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U.S. DEPARTMENT OF THE INTERIOR
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Uranium-lead ages on zircon from granitoids of the central part of the Sierra Nevada batholith and their bearing on the structure and history of the batholith

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ISOTOPIC U-Pb AGES OF ZIRCON FROM THE GRANITOIDS OF THE CENTRAL SIERRA NEVADA, CALIFORNIA

By T. W. STERN, P. C. BATEMAN, B. A. MORGAN,
M. F. NEWELL, and D. L. PECK

ABSTRACT

Sixty-two samples from well-established comagmatic granitoid sequences and certain unassigned formations and plutons of the central part of the Sierra Nevada batholith between latitudes 37° and 38° N. have been dated by the isotopic U-Pb method on zircon. The U-Pb ages indicate the following age distribution of the granitoids: (1) The axial part of the batholith is occupied by Cretaceous granitoid sequences that are progressively younger eastward over a 37-m.y. interval extending from about 125 m.y. to about 88 m.y. ago. (2) A single, but extensive, Triassic sequence with an optimum average age of about 210 m.y. is present in the east side of the batholith. (3) Plutons and granitoid sequences of Jurassic age, most of them with U-Pb ages between 186 and 155 m.y., occur in both margins and locally in the interior of the batholith. The distribution of Jurassic ages suggests that prior to the emplacement of the Cretaceous granitoids, Jurassic granitoids were widely distributed across the central Sierra Nevada but were not emplaced in a west-to-east succession as were the Cretaceous granitoids. Few of our ages fall between 155 and 125 m.y. However, a U-Pb age of 144 m.y. has been reported on the Sage Hen Flat pluton in the White Mountains, and U-Pb ages between 134 and 128 m.y. have been reported on remnants of older granitoids farther south in the Sierra Nevada, which are associated with roof pendants and septa. Also, numerous K-Ar ages on hornblende in the range of 152 to 131 m.y. have been reported on samples collected farther north along the west side of the batholith.

The distribution of U-Pb ages is consistent with the interpretation that in the central Sierra Nevada, a belt of Cretaceous granitoids trending about N. 20° W. crosses a belt of Jurassic granitoids trending about N. 40° W. However, the U-Pb ages provide little support for the existence of five cyclic intrusive epochs for California and western Nevada. Comparison of the U-Pb ages on zircon with the K-Ar ages on biotite and hornblende shows generally good agreement for the younger granitoids but decreasing agreement for increasingly older granitoids. Most of the K-Ar ages on biotite and many on hornblende from older granitoids appear to have been reduced as a result of reheating by younger plutons. The dispersion of K-Ar ages reflects the complex structural and thermal history of the batholith.

INTRODUCTION

Geologic study of the central Sierra Nevada and White Mountains has been carried on more or less continuously by geologists of the U.S. Geological Survey since 1945, and geologic mapping at a scale of 1:62,500 of a broad belt between 37° and 38° N. latitude is nearly complete (fig. 1; pl. 1). K-Ar ages on biotite and hornblende, complemented by a few Rb-Sr whole-rock isochrons, have established the general distribution of granitoid ages in the central Sierra Nevada (Curtis and others, 1958; Kistler and others, 1965; McKee and Nash, 1967; Evernden and Kistler, 1970; Crowder and others, 1973). However, repeated intrusions over a period of time extending from the Triassic into the early Late Cretaceous have caused reheating of and argon loss from minerals in many of the older granitoids. Therefore, many K-Ar ages, particularly those for biotite, are significantly younger than the ages of emplacement and solidification of many older plutons.

In an attempt to improve our knowledge of the ages of the granitoids in this region, beginning in 1971, we undertook a program of dating zircons by the U-Pb method. The study consisted of sampling and dating representative plutons in the more extensive and better established comagmatic granitoid sequences and a few large or particularly important plutons that have not been assigned to sequences. Sample locations are shown in plate 1 and tabulated in detail in table 4 at the end of this report.

Geologic mapping and petrological and chemical studies are showing with increasing certainty that the large number of plutons that make up the Sierra Nevada batholith can be grouped into a much smaller number of comagmatic granitoid sequences in which successively younger units generally (but not invariably) are progressively more felsic and represent lower temperature mineral assemblages (Bateman and Dodge, 1970; Presnall and Bateman, 1973; Bateman and Chappell, 1979). We have used the informal term "sequence" for all but one of the groupings rather than the formal term "Suite" because we regard them as being tentatively established and subject to revision. The lone exception is the well-established Tuolumne Intrusive Suite, which is cited in note 45 of the U.S. Stratigraphic Commission (Sohl, 1977). We will refer collectively to all of the groupings as sequences.

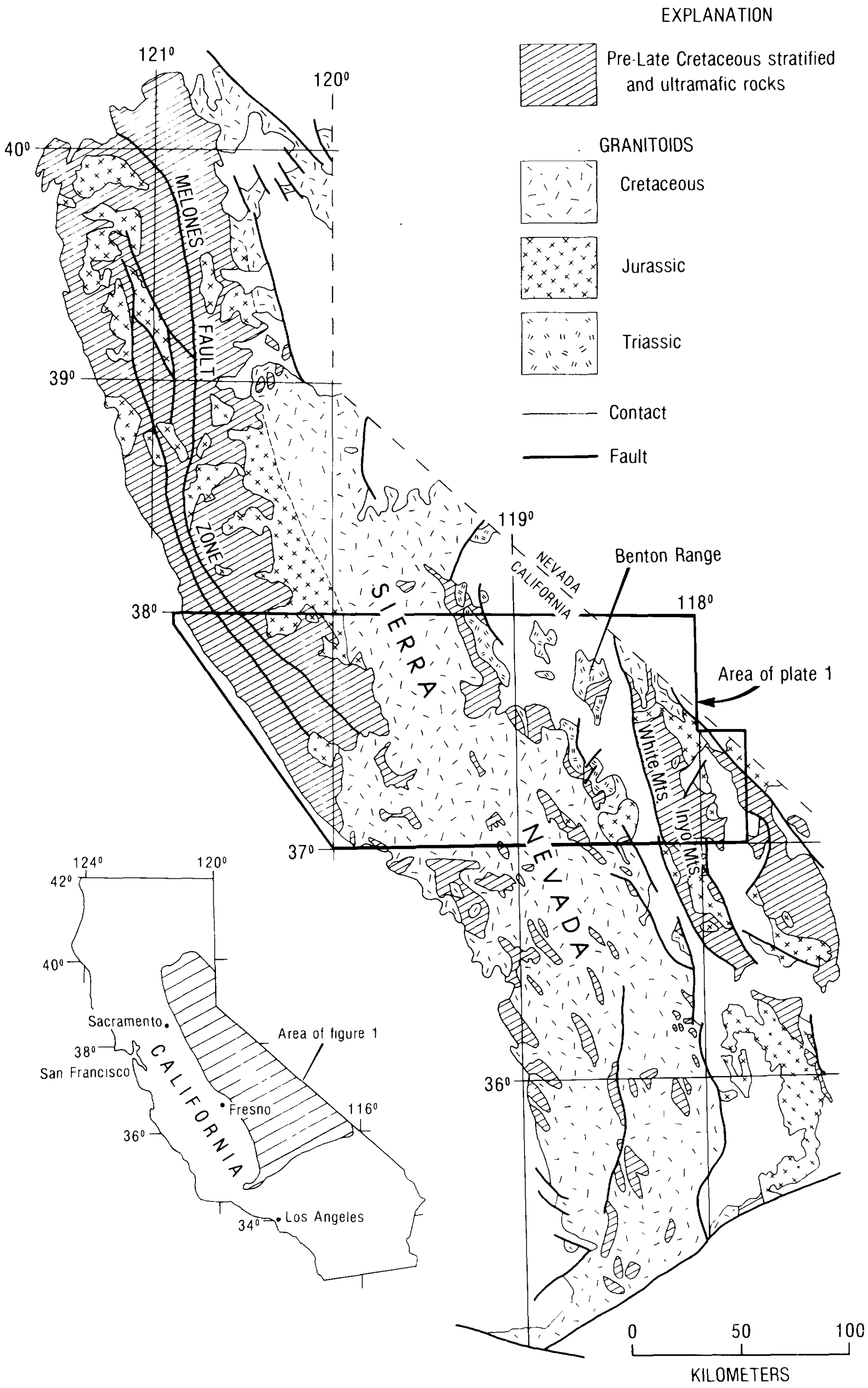


FIGURE 1.—Sierra Nevada and adjacent areas in eastern California showing approximate age distribution of granitoids by periods. Map is based chiefly on K-Ar dating and is modified from maps by Evernden and Kistler (1970).

The simplest kind of comagmatic plutonic sequence is a concentrically zoned pluton in which relatively mafic, high-temperature mineral assemblages in the margins grade inward without discontinuities to more felsic, lower temperature mineral assemblages. We believe that this compositional pattern resulted chiefly from crystal fractionation during inward solidification with falling temperature (Bateman and Chappell, 1979). More complex sequences result from movements of the less crystallized core magma, which may intrude and in places break through the solidifying carapace. Still more complicated sequences, in which the consanguinity of the different granitoid units may be difficult to establish, result from the core magma repeatedly breaking through the solidifying carapace and intruding the country rocks. Careful examination of the compositional and textural changes in relatively simple concentrically zoned plutons or in granitoid sequences having few discontinuities led us to the following criteria for identifying the units of granitoid sequences in which a concentric arrangement is not readily apparent: (1) All the plutons or granitoid formations of a sequence crop out in the same general area, and many of them are contiguous. (2) Vestiges of a concentric arrangement may be recognizable in which successively inward units are younger and more felsic. (3) Intrusive relations at contacts indicate that successively younger plutons are successively more felsic. Resurgence from below of magma containing settled crystals can produce exceptions to this generalization (Bateman and Nokleberg, 1978). (4) Textural changes are in the same order as in concentrically zoned plutons having the same range of compositions. (5) Consanguineous plutons generally have some common mineralogical, chemical, and (or) textural characteristics. (6) Septa (screens) of older rocks generally lie between granitoid sequences rather than between different units of the same sequence. (7) Cataclastic zones or dike swarms in the granitoids of an older sequence may be cut off by granitoids of a younger sequence. (8) Isotopic ages of a given sequence fall in a limited age span. The length of this span has been uncertain, but the dating in this program indicates that it is on the order of a few million years, at most.

The distribution and names of the granitoid sequences that have been tentatively identified in the central Sierra Nevada are shown on plate 1. Some of these sequences were identified by Bateman and Dodge (1970), but some are new. The John Muir sequence of Bateman and Dodge (1970) is divided in this report into three newly-named sequences—the Kaiser, Powell, and Mono Pass sequences, and the name "John Muir sequence" is abandoned. The age determinations required that few plutons be reassigned to other sequences. Most of those that did require reassignment are in the Owens Valley region. Uncertainties of age still exist in the Yosemite region.

