Late Cretaceous protolith age and provenance of the Pelona and Orocopia Schists, southern California: Implications for evolution of the Cordilleran margin

Carl E. Jacobson
Department of Geological and Atmospheric Sciences, Iowa State University, Ames, Iowa 50011-3212, USA
Andrew P. Barth
Department of Geology, Indiana University-Purdue University, Indianapolis, Indiana 46202-5132, USA
Marty Grove
Department of Earth and Space Sciences and Institute of Geophysics and Planetary Physics,
University of California, Los Angeles, California 90095, USA

ABSTRACT

The Pelona and Orocopia Schists are southern members of a eugeoclinal terrane that structurally underlies a large part of southwestern North America. Ion-microprobe U-Pb ages of >100 detrital zircons from three widely spaced samples of these two units indicate that deposition occurred after 70–80 Ma. Moreover, the distribution of zircon ages, including a significant peak centered ca. 1.7 Ga, implies a major contribution of detritus from the Mojave Desert and Transverse Ranges of southern California. Recrystallization of the schists at depths of 20–35 km occurred within 10–15 m.y. of deposition, which requires underthrusting at minimum rates of ~4–12 mm/yr for reasonable thrust dips. Considering that similar processes formed the more northern Rand Schist at somewhat earlier times, our results indicate a southward progression in timing of deformation for the schists' protoliths. This result is at odds with northward migration of deformation implied by the Baja British Columbia hypothesis. The age and provenance of the schist's protoliths are consistent with models that derive the schists from either the Franciscan Complex or Great Valley Group.

Keywords: Baja British Columbia, Mojave Desert, Transverse Ranges, zircon.

INTRODUCTION

The Pelona, Orocopia, Rand, Portal Ridge, and Sierra de Salinas Schists make up a distinctive, graywacke-dominated, intermediate-high-pressure assemblage that is thought to underlie a large region of southwestern North America (Fig. 1A; Haxel and Dillon, 1978; Ehlig, 1981). The schists were metamorphosed beneath middle crustal rocks of the Cordilleran Mesozoic magmatic arc along the Late Cretaceous to early Tertiary Vincent–Chocolate Mountains thrust system (Haxel and Dillon, 1978). Little of the original thrust is preserved, however, because of overprinting by low-angle normal faults (Haxel et al., 1985; Jacobson et al., 1996). Most workers consider the schists to be part of the Franciscan subduction complex that underplated North American crust during shallow-inclination subduction related to the Laramide orogeny (Burchfiel and Davis, 1981; Crowell, 1981; Hamilton, 1987; Malin et al., 1995; Jacobson et al., 1996). In contrast, Barth and Schneiderman (1996) and Saleeby (1997) viewed the schist as a correlative of the Great Valley Group (Fig. 1A), the Vincent–Chocolate Mountains thrust marking the boundary between arc and forearc. Haxel and Dillon (1978) and Ehlig (1981) alternatively argued that the schist formed in a suture zone between North America and an outboard microcontinent, although we consider this model unlikely (Barth and Schneiderman, 1996; Jacobson et al., 1996).

Knowledge of the depositional age and provenance of the schists is key to understanding their tectonic significance. For the Pelona and Orocopia Schists, which make up the southern half of the terrane, the protoliths must be older than the ca. 60–65 Ma age of metamorphism (Jacobson, 1990). In the more northern Rand Mountains and Salinian block, a separate constraint is provided by ca. 79–85 Ma plutons that clearly intrude the schists (Silver and Nourse, 1986; James and Mattinson, 1988). More questionable, however, are inferences that the schist protoliths have a minimum age of 163 ± 2 Ma (Mukasa et al., 1984) or 131 Ma (James and Mattinson, 1988). These latter determinations are based on ages of igneous bodies whose contact relationships with the schists are ambiguous (Haxel and Tosdal, 1986; Ross, 1989). The 163 Ma postulated minimum age is particularly significant, because it implies that the protoliths of the schists are too old to correlate with either the Franciscan Complex or Great Valley Group (Tosdal, 1984). To help resolve this conflict, we determined U-Pb ages of detrital zircons contained within the schists. Here we describe preliminary results for three widely separated samples of Pelona and Orocopia Schists that provide unequivocal evidence that the sampled part of the terrane is no older than latest Cretaceous. The data further indicate that the protoliths were derived from a source area similar to the Mojave region and/or central to eastern Transverse Ranges.

