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Chronology of Intrusion and Ore Deposition at Ray, Arizona: Part I, K-Ar Ages*

Norman G. Banks, Henry R. Cornwall, M. L. Silberman, S. C. Creasey, and Richard F. Marvin

GEOLOGICAL SURVEY RESEARCH 1962

SHORT PAPERS IN GEOLOGY, HYDROLOGY, AND TOPOGRAPHY, ARTICLES 120–179

GEOLOGIC STUDIES

ECONOMIC GEOLOGY

120. AGE OF SOME COPPER-BEARING PORPHYRIES AND OTHER IGNEOUS ROCKS IN SOUTHEASTERN ARIZONA

By S. C. Creasey and R. W. Kistler, Menlo Park, Calif.

Dating of the Mesozoic and early Cenozoic geologic events in southeastern Arizona is severely hampered by the scarcity of fossiliferous sedimentary rocks of these ages and by the isolation of individual mountain ranges. Isotopic age determinations, therefore, provide definite ages to replace permissive time intervals and aid in the correlation of geologic events from one range to another.

The K-Ar and Rb-Sr ages of biotites from some intrusive and extrusive rocks in southeastern Arizona are listed in table 120.1, and the location of the rocks sampled is shown on figure 120.1. Potassium was determined by flame photometer using lithium as an internal standard. Argon was extracted from the specimens using the technique described by Lipson (1958). Argon was analyzed with a Reynolds-type

Table 120.1.—*Analytical data and isotopic ages of biotites from Arizona*

K-Ar age determinations

No. on fig. 120.1	Rock	Location	K (weight percent) [1]	$K^{40}\times10^{-7}$ (moles per g)	$*Ar^{40}\times10^{-11}$ (moles per g)	Ar^{40}/K^{40}	Age (m. y.)
1	Juniper Flat Granite [2]	Northern Mule Mountains, Warren district.	5. 49	1. 71	171. 0	0. 01	163
2	Intrusive rhyolite	Tombstone district	7. 44	2. 32	87. 0	. 00375	63
3	Schieffelin Granodiorite	do	3. 33	1. 04	44. 6	. 00429	72
4	Equigranular granodiorite	Pima district	7. 28	2. 27	81. 0	. 00357	60
5	Quartz monzonite porphyry	do	5. 98	1. 87	61. 5	. 00329	56
6	Rhyolite tuff	do	7. 16	2. 23	74. 7	. 00335	57
7	Andesite dikes	do	3. 87	1. 21	16. 9	. 0014	24
8	Lost Gulch Quartz Monzonite	Globe-Miami district	7. 24	2. 26	83. 6	. 0037	62
9	Schultze Granite	do	7. 32	2. 28	77. 7	. 00341	58
10	Vitrophyre (dacite ash flow)	do	5. 67	1. 77	20. 4	. 00115	20
11	Granite Mountain Porphyry	Mineral Creek district	6. 86	2. 14	79. 6	. 00372	63
12	Quartz diorite porphyry	Banner district	6. 49	2. 02	73. 9	. 00366	62
13	Copper Creek granodiorite	Bunker Hill district	6. 27	1. 96	78. 8	. 00402	68

Rb-Sr age determinations

No. on fig. 120.1	Rock	Location	Rb^{87} (ppm)	Normal Sr (ppm)	$*Sr^{87}$ (ppm)	Sr^{87}/Rb^{87}	Age (m. y.)
1	Juniper Flat Granite [2]	Warren district	384	22. 2	0. 994	0. 00259	176
	do [2]	do	388	21. 3	1. 017	. 00262	178

[1] Frank Walthall analyst.
[2] Same sample used for Rb-Sr and K-Ar age determinations.
*Radiogenic.

