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Magmatism as a response to exhumation of the Priest River complex, northern Idaho: Constraints from zircon U–Pb geochronology and Hf isotopes

L.M. Stevens [a,*], J.A. Baldwin [a], J.L. Crowley [b], C.M. Fisher [c,1], J.D. Vervoort [c]

[a] Department of Geosciences, University of Montana, 32 Campus Drive #1296, Missoula, MT 59812-1296, USA
[b] Department of Geosciences, Boise State University, 1910 University Drive, Boise, ID 83725-1535, USA
[c] School of the Environment, Washington State University, Pullman, WA 99164-2812, USA

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ABSTRACT

Zircon and monazite U–Pb geochronology and zircon Hf isotopes place constraints on the temporal and source relationships between crustal anatexis, magmatism, and exhumation of the Priest River metamorphic core complex, northern Idaho. Granitoids that intruded the migmatitic, pelitic Hauser Lake gneiss include the $<76.5 \pm 0.1$ Ma Spokane granite, 50.13 ± 0.02 Ma Silver Point quartz monzonite, c. 47.9 Ma Wrencoe granodiorite, $<46.4 \pm 1.8$ Ma Rathdrum granite, and a $<49.8 \pm 0.4$ Ma leucocratic dike. Cretaceous magmatism preceded the c. 64 Ma peak metamorphism (recorded by monazite) of the Hauser Lake gneiss, whereas discrete pulses of Eocene magmatic activity post-date the onset of exhumation by 10 Ma. The relative timing of pluton emplacement in the Priest River complex indicates that it was primarily a response to decompression rather than a cause. The mylonitized Silver Point and undeformed Wrencoe plutons bracket the end of a rapid phase of exhumation to c. 50–48 Ma. Zircon $\varepsilon_{Hf(i)}$ values and Lu–Hf isotope evolution indicate that the Silver Point and Wrencoe plutons crystallized from homogeneous magmas sourced from Archean–Proterozoic basement orthogneisses, whereas the Spokane granite and two leucocratic units appear to have been produced by partial melting of the Hauser Lake gneiss. Comparison of the Priest River complex with other deeply exhumed northern Cordilleran complexes indicates variability in the timing and, therefore, relative influences of partial melting and magmatism on the initiation of exhumation, which must be accounted for in numerical models of metamorphic core complex formation and evolution.

1. Introduction

Partial melting and magmatism are spatially and temporally associated with continental metamorphic core complexes in the North American Cordillera (e.g., Armstrong, 1982; Davis and Coney, 1979). The resulting decrease in crustal viscosity and strength due to the presence of melt may initiate and/or enhance core complex exhumation during gravitational collapse of thickened crust (e.g., Armstrong, 1982; Armstrong and Ward, 1991; Coney and Harms, 1984; Foster and Fanning, 1997; Gans et al., 1989; House et al., 2002; Lister and Baldwin, 1993; Vanderhaeghe and Teyssier, 2001). In order to assess the influence of partial melting and magmatism on exhumation of core complexes, the timing of these processes must be well constrained. Variation in the volume and timing of partial melting and magmatism among Cordilleran metamorphic core complexes suggests that the influence of each on exhumation may vary (e.g., Armstrong, 1982; Whitney et al., 2013). Such differences must be either allowed or accounted for in numerical models of metamorphic core complex formation and evolution.

Core complexes within the northern North American Cordillera typically exhibit greater degrees of partial melting and were exhumed during the Paleocene and Eocene, whereas complexes of the southern belt display lesser degrees of partial melting and were exhumed during the Oligocene and/or Miocene (Fig. 1; e.g., Armstrong, 1982; Coney, 1980; Coney and Harms, 1984; Rey et al., 2009a; Whitney et al., 2013). The northern belt core complexes are also similar in position relative to the Sevier thrust front, craton margin ($^{87}Sr/^{86}Sr = 0.706$), and the compressional North American plate margin. This study focuses on the northern belt complexes as examples of metamorphic core complexes with histories of partial melting and magmatism in a far-field compressional tectonic setting.

The degree of partial melting in core complexes within the northern Cordillera varies from the diatexite (melt-dominated) migmatites of the

* Corresponding author.
E-mail address: liane.stevens@umontana.edu (L.M. Stevens).
[1] Present address: Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3, Canada.

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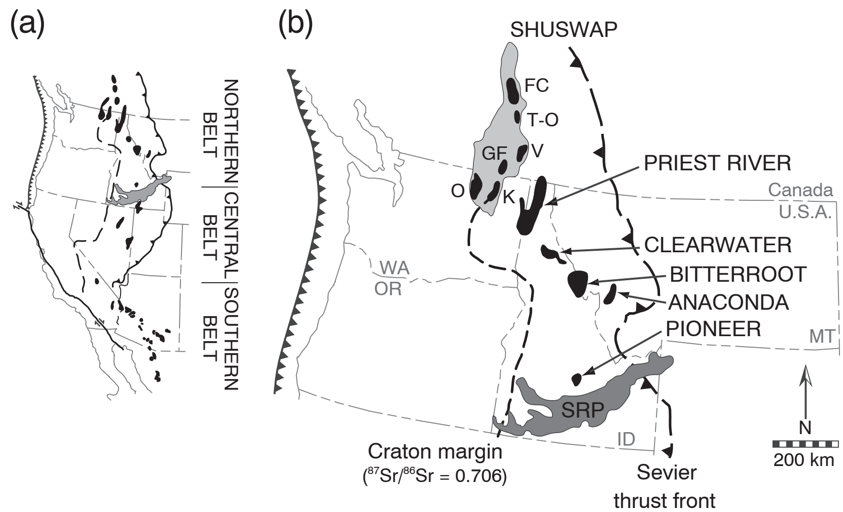

Fig. 1. Metamorphic core complexes of the northern North American Cordillera. (a) The northern, central, and southern belts of complexes in the North American Cordillera. (b) Core complexes in the northern belt of the North American Cordillera, including gneiss domes and complexes within the Shuswap complex. FC — Frenchman Cap; GF — Grand Forks; K — Kettle; O — Okanagan; SRP — Snake River Plain; T-O — Thor-Odin; V — Valhalla. (Modified from Stevens et al., 2015, and references therein).

