SHRIMP-RG U-Pb Zircon Geochronology of Mesoproterozoic Metamorphism and Plutonism in the Southwesternmost United States

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ABSTRACT

Mesoproterozoic intrusive and granulite-grade metamorphic rocks in southern California have been inferred to be exotic to North America on the basis of perceived chronologic incompatibility with autochthonous cratonal rocks. Ion microprobe geochronology indicates that zircons in granulite-grade gneisses, dated at 1.4 Ga using conventional methods, are composed of 1.68–1.80-Ga cores and 1.19-Ga rims. These Early Proterozoic gneisses were metamorphosed at extremely high temperatures and moderate pressures during emplacement of the 1.19-Ga San Gabriel anorthosite complex. The lack of a 1.4-Ga metamorphic event suggests that Proterozoic rocks in this region, rather than being exotic to North America, may in fact be a midcrustal window into Mesoproterozoic crustal evolutionary processes in southwestern North America.

Introduction

The upper crustal, anorogenic emplacement of Mesoproterozoic granitic rocks (Silver et al. 1977*b*) has proved a powerful paradigm in describing the tectonic and magmatic evolution of North America (Anderson 1983; Anderson and Morrison 1992; Bickford and Anderson 1993). Although recent detailed studies have called attention to localized strain and potential links between foliated 1.40–1.46-Ga granites and distant continental margin tectonism (Nyman et al. 1994; Dubendorfer and Christensen 1995; Kirby et al. 1995; Gonzales et al. 1996; Williams et al. 1999), the common lack of regional synplutonic deformation and postplutonic exhumation remains a characteristic of the North American Mesoproterozoic. The anorogenic paradigm has been extended to studies of potentially displaced terranes in the western United States. Proterozoic basement terranes in southern California, believed to contain ~1.4-Ga granulite-grade metamorphic rocks and 1.2-Ga intrusive rocks, have been inferred to be potentially or actually exotic to North America, in large part on the basis of the geologic mismatch with 1.40–1.46-Ga anorogenic upper crustal magmatism in southwest North America (Silver 1971, 1982; Silver et al. 1977*a*; Coney et al. 1980; Powell 1981; Howell et al. 1983, 1985; Vedder et al. 1983; Reed 1993).

In this study we reexamined the timing of Mesoproterozoic metamorphism and plutonism in southern California using ion microprobe U-Pb zircon geochronology. We concluded that no ~1.4-Ga regional metamorphism occurred in this region and that 1.19-Ga anorogenic plutonism was associated with the extremely high-temperature, moderate-pressure, granulite-grade contact metamorphism of Early Proterozoic wall rocks. Evaluation of these results suggests that, rather than exotic rocks accreted to North America at some later time, these rocks represent a window into comparatively deeper levels of the Proterozoic crust in this region.

Geologic Setting

Although most Precambrian basement in southern California is Early Proterozoic in age (Silver 1971; Wooden and Miller 1990; Barth et al. 2000), crystalline rocks of known or inferred Mesoproterozoic

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age are particularly common in the Transverse Ranges (fig. 1). In the central Transverse Ranges west of the San Andreas fault, gneisses of inferred Mesoproterozoic age are known as the Mendenhall gneiss (Ehlig 1981; Barth et al. 1995). East of the San Andreas fault, potentially correlative rocks crop out in the eastern Transverse Ranges and Orocopia Mountains (Crowell 1962; Crowell and Walker 1962; Ehlig 1981) where they have been called Augustine gneiss by Powell (1981). Palinspastic removal of the dextral slip on the San Andreas fault reunites these rocks, which constitute the Tujunga or San Gabriel terranes on many maps of suspect or exotic terranes of the western United States.

This study focuses on the Mendenhall gneiss in its type area around Mendenhall Peak, west of the San Andreas fault. Mendenhall gneiss crops out in a narrow belt along the southern and eastern margins of the San Gabriel anorthosite complex (fig. 1). The gneiss is composed of variably retrogressed mafic granulite and distinctive purple quartz felsic gneiss, interlayered at the meter scale. Rare rock types include augen gneiss and garnetiferous pelitic gneiss. Dikes of anorthosite, jotunite, and pegmatite cut the gneiss, which Carter (1980) interpreted as the roof of the San Gabriel anorthosite complex.

