Lead-Alpha Ages of the Mesozoic Batholiths of Western North America

By ESPER S. LARSEN, Jr., DAVID GOTTFRIED, HOWARD W. JAFFE, *and*
CLAUDE L. WARING

INVESTIGATIONS OF WESTERN BATHOLITHS

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LEAD-ALPHA AGES OF THE MESOZOIC BATHOLITHS OF WESTERN NORTH AMERICA

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ABSTRACT

The ages of some of the rocks from the four great groups of batholiths of western North America—Baja and Southern California, Sierra Nevada, Idaho, and Coast Range—have been determined by the ratio of lead content to alpha activity of the accessory minerals zircon, monazite, thorite, and xenotime. A suite of 10 intrusive rocks from Baja California, Guerrero, and Oaxaca, in Mexico has a mean age of 101±5 million years; the batholith of Baja California has been determined as being of early Late Cretaceous 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 a mean age of 110±13 million years; geologic evidence indicates that this batholith is early Late Cretaceous in age. Age determinations on 15 rocks from the Sierra Nevada batholith give a mean 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 batholith including the batholiths of Washington, British Columbia, and Alaska, average 105±13 million years; these batholiths are believed to be equivalent in age to the Sierra Nevada batholith.

The ages of the four groups of rocks are the same—about 106±12 million years; they are all believed to be early Late Cretaceous. The time required for emplacement of the entire batholithic system is believed to be only a few million years. The batholiths make a discontinuous echelon group of intrusive bodies 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 along the west margins of the United States, Canada, and Mexico constitute one of the most dominant geologic features of North America. They extend for a distance of nearly 4,000 miles and underlie an area of approximately 140,000 square miles (fig. 5). The batholiths are not continuous but are in echelon. From south to north the succession is as follows: The batholiths of Mexico and southern California trend a little west of north to Riverside, Calif. From here northward there is no

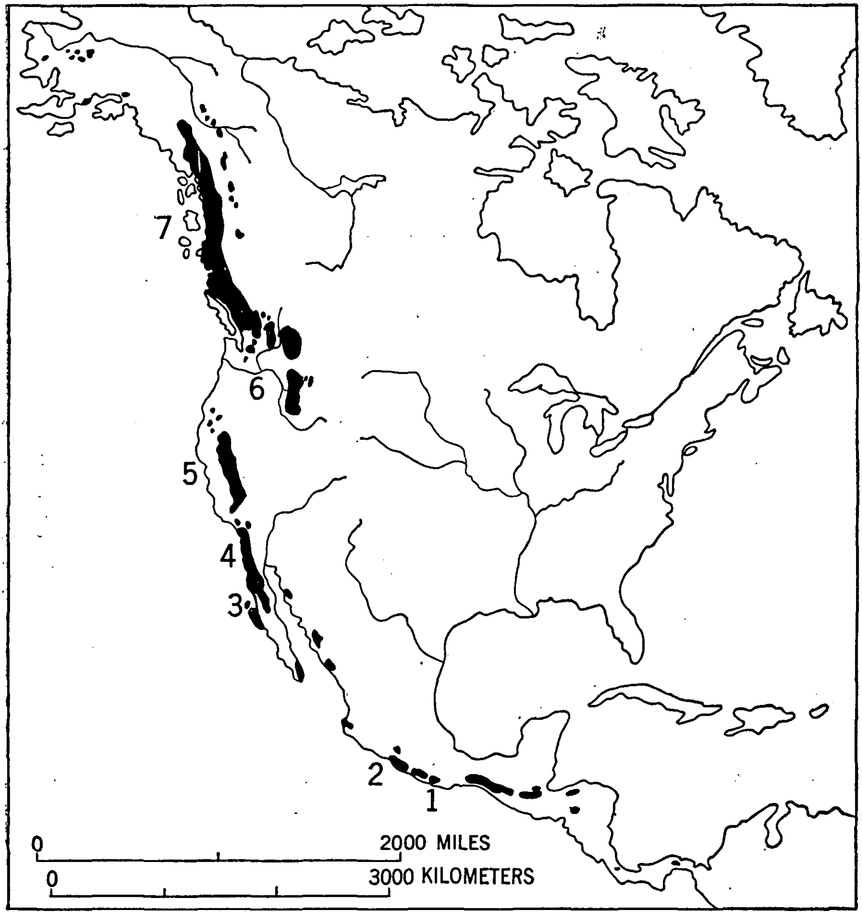

FIGURE 5.—Distribution of Mesozoic batholiths of the western part of North America. (1) Oaxaca, (2) Guerrero, (3) Baja California, (4) southern California, (5) Sierra Nevada, (6) Idaho, and (7) Coast Range. Adapted from "Igneous Rocks and the Depths of the Earth," by R. A. Daly. Copyright, 1933. By permission McGraw-Hill Book Co., Inc.

marked change in the trend, but there is a break in the continuity of the intrusion for about 100 miles. The Sierra Nevada intrusive rocks continue to the northern part of the State. To the north there is a large offset and the rocks appear as far eastward as the Idaho batholith. The Idaho batholith extends to the northern part of the State of Idaho. The next intrusive body, the Coast Range batholith, begins 50 miles northwest of the Idaho batholith and extends westward for about 300 miles, then turns northwestward and extends for 1,000 miles in this direction to the St. Elias Range, Alaska.

