Tectonic implications for the along-strike variation of the Peninsular Ranges batholith, southern and Baja California

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ABSTRACT

The Jurassic-Cretaceous Peninsular Ranges batholith of southern and Baja California exhibits several along-strike variations that are most pronounced across the Agua Blanca fault. These variations include differences in the age of magmatism, degree of inheritance in zircons, depositional environment of volcanic strata, extra-arc basin geography, lateral extent of continentally derived flysch strata, and the structures attending juxtaposition of the two segments with the North American continental margin and with each other. We propose that these variations, when taken together, imply that the two segments of the western zone currently juxtaposed by the active Agua Blanca fault were accreted to North America diachronously and did not share a common history prior to the late Early Cretaceous. The Santiago Peak arc segment north of the fault developed on oceanic lithosphere juxtaposed with the continental margin prior to and during arc magmatism. Conversely, the Alisitos arc segment developed on oceanic lithosphere exotic to North America prior to accretion at 115–108 Ma. If this model is correct, it implies that the Agua Blanca fault initiated as a transpressional continuation of the suture joining the latter arc segment to the continent and that a large portion of the forearc that existed between them was subducted.

Keywords: Peninsular Ranges batholith, accretion, island arc, Agua Blanca fault, Main Mártir thrust.

INTRODUCTION

The Peninsular Ranges batholith (Fig. 1A) of southern and Baja California is the southernmost segment of a chain of North American Mesozoic batholiths extending from Alaska to the tip of Baja. Similar to other segments of this chain, the Peninsular Ranges batholith is laterally zoned with a mafic western zone juxtaposed with a felsic eastern zone. The basement of the western zone (i.e., that through and upon which batholithic plutons and volcanics were emplaced) is inferred to be oceanic lithosphere (e.g., DePaolo, 1981). In contrast, the basement of the eastern zone is inferred to be transitional to continental crust. The timing of, and processes responsible for, the juxtaposition of these two disparate lithospheric types remains a controversial and unresolved issue in Peninsular Ranges geology.

Several tectonic models have been proposed to explain the Mesozoic evolution of the Peninsular Ranges batholith and the relationship of the western zone to the continental margin. These may be distilled to two end members: (1) a single inboard-propagating arc developed across a pre-Triassic join between oceanic and continental lithospheres (Walawender et al., 1991; Thomson and Girty, 1994); and (2) an exotic island arc accreted to the continent between 115 and 108 Ma (Johnson et al., 1999a). We suggest that the differences between these models reflect tectonically significant along-strike variations in the character of the batholith. The study areas upon which each model is based are separated by the Agua Blanca fault, an active dextral strike-slip fault that we suggest originated as a sinistrally transpressive fault during the Mesozoic evolution of the Peninsular Ranges batholith (Fig. 1A).

In this investigation we review the significant along-strike variations of the Peninsular Ranges batholith, propose a tectonic model that fits the disparate data sets from various parts of the batholith, and discuss some of the implications for this model.

Zonation of the Peninsular Ranges Batholith

The Peninsular Ranges batholith has traditionally been divided into distinct northwest-southeast–trending zones delineated by a number of criteria, including prebatholithic stratigraphy, pluton composition, Fe-Ti oxide mineralogy, geochemistry, level of crustal exposure, and structural history. Given that these criteria are not all coincident in space but rather define a relatively broad zone, we propose that a transitional zone exists between typical western and eastern zones (Fig. 1A). Furthermore, based on recent investigations of Sierra San Pedro Mártir, it appears that the transitional zone had a distinct geologic history relative to regions to the west and east (e.g., Schmidt, 2000).

