Missing Idaho arc: Transpressional modification of the ^{87}Sr/^{86}Sr transition on the western edge of the Idaho batholith

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ABSTRACT

The North American Cordillera is characterized by subduction-related Mesozoic batholiths with voluminous middle Cretaceous plutonism. In the Cordillera, the Idaho batholith is anomalous, containing only a narrow ($<$10 km) band of middle Cretaceous plutons on its extreme western margin. These plutons are spatially coincident with the Late Cretaceous, crustal-scale, dextral transpressional western Idaho shear zone. Finite strain analysis indicates that there is significant east-west shortening in the western Idaho shear zone. A reconstruction using isotopic variations as strain markers, and comparing them to the undeformed middle Cretaceous Sierra Nevada batholith, results in a middle Cretaceous magmatic arc in western Idaho similar in width ($\sim$85–100 km) to other sections of the Cordilleran magmatic arc. The tectonic implications include: (1) a full magmatic arc existed in Idaho in the middle Cretaceous prior to Late Cretaceous deformation; (2) the currently sharp ^{87}Sr/^{86}Sr transition in western Idaho represents structural modification of the batholith after emplacement (i.e., the steep isotopic gradient results from deformation); and (3) as a result of Late Cretaceous shortening in the western Idaho shear zone, the main part of the Idaho batholith (i.e., post–ca. 90 Ma) intruded farther eastward into thick North American lithosphere. Consequently, the main part of the Idaho batholith has a stronger continental signature than the other coastal batholiths.

Keywords: western Idaho shear zone, Idaho batholith, transpression, Sr 0.706 line, magmatic arc.

INTRODUCTION

The North America Cordillera is characterized by a series of granitic batholiths that records subduction under North America during the Mesozoic (Fig. 1) (e.g., Armstrong et al., 1977; Bateman, 1992). The type of lithosphere assimilated into these batholiths is recorded in their isotopic characteristics. The ^{87}Sr/^{86}Sr isotope ratios track the transition from plutons emplaced into oceanic lithosphere on the western (arc) side to those that intrude continental lithosphere on the eastern (craton) side; an ^{87}Sr/^{86}Sr isotope ratio of 0.706 is interpreted to mark the arc-craton boundary (e.g., Armstrong et al., 1977).

The arc-craton transition in western Idaho is extremely abrupt. The transition in ^{87}Sr/^{86}Sr ratios from $<$0.7045 to $>$0.707 occurs in $<$10 km (e.g., Criss and Fleck, 1987; Fleck and Criss, 1985; Manduca et al., 1992). Less well appreciated is that this abrupt transition is spatially coincident with a narrow belt of mylonites of the western Idaho shear zone (e.g., Lund and Snee, 1988; McClelland et al., 2000; Tikoff et al., 2001). Structural studies indicate that the western Idaho shear zone was deforming in dextral transpression (Lund and Snee, 1988; McClelland et al., 2000), resulting in northward translation of the island-arc complexes and east-west shortening across the shear zone (Fig. 2). The only plutons within the Idaho batholith that contain a clear oceanic-arc lithosphere isotope signature occur within or immediately adjacent to the western Idaho shear zone (e.g., Lewis et al., 1987; Fleck, 1990; Manduca et al., 1992, 1993).

The middle Cretaceous igneous rocks that record the abrupt ^{87}Sr/^{86}Sr transition are strongly deformed by the western Idaho shear zone. Previous explanations for this abrupt transition rely on intrusion of plutons along a steep arc-craton boundary formed by truncation of the craton prior to intrusion of the Idaho batholith (Davis et al., 1978; Hamilton, 1978; Selverstone et al., 1992; Manduca et al., 1993). However, east-west shortening across the western Idaho shear zone must have altered the spatial distribution of the original isotopic gradient. Thus, the abrupt nature of the ^{87}Sr/^{86}Sr gradient is the product of deformation processes overprinting magmatic processes. In this contribution we present a reconstruction of the western edge of the Idaho batholith to its middle Cretaceous geometry. Our analysis suggests that (1) initially, a much wider magmatic arc existed in western Idaho during the middle Cretaceous; (2) the existing ^{87}Sr/^{86}Sr gradient in western Idaho cannot be interpreted solely in terms of magmatic processes; and (3) the strong continental lithospheric signature of magmatism in the main Idaho batholith may be the indirect result of Late Cretaceous deformation of the western Idaho shear zone.

