained granite, Cargadero Canyon, (PED-16-59)	7.68	3.43	44.5	25.0
Fine-grained granite, Cargadero Canyon, (PED-17-59)	7.34	3.14	28.8	24.0

It is interesting that very coarse pegmatitic muscovite in the Catalina gneiss at Manning Camp yields a significantly older K-Ar date than does mica from the gneiss itself. Coarse muscovite from a pegmatite in the Leatherwood diorite near Summerhaven also yielded a significantly older K-Ar date (Table 3). We interpret these data as indicating incomplete degassing resulting from the large dimensions of the pegmatitic mica.

In conclusion, these results demonstrate the severe effect of Basin and Range orogenesis on the K-Ar dates. It is also clear that the granitic

TABLE 3

K-Ar Dates for Pegmatitic Muscovite, Santa Catalina and Rincon Mountains, Arizona

Location	K %	Radiogenic $Ar^{40} \times 10^{-10}$ moles/gm.	Atmospheric Ar^{40} %	Apparent Age m.y.
Near Oracle in Oracle granite (PED-3-59)	8.28	311.5	2.4	1,420
Near Manning Camp in Catalina gneiss (PED-30-60)	8.77	5.14	32.0	32.7
Near Summerhaven in Leatherwood diorite (PED-15-59)	8.34	7.02	58.2	48.2

block north of the Mogul fault has remained stable and at low temperatures for about 1,400 m.y. The rather uniform K-Ar dates for micas from the Catalina gneiss indicate that the uplift had progressed to the point that metamorphism had terminated by Upper Oligocene-Lower Miocene time. Furthermore, these conclusions appear to be in essential agreement with the stratigraphic-structural record.

This work was supported by the Research Corporation, National Science Foundation grant No. G-14603, and by the State of Arizona.

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Discussion

Wasserburg: The zircon ages are from the gneiss?

Damon: Yes, the zircon ages from the gneiss fit very nicely on Dr. Silver's discordia chord.

Silver: I would like to make a comment on this. I presented at the western A.G.U. meeting two lines on the Wetherill plot which were very similar and converging at the left-hand end. One of these lines, made up of the Kinow schist and associated rhyolites and intrusives, could not be distinguished from the Johnny Lyon at the lower left-hand end. The point is, at the left-hand end, you can not distinguish these two, within the limits of error. Thus the Catalina gneiss may be really metamorphically worked-over older complex.

Damon: A very good point.

The hypothesis that we might advance to explain these data is that the dates we are getting in the gneissic block represent refrigeration after block faulting. The region to the north where we find the Oracle granite, that is, north of the Mogul fault, has remained geodetically high throughout all of this Precambrian and post-Precambrian time; there has been very little burial. This is in good agreement with the geological evidence, as far as sedimentation is concerned. We now have to ask about the geological evidence for the age of the block faulting. There are well-dated (by fossils, according to Professor Lance) lower Micene beds which are turned up on end; that is, they have participated in the block faulting and have been shoved up against the gneiss. Also in the area are fossiliferous flat-lying lower and middle Pliocene beds that have been undisturbed and so are post-block faulting. Thus the block faulting event must be post-lower Miocene and pre-lower Pliocene, putting it somewhere between about 10 to 20 million years ago. Notice that we get 26 million years for the gneiss.

Professor Mayo and his students have mapped the petrofabrics, lineations, etc., in the gneiss and concluded that prior to block faulting this entire area was domed up. Thus the Mogul fault must have acted as the hinge. If this is the case we will be dating something which approximates,

not very precisely, the uplifting of this mass which was at relatively high temperature -- certainly beyond 400° C. as it was probably buried at very great depth.

Wasserburg: Does the 400° come from the burial depth?

Damon: No, it comes from the degree of metamorphism and some rather shaky information on Na/K ratios in muscovites which really is not quantitative.

Wasserburg: The degree of metamorphism in the parent gneiss? Was that imposed by the later deformation?

