Age and tectonic implications of Mid-Mesozoic calc-alkalic hornblende-rich mafic plutonic rocks of the eastern Sierra Nevada, California

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AGE AND TECTONIC IMPLICATIONS OF MID-MESOZOIC CALC-ALKALIC HORNBLENDE-RICH MAFIC PLUTONIC ROCKS OF THE EASTERN SIERRA NEVADA, CALIFORNIA

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Calc-alkalic gabbro to diorite bodies of the eastern Sierra Nevada batholith range from discrete intrusive masses to remobilized septa between younger felsic plutons. Radiometric ages and contact relations indicate that many gabbroic bodies were emplaced shortly before emplacement of the Independence dike swarm in the Late Jurassic. At least two compositionally distinct high-alumina basaltic magma types are represented in the Jurassic mafic intrusions. High initial $^{87}Sr/^{86}Sr$ ratios for Jurassic eastern Sierra Nevada mafic plutons indicate a significant radiogenic crustal component in their source, although generally low Rb contents suggest a low degree of assimilation of crustal material. Eastern Sierra mafic intrusions represent the remnants of a Middle to Late Jurassic plutonic arc emplaced in continental crust.

INTRODUCTION

The Late Triassic to Late Cretaceous Sierra Nevada batholith was emplaced straddling a major crustal discontinuity; western plutons were emplaced in accreted arc and oceanic affinity rocks, while felsic granitoids of the eastern Sierra Nevada batholith were emplaced in autochthonous lower Paleozoic miogeoclinal wall rocks and Mesozoic arc volcanic rocks (Tobisch and others, 1986; Saleeby and others, 1990). Initial Sr ratios (Sr_i) for western Sierra plutons are <0.706, and in some cases <0.704, indicating a low continental crustal component in the magmas. Eastern felsic granitoids have Sr_i>0.706, indicating a large component of radiogenic crustal material in the magmas (Kistler, 1990). Small bodies of gabbro to diorite are common in the eastern Sierra Nevada (Moore, 1963; Bateman, 1965), at least some are Late Cretaceous in age (Frost and Mahood, 1987; Frost and Mattinson, 1988). The ages, sources, and magmatic evolution of mafic plutons in the eastern bathotith in areas underlain by Jurassic and Triassic granitoids has remained problematic. New U-Pb ages, contact relations and petrologic similarities between plutons indicate that many mafic intrusions in the eastern Sierra Nevada are Middle to Late Jurassic. Strontium isotope data indicate that the Jurassic mafic intrusions also have a significant radiogenic component, although generally low Rb contents suggest relatively little crustal contamination. Small, remobilized and metamorphosed mafic masses and discontinuous septa between felsic plutons are common throughout the region; their ages remain uncertain.

AGES OF PLUTONISM

Granitoid plutonism in the eastern Sierra Nevada occurred in several pulses: Late Triassic-Early Jurassic (210-201 Ma), Middle-Late Jurassic (167-153 Ma), Early Cretaceous (114-103 Ma), and Late Cretaceous (90-80 Ma) (Stern and others, 1981; Chen and Moore, 1982). The pulses, each made up of at least several plutons, are localized in geographic belts (fig. 1). New U-Pb data from the Tungsten Hills granite are slightly discordant (table 1), but are compatible with ages determined for it elsewhere (Stern and others, 1981; Chen and Moore, 1982).

New U-Pb ages obtained from sparse zircons in the hornblende gabbros and diorites of Tungsten Hills, McMurry Meadows, and Armstrong Canyon (intrusions E, J, K on fig. 1) are between 150 and 154 Ma (tables 1,2). Stern and others (1981) have obtained a 169 Ma U-Pb age on a quartz diorite (Pine Creek mine mafic intrusion, C on fig. 1; P. C. Bateman, written communication, 1987). A 166-168 Ma U-Pb sphene age has been determined for hornblende gabbro at Onion Valley (intrusion N on fig. 1) (Sisson, 1987). The Independence mafic dike swarm is 148 Ma in the eastern Sierra Nevada (Chen and Moore, 1979). Field relations in areas of Late Triassic and Jurassic felsic plutons suggest many of the mafic intrusions are younger than their hosts but older than the Independence dike swarm (fig. 1, table 1).