GEOLOGIC SETTING

The western Idaho shear zone is a mid-crustal exposure of an intra-arc shear zone located in west-central Idaho (McClelland et al.,

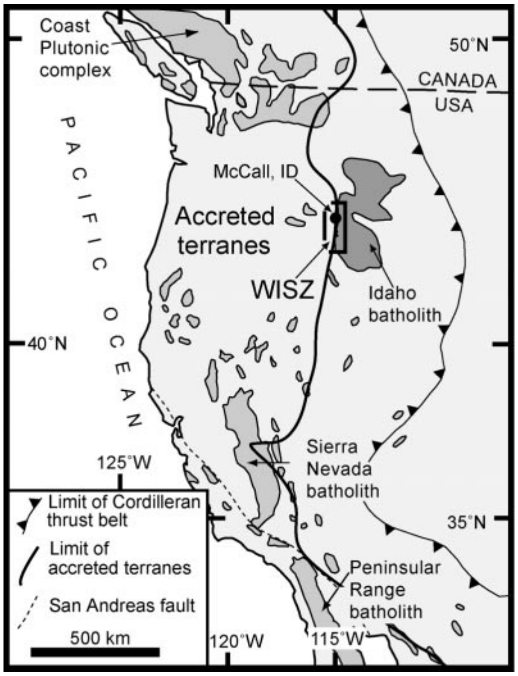

Figure 1. Location of major middle Cretaceous granitic batholiths and island-arc–craton boundary in North America Cordillera (modified from Tikoff et al., 2001). WISZ—western Idaho shear zone; ID—Idaho.

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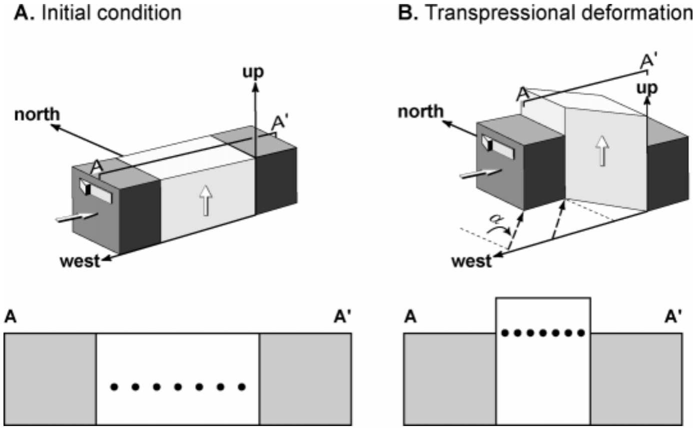

Figure 2. Transpression results in wrenching parallel to plate margin, shortening across shear zone, and vertical extrusion. Coordinate axes are labeled as appropriate for western Idaho shear zone. A: Series of material points are initially evenly distributed across deforming zone. B: Points are much more closely spaced as result of shortening component of deformation. As α, angle of oblique convergence in transpression, increases, deformation by shortening increases relative to deformation by wrenching.

2000; Tikoff et al., 2001). This high-strain zone is a Late Cretaceous structure that reactivated the Salmon River suture zone, which defines the arc-craton boundary in west-central Idaho (Manduca et al., 1993; Tikoff et al., 2001). A series of Cretaceous granitic complexes obscures the Early Cretaceous Salmon River suture zone, but is deformed by the Late Cretaceous western Idaho shear zone (Manduca et al., 1993). These plutonic complexes are subparallel to the shear zone and decrease in age from west to east with the Hazard Creek Complex, Little Goose Creek Complex, and Payette River tonalite yielding U-Pb zircon ages of 118 ± 5 Ma, 110 ± 5 Ma, and 90 ± 5 Ma, respectively (Manduca et al., 1993). A sharp isotopic gradient exists between the western plutons, which intruded the accreted island-arc complex, and those to the east, which intruded the North American craton (Fleck and Criss, 1985; Criss and Fleck, 1987; Manduca et al., 1992). These geochemical trends are coincident with the western Idaho shear zone and indicate that the change in lithosphere from island arc to craton occurs over a short distance (10–15 km), which suggests a subvertical boundary (Manduca et al., 1992).