The division into four groups of batholiths is somewhat arbitrary. In general, the structural setting and the chemical nature of the rocks are similar. It is possible that the batholiths extend southward along the west coast of South America (Eardley, 1954).

Geologist have considered most or all of these batholithic rocks to be of Mesozoic age. However, in vast areas field relations establish only rather widely separated upper and lower limits for the ages of the batholithic rocks. In the following discussion, geologic evidence regarding age is summarized in relation to the ages we have determined.

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 monzonite and granite. The data presented place some limits on the time required for the crystallization of a batholith and indicate time relations between the major batholiths.

The ± values used throughout this report are the standard deviation.

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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.

METHOD

The method used to determine the age of the rocks of the batholiths considered here is based on lead-alpha 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 measurements ± 5 to 10 percent; the lower limit of sensitivity of tests for lead is 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 alpha counts per milligram per hour, and c is a constant whose limits are 2,632 if all the radioactivity is due to uranium and is 2,013 if all the radioactivity is due to thorium. The constants used in this report are 2,485 for zircon, assuming a thorium to uranium ratio of about 1; 2,085 for monazite, assuming a ratio of 25; and 2,550 for xenotime, assuming a 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, or of uranium or thorium or any of their daughter products after the mineral is formed except within the mineral by nuclear disintegration.

The assumption of Larsen and others (1952) that the lead in zircon is mainly all of radiogenic origin was primarily based on principles of the crystal chemistry of ionic crystals. This approach is based mainly on knowing the ionic radii and charge of the ions to be considered. The Pb^{+2} ion is too large (1.33 A) to fit easily into the Zr^{+4} positions (0.87 A). On the other hand, the ionic radii of K^{+1} (1.33 A) and Pb^{+2} (1.33 A) are virtually identical, and it would seem that during crystallization of a magma lead would concentrate in the potassium-bearing minerals, mainly orthoclase and biotite. Analytical data on various rocks (table 1) appear to confirm this.

TABLE 1.—*Lead found in orthoclase, biotite, and igneous rocks from southern California and southwestern Colorado*

Sample	Rock type	Lead (parts per million) in—		
		Orthoclase	Biotite	Igneous rocks
		Southern California		
SLR 229	Norite	--------	70	10
SLR 685	Tonalite	50	--------	20
EL 38–126	Granodiorite	45	--------	10
EL 38–28	-----do	--------	12	9
SLR 2242	-----do	60	--------	--------
SLR 596	-----do	43	--------	12
SLR 135	-----do	--------	27	10
EL 38–265	Granite	45	34	20
EL 38–167	-----do	--------	30	15
		Southwestern Colorado		
----------------	Hinsdale formation	90	--------	25

Evidence that very little primary lead is present in accessory zircon is provided by some of the younger rocks we have studied. Ordinary lavas like those of the San Juan Mountains contain a smaller amount of zircon which is lower in alpha activity and in lead content than is generally found in their coarser grained equivalents. This is probably due to the fact that the volcanic rocks had not crystallized beyond the phenocryst stage and the zircon crystallization had not been completed. However, the intrusive rocks 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 and lead content of the zircon. The lead-alpha ages for zircon of the San Juan lavas and of associated intrusive rocks are quite consistent and indicate that they contain very little primary lead, generally less than 2 parts per million (table 2). The exact age of some of these rocks is not known. The Hinsdale formation is probably of Pliocene age; 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.

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 calculated ages of rocks of a given province that contain zircon with low alpha activity and lead content are in agreement with those obtained on zircon with a higher alpha activity and containing larger amounts of lead.

Monazite, xenotime, and thorite seem to be as satisfactory as zircon for age measurements. They have a higher alpha activity and contain greater amounts of lead and, hence, are especially suitable for age determinations of 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.