SAMPLING AND ANALYTICAL METHODS

Sixty-two samples of the freshest and least contaminated representative rocks were dated. Two to five samples were collected from most sequences, generally from different units. Samples were crushed and sieved, and the zircons were concentrated using a Wilfley table, heavy liquids, and a magnetic separator. The zircon separates were acid washed with hot HNO and HCl to remove any surface contamination. The zircon separates of various sizes and magnetic susceptibilities were digested in teflon bombs with hydrofluoric acid as described by Krough (1973). All reagents were purified with a subboiling technique: water and HNO_3 in a quartz still, and HF and HCl in a teflon still (Mattinson, 1972). The samples were aliquoted into concentration and composition portions prior to spiking. The concentration split was spiked with a combined ^{235}U-^{230}Th-^{208}Pb enriched solution prepared and calibrated by M. Tatsumoto. Lead was extracted from the samples by ion-exchange columns and electrodeposition (Barnes and others, 1973). Lead blanks ranged from 0.3 to 1.9 ng. Contamination by airborne particulate matter was minimized by the use of laminar-flow hoods using an absolute prefiltered air supply.

Isotope abundance measurements of lead were made with the silica gel technique (Cameron and others, 1969). National Bureau of Standards common lead isotopic standard was used to measure fractionation. The lead isotopes were depleted in the heavy isotopes by less than 0.05 percent per mass unit. No correction factor was applied. Uranium and thorium solutions which passed through the first lead resin column were collected and isolated on a nitrate resin (Tatsumoto, 1966). Accuracy of the concentration determination is estimated at 1 to 2 percent. The following values for decay constants and atomic abundance were used:

$$^{238}U = 1.55125 \times 10^{-10}/yr.$$
$$^{235}U = 9.8485 \times 10^{-10}/yr.$$
$$^{232}Th = 4.9475 \times 10^{-11}/yr.$$
$$^{238}U/^{235}U = 137.88$$

The isotopic compositions and the quantitative results for lead, uranium, and thorium as well as the calculated ages are given in table 1. The $^{206}Pb/^{238}U$ ages are the most dependable and are the ages used throughout this report. They have a laboratory analytical error of about 2 percent at the 95 percent confidence level. Common lead is present in the samples, probably from inclusions and fractures. All age calculations were corrected using the following common lead: $^{206}Pb/^{204}Pb$ = 18.51, $^{207}Pb/^{204}Pb$ = 15.72, and $^{208}Pb/^{204}Pb$ = 38.44. The correction for this lead causes a large uncertainty in the ^{207}Pb and ^{208}Pb concentrations with the result that $^{207}Pb/^{235}U$, $^{208}Pb/^{232}Th$, and

TABLE 1.—*Analytic data*

No.	Field & lab. no.	Granitoid Sequence	Formation or pluton	Ages, m.y.			Parts per million			Atomic ratios		
				$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{208}Pb/^{232}Th$	Pb	U	Th	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{204}Pb/^{206}Pb$
1	BMCC		Chinese Camp pluton	189.9	197.4	194.8	4.83	144.0	53.51	0.18583	0.07683	0.0016
2	DPD-1		Don Pedro pluton	181.7	187.2	186.0	9.24	274.0	108.6	.21991	.08087	.00242
3	PM-1		Page Mountain pluton	148.4	149.7	145.1	10.64	446.7	156.3	.12574	.05507	.00038
4	LE-1092		Granodiorite of Cottonwood Creek	150.9	152.8	111.2	19.4	811.5	249.2	.09887	.05958	.00067
5	BMSD	Jawbone	Standard pluton	163.6	153.3	155.2	9.65	275.0	127.2	.17648	.05959	.00072
6	CCr-1	do.	Cobb Creek pluton	162.5	157.4	152.9	19.20	700.7	296.4	.16526	.06197	.00097
7	LE-153	do.	Quartz diorite of Granite Creek	165.7	169.6	158.8	16.26	635.7	137.2	.07992	.05549	.00033
8	LE-244	do.	do.	162.6	163.1	156.6	20.99	841.9	172.1	.07518	.05374	.00029
9	IG-2		Guadelupe igneous complex	140.1	41.3	206.2	95.29	2728.0	2010.0	.53929	.10304	.00578
10	LE-1036		Granodiorite of Sawmill Mountain	116.1	110.7	89.3	7.45	408.9	126.7	.09928	.05440	.00057
11	MA-1	Fine Gold	Tonalite of Blue Canyon	118.5	113.5	106.2	8.04	432.6	119.0	.10005	.05392	.00052
12	RDa-1	do.	do.	111.4	107.8	102.0	5.36	295.6	69.6	.11631	.06467	.00122
13	MLa-12	do.	Plagiogranite of Ward Mountain	114.8	112.6	-----	86.97	1556.2	✓114.8	.81137	.35868	.02112
14	MLc-10	do.	Tonalite of Blue Canyon	123.6	119.4	120.1	5.06	234.8	57.71	.15999	.07919	.00220
15	MLc-51	do.	do.	110.3	105.2	99.8	4.13	218.2	46.5	.14391	.07768	.00216
16	MLc-154	do.	do.	115.1	120.8	112.0	4.24	222.1	57.2	.13467	.07152	.00141
17	Y-682	do.	Granodiorite of The Gateway	116.7	117.1	113.9	8.34	437.5	185.4	.14978	.05434	.00039
18	MLb-69	do.	Tonalite of Blue Canyon	114.3	113.9	76.3	7.12	372.3	138.9	.13709	.070198	.00150
19	SLb-64	do.	Tonalite of Ross Creek	113.3	116.7	118.7	7.77	414.5	162.9	.15703	.05885	.00061
20	MLd-52	do.	Tonalite of Blue Canyon	112.3	112.4	117.3	3.80	194.5	47.3	.16131	.07930	.00211
21	JB-1	do.	do.	115.9	170.8	149.8	14.4	569.3	364.4	.38847	.12364	.00351
22	RDb-58	do.	Granodiorite of Knowles	111.5	109.4	87.9	25.09	489.7	74.3	.79070	.33966	.01983
23	BLc-4		Oakhurst pluton	108.2	102.2	-----	8.95	411.7	-----	.41611	.05526	.00067
24	BLd-3		do.	105.0	105.2	100.3	15.7	973.9	208.0	.08063	.05363	.00037
25	Y-676		El Capitan Granite	102.8	102.5	100.4	13.06	782.8	312.4	.14344	.05429	.00043
26	Y-721		do.	96.9	92.6	84.4	42.98	2681.8	955.8	.14516	.06320	.00117
27	FD-12		Taft Granite	95.7	91.9	92.8	53.0	3260.2	1196.1	.06561	.06581	.00134
28	SPc-1	Shaver	Granodiorite of Whiskey Ridge	103.0	102.3	112.3	16.40	952.3	257.3	.14483	.06702	.00131
29	SLb-70	do.	Granite of Shuteye Peak	101.9	102.4	99.5	19.22	1166.3	339.1	.12375	.06051	.00083
30	SL-1	do.	Granodiorite of Dinkey Creek	104.1	91.0	93.9	21.9	725.0	276.5	.50689	.20396	.01086
31	Y-733	Buena Vista	Granodiorite of Ostrander Lake	112.1	104.2	99 6	29.28	1570.5	766.4	.16539	.05429	.00065
	Y-733R			107.1	100.9	95.5	28.27	1619.0	691.3	.14330	.05540	.00070
32	MP-568	Buena Vista	Granodiorite of Illilouete Creek	100.2	95.0	95.9	19.6	1092.8	855.6	.26578	.05385	.00057
33	MP-520	Merced Peak	Granodiorite of Jackass Lakes	98.1	94.6	95.7	20.23	1140.4	951.8	.28133	.05242	.00042
34	MP-846	do.	Granite porphyry of Post Peak	92.6	19.6	24.9	16.07	974.1	392.4	.17065	.06476	.00356
35	MP-847	do.	Metavolcanic rock	99.8	91.3	92.4	11.12	600.8	285.4	.23297	.08030	.00247
36	MP-789	Washburn	Granodiorite of Red Devil Lake	97.7	96.2	99.9	20.15	807.5	1949.0	.82147	.05482	.00052
37	SLc-119	Kaiser	Leucogranite of Big Sandy Bluffs	92.8	92.6	33.6	52.69	2974.2	2145.0	.22025	.10197	.00365
38	HC-1	do.	Mount Givens Granodiorite	87.9	87.4	348.2	24.1	1232.3	514.9	.56928	.05934	.00080
	HC1R			87.6	82.6	87.9	49.13	1666.8	6729.3	.13911	.06846	.00159
39	KPd-72	Kaiser	Mount Givens Granodiorite	92.8	89.9	82.5	22.47	1417.6	453.1	.15701	.07184	.00173
40	TMc-173	Tuolumne	Quartz diorite north of May Lake	88.0	86.1	87.6	16.00	1027.7	606.4	.22848	.06675	.00102
41	TMb-164	do.	Cathedral Peak Granodiorite	86.2	87.0	82.1	40.04	1819.4	4124.1	.75494	.07515	.00183
42	F76-6	do.	Granodiorite of Kuna Crest	91.1	89.0	87.6	6.75	436.3	213.4	.18406	.05893	.00083
43	DP-2		Leucogranite of Graveyard Peak	98.9	99.3	98.9	44.1	2815.4	1009.3	.12351	.05063	.00017
44	KPb-85	Mono Pass	Granodiorite of Lake Edison	89.8	88.5	84.2	43.41	2962.6	1201.4	.14591	.05565	.00058
45	DP-1	do.	Granite of Mono Recesses	75.8	75.9	70.9	25.04	1756.3	774.8	.23675	.08893	.00281
46	ABb-1	do.	do.	88.4	83.6	81.1	15.47	1020.2	509.8	.18911	.06103	.00108
47	MT-13	do.	Round Valley Peak Granodiorite	89.1	84.6	82.6	20.94	1459.2	590.9	.13808	.05134	.00041
48	MT-12	do.	Granodiorite of Lake Edison	93.2	91.6	81.8	132.7	7954.5	1298.7	.16213	.09200	.00305
49	MGb-1	Powell	Lamarck Granodiorite	89.6	87.4	86.9	18.36	1257.4	462.3	.14106	.05631	.00066
50	BIc-1		Leucogranite of Rawson Creek	95.3	89.6	86.1	29.86	1966.2	517.6	.10958	.05753	.00085
51	BN-1		Granite of Pellisier Flats	89.6	82.4	74.7	23.44	1513.1	786.3	.18994	.06352	.00133
52	MT-11	Scheelite	Tungsten Hills Quartz Monzonite	201.9	204.4	203.1	59.33	1865.6	598.4	.10845	.05213	.00009
53	MT-10	do.	Wheeler Crest Quartz Monzonite	207.0	207.6	189.5	57.50	1746.0	671.3	.11895	.05214	.00012
54	CT-27	do.	Granodiorite of the Benton Range	214.4	206.9	206.4	41.96	1211.8	484.4	.13361	.05182	.00023
55	BPd	Palisade Crest	Tinemaha Granodiorite	155.0	162.9	145.0	56.25	1135.1	4731.4	1.2720	.05654	.00034
56	BPb-1		Granite west of Warren Lake	167.3	148.4	183.2	38.83	1292.0	555.0	.21567	.06905	.00173
57	MT-14		Quartz diorite from Pine Creek mine	168.7	167.6	173.9	16.73	601.6	245.6	.15415	.05588	.00046
58	GM-13		Granite of Casa Diablo Mountain	160.7	161.7	156.7	42.48	1568.2	825.4	.18216	.05563	.00041
59	MB-1		Granodiorite of Mount Barcroft	161.1	161.2	155.9	14.80	454.4	203.5	.27994	.10584	.00384
60	MB-2	Soldier Pass	Quartz monzonite of Beer Creek	171.9	162.4	124.3	11.96	399.1	321.3	.21411	.05673	.00069
61	SD-10	do.	Monzonite of Joshua Flat	167.4	169.0	147.6	16.69	539.3	489.8	.28654	.06080	.00074
62	SD-5	do.	Quartz monzonite of Beer Creek	168.1	170.4	142.9	11.99	396.6	262.8	.22861	.06880	.00127