Pyroxene and feldspar solvus geothermometry yielded minimum metamorphic temperatures of 900°–950°C in mafic granulites and felsic gneisses (Barth et al. 1995). McCarthy and Patiño Douce (1998) have shown that the Ca-tschermak component of clinopyroxene in high-temperature mafic granulites such as these can be used to estimate pressure of crystallization. Augites in mafic granulite sample PC-20 have Al_2O_3 contents of 1.80%–1.91% (Barth et al. 1995), indicating crystallization at ca. 0.6 GPa at a minimum temperature of 950°C. This pressure is indistinguishable from that estimated for Mesozoic plutons, which intrude the anorthosite and Mendenhall gneiss (Barth 1990), suggesting that no significant exhumation followed anorthosite emplacement in the range.

Despite two conventional U-Pb zircon studies, the age and geologic evolution of this crystalline basement complex remain unclear. In a pioneering study of the U-Pb zircon geochronologic technique, Silver et al. (1963) estimated the age of the anorthosite complex as 1185 Ma (revised decay constants of Steiger and Jager 1977) on the basis of discordant U-Pb ages of zircons from a pegmatitic jotunite. Barth et al. (1995) confirmed this age assignment with a 1191 ± 4-Ma age for a syenite and a discordant 1186 ± 19-Ma age for a wallrock granophyric pegmatite. However, both studies were unable to resolve the origin and thermal evolution of the Mendenhall gneiss due to U-Pb discordance and very limited isotopic variation in zircons from the gneisses. Silver (1971, 1982) inferred that the

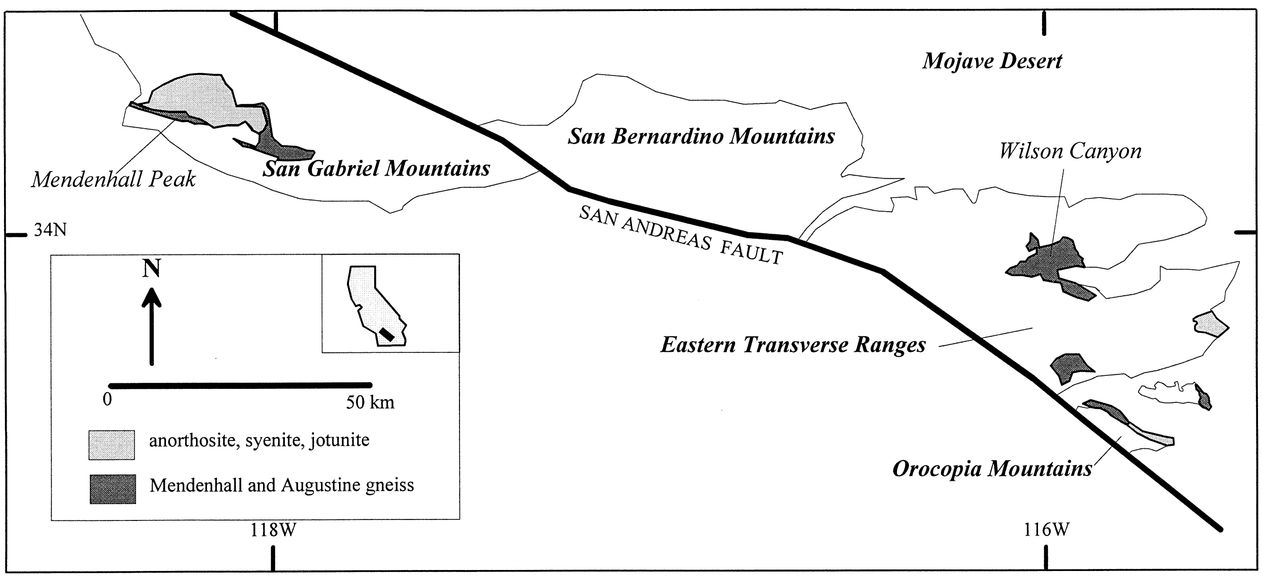

Figure 1. Location map of the central and eastern Transverse Ranges of southern California, illustrating outcrops of the Mesoproterozoic San Gabriel anorthosite complex and the Mendenhall and Augustine gneisses. Modified from Ehlig (1981) and Powell (1981).