Mafic intrusions younger than the Independence dike swarm are also widespread, especially in areas underlain by Cretaceous granitoid plutons (fig. 1, table 1) (Tobisch and others, 1986; Frost and Mahood, 1987; Sisson, 1987; Frost and Mattinson, 1988; Saleeby and others, 1990). Many highly deformed, metamorphosed, and remobilized mafic bodies are of uncertain age.

PETROLOGY OF MAFIC PLUTONS

Jurassic mafic intrusions range from olivine-augite-hornblende gabbro to hornblende gabbro to

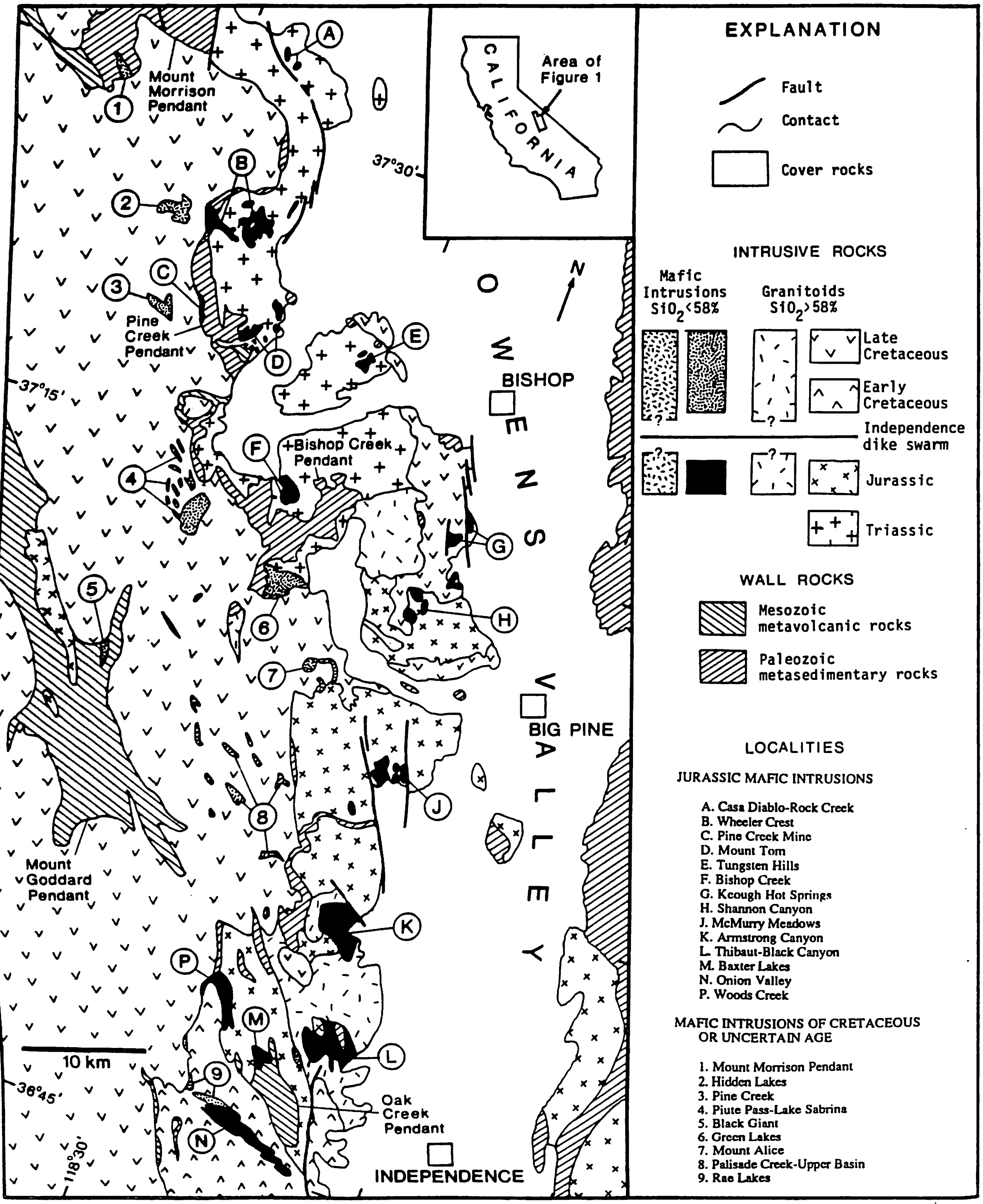

FIGURE I. Generalized geologic map of part of the eastern Sierra Nevada. Known or probable Jurassic mafic intrusions indicated by letters; mafic intrusions of Cretaceous or uncertain age indicated numerically. Sources: Stern and others, 1981; Moore, 1981; Chen and Moore, 1982; Frost and Mahood, 1987; Sisson, 1987, written communication, 1987; Frost and Mattinson, 1988; Bateman, 1987, 1988; Saleeby and others, 1990.

TABLE 1. U-Pb zircon ages, eastern Sierra Nevada mafic plutonic rocks.

Intrusion Code and Sample		U^{238} (ppm)	Pb^{206*} (ppm)	Pb^{208}/Pb^{206} [1]	Pb^{207}/Pb^{206} [1]	Pb^{204}/Pb^{206} [1]	Isotopic ages[2] Pb^{206*}/U^{238}	Pb^{207*}/U^{235}	Pb^{207*}/Pb^{206*}
Mafic intrusions									
E	TH-D	384.3	7.846	0.2363	0.05150	0.0001596	150.3	150.6	155±8
J	McM-D	1397.1	28.64	0.3968	0.05035	0.0000842	150.8	151.0	154±7
K	AC	573.9	12.00	0.2044	0.05297	0.000246	153.8	154.5	165±10
Tungsten Hills Granite									
	THG	1658.0	41.12	0.1031	0.05068	0.0000477	182.0	182.8	194±4

Radiogenic lead. [1]Isotopic ratios corrected for fractionation. [2]Age in 10^6 years. Uncertainty in 206/238 and 207*/235 ages is 1 percent.

biotite-hornblende diorite and quartz diorite. Extreme variability in grain size and texture is conspicuous; some of the textural heterogeneity may be from disruption and metamorphism due to emplacement of later granitoids. Presence of hornblende in all rock units and irregular pods of hornblende pegmatite are present locally and indicate high water contents during crystallization.