$^{207}Pb/^{206}Pb$ ages are not reliable for ages of less than about 300 m.y. Nevertheless, the fact that the $^{207}Pb/^{235}U$ ages are within 1 m.y. of the $^{206}Pb/^{238}U$ ages of 19 samples lends support to the reliability of the ages on these samples.

If a mineral has taken on no new uranium, thorium, and lead since it was formed, and if the original lead isotopic composition is known, $^{206}Pb/^{238}U$, $^{207}Pb/^{235}U$, $^{207}Pb/^{206}Pb$, and $^{208}Pb/^{232}Th$ will agree, provided that there are no geologic complications such as xenocrystic material in the sample. However, rarely do all the calculated ages agree. When the ages do not agree, they are said to be discordant. The normal sequence for discordant ages is $^{206}Pb/^{238}U > {}^{207}Pb/^{235}U >> {}^{207}Pb/{}^{206}Pb$. Reverse discordance refers to the age sequence $^{206}Pb/^{238}U > {}^{207}Pb/^{235}U$. The cause of discordant ages can be divided into two categories: (1) laboratory analytical errors, and (2) geologic uncertainties. Laboratory analytical uncertainties include errors in decay constants, isotopic measurements, blank corrections, and weight and volume. Geologic uncertainties include the isotopic composition of the original common lead in the zircon, the migration of lead, uranium or thorium and (or) their daughter products into or out of the zircon since its crystallization in the rock, and the presence of xenocrystic zircon. Of the samples analyzed, about 60 percent show reversed discordancy. This discordancy probably reflects the extreme sensitivity of the $^{207}Pb/^{235}U$ age to the corrections for common lead. For rocks of this age, the amount of radiogenic lead developed is very small, and accordingly applying the exact correction for the nonradiogenic lead present is difficult. Solutions developed by Wetherill (1956) and Tilton (1960) cannot be used for samples as young as those in the Sierra Nevada because the concordia curve is essentially a straight line from 0 to 200 m.y., and intersections to the curve by data points cannot be accurately determined.

Figure 2 schematically shows the relative ages of the better established granitoid sequences as deduced from field relations and isotopic dating by the U-Pb, K-Ar, and Rb-Sr methods. Optimum ages given in millions of years in this report represent our estimate of the average ages of the sequences on the basis of the spread of U-Pb ages, the quality of the analytic data, K-Ar and Rb-Sr ages, and intrusive relations. Three relations between the U-Pb ages and field observations strongly support the general reliability of the U-Pb ages. (1) Almost all of the U-Pb ages are compatible with the order of emplacement of the granitoid sequences where the order has been established by field relations. (2) The absence of younger ages for samples from deformed facies or adjacent to younger intrusions indicates that neither deformation nor reheating has reset the original crystallization ages. (3) The ages of samples from the same granitoid sequence are generally in good agreement, though some differ by amounts greater than the laboratory error of 2 percent for each sample (table 1). Although some of the differences between the ages of samples from the same sequence could reflect real differences in their times of crystallization, comparison of the U-Pb ages with the succession of solidification as established in the field fails to reveal convincing correlations.

INTERPRETATION OF AGE DETERMINATIONS

The pattern of ages in figures 1 and 2 shows that the main part of the Sierra Nevada batholith is occupied chiefly by Cretaceous granitoids that decrease in age toward the east, that the Scheelite sequence in the east side of the batholith is of Triassic age, and that several Jurassic sequences and unassigned formations and plutons occur on both sides of the batholith.

TRIASSIC SCHEELITE SEQUENCE

Only the Scheelite granitoid sequence is of Triassic age. As presently understood, the Scheelite sequence consists of the Wheeler Crest Quartz Monzonite (Rinehart and Ross, 1957; Bateman, 1961, 1965), the granodiorite of the Benton Range (Rinehart and Ross, 1957), which is really part of the same extensive formation, the Tungsten Hills Quartz Monzonite (Bateman, 1961, 1965), the granodiorite of Mono Dome (Kistler, 1966a), and the quartz monzonite of Lee Vining Canyon (Kistler, 1966a). These formations crop out discontinuously in an area of at least 3,000 km^2, which extends north and northwest from the vicinity of Bishop to the north boundary of the area shown in plate 1. Thus, the sequence is one of the most extensive in the central part of the Sierra Nevada batholith. In fact, the sequence undoubtedly continues north of the area shown in plate 1 and is even more extensive.

The three U-Pb ages reported here are all Triassic and are in good agreement with maximum K-Ar ages that have been published (Kistler, 1966b; Evernden and Kistler, 1970; Crowder and others, 1973). Sample 53, at 207 m.y., is from the Wheeler Crest Quartz Monzonite, and sample 54, at 214 m.y., is from the granodiorite of the Benton Range, which is the north part of the same formation. These two ages differ by only 7 m.y., although the distance between their sample locations is more than 55 km. The age on sample 53 may be more reliable than the age on sample 54 because the $^{207}Pb/^{235}U$ age on sample 53 differs from its paired $^{206}Pb/^{238}U$ age by only 1 m.y. whereas the ages on sample 54 differ by 7 m.y. The U-Pb ages compare with maximum K-Ar ages on the granodiorite of the Benton Range of 215 m.y. on biotite and 211 m.y. on hornblende (Evernden and Kistler, 1970) and of 211 m.y. on hornblende (Crowder and others, 1973), and with a Rb-Sr whole-rock isochron of 212.1 ± 5.3 m.y. determined by R. W. Kistler (written commun., 1979). K-Ar ages quoted here and elsewhere in this report have been adjusted to the decay and abundance constants recommended in 1976 by the IUGS Subcommission on Geochronology (Steiger and Jager, 1977). Published K-Ar ages of the granitoids of the Sierra Nevada and White Mountains between 37° and 38° N. latitude are summarized in table 2.

We have no U-Pb ages on the granodiorite of Mono Dome or the quartz monzonite of Lee Vining Canyon, which form the northeast part of the sequence. However, the granodiorite of Mono Dome has yielded two K-Ar ages on hornblende of 211 m.y. (Kistler, 1966b; Evernden and Kistler, 1970), and the quartz monzonite of Lee Vining Canyon has yielded an 8-point whole-rock Rb-Sr isochron of 212 ± 5 m.y. (Kistler, 1966b; R. B Kistler, written commun., 1979).

JURASSIC PLUTONS AND GRANITOID SEQUENCES

The dated Jurassic granitoids on the east side of the batholith comprise two sequences, the Soldier Pass granitoid sequence, here named for exposures of this sequence at Soldier Pass, and the Palisade Crest granitoid sequence (Bateman and Dodge, 1970), and four spatially separated unassigned formations. The Soldier Pass sequence includes the monzonite of Joshua Flat and the quartz monzonite of Beer Creek, which we sampled, and the monzonite of Eureka Valley and the monzodiorite of Marble Canyon, which we did not sample (Nelson, 1966; McKee and Nelson, 1967). Our U-Pb ages of 172, 167, and 168 m.y. (samples 60, 61, and 62) for this sequence are in good agreement with a published U-Pb age of 174 ± 5 m.y. on the monzonite of Joshua Flat (Sylvester and others, 1978) and with published K-Ar ages (McKee and Nash, 1967; Crowder and others, 1973; Evernden and Kistler, 1970). However, they are older than U-Pb ages of 161 and 159 m.y. obtained by Gillespie (1979) on the quartz monzonite of Beer Creek and the monzonite of Joshua Flat. Gillespie