Zircon is present in nearly all igneous rocks, though in gabbro and in some granite it is very small in amount. Gabbro commonly contains a few parts per million of zircon, which has a very low alpha activity. Zircon is relatively abundant in tonalite, averaging about 100 to 200 parts per million, and is present in about the same amount in granodiorite. The amount of zircon in quartz monzonite is variable but generally small. In general, zircon from the more siliceous

TABLE 2.—*Alpha activity, lead, calculated age, excess or deficiency of lead for calculated age of zircon from some intrusive and volcanic rocks of the San Juan Mountains, Colo.*

Sample	Rock type and locality	α per mg per hr	Pb (ppm)[1]	Age (millions of years)		Excess or deficiency of Pb (ppm)	Remarks
				Pb/α	Estimated geologic age		
			Volcanic rocks				
Z40	Hinsdale formation	400	2.5	15	3±	+2. 0	
Z8	Piedra rhyolite	730	7	24	16±	+2. 3	
Z43	Treasure Mountain rhyolite	111	1	22	20±	. 0	
			Intrusive rocks				
GL–3	Quartz latite dike near Creede (Fisher formation).	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±	–. 9	
GL–6	Quartz latite, Baughman Creek, Creede quadrangle.	56	0.4	17	20±	–. 1	
GL–7	Quartz latite, east slope Jackson Mountain, Summitville quadrangle.	215	1.2, 1.3 (1.25)	14	20±	–. 5	
GL–8	Quartz latite, east of Square Top Mountain, Summitville quadrangle.	188	0.7, 0.8 (0.75)	10	20±	–. 8	Zircon, 80–200 mesh.
8F	Quartz latite, east of Square Top Mountain, Summitville quadrangle.	232	1.0, 1.1 (1.05)	11	20±	–. 8	Zircon, 200–400 mesh.
SC1045	Granite porphyry dike, intruding Alboroto, Alpine Gulch, San Cristobal quadrangle.	600	5.5	23	18±	+1. 2	

[1] The figures in parentheses are the averages used in deriving the calculated ages.

rocks has greater alpha activity. In the rocks of the batholith of southern California the alpha activity of the zircon from tonalite averages 340 α per mg per hr, in zircon from granodiorite it averages 800 α per mg per hr, and it varies widely in quartz monzonite but averages 1,300 α per mg per hr. Some muscovite granite has less zircon than does ordinary granite, but the zircon generally has high alpha activity.

Monazite and xenotime have been found in a few samples of granite and quartz monzonite, 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 granodiorite. This thorite is isotropic and nonmagnetic and has an index of refraction, *n*, of 1.76±. It is concentrated with the zircon during the laboratory separation of the minerals, and age measurements on mixed samples of thorite and zircon have yielded consistent ages. Treatment with acid dissolves thorite, but fresh zircon is insoluble. Thus an age can also be obtained on the concentrate consisting entirely of zircon; such ages are in agreement, within the limits of error of the method, with ages determined on mixed samples.

AGE DETERMINATIONS

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

Batholithic intrusions in Baja California, about 100 miles south of the border, have been considered to have been emplaced in early Late Cretaceous time (Böse and Wittich, 1913; Woodford and Harriss, 1938). 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." The interval marked by the unconformity presumably represents the period of crustal disturbance during which the intrusive bodies were emplaced. Elsewhere in the same region a series of mildly metamorphosed rocks, the Alisitos formation, believed to be the equivalent of the San Telmo formation, contains fossils of Cenomanian and Albian age (late Early to early Late Cretaceous). These rocks are separated by an angular unconformity from the overlying Rosario formation, which is considered to be Maestrichtian (Late Cretaceous) on the evidence of fossils. Again, the period of deformation which accompanied the igneous activity is closely dated between early Late Cretaceous and Late

TABLE 3.—*Age data for rocks with zircon containing 10 ppm or less of lead*

Sample	Location	α per mg per hr	Pb (ppm)	Pbα age (millions of years)	Excess or deficiency of Pb (ppm) [1]	Remarks
Southern California						
G-33	Mount Wilson	143	7	122	+0.9	
S-1	Lakeview	183	10	136	+2.2	
G-3	Mountain Center	194	9	115	+.8	
G-11	El Cajon	149	6	100	−.4	
Z-19	Valverde	170	8	117	+.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	−.4	
EM-1	Ubehebe Peak quadrangle	145	6	103	−.2	
Idaho						
CPR117	Hailey	173	8	115	+0.6	
CPR118	do	120	5.5	114	+.4	
CPR119	Diana School	116	4.5	96	−.2	Zircon, 200-400 mesh.
CPR119	do	100	3.7	92	−.6	Zircon, 80-200 mesh.
G-200	South Fork, Payette River	190	10	131	+1.9	
L-70	Cascade	210	9	107	+.1	

Mexico						
BC-1-5	Baja California	42	1. 9	112	+0. 1	
F-55-52	Guerrero	47	1. 9	100	-. 1	
Washington						
G-142	Near Entiat	63	2. 2	87	-0. 5	
G-146	Near Halford	62	2. 3	92	-. 3	
FW-60-55	3 miles south of Holden	78	3. 3	107	. 0	
HC-1	Upper Knap Coulee, Chelan quadrangle	83	4. 1	121	+. 6	
HC-2	Lower Knap Coulee, Chelan quadrangle	98	4. 1	104	-. 1	
British Columbia						
G-122	Near Richter Ranch	160	7. 3	114	+0. 5	
Alaska						
55 APR-106	Near Juneau	152	5. 7	93	-0. 8	
55 ASN-242	do	142	5. 9	103	-. 1	

[1] For estimated age of 106 million years.