Decay constants:
K^{40}: $\lambda_e=0.584\times10^{-10}$ yr^{-1}, $\lambda_\beta=4.72\times10^{-10}$ yr^{-1}; $K^{40}=1.22\times10^{-4}$ g K^{40} per g K.
Rb^{87}: $\lambda=1.47\times10^{-11}$ yr^{-1}; $Rb^{87}=0.283$ g Rb^{87} per g Rb.

felin therefore establishes a minimum age of 72 m.y. for the thrusts.

PIMA DISTRICT

K-Ar ages were determined for four igneous rocks from the Pima district: equigranular granodiorite, quartz monzonite porphyry, rhyolite tuff, and andesite dikes. These rocks and their general relations to each other, to the ore deposits, and to the structures in the area have been described by Cooper (1960, p. 72, 74, 76, and 89).

After a major orogeny that formed highly complex northwest-trending fault and fold structures in sedimentary and volcanic rocks of Cretaceous(?) age, the granodiorite and quartz monzonite porphyry were intruded. Although the geologic evidence is not unequivocal, Cooper (1960, p. 74) thought the granodiorite was older, but he gave no impression of a significant time break between the two intrusives. Cooper's views are supported by the K-Ar ages of the two rocks. According to Cooper (1960, p. 63) the quartz monzonite porphyry is spatially associated with ore deposits in the Pima district, and possibly is genetically related to them. This possible genetic relation, however, is indirect because the porphyry itself is the host for the disseminated copper ore. The K-Ar age of very slightly mineralized porphyry, 56 m.y., establishes a maximum age for the ore.

According to Cooper (1960), the Helmet Fanglomerate is younger than the ore deposits, and is cut by a large thrust (San Xavier thrust) which also is younger than the ore deposits. Both the San Xavier thrust and the Helmet Fanglomerate are transected by a narrow zone of andesite dikes. The K-Ar age of the andesite dikes establishes a minimum age for the thrusting and ore deposition.

The K-Ar dates give some information on the apparent ages of structural events in the Pima district. Here, thrusts and folds are older than 60 m.y., the age of the granodiorite, whereas in the Tombstone district, thrusts are older than 72 m.y., the age of the Schieffelin Granodiorite. A Late Cretaceous-early Tertiary period of deformation that includes thrusting long has been postulated for southeastern Arizona, and these apparent dates help to define it. In addition, Cooper (1960) recognized the San Xavier thrust in the Pima district as being a distinctly younger and independent structure. The age of the andesite dikes (24 m.y.) established a significant younger age limit for this thrust. Unfortunately a reliable older age limit was not obtained. The rhyolite tuff, which is older than the Helmet Fanglomerate, was dated with the hope that it, along with the andesite dikes, would bracket the Helmet Fanglomerate and San Xavier fault within a small time span. The K-Ar age of the rhyolite tuff is virtually the same as that of the quartz monzonite porphyry, thus the time interval between the apparent maximum and minimum ages for the Helmet Fanglomerate and the San Xavier thrust is 32 m.y., a figure much larger than we anticipated. The similarity of the K-Ar ages of the quartz monzonite porphyry and rhyolite tuff, however, raises the problem of a possible genetic relation between the two.

The K-Ar ages of the four rocks in the Pima district suggest the following sequence of events:

1. Deformation intensely folded and faulted the volcanic and sedimentary rocks over 60 m.y. ago.
2. The quartz monzonite porphyry was mineralized no earlier than 56 m.y. ago.
3. The deposition of the Helmet Fanglomerate and the movement along the San Xavier thrust occurred less than 56 to 57 m.y. ago (the K-Ar ages of the quartz monzonite porphyry and the rhyolite tuff), and more than 24 m.y. ago (the K-Ar ages of the andesite dikes).

GLOBE-MIAMI DISTRICT

The Lost Gulch Quartz Monzonite and the Schultze Granite from the Globe-Miami district were dated by the K-Ar method. The Lost Gulch Quartz Monzonite is the host rock for the Castle Dome and Copper Cities disseminated copper deposits. Locally the Schultze Granite is also mineralized.

