Deep-crustal metasedimentary rocks support Late Cretaceous “Mojave-BC” translation

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ABSTRACT

Metasedimentary rocks in the mid- to lower crust of exhumed continental arcs preserve information about both sedimentary provenance and metamorphic pressure-temperature paths, providing a unique perspective on the tectonic history of an arc, including margin-parallel translation and sediment-burial mechanisms. The Swakane Biotite Gneiss (Washington State, USA) and the Pelona, Orocopia, Rand, Sierra de Salinas, and related schists (PORS) (California and Arizona) represent metasedimentary rocks that were incorporated into the deep levels of North American Cordilleran arc systems. We evaluated the provenances for the sedimentary protoliths of these units by detrital zircon U-Pb and Hf-isotope analyses to assess paleogeographic reconstructions for western North America. All samples have similar Mesozoic peaks, and Proterozoic age populations (1.38 Ga and 1.6–1.8 Ga) are present in samples with maximum depositional ages younger than ca. 86 Ma. Zircon Hf-isotope results are similar for these Proterozoic populations, but the Swakane Mesozoic zircon samples reveal slight differences in comparison to PORS samples. Similar detrital zircon patterns, timing of emplacement, lithology, and structural setting suggest that these two distinct units formed at the same latitude and are consistent with recent interpretations of paleogeographic data that indicate “moderate” (~1600 km) northward translation for the North Cascades arc. This study provides an example of how sediment provenance signatures combined with interpreted metamorphic histories can be used to track vertical displacement and horizontal translation within a complex, long-lived, convergent-margin system.

INTRODUCTION

Convergent margins are typically defined by large-scale structures that accommodate geologically rapid orogen-normal translation of crustal material. However, many convergent margins are oblique, which may lead to a component of orogen-parallel strike-slip faulting (e.g., Teysier et al., 1995). Quantifying strike-slip offsets can be difficult, as similar geologic processes can occur for potentially tens of millions of years over thousands of kilometers along strike, making it hard to establish the amount of margin-parallel translation. This is the case for wide swaths of coastal terranes that form the western North American continental margin.

The paleogeography of western North America has been widely debated since paleomagnetic studies over 40 years ago revealed anomalously shallow magnetic inclinations in rocks within the Coast Plutonic Complex–North Cascades range, British Columbia (BC; Canada) and Washington State (USA) (Fig. 1) (Beck and Noson, 1972). The paleomagnetic data were interpreted as evidence that these rocks originated in Baja California, Mexico (Baja) and were translated ~3000 km northward from 85 to 55 Ma (i.e., the “Baja-BC” hypothesis); Irving et al., 1985). More recent paleomagnetic studies suggest moderate (~1600 km) amounts of northward translation (Krijgsman and Tauxe, 2006; Rasmussen et al., 2013) from near the modern-day northwestern Mojave Desert or southernmost Sierra Nevada (California) (i.e., the “Mojave-BC” hypothesis). However, measured offsets on known strike-slip faults only account for ~700–1000 km of margin-parallel displacement (Wyld et al., 2006). The discrepancies between the paleomagnetic and geologic data sets have resulted in two main Late Cretaceous reconstructions, restoring the suspect terranes of Washington and British Columbia to the latitude of either the Klamath Mountains (California and Oregon; ~700 km) or the southern Sierra Nevada batholith (~1600 km).

Detrital zircon geochronology can serve as a “crucial test” for discerning between paleogeographic hypotheses (e.g., Mahoney et al., 1999; Matthews et al., 2017). Here, we compare detrital zircon U-Pb ages and Hf-isotope compositions with interpreted emplacement histories for deep-crustal metasedimentary rocks of the Pelona, Orocopia, Rand, Sierra de Salinas, and related schists (PORS) in southern California and Arizona (USA) and the Swakane Biotite Gneiss (herein referred to as the Swakane Gneiss) in north-central Washington (Fig. 1) to evaluate Late Cretaceous–Paleogene translation hypotheses for the western margin of the North American Cordillera.