TABLE 4.—*Comparison of ages determined on two or more minerals from the same rock or from related rocks*

Sample	Rock type and locality	Mineral	α per mg per 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 Mountain granodiorite	Xenotime	6, 400	250	104
		Zircon	1, 235	50	101
S-6	Woodson Mountain granodiorite	Monazite	6, 430	360	117
		Zircon	1, 180	46	97
X-101	Rattlesnake granite (as used by Everhart, 1951)	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

Cretaceous. 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, and Norman Silberling; L. T. Silver, and Charles E. Weaver, for the purpose of obtaining samples of the intrusive rocks 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 west edge of the San Jose pluton, about 2 miles east of Buena Vista. About 1 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 (except for *Hemiaster*, which was identified by C. W. Cooke) were examined by John B. Reeside, Jr. (written communication, 1956). A list of the fossils and his report are as follows:

Hemiaster sp.
Astarte sp.
Plicatula sp.
Cardium? sp.
Venerid? fragment
Tectus? sp.
Anchura (*Perissoptera*?) sp.
Metacerithium sp.
Douvilleiceras very close to *D. mammillatum* (Schlotheim)
Burckhardites? sp.

> 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. Samples of these rocks have been collected by Carl Fries, Jr., and B. N. Webber, and by Z. de Cserna, who also supplied information concerning their geologic setting. Two samples from Huilotopec and Jalapa, Oaxaca, are of rocks known to intrude probable lower Paleozoic metamorphosed sedimentary rocks, but their relation with rocks of known age has not been established.

In Guerrero, granite (sample F–56–19) near El Ocotito intrudes dolomite of Albian age (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.

Our lead-alpha age data for the rocks from Mexico are given in table 5. They are the same within the limits of error of the measurements. The mean age of 10 samples of rocks is 101 ± 5 million years.

TABLE 5.—*Age of 10 samples of granitic rocks from Mexico*

Sample	Rock type and locality	Mineral	α per mg per hr	Pb (ppm)[1]	Pb/α age (millions of years)
		Baja California			
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
		Oaxaca			
CF-1	Quartz diorite, Isthmus of Tehuantepec area, Huilotepec.	Zircon	310	12	96
JAL-1	Granitic, 4 miles southeast of Jalapa (near CF-1).	do	104	4.0, 5.0 (4.5)	108
		Guerrero			
F-56-19	Granitic, El Ocotito	Zircon	273	10, 11 (10.5)	96
F-56-20	Granitic, Xaltianguis.	do	650	25, 26 (25.5)	97
F-56-21	Granitic, near Apapulco.	do	572	22, 23 (22.5)	98
F-55-52	Granitic, Placeres	do	47	1.8, 2.0 (1.9)	100
Mean age of the 10 samples.					101
Standard deviation.					5

[1] The figures in parentheses are the averages used in deriving the calculated ages.

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 during the Triassic, deposition of volcanic rocks and associated sediments of possible Jurassic age, 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). The batholithic rocks are thus certainly younger than the Triassic rocks and older than the Upper Cretaceous sediments. On the basis of regional evidence Larsen (1948) considered them to be early Late Cretaceous.

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. The mean age determined on tonalite is 114 ± 10 million years (table 6); granodiorite, 105 ± 12 million years (table 7); and quartz monzonite and granite, 109 ± 16 million years (table 8).

Within limits of error of the determinations, these ages are nearly identical. The method does not have sufficient precision to distinguish the individual intrusions of the batholith. However, the data do indicate that the entire episode of emplacement was short—perhaps not more than a few million years. Larsen (1945) previously estimated that the time required for crystallization of the batholith is on the order of a few million years.