Distinctive, discontinuous, near-vertical mineral-graded trough layers (e.g., Bateman, 1965) are common in most Jurassic intrusions. Layers are arcuate, have sharp bases rich in coarse hornblende, and grade in a few centimeters to plagioclase-rich gabbros. The form of the layer truncations suggests flow and scour along steep, inwardly crystallizing magma chamber walls. The McMurry Meadows intrusion locally has near-horizontal mineral-graded cumulus layers 1-10 cm thick. The layering grades laterally and vertically into compositionally similar massive gabro.

A single small body of crosscutting medium- to fine-grained anorthosite is present in the mafic intrusion of Thibaut-Black Canyons (L on fig. 1) (Moore, 1963). Randomly oriented euhedral, zoned plagioclase (average An_{70}) comprises about 95 percent of the rock.

No complete differentiation sequence is present in any intrusion, but most Jurassic mafic intrusions are calc-alkalic (fig. 2) and have major- and trace-element characteristics of arc magmas, including silica enrichment trends, light rare-earth-element enrichment (fig. 3), low contents of high field strength elements (HFSE), and high ratios of large-ion lithophile elements to HFSE (Frost, 1987). Cumulate rocks of the McMurry Meadows intrusion are distinct in that they have constant SiO_2 (47-52%), have high MgO and CaO (8-15% and 15-18%, respectively), and low FeO* and Al_2O_3 (5-9% and 9-15%, respectively). REE are flat in cumulate rocks of the McMurry Meadows intrusion (fig. 3), despite high silica relative to cumulates from other intrusions. The overall patterns are consistent with fractionation of high-alumina basalt magmas dominated by hornblende, olivine, augite, and lesser plagioclase. Flat REE patterns of the McMurry Meadows intrusion indicate that the rocks are cumulates; the low heavy-REE also suggests that hornblende was an important fractionating phase. The low heavy-REE content of the anorthosite is consistent with fractionation of amphibole under hydrous conditions from magma similar to the gabbros and diorites the mass intrudes.