SAMPLES AND U-Pb ZIRCON RESULTS

Locations of the analyzed samples are shown in Figure 1B on a pre-San Andreas palinspastic reconstruction. Included are representatives of Orocopia Schist from the Gavilan Hills (UG1417A) and Pelona Schist from Bouquet Canyon in the Sierra Pelona (98-241) and Blue Ridge in the eastern San Gabriel Mountains (98-240). The latter is likely a slice of the Sierra Pelona body offset by the Punchbowl fault (Ehlig, 1981, Fig. 10.4). All three samples were metamorphosed in the lowermost amphibolite facies at 20–35 km depth (Graham and Powell, 1984; Jacobson, 1995).

The University of California, Los Angeles, CAMECA ims 1270 ion microprobe was used to determine U-Pb ages for 34–45 zircons from each

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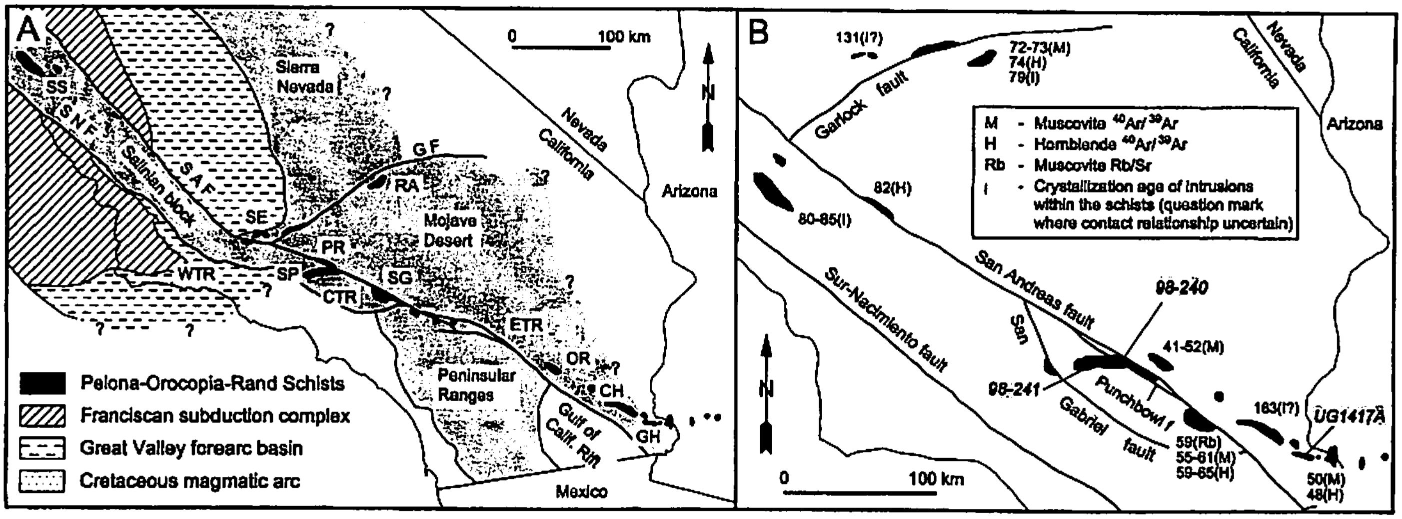

Figure 1. A: Distribution of Pelona and related schists on schematic base showing rocks related to late Mesozoic–early Tertiary convergent-margin tectonics. Abbreviations: CH—Chocolate Mountains, CTR—central Transverse Ranges, ETR—eastern Transverse Ranges, GH—Gavilan Hills, OR—Orocopia Mountains, PR—Portal–Ritter Ridge, RA—Rand Mountains, SE—San Emigdio Mountains, SG—San Gabriel Mountains, SP—Sierra Pelona, SS—Sierra de Salinas, WTR—western Transverse Ranges, GF—Garlock fault, SAF—San Andreas fault, SNF—Sur-Nacimiento fault. Contacts modified from Page (1981), Champion et al. (1984), and Haxel and Dillon (1978). B: Sample locations and geochronologic data for schists shown on pre-San Andreas reconstruction (modified from Haxel and Dillon, 1978). Ages from Ehlig (1981), Silver and Nourse (1986), James and Mattinson (1988), and Jacobson (1990).