Deformation in the western Idaho shear zone occurred in the Late Cretaceous. Magmatic fabrics within the Payette River tonalite (90 ± 5 Ma; Manduca et al., 1993) are parallel to the solid-state fabrics of the shear zone, indicating syntectonic emplacement. Thus, deformation was active by 90 ± 5 Ma. Preservation of magmatic fabrics in the Payette River tonalite indicates that little strain accumulated following emplacement of the tonalite; therefore, the main phase of deformation occurred prior to ca. 90 Ma, but after emplacement of the Little Goose Creek Complex ca. 110 Ma.

WESTERN IDAHO SHEAR ZONE

Fabric orientations and shear-sense indicators suggest that the ~5-km-wide western Idaho shear zone is best described by dextral transpressional kinematics (McClelland et al., 2000; Giorgis and Tikoff, 2004). Foliation in the shear zone generally strikes north, dips steeply to the east ($>60°$), and characteristically has a downdip lineation (Manduca et al., 1993). Boudinaged layers and quartz ribbons indicate that the downdip lineation is a stretching lineation, both in the McCall area and farther north along the Salmon River (Blake et al., 1989). Removal of the tilting caused by Miocene to Holocene extensional deformation restores foliation and lineation to a subvertical orientation (Tikoff et al., 2001). Shear-sense indicators on the lineation-normal face, including winged porphyroclasts and offset mafic layers, are consistent with a dextral sense of shear (McClelland et al., 2000).

MIDDLE CRETACEOUS RECONSTRUCTION OF THE WESTERN IDAHO BATHOLITH

The amount of east-west shortening across the western Idaho shear zone was estimated from the intensity of potassium feldspar megacryst fabrics in the Little Goose Creek Complex (Giorgis and Tikoff, 2004). Comparison of field fabrics to model results provides constraints on both the kinematics of transpressional deformation (i.e., α = angle of oblique convergence) and the total amount of finite strain. Modeling suggests a range of kinematic scenarios for the western Idaho shear zone ($\alpha = 30°–60°$), but is most consistent with an intermediate value ($\alpha = 45°$). Based on this range of kinematics, the numerical model suggests that the western Idaho shear zone records shortening by a factor in the range of 7–28. Given that the Little Goose Creek Complex is ~4 km wide and is contained entirely within the western Idaho shear zone, structural analysis suggests that the Little Goose Creek Complex was originally between 28 and 112 km wide (Fig. 2). Due to the dextral transpressional nature of deformation, northward translation occurred contemporaneously with east-west shortening. Finite strain estimates from the numerical model suggest that Early Cretaceous and older tectonic elements outboard of the western Idaho shear zone were translated 15–90 km northward.

The proposed shortening in the western Idaho shear zone is surprisingly large. Characterizing the relative movement of markers normal to the shear zone also suggests a large amount of east-west shortening (Fig. 2). We use the isotopic gradients contained within plutons of the Idaho batholith as strain markers. The ^{87}Sr/^{86}Sr data and U-Pb age data from the western Idaho batholith are compared to the data documented in the relatively undeformed Sierra Nevada batholith. We acknowledge that there is no a priori reason for a middle Cretaceous magmatic arc in Idaho to have dimensions and isotopic characteristics identical to those of the Sierra Nevada magmatic arc. Rather, the Sierra Nevada batholith is simply used as an approximation of a typical section of the Cretaceous magmatic arc in the Cordillera for purposes of comparison to the anomalous western Idaho batholith.

Restoration of Isotopic Gradients

Compilation of ^{87}Sr/^{86}Sr ratios on a transect across the middle Cretaceous part of the Idaho batholith delineates a steep transition from low values in the west to higher values in the east (Fig. 3). These data define a gradient of ~0.001 per 2 km. The same transition in the Sierra Nevada is more gradual, with a gradient of ~0.001 per 20 km (Fig. 3). Restoration of the Little Goose Creek Complex to a width of 100 km yields a gradient comparable to that observed in the Sierra Nevada batholith. This estimate is compatible with the estimate of shortening made using finite strain analysis (28–112 km).

An analysis of crystallization ages yields a similar result. The gradient in U-Pb zircon crystallization age in western Idaho is 0.25 mm/yr (Fig. 3). Chen and Moore (1982) identified a U-Pb crystallization age gradient of 2.7 mm/yr across the Sierra Nevada (Fig. 3). Restoration of the Little Goose Creek Complex to an original width of 85 km results in an age gradient in Idaho similar to that observed in the Sierra Nevada batholith.