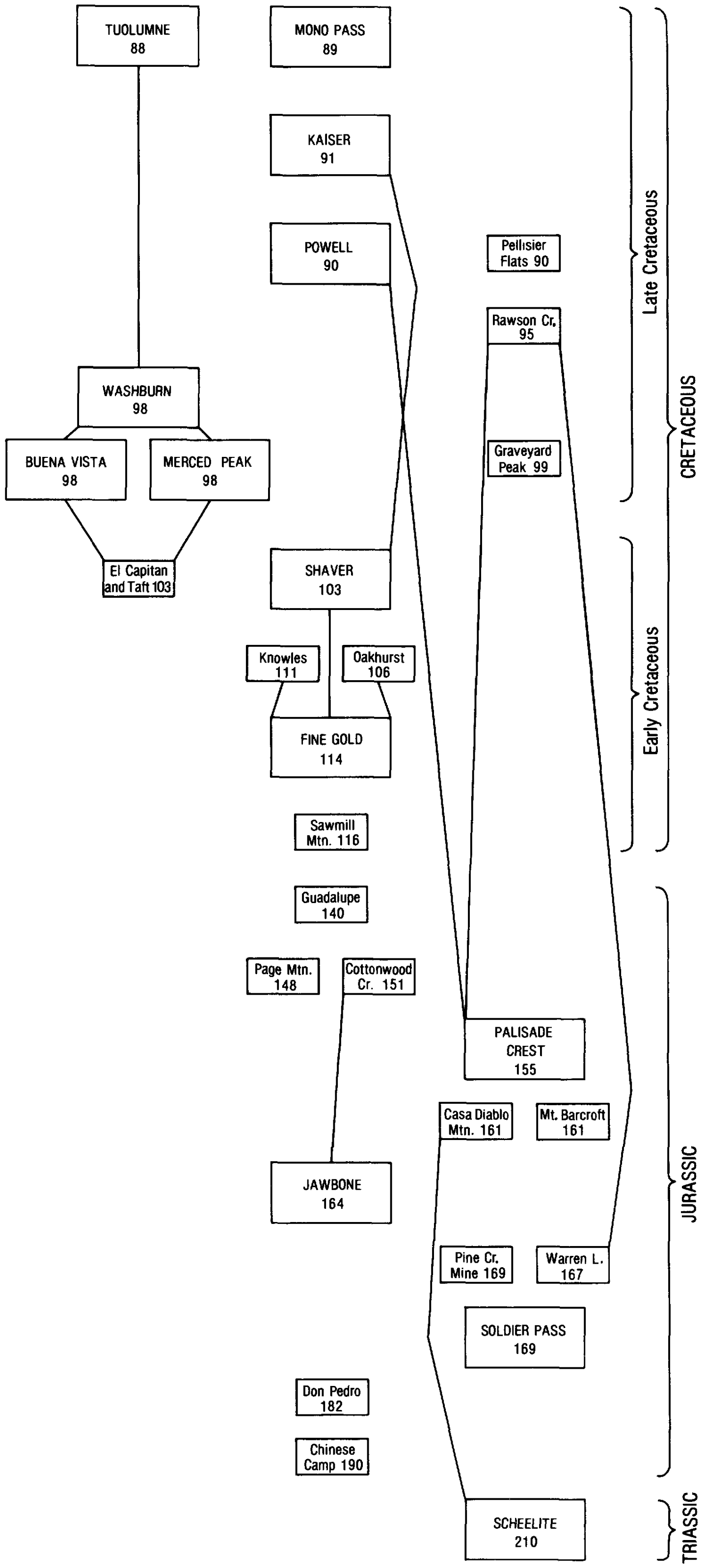


FIGURE 2.—Schematic chart showing relative ages of granitoids dated in this report as deduced from field relations and isotopic dating by U-Pb, K-Ar, and Rb-Sr methods. Granitoid sequences are shown by large boxes; unassigned plutons and formations by small boxes. Numbers are optimum average ages (in millions of years), which represent an evaluation of all pertinent data. Tie lines show diagnostic contacts between pairs of granitoids.

TABLE 2.—K-Ar *mineral ages of granitoids in the central Sierra Nevada between 37° and 38° north latitude. Ages have been adjusted to the decay and abundance constants recommended in 1976 by the I.U.G.S. Subcommission on geochronology (Steiger and Jager, 1977)*

Granitoid Sequence	Formation or pluton	Age, m.y.		Reference	Sample number
		Biotite	Hornblende		
Jawbone	Standard pluton	156	166	Evernden and Kistler (1970)	89 (1632)
Do.	do.	147	160	do.	90 (1634)
	Guadelupe igneous complex	139		do.	159
Fine Gold	Tonalite of Blue Canyon	91	112	Bateman and Lockwood (1976)	SL-32
Do.	do.	91		do.	SL-36
Do.	do.	93	105	do.	SLd-11
Do.	do.	114	118	R. W. Kistler (written commun., 1976)	MA-1
Do.	do.	100	102	Evernden and Kistler, 1970	87 (1627)
	Plagiogranite of Ward Mountain	106		Naeser, Kistler, and Dodge, 1971	S.J.
	Plagiogranite from Sherman-Thomas boring	129		do.	S.T.
	Granodiorite of Knowles	110		Evernden and Kistler, 1970	93 (1666)
	do.	113		do.	220 (61-042)
	Oakhurst pluton	102	147	do.	88 (1628)
Granitoids of Yosemite Valley	Granodiorite of Arch Rock	95		do.	62 (67-64)
Do.	do.	95		do.	63 (71-64)
Do.	do.	97		Curtis, Evernden, Lipson, 1958	KA-67
Do.	Granodiorite of The Gateway		103	Evernden and Kistler, 1970	91 (1663)
Do.	do.	111		do.	92 (1665)
Do.	do.	95		Curtis, Evernden, and Lipson, 1958	KA-71
Do.	El Capitan Granite	94		do.	KA-77
Do.	do.	92		Evernden and Kistler, 1970	64 (72-64)
Do.	Granite of Mount Hoffman	85		Curtis, Evernden, and Lipson, 1958	KA-177
Shaver	Granodiorite of Dinkey Creek	94	93	Bateman and Lockwood, 1976	SL-18
Do.	do.	92		do.	SL-25
Do.	do.	94	101	do.	SLd-8
Do.	do.	78	80	Bateman and Wones, 1972	HL-9
Do.	do.	85	95	Kistler, Bateman, and Brannock, 1965	BCc-13
Do.	do.	87		do.	BCc-14
Do.	do.	90		do.	KP-12
Do.	Granite of Dinkey Dome	85		Bateman and Wones, 1972	HL-29
Do.	do.	90		do.	HLc-126
Do.	do.	90		do.	HLd-102
Do.	Granite of lower Bear Creek	92		do.	HLc-68
Do.	Granite north of Snow Corral Meadow	89		do.	HLd-20
Merced Peak	Granodiorite of Jackass Lakes	86	95	D. L. Peck and R. W. Kistler, (unpub. data, 1979)	MP-82
Buena Vista	Granodiorite of Illilouete Creek	89	85	do.	MP-455
Washburn	Granodiorite of Red Devil Lake	84	87	do.	MP-789
Kaiser	Mount Givens Granodiorite	89	88	Kistler, Bateman, and Brannock, 1965	BCc-12
Do.	do.	87	89	do.	BCa-20
Do.	do.	84		do.	KP-5
Do.	Granodiorite of Red Lake	84		Bateman and Wones, 1972	HL-4
Do.	do.	90		do.	HLa-80
Do.	Granodiorite of Eagle Peak	89		do.	HLd-6
Do.	Granodiorite of Big Creek	88		do.	HLa-46
Do.	Granite of Bald Mountain	91		do.	HLa-16
Tuolumne	Sentinel Granodiorite	90		Curtis, Evernden, and Lipson, 1958	KA-68
Do.	do.	92	92	Kistler and Dodge, 1966	FD-13
Do.	Granodiorite of Kuna Crest	85		Kistler, 1966b	
Do.	do.	84		Evernden and Kistler, 1970	218 (BKA-556)
Do.	Half Dome Granodiorite	86		Curtis, Evernden, and Lipson, 1958	KA-73
Do.	do.	85		Evernden and Kistler, 1970	69 (1526)
Do.	do.	85		do.	74 (1532)
Do.	do.	84		do.	38 (1525)
Do.	Cathedral Peak Granodiorite	86		Curtis, Evernden, and Lipson, 1958	KA-135
Do.	do.	84		Evernden and Kistler, 1970	70 (1527)
Do.	do.	87		do.	71 (1528)
Do.	do.	86		do.	72 (1530)
Do.	do.	86		do.	73 (1531)
Do.	do.	85	86	do.	75 (1533)
Do.	Johnson Granite Porphyry	84		Curtis, Evernden, and Lipson, 1958	KA-133
Mono Pass	Granodiorite of Lake Edison	77		Kistler, Bateman, and Brannock, 1965	MT-5
Do.	do.	82	85	Evernden and Kistler, 1970	221 (61-001, 61,020)
Do.	Round Valley Peak Granodiorite	89	84	Kistler, Bateman, and Brannock, 1965	MT-2
Do.	Granodiorite of Mono Recesses	81		Evernden and Kistler, 1970	76 (1551)
Do.	do.	80		do.	77 (1552)
Do.	do.	81	79	do.	78 (1553)
Do.	do.	81		do.	81 (1559)
Do.	do.	79		do.	82 (1560)
Do.	do.	82		do.	83 (1561)
Powell	Lamarck Granodiorite	85	90	do.	86 (1601)
Do.	do.	79	86	Kistler, Bateman, and Brannock, 1965	MG-1
Do.	Leucogranite of Evolution Basin	82		Evernden and Kistler, 1970	79 (1554)
?	??	82		do.	80 (1555)
?	??	86		do.	85 (1600)

TABLE 2. — Continued

Granitoid Sequence	Formation or pluton	Age, m.y.		Reference	Sample number
		Biotite	Hornblende		
	Leucogranite of Rawson Creek	89		Kistler, Bateman, and Brannock, 1965	BP-4
	do.	83		do.	BP-9
	do.	87		do.	BP-3
	Granodiorite of Coyote Flat	90		do.	BP-5
Scheelite	Wheeler Crest Quartz Monzonite	100		do.	MT-1
Do.	do.	71	98	do.	MT-3
Do.	do.	72	101	do.	MT-4
?	??	92		Evernden and Kistler, 1970	215 (MKA-92)
?	??	90	99	do.	217 (BKA-847; MKA-458)
Do.	Granodiorite of the Benton Range	153	162	do.	226 (61-019; 61-025)
Do.	do.	158		do.	227 (51-166)
Do.	do.	142		do.	228 (61-003)
Do.	do.		199	do.	229 (61-017)
Do.	do.	215	211	do.	230 (61-008; 61-026)
Do.	do.		211	Crowder and others, 1973	
Scheelite	Granodiorite of Mono Dome	86		Evernden and Kistler, 1970	209 (DKA-1028)
Do.	do.	89	97	do.	210 (DKA-1029; MKA-409)
Do.	do.	85	95	do.	212 (DKA-1031; DKA-1032)
Do.	do.	101	211	do.	213 (DKA-1030; MKA-410)
Do.	do.	84		do.	214 (BKA-558)
Do.	do.	84	211	Kistler, 1966b	
Do.	Tungsten Hills Quartz Monzonite	77		Kistler, Bateman, and Brannock, 1965	MG-2
Do.	do.	76		do.	MT-6
Palisade Crest	Inconsolable Granodiorite	89	100	do.	MG-3
Do.	Tinemaha Granodiorite	77	159	do.	BP-1
Do.	do.	93	174	do.	BP-4
Do.	do.	134	184; 187	do.	BP-7
Do.	do.	85		do.	BP-8
Do.	Granodiorite of McMurry Meadow	107	155	do.	BP-2
Granitoids nr. Tioga Pass	Quartz monzonite of Ellery Lake	96		Evernden and Kistler, 1970	211 (MKA-41)
Do.	Quartz monzonie of Aeolian Buttes	90	88	do.	216 (BKA-488; 61-192)
Do.	Granodiorite of Rush Creek	71		do.	219 (BKA-557)
	Granodiorite of Mount Barcroft	92		Crowder and others, 1973	
	do.	106		do.	
	do.	130		do.	
	do.	135	231	do.	
Soldier Pass	Monzodiorite of Eureka Valley	167		McKee and Nash, 1967	12
Do.	do.	175		do.	13
Do.	Monzonite of Joshua Flat	157		do.	4
Do.	do.	175	172	do.	8
Do.	do.		183	do.	9
Do.	do.	172	188	do.	10
Do.	do.		182	do.	11
Do.	Quartz monzonite of Beer Creek	155	162	do.	5
Do.	do.	174		do.	6
Do.	do.	166		do.	7
Do.	do.	154		Crowder and others, 1973	
Do.	do.		174	do.	
Do.	do.	165	180	do.	
Do.	do.	174		Evernden and Kistler, 1970	65 (579)
Do.	do.	166		do.	68 (902)
Cretaceous granites of the northern White Mtns.	Granite of Pellisier Flats		92	Crowder and others, 1973	
Do.	do.		100	do.	
Do.	Granite of Boundary Peak	74		do.	
Do.	Granite of Leidy Creek	76		do.	
Do.	Granite of Marble Canyon	73		do.	
Do.	do.	77		do.	
Do.	do.	80		do.	
Do.	Granite of McAfee Creek	85		do.	
Do.	do.	87		do.	