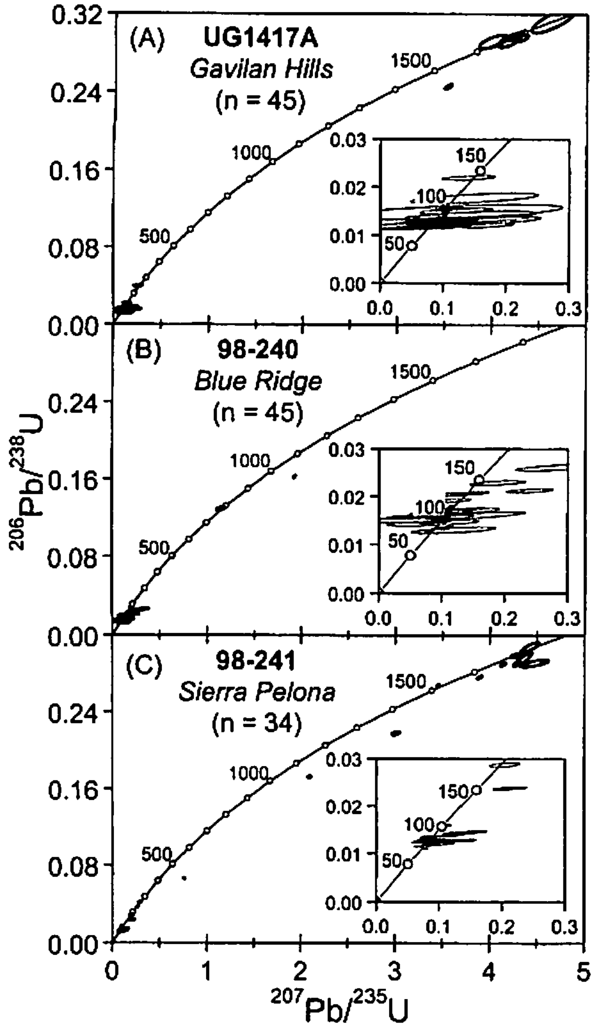

Figure 2. Concordia diagrams of detrital zircon ages from three analyzed samples. Ellipses indicate one standard error. Insets show detail for ages in range 0 Ma to ca. 180 Ma.

of the three samples. The methods employed are described in Appendix 1[1] (see also Quidelleur et al., 1997). Zircons were hand-selected from heavy-mineral concentrates derived from each of the samples after application of conventional crushing, density, and magnetic methods. The grains chosen were generally morphologically simple prisms that exhibited minor to distinct abrasion of crystal faces characteristic of sedimentary transport.

Results of the analyses are listed in Tables 1–3 (see footnote 1) and plotted on ^{207}Pb/^{235}U vs. ^{206}Pb/^{238}U concordia diagrams in Figure 2 and in histograms of ^{206}Pb/^{238}U ages in Figure 3 (A–C). The single most striking characteristic of the results is the abundance of Late Cretaceous ages, many of which are as young as 70–80 Ma. Two of the samples (UG1417A and 98-241) display strongly bimodal age distributions (Figs. 2 and 3). For example, nearly three-quarters of the ^{206}Pb/^{238}U ages in sample UG1417A are between 70 and 100 Ma, whereas most of the remaining values are either ca. 1.7 Ga or yield upper intercepts near this age when projecting from 100 Ma. Sample 98-241 shows a broadly similar distribution, but with a higher proportion of pre-100 Ma dates and a greater degree of discordance. Zircons from the third sample (98-240) are mostly Cretaceous, although skewed to somewhat older ages (80–125 Ma) than the Cretaceous fractions from the other two samples. Another major distinction of sample 98-240 is that only two Precambrian grains were identified. All three samples include a small number of Jurassic and/or Triassic grains.

