A Strontium Isotopic Study of Plutons and Associated Rocks of the Southern Sierra Nevada and Vicinity, California

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A Strontium Isotopic Study of Plutons and Associated Rocks of the Southern Sierra Nevada and Vicinity, California

By R.W. KISTLER and D.C. ROSS

Rubidium and strontium concentrations and strontium isotopic compositions for granitic rocks of the southern Sierra Nevada and vicinity

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A Strontium Isotopic Study of Plutons and Associated Rocks of the Southern Sierra Nevada and Vicinity, California

By R.W. Kistler *and* D.C. Ross

Abstract

Plutons and associated rocks in the southern Sierra Nevada and vicinity range in age from about 240 to 80 Ma. Triassic plutons form a narrow northwest-trending belt that lies between predominantly Middle Jurassic plutons on the east and Cretaceous plutons on the west. The belt of Triassic plutons is along a boundary between plutons with chemical and isotopic compositions that reflect source materials derived from two different lithospheres called North American and Panthalassan. The two lithospheres are in tectonic contact expressed by sheared plutons of the Middle Jurassic Inyo Mountains intrusive epoch, by sheared plutons in the Triassic belt, and by fault zones exposed in scattered roof pendants of metamorphosed sedimentary rocks of probable Paleozoic age. Late Cretaceous plutons engulf the tectonic contact along much of its length, and in the southern Sierra Nevada constrain the time of shearing to between about 160 and 80 Ma.

Oxygen isotopes are different in plutons with initial $^{87}Sr/^{86}Sr$ (Sr_i) values greater than 0.706 in the two lithosphere types, and they indicate a significantly greater sedimentary component in plutons with source materials in Panthalassan lithosphere than in plutons with source materials in North American lithosphere. In contrast to the North American lithosphere, there is no evidence that a Proterozoic sialic crystalline basement is present in the Panthalassan lithosphere. The plutons with $Sr_i>0.706$ and with source materials in Panthalassan lithosphere probably acquired that isotopic characteristic by assimilation of sediments derived from a Proterozoic sialic crust. Plutons with $Sr_i<0.706$ have chemical and Nd isotopic compositions that indicate time-integrated depletion of large-ion-lithophile elements in the magma source regions in Panthalassan lithosphere relative to the magma source regions in North American lithosphere.

INTRODUCTION

Rubidium and strontium concentrations and $^{87}Sr/^{86}Sr$ values are documented herein for samples of plutons and associated rocks from 238 locations in the southern Sierra Nevada and vicinity. The goals of this investigation were to determine ages of rock units, to aid in the separation of plutons in poorly exposed areas, to determine the pattern of variation of initial $^{87}Sr/^{86}Sr$ (hereafter called Sr_i) for plutons, and to constrain more rigorously the boundaries of the continental Sierran and Salinian-western Mojave terranes defined on the basis of the Sr_i of their plutons by Kistler (1978) and by Kistler and Peterman (1978). These new data expand the boundaries of the Salinian-western Mojave terrane and make it part of the Panthalassan lithosphere that lies west of the tectonic boundary, whereas the Sierran terrane is made part of the North American lithosphere that lies east of the tectonic boundary.

The $Sr_i=0.706$ isopleth (modified from Kistler, 1983) determined for plutons in California and Nevada (fig. 1) was interpreted to approximate the position of the margin of Proterozoic sialic crust in the region (Kistler and Peterman, 1978). This isopleth was also used as a piercing point across faults, like the San Andreas and Garlock, to restore offsets of basement rocks along these structures (Kistler and others, 1973; Kistler and Peterman, 1978). A simplified bedrock map of the southern Sierra Nevada and the El Paso Mountains with numbered locations of samples analyzed for this report is shown in figure 2. Most of these same locations are shown on the more detailed basement map of the southern Sierra Nevada by Ross (1987). The area shown in figure 2 is entirely of Panthalassan lithosphere except for an area of North American lithosphere in the eastern Sierra Nevada intruded predominantly by Jurassic plutons.

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Analytical Methods

Analytical data are given in table 1. Concentrations of Rb and Sr were determined by energy-dispersive X-ray fluorescence using a direct-comparison method on standard samples of similar bulk composition. Uncertainties in Rb/Sr are in the range ±3 percent or less at 2 sigma by this method. All Sr isotopic ratios were normalized to $^{86}Sr/^{88}Sr=0.1194$. The measured $^{87}Sr/^{86}Sr$ values have a coefficient of variation less than 0.01 percent and were obtained from a mass spectrometer that yielded $^{87}Sr/^{86}Sr$ values of 0.70800±3 and 0.71023±3 from replicate analyses of the E and A and NBS 987 $SrCO_3$ standards, respectively. Values of Sr_i for plutons were determined from values of the intercept on the ordinate using York (1969) isochron regressions, by calculation for individual samples of known age, and by calculation for an assumed age of 100 Ma for those units with only one sample and no other age data. The decay constant for Rb is 1.42×10^{-11} yr^{-1}. Pluton names given in table 1 are from Ross (1987).

OBSERVATIONS

Ages of the plutons investigated range from about 240 Ma to about 80 Ma. Triassic plutons (240 to 218 Ma) lie in a narrow northwest-trending belt (fig. 2) that extends from the El Paso Mountains through the Walker Pass area almost to Sherman Peak just north of the map area in the Hockett Peak quadrangle at about long. 118° 22′ W. These plutons are bounded on the east by plutons of Middle Jurassic age (177±5 Ma) collectively called the Sacatar Quartz Diorite of Miller and Webb (1940), by isolated roof pendants of sedimentary rocks that contain bedded barite (Taylor, 1984) similar to the Paleozoic metamorphic rocks of the western Sierra Nevada foothills (Weber, 1963), and by scattered small felsic plutons of Late Cretaceous age. To the west of the belt of Triassic plutons, the bedrock is predominantly plutons of Cretaceous age (120 to 80 Ma) that intruded scattered roof pendants of sedimentary and volcanic rocks of Paleozoic and Mesozoic age called the Kings and Erskine Canyon sequences (Saleeby and Busby-Spera, 1986) and Pampa Schist of Dibblee and Chesterman (1953).

The $Sr_i=0.706$ isopleth extends from the Garlock fault to the north margin of the map area in several northeast- and northwest-trending segments (fig. 2). The 0.706 isopleth is offset about 9 km in a right-lateral sense by the Kern Canyon fault. The Sr_i values less than 0.706 can be contoured. However, these isopleths do not parallel the 0.706 isopleth, and the 0.704 contours intersect the 0.706 contour at a 90° angle. This results in plutonic rocks with Sr_i of 0.70325 and 0.70656 (Nos. 97 and 82, respectively, fig. 2) within 1 km of each other in the west-central part of the map area. The Sr_i values of the Triassic plutons, in the belt trending northwest from the El Paso Mountains to the vicinity of Sherman Peak just north of the map area, are all less than 0.706 and are as low as 0.70362 in the quartz diorite of Walker Pass and the quartz diorite and trondjhemite of the El Paso Mountains. Plutons of this age and isotopic characteristic are found in a narrow belt discontinuosly exposed for 240 km from the Mineral King pendant in the north to near Barstow in the Mojave Desert to the south (fig. 1). The unradiogenic Sr_i values of these plutons are a major anomaly in the region of plutons with $Sr_i>0.706$ in California.

Four samples in a traverse across the map area (Nos. 97, 82, 202, and 206, fig. 2 and table 1) with Sr_i values that range from 0.7032 to 0.7083 were investigated for Sm and Nd concentrations and initial $^{143}Nd/^{144}Nd$ values (DePaolo, 1981). Initial $^{143}Nd/^{144}Nd$ (Nd_i) correlates negatively with Sr_i. The Nd_i (epsilon Nd(T)) for sample 26–73 (No. 206, fig. 2 and table 1) from the quartz diorite of Walker Pass was recalculated to be +2.8 at the emplacement age of 240 Ma given in this report, rather than +0.6 at the 86 Ma K-Ar age for hornblende (Evernden and Kistler, 1970) used by DePaolo (1981).