FIGURE 2. AFM diagram. Calc-alkalic-tholeiitic boundary added for reference. Intrusions symbols as in table 2 and figure. 1. See text for discussion.

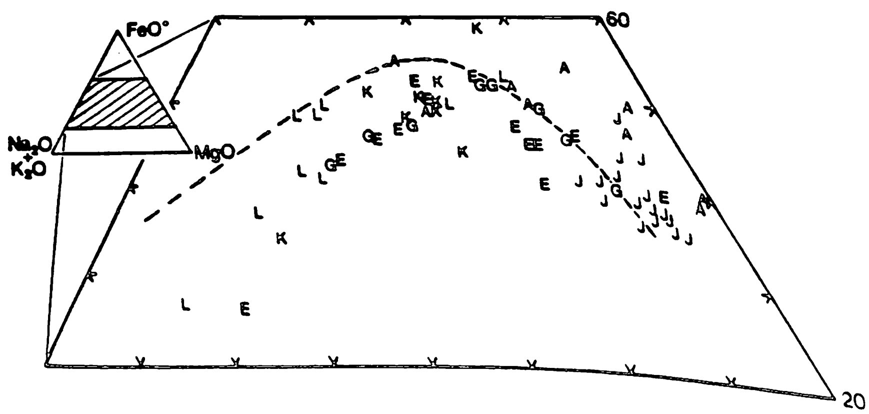

TABLE 2. Age constraints and lithology summary, eastern Sierra Nevada mafic intrusions.

Key to figure 1 and name	Age	Constraints	Lithologies present	References
JURASSIC MAFIC INSTRUSIONS				
A. Casa Diablo-Rock Creek	210-148 (?)Ma	1,4	ol gabbro, two-px-ol. grabbo, cpx-hb gabbro, bio-hd diorite bio-hb qtz diorite	3,4,11,17
B. Wheeler Crest	210-148 Ma	1,4	cpx-hb gabbro, hb gabbro, bio-hb gabbro	1,3,4,17
C. Pine Creek	169 Ma	U-Pb zircon	bio-hb qtz diorite	1,14
D. Mt. Tom	>148 Ma	1,4	hb gabbro, hb diorite, bio-hb qtz diorite	1,3,4,17
E. Tungsten Hills	150 Ma	U-Pb zircon	cpx(hb) gabbro, hb gabbro, hb diorite	1,4,14,17
F. Bishop Creek-Habeggar's	210-148 Ma	1,4	cpx-hb gabbro, hb gabbro, bio-hb gabbro	1,3,4,17
G. Keough Hot Springs	>148 Ma	1	ol-cpx (hb) gabbro, hb gabbro	1,14,17
H. Shannon Canyon	167-148 Ma	1,4	cpx (hb) gabbro, hb gabbro, bio-hb diorite, qtz diorite	1,3,4,17
J. McMurry Meadows	150 Ma	U-Pb zircon	ol-cpx (hb) gabbro, hb gabbro, bio-hb diorite	1,14,17
K. Armstrong Canyon	154 Ma	U-Pb zircon	cpx-hb gabbro, hb gabbro, bio-hb gabbro, qtz diorite	3,4,10,17
L. Thibaut-Black Canyon	165-148 Ma	1,4	cpx-hb gabbro, hb gabbro, bio-hb gabbro, qtz diorite, anorthosite	3,4,10,17
M. Baxter Lakes	165(?)-148 Ma	1,4	cpx-hb gabbro, hb gabbro, hb diorite	3,4,10,17
N. Onion Valley	166-168 Ma	U-Pb sphene	ol-hb ultramafics, cpx-hb gabbro, hb gabbro, hb diorite	15
P. Wood Creek	>148 Ma	1	hb gabbro, hb diorite	3,4,10,17
MAFIC INTRUSIONS OF CRETACEOUS OR UNCERTAIN AGE				
1 Mt. Morrison Pendant	Post-Late Pz	6	Hb diorite	12
2 Hidden Lakes	Late Cretaceous(?)	2(?),3,4	Hb gabbro,bio-hb diorite	1,8,9,12,14
3 Pine Lake	97.5 Ma	U-Pb zircon	Hb diorite - qtz diorite	8,16
4 Piute Pass-Lake Sabrina	Lake Cretaceous	4,5	hb gabbro - mafic grd	1,7,14
5 Black Giant	147-81 Ma (?)	3,6	hb gabbro	2,4,6,13,14,18
6 Green Lake	Late Cretaceous(?)	2(?),5	hb-gabbro - mafic grd	1,7,16
7 Mt. Alice	Late Cretaceous(?)	2(?),4	hb diorite - qtz diorite	1,16
8 Palisade Creek-U. Basin	Late Cretaceous	4,5	hb-gabbro - mafic grd	1,5,6,7,14
9 Rae Lakes	Early Cretaceous(?)	4,5	ol-hb ultramafic, cpx-hb gabbro, hb gabbro and diorite	10,13,15,16,18