AGE AND PROVENANCE OF THE SCHIST

The distribution of U-Pb zircon ages obtained in this study is most consistent with the derivation of the schists' protoliths from a middle to Late Cretaceous batholith intruded into dominantly ca. 1.7 Ga crystalline basement. The youngest detrital zircon ages indicate maximum depositional ages for the three samples of 70–80 Ma, substantially different from the 163 and 131 Ma minimum ages proposed by Mukasa et al. (1984) and James and Mattinson (1988). It is conceivable that all these age inferences are correct and that accumulation of the protolith occurred over a time span of 90 m.y. or longer. However, inasmuch as the igneous units dated by Mukasa et al. (1984) and James and Mattinson (1988) do not definitely intrude the

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[1] GSA Data Repository item 200024, Appendixes 1 and 2 and Tables 1–3, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/drpint.htm.

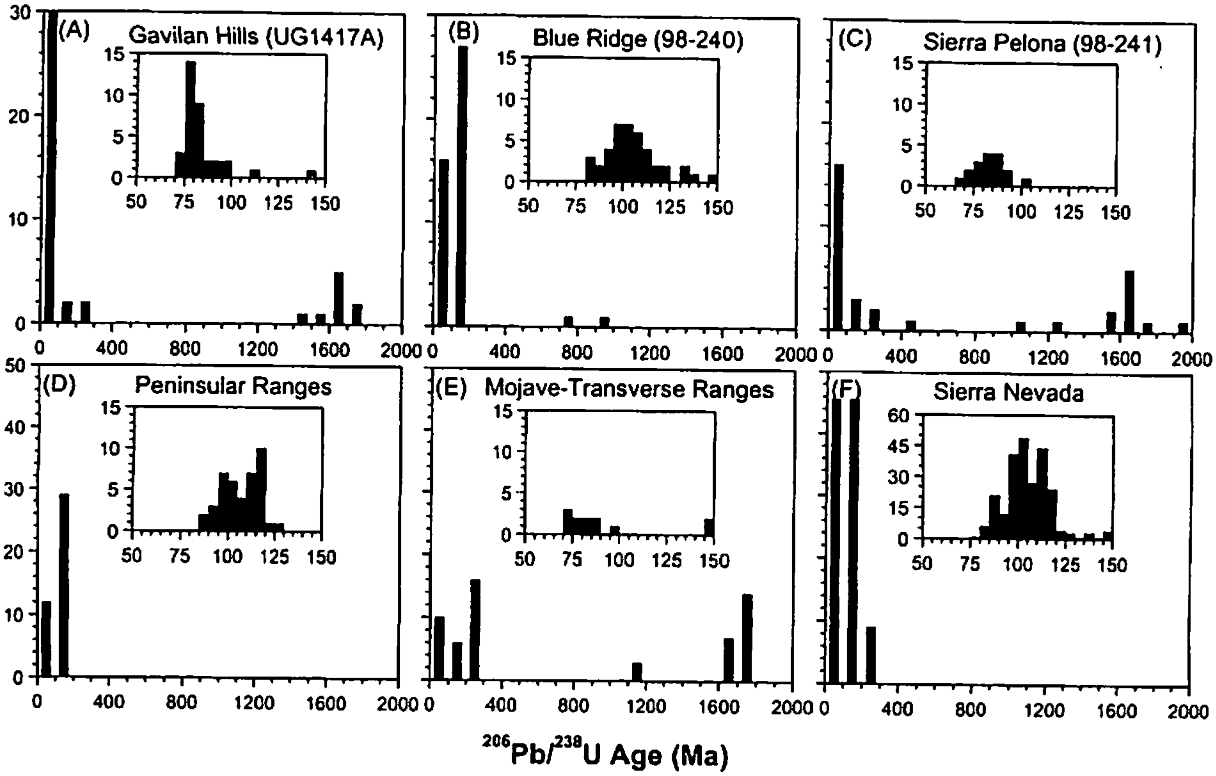

Figure 3. Histogram plots of detrital zircon ages from three analyzed samples of Pelona and Orocopia Schists (A–C) and inferred crystallization ages of Cretaceous and older igneous rocks in Peninsular Ranges (D), Mojave Desert and Transverse Ranges (E), and Sierra Nevada (F). Sources of data for D–F are listed in Appendix 2 (see footnote 1). Insets show detail for ages in range 50–150 Ma.

schists, sedimentation could also have occurred solely within the Late Cretaceous. Evidence that this is the case is the remarkably uniform composition of the schists (Ross, 1976; Haxel and Dillon, 1978), which contrasts sharply with the pronounced variation in composition with age exhibited by the Upper Jurassic to Upper Cretaceous Great Valley Group and Franciscan Complex (Dickinson et al., 1982; Ingersoll, 1983; Linn et al., 1992). Notably, those parts of the Great Valley Group and Franciscan Complex compositionally most similar to the schists (high sand/shale ratio) are Late Cretaceous age (Smith et al., 1979; Ingersoll, 1983).