Plutons of the Peninsular Ranges batholith intrude a series of batholith-parallel, lithostratigraphic belts (Fig. 1A) that define the three zones of the batholith. Jurassic-Cretaceous arc volcanics and volcaniclastics compose the western zone, Triassic to Cretaceous continentally derived flysch and, locally, Ordovician-Permian slope basin deposits dominate the transitional zone, and Ordovician-Permian slope basin to Late Proterozoic–Paleozoic miogeoclinal assemblages characterize the eastern zone (Gastil, 1993). Western zone plutons are generally gabbros to granodiorites characterized by depleted rare earth element

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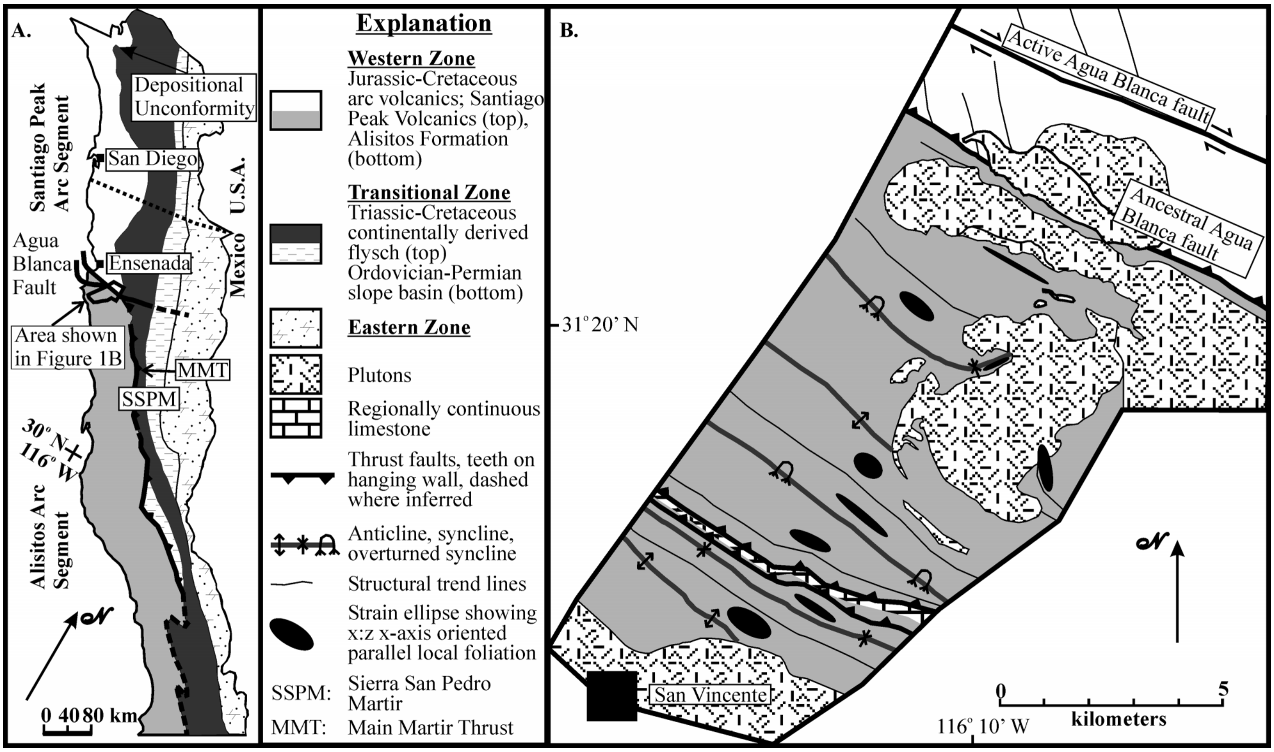

Figure 1. A: Tectonic map of Peninsular Ranges batholith (PRb) showing three zones of batholith, component lithologies of western and transitional zones, and segments of western zone. Modified from Gastil (1993). B: Preliminary geologic map of San Vincent–Agua Blanca fault region of western PRb.

(REE) abundances (Gromet and Silver, 1987) and primitive isotopic signatures (Taylor and Silver, 1978; DePaolo, 1981). Transitional and eastern zone plutons are generally granodiorites to granites characterized by eastward-increasing light REE enrichments and evolved isotopic signatures. The change from western to transitional and eastern zones also includes a change from punctuated weak to moderate deformation at shallow crustal levels (~2 kbar; Johnson et al., 1999b) in the western zone, to protracted intense deformation at deeper crustal levels (4–6+ kbar) in the transitional and eastern zones. However, a critical structure in the late Early Cretaceous evolution of the batholith is the ancestral Agua Blanca fault, which is coincident with several significant along-strike variations to the character of western and transitional zones.