Damon: Yes, in the parent gneiss. It is a problem whether the metamorphism that first created the gneiss is an older Precambrian metamorphism or younger. Professor DuBois has studied the petrography and concluded this is a polymetamorphic gneiss. It has undergone two metamorphisms, and in general the exposed older Precambrian is not as metamorphosed as is this particular gneissic block.

Gast: Does this contrast exist across the Mogul fault?

Damon: You do not find the gneiss north of the fault at all. When you go across the fault you are in the distinct Oracle granite. DuBois believes that the post-Laramide metamorphism was a very severe one, much more severe than the first one. Thus, if this is true, the gneiss was formed during Tertiary times.

Now, although we do not know with precision what we are dating -- we think we are dating the time of the uplifting -- the consistency of the ages (standard deviation of ±1.7 m.y.) perhaps is some indication that the uncovering and cooling was not a slow process, within this crude limit of several million years. Perhaps we are getting near to the time of refrigeration.

Wasserburg: I do not understand what you mean by refrigeration.

Damon: This means simply to lift it up to the point where the temperature is such that you cannot activate diffusion at a significant rate any longer.

Wasserburg: Then you are saying that this effect is predominantly a depth of burial effect.

Damon: No, I believe this is a metamorphic effect, under a fairly great depth of burial. I think there was some sort of a geothermal anomaly -- this was not the usual 1°/40 meters gradient in this particular area.

Silver: This picture of an intense history in the mid- or early-Tertiary is developing more and more strongly, and the probability exists there was a raised geothermal anomaly in this area. I think there will be even some good-sized intrusives which will fall into the 30 m.y. age group found in this area.

Wasserburg: I was really more concerned with the point of view, which may be quite defensible, that just depth of burial, without any real heat forces of deformation, could cause these losses.

Damon: I was not referring to these losses; this is a very severe case. What I said was, that when you went into the field you could show the geological reason for these highly discordant events. I was referring to the Precambrian peak in the histogram when I was talking about depth of burial. We get quite a few ages of about 1,300 m.y., but I do not believe these are necessarily the ages of crystallization of the biotite. I believe burial of only 7 km over a long period of time is quite sufficient to skew the mica dates, using the diffusion coefficients of Evernden or Hurley.

Wasserburg: But there are examples of rocks buried just as deeply which show no effect at all.

Damon: Of course, there is a time factor. They must be buried for very long periods at these modest temperatures in order to have significant diffusion.

Wetherill: If there is a difference in the heat flow of even a factor of two you may have an entirely different picture.

Wasserburg: But that would imply a heat source. The body may have been buried only two kilometers but with a pluton right under it. I am only worried about intrinsic burial, with the normal geothermal gradient, being the cause of diffusion.

Damon: At 30°/kilometer and 7 km depth, the temperature should be between 200° and 225°. If I use Evernden's data for phlogopite, there must be argon loss.

W.E.S.
APR 22 1964

S. A. B
APR 6 1964

J. H. C.
APR 6 1964

K-Ar Dating of Laramide Plutonic and Volcanic Rocks within the Basin and Range Province of Arizona and Sonora*

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MAY 5 - 1964

Paul E. Damon, Richard L. Mauger, and Michael Bikerman
University of Arizona Geochronology Laboratories

MR. ~~IDS~~, ~~SAB~~, JRW, ~~WES~~
READ AND RETURN
PREPARE ANSWERS ..... HANDLE .....
FILE ..... INITIALS .....

ABSTRACT: K-Ar dating of plutonic and volcanic rocks from the Basin and Range province, primarily in Arizona and Sonora, demonstrate that the most intense Laramide magmatic activity occurs at the Mesozoic-Tertiary boundary. Magmatism is primarily confined to the time encompassed by the Laramie, Fort Union and Wasatch formation, i.e., a span of 20 m.y. from Maestrichtian through Wasatchian time. The Laramide revolution in the Basin and Range province constitutes a single, intense pulse which does not appear to significantly overlap the preceding middle Cretaceous orogeny or the subsequent middle Tertiary orogeny.