Oxygen isotopic compositions were determined for many of the same samples for which strontium isotopic data were already obtained (Masi and others, 1976, 1981; Saleeby and others, 1987). In the southern Sierra Nevada, there is a good correlation between strontium and oxygen isotope ratios, but there is a pronounced greater proportion of plutons with high-^{18}O upper-crustal isotopic signatures relative to plutons in other parts of the Sierra Nevada and in the Mojave Desert (fig. 3). The high-^{18}O signature is similar to that of plutons in the northwestern Mojave Desert and the Salinian block to the south and northwest, respectively (Masi and others, 1976, 1981).

Terrane Boundary in the Southern Sierra Nevada

The narrow northwest-trending belt of Triassic plutons marks a boundary between two different terranes, each characterized by distinct metamorphosed sedimentary rocks in roof pendants. The boundary, where not engulfed by Cretaceous plutons, appears to be tectonic and is characterized by sheared and foliated plutons of Triassic and Jurassic age. The east margins of the Triassic plutons and the west margins of the Middle Jurassic plutons are sheared. This same boundary is exposed discontinuously northwestward as fault zones in the Mineral King and Boyden Cave roof pendants and is expressed as the Melones fault zone in the western foothills of the Sierra Nevada (fig. 1). The fault zone in the Mineral King roof pendant contains a mylonitic dacite with Sr_i of 0.7046 and a U/Pb zircon age of 240 Ma (Busby-Spera, 1983), whereas the fault zone in the Boyden Cave roof pendant contains badly deformed Triassic and Jurassic fossils (Moore and Dodge, 1962; Girty, 1985). South of the Garlock fault, the boundary can be followed almost to Barstow in the Mojave Desert as a narrow belt of plutons of Triassic and Jurassic age that have unradiogenic $Sr_i<0.706$ (Kistler and Peterman, 1978; Kistler, unpublished data). The southern part of the boundary from the vicinity of Walker Pass in the southern Sierra Nevada to the vicinity of Barstow in the Mojave Desert is the same as the boundary between two terranes characterized by plutons with $Sr_i > 0.706$ called the Sierran and the Salinian-western Mojave by Kistler and Peterman (1978).

These new data indicate that the Salinian-western Mojave terrane of Kistler and Peterman (1978) extends well into the Sierra Nevada and that wall rocks of plutons with $Sr_i > 0.706$ include the metamorphosed sedimentary and volcanic rocks of early Mesozoic and mid-Cretaceous age called the Kings sequence and the Erskine Canyon sequence, respectively, near Lake Isabella (Saleeby and Busby-Spera, 1986). The expanded terrane is herein called the Salinian-western Mojave-Kings terrane. The Kings sequence was first defined for Upper Triassic and Lower Jurassic sedimentary and volcanic rocks exposed in the Kings River Canyon north of the map area of figure 2 in the Boyden Cave roof pendant (Bateman and Clark, 1974); rocks of similar age and lithology (Christensen, 1963) are also found in the Mineral King roof pendant between the Boyden Cave roof pendant and the map area of figure 2. The region in the Sierra Nevada batholith that contains metamorphosed sedimentary and volcanic rocks of the Kings sequence was called the Kings terrane by Nokleberg (1983). However, the eastern part of the Kings terrane and rocks in roof pendants in the eastern part of the southern Sierra Nevada assigned to the Kings sequence (Saleeby and others, 1978; Nokleberg, 1983) are in the Sierran terrane and are excluded from the combined Salinian-western Mojave-Kings terrane of this report. These metamorphosed sedimentary rocks of roof pendants on the west margin of the Sierran terrane are similar to those found to the north in the western Sierra Nevada foothills (Weber, 1963). These pendants contain bedded barite indicating a protolith of Paleozoic age (Taylor, 1984; Diggles and others, 1985). To the south in the El Paso Mountains and along the west margin of the Sierran terrane into the central Mojave desert near Barstow, other metamorphic rock sequences crop out that are early and late Paleozoic in age and lithologically similar to the western facies rocks of west-central Nevada (Carr and others, 1981).

Other metamorphosed wall rocks of the batholith in the western part of the southern Sierra Nevada are called the Pampa Schist, which consists of sillimanite and andalusite-bearing graphitic pelite interlayered with psammitic schist and local lenses of amphibolitic mafic to intermediate volcaniclastic rocks (Dibblee and Chesterman, 1953). This assemblage strongly resembles lower Mesozoic slaty rocks that lie depositionally above the Paleozoic Kings-Kaweah ophiolite belt about 50 km to the north (Saleeby, 1979). Blocks of quartzite and stratified sequences of quartz-rich turbidites intermixed with the Kings-Kaweah slaty strata suggest that these rocks and the Pampa Schist are a western facies of the Kings sequence (Saleeby and others, 1978). Basement rocks for the Kings sequence are unknown, except for the apparent westward overlap relation with Paleozoic ophiolitic rocks (Saleeby and others, 1978). Plagiogranite dikes that are about 300 Ma in age intruded the Paleozoic Kings-Kaweah ophiolite belt (Saleeby, 1982). Rocks mapped as the Kings sequence in the Tule River roof pendants (Saleeby and others, 1978) east of the Kaweah serpentinite melange (Saleeby, 1979) include 300-Ma volcanic rocks (Kistler and Sawlan, unpub. data, 1986). Other volcanic rocks in the Bean Canyon metamorphosed rocks section south of the Garlock fault and in the Salinian-western Mojave terrane were tentatively dated at about 300 Ma (R. J. Fleck, written commun., 1986) and give further support to a correlation of the metamorphosed sedimentary and volcanic rocks of the Salinian-western Mojave terrane with the Kings sequence.

Isotopic and Chemical Characteristics of Plutons in the Southern Sierra Nevada

The plutons that intruded the Salinian-western Mojave-Kings and Sierran terranes have isotopic and chemical characteristics that indicate different source materials for the magmas of each terrane. The lithospheres that include the Salinian-western Mojave-Kings and Sierran terranes are the Panthalassan and North American lithospheres, respectively.

Plutons, in a northwest-trending belt in the western Sierra Nevada, which are described as strongly contaminated and reduced (Ague and Brimhall, 1987) on the basis of less than 6 mole percent Fe_2O_3 in their contained ilmenite and which lack hornblende and sphene in their mineral assemblages, have source materials in the Panthalassan lithosphere. Their chemical characteristics, unique in the Sierra Nevada, are interpreted to be due to assimilation of highly reducing pelites in the sedimentary rocks of the Kings sequence (Ague and Brimhall, 1987). The strongly contaminated and reduced plutons identified by Ague and Brimhall occur only in the restricted area of the Kings terrane as defined in this report.

The high $\delta^{18}O$ values of plutons with source materials in Panthalassan lithosphere (Masi and others, 1976, 1981; Ross, 1983; Saleeby and others, 1987), consistently greater than +9 per mil in those with $Sr_i > 0.706$ and often greater than +9 per mil in those with $Sr_i < 0.706$, also indicate significant sedimentary components in their parent magmas (fig. 3). In contrast, $\delta^{18}O$ values for all plutons with source materials in the North American lithosphere are less than +9 per mil (fig. 3).

Concentrations of Rb in plutons having $Sr_i < 0.706$ along the northern boundary of the Salinian-western Mojave-Kings terrane and derived from sources in Panthalassan lithosphere were consistently less than the concentrations of Rb in plutons having similar Sr_i values along the margins of the Sierran terrane and derived from sources in North American lithosphere (Kistler and Peterman, 1978). This observation is still valid with the increased data now available. Rb is plotted against Sr for plutons with $Sr_i < 0.706$ that intruded the North American lithosphere in the Walker Lake 1° by 2° quadrangle (Robinson and Kistler, 1986) and intruded the Panthalassan lithosphere in the southern Sierra Nevada and vicinity (fig. 4). Plutons with these $Sr_i < 0.706$ values have, in general, Rb concentrations less than or greater than 100 ppm in the Panthalassan and North American lithospheres, respectively. Also, in samples with $Sr_i < 0.706$, Sm and Nd concentrations are generally lower in plutons with source materials in the Panthalassan lithosphere than in plutons with source materials in North American lithosphere. In addition, the epsilon Nd values of plutons that intruded North American lithosphere are less positive than those for plutons with the same Sr_i (0.704) that intruded Panthalassan lithosphere. These chemical and isotopic characteristics indicate that the magma source for plutons with $Sr_i < 0.706$ is depleted in large-ion-lithophile elements in the Panthalassan lithosphere relative to the North American lithosphere.