The Lost Gulch Quartz Monzonite is known to be post-Paleozoic, but there are no Mesozoic rocks in the area by which its age relative to that era can be determined. It is cut by granite porphyry that seems to be genetically related to the Schultze Granite, and on this basis the Schultze Granite was thought by Peterson (1954) to be younger. Peterson (1954) thought the extensive copper mineralization in the Globe-Miami district closely followed the intrusion of the Schultze Granite and granite porphyry and was the culminating event in the long period of igneous activity. The close spatial relation of the Lost Gulch Quartz Monzonite and Schultze Granite supports the close isotopic ages and, indirectly therefore, the general time of the igneous activity in the Globe-Miami district. Until further information on the age of the deposits is available, a tentative maximum age of 58 m.y. for the disseminated copper deposits seems reasonable.

In the Globe-Miami district, a large ash-flow deposit of post-mineralization dacite accumulated on a well-developed erosion surface. Here and there as much as several hundred feet of conglomerate (Whitetail Conglomerate) separates the dacite from the under-ore deposition. They, like the neighboring schist, have themselves been altered by the ore-bearing solutions, and, where favorably situated, have been changed into protore just as the schist was changed under similar circumstances. Their significance lies in their testimony to the probable presence of much larger masses of similar igneous material below any depths likely to be reached in mining, and it is from these larger and deeper masses, which must have taken far longer to solidify and cool than the bodies now exposed by natural erosion and in the mines, that most of the energy and at least a part of the materials were derived to form the protore.

Following Ransome's beliefs, the data presented here suggest that the range in age of the ore deposits is essentially the range in K-Ar age of the "porphyries," that is, 56 to 72 m.y. On the Holmes (1960) time scale, the Cretaceous period ended 70±2 m.y. ago and the Eocene 40 m.y. ago. Using these terminal dates, the ore deposits are early Tertiary, and the range in time of 16 m.y. seems small to us. We find considerable support in the data for the concept of a Laramide period of mineralization in southeastern Arizona.

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John E Kinnison

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EPEIROGENY-OROGENY VIEWED FROM THE BASIN AND RANGE PROVINCE

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This paper is to be presented at the Fall Meeting and Rocky Mountain Minerals Conference of the Society of Mining Engineers of AIME, Ramada Inn, Phoenix, Arizona, October 7 to 9, 1965

Epeirogeny-Orogeny Viewed from the Basin and Range Province

Paul E. Damon and Richard L. Mauger
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Tucson, Arizona

"First of all we have seen hardly anything of the earth's crust below a depth of 2 km; secondly, only one third of the globe is open to geological investigation--the rest is ocean; thirdly, a large portion of the continents is covered by shallow water or alluvial deposits, and of the remaining fraction only a very small portion is really well known."

L. U. DeSitter
in _Structural Geology_, 1956, p. 483

"This digression from discussion of the familiar ocean basins to the mysterious continents may serve to emphasize that large elevated regions of the continents and the ocean basins may be produced by the same bulges of the mantle. The origin of rises may be determined by studying plateaus. Unfortunately we know even less about plateaus than about rises."

H. W. Menard
in _Marine Geology of the Pacific_, 1964, p. 152

ABSTRACT:

Potassium-argon dating of the late Mesozoic and Cenozoic intermediate to acidic plutons and volcanic rocks of Arizona and northern Sonora demonstrates the existence of two distinct magmatic episodes. The earlier episode begins in late Campanian time and dies out before the middle Eocene. Following a quiescent period in middle and late Eocene time, magmatism increases in Oligocene time, becomes most intense at the Oligocene-Miocene boundary and dies out as the Pliocene is approached. Pliocene magmatism is primarily confined to extrusion of post-orogenic basalts.

The late Mesozoic-early Cenozoic magmatic pulse is essentially confined within the limits of the classical Laramide orogeny (Laramie through Wasatch time). The mid-Tertiary pulse is contemporaneous with the mid-Tertiary Basin and Range orogeny. The Laramide provides an excellent specific example of Umbgrove's concept of the pulse of the earth and in general his concept appears to be meaningful.