timing of granulite facies metamorphism was best approximated by a $^{207}Pb^{*}/^{206}Pb^{*}$ age of ca. 1400 Ma. In contrast, Barth et al. (1995) inferred that poorly constrained lower intercept ages of 1250 Ma were consistent with a younger granulite-grade event, approximately synchronous with emplacement of the adjacent San Gabriel anorthosite complex (see also Ehlig 1981; Powell 1993), a conclusion bolstered by extraordinarily high metamorphic temperatures recorded in these rocks.

Geochronology

Analytical Methods. Zircon U-Pb geochronology was carried out on the SHRIMP-RG (sensitive high-resolution ion microprobe–reverse geometry) ion microprobe at Stanford University. The SHRIMP-RG employs magnetic analysis of the secondary ion beam before electrostatic analysis to achieve greater mass resolution compared with previous SHRIMP designs (Clement and Compston 1994). Zircons analyzed from the gneiss and syenite were selected from the same mineral separates analyzed by Barth et al. (1995). Zircon separates or crystal fragments were mounted in epoxy, polished, and coated with gold before analysis. Analytical spots ~30 μm in diameter were sputtered using an ~10-nA O_2^- primary beam. The primary beam was rastered across the analytical spot for 90 s before analysis to reduce common Pb, and resulting analyses show ^{204}Pb is generally <0.01% of total Pb. Concentration data were standardized against Sri Lankan zircon standard SL-13 and Duluth Gabbro zircon standard AS57, and isotope ratios were calibrated against AS57, with an assumed age of 1099 Ma (Paces and Miller 1993). Data reduction followed procedures described by Williams (1997). Errors on concordia intercepts were calculated at the 95% confidence level. Sm-Nd isotopic compositions in pelitic gneiss were measured on the VG thermal ionization mass spectrometer at the University of North Carolina.

Geochronologic Results. Zircons in augen gneiss sample PC-58 are subhedral to anhedral grains ranging from equant to prismatic 4 : 1. The zircons are homogeneous in transmitted light; in SEM-CL (scanning electron microscope cathodoluminescence) images, grain interiors are usually dark and exhibit euhedral oscillatory zoning that is truncated and overgrown by a lighter, U-poor rim with diffuse zoning (fig. 2). Approximately 10% of grains are comparatively homogeneous in SEM-CL, containing no visible dark, oscillatory-zoned core, but are entirely composed of lighter zircon with diffuse zoning texturally similar to the rims present on most grains.