*University of Arizona Geochronology Laboratories Contribution No. 91.

INTRODUCTION:

"Geologists to date in the Rocky Mountains have discovered a long succession of dynamic events through late Mesozoic and Tertiary time. At first, a single rather violent orogeny was visualized, but now numerous unconformities, coarse conglomerates, and structural relations attest a condition of unrest in the general Rocky Mountain region from middle Mesozoic to the present, and it has become urgent that the meaning of the term Laramide orogeny be circumscribed by time limits" (Eardley, 1951, p. 284). It is the purpose of this paper to demonstrate by K-Ar dating that volcanic and plutonic activity associated with the Laramide orogeny in the Basin and Range province occurs within a relatively short period of time which does not, in general, overlap with the preceding middle Cretaceous activity or subsequent middle Tertiary activity. Furthermore, it will be shown that the duration of intense Laramide igneous activity within this region is essentially temporally coextensive with the classical limits placed on the Laramide orogeny within the eastern Cordillera, i.e., the time encompassed by the Maestrichtian Laramie formation, the Paleocene Fort Union formation, and the Sparnacian-Ypresian Wasatch formation.

The Basin and Range province of Southeastern Arizona and Northwestern Sonora was the locus of a deep, northwestward-trending trough during the Cretaceous. Over 21,000 feet of sediment accumulated within this trough during early Cretaceous time. In late Cretaceous time, a maximum of over 8500 feet of sediment was accumulated in northwestern Sonora and the sea occupying the Rocky Mountain trough expanded westward across Northern Arizona (McKee, 1961). Following this profound marine transgression there occurred diastrophism, extrusion of extensive ash flow sheets and the intrusion of many hypabyssal plutons of dioritic to granitic composition. The Laramide question in the Basin and Range province as elsewhere, concerns the intensity, time and duration of the Laramide revolution. Can the Laramide revolution be clearly delineated as a discrete intense pulse? This question has economic as well as academic significance because most of the famous copper bearing porphyries of the Basin and

Range province have been associated with the Laramide revolution (Wilson, 1962, p. 71).

Techniques: K analyses were made by flame photometry using a modified Perkin Elmer instrument. The Perkin Elmer internal standard procedure, without chemical separations and with the addition of a Sodium buffer, was used (Cooper, 1962). Analytical precision was about $\pm$ 1% 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% 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 also 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 about $\pm$ 3% was obtained for argon analyses within the time range under consideration.

The above mentioned precision for argon and potassium analyses implies a probable error not exceeding $\pm$ 3% for the overall age analysis. Several rocks of Laramide age have been dated by both the U.S.G.S. (Creasey and Kistler, 1962) and this laboratory. The analyses are for the same rock unit but not for identical biotite separates. The comparisons are given in table 1. The results are well within the stated probable error.

Table 1 Comparison of Arizona with U.S.G.S.
K/A dates for biotite separates.

Rock, mineral and location	Arizona date 10^6	U.S.G.S. date 10^6yr.
Pima granodiorite, Pima district	59	60
Schultze granite, Globe-Miami district	58	58
Dacite ash flow, Globe-Miami district	20 (f)	20
	17 (w)	

f = fresh, w = weathered

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

Results: The analytical results for 21 samples are given in table 2. All of the analyses now completed in this laboratory for Basin and Range plutonic and volcanic rocks, which fall in the time range from 40 to 90 m.y., are included. This time range was chosen so as to coincide with the extent of the Laramide orogeny as suggested by Gilluly (1962), i.e., the entire interval from Turonian to late Eocene.

Sample localities are shown in figure 1. Included in figure 1 are 5 analyses from Nevada and Utah (Armstrong, 1963) and 8 U.S.G.S. analyses for Arizona plutonic and volcanic rocks (Creasey and Kistler, 1962) in addition to the 21 samples listed in table 1. Thus the provenience of the dated samples ranges throughout the Basin and Range province from Northern Sinaloa (El Fuerte, no. 21) to the Bingham district in Northern Utah. However, 28 of 34 samples are from Northern Sonora and Southern Arizona.

