Geology and Mineralogy

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

AGE DETERMINATIONS OF THE ROCKS OF THE BATHOLITHS OF BAJA AND SOUTHERN CALIFORNIA, SIERRA NEVADA, IDAHO, AND THE COAST RANGE OF WASHINGTON, BRITISH COLUMBIA, AND ALASKA*

By

E. S. Larsen, Jr., David Gottfried, H. W. Jaffe, and C. L. Waring

August 1957

Trace Elements Investigations Report 695

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

---

*This report concerns work done on behalf of the Division of Research of the U. S. Atomic Energy Commission.

USGS - TEI-695

GEOLOGY AND MINERALOGY

Distribution	No. of copies
Division of Raw Materials, Albuquerque	1
Division of Raw Materials, Austin	1
Division of Raw Materials, Casper	1
Division of Raw Materials, Denver	1
Division of Raw Materials, Rapid City	1
Division of Raw Materials, Salt Lake City	1
Division of Raw Materials, Spokane	1
Division of Raw Materials, Washington	3
Division of Research, Washington	1
Exploration Division, Grand Junction Operations Office	1
Grand Junction Operations Office	1
Technical Information Service Extension, Oak Ridge	6
U. S. Geological Survey:	
Foreign Geology Branch, Washington	1
Fuels Branch, Washington	1
Geochemistry and Petrology Branch, Washington	25
Geophysics Branch, Washington	1
Mineral Deposits Branch, Washington	1
P. C. Bateman, Menlo Park	1
A. L. Brokaw, Grand Junction	1
N. M. Denson, Denver	1
R. L. Griggs, Albuquerque	1
W. R. Keefer, Laramie	1
H. W. Lakin, Denver	1
E. M. MacKevett, Menlo Park	1
L. R. Page, Washington	1
P. K. Sims, Denver	1
Q. D. Singewald, Beltsville	1
A. E. Weissenborn, Spokane	1
TEPCO, Denver	2
TEPCO, RPS, Washington, (including master)	2
	63

CONTENTS

ILLUSTRATIONS

TABLES

AGE DETERMINATIONS OF THE ROCKS OF THE BATHOLITHS OF BAJA AND SOUTHERN CALIFORNIA, SIERRA NEVADA, IDAHO, AND THE COAST RANGE OF WASHINGTON, BRITISH COLUMBIA, AND ALASKA

By

E. S. Larsen, Jr., David Gottfried, H. W. Jaffe, and C. L. Waring

ABSTRACT

The ages of some of the rocks from the four great batholiths of western North America have been determined by the lead-alpha activity ratios on the accessory minerals--zircon, monazite, thorite, and xenotime. A suite of 10 intrusive rocks from Baja California, Guerrero and Oaxaca, in Mexico, give an average age of 101 ± 5 million years. Those from the batholith of Baja California have been determined as early Late Cretaceous in age on the basis of stratigraphic and paleontologic evidence. Twenty-five age determinations on rocks from the batholith of southern California ranging from tonalite to granite give an average age of 110 ± 13 million years. Age determinations on 15 rocks from the Sierra Nevada batholith give an average age of 102 ± 11 million years. On geologic evidence the Sierra Nevada batholith is considered to be Late Jurassic. Age determinations on 16 rocks from the Idaho batholith average 108 ± 12 million years. This batholith has been geologically dated as Cretaceous in age. Age determinations on 16 rocks of the Coast Range including the batholiths of Washington, British Columbia, and Alaska average 105 ± 13 million years.

The ages of the four groups of rocks are essentially the same and about 106 ± 12 million years. They make a discontinuous en echelon group of intrusives about 4,000 miles long and possibly much longer.

INTRODUCTION

The great batholiths of Baja and southern California, Sierra Nevada, Idaho, and the Coast Range situated along the western margins of the United States, Canada, and Mexico constitute one of the most dominant geologic features of North America. They extend over a distance of nearly 4,000 miles in length and underlie an area of approximately 140,000 square miles (fig. 1). In general the structural setting and the chemical nature of the rocks are similar for each of the batholiths. It is possible that the batholiths extend southward along the west coast of South America (Eardley, 1954).

Age determinations using the lead-alpha method have been made on suitable accessory minerals from suites of batholithic rocks ranging in composition from tonalite to quartz monzonites and granites. The data presented place some limits on the time required for the crystallization of a batholith and indicate time relations between the major batholiths.

This research was undertaken as part of the investigations concerning the distribution of uranium in igneous rocks by the U. S. Geological Survey on behalf of the Division of Research of the U. S. Atomic Energy Commission.