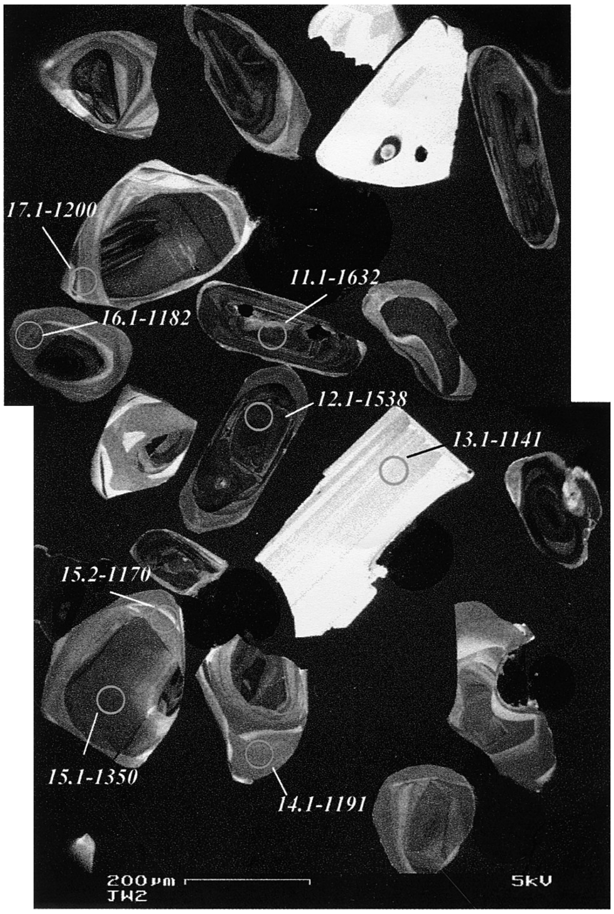

Figure 2. SEM-CL image of zircons in augen gneiss sample PC-58, showing the relatively dark, oscillatory-zoned cores and rims with diffuse zoning, which truncate zoning in cores. Circles highlight ion microprobe analytical spots generally not visible in the image and are labeled with spot number and $^{207}Pb^{*}/^{206}Pb^{*}$ ages in millions of years. Note the relatively consistent and younger ages of rims relative to cores.

Four conventional zircon fractions in sample PC-58 yielded discordant Pb/U ages at ~1410–1550 Ma (Barth et al. 1995). However, limited variation in Pb/U and consequent poorly constrained upper and lower intercepts precluded precise geochronologic interpretation. Ion microprobe spot analyses from zircon cores, homogeneous grains, and rims clearly indicate that prior conventional analyses averaged two distinct isotopic populations (table 1; fig. 3*a*). Dark, oscillatory-zoned cores were dated by the Pb/U method at 1307–1741 Ma, defining a discordia array with intercepts at 1679 and 1268 Ma. We interpret the upper intercept age to approximate the

Table 1. U-Pb Geochronologic Data for Mendenhall Gneiss and San Gabriel Anorthosite