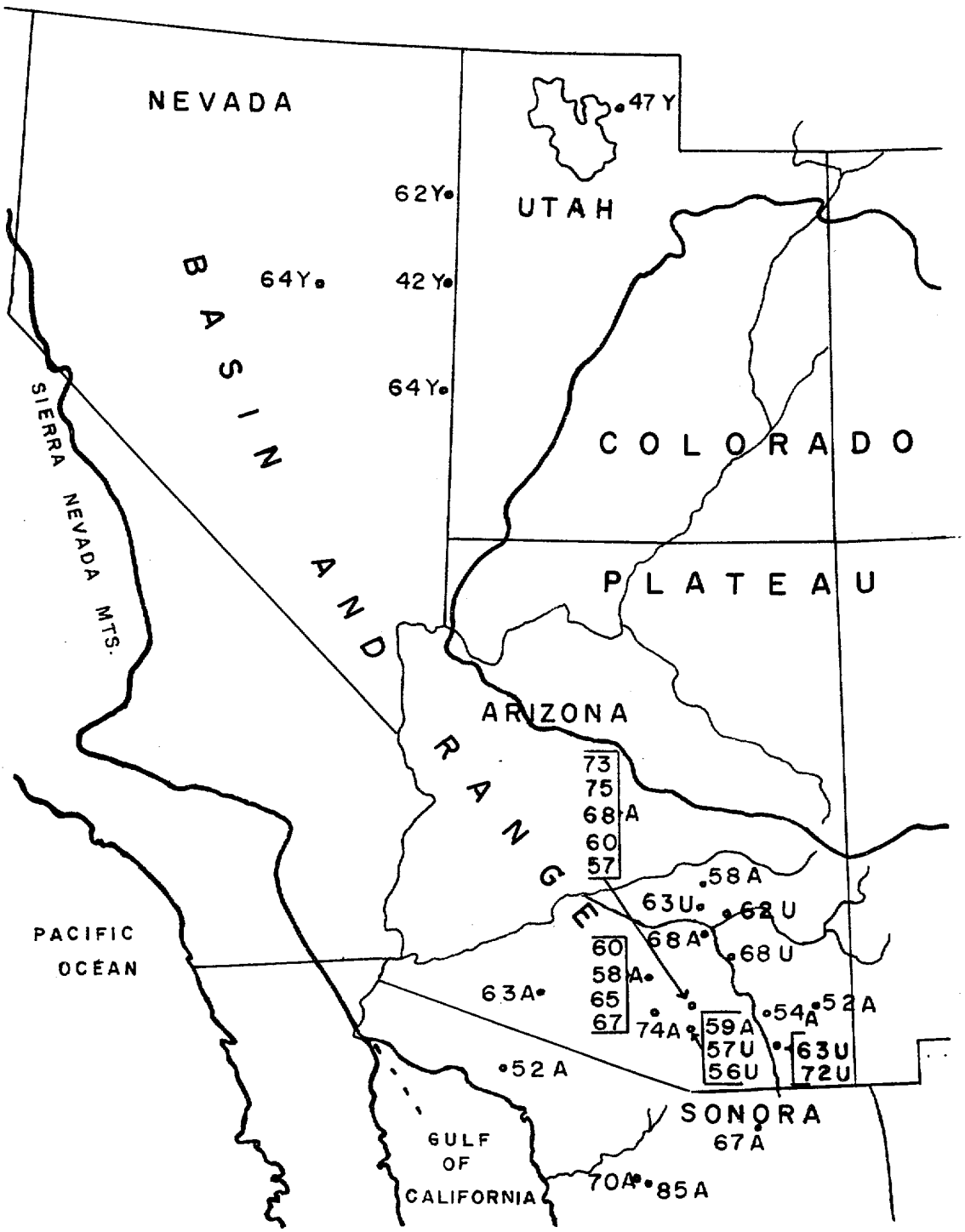

Figure 1: Sample localities (A = Arizona dates, U = U.S.G.S. dates, Y = Yale dates).

