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Characterization of the crust of the Coast Mountains Batholith, British Columbia, from P to S converted seismic waves and petrologic modeling

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ABSTRACT

The late Triassic to early Tertiary Coast Mountains Batholith (CMB) of British Columbia provides an ideal locale to study the processes whereby accreted terranes and subduction-related melts interact to form stable continental crust of intermediate to felsic composition and complementary ultramafic residuals. Seismic measurements, combined with calculated elastic properties of various CMB rock compositions, provide a window into the deep-crustal lithologies that are key to understanding the processes of continental growth and evolution. We use a combination of seismic observations and petrologic modeling to construct hypothetical crustal sections at representative locations across the CMB, then test the viability of these sections via forward modeling with synthetic seismic data. The compositions that make up our petrologic forward models are based on calculations using the free energy minimization program Perple_X to predict mineral assemblages at depth for the bulk compositions of exposed plutonic rocks collected in the study area. Seismic data were collected along two transects in west-central British Columbia: a southern line that crossed the CMB near the town of Bella Coola (near 52° N), and a northern line centered on the towns of Terrace and Kitimat (near 54° N). Along both transects, seismic receiver functions reveal high V_p/V_s ratios near the Insular/Intermontane terrane boundary and crustal thickness increasing from 26 ± 3 km to 34 ± 3 km (at the 1 sigma certainty level) from west to east across the Coast Shear Zone (CSZ). On the southern line, we observe an anomalous region of complex receiver functions and diminished Moho signals beneath the central portion of the CMB. Our petrologic and seismic profiles show that observed seismic data from much of the CMB can be well-matched in terms of crustal thickness and structure, average V_p/V_s, and amplitude of the Moho converted phase, without including ultramafic residual material in the lower crust.

1. Introduction

The western margin of the Canadian Cordillera has been the locus of significant growth of the North American continent via complex tectonic interactions at an evolving ocean/continent margin throughout the Phanerozoic (e.g., Monger, 1993). Along its leading edge, the accreted terranes of the Insular and Intermontane assemblages hosted the emplacement of an enormous magmatic arc for the duration of the Mesozoic and into the early Tertiary. Cessation of arc magmatism around 50 Ma and subsequent exhumation resulted in the exposure of the intermediate to felsic batholithic roots of the arc, known collectively as the Coast Mountains Batholith (CMB) (Hollister and Andronicos, 2000). The northern CMB has been presented as a model case for creation of felsic continental crust via heat and magma input from the mantle combined with fractionation of more mafic accreted island arc crust (e.g. Hollister and Andronicos, 2006). This process, however, necessarily creates a complementary mafic to ultramafic residue that, depending on composition and *P–T* conditions at the time of formation, may be dense enough to become gravitationally unstable and sink (e.g., Kay and Kay, 1991, 1993; Ducea, 2001; Kelemen et al., 2003; Greene et al., 2006) or may become a longer term constituent of the continental lithosphere (e.g. Griffin and O'Reilly, 1987). Studies of other Cordilleran arcs have found strong evidence for convective removal of dense roots (e.g. Ducea and Saleeby, 1998; Kelemen et al., 2003; Zandt et al., 2004), but the current state of the lithosphere beneath the CMB, North America's largest exposed continental batholith (Barker and Arth, 1990), remains largely unknown.

In conjunction with the multi-disciplinary Batholiths project, we collected an average of 14 months of 3-component broadband seismic data along two roughly strike-perpendicular transects (Fig. 1) between the summer of 2005 and fall of 2006. Each of the 43 sites, deployed with an inter-station spacing of ~10 km, consisted of either a Guralp CMG3T or a Streckheisen STS-2 seismometer linked to a

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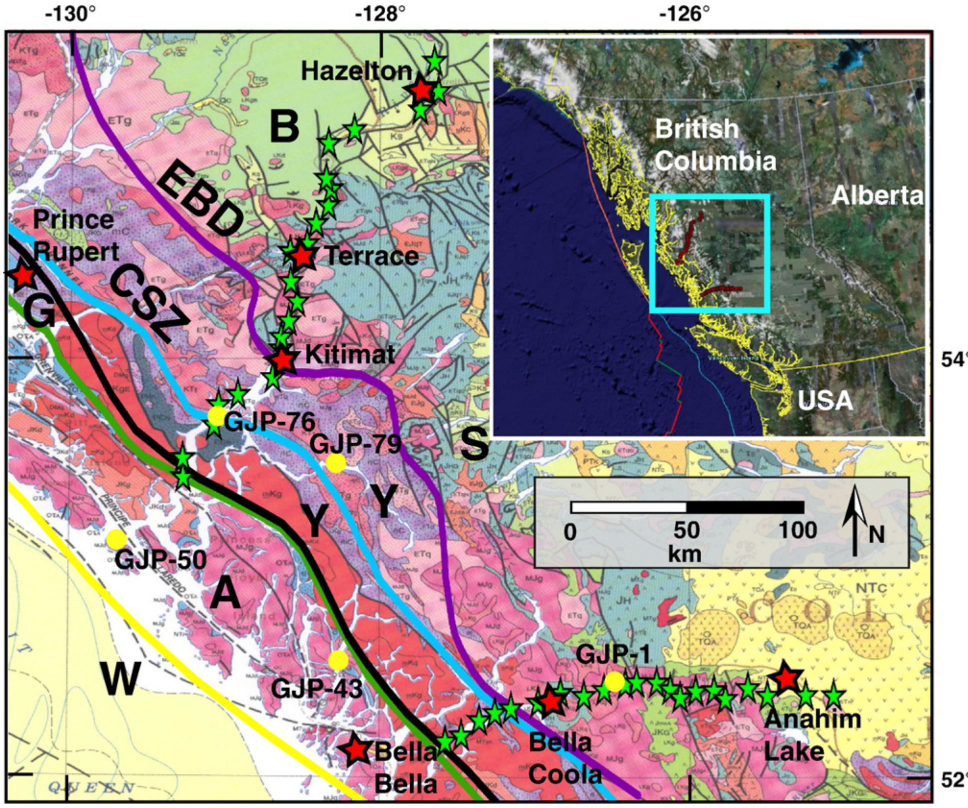