Spot number	Spot[a]	U[b] (ppm)	Th (ppm)	^{204}Pb (ppb)	^{206}Pb*/^{238}U[c]	^{207}Pb*/^{235}U	^{207}Pb*/^{206}Pb*[d] (Ma)
PC-58, augen gneiss (34°21.72′N, 118°22.23′W):							
s2.1	c.o	361	92	2	.3029 (33)	4.3069 (605)	1681 (14)
s4.1	c.o	256	149	1	.3029 (25)	4.3567 (604)	1702 (19)
s5.1	c.o	263	133	1	.3100 (45)	4.5199 (853)	1727 (19)
s6.1	c.o	227	124	1	.2496 (22)	3.1803 (550)	1476 (26)
s7.1	c.d	37	23	1	.1996 (57)	2.1435 (1215)	1144 (93)
s8.1	c.d	56	52	1	.2038 (38)	2.2218 (708)	1174 (47)
s10.1	c.o	223	73	0	.2878 (57)	4.0825 (1030)	1677 (25)
s11.1	c.o	283	190	1	.2864 (61)	3.9664 (990)	1632 (19)
s12.1	c.o	217	62	1	.2618 (27)	3.4473 (544)	1538 (20)
s13.1	c.d	36	17	0	.2072 (51)	2.2223 (850)	1141 (53)
s14.1	r	39	155	0	.2016 (37)	2.2168 (589)	1191 (34)
s15.1	c.o	116	11	0	.2267 (28)	2.7039 (527)	1350 (27)
s15.2	r	37	132	1	.1970 (49)	2.1432 (849)	1170 (56)
s16.1	r	43	137	1	.1960 (39)	2.1460 (711)	1182 (48)
s17.1	r	47	62	1	.1973 (38)	2.1788 (771)	1200 (55)
PC-60, felsic gneiss (34°21.13′N, 118°18.67′W):							
s1.1	r	1016	413	2	.2065 (16)	2.2688 (217)	1189 (10)
s2.1	c.o	411	96	1	.2398 (30)	3.0045 (555)	1444 (23)
s3.1	c.o	1020	161	2	.2314 (20)	2.8569 (315)	1416 (11)
s4.1	c.o	1459	161	1	.2263 (13)	2.7408 (245)	1379 (12)
s6.1	r	747	343	0	.2043 (12)	2.2492 (205)	1193 (12)
s7.1	c.o	2222	304	1	.2292 (14)	2.7043 (191)	1328 (6)
s8.1	c.o	1439	87	2	.2660 (30)	3.6526 (590)	1616 (19)
s9.1	c.o	2693	319	2	.2793 (11)	3.8543 (203)	1626 (6)
s10.1	r	716	318	0	.1957 (17)	2.1579 (239)	1197 (12)
s11.1	r	1092	438	0	.2034 (13)	2.2258 (211)	1181 (12)
s12.1	c.o	1217	206	2	.2229 (14)	2.6837 (232)	1367 (10)
s13.1	c.o	423	188	1	.2218 (25)	2.6811 (396)	1375 (16)
s14.1	c.o	236	95	2	.2799 (35)	3.9541 (712)	1669 (21)
s15.1	c.o	128	48	5	.2767 (47)	3.9024 (921)	1666 (27)
s16.1	c.o	437	86	0	.2678 (30)	3.7666 (519)	1661 (12)
s18.1	c.o	135	53	0	.3382 (77)	5.0868 (1574)	1784 (34)
s19.1	c.o	770	96	2	.3143 (28)	4.6297 (606)	1746 (16)
s20.1	c.o	177	70	1	.3070 (31)	4.6358 (763)	1791 (21)
s21.1	c.o	441	34	0	.2537 (47)	3.3376 (937)	1536 (36)
s22.1	c.o	301	65	0	.2824 (30)	4.1035 (617)	1721 (17)
s23.1	c.o	172	40	0	.2674 (36)	3.7290 (703)	1645 (21)
s24.1	c.o	708	86	2	.2580 (29)	3.3752 (610)	1526 (24)
s25.1	c.o	117	47	0	.2550 (43)	3.5677 (959)	1651 (36)
s26.1	c.o	506	145	1	.2972 (66)	4.2825 (1439)	1705 (42)
SGA-65, jotunite (34°22.11′N, 118°15.63′W):							
s1.1	c	165	149	9	.2005 (27)	2.2115 (472)	1197 (30)
s2.1	c	84	72	4	.2094 (24)	2.2454 (564)	1141 (42)
s3.1	c	78	40	2	.2038 (24)	2.2060 (573)	1160 (43)
s4.1	c	60	38	2	.1998 (35)	2.2590 (670)	1245 (44)
s5.1	c	328	198	10	.2099 (24)	2.2676 (394)	1156 (23)
s5.2	c	55	28	5	.1967 (32)	2.0141 (800)	1049 (71)
s6.1	c	63	27	7	.2071 (32)	2.2170 (686)	1138 (50)
s7.1	c	62	35	8	.2026 (28)	2.2250 (707)	1189 (54)
s8.1	c	160	124	2	.2096 (20)	2.3266 (330)	1209 (18)
s9.2	c	132	115	5	.2052 (53)	2.2720 (908)	1204 (18)
s10.1	c	71	31	7	.2101 (29)	2.3730 (685)	1244 (52)
s11.1	c	67	39	7	.2044 (40)	2.2983 (807)	1235 (49)
s12.1	c	65	46	2	.1994 (32)	2.1220 (470)	1126 (61)
s13.1	c	103	80	0	.2013 (32)	2.2300 (430)	1206 (23)
s14.1	c	54	24	4	.2038 (46)	2.2303 (847)	1182 (56)
s15.1	c	95	80	3	.1970 (25)	2.1422 (458)	1169 (31)
s16.1	c	72	41	4	.1918 (26)	2.0949 (565)	1178 (43)

Table 1 (*Continued*)