Table 2 K-Ar Dates for Laramide Plutonic and Volcanic Rocks from Arizona and Northwestern Mexico

No.	Rock, mineral dated, location and catalog no.	K %	Ar^{40} Radiogenic x 10^{-10} moles/g	Ar^{40} Atmospheric %	Ar^{40}/K^{40} x 10^{-3}	Apparent age x 10^{6} yr.	Geologic Reference
1	Schultze granite, biotite, Globe Miami district, Gila Co., Arizona (PED-5-59)	7.01_5	7.31	19.6	3.45	58	Peterson (1954), Ransome (1903)
2	Copper Hill quartz monzonite, biotite, 13 Km. W.S.W. of Winkelman, Pinal Co., Arizona (PED-27-61)	6.53_5	8.03	8.0	4.07	68	Evensen (1961)
3	Alaskite, biotite, Silver Bell district, Pima Co., Arizona (PED-22-59)	6.26	7.31	28.8	3.87	65	Richard and Courtright (1954)
4	Quartz monzonite, biotite, Silver Bell district, Pima Co., Arizona (PED-21-59)	5.54	6.72	35.3	4.02	67	Richard and Courtright (1954)
5	Dacite, biotite, Silver Bell district, Pima Co., Arizona (PED-23-59)	6.42	6.65	30.6	3.43	58	Richard and Courtright (1954)
6	Rhyolite ash flow, Sanidine, Silver Bell district, Pima Co., Arizona (PED-6-63)	7.40	7.94	7.1	3.56	60	Richard and Courtright (1954)
7	Amole quartz monzonite, biotite, Tucson Mts., Pima Co., Arizona (PED-11-63)	6.66	8.79	12.0	4.46	73	Brown (1939) Kinnison (1958)
8	Granophyre, biotite, Tucson Mts., Pima Co., Arizona (PED-12-63)	7.08	9.63	5.3	4.51	75	Brown (1939) Kinnison (1958)

9	Cat. Mt. rhyolite, Tucson Mts. Pima Co., Arizona:	5.57	7.09	28.6	4.22	70	Brown (1939)
	(MB-1-62) Feldspar concentrate	10.32	12.11	39.6	3.89	65	Kinnison (1958)
	(MB-3-62) " "						
10	Biotite rhyolite, biotite, Tucson Mts., Pima Co., Arizona (PED-19-62)	7.32	7.99	9.8	3.62	61	Brown (1939) Kinnison (1958)
11	Shorts Ranch 'Andesite', biotite, A Mt., Pima Co., Arizona (PED-15-62)	6.84	7.01	14.8	3.40	57	Brown (1939) Kinnison (1958)
12	Viopuli red ignimbrite, biotite, Viopuli village, Papago Reservation, Pima Co., Arizona (PED-12-61)	6.16	8.27	19.0	4.44	74	Brown (1939) Kinnison (1958)
13	Pima granodiorite, biotite, Pima Mining district, Pima Co., Arizona (PED-8-62)	7.71	8.17	9.4	3.51	59	Cooper (1960)
14	Quartz-orthoclase veinlet in Cornelia quartz monzonite, biotite, Ajo district, Pima Co., Arizona (RM-2-62)	5.97_5	6.81	28.6	3.77	63	Gilluly (1946)
15	Texas Canyon granite, muscovite, Little Dragoon Mts., Cochise Co., Arizona (PED-11-60)	8.75	8.54	22.0	3.24	54	Cooper (1959)
16	Rattlesnake Point Rapakivi granite, biotite, 3 Km. south of Dos Cabezas, Cochise Co., Arizona (PED-25-61)	6.34	5.94	14.7	3.10	52	Sabins (1955)
17	Quartz monzonite, biotite, 2 Km. S.W. of Torreon, Sonora Mexico (PED-29-60)	6.91	8.39	22.5	4.02	67	Fries (1962)
18	Puerto Blanco quartz monzonite, biotite, 10 Km. due west of Caborca, Sonora, Mexico (PED-11-59)	7.04_5	8.87	26.5	4.17	70	Arellano (1956)