Constraint code: 1) older than Independence dikes, 2) younger than Independence dikes, 3) older than surrounding dated granitoids, 4) younger than surrounding granitoids, 5) mutually crosscutting relations and hybridization with surrounding plutons, 6) intrudes metamorphic rocks.

References: 1) Bateman, 1965; 2) Bateman and Moore, 1965; 3) Chen and Moore, 1979; 4) Chen and Moore, 1982; 5) Dodge and Moore, 1968; 6) Evernden and Kistler, 1970; 7) Frost and Mahood, 1987; 8) Frost and Mattinson, 1988; 9) Lockwood and Lyndon, 1975; 10) Moore, 1963; 11) Rinehart and Ross, 1957; 12) Rinehart and Ross, 1964; 13) Tobisch and others, 1986; 14) Stern and others, 1981; 15) Sisson, 1987; 16) Frost, unpub. data; 17) this report.; 18) Saleeby and others, 1990.

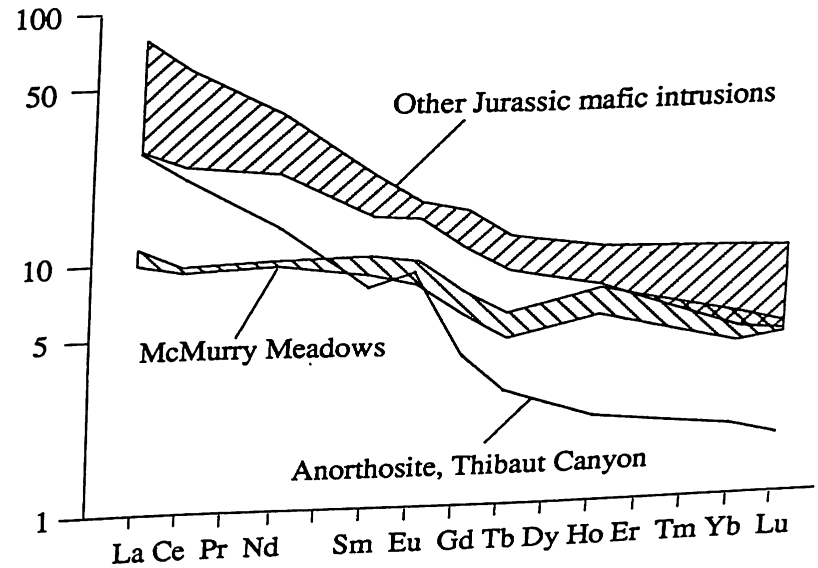

FIGURE 3. Chondrite-normalized REE diagrams. See text for discussion.

Initial $^{87}Sr/^{86}Sr$ (Sr^{i}) ranges from 0.7048-0.7069 (table 3; R.W. Kistler, written communication). The lower ratios for the McMurry Meadows intrusion indicate a lower crustal component compared to other intrusions, which have a radiogenic Sr component similar to those of eastern Sierra Nevada felsic granitoids (Kistler and Peterman, 1973). The high Sri indicates a significant radiogenic crustal component in the mafic magmas. Rubidium content in gabbroic rocks is below 20 ppm, and Rb/Sr ratios are correspondingly low (Frost, 1987), suggesting small amounts of crustal contamination in the magmas. The mafic magmas apparently represent partial melts of evolved subcontinental lithosphere.