Spot number	Spot[a]	U[b] (ppm)	Th (ppm)	^{204}Pb (ppb)	^{206}Pb*/^{238}U[c]	^{207}Pb*/^{235}U	^{207}Pb*/^{206}Pb*[d] (Ma)
JW93-SGS, syenite (34°22.52′N, 118°14.75′W):							
xs1.1	c	77	47	5	.2086 (39)	2.3124 (715)	1207 (44)
xs2.1	c	69	33	6	.2077 (61)	2.2889 (1181)	1195 (79)
xs3.1	c	80	56	2	.1986 (38)	2.2284 (788)	1230 (55)
xs4.1	c	88	45	1	.2063 (27)	2.3143 (482)	1230 (29)
xs5.1	c	122	103	4	.2091 (27)	2.3238 (612)	1212 (43)
xs6.1	c	47	22	6	.2071 (38)	2.2141 (922)	1135 (71)
xs7.1	c	61	35	0	.2033 (47)	2.1914 (706)	1151 (40)
xs8.1	c	102	82	0	.2079 (44)	2.2920 (579)	1196 (23)
PCyn: Pacoima Canyon pegmatitic jotunite (34°22.11′N, 118°15.96′W):							
s1.1	c	26	21	0	.1939 (65)	2.2013 (1107)	1253 (67)
s2.1	c	38	21	0	.2071 (55)	2.3135 (845)	1222 (43)
s2.2	c	44	27	0	.2063 (29)	2.2558 (773)	1179 (60)
s3.1	c	25	19	0	.1971 (48)	2.1517 (1057)	1177 (80)
s4.1	c	35	29	1	.2064 (35)	2.1784 (715)	1109 (53)
s5.1	c	28	24	0	.2072 (56)	2.2907 (839)	1202 (43)
s6.1	c	25	19	0	.2094 (49)	2.2715 (879)	1164 (56)
s7.1	c	26	21	0	.2116 (63)	2.2578 (938)	1131 (51)
s8.1	c	88	92	1	.2074 (65)	2.2382 (911)	1153 (45)
s8.2	c	49	43	0	.1957 (58)	2.1527 (824)	1191 (42)

[a] Abbreviations: c, core; o, oscillatory zoning; d, diffuse zoning; r, rim.
[b] Uranium and thorium concentrations and isotopic compositions of individual zircon grains were analyzed using the SHRIMP-RG ion microprobe at Stanford University. Replicate analyses of standard zircons SL-13 and AS-57 were used to calibrate U and Th concentrations, and AS-57 (1099 Ma) was used to calibrate Pb isotopic compositions. SHRIMP-RG measurement and data reduction procedures followed Williams (1997).
[c] Values in parentheses are absolute 1σ counting errors, referring to errors in the last decimal places.
[d] Values in parentheses are 2σ errors in millions of years.

crystallization of the protolith porphyritic plutonic rock. The lower intercept approximates the time of Pb loss from zircon cores but has a relatively large uncertainty due to the low angle of intercept with concordia. Both homogeneous grains with diffuse zoning and rims on oscillatory-zoned grains are significantly younger than cores, yielding Pb/U ages at 1163–1214 Ma that are not significantly different from the lower intercept age defined by the cores. Therefore, our best estimate of the timing of Pb loss and new zircon growth is 1172 ± 22 Ma, the pooled ^{207}Pb*/^{206}Pb* age of rims and homogeneous grains.

Zircons in felsic gneiss sample PC-60 are subhedral to anhedral grains ranging from equant to prismatic 4 : 1. These zircons are also homogeneous in transmitted light, but in SEM-CL images these zircons are texturally more variable than those in the augen gneiss, exhibiting complex patchy to euhedral oscillatory zoning that is commonly truncated and overgrown by a rim with diffuse zoning. Approximately 5% of grains are comparatively homogeneous with diffuse zoning.

Three conventional zircon fractions in sample PC-60 yielded discordant Pb/U ages of ∼1350–1400 Ma (Barth et al. 1995). Ion microprobe spot analyses again indicate that these ages are mixtures of two chronologically distinct populations (table 1; fig. 3*b*). Cores were dated by the Pb/U method at 1315–1756 Ma, scattering along a poorly defined discordia array with intercepts at 1789 and 1185 Ma. We interpret the upper intercept age to approximate the crystallization of the protolith; zircon textures and the greater scatter in Pb/U ages suggest that multiple zircon-age populations existed in this rock before metamorphism, implying a sedimentary protolith. The lower intercept has a relatively large uncertainty but is not significantly different from the measured rim Pb/U ages of 1152–1210 Ma. We therefore estimate the timing of core Pb loss and subsequent new zircon growth on the basis of the pooled ^{207}Pb*/^{206}Pb* age of the rims, at ∼1190 ± 7 Ma.