Summary

Reconstruction of the middle Cretaceous section of the Idaho batholith, based on the isotopic gradients preserved in the Sierra Nevada batholith, results in an initial middle Cretaceous width of ~85–100 km for the Idaho batholith. This result is compatible with finite strain estimates that suggest an original width of 28–112 km. Neither approach provides a rigorously quantitative picture of the middle Cretaceous Idaho batholith; however, two conclusions are drawn from

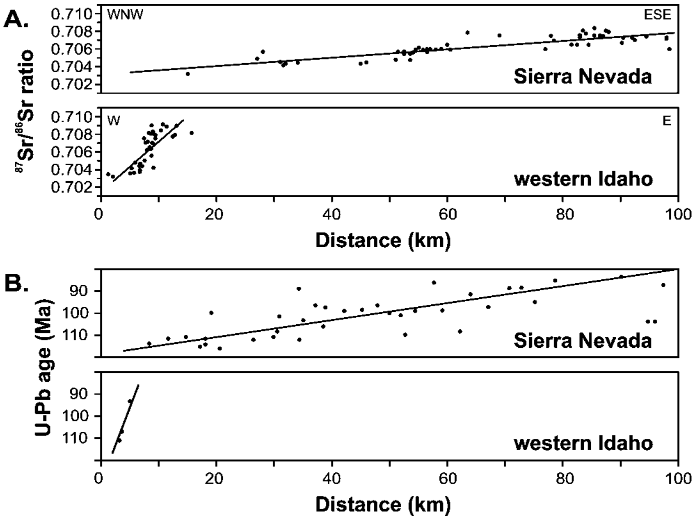

Figure 3. Isotopic gradients across Sierra Nevada (from Mariposa quadrangle) and western edge of Idaho batholith (near McCall, Idaho). A: ^{87}Sr/^{86}Sr ratios across Sierra Nevada batholith and western Idaho batholith (Manduca et al., 1992). Sierra Nevada data were compiled by J.S. Lackey (2004, personal commun.) from Kistler et al. (1986), Bateman et al. (1991), Chen and Tilton (1991), Kistler (1990; 1994; 1999, personal commun.), Kistler and Fleck (1994), and Truschel (1996). B: U-Pb crystallization ages across Sierra Nevada (Chen and Moore, 1982) and western Idaho batholith (Manduca et al., 1993).

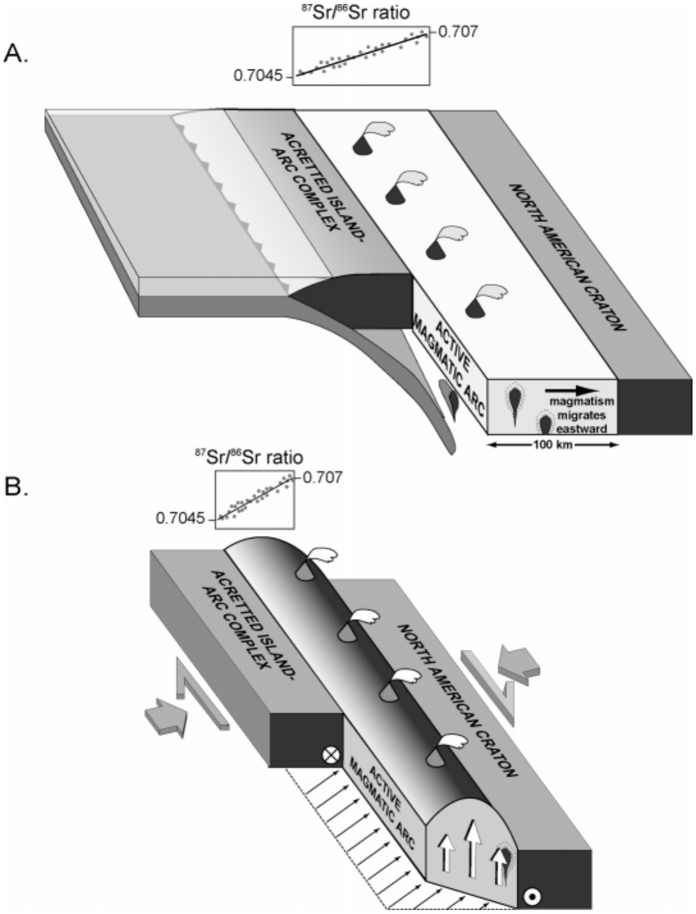

Figure 4. Tectonic model. A: During middle Cretaceous time, full magmatic arc developed in western Idaho after suturing of Wallowa–Seven Devils island-arc complex. B: In Late Cretaceous time, while magmatic arc was still active, transpressional deformation in western Idaho shear zone resulted in east-west shortening.

these analyses: (1) the western Idaho shear zone records a large amount of east-west shortening strain in the Late Cretaceous; and (2) there was a much wider middle Cretaceous magmatic arc in western Idaho prior to Late Cretaceous deformation.