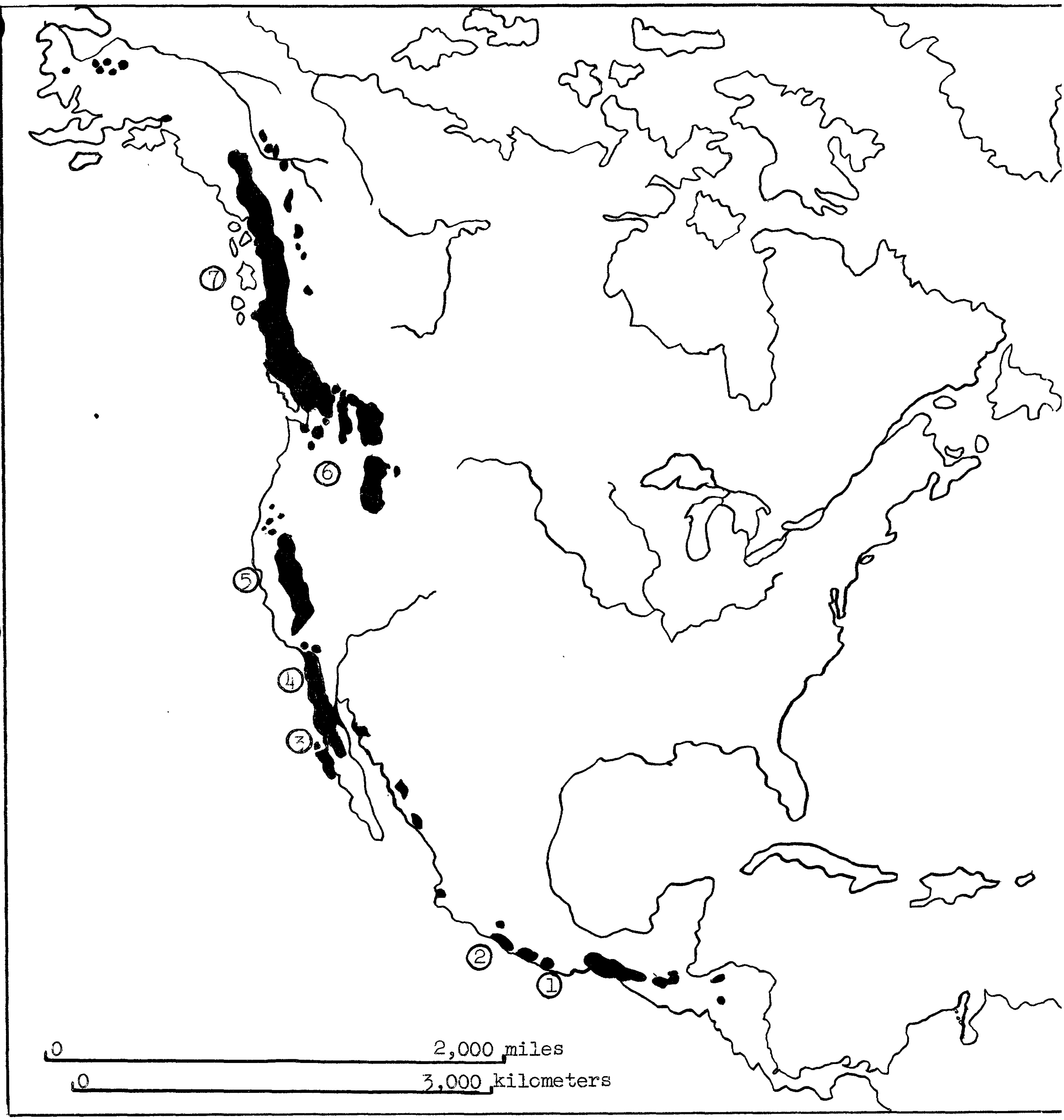

Figure 1. Outline map showing distribution of Mesozoic batholiths of the western part of North America. 1) Oaxaca, 2) Guerrero, 3) Baja California, 4) southern California, 5) Sierra Nevada, 6) Idaho, and 7) Coast Range. Adapted from Igneous rocks and the depths of the earth, by R. A. Daly. Copyright, 1933. By permissic McGraw-Hill Book Co., Inc.

METHOD

The method used to determine the age of the rocks of the batholiths considered here is based on lead-alpha activity ratios in the radioactive accessory minerals zircon, monazite, thorite, and xenotime (Larsen and others, 1952). The total lead content of each mineral concentrate was measured by a spectrographic method developed by Waring and Worthing (1953) and the alpha activity for each accessory mineral by a thick-source alpha-counting method. The accuracy of the alpha-activity measurements is believed to be ± 5 percent and that for the lead analyses 5 to 10 percent with the lower limit of sensitivity of about 0.1 part per million.

The formula for calculating the age is

$$T = \frac{C\ Pb}{\alpha},$$

where T is the age in millions of years, Pb is the lead content in parts per million, α is the radioactivity of the mineral in units of alpha per milligram per hour, and C is a constant equal to 2,632 if all the activity is due to uranium and is 2,013 if all the activity is due to thorium. The values for the constants used in this report are: 2,485 for zircon assuming a thorium to uranium ratio of approximately 1; 2,085 for monazite for an assumed thorium to uranium ratio of 25; and 2,550 for xenotime for an assumed thorium to uranium ratio of 0.5. The choice of these values for the constant will yield a maximum error of approximately 7 percent in the age if the assumed thorium to uranium ratio is seriously in error.

For the equation used in this calculation to be valid there must be no primary lead in the mineral analyzed and there must be no addition or loss of lead, uranium, or thorium after the mineral is formed except within the mineral by nuclear disintegration.

PRIMARY LEAD IN ZIRCON

The assumption of Larsen and others (1952) that the lead in zircon is essentially all of radiogenic origin was primarily based on principles of crystal chemistry of ionic crystals. This approach is based mainly on the knowledge of the ionic radii and charge of the ions to be considered. As the ionic radii of K^+ (1.33 A) and Pb^{++} (1.33 A) are similar, it would seem that during crystallization of a magma, lead would concentrate in the potassium-bearing minerals, mainly orthoclase and biotite (table 1).

Ordinary lavas like those of the San Juan volcanics contain a smaller amount of zircon which is lower in alpha activity than is generally found in their coarser grained equivalents. This is probably due to the fact that the volcanic rocks have not crystallized beyond the phenocryst stage and the zircon crystallization has not been completed. However, the intrusives associated with the lavas are similar to the more common intrusive rocks in regard to the amount of zircon they contain and to the alpha activity of the zircon. The lead-alpha data for zircon of the San Juan lavas and associated intrusives indicate that they contain very little primary lead, less than two parts per million (table 2). The exact age of some of these rocks is not known. The Hinsdale rhyolite is known to be Pliocene. The Fisher is very late Miocene or very early Pliocene. The others are of Miocene age.

Age data for all zircon separated from the rocks of the Mesozoic batholiths that contain 10 parts per million or less of lead are given in table 3. The excess or deficiency of lead for an estimated age of 106 million years is not greater than the experimental errors in the method.

Table 1.--Lead found in orthoclase, biotite, and the igneous rocks from southern California and southwestern Colorado.

Sample no.	Rock type	Lead (parts per million)		
		Orthoclase	Biotite	Igneous rocks
	Southern California			
SLR 229	norite	--	70	10
SLR 685	tonalite	50	--	20
E138-126	granodiorite	45	--	10
E138-28	do.	--	12	9
SLR 2242	do.	60	--	--
SLR 596	do.	43	--	12
SLR 135	do.	--	27	10
E138-265	granite	45	34	20
E138-167	do.	--	30	15
	Southwestern Colorado			
	Hinsdale rhyolite	90	--	25

Table 2.--Alpha activity, lead, calculated age, excess or deficiency of lead for calculated age of zircon of some intrusives and volcanics of the San Juan Mountains, Colorado.

Sample no.	Rock type and locality	α/mg/hr	Pb (ppm)	Pb/α age (millions of years)	Estimated geologic age (millions of years)	Excess or deficiency Pb (ppm)
	Volcanics					
Z_{40}	Hinsdale rhyolite	400	2.5	15	3 ±	+2.0
Z8	Piedra rhyolite	730	7	24	16 ±	+2.3
Z_{43}	Treasure Mountain rhyolite	111	1	22	20 ±	0.0
	Intrusives					
GL-3	Quartz latite dike near Creede (Fisher)	95	0.8, 0.9 (0.85)	22	12 ±	+0.4
GL-5	Quartz latite stock Klondike Mountain, Summitville quadrangle	285	1.2, 1.5 (1.35)	12	20 ±	-0.9
GL-6	Quartz latite, Baughman Creek, Creede quadrangle	56	0.4	17	20 ±	-0.1
GL-7	Quartz latite, east slope Jackson Mountain, Summitville quadrangle	215	1.2, 1.3 (1.25)	14	20 ±	-0.5
GL-8	Quartz latite, east of Square Top Mountain, Summitville quadrangle. (80-200 mesh zircon)	188	0.7, 0.8 (0.75)	10	20 ±	-0.8

Table 2.--Alpha activity, lead, calculated age, excess or deficiency of lead for calculated age of zircon of some intrusives and volcanics of the San Juan Mountains, Colorado.--Continued.