Copper porphyry mineralization is time-congruent with Laramide magmatism and there seems to be no doubt as to the existence of a genetic relationship between the two phenomena. Two origins are tenable: direct accumulation of the copper sulfides in the copper porphyry liquid magmatic environment; or, introduction of the mineral constituents entirely from a larger source magma when the host rock

February 7, 1964

Mr. Paul E. Damon
Geology Department
University of Arizona
Tucson, Arizona

ISOTOPIC DATING OF ARIZONA ORE DEPOSITION, by Richard L. Mauger and Paul E. Damon

Dear Paul:

Reference is made to our telephone conversation wherein you asked for my comments on the subject paper.

The paper is, I believe, a real contribution and the work should ultimately assist considerably in unraveling Arizona geology.

My comments are as follows:

Page 10, paragraph 1:

"Richards" should be spelled "Richard".

"On the basis of one questionable exposure of contact metamorphism." It is stated in our paper on Silver Bell that inclusions of Paleozoic limestone occur in the alaskite, consequently the above statement is incorrect. Furthermore, the sample alaskite which you collected came from an area where the alaskite intrudes amole type sediments, thus the alaskite is not only post-Paleozoic, but post-early Cretaceous at least. Barry Watson is in accord with this observation. This comment also applies to the last part of the paragraph. "There is a distinct possibility the alaskite is older..." Just what is the basis for such a conclusion?

Page 10, paragraph 4, first sentence:

I suggest "fragments of leached rock which previously contained disseminated sulfides", rather than "leached ore".

Page 13, paragraph 3, second sentence:

"The pit monzonite...sampled from fresh rock in the bottom of El Tiro Pit..." The sample collected from the bottom of the El Tiro Pit was a completely recrystallized looking monzonite with black biotite which also should be a product of recrystallization. Perhaps you have some petrographic evidence otherwise, "unaffected by supergene solutions" might be more appropriate.

Page 14, paragraph 3:

"...the Cat Mountain rhyolite was affected, if only mildly, by thermal and hydrothermal processes accompanying intrusion and mineralization of monzonite." I don't believe that widespread metamorphic effects existing in the Cat Mountain rhyolite throughout the Silver Bell Mountains as well as in the Tucson Mountains can be spatially, or any other way, related to the monzonite intrusion. I think this widespread effect, producing a dense flinty rock, might be related to regional metamorphism or possibly to intrusive activity on the part of the intrusive tuffs, or, in the case of the Tucson Mountains, to the so called spherulitic rhyolite and/or intrusive tuffs.

Page 15, line 7:

"Sericite." I suggest "formation" rather than "introduction" of sericite.

Page 15, paragraph 2; also page 10, paragraph 3:

"Monzonite magma carrying pyrite and chalcopyrite." As you state in the beginning of the paragraph, mineralization occurred after solidification of the ore zone monzonite. I see no reason to assume that dikes carried pyrite and chalcopyrite during their intrusion. In fact, the monzonite, dacite, alaskite, and other rocks within the alteration zone contain sulphide mineralization comparable to that in the dikes. This mineralization is unquestionably introduced, not syngenetic. Why should it be otherwise in the dikes?

Page 17, paragraph 2:

The conclusion that the K-Ar ages of older rocks in the area were altered by monzonite intrusion and mineralization seems plausible, however, alteration and mineralization also affected the monzonite, thus I see no valid reason for concluding that the K-Ar dates of the monzonite reflects anything more than the date of mineralization.

There has, of course, been general agreement that porphyry copper mineralization "closely followed intrusion", simply because of the close association spatially. But just how close --- less than a million years, 5 or 10 million? --- is, I believe, yet to be determined.