TABLE 6.—*Age determinations of zircon in 11 samples of tonalite from southern California*

Sample	Locality	α per mg per hr	Pb (ppm)	Pb/α age (millions of years)
G–33	Crest of Mount Wilson	143	7	122
EL–134	3½ miles northwest of Perris	752	35	116
G–13	Near La Posta Ranch	594	28	117
G–30	3 miles west of Palm Springs	317	14	110
S–1	2 miles east of Nuevo	183	10	136
G–10	1 mile east of Aguanga	280	11	98
G–3	Southwest of Mountain Center	194	9	115
G–11	Near El Cajon	149	6	100
SLR–138	Green Valley	340	15	110
Z–19	Valverde tunnel	170	8	117
Z–7	Lakeview	646	30	115
Mean age				114
Standard deviation.				10

TABLE 7.—*Age determinations of seven samples of granodiorite from southern California*

Sample	Locality	Mineral	α per mg per hr	Pb (ppm) [1]	Pb/α age (millions of years)
Z–16	Woodson Mountain grandiorite, north of Descanso.	Zircon Xenotime	1, 235 6, 400	50 260	101 104 } 103
Z–20	Woodson Mountain granodiorite, Descanso.	Zircon	786	29	92
Z–17	Mount Hole granodiorite, east of Mount Hole.	do	1, 204	46	95
S–6	Woodson Mountain granodiorite, BM3772, northeast of Descanso.	do Monazite	1, 180 6, 430	46 360	97 117 } 107
S–2	Woodson Mountain granodiorite 1 mile south of Temecula.	Zircon	433	20, 22 (21)	121
G–32A	Woodson Mountain granodiorite Morrell trail west of Elsinore.	do	457	22	120
G–48	Stonewall Mountain	do	545	21	96
Mean age					105
Standard deviation.					12

[1] The figure in parenthesis is the average used in deriving the calculated ages.

The rocks for which age determinations were made are from widely separated places—Riverside, Calif., at the northern part of the batholith, scattered masses of granite in the Mojave desert east of the main body 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 mean age for the 25 samples of rock from the batholith is 110±13 million years.

SIERRA NEVADA AND RELATED BATHOLITHS

The Sierra Nevada batholith intrudes the Mariposa formation of Late Jurassic age and is overlain by the Chico formation of Late Cretaceous age. The Shasta Bally batholith in the southern Klamath Mountains has been considered to be contemporaneous with the main mass of the Sierra Nevada batholith (Hinds, 1934). The Shasta Bally is unconformably overlain by the Shasta series (Horsetown and Paskenta formations) which contain fossils believed to be of Early Cretaceous age. Hinds (1934) concluded that both the Shasta Bally and Sierra Nevada batholiths are probably of Late Jurassic age.

TABLE 8.—*Age determinations of seven samples of quartz monzonite and granite from southern California*

Sample	Locality	Mineral	α per mg per hr	Pb (ppm)	Pb/α age (millions of years)
G-21	North Providence Mountains.	Zircon	610	23	94
G-24M	Soda Lake Mountains.	do	4, 660	180	96
Z-15	Quartz monzonite of Rubidoux Mountain, fine, Riverside.	do	2, 700	106	98
EL-167	Quartz monzonite of Rubidoux Mountain, 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 (as used by Everhart, 1951).	Xenotime	1, 743	80	117
Mean age					109
Standard deviation.					16

Ten rock samples from the eastern part of the Sierra Nevada batholith were collected by Paul Bateman from an area near Bishop, Calif. Two samples yielded insufficient amounts of zircon for age measurements, 7 contained zircon and 1 of these contained thorite in addition to the zircon, and 1 contained monazite alone. In addition, 2 other samples from the Shasta Bally batholith in the southern Klamath Mountains were collected by J. F. Robertson, 3 from Yosemite National Park were collected by Dan Tatlock, and 2 from Inyo County and Kern County were collected by E. M. MacKevett. The mean age of the 15 samples of rocks is 102 million years, with a standard deviation of 11 million years (table 9).

IDAHO BATHOLITH

C. P. Ross (1936) proposed a single age for the entire mass of the Idaho batholith, stating that "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) show the distribution of the batholithic rocks on a geologic map of Idaho. A. L. Anderson believes that the Idaho batholith was introduced by multiple emplacement. He states (1952, p. 255), "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 close to the age of the Boulder batholith. A large mass of this type of granodiorite occupies the drainage system of Lost Horse Canyon in Montana and extends at least to the Continental Divide; lead-alpha ages of these rocks average about 60 million years (Larsen and Schmidt, 1958).

The rocks for which measurements of age were made are listed in table 10. If the ages of placer monazite are omitted, the mean age of 16 samples of granitic 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 in Baker County, Oreg. We consider this rock mass to be related to the same batholitic episode.

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), 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 magmatic contamination at depth.

COAST RANGE BATHOLITH

Northwest of the Idaho batholith and extending nearly across the State of Washington are other intrusive bodies which extend for a hundred miles southward into Washington, 550 miles northward into Canada, and, in smaller bodies, for 600 miles 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 principally a single unit.