Finally, a crustal model that compares near-surface geology with residual gravity, assuming perfect Airy-type isostasy, along a traverse from Visalia to Lone Pine across the southern Sierra Nevada (Oliver and Robbins, 1982) crosses the tectonic boundary between the Panthalassan and North American lithospheres in the Mineral King roof pendant. In the Oliver and Robbins model, the depth to the Moho increases abruptly by 4 km, from about 30 to 34 km, across the subsurface projection of the lithospere boundary . This change indicates that the Panthalassan lithosphere is thinner. Therefore, the two lithospheres differ not only in chemical and isotopic characteristics but also in thickness.

In the southernmost Sierra Nevada, distinctive gneisses are present that represent the deepest exposed levels of the Cretaceous Sierra Nevada batholithic belt (Sharry, 1981; Ross, 1985; Sams, 1986; Saleeby and others, 1987). Thermobarometric estimates of up to 8 kb for mineral equilibration in the gneiss complex and the plutons indicate that mid-crustal levels of the batholith are exposed here. These gneisses are predominantly Early Cretaceous (110–120 Ma) in age, and no direct remnants of Proterozoic sialic basement have been found at this level of the Panthalassan lithosphere (Sams, 1986; Saleeby and others, 1987). In contrast, strontium isotopic systematics of Phanerozoic plutons with $Sr_i > 0.706$ and sources in the North American lithosphere are interpreted to indicate source materials for the plutons that are predominantly Proterozoic lower crust (Kistler and Peterman, 1978; Kistler and others, 1986). In addition, xenoliths entrained in Tertiary volcanic rocks that penetrate the North American lithosphere in the central Sierra Nevada include garnet granulites that represent a direct sample of the Proterozoic lower crust in that area (Domenick and others, 1983).

SUMMARY AND CONCLUSIONS

Three geographically distinct age groups of plutons were classified on the basis of this strontium isotopic study in the southern Sierra Nevada. In the study area, plutons in the eastern part are mostly Middle Jurassic in age (177±5 Ma), whereas plutons in the western part are mostly of Cretaceous age (120 to 80 Ma). A narrow northwest-trending belt of plutons of Triassic age (240 to 218 Ma) lies between the Jurassic and Cretaceous plutons.

The Triassic and Jurassic plutons are in tectonic contact along a shear zone that is engulfed by Late Cretaceous plutons along much of its length. The shear zone is exposed to the north as faults in pre-Jurassic wall rocks in the Mineral King and Boyden Cave roof pendants and as the Melones fault zone along the northwestern foothills of the Sierra Nevada. Distinct chemical, isotopic, and geophysical characteristics of the plutons on either side of this tectonic boundary permit the cryptic trace of the shear to be followed, even where it is destroyed by Cretaceous plutons. The profound differences in the chemical, isotopic, and geophysical characteristics of the plutons are interpreted to reflect magma sources in two different lithospheres called Panthalassan and North American on the west side and the east side of the tectonic boundary, respectively.

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FIGURES 1–4; TABLE 1

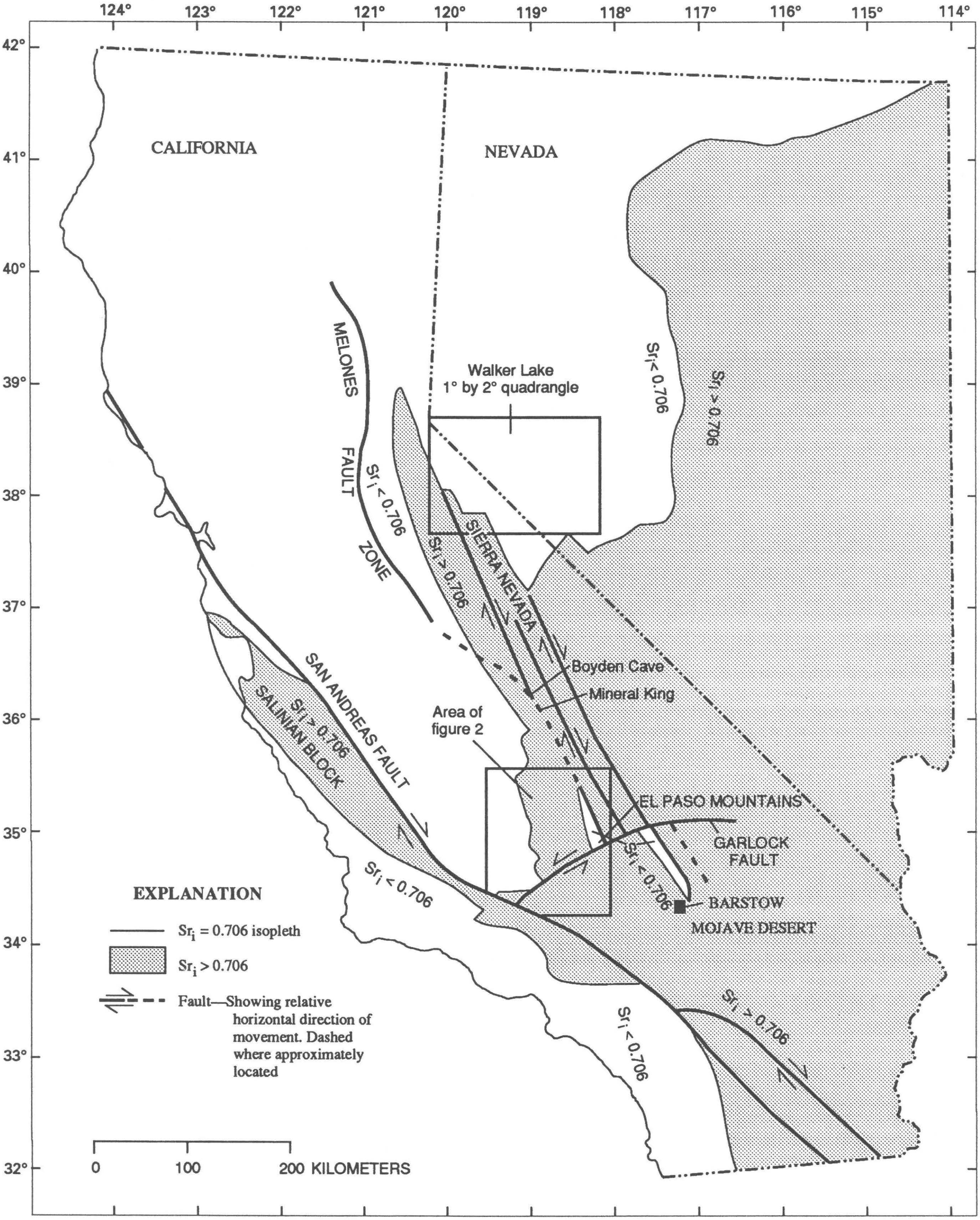

Figure 1. Map of California and Nevada showing the Sr_i=0.706 isopleth determined for Mesozoic and Cenozoic plutons. Shaded area has plutons with Sr_i > 0.706.