Shuswap complex gneiss domes (e.g., Gordon et al., 2008; Norlander et al., 2002; Vanderhaeghe, 1999), to the metatexite (lower melt fraction) migmatites of the Priest River complex (e.g., Stevens et al., 2015), to migmatite-absent complexes, such as the Clearwater complex (e.g., Lang and Rice, 1985) (Fig. 1). Similarly, magmatism varies in character, volume, and timing. Leucogranite in the Thor-Odin dome within the Shuswap complex crystallized during exhumation (Fig. 1; Vanderhaeghe, 1999). In the Priest River complex, granitoid intrusions formed either well prior to peak metamorphism or following the onset of extension (syn- to post-kinematic) (Fig. 1; Archibald et al., 1984; Bickford et al., 1985; Doughty and Price, 1999; Harms and Price, 1992; Stevens et al., 2015; Whitehouse et al., 1992).

The Priest River complex (PRC) is located at the southern end of the Omineca crystalline belt, the eastern metamorphic core of the Cordillera; the Shuswap complex is also located within the Omineca Belt (Fig. 1; Parrish et al., 1988). The PRC, Shuswap, Clearwater, and Bitterroot complexes were exhumed from similar depths (~7–11 kbar, or ~23–33 km) (Fig. 1; Doughty et al., 2007; Foster et al., 2001; House et al., 1997; Norlander et al., 2002; Stevens et al., 2015). The PRC, along with the Shuswap and Bitterroot complexes, is among the larger complexes in the northern belt (Fig. 1); however, the Shuswap complex contains melt-dominated, vertically exhumed gneiss domes (e.g., Gordon et al., 2008; Norlander et al., 2002), and the Bitterroot complex is dominated by the Idaho batholith and behaved as a gneiss dome (e.g., Chase et al., 1983; Foster and Fanning, 1997; Hyndman, 1980). The PRC's shared characteristics with other northern belt complexes, as well as its lesser degree of partial melting and late pluton emplacement, suggest that it is a representative northern belt complex that will provide constraints on the relative influences of crustal anatexis and plutonism on exhumation.

In order to characterize the relationships between partial melting, magmatism, and exhumation in the PRC and other northern belt core complexes, two hypothetical end member scenarios are presented here. In the first scenario, partial melting and/or pluton emplacement occur during prograde metamorphism and crustal thickening, and thermal weakening initiates core complex exhumation. In the second scenario, partial melting and/or pluton emplacement are responses to decompression during exhumation and retrograde metamorphism. While melt may aid continued exhumation, it does not have a role in initiating exhumation in this scenario. The Valhalla dome of the Shuswap complex (Fig. 1) serves as an example of the first end member scenario, as leucogranite crystallized during exhumation, immediately following peak metamorphism (Gordon et al., 2008; Spear and Parrish, 1996). The Clearwater complex (Fig. 1) represents the latter scenario, as intrusion of Eocene (c. 52–46 Ma) granites followed Cretaceous–Tertiary prograde metamorphism and exhumation (Burmester et al., 2004; Doughty et al., 2007; Gaschnig et al., 2010; Marvin et al., 1984).

Evaluation of the scenarios presented above requires precise constraints on the timing of prograde metamorphism, exhumation, crustal melting, and magmatism. Constraints on the timing of the first three events in the PRC are based on monazite and xenotime petrochronology (Stevens et al., 2015); however, previous geochronological constraints on granitoids in the PRC lack the precision to determine the timing of emplacement relative to metamorphism and exhumation. This study analyzes zircon from metapelitic rocks and granitoids for U–Pb geochronology, trace element geochemistry, and Lu–Hf isotopes using laser-ablation inductively coupled plasma mass spectrometry (LA-ICPMS), chemical abrasion thermal ionization mass spectrometry (CA-TIMS), and laser-ablation split-stream multi-collector inductively coupled plasma mass spectrometry (LASS-MC-ICPMS). These new data improve the geochronological constraints on the emplacement of granitoids in the PRC footwall and clarify the temporal relationships between crustal melting, magmatism, and exhumation of the PRC, allowing for comparison with other core complexes in the northern belt of the North American Cordillera. These results thus have implications for the significance of crustal melting and magmatism in the formation of metamorphic core complexes.

2. Background

The majority of the PRC is located within the northern Idaho panhandle (Fig. 2). The footwall of the PRC was exhumed by the Purcell Trench fault to the east and the Newport fault to the northwest (Fig. 2). The footwall contains the Hauser Lake gneiss, which is a migmatitic, mylonitic, pelitic schist and gneiss that is considered the metamorphosed equivalent of the Prichard Formation, the lowermost unit of the Mesoproterozoic Belt Supergroup (Cressman, 1989; Doughty and Chamberlain, 2008; Lewis et al., 2010; Sears et al., 1998). The Hauser Lake gneiss was intruded by Cretaceous and Eocene granitoids (Fig. 2), as was the low-grade Belt Supergroup in the PRC hanging walls.

The pressure–temperature (P–T) conditions and timing of metamorphism of the Hauser Lake gneiss were reported by Stevens et al. (2015). Monazite and xenotime Th-Pb dating indicates metamorphism spanned