Smith and Stevenson (1955) point out that in southern British Columbia, in the western part of the Coast Range, the earliest intrusive rocks are gabbroic and of Late Jurassic age, and that 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 that the batholithic intrusions began

TABLE 9.—*Age determinations of 15 samples of granitic rocks from the Sierra Nevada, and Klamath Mountains*

Sample	Rock type and locality	Mineral	α per mg per hr	Pb (ppm)[1]	Pb/α age (millions of years)	Remarks
Bishop area						
PB-1	Quartz monzonite	Zircon	618	26	105	
2	do	do	796	37	116	
3	Granodiorite	do	400	15	93} 91	
		Thorite	4, 670	205	88}	
4	Quartz monzonite	Zircon	792	35	110	
5	Granodiorite	do	331	15, 16 (15.5)	116	
6	do	do	396	12, 13, 14, 16 (13.8)	88	
7	do	do	221	10	112	
10	Quartz monzonite	Monazite	4, 897	234, 238 (236)	100	
Klamath Mountains, Shasta County						
MD-180-3	Tonalite, Shasta Bally	Zircon	276	9	81	
4	Tonalite, southeast part of French Gulch quadrangle.	do	210	9.5	112	
Yosemite National Park						
53 PB-8	Granodiorite	Zircon	385	16	103	
9	El Capitan granite	do	395	15	94	
10	Half Dome quartz monzonite	do	330	15, 16 (15.5)	117} 103	
		Thorite	10, 370	454	88}	

Kern County

EMM1	Granodiorite, Kern River	Zircon	283	9, 10 (9.5)	83	89	Zircon 80–200 mesh
		do	320	11, 12 (11.5)	89		Zircon 200–400 mesh
		do	351	13, 14 (13.5)	96		Zircon 400 mesh

Inyo County

54 EM–1	Quartz monzonite, Hunter Mountain batholith, southwest corner of Ubehebe quadrangle.	Zircon	145	6	103		
Mean age of the 15 samples.					102		
Standard deviation					11		

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[1] The figures in parentheses are the averages used in deriving the calculated ages.

TABLE 10.—*Age determination of 16 samples of granitic rocks from the Idaho batholith*

Sample	Rock type and locality	Mineral	α/mg/hr	Pb (ppm)[1]	Pb/α age (millions of years)	Remarks
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.	do	116 100	4.0, 5.0 (4.5) 3.0, 4.0, 4.0 (3.7)	96 92 } 94	200–400 mesh 100–200 mesh
L–81	Tonalite, South Fork Payette River.	do	370	16	107	
L–113	Tonalite, Boise Basin, below Stanley.	do Thorite	825 1, 375	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	1, 000	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 2, 726	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.	1, 739	100	116	
G–199	Muscovite quartz monzonite, Silver Creek, north of Garden Valley.	Zircon Xenotime Monazite	1, 970 6, 025 5, 617	90 220 250	114 93 } 100 93	
L53–88	Muscovite-biotite granodiorite, Big Creek Ranger Station, Big Creek quadrangle.	Monazite	2, 678	145	113	

M60	From placer deposits, Idaho City.	do	2, 983	150	105	
L-267	do	do	2, 634	160	127	
O7	do	do	3, 241	155	100	
L-264	do	do	2, 994	150	104	
L-269	do	do	2, 888	155	112	
Mean age of granitic rocks (omitting placer monazite).					108	
Standard deviation					12	

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[1] The figures in parentheses are the averages used in deriving the calculated ages.

near the end of the Jurassic and were nearly continuous almost until the end of the Tertiary.

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

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

We agree with Smith and Stevenson regarding progressive eastward emplacement of the intrusive rocks in the order of increasing silica content, but we believe that the time elapsed between the emplace-

TABLE 11.—*Age determinations of zircon in 16 samples of granitic rocks from the Coast Range batholith*

Sample	Rock type and locality	α per mg per hr	Pb (ppm) [1]	Pb/α age (millions of years)
	Washington			
G-115	Quartz monzonite, near Arden, Chewelah quadrangle.	876	34, 36 (35)	99
G-124	Tonalite, 2 miles east of Tonasket, Osoyoos quadrangle.	275	10, 11 (10.5)	95
G-125	Granodiorite, 2 miles south of Anglin, Osoyoos quadrangle.	296	10, 12 (11)	92
G-142	Tonalite, 3 miles north of Entiat, Chelan quadrangle.	63	2.0, 2.4 (2.2)	87
FC-1	Tonalite, near G-142	74	4	134
G-146	Tonalite, 3 miles southeast of Halford, Sultan quadrangle.	62	2.1, 2.5 (2.3)	92
FW-60-55	Tonalite, 3 miles south of Holden, Holden quadrangle.	78	3.2, 3.5 (3.3)	107
DFC-107-55	Tonalite, east of Holden schoolhouse, Holden quadrangle.	56	2.5, 3.2 (2.8)	124
HC-1	Tonalite, Upper Knap Coulee, Chelan quadrangle.	83	4.0, 4.1 (4.1)	121
HC-2	Tonalite, Lower Knap Coulee, Chelan quadrangle.	98	4.0, 4.2 (4.1)	104
DFC-106-55	Granodiorite, 1 mile west of Hart Lake, Holden quadrangle.	110	5.4, 4.4 (4.9)	111