Sample no.	Rock type and locality	α/mg/hr	Pb (ppm)	Pb/α age (millions of years)	Estimated geologic age (millions of years)	Excess or deficiency Pb (ppm)
	Intrusives-- Continued					
8F	Quartz latite, east of Square Top Mountain, Summitville quadrangle. (200-400 mesh zircon)	232	1.0, 1.1 (1.05)	11	20 ±	-0.8
SC1045	Granite porphyry dike, intruding Alboroto Alpine Gulch, San Cristobal quadrangle	600	5.5	23	18 ±	+1.2

Table 3.--Age data for rocks with zircon containing 10 ppm or less of lead.

Sample no.	Location	α/mg/hr	Pb (ppm)	Pb/α (millions of years)	Excess or deficiency of Pb (ppm) for estimated age of 106 million years
	Southern California				
G-33	Mt. Wilson	143	7	122	+0.9
S-1	Lakeview	183	10	136	+2.2
G-3	Mountain Center	194	9	115	+0.8
G-11	El Cajon	149	6	100	-0.4
Z-19	Valverdi	170	8	117	+0.8
G-15	Cottonwood Springs	190	10	131	+1.9
	Sierra Nevada				
PB-7	Bishop	221	10	112	+0.6
MD180-3	Shasta	276	9	81	-2.7
MD180-4	do.	197	8	101	-0.4
EM-1	Ubehebe Peak quadrangle	145	6	103	-0.2
	Idaho				
CPR117	Hailey	173	8	115	+0.6
CPR118	do.	120	5.5	114	+0.4
CPR119	Diana School (200-400 mesh)	116	4.5	96	-0.2
CPR119	Diana School (80-200 mesh)	100	3.7	92	-0.6

Table 3.--Age data for rocks with zircon containing 10 ppm or less of lead.--Continued.

Sample no.	Location	α/mg/hr	Pb (ppm)	Pb/α (millions of years)	Excess or deficiency of Pb (ppm) for estimated age of 106 million years
	<u>Idaho</u>--Continued				
G-200	South Fork, Payette River	190	10	131	+1.9
L-70	Cascade	210	9	107	+0.1
	<u>Mexico</u>				
BC-1-5	Baja California	42	1.9	112	+0.1
F-55-52	Guerrero	47	1.9	100	-0.1
	<u>Washington</u>				
G-142	Near Entiat	63	2.2	87	-0.5
G-146	Near Halford	62	2.3	92	-0.3
FW-60-55	Three miles south of Holden	78	3.3	107	0.0
HC-1	Upper Knap Coulee, Chelan quadrangle	83	4.1	121	+0.6
HC-2	Lower Knap Coulee, Chelan quadrangle	98	4.1	104	-0.1
	<u>British Columbia</u>				
G-122	Near Richter Ranch	160	7.3	114	+0.5
	<u>Alaska</u>				
55 APR-106	Near Juneau	152	5.7	93	-0.8
55 ASN-242	do.	142	5.9	103	-0.1

Therefore, the belief that little lead is incorporated into zircon at its time of crystallization is based on the following:

1. The ionic radii and charge of the ions are unfavorable to the primary crystallization of lead in zircon.

2. The young rocks contain zircon with very little lead, although the lead content in the orthoclase, biotite, and the rock is high.

3. The zircon from rocks of a given province that are low in alpha activity and lead yield ages in agreement with those obtained on zircon containing larger amounts of alpha activity and lead.

ZIRCON, MONAZITE, XENOTIME, AND THORITE

Zircon is present in nearly all igneous rocks though in gabbros and in some granites it is very small in amount. Gabbros commonly contain a few parts per million zircon which is very low in alpha activity. Zircon is relatively abundant in the tonalites, averaging about 100 to 200 parts per million, and is present in about the same amount in granodiorites. The amount of zircon in quartz monzonites is variable but generally small. In general, the zircons from the more siliceous rocks have greater alpha activity. In the rocks of the batholith of southern California the alpha activity of the zircon from tonalite averages 340 α/mg/hr, zircon from the granodiorites averages 800 α/mg/hr, and it varies widely in the quartz monzonites but averages 1,300 α/mg/hr. Some muscovite granites carry less zircon than do the ordinary granites, but the zircon is generally high in activity.

Monazite and xenotime have been found in a few granites and quartz monzonites, especially those with garnet and muscovite. Monazite was found without xenotime, but xenotime invariably seems to be associated with monazite.

Thorite has been found chiefly in granodiorites. This thorite is isotropic, nonmagnetic and with $\underline{n}$ = 1.76 $\underline{+}$. It is concentrated with the zircon, and age measurements on mixed samples of thorite and zircon have yielded consistent ages. Acid treatment dissolves thorite while fresh zircon is insoluble. Thus, an age can also be obtained on the concentrate consisting entirely of zircon.

Monazite, xenotime, and thorite seem to be as satisfactory as zircon for age measurements. They contain greater amounts of alpha activity and lead and, hence, are especially suitable for young rocks. Although most of the age determinations have been made on zircon, a comparison of the results obtained on two or more minerals from the same rock or associated rocks is given in table 4.

Table 4.--Comparison of ages determined on two or more minerals from the same rock or from related rocks.

Sample no.	Rock type and locality	Mineral	α/mg/hr	Pb (ppm)	Pb/α age (millions of years)
	Baja California				
BC-1-2	Granodiorite	Monazite	3,529	168	99
BC-1-4	Tonalite	Zircon	156	6.2	98
	Southern California				
Z-16	Woodson granodiorite	Xenotime	6,400	250	104
		Zircon	1,235	50	101
S-6	do.	Monazite	6,430	360	117
		Zircon	1,180	46	97
X-101	Rattlesnake granite	Xenotime	1,743	80	117
	Sierra Nevada, Bishop area				
PB-3	Granodiorite	Zircon	400	15	93
		Thorite	4,670	205	88
PB-10	Quartz monzonite	Monazite	4,897	236	100
	Sierra Nevada, Yosemite National Park				
53Pb-10	Half Dome quartz monzonite	Zircon	330	15.5	117
		Thorite	10,370	455	88
	Idaho batholith				
G-199	Muscovite quartz monzonite, Garden Valley	Monazite	5,617	250	93
		Zircon	1,970	90	114
		Xenotime	6,025	220	93
L-53-573A	Porphyritic biotite, muscovite granodiorite, Big Creek quadrangle	Monazite	2,726	146	112
		Zircon	340	14	102
L-53-88	Porphyritic granodiorite, Big Creek quadrangle	Monazite	2,678	145	113
L-113	Tonalite, Salmon River below Stanley	Zircon	825	30	90
		Thorite	1,375	70	102
HCD-62	Quartz monzonite, Coeur d'Alene district, Gem Stock	Thorite and zircon	1,739	101	116
HCD-63	do.	Zircon	292	11	94

BATHOLITHIC ROCKS FROM BAJA, CALIFORNIA, OAXACA, AND GUERRERO, MEXICO

In Baja California, about one hundred miles south of the Mexican border, Böse and Wittich (1913) and Woodford and Harriss (1938) concluded that batholithic intrusions in that area occurred in early Late Cretaceous time. These granitic rocks, the San Pedro Mártir intrusives, intrude the San Telmo formation. Woodford and Harriss (1938, p. 1331) state, "The San Telmo belongs to the belt of rocks which includes Lower Cretaceous and probably early Upper Cretaceous elements, and which is unconformably overlain by late Upper Cretaceous rocks. The San Pedro Mártir intrusives are, therefore, probably of Upper Cretaceous age."