Santiago Peak Arc Segment and Adjacent Transitional Zone

The Santiago Peak arc segment extends from the Agua Blanca fault to the Transverse Ranges of southern California (Fig. 1A). The Santiago Peak Volcanics, the Jurassic-Cretaceous arc stratigraphy of this segment, yield Late Jurassic fossils (Fife et al., 1967) and U-Pb zircon ages that range from 138 to 120 Ma (Silver and Chappell, 1988); many samples exhibit Precambrian inheritance[1]. The volcanics are characterized by densely welded, subaerially deposited ridge-forming tuffs of mafic to felsic composition, rare interbedded sediments (Herzig, 1991), and a deep marine basin along the western side of the Santiago Peak arc in southern California (Balch et al., 1984).

The transitional zone adjacent to the Santiago Peak arc segment is relatively broad (>100 km), due both to laterally extensive exposures of continentally derived flysch (>50 km) and relatively gentle west-east geochemical gradients (e.g., Taylor and Silver, 1978). The boundary between this arc segment and the transitional zone is not observed as tectonic. Kimbrough and Herzig (1994) reported a depositional unconformity between the flysch and the Santiago Peak Volcanics in the Santa Ana Mountains.

The southern part of the Santiago Peak arc segment exhibits little evidence to suggest displacement with respect to the transitional zone or the Agua Blanca fault. The boundary between the arc segment and the transitional zone is characterized by depositional contacts with little to no deformation. Similarly, the regional trends of strata and broad open folds are truncated by the west-northwest–trending Agua Blanca fault without significant deflection, increased strain intensity, or metamorphism (Fig. 1B).

Alisitos Arc Segment and Adjacent Transitional Zone

The Alisitos arc segment extends from the Agua Blanca fault to at least the Sierra Calamajue area, south of which it is covered by younger strata. The Alisitos Formation, the Jurassic-Cretaceous arc stratigraphy of this segment, yields Albian-Aptian fossils (Silver et al., 1963; Allison, 1974) and U-Pb zircon ages of 116 ± 2 Ma and 115 ± 1.1 Ma (Carrasco et al., 1995; Johnson, 2002) without observed inheritance. The formation is characterized by poorly welded, subaqueously deposited tuffs, abundant interbedded volcaniclastics, a regionally extensive ridge-forming limestone, and locally abundant pillow basalts. Suarez-Vidal (1986) noted that the strata along the eastern side of the arc segment represent deposition in a tectonically calm marine environment.

The transitional zone adjacent to the Alisitos arc segment is fairly restricted in lateral extent (≤25 km; Fig. 1A), with limited exposures of the continentally derived flysch strata (≤10

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[1] GSA Data Repository item 2002025, U/Pb zircon data from Santiago Peak volcanic samples, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80901-9140, USA, editing@geosociety.org, or at www.geosociety.org/pub/ft2002.htm.

TABLE 1. VARIATIONS BETWEEN THE TWO WESTERN ZONE ARC SEGMENTS

Arc segment	Santiago Peak	Alisitos
Age of magmatism	130 to 120 Ma	117 to 108 Ma
Inherited zircons	Observed within both volcanics and plutonics	Not observed
Depositional environment of Jurassic-Cretaceous stratigraphy	Subarial	Submarine
Geography of extraarc basins	West of active arc	East of active arc
Lateral extent of flysch and transitional zone	Flysch ≤ 50 km Transitional zone ≤ 100 km	Flysch ≤ 5 km Transitional zone ≤ 25 km
Western to transitional zone boundaries	Depositional unconformity	Large ductile shear zone
Distribution of deformation	Distribution of deformation	Plutonic aureoles, along eastern and northern limits to the arc segment
Deformation associated with Agua Blanca fault	Deformation associated with Agua Blanca fault	Regional change in structural trend, high strain intensities and amphibolite grade metamorphism