Yours very truly,

Original signed by
J. H. Courtright

J. H. COURTRIGHT

JHC/jk
cc: KERichard
JEKinnison

Geology 202 - Comparison of Geologic Time Scales

PERIOD	EPOCH	Kulp, 1961	Holmes, 1960	USGS, 1956
		Beginning of Interval - Million Years Ago		
QUATERNARY	Pleistocene	1	1	1
TERTIARY	Pliocene	13	11	12
	Miocene	25	25	28
	Oligocene	36	40	40
	Eocene	58	60	--
	Paleocene	63	70±2	60
CRETACEOUS		135	135±5	130
JURASSIC		181	180±5	155
TRIASSIC		230	225±5	185
PERMIAN		280	270±5	210
PENNSYLVANIAN		310	-----	235
MISSISSIPPIAN		345	350±10	265
DEVONIAN		405	400±10	320
SILURIAN		425	440±10	360
ORDOVICIAN		500	500±15	440
CAMBRIAN		600	600±20	520

TERRESTRIAL TIME SCALE

ERA	PERIOD	EPOCH	BEGINNING OF EPOCH-IN MILLIONS OF YEARS	PRINCIPAL LIFE FORMS	REVOLUTIONS & OROGENIES
CENOZOIC	QUATERNARY	Recent	0.01	Modern Man	
		Pleistocene	1	Development of Man	Cascadian
	TERTIARY	Pliocene	13	Large carnivores, horses and elepnants	
		Miocene	25	Whales, bats, monkeys and horses	(Basin and Range)
		Oligocene	36	Abundant grasses and grazing animals – compositae appear	
		Eocene	58	Development of modern mammals	
		Paleocene	63	First placential mammals	
MESOZOIC	CRETACEOUS	UPPER	90	Climax and extinction of dinosaurs, ammonites and cycadeoids	Laramide
		MIDDLE	120		
		LOWER	135	Angiosperms appear	Nevadian
	JURASSIC	UPPER	150	First birds	
		MIDDLE	170	Abundant dinosaurs and ammonites	
		LOWER	181		
	TRIASSIC	UPPER	200		Palisades
		MIDDLE		First dinosaurs and rapid development of reptiles	
		LOWER	230	Abundant cycads and conifers	
PALEOZOIC	PERMIAN	UPPER	235		
		MIDDLE	260	Spread of reptiles	Appalachian
		LOWER	280	Development of conifers	
	CARBONIFEROUS: PENNSYLVANIAN		320	Earliest reptiles Abundant insects	
	CARBONIFEROUS: MISSISSIPPIAN		345	Coal forming forests Echinoderms abundant	
	DEVONIAN	UPPER	365	Sharks and amphibians First gymnosperms	Acadian
		MIDDLE	390	First amphibians	
		LOWER	405		
	SILURIAN	UPPER		First terrestrial plants (megafossil)	
		MIDDLE			
		LOWER	430		
	ORDOVICIAN	UPPER			Taconic
		MIDDLE		Primitive fishes	
		LOWER	500	First known vertebrates	
	CAMBRIAN	UPPER	530		
		MIDDLE		Trilobites and brachiopods	
		LOWER	600	Abundant marine life	
PRECAMBRIAN ERA		LATE	1.6×10^9 yrs	All major phyla probably in existance by this time First pteridophytic spores	Killarney Penokean
		EARLY	2.1×10^9 yrs	First record of "organized" or complex organic life	Algoman Laurentian

CRUST OF EARTH 3×10^9 yrs

AGE OF EARTH 5×10^9 yrs

All dividing lines, dates, life forms and orogenies are in approximate position

(Epochal dates after J. L. Kulp, SCIENCE, Vol. 133, p. 1111, 1961)