A series of metamorphic rocks, the Alisitos formation, are believed to be equivalent to the San Telmo formation and contain fossils of Cenomanian and Albian age (late Early to early Late Cretaceous). The upper-age limit of the intrusives is believed to be Late Cretaceous on the basis of fossils found in the Rosario formation which overlies the beds of the Alisitos formation with an angular unconformity. An outline of the geologic history of the Baja California region is given by Wisser (1954).

In 1955, the area described by Woodford and Harriss was visited by Earl Ingerson, David Gottfried, L. R. Stieff, T. W. Stern, Norman Silberling, of the U. S. Geological Survey; L. T. Silver, California Institute of Technology; and Charles E. Weaver, formerly of the University of Washington, for the purpose of obtaining samples of the intrusives and to collect fossils from the sedimentary rocks as near as possible to the intrusive contact.

An excellent exposure of the intrusive relations of the San Jose tonalite (Woodford and Harriss, 1938) into the San Telmo slates was found at the western edge of the San Jose pluton, about two miles east of Buena Vista. About one mile northwest of Buena Vista, fossils were collected from the San Telmo slates which cropped out continuously from the contact of the slate with the border phase of the tonalite. The fossils were examined by John B. Reeside, Jr., of the Geological Survey (written communication). A list of the fossils and his report are as follows:

Hemiaster sp. - determined by C. W. Cooke
Astarte sp.
Plicatula sp.
Cardium ? sp.
Venerid ? fragment
Tectus ? sp.
Anchura (Perissoptera?) sp.
Metacerithium sp.
Douvilleiceras very close to D. Mammillatum (Schlotheim)
Burckhardites

"The Douvilleiceras so definitely places this assemblage in the Lower part of the Middle Albian, about equivalent to the Upper part of the Glen Rose formation of Texas and to some part of the Upper Horsetown, that it does not seem worth while to try to run down the other elements of the fauna. Most of them belong to long-ranging genera or are dubious and would have inferior value anyway."

The geologic ages of the granitic rocks from the states of Oaxaca and Guerrero in southern Mexico are not very accurately known. These rocks have been collected by Carl Fries, Jr., and B. N. Webber, U. S. Geological Survey, and Z. de Cserna of the Instituto de Geologica, National University of Mexico, who have also supplied information concerning their geologic setting. The two rocks from Huilotopec and Jalapa, Oaxaca, are known to intrude probable lower Paleozoic metamorphosed sedimentary rocks, but their relationship with rocks of known age have not been established.

In Guerrero, a granite (F-56-19) near El Ocotito intrudes Albian dolomite (top of the Lower Cretaceous) thus fixing its older age limit. The other rocks intrude metamorphic rocks of probable Paleozoic age. All the granitic rocks are considered to be of magmatic origin and are not believed to have undergone metamorphism since their emplacement.

Age data for the rocks from Mexico are given in table 5. The average age for 10 rocks is 101 ± 5 million years.

Table 5.--Age of 10 granitic rocks from Mexico.

Sample no.	Rock type and locality	Mineral	α/mg hr	Pb (ppm)	Pb/α age (millions of years)
	<u>Baja California</u>				
BC-1-5	Tonalite, border phase of San Jose pluton	Zircon	42	1.8, 2.0 (1.9)	112
BC-1-4	San Jose tonalite, west slope of Sierra San Pedro Mártir	do.	156	6.3, 6.0 (6.15)	98
BC-1-2	Granodiorite, La Grulla mass	Monazite	3,529	165, 170 (167.5)	99
SV-1	Tonalite, north edge of town of San Vincente	Zircon	123	5.1, 5.0 (5.05)	102
	<u>Oaxaca</u>				
CF-1	Quartz diorite, Isthmus of Tehuantepec area, Huilotepec	do.	310	12	96
JAL-1	Granitic, 4 miles southwest of Jalapa (near CF-1)	do.	104	4.0, 5.0 (4.5)	108
	<u>Guerrero</u>				
F-56-19	Granitic, El Ocotito	do.	273	10, 11 (10.5)	96
F-56-20	Granitic, Xaltianguis	do.	650	25, 26 (25.5)	97
F-56-21	Granitic, near Acapulco	do.	572	22, 23 (22.5)	98
F-55-52	Granitic, Placeres	do.	47	1.8, 2.0 (1.9)	100
	Mean age				101
	Standard deviation				5

SOUTHERN CALIFORNIA AND RELATED BATHOLITHS

In southern California, the succession of events bearing on the age of the batholith is deposition of fossiliferous Triassic rocks; folding and mild metamorphism of the Triassic; deposition of volcanic rocks and associated sediments; folding and metamorphism of all these rocks; intrusion of the batholith; erosion to a mature surface; deposition of gravels followed by deposition of fossiliferous Upper Cretaceous sediments (Larsen, 1948).

A composite batholith such as the batholith of southern California was not intruded at one time but over a range of time. The order of injection follows in a general way from gabbro to tonalite to granodiorite and finally to quartz monzonite and granite. Larsen (1945) has estimated that the time required for crystallization of the batholith is on the order of a few million years. The average age determined on the tonalites is 114 ± 10 million years (table 6); the granodiorites, 105 ± 12 million years (table 7); and the quartz monzonites and granites, 109 ± 16 million years (table 8). The ages of all these rock types are nearly the same and within the limits of error of the determinations. Thus, it is believed that the time interval between the emplacement of the tonalites and the later formed granites was at most a few million years.

The rocks for which age determinations were made are from widely separated places, Riverside at the northern part of the batholith, scattered masses of granite in the Mojave desert east of the batholith, the western part of the batholith in the Peninsular Ranges, and the southern part of the mass near the Mexican border.

The average age for the 25 specimens of the batholith is 110 ± 13 million years.

Table 6.--Age determinations of 11 tonalites of southern California.