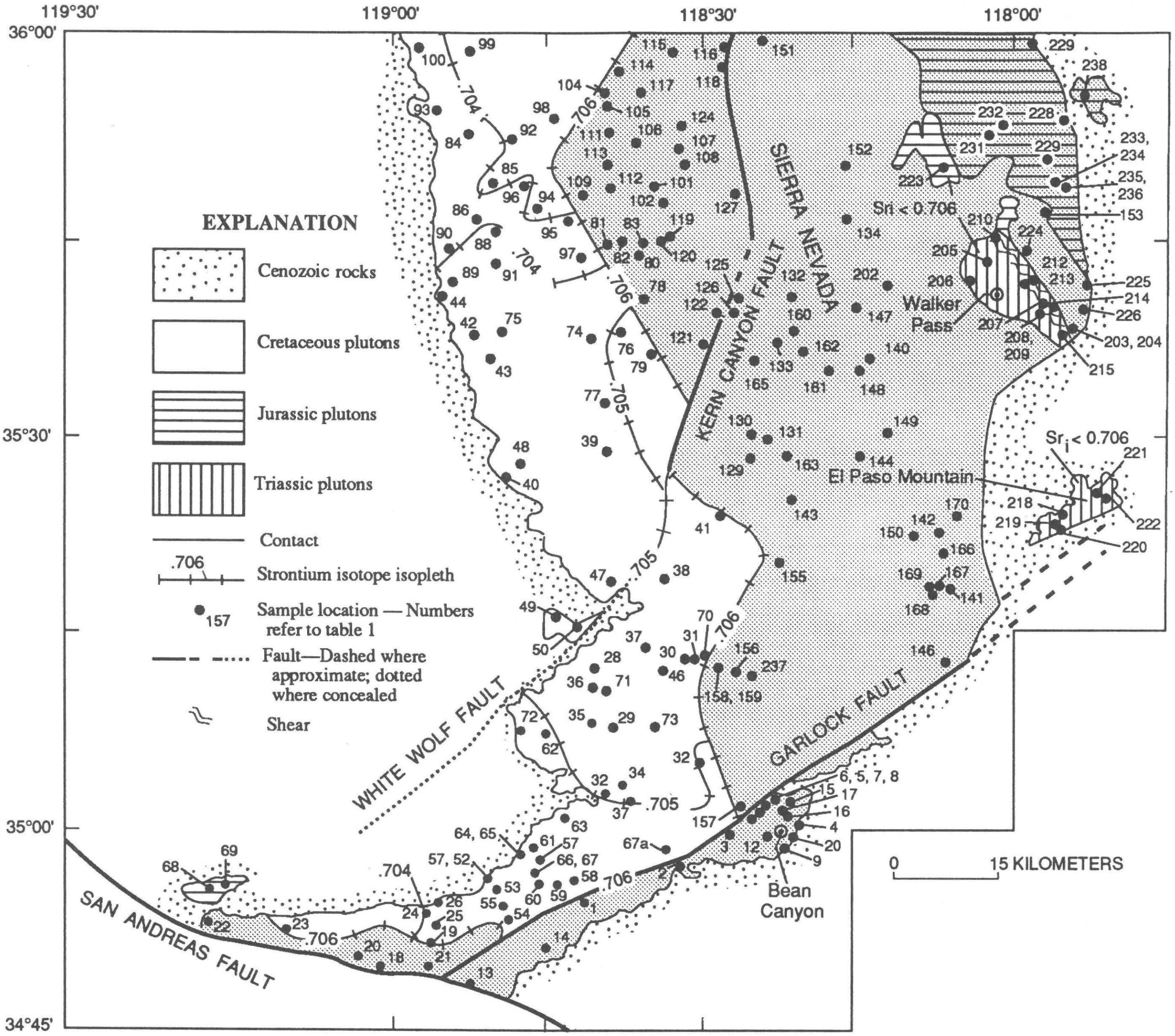

Figure 2. Map of the southern Sierra Nevada and El Paso Mountains showing strontium isotope isopleths and the three age groups of plutons that crop out in the area. Shaded area has plutons with $Sr_i > 0.706$.

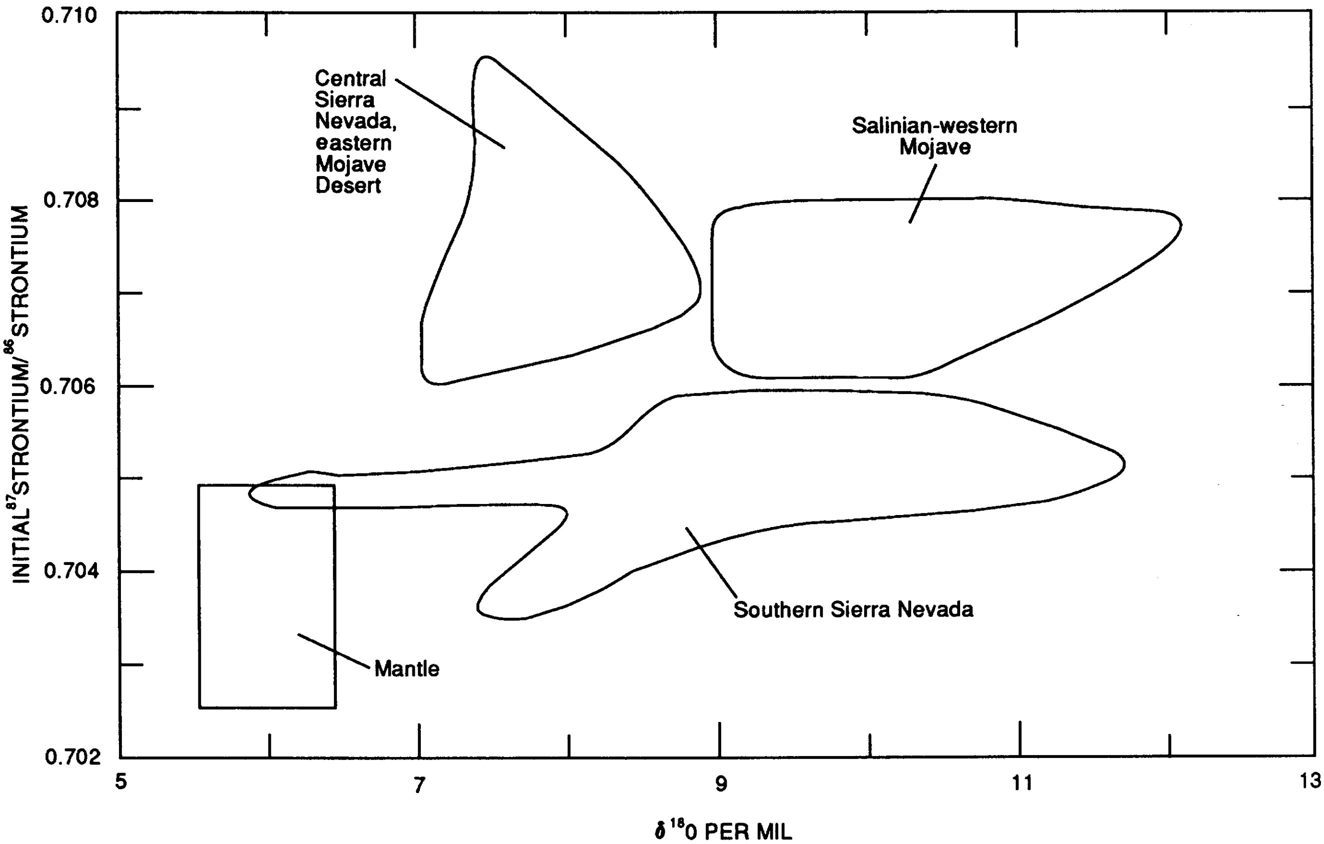

Figure 3. Fields of Sr_i versus $\delta^{18}O$ per mil for plutons in and peripheral to the Salinian-western Mojave terrane (Panthalassan lithosphere) in the southern Sierra Nevada and for plutons in the central Sierra Nevada and eastern Mojave Desert (North American lithosphere).