Fig. 1. Batholiths project seismic stations overlain on the GSC Canadian Geologic map (1996). The light blue rectangle on the inset Google Earth map shows the regional location of the study area. Seismic stations are marked with green stars and rock sample locations with yellow circles and GJP-XX labels. See Table 1 for sample compositions. W = Wrangellia, A = Alexander, Y = Yukon Tanana, CSZ = Coast Shear Zone, S = Stikine, B = Bowser Basin EBD = Eastern Boundary Detachment.

Quanterra 330 data acquisition system. The southern line ran from Burke Channel in the west, through the town of Bella Coola, and onto the Chilcotin Plateau near the town of Anahim Lake. The northern transect traversed Douglass Channel from Hartley Bay to Kitimat and then followed the Skeena River northeast from Terrace to New Hazelton. Data quality was high across the study area with the exception of the stations on the far southwestern end of the northern line, which, due to siting issues and ocean storms, had higher noise levels and were out of service for a portion of the deployment.

Herein, we describe our use of receiver functions to image the Moho and other crustal discontinuities and constrain crustal V_p/V_s along the two transects. Combining the seismic data with potential deep crustal compositions inferred from thermodynamic modeling, we test various structural and compositional models for the crust at a series of representative stations across the seismic array. Our forward models are in no way unique, and we do not attempt to test the wide range of possible arc lithologies presented in the petrologic literature, a task which would lead to an infinite number of possible models and a large number of models that would match the data within error. Our approach is rather to test whether we can match seismic observations using only the deeper equivalents of plutonic rocks exposed at the surface, or if the data dictates that we add an ultramafic root to our models. We compare our best fitting models with the lithologic columns proposed by Behn and Kelemen (2006) for the Talkeetna arc in Southern Alaska and with models proposed for the CMB by Hollister and Andronicos (2006).

2. Geologic setting

The Batholiths project study area (Fig. 1) is located in central western British Columbia where subduction-related magmatism of the CMB intrudes upon and obscures the boundary between the outboard Insular superterrane and the inboard Intermontane superterrane (tectonostratigraphic nomenclature follows Monger, 1993). The Intermontane group is an amalgamation of peri-cratonic arc-related units that formed along the Laurentian margin during the Paleozoic and early Mesozoic. The oceanic and continental slivers of the Insular group (primarily Alexander and Wrangellia terranes) appear to have an origin in the arctic realm (Colpron et al., 2007). Although the timing and geometry of accretion of the Intermontane and Insular superterranes to the North American margin is a matter of vigorous debate (e.g. Cowan et al., 1997; Butler et al., 2001), there is considerable geologic evidence supporting the consolidation of the two superterranes by mid-Jurassic (Colpron et al., 2007), and post accretion dextral transport of the combined terranes of at least 850 km along the North American margin (Butler et al., 2001; Gabrielse et al., 2006).

The Coast Shear Zone (CSZ), a steeply east-dipping zone of intense ductile deformation, splits the CMB along strike on a >1200 km line roughly paralleling the suture between the two superterranes (Rusmore et al., 2001). Geologic studies indicate a complex history of strike slip, reverse, and normal offset along the CSZ, with the last documented motion occurring around 51 Ma (Klepeis and Crawford, 1999; Andronicos et al., 1999; Rusmore et al., 2001). In the northern portion of the study area, the CSZ marks the western boundary of the Central Gneiss Complex (CGC), a package of amphibolite to granulite grade mid-crustal rocks exhumed from depths of up to 25 km by ~50 Ma (Hollister and Andronicos, 2000; Rusmore et al., 2005). The CGC is bounded on the east by the Eastern Boundary Detachment (hereafter the EBD; also known as the Shames mylonite zone), a more shallowly NE dipping ductile shear zone active between 67 and 52 Ma (Rusmore et al., 2005). Neither the CGC nor the EBD have been