The preponderance of zircon ages younger than 80 Ma (Fig. 2) places an important constraint on the source area of the schists. Although plutons younger than about 80 Ma are uncommon within the Sierra Nevada batholith (Fig. 3A; Bateman, 1992) and absent from the Peninsular Ranges batholith (Fig. 3B; Silver and Chappell, 1988), intrusions of this age characterize the Mojave Desert and central to eastern Transverse Ranges of southern California (Fig. 3C; Foster et al., 1989; Walker et al., 1990; Barth et al., 1995). The Mojave Desert and Transverse Ranges also provide good matches for the schists in terms of the pre-Cretaceous part of the age distribution (Figs. 2 and 3; Wooden and Miller, 1990).

IMPLICATIONS FOR RATE OF THRUSTING

Rb-Sr and ^{40}Ar/^{39}Ar ages from metamorphic white mica and hornblende from the Pelona and Orocopia Schists in the San Gabriel, Orocopia, and Chocolate Mountains indicate a minimum metamorphic age of ca. 60–65 Ma (Fig. 1B; Ehlig, 1981; Jacobson, 1990). This constrains the interval between deposition (<70–80 Ma) and maximum burial of the Pelona and Orocopia Schists to at most 10–15 m.y. The 20–35 km depth of peak-grade recrystallization inferred for these rocks (Graham and Powell, 1984; Jacobson, 1995) thus requires a minimum burial rate of ~1–3 mm/yr. Assuming a thrust dip of 15° (Grove and Lovera, 1996), our results indicate a minimum slip rate prior to 65 Ma of ~4–12 mm/yr. If the movement was continuous between 75 and 50 Ma, this slip rate would imply that the Vincent–Chocolate Mountains thrust accommodated ~250 km of displacement during the interval, which corresponds to a horizontal component of convergence of ~200 km. Additional data of this type may assist in selecting between contrasting models for the evolution of the fault (e.g., Barth and Schneiderman, 1996; Jacobson et al., 1996).

REGIONAL VARIATION WITHIN THE SCHISTS

The 70–80 Ma maximum depositional age for the schists' protoliths determined in this study is based on samples from the southern half of the terrane (Fig. 1B). Available data indicate that the protoliths of the more northern schists must be somewhat older, as demonstrated by their mica and hornblende ^{40}Ar/^{39}Ar ages of 72–82 Ma (Fig. 1B; Jacobson, 1990) and clear intrusive contacts with plutons dated as about 79–85 Ma (Silver and Nourse, 1986; James and Mattinson, 1988). An age difference between northern and southern parts of the terrane has long been suspected (Burchfiel and Davis, 1981), and Barth and Schneiderman (1996) proposed that it was due to the southward-migrating point of impingement between the Farallon–North America trench and an obliquely subducting oceanic plateau. Whatever the origin, the spatial variation in age seems opposite to that predicted for large-scale northward strike-slip passage of exotic terranes along the California margin during the Late Cretaceous to early Tertiary, such as that proposed in the Baja British Columbia hypothesis (Cowan et al., 1997).

CONCLUSIONS

On the basis of our results and those of previous workers, we conclude that (1) at least part, if not all, of the schists' protoliths were deposited in the Late Cretaceous and were derived largely from the Late Cretaceous granitoids and Proterozoic host rocks that characterize the Mojave Desert and Transverse Ranges; (2) the protolith age is consistent with the schists being related to either the Great Valley Group or the Franciscan Complex;

(3) the schists were thrust beneath western North America at a minimum rate of ~4–12 mm/yr; and (4) emplacement of the schists propagated southward along the margin, contrary to the northward migration of deformation that might be expected from the Baja British Columbia hypothesis.

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