Compiled by T. L. Smiley, 1965

MAJOR DIVISIONS OF GEOLOGIC TIME IN USE BY THE U.S. GEOLOGICAL SURVEY

Era	System or Period	Series or Epoch	Approx. no. of million years ago.[5]	Approx. length in millions of years.[5]
Cenozoic	Quaternary	Recent Pleistocene	0-1	1
	Tertiary	Pliocene	1-12	11
		Miocene	12-28	16
		Oligocene	28-40	12
		Eocene Paleocene	40-60	20
Mesozoic	Cretaceous[1]	Upper (Late) Lower (Early)	60-130	70
	Jurassic	Upper (Late) Middle (Middle) Lower (Early)	130-155	25
	Triassic	Upper (Late) Middle (Middle) Lower (Early)	155-185	30
Paleozoic	Permian[2]	Provincial series recognized in west Texas and southeastern New Mexico	185-210	25
	Carboniferous systems: Pennsylvanian[3]	Upper (Late) Middle (Middle) Lower (Early)	210-235[6]	25
	Carboniferous systems: Mississippian[4]	Upper (Late) Lower (Early)	235-265[6]	30
	Devonian	Upper (Late) Middle (Middle) Lower (Early)	265-320	55
	Silurian	Upper (Late) Middle (Middle) Lower (Early)	320-360	40
	Ordovician	Upper (Late) Middle (Middle) Lower (Early)	360-440	80
	Cambrian	Upper (Late) Middle (Middle) Lower (Early)	440-520	80
Proterozoic	Precambrian	Upper Precambrian rocks. (Keweenawan and other provincial series.) Middle Precambrian rocks. (Huronian and other provincial series.) Lower Precambrian rocks. (Provincial series.)	520-2100+	1600+

[1] Comanche and Gulf provincial series recognized in the Gulf Coastal Plain area.
[2] Wolfcamp, Leonard, Guadalupe, and Ochoa provincial series recognized in west Texas and southeastern New Mexico. Formal series subdivisions of the Permian are not recognized elsewhere.
[3] Morrow, Atoka, Des Moines, Missouri, and Virgil provincial series recognized in the Mid-continent region.
[4] Kinderhook, Osage, Meramec, and Chester provincial series recognized in the upper Mississippi Valley region.

[5]Report of the National Research Council, Committee on the Measurement of Geologic Time, 1949-50.
[6]Estimate of J. P. Marble, Chairman of Committee on Measurement of Geologic Time, March 17, 1954.

For the age of the crust of the earth, the data are at present uncertain, but the order of magnitude is about 3,250 million years. The margin of error in the estimate of the age for the Quaternary is ± 50,000 years; Tertiary ±1 to 2 million years; Mesozoic ±5 million years; Paleozoic ± 10 million years; Proterozoic ±10 to 300 million years.

Terms designating time are in parentheses. Informal time terms early, middle, and late may be used for the eras, and for periods where there is no formal subdivision into Early, Middle, and Late, and for epochs. Informal rock terms lower, middle, and upper may be used where there is no formal subdivision of a system or of a series. There is no formal subdivision of time of the Proterozoic; subdivisions of the Precambrian have only local significance.

GEOLOGIC NAMES COMMITTEE, 1956

Arthur Holmes (1960) gives this new time-scale:

Tertiary	70	70±2
Cretaceous	65	135±5
Jurassic	45	180±5
Triassic	45	225±5
Permian	45	270±5
Carboniferous	80	350±10
Devonian	50	400±10
Silurian	40	440±10
Ordovician	60	500±15
Cambrian	100	600±20
Precambrian?		

CENOZOIC

Pleistocene	1	1
Pliocene	10	11
Miocene	14	25
Oligocene	15	40
Eocene	20	60
Paleocene	10	70±2

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

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

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.