TABLE 3. Rb/Sr isotopic analyses, eastern Sierra Nevada mafic plutonic rocks. Intrusions keyed to figure 1.

Sample	Rb	Sr	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Initial $^{87}Sr/^{86}Sr$
Tungsten Hills (intrusion E)						
TH-D	16.3	593	0.0275	0.0795	0.706453	0.7061
Armstrong Canyon (intrusion K)						
AC	164	627	0.2620	0.7570	0.70855	0.7069
McMurry Meadows (intrusion J)						
McM-D	12.7	531	0.0239	0.0692	0.70521	0.7051
PAL 11	5.7	492	0.0116	0.0335	0.70491	0.7048
PAL 12	7	227	0.0308	0.0892	0.70533	0.7051
PAL 13	4.4	299	0.0147	0.0426	0.70489	0.7048

The difference in major- and trace-element chemistry, Sri, and petrography of the McMurry Meadows intrusion indicates it to be the product of a distinct high alumina magma relative to the other Jurassic mafic intrusions of the eastern Sierra Nevada.

REGIONAL IMPLICATIONS

The ages obtained here are younger than for Jurassic granitic rocks of the region (Stern and others, 1981; Chen and Moore, 1982), and are older than the 148 Ma Independence dike swarm (Chen and Moore, 1979). Age data suggest that magmatism ceased following emplacement of the Independence dikes until about 114 Ma in the eastern Sierra (Stern and others, 1981; Chen and Moore, 1979, 1982).

The similar ages of the Independence dike swarm and the Jurassic mafic intrusions invites comparison of their compositions. No significant differences in major-element compositions are evident between noncumulate rocks of the plutons and the dikes (Chen and Moore, 1979). If the two groups are comagmatic, significant changes in the regional stress field must have occurred to account for the differences in style of emplacement.

Mafic plutons similar to those of the eastern Sierra Nevada have not been recognized in the White-Inyo

Mountains, although abundant calc-alkalic granitic plutons (152-180 Ma) are present (Dunne and others, 1978; Stern and others, 1981; Chen and Moore, 1982). Gabbroic to dioritic intrusions of any age are sparse among the Late Cretaceous granitic rocks of the central Sierra Nevada. Ultramafic to dioritic intrusions (174-140 Ma) are abundant in the western Sierra Nevada (Saleeby and Sharp, 1980; Saleeby, 1981; Stern and others, 1981; Chen and Moore, 1982; Snoke and others, 1982). The western Sierra mafic plutonic rocks have mantle values for initial Sr ratios (Snoke and others, 1982).

Western and eastern Sierra Nevada mafic intrusions are broadly calc-alkalic and have similar ranges in rock types, although peridotite and abundant olivine in the gabbroic rocks are more common in the west (Snoke and others, 1982). High water contents and oxygen fugacities in both groups are indicated by the presence of abundant hornblende and magnetite in gabbroic and ultramafic rocks.

Despite the petrologic similarity of eastern and western Sierra mafic intrusions, the nature of the crust in which they were emplaced is strikingly different. Eastern Sierra intrusions were emplaced in well-developed continental crust characterized by Paleozoic miogeoclinal sedimentary rocks (Moore and Foster, 1980) and abundant Triassic through Jurassic felsic granitoids (Stern and others, 1981; Chen and Moore, 1982). Western Sierra mafic plutons were emplaced in crust characterized by ophiolitic remnants, arc-related and other metavolcanic rocks, and deep-water metasedimentary rocks (Saleeby, 1978,1979,1982; Saleeby and Sharp, 1980; Snoke and others, 1982). The differences in the types of crust into which they were emplaced and or the relative proportions of crustal to mantle components in the source is reflected in the higher initial Sr isotopic ratios in the eastern group. Eastern and western Sierra intrusions represent mafic magmas with distinctly different sources and evolution, despite similarities in age.

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