km). The Main Mártir thrust (Fig. 1A; a prominent ductile, east-dipping, west-vergent shear zone within a larger fold-and-thrust belt along this boundary) of the northern Sierra San Pedro Mártir, and its along-strike correlatives (Griffith and Hoobs, 1993; Schmidt, 2000), marks the lithologic, petrochemical, barometric, and structural boundaries between the arc segment and the transitional zone. These boundary faults also mark the western limit of all continentally derived material and form the only means of juxtaposition of such strata with the Alisitos Formation. Johnson et al. (1999a) defined the timing of this juxtaposition by the age of stitching plutons between 115 and 108 Ma.

The Alisitos arc segment exhibits evidence of substantial displacement with proximity to both the Main Mártir thrust and the Agua Blanca fault. The regional structural trend of the Alisitos arc segment, defined by folds axes and the strike of intraformational thrust faults of the southwest-vergent fold-and-thrust belt, generally range between N15°W and N40°W (e.g., Johnson et al., 1999a). This trend is subparallel to that of the eastern boundary faults. Open folds, lower greenschist metamorphism, and low strain intensities (<20% shortening) in the western and central portions of the arc segment change to tight and isoclinal folds, lower amphibolite-grade metamorphism, and intense strain (>60% shortening) along the eastern boundary (Fig. 1B; Schmidt, 2000). North of the Sierra San Pedro Mártir the fold-and-thrust belt exhibits a gradual rotation from subparallel to the Main Mártir thrust to subparallel to the Agua Blanca fault (i.e., N60°–65°W). Along the Agua Blanca fault, this fold-and-thrust belt is also characterized by increased metamorphic grade and strain, similar to that observed adjacent to the Main Mártir thrust (Fig. 1B).

TECTONIC IMPLICATIONS

A comparison of the Alisitos and Santiago Peak arc segments defines several variations in the along-strike character of the western and transitional zones of the batholith. These include (Table 1): (1) age of magmatism; (2) existence of inherited zircons; (3) depositional environment of the arc strata; (4) location of extraarc basins; (5) lateral extent of the transitional zone and continentally derived flysch strata; (6) nature of the boundary between the arc segments and the transitional zone; and (7) character of deformation associated with the ancestral Agua Blanca fault. These variations are most pronounced across the Agua Blanca fault and, when taken together, imply profound differences in the tectonic evolution of the Peninsular Ranges batholith north and south of the fault.

Models suggesting a prebatholithic juxtaposition of the western zone with the continental margin (e.g., Walawender et al., 1991) are most applicable to observations made of the Santiago Peak arc segment and the adjacent transitional zone, where zircon inheritance and depositional contacts between the volcanics and the underlying flysch indicate that at least the eastern portion of the Santiago Peak arc segment must be developed through and on basement that included continental deposits. Furthermore, the lack of a discrete boundary (i.e., high strain and/or shear zone) between the arc segment and the transitional zone, or even synmagmatic basin strata preserved between the two zones and with the observed depositional contacts between volcanics and flysch, clearly implies that the arc developed in situ and not as a rifted fringing arc.

In contrast, the exotic arc model is best supported by observations of the Alisitos arc segment and its adjacent transitional zone. The lack of observed zircon inheritance suggests that it did not develop through crust with a continental component. Similarly, the lack of observed depositional contacts between arc and continentally derived strata, and the identification of a laterally continuous west-vergent ductile shear zone (e.g., Main Mártir thrust) that separates the two zones, suggests that this arc segment did not develop on basement that evolved juxtaposed to the continental margin.

If correct, then the following must be true. (1) A large proportion of the transitional zone currently adjacent to the Alisitos arc segment was tectonically removed from the margin. (2) The Agua Blanca fault originated as a continuation of the suture between the arc segment and the North American margin, here juxtaposing the two arc segments; it likely underwent sinistral transpression.