TABLE 2. — Continued

Granitoid Sequence	Formation or pluton	Age, m.y. Biotite	Age, m.y. Hornblende	Reference	Sample number
Misc. granitoids of the White Mountains	Granite of Indian Garden	95		do.	
Do.	do.	111		do.	
Do.	Granodiorite of Cabin Creek	88	153	do.	
Do.	Granite of Sugar Peak	151	154	do.	
Do.	Sage Hen Flat pluton	133	141	McKee and Nash, 1967	1
Do.	Birch Creek pluton	82		do.	2
Do.	do.	79		do.	3
Do.	Foliated granodiorite at foot of Birch Creek	93		do.	24
Do.	do.		218	do.	26
Do.	Granite of Sylvania Mountain	159		Evernden and Kistler, 1970	67 (840)
Do.	Papoose Flat pluton	80		do.	66 (804)
Do.	Granite at north end of the White Mountains (Pellisier Flats?)	161		do.	225 (61-005)
	Sheared granodiorite of the Goddard pendant	88		Kistler and others, 1965	BCb-53

(1979) also reports a U-Pb age of 179 m.y. on the monzonite of Eureka Valley (table 3).

From the Palisade Crest granitoid sequence (Bateman and Dodge, 1970), only the Tinemaha Granodiorite was dated. The age of 155 m.y. on sample 55 (table 1) is in only fair agreement with a U-Pb age of 164 m.y. determined by Chen (1977) on a sample from the same formation farther south. The 155-m.y. age is also considerably younger than maximum K-Ar ages of 174, 184, and 187 m.y. on hornblende from the Tinemaha Granodiorite (Kistler and others, 1965). Consequently, the true age of this sequence may be somewhat greater than 155 m.y.

The four unassigned granitoid formations in the east side of the Sierra Nevada batholith, which yielded Jurassic ages, are in the White Mountains, the Benton Range, and the eastern escarpment of the Sierra Nevada. Their ages range from 161 to 169 m.y. Two of the formations, the granite of Casa Diablo Mountain (sample 58) and the granodiorite of Mount Barcroft (sample 59) have the same U-Pb age of 161 m.y., and both are concordant with their paired ^{207}Pb/^{235}U ages within a million years. Nevertheless, petrologic similarities are lacking, and the only other evidence of consanguinity is that these two granitoids are in the same general area.

The other two unassigned granitoid formations have yielded somewhat older ages. The age of a body of quartz diorite that lies along the intrusive contact at the Pine Creek tungsten mine (sample 57) is 169 m.y., and the age of the granite west of Warren Lake, in the eastern escarpment of the Sierra Nevada south of Bishop, is 167 m.y. (sample 56). These ages suggest that these formations may be comagmatic with the Soldier Pass sequence. However, these granitoids are petrographically distinct, and other evidence pointing to their consanguinity either with each other or with the Soldier Pass sequence has not been recognized.

On the west side of the batholith, eight plutons and formations have yielded Jurassic U-Pb ages. The quartz diorite of Granite Creek and the Standard and Cobb Creek plutons are here assigned to the Jawbone

TABLE 3.—*Previously published* U-Pb *ages of zircon from granitoids of the White Mountains*

Granitoid sequence	Formation or pluton	Age, m.y. ^{266}Pb/^{238}U	Age, m.y. ^{207}Pb/^{235}U	Reference
Soldier Pass	Monzonite of Eureka Valley	179	180	Gillespie (1979)
Do.	Monzonite of Joshua Flat	159	160	Do.
Do.	do.	173*	173*	Sylvester, Miller, and Nelson (1978)
Do.		178*	176*	Do.
Do.	Quartz monzonite of Beer Creek	161	180	Gillespie (1979)
	Granodiorite of Mount Barcroft	165	166	Do.
	Sage Hen Flat pluton	144	145	Do.

* Same sample, two fractions.

TABLE 4.—*Sample locations*

No.	Field & lab no.	UTM Zone II coordinates		USGS quad	Physical location of sample site
1	BMCC	$^{41}95^{120}$ N.	$^{7}25^{280}$ E.	Sonora 15'	Roadside outcrop on Hwys. 120 and 49, 1.7 km east of Chinese Station.
2	DPD-1	$^{41}79^{310}$ N.	$^{7}35^{490}$ E.	Merced Falls 15'	West side of Marsh Flat Road, 0.15 km north of the Buzzard Roost mine.
3	PM-1	$^{41}95^{420}$ N.	$^{7}30^{440}$ E.	Sonora 15'	1.2 km south of Page Mountain.
4	LE-1092	$^{42}D6^{200}$ N.	$^{2}37^{050}$ E.	Lake Eleanor 15'	East side of Skunk Creek, 2.5 km WNW of Wood Ridge Lookout.
5	BMSD	$^{42}01^{720}$ N.	$^{7}34^{760}$ E	Standard 7.5'	Roadside outcrop, 1.6 km NW of Morgan Chapel.
6	CCr-1	$^{41}87^{000}$ N.	$^{7}41^{900}$ E.	Moccasin 7.5'	Roadside outcrop, where unnamed road crosses Cobbs Creek, 1 km east of Priest Reservoir.
7	LE-153	$^{41}98^{850}$ N.	$^{2}36^{500}$ E.	Lake Eleanor 15'	Dirt Road, 0.8 km NW of Meyers Ranch.
8	LE-244	$^{41}89^{150}$ N.	$^{2}46^{300}$ E.	do.	North side of Big Oak Flat Road, 0.9 km west of Carlon Guard Station.
9	IG-2	$^{41}51^{500}$ N.	$^{7}6D^{450}$ E.	Indian Gulch 15'	South side of Hwy. 140, 1 km northeast of Catheys Mtn.
10	MA-1	$^{41}48^{900}$ N.	$^{2}39^{700}$ E.	Mariposa 15'	West side of Ben Hur Road, 1.5 km south of Mormon Bar.
11	RDa-1	$^{41}14^{900}$ N.	$^{2}41^{200}$ E.	Raymond 15'	West side of Road 600, 0.3 km south of junction with Road 407.
12	LE-1036	$^{41}90^{400}$ N.	$^{2}45^{250}$ E.	Lake Eleanor 15'	South side of Ascension Mtn., 1.0 km west of the Five Star mine.
13	MLa-12	$^{41}21^{100}$ N.	$^{2}59^{150}$ E.	Millerton Lake 15'	West side of Hwy. 41, 2.6 km south of Picayune Cemetery Road.
14	MLc-10	$^{41}04^{500}$ N.	$^{2}57^{100}$ E.	do.	North side of Road 208, 1.8 km west of junction with Road 211.
15	MLc-51	$^{41}04^{200}$ N.	$^{2}58^{450}$ E.	do.	0.35 km SW of junction of Road 208 and Road 211.
16	MLc-154	$^{41}10^{100}$ N.	$^{2}63^{500}$ E.	do.	South of Road 210, 4 km east of O'Neal Ranch.
17	Y-682	$^{41}70^{900}$ N.	$^{2}60^{500}$ E.	Yosemite 15'	Roadsite outcrop in Yosemite West development.
18	MLb-69	$^{41}18^{250}$ N.	$^{2}68^{200}$ E.	Millerton Lake 15'	South of dirt road, 1 km NNE of Fresno Banner mine.
19	SLb-64	$^{41}23^{250}$ N.	$^{2}94^{100}$ E.	Shaver Lake 15'	Ross Creek, 1 km east of junction with Clearwater Creek.
20	MLd-52	$^{41}01^{200}$ N.	$^{2}76^{050}$ E.	Millerton Lake 15'	West side of Morgan Canyon Road, 0.9 km south of junction with Auberry Road.
21	Jb-1	$^{41}08^{400}$ N.	$^{2}88^{550}$ E.	do.	West side of Jose Creek, 1 km north of junction with Musick Creek.
22	RDb-58	$^{41}20^{800}$ N.	$^{2}50^{650}$ E.	Raymond 15'	0.8 km south of BM 1024 along Road 400.
23	BLc-4	$^{41}33^{500}$ N.	$^{2}64^{250}$ E.	Bass Lake 15'	West side of Hwy. 41, 1.5 km south of Oakhurst.
24	BLd-3	$^{41}39^{200}$ N.	$^{2}68^{450}$ E.	do.	North side of Bass Lake Road, 1 km east of junction with Hwy. 41.
25	Y-676	$^{41}77^{500}$ N.	$^{2}61^{800}$ E.	Yosemite 15'	Roadside outcrop on Hwy. 41 on Turtleback Dome at west end of Yosemite Valley.
26	Y-721	$^{41}60^{600}$ N.	$^{2}68^{800}$ E.	do.	Trailside outcrop near Chilnalna Falls, NE of Wawona.
27	FD-12	$^{41}76^{950}$ N.	$^{2}70^{600}$ E.	do.	Taft Pt. near the Fissures.
28	SPc-1	$^{41}26^{350}$ N.	$^{2}83^{600}$ E.	Shuteye Peak 15'	Roadside, 1.0 km east of Peckinpah Meadow at Whiskey Creek.
29	SLb-70	$^{41}15^{250}$ N.	$^{2}93^{900}$ E.	Shaver Lake 15'	East side of Dawn Road, 1.9 km SW of Musick Mtn.
30	SL-1	$^{41}07^{750}$ N.	$^{2}95^{250}$ E.	do.	0.25 km south of Dinkey Creek Road, 0.8 km west of BM 5723, 2 km east of Shaver Lake Heights.
31	Y-733	$^{41}66^{800}$ N.	$^{2}74^{700}$ E.	Yosemite 15'	Outcrop near head of Ostrander Lake.