Sample no.	Locality	Mineral	α/mg/hr	Pb (ppm)	Pb/α age (millions of years)
G-33	Crest of Mount Wilson	zircon	143	7	122
EL-134	3 1/2 miles northwest of Perris	do.	752	35	116
G-13	Near La Posta Ranch	do.	594	28	117
G-30	3 miles west of Palm Springs	do.	317	14	110
S-1	2 miles east of Neuevo	do.	183	10	136
G-10	1 mile east of Aguanga	do.	280	11	98
G-3	Southwest of Mountain Center	do.	194	9	115
G-11	Near El Cajon	do.	149	6	100
SLR-138	Green Valley	do.	340	15	110
Z-19	Valverdi tunnel	do.	170	8	117
Z-7	Lakeview	do.	646	30	115
	Mean age				114
	Standard deviation				10

Table 7.--Age determinations of 7 granodiorites of southern California.

Sample no.	Locality	Mineral	α/mg/hr	Pb (ppm)	Pb/α age (millions of years)	
Z-16	Woodson, north of Descanso	zircon xenotime	1235 6400	50 260	101 104	103
Z-20	Woodson, Descanso	zircon	786	29	92	
Z-17	Mt. Hole, east of Mt. Hole	do.	1204	46	95	
S-6	Woodson, BM3772, northeast of Descanso	do. monazite	1180 6430	46 360	97 117	107
S-2	Woodson, 1 mile south of Temecula	zircon	433	20,22(21)	121	
G-32A	Woodson, Morrell trail west of Elsinore	do.	457	22	120	
G-48	Stonewall Mountain	do.	545	21	96	
	Mean age				105	
	Standard deviation				12	

Table 8.--Age determinations of 7 quartz monzonites and granites of southern California.

Sample no.	Locality	Mineral	α/mg/hr	Pb (ppm)	Pb/α age (millions of years)
G-21	North Providence Mountains	zircon	610	23	94
G-24M	Soda Lake Mountains	do.	4660	180	96
Z-15	Rubidoux quartz monzonite, fine, Riverside	do.	2700	106	98
EL-167	Rubidoux quartz monzonite, coarse, Riverside	do.	725	29	99
G-15	Cottonwood Springs	do.	190	10	131
G-28	Berdoo Canyon, Little San Bernadino Mountains	do.	385	20	129
X101	Rattlesnake granite	xenotime	1743	80	117
	Mean age				109
	Standard deviation				16

SIERRA NEVADA AND RELATED BATHOLITHS

Ten rock samples from the eastern part of the Sierra Nevada batholith were collected by Paul Bateman, U. S. Geological Survey, from an area near Bishop, Calif. Two rocks yield insufficient amounts of zircon for age measurements. Seven of the rocks contained zircon, one of these contained thorite in addition to the zircon, and one contained monazite alone. In addition, two other samples from the Shasta Bally batholith in the southern Klamath Mountains were collected by J. F. Robertson, three rocks from Yosemite National Park were collected by Dan Tatlock, and two rocks from Inyo County and Kern County were collected by E. M. MacKevett, all of the U. S. Geological Survey.

The mean age determined from the accessory minerals of 15 rocks is 102 million years with a standard deviation of 11 million years (table 9).

The Shasta Bally batholith in the southern Klamath Mountains is unconformably overlain by the Shasta series (Horsetown and Paskenta beds) which contains fossils believed to be of Early Cretaceous age. On this evidence Hinds (1934) concluded that both the Shasta Bally and Sierra Nevada batholiths are probably of Late Jurassic age.

The Sierra Nevada batholith intrudes the Mariposa formation of Late Jurassic age and is overlain by the Chico formation of Late Cretaceous age. The lead-alpha age determinations suggest that the Sierra Nevada batholith is early Late Cretaceous. From the geologic control alone, either of the two ages is possible for the main mass of Sierra Nevada batholith.

Table 9.--Age determinations of 15 granitic rocks from the Sierra Nevada and Klamath Mountains.

Sample no.	Rock type and locality	Mineral	α/mg/hr	Pb (ppm)	Pb/α age (millions of years)
	Bishop area				
PB-1	Mt. Alice quartz monzonite	zircon	618	26	105
PB-2	Tungsten Hills quartz monzonite	do.	796	37	116
PB-3	Lamarck granodiorite	do. thorite	400 4670	15 205	93 88 } 91
PB-4	Tungsten Hills quartz monzonite	zircon	792	35	110
PB-5	Tinemaha granodiorite	do.	331	15, 16 (15.5)	116
PB-6	Round Valley Peak granodiorite	do.	396	12, 13, 14, 16 (14)	88
PB-7	Inconsolable Peak granodiorite	do.	221	10	112
PB-10	McMurry quartz monzonite	monazite	4897	234, 238 (236)	100
	Klamath Mountains, Shasta County				
MD-180-3	Tonalite, Shasta Bally	zircon	276	9	81
MD-180-4	Tonalite, southeast part of French Gulch quadrangle	do.	210	9.5	112
	Yosemite National Park				
53-PB-8	Gateway granodiorite	do.	385	16	103
53 PB-9	El Capitan granite	do.	395	15	94
53 PB-10	Half Dome quartz monzonite	do. thorite	330 10370	15, 16 (15.5) 454	117 88 } 103

Table 9.--Age determinations of 15 granitic rocks from the Sierra Nevada and Klamath Mountains.--Continued.

Sample no.	Rock type and locality	Mineral	α/mg/hr	Pb (ppm)	Pb/α age (millions of years)	
	Kern County					
EMM1	Isabella granodiorite, Kern River.					
	80-200 mesh	zircon	283	9, 10 (9.5)	83	89
	200-400 mesh	do.	320	11, 12 (11.5)	89	
	400 mesh	do.	351	13, 14 (13.5)	96	
	Inyo County					
54 EM-1	Quartz monzonite, Hunter Mountain batholith, southwest corner of Ubehebe quadrangle	do.	145	6	103	
	Mean age				102	
	Standard deviation				9	

IDAHO BATHOLITH

C. P. Ross (1936) proposed a single age for the entire mass of the Idaho batholith, stating "The Idaho batholith is probably younger than Triassic and probably as old as Lower Cretaceous, at least as old as Cretaceous." Ross and Forrester (1947) published a geologic map of Idaho. A. L. Anderson believes that the Idaho batholith was introduced by multiple emplacement. He (1952, p. 255) states, "The older rocks of the batholith resemble and are tentatively correlated with the granitic rocks of Oregon and Washington which were emplaced at the close of the Sierra Nevada orogeny hence near the end of Jurassic time. The younger rocks appear to be associated with Laramide structures and are believed to be a product of the Laramide orogeny of Late Cretaceous time."

We conclude that the Idaho batholith is early Late Cretaceous in age and that it was intruded in a short time, not over a few million years. Within the general area of the Idaho batholith are bodies of igneous rock that are much younger--probably Laramide in age and about the equivalent of the Boulder batholith. A large mass of this type of granodiorite occupies the drainage of Lost Horse Canyon in Montana at least to the Continental Divide (Larsen and Schmidt, in press).