TABLE 11.—*Age determinations of zircon in 16 samples of granitic rocks from the Coast Range batholith*—Continued

Sample	Rock type and locality	α per mg per hr	Pb (ppm) [1]	Pb/α age (millions of years)
	British Columbia			
G–122	Tonalite, 2 miles south of Richter Ranch.	160	7.2, 7.5 (7.3)	114
REF–1	Granodiorite, Lower Arrow Lake district.	310	13, 14 (13.5)	108
	Southeastern Alaska			
55APR–106	Granodiorite, Taku Inlet, near Turner Lake, west of Juneau.	152	5.6, 5.8 (5.7)	93
55ASN–242	Diorite, Tolstoy Point, northeast part of Craig quadrangle.	142	5.8, 6.0 (5.9)	103
	Mount Fairplay area, Fortymile district, east-central Alaska			
3881	Leucosyenite, Tanacross quadrangle, splits of zircon:			
	Fresh, split B:			
	Untreated	1,620	68	104
	Acid treated [2]	1,134	45	99
	Fresh, split C:			
	Untreated	1,930	72	93
	Acid treated [2]	1,476	63	106
	Acid treated [3]	1,270	48, 52 (50)	98
	Metamict, split E:			
	Untreated	2,600	115	110
	Acid treated [2]	1,594	72	112
	Acid treated [3]	1,550	60, 63 (62)	99
Mean age of leucosyenite				103
Mean age of the 16 samples				105
Standard deviation				13

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[1] The figures in parentheses are the averages used in deriving the calculated ages.
[2] 15 minutes in boiling 1 + 1 nitric acid.
[3] 15 minutes in boiling concentrated nitric acid.

ment of the extreme rock types is probably only a few million years. This was followed after an interval of nearly 40 million years by the intrusion of the Boulder batholith (Chapman and others, 1955), the Snoqualmie batholith (Larsen and others, 1952), the Lost Horse Creek batholiths (Larsen and Schmidt, 1958), and other small scattered intrusive bodies.

COMPARISON WITH OTHER AGE DETERMINATIONS

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 of 121 million years for lepidolite from the pegmatites from Pala, 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 pegmatites from Pala are known to be related to the rocks of the southern California batholith for which we report a mean age of 110 million years.

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. We report a mean age of 102 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, written communication, 1956). A lead-alpha age of 99 million years has been obtained by us on monazite from the same rock. This rock is related to the series of intrusive rocks whose geologic age has been well established on the basis of fossils as being early Late Cretaceous.

The ages we have determined are in good agreement with ages determined by isotopic methods.

SIGNIFICANCE OF THE DATA

Our lead-alpha age determinations show that the batholithic rocks considered have nearly identical mean ages: for the batholith of Mexico, and Baja and southern California, 107 million years; for the Sierra Nevada, 102 million years; for the Idaho batholith, 108 million years; and for the Coast Range and its northward extension, 105 million years. These values are virtually the same within the limits of error of the method. The range of ages obtained is shown graphically in figure 6. The mean for the entire suite of batholithic rocks (83 determinations) is 107 million years (table 12). All the batholiths considered are believed to have been emplaced nearly simultaneously, indicating that the same types of forces were acting on a huge section of the earth's crust at the same time; this section of crust is at least 4,000 miles long and may be much longer. The rocks of the different bodies are similar petrographically and chemically.