granitoid sequence, which is named after Jawbone Ridge, a prominent feature within the quartz diorite of Granite Creek. The five other units are not assigned to sequences. The oldest ages are from two small plutons in the western foothills. Sample 1, from the Chinese Camp pluton, yielded an age of 190 m.y., and sample 2, from the Don Pedro pluton, yielded an age of 182 m.y. Both plutons lie west of the Melones fault zone (Clark, 1964), which many consider to separate terranes that originated in widely separated places, and their structural and spatial relations to other Sierran granitoids is uncertain. These plutons intrude the Penon Blanco Volcanics, which previously was thought to be equivalent to other lavas and volcanic breccias in the western Sierra Nevada of Middle and Late Jurassic age, especially the Logtown Ridge Formation (Clark,

TABLE 4. — Continued

No.	Field & lab no.	UTM Zone II coordinates		USGS quad	Physical location of sample site
32	MP-568	$^{41}68^{700}$ N.	$^{2}86^{200}$ E.	Merced Peak 15'	Trailside outcrop below Lower Ottoway Lake.
33	MP-520	$^{41}63^{200}$ N.	$^{2}88^{200}$ E.	do.	Talus near trail west of Fernandez Pass.
34	MP-846	$^{41}68^{900}$ N.	$^{2}90^{600}$ E.	do.	Outcrop east of Edna Lake.
35	MP-847	$^{41}69^{900}$ N.	$^{2}90^{300}$ E.	do.	Outcrop on north slope of Ottoway Peak.
36	MP-789	$^{41}71^{200}$ N.	$^{2}89^{700}$ E.	do.	Outcrop near the foot of Red Devil Lake.
37	SLc-119	$^{41}02^{000}$ N.	$^{2}85^{250}$ E.	Shaver Lake 15'	0.75 km south of Beal Fire Road, and past Peak 3938'.
38	HC-1	$^{41}09^{250}$ N.	$^{3}24^{300}$ E.	Blackcap Mtn. 15'	North side of Courtwright Reservoir on point between Helms Creek and Dusy Creek.
39	KPd-72	$^{41}31^{450}$ N.	$^{3}20^{800}$ E.	Kaiser Peak 15'	2 km SSW of Mono Hot Springs, 1.5 km east of Bolsillo Campground.
40	TMc-173	$^{41}92^{300}$ N.	$^{2}81^{800}$ E.	Tuolumne 15'	1 km NE of May Lake.
41	TMb-164	$^{41}94^{650}$ N.	$^{2}93^{750}$ E.	do.	South side of Lembert Dome.
42	F76-6	$^{41}75^{450}$ N.	$^{3}08^{450}$ E.	Devils Post Pile 15'	NW side of Garnet Lake.
43	Dp-2	$^{41}55^{450}$ N.	$^{3}20^{450}$ E.	do.	South side of Fish Creek, 1.6 km west of Fish Creek Hot Springs.
44	KPb-85	$^{41}42^{500}$ N.	$^{3}15^{750}$ E.	Kaiser Peak 15'	On trail north of Four Forks Creek, 0.5 km SW of Peak 8254'.
45	DP-1	$^{41}68^{800}$ N.	$^{3}17^{650}$ E.	Devils Post Pile 15'	East side of road to Devils Post Pile, 1.75 km south of Starkweather Lake.
46	ABb-1	$^{41}43^{150}$ N.	$^{3}44^{500}$ E.	Mt. Tom 15'	Little Lakes Valley at head of Rock Creek, 3 km SW from Rock Creek Lake on west side.
47	MT-13	$^{41}47^{000}$ N.	$^{3}46^{850}$ E.	do.	East side of Rock Creek Road, 0.5 km north of Rock Creek Lake.
48	MT-12	$^{41}37^{650}$ N.	$^{3}47^{850}$ E.	do.	Pine Creek mine, 1500' level.
49	MGb-1	$^{41}14^{950}$ N.	$^{3}61^{250}$ E.	Mount Goddard 15'	Northeast shore of South Lake.
50	BIc-1	$^{41}23^{850}$ N.	$^{3}77^{750}$ E.	Bishop 15'	West of Hwy. 395 at Keough Hot Springs.
51	Bn-1	$^{41}80^{550}$ N.	$^{3}76^{500}$ E.	Benton 15'	Float collected from the mouth of Queen Dicks Canyon.
52	MT-11	$^{41}38^{350}$ N.	$^{3}51^{300}$ E.	Mt. Tom 15'	North side of Pine Creek Road, 0.75 km north of Scheelite.
53	MT-10	$^{41}40^{650}$ N.	$^{3}53^{300}$ E.	do.	North side of Pine Creek Road, 2 km east of Scheelite.
54	CT-27	$^{41}85^{350}$ N.	$^{3}37^{550}$ E.	Cowtrack Mtn. 15'	North side of Hwy. 120 at Gaspipe Spring.
55	BPd-1	$^{41}03^{500}$ N.	$^{3}85^{400}$ E.	Big Pine 15'	Along dirt road, 1.5 km south of Fish Spring Hill.
56	BPb-1	$^{41}80^{900}$ N.	$^{3}80^{900}$ E.	do.	South of unnamed road, 1 km west of Warren Lake.
57	MT-14	----------	----------	Mt. Tom 15'	Pine Creek mine; Curly level at 26.760 N; 37.920 (mine coordinates).
58	GM-13	$^{41}83^{500}$ N.	$^{3}62^{450}$ E.	Glass Mtn. 15'	North side of Hwy. 120, 0.5 km east of Dutch Bates Ranch.
59	MB-1	$^{41}58^{750}$ N.	$^{3}90^{850}$ E.	Mt. Barcroft 15'	Mt. Barcroft Road, 1.3 km south of Barcroft Laboratory.
60	MB-2	$^{41}54^{200}$ N.	$^{3}98^{450}$ E.	do.	South side of Cottonwood Creek at McCloud Camp.
61	SD-10	$^{41}41^{250}$ N.	$^{4}15^{100}$ E.	Soldier Pass 15'	East side of Hwy. 63, 4 km north of the Deep Spring Maintenance Station.
62	SD-5	$^{41}44^{900}$ N.	$^{4}17^{750}$ E.	do.	Hyw. 63, 2.5 km south of junction with Canyon Road.

1960). However, detailed mapping in the Sonora area has shown that the Penon Blanco is in fault contact with the established Upper Jurassic rocks (Morgan, 1977), so an Early Jurassic or older age for the Penon Blanco is possible. The Chinese Camp pluton also intrudes a large ultramafic complex on the Tuolumne River, and this relation suggests pre-Jurassic emplacement of the ultramafic rocks in this part of the Sierra Nevada. Attempts to obtain zircons from silicic units within the volcanic rocks were not successful.

The Guadalupe igneous complex, a gabbroic pluton with a granophyric top from which sample 9 was collected, also lies west of the Melones fault zone. The U-Pb age of 140 m.y. on sample 9 is important because it places a lower age limit on the Late Jurassic Nevadan orogeny. A K-Ar age on biotite of 139 m.y. (Curtis and others, 1958) supports the reliability of the U-Pb age. The pluton intrudes steeply dipping strata of the Upper Jurassic Mariposa Formation, which is generally considered to be the youngest formation affected by the Nevadan orogeny. That the strata were already folded when the pluton was emplaced is shown by the presence of a thermal aureole around the pluton, which cuts across steeply dipping structures, and by the nearly horizontal altitude of the transition zone between the capping granophyre and the gabbro. The Mariposa Formation contains upper Oxfordian and Kimmeridgian fossils (Clark, 1964). The Jurassic time scale of Van Hintze (1976) shows the Oxfordian to extend from 149 to 143 m.y. ago and the Kimmeridgian from 143 to 138 m.y. ago. If the U-Pb age on sample 9 and the age assignments of Van Hintze are correct, the Mariposa Formation must have been both deposited and deformed between 149 and 140 m.y. ago.

The Jurassic granitoids east of the Melones fault zone intrude the Calaveras Formation, which is generally considered to be late Paleozoic in age. The Standard and Cobb Creek plutons and the quartz diorite of Granite Creek, which we have assigned to the Jawbone granitoid sequence, are composed of similar rocks that yield similar U-Pb ages of 164, 163, 166, and 163 m.y. (samples 5, 6, 7, and 8). Previously, Morgan and Stern (1977) reported a Paleozoic age of 259 m.y. for the Standard pluton, but after dating of the same outcrop by Jason Saleeby (written commun., 1978) indicated a Jurassic age, sample 5 was reanalyzed, and the age of 164 m.y. reported here was obtained. This age agrees well with the maximum hornblende age of 166 m.y. reported by Evernden and Kistler (1970) for the Standard pluton. Small granitoid bodies satellitic to the Cobb Creek pluton are cut by the Melones fault zone, relations indicating that the faulting occurred after the 163-m.y.-old Cobb Creek pluton (sample 6) was emplaced. The isolated Page Mountain pluton and the granodiorite of Cottonwood Creek have U-Pb ages of 148 m.y. (sample 3) and 151 m.y. (sample 4), respectively. According to F.C.W. Dodge (oral commun., 1978), the granodiorite of Cottonwood Creek intrudes the quartz diorite of Granite Creek.

CRETACEOUS GRANITOID SEQUENCES

Intrusive relations show that the Cretaceous granitoid sequences are generally younger eastward (fig. 2), and the U-Pb ages confirm this pattern. Intrusive relations in the field show that the order of emplacement of Cretaceous sequences across the southern part of the map area of figure 1 is, from oldest to youngest: (1) Fine Gold, (2) Shaver, (3) Powell, (4) Kaiser, and (5) Mono Pass (fig. 2). The $^{206}Pb/^{238}U$ ages for these sequences indicate the following optimum ages and possible age ranges, in millions of years: Fine Gold, 114 (110-118.5); Shaver, 103 (102-104); Powell, 90; Kaiser, 91 (88-93); Mono Pass, 89 (88-93). In these tabulations, sample 14 from the Fine Gold sequence and sample 45 from the Mono Pass sequence have been omitted because they fall well outside the general range of ages for these sequences.

Intrusive relations show that the unassigned granodiorite of Knowles and the Oakhurst pluton are younger than the Fine Gold sequence. Sample 22 from the granodiorite of Knowles has a U-Pb age of 112 m.y. The facts that this sample was collected close to the contact with rocks of the Fine Gold sequence and that two other samples from the interior of the pluton contained too little zircon to be dated suggest that the zircon in sample 22 may have been picked up from rocks of the Fine Gold sequence rocks and that the 112 m.y. age may not represent the age of the Knowles. However, we believe this age to be approximately correct because two samples from the Knowles yielded K-Ar ages on biotite of 110 and 113 m.y. (Evernden and Kistler, 1970). Samples 23 and 24 from the Oakhurst pluton give ages of 108 and 105 m.y., somewhat younger than the age from the Knowles and older than U-Pb ages from the Shaver sequence. The 105 m.y. age on sample 24 is almost identical with the $^{207}Pb/^{235}U$ age and probably is closer to the crystallization age of the rock than the 108 m.y age on sample 23.