DISCUSSION

Shortening of the middle Cretaceous magmatic arc has significant tectonic and magmatic implications for western Idaho and may explain a wide variety of geologic and geochemical data (Fig. 4). Assuming that the reconstruction is correct, the middle Cretaceous Idaho batholith was built on a continental margin similar to that present in the Sierra Nevada, and the steep isotopic transition reflects subsequent deformation. Models for pre-Cretaceous truncation of the North American craton are not necessary to explain the abrupt Sr isotopic transition. Shortening of the spatial distribution of these units may be the cause of the broad igneous trends mapped across western Idaho: a suite of more mafic granitoids (Hazard Creek Complex), a suite of intermediate-composition granitoids (Little Goose Creek Complex), and a suite of the more felsic granitoids (Payette River tonalite) (Manduca, 1988; Manduca et al., 1993; Lund et al., 1997). This same trend is observed over a much wider zone (~100 km) in the Sierra Nevada batholith (e.g., Bateman, 1992).

In western Idaho, it is difficult to explain how a single granitic pluton, the Little Goose Creek Complex, recorded a sharp Sr isotopic contrast with a consistent spatial trend. Undeformed plutons in the Sierra Nevada batholith can display significant variability in Sr isotope ratios (Kistler and Peterman, 1973). The consistent trends in Sr isotope ratios within the Sierra Nevada batholith occur at the batholith scale. If the isotope ratios in the Little Goose Creek Complex are the result of a telescoped gradient of normal isotopic variations, then the Little Goose Creek Complex is an aggregate of many plutons initially intruded over a wide region. Deformation of these plutons has obscured the variations in Sr isotope ratios of the individual plutons, but preserves the batholith-scale isotopic trends.

An unexpected outcome of this work is a possible explanation of the dominantly continental lithospheric signature of the post–90 Ma plutons of the Idaho batholith. Shortening of the magmatic arc may have forced the locus of magmatism in Idaho farther eastward under North America than most other coastal batholiths. The result of magmas intruding a thicker continental lithosphere may explain the pervasive strong continental affinity in the Idaho batholith (e.g., Lewis et al., 1987).

Further implications of this study for other elements in the Cordilleran orogen are not investigated in detail here. However, we recognize: (1) immediately west of the western Idaho shear zone there is no simple forearc and accretionary prism complex, but rather a series of accreted arc terranes (Vallier, 1995); and (2) there is a limited amount of demonstrable dextral movement accommodated in the western Idaho shear zone; therefore, major northward terrane translation cannot exclusively rely on this structure to accommodate large (>1000 km) motion.

CONCLUSIONS

Tectonic reconstruction (Fig. 4) of the western Idaho shear zone suggests that, in western Idaho, there was a full magmatic arc during the middle Cretaceous. Structural analysis of isotopic gradients suggests that this arc was possibly as wide as ~100 km. This arc and its isotopic signature were subsequently modified by transpressional deformation in the Late Cretaceous western Idaho shear zone. A magmatic arc in Idaho prior to deformation suggests that the western edge of North America was characterized by a normal continental margin at these latitudes in the middle Cretaceous. The modification of a preexisting arc by a shear zone—rather than granitic intrusion into a steep tectonic boundary—explains the shape and distribution of plutons in western Idaho. Furthermore, the continental nature of the Idaho batholith may be attributed to the shortening of the forearc, which may have forced the locus of magmatism under the North American craton. Our study highlights the connection between structural analysis and geochemical data. Later deformation events can significantly change the spatial distribution of isotopic signatures, obscuring a direct link to plutonic processes. Conversely, isotopic variations make excellent tectonic strain markers, provided there is some undeformed marker (e.g., the Sierra Nevada) for comparison.

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