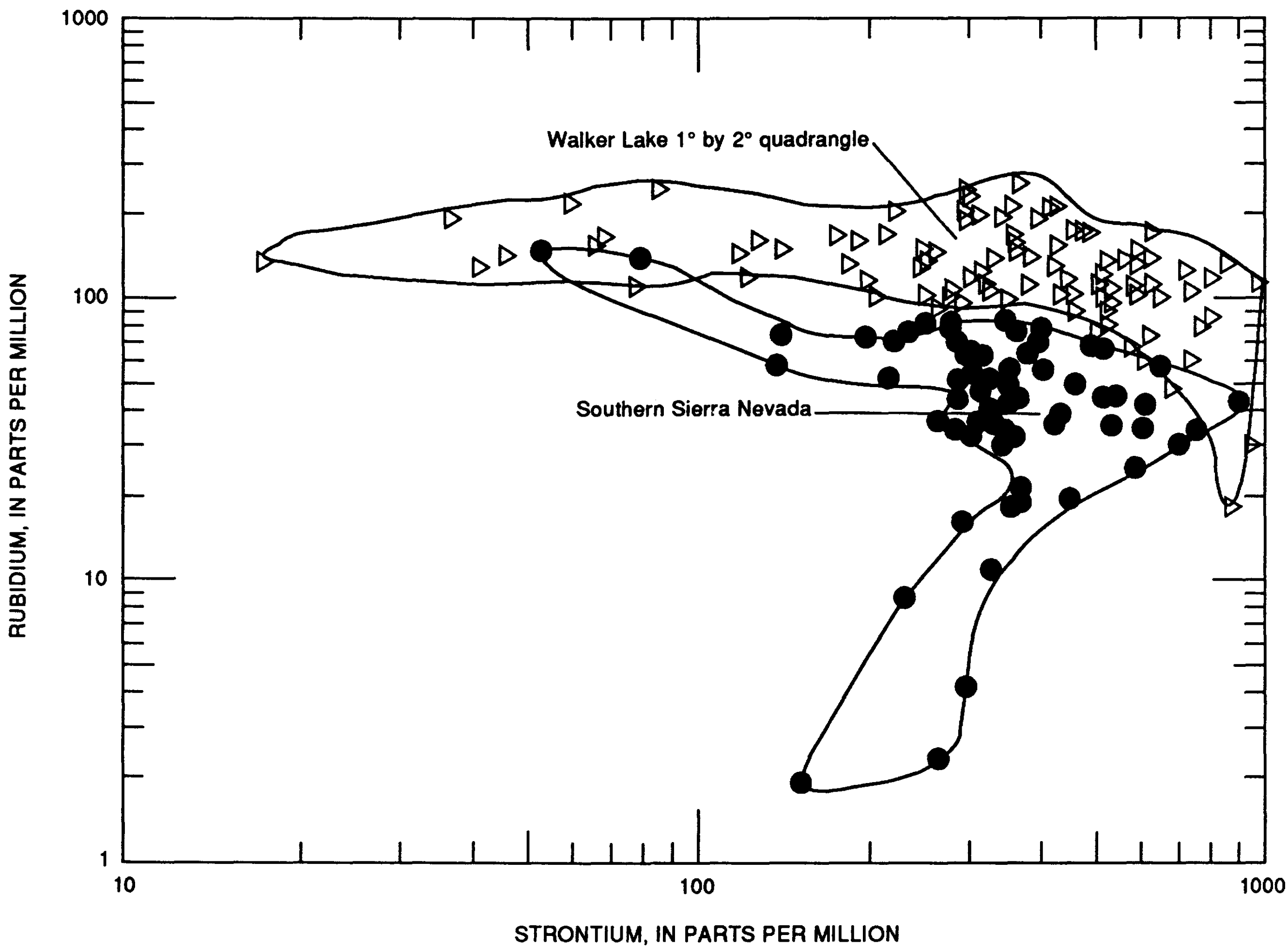

Figure 4. Rb versus Sr for plutons with $Sr_i < 0.706$ peripheral to the Salinian-western Mojave terrane in Panthalassan lithosphere and peripheral to the Sierran terrane in North American lithosphere in the Walker Lake 1° by 2° quadrangle. Each data point represents a single sample. Open triangles are samples from North American lithosphere. Closed circles are samples from Panthalassan lithosphere.

Table 1. Rubidium and strontium data for plutons and associated rocks of the southern Sierra Nevada and vicinity

[Pluton names and symbols from Ross (1987); n, number of samples tested; T, age in millions of years before present; MSWD, mean squares of weighted deviates; Sr_i, initial $^{87}Sr/^{86}Sr$ value calculated; – –, Sr_i determined from isochron]

Map no. (fig.2)	Sample no.	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Sr_i
			Granodiorite of Gato-Montes (Kgm) [T=96.3±8.7 Ma, Sr_i=0.70786±0.00016, n=10, MSWD=2.4, * sample not used for isochron]				
1	DR-3356	80.4	632	0.127	0.368	0.70833	– –
2	DR-3534B	129	416	.310	.897	.70895	– –
3	DR-3733A	82.7	618	.134	.387	.70840	– –
4	DR-3756A*	131	370	.357	1.032	.70991	0.70850
5	DR-3740	113	844	.134	.388	.70837	– –
6	DR-3745	137	590	.232	.671	.70878	– –
7	DR-3746	98.5	579	.170	.492	.70865	– –
8	DR-3747A	84.1	744	.113	.327	.70831	– –
9	DR-3818	90.2	582	.155	.449	.70837	– –
10	DR-3819	89.9	632	.142	.411	.70848	– –
11	DR-3820*	90.7	358	.253	.732	.70716	.70681
12	DR-3829A*	110	449	.245	.709	.70952	.70855
			Granite of Tejon Lookout (Ktj) [T=96.0±1.9 Ma, Sr_i=0.70727±0.00010, n=3, MSWD=1.2]				
13	DR-3401	173	79.3	2.18	6.32	0.71578	– –
14	DR-3466	191	89.2	2.14	6.20	.71583	– –
15	DR-3752	172	307	.560	1.62	.70948	– –
			Mafic inclusion in granite of Tejon Lookout (Ktj)				
16	DR-3754	146	353	0.414	1.20	0.70775	0.70612
17	[1]Sr12–73	80.1	612	.131	0.381	.7062	.70568
			Granodiorite of Lebec (Kle)				
18	[2]DR–698	127	376	0.338	0.978	0.70930	– –
19	DR-3088	93.2	659	.14	.41	.70797	0.70741
20	DR-3181	89.9	489	.184	.53	.70814	.70742
This pluton is equivalent to and offset from the granodiorite of Gato-Montes by the Garlock Fault. Sample DR–698 used in the Gato-Montes isochron.							
			Granite of Brush Mountain (Kbm) [T=91.1±1.6 Ma, Sr_i=0.70846±0.00010, n=2. T=98 Ma, U/Pb zircon (James and others, 1986)]				
21	DR-3221	237	13.6	17.4	50.8	0.77414	– –
22	DR-3005	170	78.4	2.17	6.28	.71658	– –
			Tonalite of Antimony Peak (KJap)				
23	DR-3023	<5	603	<0.01	<0.024	0.70337	0.70334
			Diorite Gneiss (Kset)				
24	DR-3097	2.4	261	0.01	0.026	0.70364	0.70360
25	DR-3098A	16.6	289	.06	.166	.70446	.70422
26	[3]PC–129	40.6	332	.122	.352	.70650	.70593
			Tonalite of Bear Valley Springs (Kbv) [T=100 Ma, U/Pb zircon (Sams, 1986)]				
27	[3]CM–9	104	388	0.268	0.775	0.70785	0.70677
28	[3]CM–25	55.9	399	.140	.405	.70648	.70591
29	[3]CM–26	69.2	392	.177	.512	.70708	.70637

Table 1. Rubidium and strontium data for plutons and associated rocks of the southern Sierra Nevada and vicinity—Continued