The ages of the granitoids in the Yosemite region remain uncertain, because some U-Pb ages on the same units differ significantly from one another, the U-Pb ages do not clearly reflect the order of intrusion as shown by field relations, and the affiliations of some formations have not been established by geologic or geochemical criteria. The U-Pb ages of 117 m.y. on sample 10 of the granodiorite of Sawmill Mountain and of 116 m.y. on sample 17 of the granodiorite of The Gateway are both within the range of ages from the Fine Gold sequence. Nevertheless, only the granodiorite of The Gateway is assigned to the Fine Gold sequence. The granodiorite of The Gateway, despite its name, is dominantly tonalite, similar to the tonalite of Blue Canyon of the Fine Gold sequence, and is separated from that formation only by an area of unmapped geology. On the other hand, the granodiorite of Sawmill Mountain is left unassigned because it differs in composition from typical granitoids of the Fine Gold sequence and is separated from them by other granitoids.

The relations of the granodiorite of The Gateway to the younger El Capitan and Taft Granites also are uncertain. Traditionally, all of these granitoids have been considered to have been intruded during the

Yosemite intrusive epoch (Evernden and Kistler, 1970). However, the El Capitan and Taft Granites resemble rocks of the Shaver sequence and have U-Pb ages much too young for them to be consanguineous with the granodiorite of The Gateway. The U-Pb ages on samples 25 and 26 from the El Capitan Granite are 103 and 97 m.y., and the U-Pb age on sample 27 from the Taft Granite is 96 m.y. Of these ages, only the 103-m.y. age on sample 25 is in the range of ages on the Shaver sequence. Although the age is concordant with its companion $^{207}Pb/^{235}U$ age and appears to be analytically superior to the other ages, this age alone is not sufficient to assign the El Capitan Granite to the Shaver sequence. Further uncertainty as to the true age of the El Capitan Granite results from a 107.2 ± 15.6-m.y. age on the El Capitan shown by a 5-point whole-rock Rb-Sr isochron assembled by R. W. Kistler (written commun., 1979).

Farther east, in the north-central part of the area shown in figure 1, are the relatively small Buena Vista, Washburn, and Merced Peak granitoid sequences (new names). Intrusive relations show that all of these sequences are younger than the El Capitan Granite and that the Buena Vista and Merced Peak sequences are older than the Mount Givens Granodiorite, the most extensive formation of the Kaiser sequence.

Intrusive relations at contacts between members of these three small sequences show that the Buena Vista and Merced Peak sequences are of about the same age and that the Washburn sequence is younger. The contemporaneity of the Buena Vista and Merced Peak sequences is indicated by the fact that the granodiorite of Jackass Lakes, the most extensive member of the Merced Peak sequence, intrudes the granodiorite of Illilouette Creek, the outer member of the Buena Vista sequence, but that the Jackass Lakes is in turn intruded by the granodiorite of Ostrander Lake, an inner member of the Buena Vista sequence. However, the U-Pb ages do not reflect these relations. Two of the ages on the Buena Vista sequence differ by 12 m.y., sample 31 of the granodiorite of Ostrander Lake giving ages of 107 and 112 m.y. on two analyses and sample 32 of the granodiorite of Illilouette Creek giving an age of 100 m.y. None of these ages is concordant with its companion $^{207}Pb/^{235}U$ age. The 107- and 112-m.y. ages on sample 31 are both older than any of the U-Pb ages on the older El Capitan Granite; thus either the U-Pb ages of the El Capitan are too young or the ages of the granodiorite of Ostrander Lake are too old.

The U-Pb ages of the samples from the Merced Peak sequence differ by 5 m.y., sample 33 of the granodiorite of Jackass Lakes giving an age of 98 m.y. and sample 34 of the granite porphyry of Post Peak giving an age of 93 m.y. The 93-m.y. age is probably incorrect because the granite porphyry is intruded by the granodiorite of Jackass Lakes of the Merced Peak sequence and by the granodiorite of Red Devil Lake (the outer member of the Washburn sequence), both of which have been dated at 98 m.y. Tentatively, we assume the ages of all three of these small sequences to be about 98 m.y. as indicated by the intrusive relations and the U-Pb ages on samples 33 and 36. Thus, they are all probably younger than the Shaver sequence.

The Mono Pass sequence does not extend northward, but petrologically, it closely resembles the Tuolumne Intrusive Suite, which has yielded similar U-Pb ages. In addition, the Sonora pluton, north of the area shown in figure 1, and a granitoid sequence in the Mount Whitney region to the south resemble the Mono Pass sequence and the Tuolumne Intrusive Suite and have comparable K-Ar ages (Evernden and Kistler, 1970). Chen (1977) has also determined that the U-Pb ages of the granitoids near Mount Whitney are similar. If these separated but very similar groups of granitoids are consanguineous, as we think they are, they constitute a grouping larger than a granitoid sequence (or Suite).

The U-Pb ages also indicate that two plutons farther east are of early Late Cretaceous age. Sample 50 indicates an age of 95 m.y. for the leucogranite of Rawson Creek in the eastern escarpment of the Sierra Nevada, west and southwest of Bishop, and sample 51 indicates an age of 90 m.y. for the granite of Pellisier Flats in the White Mountains. Correlation of a small isolated pluton with a K-Ar biotite age of 161 m.y. (Evernden and Kistler, 1970) with the granite of Pellisier Flats probably is incorrect. Dating by the K-Ar method has indicated that most of the plutons in the northeast part of the White Mountains (uncolored on pl. 1) are also of early Late Cretaceous age (Crowder and others, 1973) and suggests that the granite of Pellisier Flats may be part of a Late Cretaceous sequence in that area.

CONCLUSIONS

The U-Pb ages reported here show that in the central Sierra Nevada Cretaceous granitoids occupy the core of the batholith and are flanked by Jurassic granitoids on the west and by Triassic and Jurassic granitoids on the east. The presence of Jurassic granitoids on both sides of the batholith suggests that before the Cretaceous granitoids were emplaced, Jurassic granitoids were widely distributed across the central Sierra Nevada. Former wide distribution of the Jurassic granitoids in this region is supported by a U-Pb age of 155 m.y. reported by Chen (1977) on an older sheared pluton in the south-central part of the area shown in plate 1 and by the presence in the same general area of numerous dikes, believed to be part of the Independence dike swarm, in other deformed granitoids. Elsewhere, dikes from this swarm have yielded U-Pb ages of 148 m.y. (Chen, 1977; Chen and Moore, 1979), so the deformed granitoids are probably all older than 148 m.y.

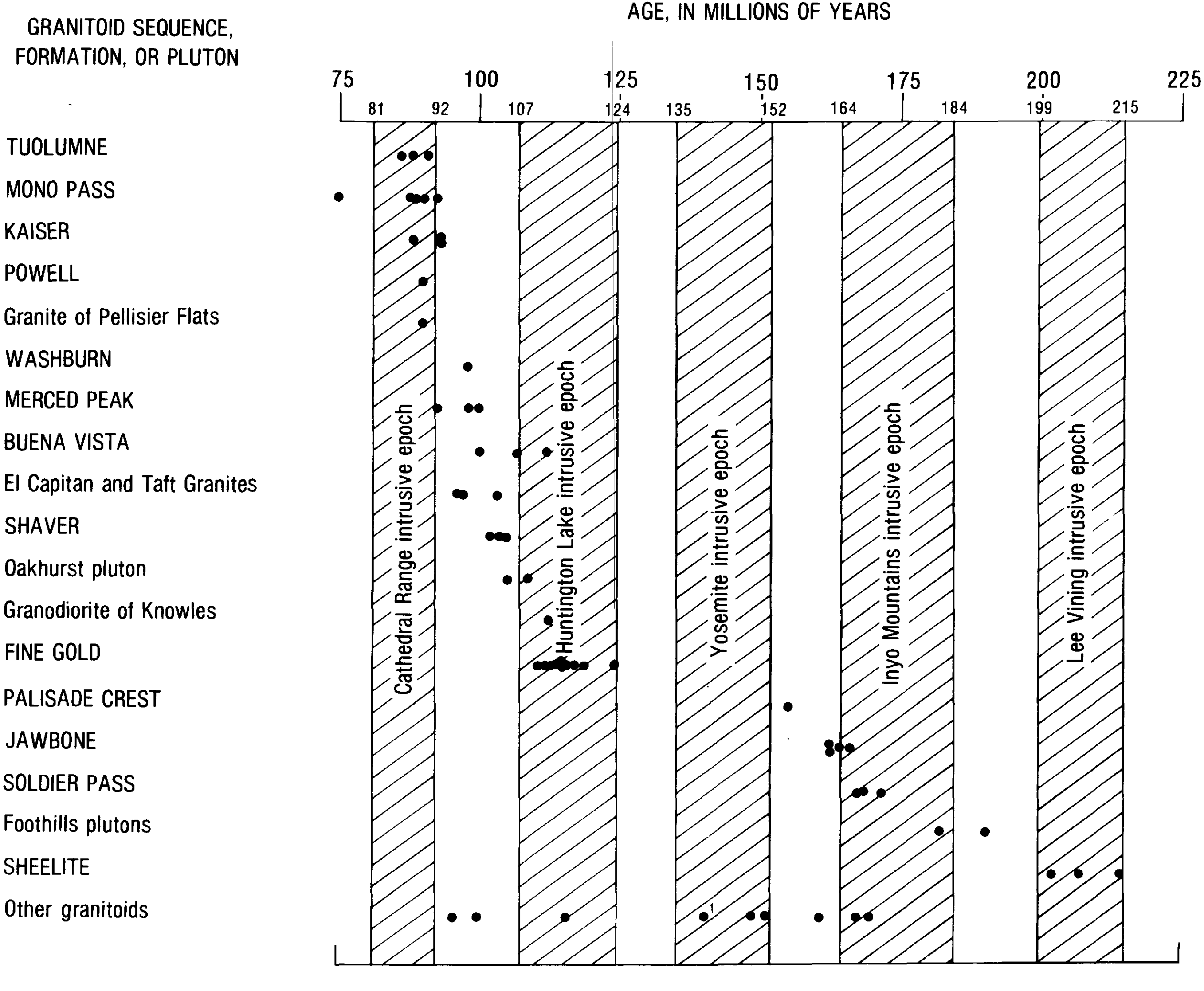
The gross distribution of ages in the central Sierra Nevada results from the crossing of a discontinuous belt of Jurassic granitoids trending N. 40° W. by a wide continuous belt of Cretaceous granitoids trending about N. 20° W. (fig. 1). These belts were recognized by K-Ar dating (Evernden and Kistler, 1970; Kistler and others, 1971). The Cretaceous granitoids trend northward along the axis of the Sierra Nevada into northeastern California and northwestern Nevada. Jurassic granitoids lie generally east of the Cretaceous granitoids south of the area shown in figure 1 and west of the Cretaceous granitoids north of the area shown in figure 1. The K-Ar ages on the west side of the northern Sierra Nevada are generally younger than those in the desert ranges east of the southern Sierra Nevada and include a few Early Cretaceous ages. Both field relations and the U-Pb ages show that the Cretaceous granitoid sequences are progressively younger eastward, but additional isotopic dating will be required to understand the pattern of intrusion during the Jurassic. Our U-Pb ages indicate that the bulk of the Triassic and Jurassic granitoids were emplaced between about 210 and 155 m.y. ago and that the Cretaceous granitoids were emplaced between about 114 and 88 m.y. ago. However, U-Pb ages reported by Saleeby (1976) on granitoids in the western foothills of the Sierra Nevada, (just south of the area shown in fig. 1), cluster between 125 and 115 m.y. and extend the range of Cretaceous ages back to about 125 m.y. Thus, the U-Pb data indicate that in the central Sierra Nevada, the Triassic and Jurassic plutonism lasted 55 m.y., the Cretaceous plutonism about 37 m.y., and the intervening interval of few intrusions about 30 m.y.