One aberrant result was obtained on a biotite microantiperthite syenite (L53/377) from a contaminated border facies of the batholith in the Big Creek quadrangle. According to B. F. Leonard (written communication, 1956, U. S. Geological Survey), the rock contains sporadic amphibolite inclusions and two sizes and colors of zircon. An anomalous age of 460 million years may be the result of contamination.

The rocks for which measurements for age were made are listed in table 10. If the ages determined on placer monazite are omitted, the mean age for 16 rocks of the Idaho batholith is 108 ± 12 million years. A similar lead-alpha age, 102 million years, was obtained on zircon from the Bald Mountain batholith from Baker County, Oreg.

COAST RANGE BATHOLITH

Northwest of the Idaho batholith extending nearly across the State of Washington are other intrusives which extend for a hundred miles south into Washington and northward for 550 miles into Canada and in smaller bodies for 600 miles farther into Alaska to the St. Elias Range. Phemister (1945) states that this is probably the largest batholith in the world. It underlies an area of about 90,000 square miles. The southern parts of the mass are given separate names, but they form essentially a single unit.

In southern British Columbia, Smith and Stevenson (1955) point out that in the western part of the Coast Range, the earliest intrusives are gabbroic and of Late Jurassic age, and those on the east side of the batholith are more siliceous and younger than Early Cretaceous in age. This same general pattern, regarding the distribution of rock types with time, was first noted by Lindgren (1915) when he postulated the batholithic intrusions began near the end of the Jurassic and were nearly continuous almost until the end of the Tertiary.

We agree with these authors regarding the progressive eastward emplacement of the intrusives in the order of increasing silica content, but believe that the time elapsed between the emplacement of the extreme rock types is probably only a few million years. This was followed after

Table 10.--Age determinations of 16 granitic rocks from the Idaho batholith.

Sample no.	Rock type and locality	Mineral	α/mg/hr	Pb (ppm)	Pb/α age (millions of years)	
L-217	Tonalite, Bungalow	zircon	225	9, 10 (9.5)	105	
CPR117	Tonalite, south of Hardy, Croesus mine	do.	173	8.0, 8.0 (8.0)	115	
CPR118	Tonalite, south of Hailey	do.	120	5.0, 6.0 (5.5)	114	
CPR119	Tonalite, 1 mile south of Diana School. 200-400 mesh 100-200 mesh	 do. do.	 116 100	 4.0, 5.0 (4.5) 3.0, 4.0, 4.0 (3.7)	 96 92	94
L-81	Tonalite, South Fork Payette River	do.	370	16	107	
L-113	Tonalite, Boise Basin, below Stanley	do. thorite	825 1375	30 70	90 102	96
L-288	Tonalite, Atlanta	zircon	700	38	135	
G-200	Tonalite, South Fork Payette River	do.	190	10	131	
L-110	Granodiorite, below Stanley	do.	1000	38	94	
L-70	Granodiorite, below Cascade	do.	210	9	107	
L-207	Quartz monzonite, Indian Grave, near Powell	do.	922	37	100	
L53-573A	Quartz monzonite, northwest Ninth Big Creek quadrangle	do. monazite	340 2726	13, 15 (14) 144, 148 (146)	102 112	107
HCD-63	Quartz monzonite, Coeur d'Alene district, Gem stock	zircon	292	11	94	
HCD-62	Quartz monzonite, Coeur d'Alene district, Gem stock	zircon and thorite	1739	100	116	

Table 10.--Age determinations of 16 granitic rocks from the Idaho batholith.--Continued.

Sample no.	Rock type and locality	Mineral	α/mg/hr	Pb (ppm)	Pb/α age (millions of years)
G-199	Muscovite quartz monzonite, Silver Creek, north of Garden Valley.	zircon xenotime monazite	1970 6025 5617	90 220 250	114 93 } 100 93
L53-88	Muscovite-biotite granodiorite, Big Creek Ranger Station, Big Creek quadrangle	monazite	2678	145	113
M60	From placer deposits, Idaho City	do.	2983	150	105
L-267	do.	do.	2634	160	127
07	do.	do.	3241	155	100
L-264	do.	do.	2994	150	104
L-269	do.	do.	2888	155	112
	Mean age of granitic rocks from Idaho (omitting placer monazite)				108
	Standard deviation				12

a longer interval of nearly forty million years by the intrusion of the Boulder batholith, the Snoqualamie batholith, the Lost Horse Creek batholiths, and other small scattered intrusives.

Ages have been determined on zircon separated from 16 granitic rocks of the Coast Range batholith from localities in Washington, British Columbia, and Alaska. The mean age of the 16 rocks is 105 ± 13 million years (table 11).

The Alaskan rocks described in greater detail by Matzko, Jaffe, and Waring (1957), are believed to be Late Jurassic or Early Cretaceous on the basis of geologic evidence in southeastern Alaska (Buddington and Chapin, 1929).

AVERAGE AGE

The average age of each of the four batholiths and the intrusives of Mexico are very much alike and are presumed to be of the same age, (table 12). The range of lead-alpha ages of the accessory minerals from the different rock types of the batholiths are given in figure 2.

The batholith of Baja California is essentially continuous with the rocks of the batholith of southern California. Both have an average composition of tonalite, an older rock in the batholith. The average composition of the Sierra Nevada is that of a granodiorite, which is younger than the tonalites in the sequence. The composition of the Idaho batholith averages a quartz monzonite, a younger rock than the southern California batholith, and the average rock type of the Coast Range batholith is much like that of the Sierra Nevada.

Table 11.--Age determinations of 16 granitic rocks of the Coast Range batholiths.

Sample no.	Rock type and locality	Mineral	α/mg/hr	Pb (ppm)	Pb/α age (millions of years)
	Washington				
G-115	Quartz monzonite, near Arden, Chewelah quadrangle	zircon	876	34, 36 (35)	99
G-124	Tonalite, 2 miles east of Tonasket, Osoyoos quadrangle	do.	275	10, 11 (10.5)	95
G-125	Granodiorite, 2 miles south of Anglin, Osoyoos quadrangle	do.	296	10, 12 (11)	92
G-142	Tonalite, 3 miles north of Entiat, Chelan quadrangle	do.	63	2.0, 2.4 (2.2)	87
FC-1	Tonalite, near G-142	do.	74	4	134
G-146	Tonalite, 3 miles southeast of Halford, Sultan quadrangle	do.	62	2.1, 2.5 (2.3)	92
FW-60-55	Tonalite, 3 miles south of Holden, Holden quadrangle	do.	78	3.2, 3.5 (3.3)	107
DFC-107-55	Tonalite, east of Holden schoolhouse, Holden quadrangle	do.	56	2.5, 3.2 (2.8)	124
DFC-106-55	Granodiorite, 1 mile west of Hart Lake, Holden quadrangle	do.	110	5.4, 4.4 (4.9)	111
HC-1	Tonalite, Upper Knap Coulee, Chelan quadrangle	do.	83	4.0, 4.1 (4.1)	121
HC-2	Tonalite, Lower Knap Coulee, Chelan quadrangle	do.	98	4.0, 4.2 (4.1)	104

Table 11.--Age determinations of 16 granitic rocks of the Coast Range batholiths--Continued.