Several plutonic bodies <5 km east of the Main Mártir thrust yield ages between 133.9 ± 1.5 and 127.8 ± 1.6 Ma (Johnson et al., 1999a) and possibly as young as 118 ± 3 Ma (Schmidt, 2000). Thus, an arc, the southward continuation of the Santiago Peak arc, existed within the transitional zone just prior to the accretion of the Alisitos arc. However, the forearc to this arc is not preserved. The identification of juxtaposition of disparate lithospheric types such as that observed in the Sierra San Pedro Mártir suggests the potential for major strike-slip dislocations (e.g., Salmon River suture, Idaho; Lund and Snee, 1988). Nevertheless, detailed structural studies in the Sierra San Pedro Mártir by Johnson et al. (1999a) and Schmidt (2000) identified little

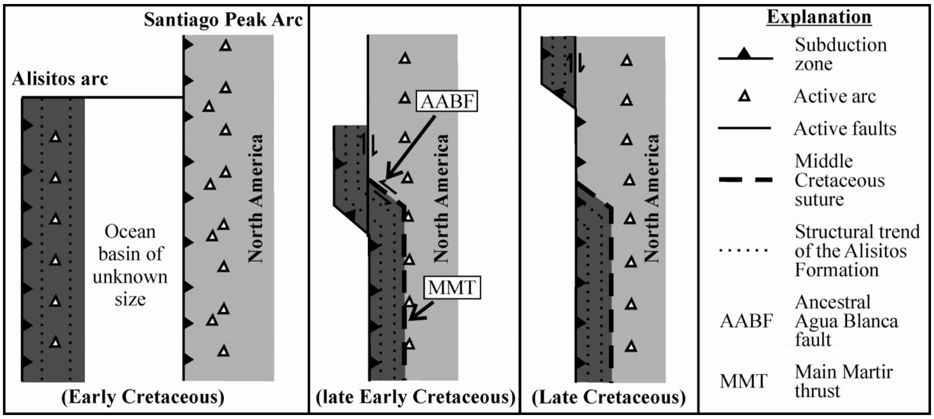

Figure 2. Tectonic model for Mesozoic evolution of Peninsular Ranges batholith.

evidence to support arc-parallel translations. An alternative to translation is subduction of the forearc. This alternative is easily tested because forearc subduction may produce a geochemically observable signature identifiable through comparison of the transitional and eastern zone plutons north and south of the Agua Blanca fault.

If the Alisitos arc segment was exotic to North America, then the Main Mártir thrust and its along-strike equivalents form a nonterminal suture (Dewey, 1977). Similar arguments must be true for the Agua Blanca fault because it juxtaposes two arc segments that were not related prior to accretion of the Alisitos. However, the fault strikes oblique to the axis of the batholith and thus must have undergone both contraction and sinistral translation. The observed counterclockwise rotation of the structural trends in the northern portion of the Alisitos arc segment away from subparallelism with the Main Mártir thrust and to subparallelism with the Agua Blanca fault is consistent with a deflection associated with a sinistral shear zone.

SUMMARY

Several tectonic models have been proposed to explain the origin of the lateral zonation of the Peninsular Ranges batholith. However, these models typically fail to agree even on the most fundamental aspects of the timing and means by which the mafic western zone came to be juxtaposed with the continental margin. The differences in these models result partly from the observation that the western and transitional zones of southern and Baja California exhibit several along-strike variations in character that are most pronounced across the Agua Blanca fault. We propose a model (Fig. 2) wherein the Santiago Peak arc segment developed on oceanic basement that had been structurally juxtaposed with the continental margin prior to arc magmatism, and the Alisitos arc segment and its oceanic basement was exotic to North America prior to its accretion in the late Early Cretaceous. Santiago Peak basement served as a depositional substratum for material being shed from the continent during the early and middle Mesozoic evolution of the Peninsular Ranges batholith. Basins of similar composition and size probably extended the length of the batholith. However, accretion of the Alisitos arc segment implies that a significant proportion of these basins, which also formed the forearc to the southward continuation to the Santiago Peak arc, must have been removed, possibly through subduction. Furthermore, this diachronous accretion model also implies that the currently active Agua Blanca fault is an inherited structure that originated as a sinistral transpressional continuation of the suture that juxtaposes the Alisitos arc segment with the continent.

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