Viewed broadly, the U-Pb ages indicate more or less continuous plutonism within the two intervals of granitoid emplacement, but viewed more closely, the plutonic sequences and larger plutons not assigned to sequences can be seen to have been emplaced episodically. Nonplutonic intervals range widely from more than 15 m.y. between some older granitoid sequences to time spans between some younger sequences too brief to be shown by the U-Pb ages. Several younger sequences have optimum ages of about 90 m.y., and several others have optimum ages of about 98 m.y. (table 1). In view of their similar ages, it seems very likely that only the older, generally outer, parts of a sequence had solidified when a succeeding sequence of the same U-Pb age was emplaced and that the younger, generally interior, parts were still partially fluid.

Our data provide only partial support for five cyclic epochs of plutonism in California and western Nevada proposed by Evernden and Kistler (1970) and Kistler, Evernden, and Shaw (1971) on the basis of extensive K-Ar dating and a few Rb-Sr whole-rock isochrons. Their intrusive epochs are plotted in figure 3 together with the U-Pb ages from this study. Our U-Pb data indicate that plutonism was episodic rather than periodic. The data give some support to their Lee Vining and Inyo Mountains intrusive epochs, almost none to the Yosemite intrusive epoch, and show a continuum of plutonic events during a part of the Cretaceous that spans the Huntington Lake and Cathedral Range intrusive epochs.

Sample-by-sample comparison of U-Pb and K-Ar ages is not possible because the ages were determined on different samples. However, many published K-Ar ages were determined on samples that were collected from the same granitoid units as the samples for the U-Pb ages. Optimum U-Pb ages and K-Ar and Rb-Sr ages from the same units are plotted together in the graph in figure 4. The plot shows that the K-Ar ages of the youngest granitoid sequences agree well with the U-Pb ages, although the U-Pb ages are generally as old or older than the oldest K-Ar ages. With increasing age, however, the K-Ar ages are increasingly dispersed, largely because some ages have been reduced as the result of reheating by younger granitoids and probably also of cataclasis during regional deformations. Some K-Ar ages on hornblende from Triassic and Jurassic granitoids are as old or older than U-Pb ages, whereas others are reduced to near that of nearby Cretaceous granitoids. Fission-track ages on sphene published by Naeser and Dodge (1969) on several of the intrusive sequences listed in figure 1 are similarly dispersed and correspond rather closely to K-Ar ages on biotite. Fission-track ages on apatite are even more widely dispersed. The dispersion of K-Ar and fission-track ages for the older rocks is an indicator of the complex deformational and thermal history of the granitoids since they were originally emplaced.

Doubtless, additional isotopic dating will identify granitoid sequences with ages intermediate to those of the established sequences, but some time gaps, especially between some older sequences, are quite large and may persist. The largest time gap, except for the extended interval of few intrusions between the Jurassic and Cretaceous granitoids, is between the Triassic Scheelite granitoid sequence and the Jurassic granitoids. This time gap corresponds to the interval between the Lee Vining and Inyo Mountains intrusive epochs of Evernden and Kistler (1970) and Kistler, Evernden, and Shaw (1971). The Scheelite sequence is in the east side of the batholith and has a spread of U-Pb



[1] Guadalupe intrusive complex-not granitoid

FIGURE 3.—U-Pb ages of granitoids in central Sierra Nevada plotted on intrusive epochs of Evernden and Kistler (1970) and Kistler, Evernden, and Shaw (1971). Boundaries of epochs adjusted to decay and abundance constants recommended for K-Ar ages by I.U.G.S. Subcommission on geochronology (Steiger and Jager, 1977). Names of granitoid sequences in capital letters.

ages of 214 to 202 m.y. and an optimum age of 210 m.y. The next younger granitoids are two small plutons west of the Melones fault zone in the western foothills, which have U-Pb ages of 190 and 182 m.y. (samples 1 and 2), significantly younger than the ages on the Scheelite sequence. The next younger granitoids are in the White and Inyo Mountains and constitute the Soldier Pass granitoid sequence. This sequence has an optimum age of 169 m.y., substantially younger than the foothills granitoids and 41 m.y. less than the optimum age of the nearby Triassic Scheelite sequence.

On the other hand, the indicated time gap of 155 to 125 m.y. between the Jurassic and Cretaceous granitoids is not established beyond all doubt. Three plutons, all from the west side of the batholith, have yielded U-Pb ages that fall in this interval. Of these, sample 9 is from the granophyric top of the dominantly gabbroic Guadalupe igneous complex, which is not considered to be a granitoid body. Nevertheless, the small Page Mountain pluton and the granodiorite of Cottonwood Creek are granitoids and have apparently reliable ages of 148 (sample 3) and 151 m.y. (sample 4). Farther south, Chen (1977) has reported ages between 134 and 128 m.y. on small remnants of older granitoids associated with roof pendants and septa. Also, Evernden and Kistler (1970) have reported numerous K-Ar

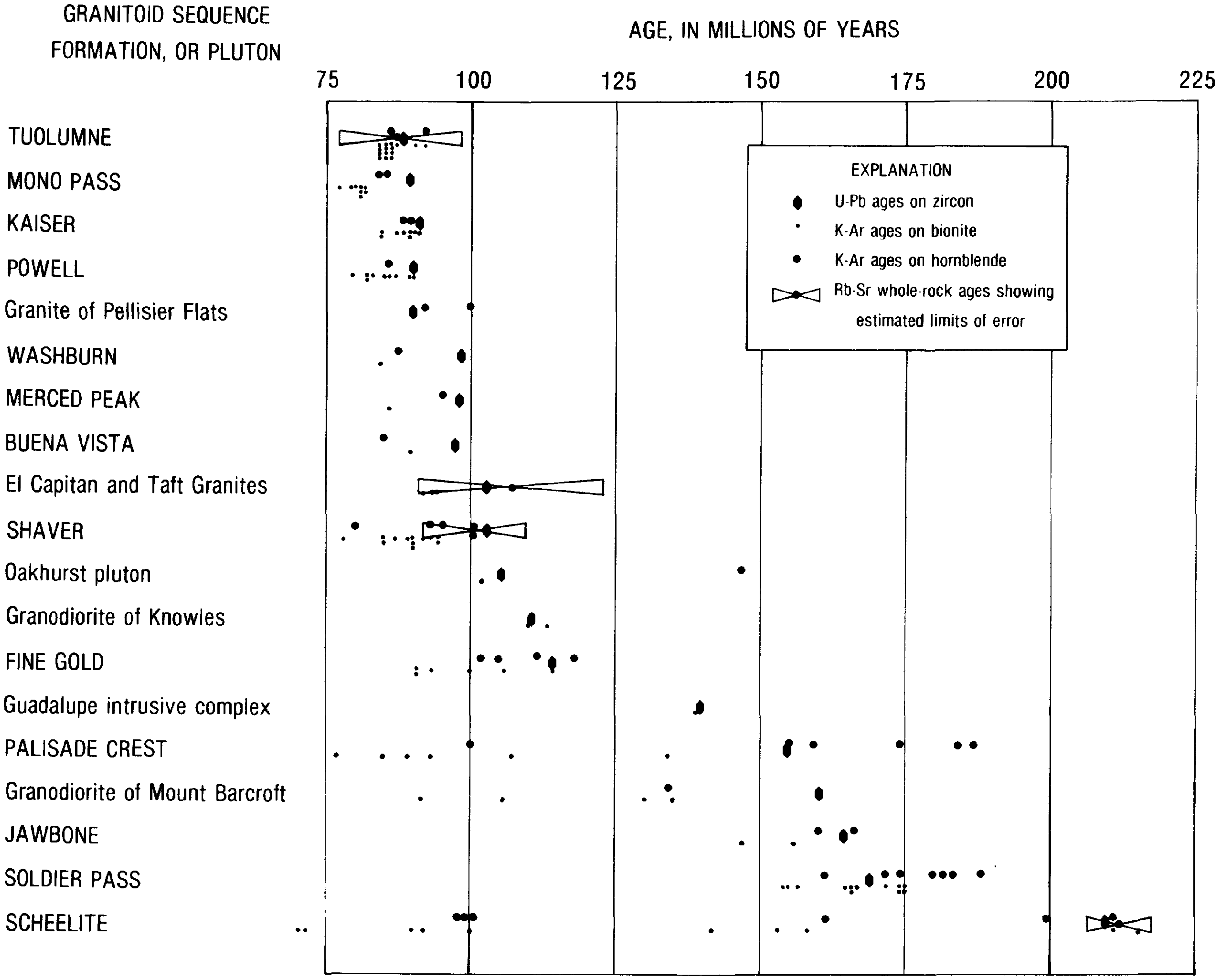


FIGURE 4.—Composite plot of optimum average U-Pb ages on zircon, K-Ar ages on biotite and hornblende, and Rb-Sr whole-rock ages. K-Ar ages are from sources shown in table 2. Rb-Sr data were supplied by R. W. Kistler (written commun., 1979). Names of granitoid sequences in capital letters.

hornblende ages in the range of 154 to 134 m.y. on isolated plutons intruded into the western metamorphic belt farther northwest. Detailed knowledge of intrusive activity during the Late Jurassic and Early Cretaceous is particularly important because it was during this interval that the Nevadan orogeny occurred. Did plutonic activity accompany this orogeny? Or was plutonism suspended during the orogeny?

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