Map no. (fig.2)	Sample no.	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Sr_i
			Tonalite of Bear Valley Springs (Kbv)—Continued				
30	[3]TC–15	18.5	360	.051	.148	.70603	.70583
31	[3]TC–42	30.8	341	.090	.261	.70606	.70570
32	[1]Sr14–73	55.0	347	.158	.460	.7055	.70485
33	DR–3427B	63.0	297	.212	.614	.70649	.70562
34	DR–3575	85.5	346	.247	.715	.70701	.70600
35	DR–3837	81.8	250	.327	.947	.70725	.70591
36	DR–3670	63.2	313	.202	.584	.70684	.70601
37	DR–3791	41.4	344	.120	.348	.70546	.70497
38	DR–3858	72.6	285	.255	.737	.70616	.70512
39	DR–4181	62.7	378	.165	.480	.70493	.70425
40	DR–4184	53.8	323	.167	.481	.70498	.70430
41	DR–4281	86.2	274	.315	.910	.70722	.70593
42	DR–6300	48.9	348	.141	.41	.70529	.70471
43	Dr-6336	52.3	295	.177	.51	.70552	.70480
44	DR–6356	44.9	370	.121	.35	.70474	.70424
45	DR–6369	44.6	284	.157	.45	.70587	.70523
			Granodiorite of Keene (Kk)				
46	[1]Sr15–73	53.8	341	0.158	0.460	0.7060	0.70535
			Tonalite of Mount Adelaide (Kma) [T=100 Ma, U/Pb zircon (Sams, 1986)]				
47	[3]BM–684	19.6	455	0.043	0.125	0.70458	0.70440
48	DR–4189	35.2	418	.084	.243	.70483	.70449
49	DR–3631	57.8	640	.090	.261	.70462	.70427
			Quartz diorite of Caliente (Kca)				
50	Dr-3635	36.4	417	0.087	0.253	0.70479	0.70443
			Mafic gneiss complex of San Emigdio and Tehachapi Mountains (Kset) [T=116.7±2.45 Ma, Sr_i=0.70488±0.00019, n=13, MSWD=63.1. T=117–110 Ma, U/Pb zircon (Sams, 1986)]				
51	[3]PC–31	52.1	215	0.242	0.700	0.70627	--
52	[3]PC–32	145	79.1	1.83	5.30	.71336	--
53	[3]PC–34	33.3	352	.095	.273	.70511	--
54	[3]PC–35	149	49.5	3.01	8.72	.71965	--
55	[3]PC–36	11.2	324	.035	.100	.70515	--
56	[3]PC–37	69.7	222	.314	.908	.70613	--
57	[3]WR–30/2	1.9	447	.004	.012	.70480	--
58	[3]WR–39	2.4	696	.003	.010	.70501	--
59	[3]WR–40	56.7	138	.411	1.18	.70670	--
60	[3]WR–91A	18.7	353	.053	.153	.70560	--
61	[3]WR–171	35.8	308	.116	.336	.70518	--
62	[3]CM–630	36.1	257	.140	.405	.70534	--
63	[3]WR–643	21.0	367	.057	.165	.70545	--
			Metagabbro of Tunis Creek (Ktmg) [T=94.1±12.5 Ma, Sr_i=0.70499±0.00003, n=5, MSWD=2.84. T=102–101 Ma, U-Pb zircon (Sams, 1986)]				
64	[3]PC–227	4.2	709	0.006	0.017	0.70495	--
65	[3]WR–190	5.7	500	.011	.033	.70504	--
66	[3]WR–84	3.7	583	.006	.018	.70502	--
67	[3]WR–86	2.2	504	.004	.013	.70506	--
67a	[3]TL–197	36.6	330	.111	.321	.70542	--

Table 1. Rubidium and strontium data for plutons and associated rocks of the southern Sierra Nevada and vicinity—Continued

Map no. (fig.2)	Sample no.	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Sr_i
			Gabbro of Eagle Rest Peak (Jer)				
	[Minimum age is 161 Ma, U/Pb zircon, James and others (1986). Maximum age is 200 Ma, K/Ar hornblende (Ross and others, 1973)]						
68	[2]DR–1182C	8.8	228	0.016	0.046	0.7042	0.70407
69	[2]DR–671B	<2	147	--	--	.7031	.7031
69	[2]DR–671Pl	4.2	293	.014	.041	.7035	.70337
			Gneiss of Tweedy Creek (Kset)				
			[T=110 Ma, U/Pb zircon (Sams, 1986)]				
70	[3]TC–12A	66.7	216	0.309	0.890	0.70818	0.70679
			Inclusion in the tonalite of Bear Valley Springs (Kbv)				
71	[3]CM–22B	16.0	265	0.060	0.173	0.70629	0.70604
			Paragneiss of Cummings Mountain (Kset)				
72	[3]CM–110	110	165	0.667	1.931	0.71442	0.71168
			Quartzite in the Tehachipi metasedimentary belt of Ross (1987)				
73	[3]CM–640	32.3	90.3	0.358	1.037	0.72581	0.72434
			Granodiorite of Poso Flat (Kpf)				
			[T=100 Ma. Probable facies of tonalite of Bear Valley Springs]				
74	DR–6292	80.5	227	0.291	0.84	0.70609	0.70490
75	DR–6297	52.3	285	.183	.53	.70534	.70459
76	DR–6359	61	300	.205	.59	.70587	.70503
77	DR–6373	53.6	310	.172	.50	.70549	.70478
			Granodiorite of Alder Creek (Kal)				
			[T=91 Ma. Probable facies of tonalite of Dunlap Meadow]				
78	DR–5236	108	328	0.329	0.953	0.70812	0.70677
79	DR–5261	116	305	.380	1.10	.70831	.70675
80	DR–6245	123	232	.530	1.53	.70855	.70638
81	DR–6269	117	220	.532	1.54	.70861	.70644
82	[1]Sr4–73	146	249	.586	1.69	.7089	.70656
83	[1]Sr5–73	154	238	.646	1.86	.7084	.70576
			Tonalite of Walt Klein Ranch (Kwk)				
			[T=111±2.5 Ma, K/Ar hornblende (Evernden and Kistler, 1970)]				
84	DR–6061	33.1	294	0.113	0.326	0.70433	0.70382
85	DR–6088	46.1	311	.148	.429	.70485	.70417
86	DR–6096	60.6	295	.205	.594	.70485	.70391
87	DR–6281A	37.7	423	.089	.26	.70460	.70419
88	DR–6314–1	79.3	288	.275	.80	.70540	.70414
89	DR–6321	42.4	349	.121	.35	.70476	.70421
90	[1]Sr1–73	77.2	360	.215	.62	.7048	.70382
91	[1]Sr2–73	57.7	399	.145	.42	.7050	.70434
			Tonalite of Fountain Springs (Kfs)				
			[T=102 Ma, U/Pb zircon (Saleeby and Sharp, 1980)]				
92	DR–6024	34.6	341	0.101	0.293	0.70432	0.70390
93	DR–6106	34.4	281	.122	.354	.70441	.70390

Table 1. Rubidium and strontium data for plutons and associated rocks of the southern Sierra Nevada and vicinity—Continued