Zircon data indicating high-grade metamorphism at ca. 1.17–1.19 Ga is supported by the Sm-Nd isotopic composition of garnetiferous pelitic gneiss (table 2). Garnet and plagioclase were separated from pelitic gneiss (sample PC73) interlayered with much more common felsic gneiss and mafic granulite. Regression of data for garnet, plagioclase, and

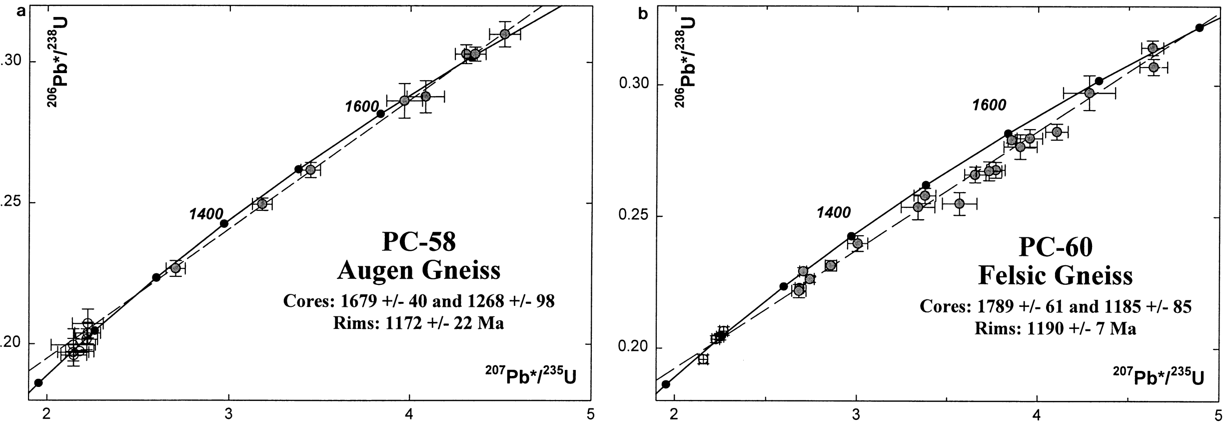

Figure 3. Concordia diagrams of U-Pb zircon data for Mendenhall gneiss in the San Gabriel Mountains. *a*, Augen gneiss sample PC-58. *b*, Felsic gneiss sample PC-60. In both diagrams, shaded circles are grain core and other interior analyses, and open circles are rims. Dashed lines are discordia lines defined only by zircon cores. Note the significantly less dispersed and younger ages of rims relative to cores.

the whole rock using errors of 0.1% and 0.004% for $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$, respectively, yields an age of 1114 ± 3 Ma (MSWD = 0.1) and $\epsilon_{Nd}(t) = -8.5$. Although the slope of this isochron is controlled by the garnet analysis (because of its very high Sm/Nd ratio), regression of whole rock and plagioclase data alone yields an age of 1102 ± 70 Ma, which agrees within error with the isochron including garnet. Consequently, we interpret this age as a cooling age approximating the timing of closure of the Sm-Nd system in the pelitic gneiss following peak granulite-grade metamorphism (Mezger et al. 1992).

The age of the adjacent anorthosite complex is approximated by the age of zircon-bearing jotunite and syenite. Ion microprobe analysis of these zircons is hampered by very low U and Th concentrations, but our results confirm the previously reported 1.19-Ga age for this pluton. Ion microprobe spot analyses of eight zircons from a syenite yielded a pooled $^{207}Pb^*/^{206}Pb^*$ age of 1194 ± 35 Ma (table 1), in agreement with the conventional age of 1191 ± 3.5 Ma for this rock (Barth et al. 1995). Spot analyses of 13 zircons from a jotunite yielded a pooled $^{207}Pb^*/^{206}Pb^*$ age of 1193 ± 39 Ma. Four additional spots from this sample yielded younger U-Pb ages and $^{207}Pb^*/^{206}Pb^*$ ages as young as 1049 Ma, which we attribute to minor Pb loss. Eight fragments from a single zircon crystal collected at the Pacoima Canyon pegmatitic jotunite locality studied by Silver et al. (1963) yielded a pooled $^{207}Pb^*/^{206}Pb^*$ age of 1178 ± 42 Ma, in agreement with the $^{207}Pb^*/^{206}Pb^*$ ages of 1183–1188 Ma reported by Silver et al. (1963) for this dike.