19	Loma petroglifica quartz monzonite, biotite, Cerros del Arpa area, S. of Caborca, Sonora, Mexico (PED-7-59)	6.37	9.80	46.3	5.10	85	Damon et. al. (1962)
20	Granite, muscovite, 5 Km. S. of Sonoyta on highway 10, Sonora, Mexico (PED-10-58)	8.63_5	8.02	12.0	3.08	52	Fries (1962)
21	Capomos quartz monzonite, biotite, 4 Km. N.E. of El Fuerte, Northern Sinaloa, Mexico (CS-24-60)	4.72	6.41	14.7	4.50	75	De Cserna et. al. (1962)

The geology of individual samples will not be discussed but references to the pertinent geologic literature are included in table 2. The samples provide a good representation of typical rock types associated with this time range (40-90 m.y.), mostly quartz monzonite, granite, and rhyodacitic volcanic rocks. A number of important copper bearing porphyries are included as well as plutons not known to be associated with copper ores.

The 34 dates are plotted as a histogram in figure 2. No duplicate analyses are included for any formation. Each block represents a single date for a distinct rock unit. Eight volcanic rocks are included, the remaining 26 dates are for granitic rocks. The Cretaceous time scale was taken from Kulp (1961). The Tertiary time scale is from Evernden et. al., (1964), and the date for the Cretaceous-Tertiary boundary was established by the definitive work of Folinsbee et. al., (1961) on upper Cretaceous ash falls in Alberta. The range of the Laramie, Fort Union and Wasatch formation encompassing the classical Laramide revolution is taken from the correlation tables published by Moore (1958). In those cases where the date falls between a class interval on the histogram, the date was computed to a third decimal place to establish the nearest class interval.

The data thus plotted provides a symmetrical gaussian distribution peaking exactly at the Cretaceous-Tertiary boundary. Only 15% of the dates fall outside of the time encompassed by the Laramie-Fort Union-Wasatch formations and 65% of the dates fall within the span of 15 m.y. from 55 to 70 m.y. When one considers the experimental error and perturbations caused by subsequent geologic events, the data provide good evidence for a "single rather violent orogeny" as visualized by geologists of an earlier generation.

Despite the fact that the rocks dated cooled relatively quickly and have not been affected by the many vicissitudes affecting older or more deep seated rocks, it is still surprising to the authors that variable cooling history and subsequent geologic events have not skewed the histogram towards younger apparent ages.