Sample no.	Rock type and locality	Mineral	α/mg/hr	Pb (ppm)	Pb/α age (millions of years)	
	British Columbia					
G-122	Tonalite, 2 miles south of Richter Ranch	zircon	160	7.2, 7.5 (7.3)	114	
REF-1	Granodiorite, Lower Arrow Lake district	do.	310	13, 14 (13.5)	108	
	Southeastern Alaska					
55APR-106	Granodiorite, Taku Inlet, near Turner Lake, west of Juneau	do.	152	5.6, 5.8 (5.7)	93	
55ASN-242	Diorite, Tolstoy Point, northeast part of Craig quadrangle	do.	142	5.8, 6.0 (5.9)	103	
	Mt. Fairplay area, Fortymile district east-central, Alaska					
3881	Leucosyenite, Tanacross quadrangle					
Splits of zircon	Fresh, B, Untreated		1620	68	104	103
	Fresh, B, Acid treated 1/		1134	45	99	
	Fresh, C, Untreated		1930	72	93	
	Fresh, C, Acid treated 1/		1476	63	106	
	Fresh, C, Acid treated 2/		1270	48, 52 (50)	98	
	Metamict, E, Untreated		2600	115	110	
	Metamict, E, Acid treated 1/		1594	72	112	
	Metamict, E, Acid treated 2/		1550	60, 63 (62)	99	
			Mean age		105	
			Standard deviation		13	

1/ Fifteen minutes in 1+1 HNO_3.

2/ Fifteen minutes in concentrated HNO_3.

Table 12.--Comparison of the mean ages of rocks of the batholiths of Mexico and southern California, Sierra Nevada, Idaho, and the Coast Range.

Batholith	Number of rocks	Mean age Pb/α (millions of years)	Standard deviation
Mexico and southern California	35	107	11
Sierra Nevada	15	102	11
Idaho	17	108	12
Coast Range	16	105	13
Mean age of the 4 groups		106	4
Mean age of 83 rocks		107	12

ACCURACY OF THE DATA

At the present time only few data are available to make direct comparisons between the ages of the batholiths as determined by the lead-alpha method and those obtained by the other more precise physical methods.

Herzog and Pinson (1956) report a rubidium-strontium age on lepidolite from the Pala pegmatites of 121 million years, and that an age of 114 million years has been obtained by the same method by L. T. Aldrich and his associates of the Carnegie Institution of Washington. Using the potassium-argon method Baadsgaard, Nier, and Goldich (1957) obtained an age of 100 million years on lepidolite from Pala. The Pala pegmatites are known to be

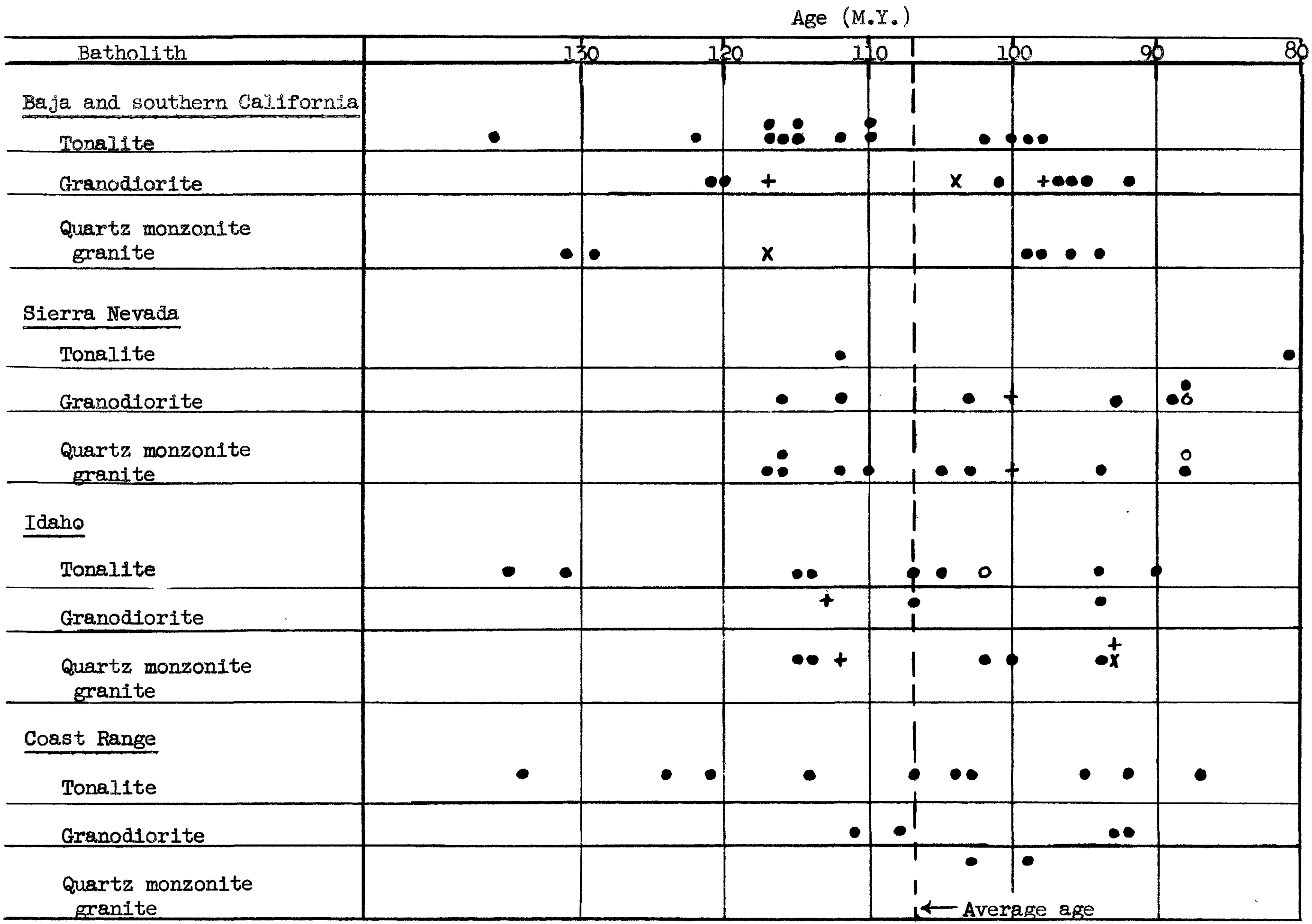

Figure 2. Comparison and range of lead-alpha ages of accessory minerals from different rock types of the batholiths.

related to the rocks of the southern California batholith. Lipson (1956) has applied the potassium-argon method to micas from a series of igneous rocks from the Sierra Nevada and obtained ages of about 90 million years. Preliminary isotopic analyses of monazite separated from the La Grulla granodiorite from Baja California have yielded concordant lead-uranium ages of 115 ± 5 million years (L. T. Silver, California Institute of Technology, personal communication, 1956). A lead-alpha age of 99 million years has been obtained on monazite from the same rock. This rock is related to the series of intrusives whose geologic age has been well established by fossil data as early Late Cretaceous.