Conclusions

Ion microprobe results clarify the Mesoproterozoic history of the San Gabriel (Tujunga) terrane. Zircon dissolution and subsequent new growth of zircon rims in samples of augen and felsic gneisses from the Mendenhall gneiss caused variable Pb loss from remnant protolith zircon cores, generating discordia arrays between ~1.7 and ~1.2 Ga. Lower intercepts are statistically indistinguishable from both the $^{207}Pb^*/^{206}Pb^*$ ages of rims, which overgrow and truncate zoning in the cores, and from the age of the adjacent San Gabriel anorthosite complex. We conclude that extremely high-temperature, moderate-pressure contact metamorphism of ~1.68–1.8-Ga Early Proterozoic rocks in the Mendenhall gneiss was caused by emplacement of the anorthosite complex at 1.19 Ga, followed by slow cooling and minimal exhumation. There is no evidence for the 1.4-Ga granulite grade event widely cited for these rocks.

The lack of a 1.4-Ga granulite-grade metamorphic event in southern California removes much of the suspicion from the suspect San Gabriel (Tujunga) terrane. The crystallization ages and geochemistry of Early Proterozoic rocks in this region are consistent with an origin within the southwestern United States (Bender et al. 1993; Powell 1993), but the 1.19-Ga San Gabriel anorthosite remains anomalous. However, late Mesoproterozoic magmatism is recognized as a widespread, though volumetrically minor, component of the crust in southwestern North America, including the 1.09-Ga Pikes Peak batholith (Barker et al. 1975; Smith

Table 2. Sm-Nd Isotopic Data for Mendenhall Pelitic Gneiss

Sample	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd_{meas}$	$^{143}Nd/^{144}Nd_{meas}$
PC-73 whole rock	6.51	35.1	.11200	.511580
PC-73 plagioclase	1.85	19.2	.05810	.511190
PC-73 garnet	26.1	16.2	.97479	.517888

Note. Samples were spiked with mixed $^{150}Nd/^{149}Sm$ and dissolved in a mixture of HF and HNO_3 in a sealed Teflon bomb at 220°C for 5 d. The garnet separate was dried and then rebombed for an additional 5 d. After conversion to chlorides, separation of Sm and Nd was accomplished using standard cation exchange techniques and HDEHP on Teflon columns (White and Patchett 1984). Nd was loaded on triple-Re filaments with H_3PO_4 and Sm was loaded on single-Ta filaments with H_3PO_4. All analyses were performed on the VG sector-54 mass spectrometer housed at the University of North Carolina. Nd was analyzed in dynamic multicollector mode with $^{144}Nd = 1$ V, and Sm was analyzed in static multicollector mode with $^{152}Sm = 500$ mV. Nd data are normalized to $^{146}Nd/^{144}Nd = 0.7219$. Replicate analyses of La Jolla Nd standard give $^{143}Nd/^{144}Nd = 0.511848 \pm 0.000010$ (2σ; $n = 50$). Ages and ϵ_{Nd} are calculated using $^{143}Nd/^{144}Nd_{CHUR} = 0.512638$, $^{147}Sm/^{144}Nd_{CHUR} = 0.1967$, and $\lambda^{147}Sm = 6.54 \times 10^{-12}$ yr^{-1}.

et al. 1999), 1.09-Ga diabase dikes (Hammond 1986; Heaman and Grotzinger 1992), the 1.1-Ga Aibo granites (Anderson and Silver 1981), and 1.11–1.17-Ga mafic and felsic intrusive rocks and flows in west Texas (Keller et al. 1989; Shannon et al. 1997; Bickford et al. 2000). Furthermore, Stewart et al. (1999) suggest that 1.1–1.26-Ga magmatism in western North America may have been more widespread than previously recognized, based on the common occurrence of detrital zircons of these ages in Mesoproterozoic to Cambrian sediments throughout the southwest. Therefore, the suspicious San Gabriel (Tujunga) terrane may in fact be a midcrustal window that serves to expand understanding of Mesoproterozoic crustal evolution in southwestern North America.

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