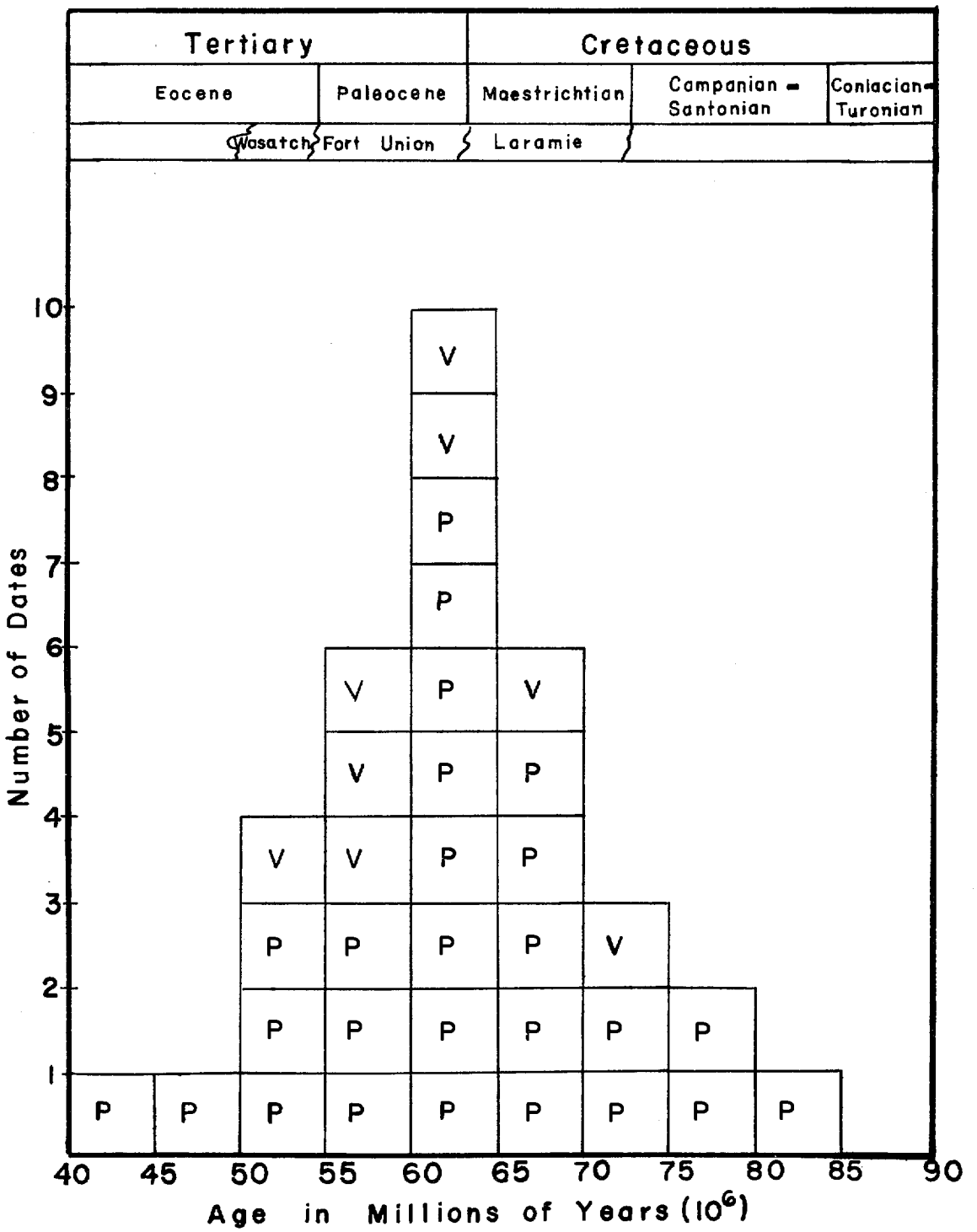

Figure 2: Histogram of K-Ar dates falling within the time range of 40 to 90 m.y. (10^6yr.) (P = plutonic) (V = volcanic).

K-Ar dates from regionally metamorphosed schistose terrains have been found, in several cases, to fall well within the classical Laramide range. The Altar Schist in the Cerros del Carnero area of Sonora, for example, has been dated at 57 $\pm$ 3 m.y. (Damon et. al., 1962). These dates have not been included in this paper, which is concerned with plutonic and volcanic rocks, but they do provide corollary information pertinent to the general Laramide problem.

Concluding Remarks: The following conclusions appear to be warranted by the data:

1) The most intense Laramide plutonic and volcanic activity in the Basin and Range province occurred at the Mesozoic-Tertiary boundary.
2) Laramide plutonic-volcanic activity in the Basin and Range province is 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.
3) Diastrophism was accompanied by coeval volcanism, plutonism, metamorphism and ore deposition during the Laramide Revolution.
4) The Laramide Revolution within the Basin and Range province constitutes a single, intense orogenic pulse which does not appear to significantly overlap the preceding middle Cretaceous orogeny or the subsequent middle Tertiary orogeny.