GEOLOGIC SETTING

The PORS and Swakane Gneiss are composed of ~290% homogeneous quartzofeldspathic schist or gneiss with minor metabasite and rare ultramafite, metachert, and marble (Haxel and Dillon, 1978; Tabor et al., 1987), consistent with a sandstone protolith imbricated with slices of oceanic material. These protoliths reached depths of as much as ~40 km within a few million years after deposition within the trench and/or forearc basin (Grove et al., 2003; Matzel et al., 2004). Neither unit is intruded by Late Cretaceous–Eocene arc-related plutons, nor are...
Figure 1. Major Mesozoic tectonic elements of western North American Cordilleran arc and sample locations of Pelona, Orocopia, Rand, and Sierra de Salinas schists and Swakane Gneiss. CPC—Coast Plutonic Complex; FC—Franciscan Complex; GF—Garlock fault; GV—Great Valley Group; IB—Idaho batholith; KM—Klamath Mountains; NC—North Cascades; NF—Nacimiento fault; PR—Peninsular Ranges batholith; RLF—Ross Lake fault zone; SAF—San Andreas fault; SCF—Straight Creek fault; SN—Sierra Nevada. States and provinces: AZ—Arizona; BC—British Columbia; CA—California; ID—Idaho; MT—Montana; NV—Nevada; OR—Oregon; UT—Utah; WA—Washington.

the bases of the units exposed. Both are separated by low-angle faults from overlying units.

The PORS are interpreted as underplated accretionary wedge and/or forearc basin sediments analogous to the Franciscan Complex and Great Valley Group of California (Grove et al., 2003; Jacobson et al., 2011; Chapman, 2016). Progressive underplating of sediment along a low-angle subduction system began by ca. 90 Ma (Grove et al., 2003; Saleeby, 2003) followed with the number of 250–100 Ma dates. The ca. 87 Ma Rand sample is characterized by dominantly Mesozoic zircon, whereas the ca. 85 Ma Swakane Gneiss samples also have Late Cretaceous zircon have uniform, near–radiogenic εHf values (+13 to +15), whereas the majority in the Orocopia and Sierra de Salinas samples show mostly unradiogenic εHf values (+1 to −15). However, the majority of the samples have a wide range of εHf values (+13 to −15), whereas the majority in the Orocopia and Sierra de Salinas samples show mostly unradiogenic εHf values (+1 to −15). (Fig. 2B).

Sediment provenance

The Swakane Gneiss, PORS, and California accretionary wedge strata (Franciscan Complex) all record a switch in zircon provenance ca. 86 Ma: pre–86 Ma rocks contain dominantly Mesozoic zircon, whereas stratigraphic data at post–86 Ma sample includes 10%–65% Proterozoic grains (Jacobson et al., 2011; Dimitrutu et al., 2016; Sauer et al., 2018). The shift in sediment provenance has been linked to two different sources. Dimitrutu et al. (2016) proposed that Proterozoic zircon in the ca. 85 Ma Sierra de Salinas schist and the post–ca. 86 Ma Swakane Gneiss are
derived from sediment partly eroded from ca. 1.38 Ga anorogenic intrusions in the Lemhi subbasin of the Belt Supergroup (northwestern Laurentia) and the Late Cretaceous Idaho batholith (Fig. 1). In contrast, others have linked the influx of Proterozoic grains in the protolith of the PORS to the tectonic dismemberment of the southern Sierra Nevada batholith, which allowed sediment derived from the Mojave terrane (southwestern Laurentia) to reach west of the arc (Jacobson et al., 2011).

Hafnium isotopes can be used to distinguish between these sources. The Proterozoic zircon from the Mojave terrane and the Lemhi subbasin have similar εHfi values (cf. Stewart et al., 2010; Wooden et al., 2013); however, the unradiogenic εHfi values for the Late Cretaceous detrital zircon are distinct. Late Cretaceous zircon from both the Idaho batholith and intrusions in the Mojave province have εHfi values that reflect assimilation of Proterozoic crust. Idaho batholith zircon yield a more unradiogenic range of εHfi values (~9 to ~23; Gaschnig et al., 2011) than are observed in the majority of Swakane Gneiss (+13 to −15) and PORS (+1 to −15) zircon. In comparison, zircon from the Late Cretaceous plutons that intrude Mojave crust have a wider range of εHfi values (~2 to ~25) and include xenocrystic Proterozoic cores (Barth et al., 2016). The mantle overgrowths on Proterozoic cores and unradiogenic εHfi values for ~100 Ma zircon in the Swakane and PORS are characteristic of reworked older crust, and, together, likely tie the sediment provenance to the Mojave region. In addition, Archean grains would likely be found in the Lemhi subbasin (Stewart et al., 2010), but these have not been observed in the samples studied here.