Map no. (fig.2)	Sample no.	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Sr_i
			Granite of Arrastre Creek (Kac)				
94	DR–6093	73.8	140	0.527	1.53	0.70620	0.70403
			Tonalite of Carver Bowen Ranch (Kcb)				
95	DR–5980	44.9	282	0.159	0.459	0.70447	0.70382
96	DR–6079A	70.8	282	.251	.726	.70493	.70390
97	[1]Sr3–73	44.0	514	.086	.25	.7036	.70325
			Granodiorite of Deer Creek (Kdc)				
98	DR–6030	77.6	230	0.337	0.976	0.70546	0.70408
99	DR–6117	74.1	195	.380	1.10	.70567	.70411
			Tonalite of Zumwalt Ranch (Kzr)				
100	DR–6123	41.1	320	0.128	0.371	0.70419	0.70366
			Granite of Portuguese Pass (Kpp) [T=105.6±9.2 Ma, Sr_i=0.70628±0.00049, n=3, MSWD=36.2]				
101	DR–5017	116	141	0.823	2.38	0.70951	--
102	DR–5062	189	94.7	1.996	5.78	.71504	--
103	DR–5592B	76.7	168	.457	1.32	.70852	--
			Granodiorite of Pyles Camp [Hockett Peak quadrangle north of map at 36° 06′ 15″ N. lat, 118° 28′ 01 ″ W. long]				
	DR–4692	106	403	0.293	0.761	0.70720	0.70623
			Tonalite of Dunlap Meadow (Kdm)				
104	DR–5871	51.4	326	0.158	0.456	0.70697	--
105	DR–5887	59.8	377	.159	.459	.70665	--
106	DR–5922	45.6	398	.115	.331	.70663	--
107	DR–5008	70.0	296	.236	.684	.70706	--
108	DR–5285	62.6	305	.205	.594	.70710	--
109	DR–5974	84.1	321	.262	.758	.70717	--
110	DR–6004	59.3	461	.129	.372	.70658	--
			Granodiorite of Pine Flat (Kpi) [Combined tonalite of Dunlap Meadow and granodiorite of Pine Flat. T=91.4±11.3 Ma, Sr_i=0.70618±0.00024, n=10, MSWD=4.0]				
111	DR–5801R	71.1	451	0.158	0.456	0.70669	--
112	DR–5946	94.3	300	.314	.909	.70731	--
113	DR–5965	113	343	.329	.953	.70742	--
			Granodiorite of Hatchet Peak (Khp)				
114	DR–5865A	121	174	0.695	2.01	0.70966	0.70681
			Granodiorite of Peppermint Meadow (Kpm) [T=106.7±21.1 Ma, Sr_i=0.70616±0.00023, n=4, MSWD=24.3. DR–4688 is north of map in Hockett Peak quadrangle at 36° 08′ 50″ N.lat, 118° 29′ 50″ W. long]				
115	DR–4995	78.7	614	0.128	0.371	0.70664	--
116	DR–5034	79.1	577	.137	.397	.70706	--
117	DR–5852	76.6	621	.123	.357	.70649	--
	DR–4688	134	277	.484	1.40	.70827	--
			Granodiorite of Brush Creek (Kbru) [T=90.0±2.0 Ma, K/Ar biotite (Evernden and Kistler, 1970)]				
118	DR–5031	133	408	0.325	0.943	0.70746	0.70625

Table 1. Rubidium and strontium data for plutons and associated rocks of the southern Sierra Nevada and vicinity—Continued

Map no. (fig.2)	Sample no.	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Sr_i
Granodiorite of Alta Sierra (Kas) [T=89.0±2.1 Ma, K/Ar biotite (Evernden and Kistler, 1970)]							
119	DR–5423	60.1	527	0.114	0.330	0.70658	0.70616
120	DR–5425	42.6	676	.063	.182	.70676	.70653
121	DR–4796–1	63.1	567	.111	.321	.70660	.70619
122	DR–4789A	63.7	541	.118	.341	.70670	.70626
Granite of Kern River (Kkr) [T=87 and 89 Ma, K/Ar biotite (Evernden and Kistler, 1970). T=81.1±11.1 Ma, Sr_i=0.70810±0.00039, n=4, MSWD=12.6, Rb/Sr whole-rock isochron]							
124	DR–5006	127	200	0.635	1.84	0.70999	0.70767
125	DR–4763	155	147	1.054	3.05	.71158	.70773
126	DR–4819A	155	148	1.047	3.03	.71169	.70767
127	[4]24–73	105	203	.516	1.49	.7100	.70812
Granodiorite of Wagy Flat(Kwf)							
128	DR–4273	74.1	623	0.119	0.344	0.70698	0.70649
129	DR–4294	59.5	583	.102	.295	.70722	.70680
Granite of Saddle Springs (Kss) [mafic inclusions]							
130	DR–5089	50.1	387	0.129	0.373	0.70724	0.70671
131	DR–5153	56.7	480	.118	.341	.70656	.70608
Granodiorite of Rabbit Island (Kri) [T=99 Ma, U/Pb zircon (Saleeby and Busby-Spera, 1986)]							
132	DR–4848	107	604	0.177	0.512	0.70712	0.70639
133	DR–5421	70.6	530	.133	.385	.70648	.70593
134	DR–5407	108	623	.173	.502	.70716	.70645
135	[5]LGC–4	82.9	732	.113	.328	.70713	.70664
136	[5]LGC–5	107	615	.174	.503	.70746	.70675
137	[5]LGC–6	69.3	776	.089	.258	.70706	.70669
138	[5]LGC–7	116	378	.307	.888	.70805	.70679
139	[5]LGC–8	124	480	.258	.747	.70813	.70707
140	DR–5191A	56.7	956	.059	.171	.70814	.70790
Granodiorite of Castle Rock (Kcr)							
141	DR–4528	117	449	0.261	0.754	0.70909	0.70813
142	DR–4402	89.9	573	.157	.454	.70851	.70793
143	DR–4354	99.4	526	.189	.547	.70852	.70782
144	DR–4341	82.0	603	.136	.393	.70850	.70800
145	DR–5356	101	456	.221	.641	.70752	.70671
146	DR–4093	81.3	652	.125	.361	.70864	.70818
147	[5]LGC–3	195	470	.415	1.200	.70875	.70706
148	[1]Sr6–73	140	349	.401	1.16	.7073	.70582
149	[1]Sr8–73	98	737	.133	.384	.7080	.70751
150	[1]Sr9–73	81.8	695	.118	.341	.7084	.70746
151	DR–5133R	182	75.5	2.41	6.98	.71654	.70762
152	DR–5403	130	460	.283	.818	.70791	.70687
153	DR–6539	94.9	713	.133	.385	.70786	.70731
154	DR–4686	170	511	.333	.962	.70783	.70660
Whiterock facies of the granodiorite of Castle Rock (Kcw) [T=90 Ma, U/Pb zircon (Sams, 1986)]							
155	DR–4314	103	552	0.187	0.540	0.70835	0.70766
156	DR–4102A	96.6	504	.192	.554	.70817	.70746
157	DR–3737	86.0	893	.096	.279	.70813	.70777

Table 1. Rubidium and strontium data for plutons and associated rocks of the southern Sierra Nevada and vicinity—Continued

Map no. (fig.2)	Sample no.	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Sr_i
			Whiterock facies of the granodiorite of Castle Rock (Kcw)—Continued				
158	[3]TC–27	71.2	562	.127	.367	.70777	.70730
159	[3]TC–40	48.1	578	.083	.241	.70735	.70704
			Dikes in Isabella roof pendant in the Long Canyon metasedimentary belt of Ross (1987)				
160	PM–505	123	186	0.661	1.91	0.71701	0.71443
161	PM–536	144	289	.498	1.44	.70981	.70787
162	DR–5629	67.5	621	.109	.315	.70725	.70683
			Volcanic rocks of Piute Peak in the Erskine Canyon sequence of Saleeby and Busby-Spera (1986) [T=97.3±0.5 Ma, Sr_i=0.70576±0.00011, n=3, MSWD=0.01. T=98 Ma, U/Pb zircon (Saleeby and Busby-Spera, 1986)]				
163	EM–10	77.6	136	0.571	1.651	0.70804	--
163	EM–1OB	71.8	232	.309	.895	.70699	--
163	EM–10C	58.2	242	.240	.696	.70672	--
			Volcanic rocks in Erskine Canyon sequence of Saleeby and Busby-Spera (1986) [T=102 Ma, U/Pb zircon (Saleeby and Busby-Spera, 1986)]				
164	82SS7	137	143	0.958	2.77	0.71038	0.70637
			Granite of Bodfish Canyon (Kbo)				
165	DR–5071	194	41.1	4.72	13.7	0.72647	0.70896
			Tonalite of Hoffman Canyon (Khc)				
166	[1]Sr10–73	89.6	634	0.141	0.408	0.7076	0.70708
			Amphibolite of Jawbone Canyon (Kjc)				
167	DR–4497B	29.8	662	0.045	0.130	0.70814	0.70793
168	DR–4498B	64.5	237	.272	.787	.70877	.70750
169	DR–4499	33.1	719	.046	.133	.70779	.70758
			Granite of Bishop Ranch (Kbr)				
170	DR–4472	93.1	665	0.140	0.405	0.70904	0.70852
			Granite of Cannell Creek (Kcc) [T=80±2 Ma, U/Pb zircon (Saleeby and Busby-Spera, 1986)]				
171	[5]LGC–9	99	366	0.270	0.783	0.70854	0.70743
172	[5]LGC–11	195	29.6	6.59	19.1	.73642	.70930
173	[5]LGC–17	57.7	517	.117	.323	.70768	.70723
174	[5]LGC–18	148	318	.465	1.35	.70925	.70734
175	[5]LGC–23	171	392	.436	1.26	.70904	.70725
176	[5]LGC–25	133	28.9	4.60	13.34	.73010	.71116
			Quartz diorite of Cyrus Flat (Kcf) (Unit "A" Fox, 1981)				
177	[5]LGC–12	10.0	780	0.013	0.037	0.70681	0.70676
178	[5]LGC–13	13.5	623	.027	.063	.70686	.70677
			Quartz diorite of Cyrus Flat (Kcf) [T=100 Ma, U/Pb zircon (Saleeby and Busby-Spera, 1986)]				
179	[5]LGC–14	117	408	0.287	0.830	0.70814	0.70796
180	[5]LGC–15	110	407	.270	.782	.70811	.70700
181	[5]LGC–16	113	384	.294	.851	.70770	.70650