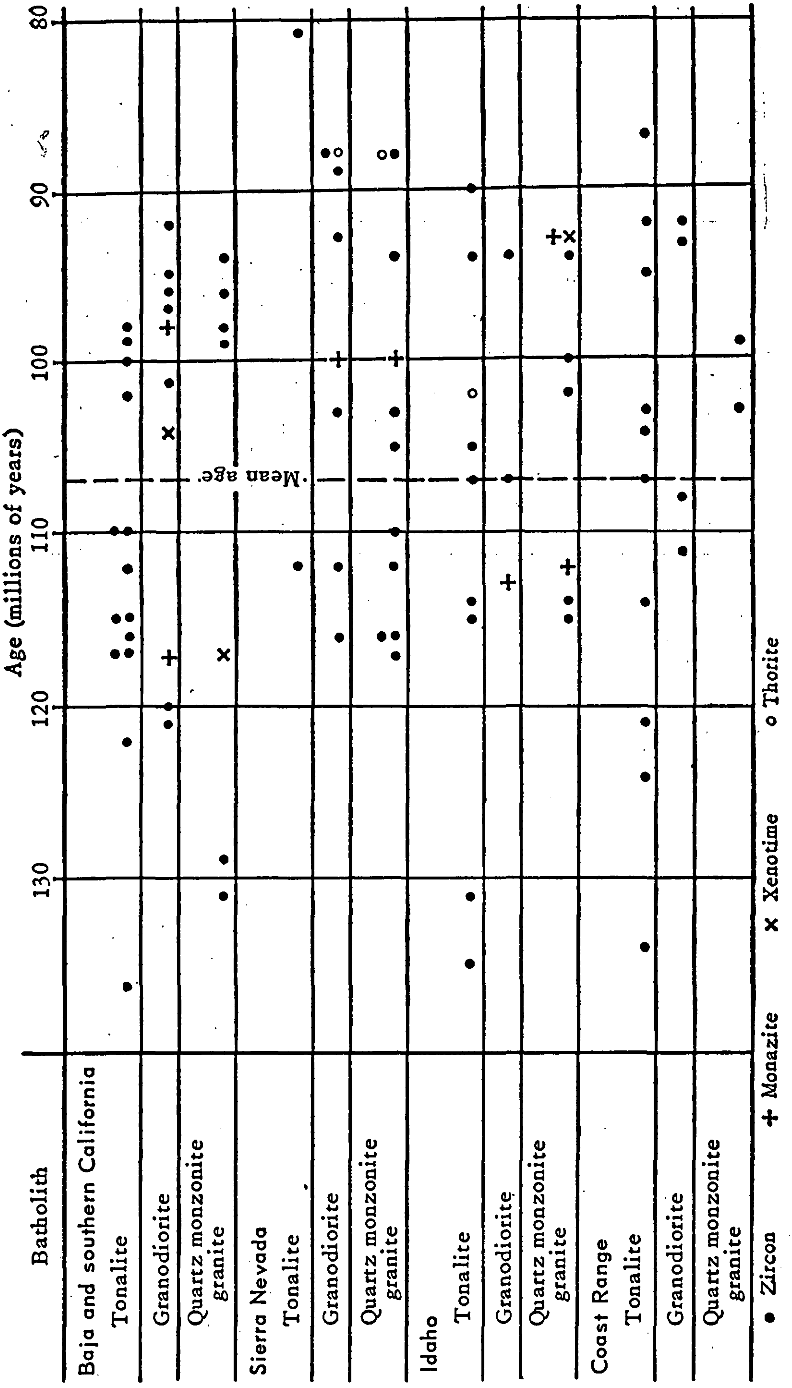

FIGURE 6.—Comparison and range of lead-alpha ages of accessory minerals from different rock types of batholiths.

The dispersion of ages obtained, when considered in the light of the possible errors in measurement, is small, and indicates, we believe, that the entire batholithic emplacement required only a few million years—perhaps less than 10 million.

TABLE 12.—*Comparison of the mean ages of rock samples of the Mexican and southern California, Sierra Nevada, Idaho, and the Coast Range batholiths*

Batholith	Number of samples	Mean Pb/α age (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 four groups of batholiths		106	4
Mean age of 83 rock samples		107	12

The geologic age equivalent to 107 million years old can be derived from Holmes (1947). Mesozoic time points cited by Holmes 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 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 most reliable geologic age of the rocks discussed in this paper comes from Baja California, where the batholithic rocks intrude sediments of late Early Cretaceous age (Albian) and are overlain by sediments of Late Cretaceous age (Maestrichtian). Thus we believe all of the batholithic rocks are of early Late Cretaceous age. An early Late Cretaceous age for all the batholiths does not agree with the ages assigned by some geologists on the basis of stratigraphic evidence or on the basis of rather speculative long-range correlations. A considerable amount of fieldwork is needed to settle the matter unequivocally.

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 considerable number of samples have been measured.

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: Instituto geológica Mexico 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.

Chapman, R. W., Gottfried, David, and Waring, Claude L., 1955, Age determinations on some rocks from the Boulder batholith and other batholiths of western Montana: Geol. Soc. America Bull., v. 66, p. 607–610.

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

Everhart, D. L., 1951, Geology of the Cuyamaca Peak quadrangle, San Diego County, California: California Dept. Nat. Res., Div. Mines Bull. 159, p. 51–115.

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 quadrangles, 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., 1958, 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., Yale University Press, p. 234–286.

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, no. 1, 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.

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