The zircon results demonstrate that both the PORS and Swakane protoliths likely contain sediment eroded from the Mojave province; however, some of the Swakane age populations show important Hf-isotope differences in comparison to the PORS. The oldest Swakane samples (MDAs = ca. 93 and 88 Ma) are characterized by 160–140 and 120–90 Ma peaks that have mostly supra-chondritic εHfi values, whereas similar-aged zircon from the PORS have a wider range, including subchondritic εHfi values (Fig. 2). The age peaks and limited range of radiogenic εHfi values in the 160–90 Ma Swakane zircon strongly match those of plutonic zircon from the southern Coast Plutonic Complex (Homan et al., 2017). Swakane samples deposited after ca. 86 Ma also include 100–81 Ma unradiogenic zircon (Fig. 2), likely derived from the Mojave intrusions, as described above.

A CONNECTED ORIGIN FOR THE METASEDIMENTARY UNITS

In addition to the zircon similarities, the PORS and Swakane Gneiss were coevally buried to as much as 40 km depth during the Late Cretaceous. Overall, the similarities in lithology, tectonic setting, timing of burial, and zircon characteristics suggest a link between the protolith and emplacement of the Swakane Gneiss and those of the PORS. These combined results indicate that the Swakane protoliths likely originated at similar latitudes as those of the PORS. The PORS were probably underplated beneath the arc, as there is strong evidence for shallow-angle subduction in southern California during the Late Cretaceous (e.g., Saleeby, 2003). Underplating has been less favored for the Swakane Gneiss, as previous studies have highlighted differences in peak pressure-temperature conditions and the lack of evidence for lowangle subduction north of Idaho (e.g., Matzel et al., 2004). If, however, the Swakane Gneiss did originate at the latitude of southern California, it would restore to the shallowly subducting segment of the slab, and the Swakane may represent the outboard continuation of the PORS (Fig. 3). This interpretation is consistent with previous reconstructions based on both geologic and paleomagnetic data (e.g., Umhoefer and Blakey, 2006). Furthermore, the detrital zircon results indicate that the Swakane protolith was deposited near the Coast Plutonic Complex, which implies that the latter was likely translated ~1600 km northward as well.

CONCLUSIONS

Detrital zircon from the PORS and the Swakane Gneiss share distinct U-Pb date and Hf-isotope provenance markers that, when coupled with MDA estimates, analogous structural settings, similar lithologies, and coeval burial, demonstrate that these units formed in the same place at the same time. These results support paleomagnetic data, which indicate that ~1600 km of northward, margin-parallel displacement occurred at 85–55 Ma. Many questions remain pertaining to the mechanism and history of translation along the western North American continental margin, e.g., which terranes are included in the Mojave-BC block, whether there is evidence for the presence of the Coast Plutonic Complex outboard of the Sierra Nevada batholith, and which structure(s) accommodated this translation. However, the connected origin of
Figure 3. Cartoon of connected burial of Swakane Gneiss and Pelona, Orocordia, Rand, Sierra de Salinas, and related schists (PORS) at ca. 75 Ma. Boxed numbers indicate range of maximum depositional ages and peak metamorphic temperature for metasedimentary rocks (Valley et al., 2003; Chapman, 2016). Gray dashed line indicates hypothetical Mojave-BC (British Columbia) fault zone. Gray arrow represents decreasing metamorphic grade and maximum depositional ages. BC—British Columbia; CPC—Coast Plutonic Complex; NC—Northern Cascades; O—Orocordia Schist; P—Pelona Schist; PRB—Peninsular Range batholith; R—Rand Schist; SDs—schist of Sierra de Salinas; SE—San Emigdio Schist; SWK—Swakane Gneiss.

these distinct metasedimentary assemblages support a “Mojave-BC” hypothesis. Thus, translation at convergent margins that includes both vertical and horizontal components can be tracked using sediment provenance markers coupled with interpreted metamorphic histories.

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