Mesozoic time points cited by Holmes (1947) are based on apparent ages obtained by chemical lead, uranium, and thorium analyses. The apparent age of uraninite from the Iiasaka pegmatite of Japan is given as 105 million years. On geologic evidence the pegmatite is believed to be middle Cretaceous in age. An isotopic analysis of the lead in uraninite from the same rock by L. R. Stieff of the U. S. Geological Survey indicates that the amount of common lead present is negligible. It appears that the age of 105 million years for this uraninite is a reasonably accurate age.

The average age of the four major Mesozoic batholiths of western North America as determined by lead-alpha method is 107 million years. Based on our present knowledge of this part of the absolute time scale, the lead-alpha method appears to yield a reasonably accurate age for a related series of rocks when a sufficiently large number of samples have been measured.

CONCLUSIONS

From the data given in the preceding pages, the average age of the batholith of Baja and southern California is 107 million years, the Sierra Nevada batholith, 102 million years, the Idaho batholith, 108 million years, and the Coast Range batholith, 105 million years. The average age of 83 rocks from the four batholiths is 107 million years, and they are believed to be about the same age. The rocks are of about the same type and fit closely to a single variation diagram. All of this indicates that the same type of forces were acting on a huge section of the earth's crust (4,000 miles long) at the same time. This section of the crust may be much greater. The batholiths are not continuous but are en echelon. From south to north the succession is as follows: The Mexican and southern California batholith trends a little west of north to Riverside, Calif. From here northward there is no marked change in the direction of the curve, but there is a break in the continuity of the intrusion for about 100 miles. The Sierra Nevada intrusives continue to the northern part of the state. To the north there is a large offset and the rocks appear far eastward as the Idaho batholith. The Idaho batholith extends to the northern part of the State of Idaho. The next body, the Coast Range batholith, begins 50 miles northwest of the Idaho batholith and extends westward for about 300 miles then turns northwest and extends for 1,000 miles in this direction to the St. Elias Range, Alaska. The division into 4 batholiths is somewhat arbitrary.

Thus, the mountain ranges of southern and Baja California, that of the Sierra Nevada, Idaho, and Coast Range with their extension northward into Alaska were formed at the same time or nearly so.

REFERENCES

Anderson, A. L., 1952, Multiple emplacement of the Idaho batholith: Jour. Geology, v. 60, p. 255-265.

Baadsgaard, H., Nier, A. O. C., and Goldich, S S., 1957, Investigations in A^{40}/K^{40} dating (abs.): Am. Geophys. Union Trans., v. 38, no. 3, p. 385-386.

Böse, E., and Wittich, E., 1913, Informe relativo á la exploración de la región norte de la costa occidental de la Baja California: Mexico Instituto geológica,Parergones, v. 4, p. 307-529.

Buddington, A. F., and Chapin, Theodore, 1929, Geology and mineral deposits of southeastern Alaska: U. S. Geol. Survey Bull. 800, 398 p.

Eardley, A. J., 1954, Tectonic relations of North and South America: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 707-773.

Herzog, L. F., Pinson, W. H., Jr., and staff members, Massachusetts Institute of Technology, Department of Geology and Geophysics, 1956, Rb-Sr analysis and age determination by mass spectrometry and related studies (abs.): Resumenes de los Trabajos Presentados, 20th Congreso Geológico Internacional, p. 217-218.

Hinds, N. E. A., 1934, The Jurassic age of the last granitoid intrusives in the Klamath Mountains and Sierra Nevada, California: Am. Jour. Sci., 5th ser., v. 27, p. 182-192.

Holmes, Arthur, 1947, The construction of a geological time-scale: Geol. Soc. Glasgow Trans., v. 21, pt. 1, (1945-1946), p. 117-152.

Larsen, E. S., Jr., 1945, Time required for the crystallization of the great batholith of southern and Lower California: Am. Jour. Sci., v. 243-A, Daly Volume, p. 339-416.

__________,1948, Batholith and associated rocks of Corona, Elsinore, and San Luis Rey quadrangle, southern California: Geol. Soc. America Mem. 29, 182 p.

Larsen, E. S., Jr., Keevil, N. B., and Harrison, H. C., 1952, Method for determining the age of igneous rocks using the accessory minerals: Geol. Soc. America Bull., v. 63, p. 1045-1052.

Larsen, E. S., Jr., and Schmidt, R. G., in press, A reconnaissance of the Idaho batholith and comparison with the southern California batholith: U. S. Geol. Survey Bull. 1070-A.

Lipson, Joseph, 1956, Potassium-argon dating of sedimentary and igneous rocks (abs.): Geol. Soc. America Bull., v. 67, no. 12, pt. 2, p. 1818.

Lindgren, Waldemar, 1915, The igneous geology of the Cordilleras and its problems, in Problems of American geology: New Haven, Conn., p. 234-286.

Matzko, J. J., Jaffe, H. W., and Waring, C. L., 1957, Lead-alpha age determinations on granitic rocks from Alaska: U. S. Geol. Survey Trace Elements Inv. Rept. 618, 27 p.

Phemister, T. C., 1945, The Coast Range batholith near Vancouver, British Columbia: Geol. Soc. London Quart. Jour., v. 101, pts. 1-2, p. 37-88.

Ross, C. P., 1936, Some features of the Idaho batholith: 16th Internat. Geol. Cong. Rept., v. 1, p. 369-385.

Ross, C. P., and Forrester, J. D., 1947, Geologic map of the State of Idaho: U. S. Geol. Survey; and Idaho Bur. Mines and Geology.

Smith, A. R., and Stevenson, J. S., 1955, Deformation and igneous intrusion in southern British Columbia, Canada: Geol. Soc. America Bull., v. 66, no. 7, p. 811-818.

Waring, C. L., and Worthing, Helen W., 1953, A spectrographic method for determining trace amounts of lead in zircon and other minerals: Am. Mineralogist, v. 38, p. 827-833.

Wisser, Edward, 1954, Geology and ore deposits of Baja California, Mexico: Econ. Geology, v. 49, p. 44-76.

Woodford, A. O., and Harriss, T. F., 1938, Geological reconnaissance across Sierra San Pedro Mártir, Baja California: Geol. Soc. America Bull., v. 49, no. 9, p. 1297-1336.