Exhumational history of the central Rocky Mountain Trench using low-temperature thermochronology

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Abstract

The Rocky Mountain Trench (RMT) is a 1600 km long valley that extends from Montana northwest into northern British Columbia where it joins up with the Tintina Trench, another long valley similar to the RMT. The RMT's impressive length and continuous nature have been interpreted to be the result of faulting, and localized erosion, along a continent scale crustal weakness located beneath the RMT, possibly the ancient continental margin (e.g. Leech, 1966). Seismic reflection profiles indicate a step in the Moho that aligns with the RMT, where the Moho is ~10 km shallower to the west of the RMT than to the east (Cook and van der Velden, 1993). This step is thought to have been formed ~55 Ma with the delamination of the Cordilleran lithospheric mantle (Bao et al., 2014). Delamination and formation of the Moho step would have further weakened the crust below the RMT, allowing for such continuous faulting along it. Delamination is also coincident with widespread Eocene extension that affected the southeastern Canadian Cordillera west of the RMT.

Despite the continuous nature of the RMT, the faults within the RMT vary along strike from dextral strike-slip faults in the north to normal faults in the south (e.g. Leech, 1966). The normal faults in the south are thought to be related to Eocene extension (e.g. Thompson, 1962). The approximate displacement along the faults within the RMT during the Cenozoic is ~125 km of dextral displacement in the north and ~10 km of dip-slip extensional displacement in the south (Gabrielse, 1985; van der Velden and Cook, 1996). The central RMT, located near Valemount, BC, is thought to be the transition zone between dextral strike-slip faulting in the north and normal faulting in the south. The stratigraphy and structures along the RMT vary considerably along strike. The Valemount area consists of Windermere Supergroup strata, the Malton Gneiss Complex and other gneiss bodies, and three major Cretaceous to Cenozoic faults: the Purcell Thrust (PT), the North Thompson-Albreda normal fault (NTAF), and the RMT. Further north, the McBride, BC area consists predominately of deformed Windermere Supergroup strata on both sides of the RMT.

We use low-temperature thermochronology, a set of temperature sensitive dating methods, along a ~150 km long section of the central RMT, from McBride south to Valemount, to compare the cooling histories across the RMT. We use apatite fission track (AFT), which records cooling through the apatite partial annealing zone (PAZ) (~60 °C and ~110 °C), and apatite (U-Th)/He (AHe), which records cooling through the apatite partial retention zone (PRZ) (~40 °C and ~80 °C) (e.g. Gleadow et al., 1986; Wolf et al., 1996). The PAZ is the temperature window where an

apatite grain partially anneals fission tracks as they form, and the PRZ is the window where He is both partially retained within and diffused out of an apatite grain.

In total we dated 29 bedrock samples collected on both sides of the central RMT and from two elevation profiles. We report AFT ages from 23 samples and AHe ages from 25 samples. AFT central ages range from 16.0 ± 2.1 Ma to 82.0 ± 11 Ma. Six of the 23 AFT samples passed the χ^2 test, while the remaining 17 samples yielded high dispersion between single-grain ages and failed the χ^2 test. All AHe single-grain ages range from 0.36 ± 0.03 Ma to 238.0 ± 27.55 Ma. For 17 of the samples the single-grain ages reproduce well so we report a mean age, which range from 8.2 ± 0.8 Ma to 74.8 ± 13.1 Ma. The remaining 8 samples we do not report a mean age because the single-grain ages are widely dispersed. For rocks with more complex cooling histories, that involve reheating or slow cooling through the PAZ/PRZ, disperse age distributions are common. Thus, the high dispersion within our AFT and AHe data indicate that our samples have experienced complex cooling histories, which have partially reset the AFT and AHe systems. Additionally, our apatite grains contain very low amounts of uranium, which could be contributing to the high dispersion of ages within our samples. In addition to high dispersion we observe an “inverted” relationship between our AHe and AFT ages in several of our samples. The majority of these “inverted” samples are located in the Valemount area within, or around, the Malton Gneiss Complex, on either side of the RMT and the NTAF. A possible explanation for inverted ages is that a reheating phase has fully reset the AFT system but only partially the AHe system (Reiners et al., 2007).

High dispersion in our dataset generally made the interpretation of ages difficult; however, in the north, near McBride, our data along the two elevation profiles show variation in timing of cooling with slightly older and more disperse ages to the west of the RMT than to the east. This suggests at least ~2 km of west-side down normal faulting along the RMT in this area. Thermal-history modelling reveal three major rapid cooling phases since the start of the Eocene including an Eocene phase, early–mid Miocene phase, and a mid–late Miocene phase. During the two most recent rapid cooling phases there is differential cooling across the RMT and NTAF, therefore indicating that these structures aided in cooling. Conversely, during the Eocene cooling was widespread across our study area suggesting other factors were involved in the rapid cooling such as increased erosion following uplift from lithospheric delamination. Additionally, previous studies indicate the RMT near Valemount was in part carved from recent glacial incision and a second phase of delamination, which our data supports (Currie et al., 2008; Szameitat, 2015). However, our data also indicates that there was likely additional normal displacement across the RMT in late Miocene time.

References

Bao, X., Eaton, D.W., and Guest, B., 2014, Plateau uplift in western Canada caused by lithospheric delamination along a craton edge: Nature Geoscience, v. 7, p. 830-833.
Cook, F.A., and van der Velden, A.J., 1993, Three dimensional crustal structure of the Purcell Anticlinorium, southeastern Canadian Cordillera: EOS, Transactions, American Geophysical Union, v. 74, no. 16, p. 303.
Currie, C.A., Huismans, R.S., and Beaumont, C., 2008, Thinning of continental backarc lithosphere by flow-induced gravitational instability: Earth and Planetary Science Letters, v. 269, no. 3, p. 4436–447.
Gabrielse, H., 1985, Major dextral transcurrent displacements along the Northern Rocky Mountain Trench and related lineaments in north-central British Columbia: Geological Society of America Bulletin, v. 96, p. 1-14.
Gleadow, A.J.W., Duddy, I.R., Green, F., and Lovering, J.F., 1986, Confined fission track lengths in apatite: A diagnostic tool for thermal history analysis: Contributions to Mineralology and Petrology
Leech, G.B., 1966, The Rocky Mountain Trench, *in* Irvine, T.N., ed., The World Rift System: Geological Survey of Canada Paper 66-14, p. 307-329.
Reiners, P.W., Thomson, S.N., McPhillips, D., Donelick, R.A., and Roering, J.J., 2007, Wildfire thermochronology and the fate and transport of apatite in hillslope and fluvial environments: Journal of Geophysical Research, v. 112, F04001.
Szameitat, A., 2015, The Rise and Erosion of the South Eastern Canadian Cordillera: Cenozoic Cooling, Exhumation and Elevation of the Columbia Mountains and Southern Rocky Mountains in Western Canada from Low-Temperature Thermochronology [Ph.D. thesis]: Leicester, University of Leicester.
Thompson, T.L., 1962, Origin of the Rocky Mountain trench in southeastern British Columbia by Cenozoic block faulting: Journal of the Alberta Society of Petroleum Geologists, v. 10, no. 7, p. 408-427.
van der Velden, A.J., and Cook, F.A., 1996, Structure and tectonic development of the southern Rocky Mountain Trench: Tectonics, v. 15, no. 3, p. 517-544.
Wolf, R.A., Farley, K.A., Silver, L.T., 1996, Modeling of the temperature sensitivity of the apatite (U-Th)/He thermochronometer: Chemical Geology, v. 148, p. 105-11