Table 1. Rubidium and strontium data for plutons and associated rocks of the southern Sierra Nevada and vicinity—Continued

Map no. (fig.2)	Sample no.	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Sr_i
			Quartz diorite of Cyrus Flat (Kcf)—Continued				
182	[5]LGC-20	57.7	471	.123	.354	.70821	.70771
183	[5]LGC-21	103	366	.281	.814	.70908	.70793
184	[5]LGC-22	99.5	306	.325	.941	.70918	.70785
185	[5]LGC-24	91.2	521	.175	.506	.70763	.70691
186	[5]LI-33	74.8	498	.150	.435	.70813	.70751
187	[5]LI-34	46.9	683	.069	.199	.70827	.70799
188	[5]LI-35	203	198	1.025	2.97	.71134	.70712
189	[5]LI-36	195	243	.802	2.32	.70951	.70622
190	[5]LI-37	218	249	.876	2.53	.71104	.70745
191	[5]LI-38	105	569	.184	.534	.70887	.70811
192	[5]LI-39	102	579	.176	.510	.70848	.70776
193	[5]LI-40	93.4	445	.210	.607	.70857	.70771
194	[5]LI-41	129	265	.487	1.41	.70937	.70737
195	[5]LI-42	125	406	.308	.891	.70886	.70760
196	[5]LI-43	180	242	.744	2.15	.71044	.70739
197	[5]LI-44	59.0	511	.115	.334	.70776	.70729
			Sedimentary rocks south of the quartz diorite of Cyrus Flat in the Long Canyon metasedimentary belt of Ross (1987)				
198	[5]LGC-1	67.5	445	0.152	0.439	0.72032	0.71970
199	[5]LGC-2	123	165	.745	2.16	.73827	.73520
200	[5]LGC-10	122	35.6	3.43	9.96	.75232	.73818
201	[5]LGC-19	71.6	459	.156	.451	.70917	.70853
			Granite of Onyx [T=81 Ma, K/Ar biotite (Evernden and Kistler, 1970)]				
202	[4]25–73	170	343	0.496	1.435	0.7098	0.70801
			Quartz diorite of Freeman Junction (Trfj) [T=222 Ma, Sr_i=0.70428, n=2]				
203	DR-6438A	35.5	531	0.067	0.19	0.70488	--
204	DR-6439	49.8	456	.109	.32	.70529	--
			Quartz diorite of Walker Pass, unsheared part (Trwp) [T=240.4±14 Ma, Sr_i=0.70362±0.00007, n=10, MSWD=4.06. Isochron from these and unsheared quartz diorites and trondjhemites of the El Paso Mountains]				
205	DR-6226	35.0	599	0.058	0.169	0.70434	--
206	[4]26–73	76.8	396	.194	.561	.7056	--
207	DR-6179	30.8	694	.044	.128	.70411	--
208	DR-6391	33.0	762	.043	.13	.70416	--
209	DR-6217	70.8	633	.111	.324	.70475	--
			Quartz diorite of Walker Pass, sheared part (Trwps) [Samples do not yield an isochron]				
210	DR-6220	43.4	539	0.081	0.233	0.70475	0.70396
211	DR-6394A	27.2	714	.038	.110	.70440	.70403
212	DR-6400	30.6	668	.045	.132	.70452	.70407
213	DR-6176A	36.1	577	.062	.181	.70460	.70398
214	DR-6174D	26.9	643	.042	.121	.70441	.70400
215	DR-6385A	73.5	654	.112	.325	.70538	.70428
			Gray gneiss in the summit gabbro of Miller and Webb (1940) (JTrsg) [T=218 Ma, Sr_i=0.70366]				
216	DR-6511	58.2	616	0.094	0.273	0.70451	--
217	DR-6516	93.2	446	.209	.605	.70554	--

Table 1. Rubidium and strontium data for plutons and associated rocks of the southern Sierra Nevada and vicinity—Continued

Map no. (fig.2)	Sample no.	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Sr_i
Quartz diorite and trondjhemite of El Paso Mountains (TrPe)							
[T=240±14 Ma, Sr_i=0.70362±0.00007, n=10, MSWD=4.1. T=247–223 Ma, K/Ar hornblende (Cox and Morton, 1980)]							
218	GR–151	42	604	0.069	0.200	0.70424	--
219	GR–152	26	574	.045	.130	.70392	--
220	[1]Sr16–73	98.1	382	.257	.743	.7062	--
221	S28–84	67.8	500	.136	.393	.70477	--
222	S31–84	67.0	512	.131	.379	.70489	--
Quartz diorite of Long Valley (Trlv)							
223	DR–6509A	43.4	925	0.047	0.136	0.70558	0.70512
Granodiorite of Five Fingers (Kff)							
[T=90 Ma, estimated from Rb/Sr data]							
224	DR–6535	92.7	799	0.116	0.336	0.70721	0.70679
225	DR–6415	76.6	809	.095	.27	.70716	.70682
226	DR–6208	93.2	544	.171	.496	.70738	.70675
Sacatar quartz diorite of Miller and Webb (1940) (Js)							
[T=177.4±4.9 Ma, Sr_i=0.70718±0.00015, MSWD=12.5, n=19. T>170 Ma, U/Pb zircon preferred intrusive age (Chen and Moore, 1982) for unit 6 of Moore and DuBray (1978), which is Sacatar Quartz Diorite equivalent in the Hockett Peak quadrangle north of map (fig. 2)]							
227	DR–6483A	94.2	659	0.143	0.413	0.70883	--
228	DR–6472A	88.7	525	.169	.489	.70847	--
229	DR–6523A	132	460	.287	.830	.70952	--
230	DR–6425	105	532	.197	.57	.70861	--
231	S66–84	137	470	.291	.843	.70963	--
231	S66A-84	178	132	1.35	3.90	.71710	--
232	S67–84	188	348	.540	1.56	.71117	--
Granite of No Name Canyon (Knc)							
[T=80.5±1.7 Ma, Sr_i=0.70880±0.00008, MSWD=0.17, n=4. T=80.1±5.3 Ma, K/Ar muscovite (Diggles, 1984). Samples are from Griffis (1987)]							
233	NM–4A	366	5.54	66.06	195.3	0.93265	--
234	NM–4B	329	11.8	27.88	81.40	.80172	--
235	NM–30	119	478	.25	.720	.70960	--
236	NM–31	155	462	.335	.971	.70993	--
Granite of Tehachapi Airport (Kta)							
237	DR–4100A	165	78.7	2.097	6.07	0.71645	0.70955
Granodiorite of Little Lake (Jll)							
[T=175±5 Ma, Rb/Sr whole-rock isochron from 5 samples outside map area]							
238	Sr20–73	132	339	0.389	1.126	0.7089	0.7061

[1]Kistler and Peterman (1978)
[2]Kistler and others (1973)
[3]Sams (1986)
[4]Kistler and Peterman (1973)
[5]Collins (1988)

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