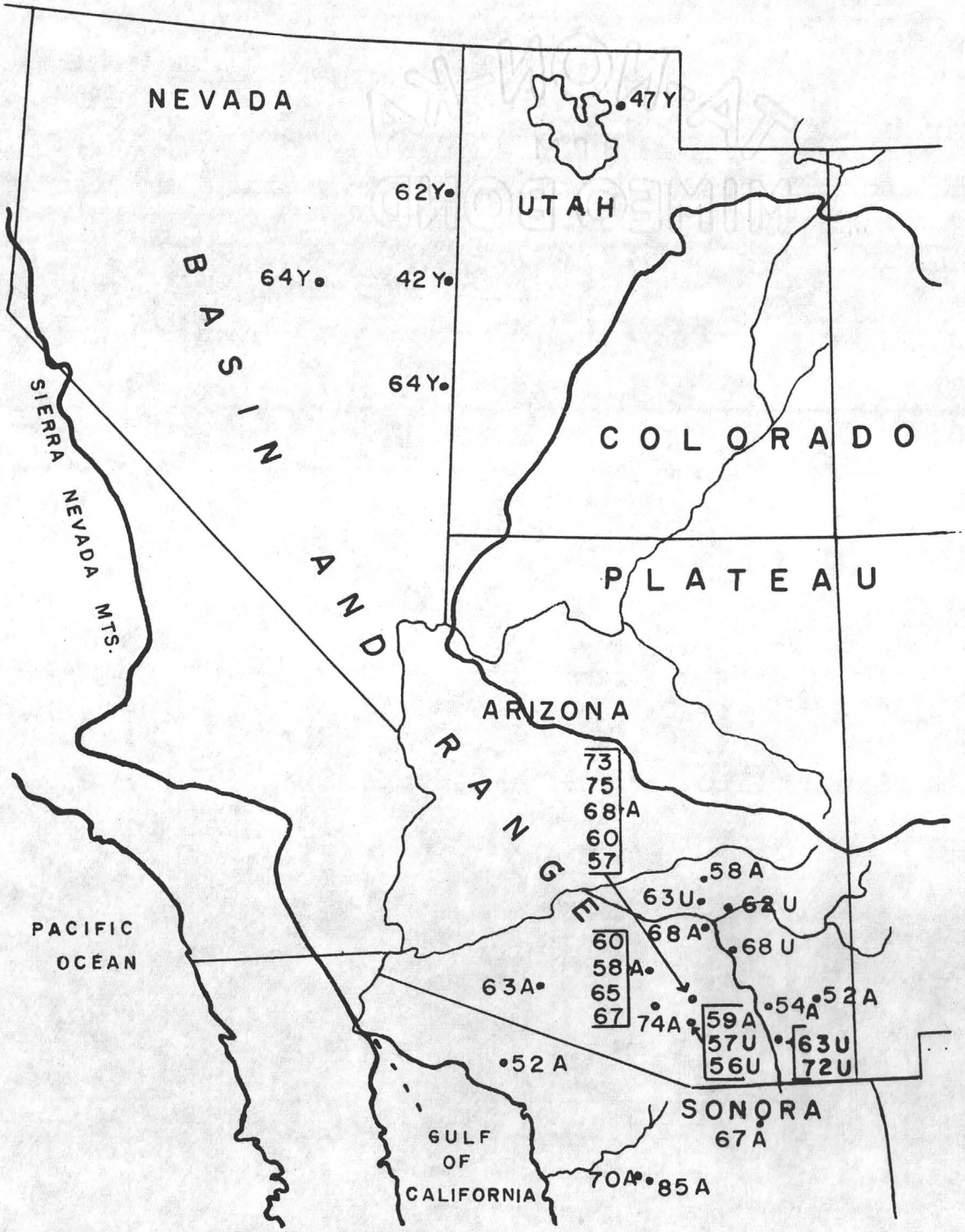

Figure 1: Sample localities (A = Arizona dates, U = U.S.G.S. dates, Y = Yale dates).

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} Radio-genic x 10^{-10} moles/g	Ar^{40} Atmos-pheric %	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: (MB-1-62) Feldspar concentrate (MB-3-62) " "	5.57 10.32	7.09 12.11	28.6 39.6	4.22 3.89	70 65	Brown (1939) Kinnison (1958)
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.

