Bedrock Exhumation Across the Columbia River Fault near Revelstoke, BC

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Abstract

In the southeastern Canadian Cordillera, Paleocene–Eocene post-orogenic extension exhumed metamorphic core complexes along low-angle detachments (Brown and Murray, 1987). The largest metamorphic core complex in the Canadian Cordillera is the Shuswap Metamorphic Core Complex in the Columbia Mountains (Armstrong, 1982). Within the Shuswap Metamorphic Core Complex, two migmatite domes known as the Frenchman's Cap and the Thor-Odin dome form the Monashee Complex (Carr, 1991). This pair of domes are bounded on the east by the east-dipping, Eocene brittle-ductile Columbia River Fault (CRF) (Read and Brown, 1981). Hornblende and mica $^{40}Ar/^{39}Ar$ and apatite fission track ages suggest the Columbia River Fault initiated ~56 Ma and accommodated rapid vertical displacement of the Monashee Complex from 25 km depth to ~2 km below the surface in Eocene time (Vanderhaeghe et al., 2003; Toraman et al., 2014). In this study, we aim to quantify the upper crustal cooling history of bedrock across the CRF. We use apatite (U-Th)/He (AHe) low temperature thermochronology to quantify when bedrock cooled below ~50–60^{o}C (Farley, 2000). We aim to answer three questions: When did normal faulting along the CRF end? How much vertical displacement was accommodated by the CRF? What role has erosion played in exhumation of the Columbia Mountains since the end of extension? Quantifying the time when normal faulting ended along the CRF will help constrain when post-orogenic gravitational collapse and extension of the orogen ceased in this portion of the cordillera. Determining the amount of exhumation accommodated by the CRF will constrain the degree to which tectonic processes effected the formation of the Columbia Mountains. Constraining the amount of tectonic exhumation will also help quantify the role erosion has played in landscape development, particularly since the onset of Northern Hemisphere glaciation 2.7 Ma (Haug et al., 2005).

We present 61 new AHe ages from 12 bedrock samples collected along the CRF north of Revelstoke, BC. Single grain AHe ages range from 4–105 Ma. Single grain ages reproduced generally well and a mean sample age is calculated. However, the AHe ages from the hanging wall showed more dispersion compared to those in the footwall. Good reproducibility of the sample ages indicates that bedrock cooled quickly through the temperature window of the apatite He partial retention zone (80–40^{o}C) (Wolf et al., 1996). In contrast, increased age dispersion in the hanging wall samples suggests a longer residence time within this temperature window (Wolf et al., 1996). Combining the results of thermal history modeling with age-elevation profiles, two possible cooling histories can be derived. In scenario one, the CRF was active and exhumed bedrock in the footwall during the early Miocene (21–18 Ma). Thermal history models suggest the footwall of the CRF underwent rapid cooling between 80^{o}C and 40^{o}C between 21–18 Ma, whereas the hanging wall of the CRF experienced gradual cooling until the late Miocene–early Pliocene (28–5 Ma). Age-elevation relationships also show a rapid cooling trend in the footwall between 21–19 Ma contrasted by a shallower cooling trend in the hanging wall between 28–5 Ma. Differential cooling histories across the CRF suggests normal faulting may have been active in the Miocene, which extends tectonic activity in the Columbia Mountains from the Eocene to the

Miocene. In scenario two, the Columbia Mountains underwent a phase of regional uplift and exhumation during the early Miocene (20–19 Ma). Age-elevation relationships show a rapid cooling trend in both the footwall and hanging wall ~20 Ma. Increased age dispersion in the hanging wall samples suggests bedrock was exhumed from shallow crustal levels within the apatite He partial retention zone, whereas the footwall samples were exhumed from below this temperature window at the same time. A shared cooling trend suggests faulting along the CRF was not active in the Miocene, but a phase of regional uplift and incision in the early Miocene exhumed the Columbia Mountains ≥2 km. Additional investigation including apatite fission track dating on the same bedrock samples and comparison with existing thermochronological data will help us determine the most likely interpretation of the upper crustal cooling history of the Columbia Mountains.

Methodology

We collected 12 bedrock samples (gneisses and granites) north of Revelstoke on both sides of the CRF at different elevations. Apatite grains were separated using standard mineral separation procedure. Apatite (U-Th)/He analysis was conducted in the University of Calgary's Geo-and Thermochronology Lab. On average, five apatite grains were analyzed for each bedrock sample. The ^{4}He content was measured using an Alphachron™ He-extraction line, and U-Th ratios were measured using isotope dilution inductively coupled plasma mass spectrometry (ID-ICP-MS).

References

Armstrong, R.L., 1982, Cordilleran Metamorphic Core Complexes - From Arizona to Southern Canada: Annual Review of Earth and Planetary Sciences, v. 10, p. 129–154.

Brown, R.L., and Murray, J., 1987, Tectonic denudation of the Shuswap metamorphic terrane of southeastern British Columbia: Geology, v. 15, p. 142–146, doi:10.1130/0091-7613(1987)15<142:tdotsm>2.0.co;2.

Carr, S.D., 1991, Three crustal zones in the Thor–Odin – Pinnacles area, southern Omineca Belt, British Columbia: Canadian Journal of Earth Sciences, v. 28, p. 2003–2023, doi:10.1139/e91-182.

Farley, K.A., 2000, Helium diffusion from apatite: General behavior as illustrated by Durango fiuorapatite: Journal of Geophysical Research, v. 105, p. 2903–2914.

Haug, G.H. et al., 2005, North Pacific seasonality and the glaciation of North America 2.7 million years ago: Nature, v. 433, p. 821–825, doi:10.1038/nature03332.

Read, P.B., and Brown, R.L., 1981, Columbia River fault zone: southeastern margin of the Shuswap and Monashee complexes, southern British Columbia: Canadian Journal of Earth Sciences, v. 18, p. 1127–1145.

Toraman, E., Teyssier, C., Whitney, D.L., Fayon, A.K., Thomson, S.N., and Reiners, P.W., 2014, Low-temperature thermochronologic record of Eocene migmatite dome emplacement and late Cenozoic landscape development, Shuswap core complex, British Columbia: Tectonics, v. 33, p. 1616–1635, doi:10.1002/2013TC003442.

Vanderhaeghe, O., Teyssier, C., McDougall, I., and Dunlap, W.J., 2003, Cooling and exhumation of the Shuswap metamorphic core complex constrained by 40 Ar- 39 Ar thermochronology: Geological Society of: GSA Bulletin, v. 115, p. 200–216.

Wolf, R.A., Farley, K.A., Silver, L.T., Geological, D., Sciences, P., and Stop, M., 1996, Helium diffusion and low-temperature thermochronometry of apatite: Geochimica et Cosmochimica Acta, v. 60, p. 4231–4240.