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ISOTOPIC DATING OF ARIZONA ORE DEPOSITS

by R. L. Mauger, P. E. Damon and B. J. Giletti

W.E.S. OCT 29
J. H. C.
AUG 10 1965

Reprinted from Transactions of SME, March 1965, Vol. 232

Table I. Pb^{206}/Pb^{207} Ages for Arizona Galenas Determined by the Method of Russell-Stanton-Farquhar

KRUEGER ENTERPRISES, INC.
GEOCHRON LABORATORIES DIVISION
24 BLACKSTONE STREET • CAMBRIDGE, MA. 02139 • (617)-876-3691

PRIORITY BASIS
POTASSIUM-ARGON AGE DETERMINATION

REPORT OF ANALYTICAL WORK

Our Sample No. F-6260

Date Received: 6/29/82

Your Reference: Letter of 6/24/82

Date Reported: 7/1/82

Submitted by: L. Clark Arnold
Pillar, Lowell and Associates
5115 North Oracle Road
Tucson, AZ 85704

Sample Description & Locality: Sample AO-20, rhyolite porphyry.

Material Analyzed: feldspar concentrate, -80/+200 mesh. Treated with dilute HF and HNO_3 to remove alterations.

Ar^{40*}/K^{40} = .004069

AGE = 68.3 +/- 2.8 M.Y.

Argon Analyses:

Ar^{40*}, ppm.	Ar^{40*}/ Total Ar^{40}	Ave. Ar^{40*}, ppm.
.01349	.609	.01339
.01329	.629	

Potassium Analyses:

% K	Ave. %K	K^{40}, ppm
2.729	2.698	3.291
2.666		

Constants Used:

$\lambda_\beta = 4.72 \times 10^{-10}$/ year

$\lambda_e = 0.585 \times 10^{-10}$/ year

$K^{40}/K = 1.22 \times 10^{-4}$ g./g.

$$AGE = \frac{1}{\lambda_e + \lambda_\beta} \ln\left[\frac{\lambda_\beta + \lambda_e}{\lambda_e} \times \frac{Ar^{40*}}{K^{40}} + 1\right]$$

SE 1/4, Sec. 20
T 18S, R 11E

Red Bay rhyolite
Amargosa area.

Note: Ar^{40*} refers to radiogenic Ar^{40}.
M.Y. refers to millions of years.

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KRUEGER ENTERPRISES, INC.
GEOCHRON LABORATORIES DIVISION
24 BLACKSTONE STREET • CAMBRIDGE, MA 02139 • (617)-876-3691

PRIORITY BASIS
POTASSIUM-ARGON AGE DETERMINATION

REPORT OF ANALYTICAL WORK

Our Sample No. M-6350 Date Received: 9/28/82

Your Reference: Letter of 9/20/82 Date Reported: 9/30/82

Submitted by: L. Clark Arnold
Pillar, Lowell and Associates
5115 North Oracle Road
Tucson, AZ 85704

Sample Description & Locality: Sample EH-AD-1, altered granite or granodiorite.

Material Analyzed: Sericite concentrate, -60/+200 mesh.

Ar^{40*}/K^{40} = .002035 AGE = 34.5 +/- 1.4 M.Y.

Argon Analyses:

Ar^{40*}, ppm.	Ar^{40*}/ Total Ar^{40}	Ave. Ar^{40*}, ppm.
.01416	.317	.01410
.01404	.477	

Potassium Analyses:

% K	Ave. %K	K^{40}, ppm
5.602	5.678	6.927
5.754		

Constants Used:

$\lambda_\beta = 4.72 \times 10^{-10}$/ year

$\lambda_e = 0.585 \times 10^{-10}$/ year

$K^{40}/K = 1.22 \times 10^{-4}$ g./g.

$$AGE = \frac{1}{\lambda_e + \lambda_\beta} \ln\left[\frac{\lambda_\beta + \lambda_e}{\lambda_e} \times \frac{Ar^{40*}}{K^{40}} + 1\right]$$

Note: Ar^{40*} refers to radiogenic Ar^{40}.
M.Y. refers to millions of years.

Emigrant Hill
Cochise Co., AZ
Sec. 33, T14S, R.29E.

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