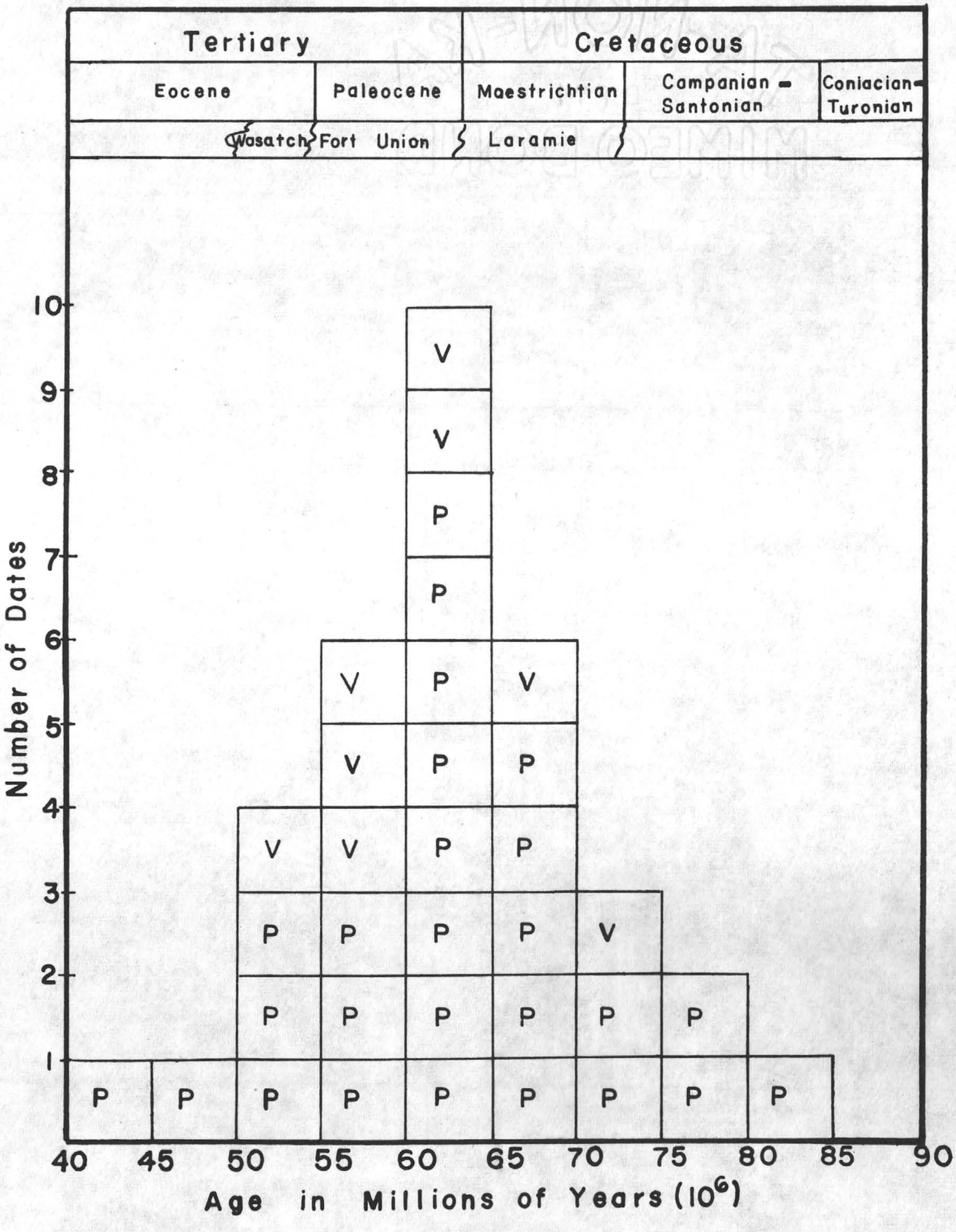

Figure 2: Histogram of K-Ar dates falling within the time range of 40 to 90 m.y. (10^6yr.) (P = plutonic) (V = volcanic).

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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POTASSIUM-ARGON DATES OF UPPER CRETACEOUS ASH FALLS, ALBERTA, CANADA*

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Introduction

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