Cenozoic exhumation history of the northern Richardson Mountains, Canada: Results from (U-Th-Sm)/He analysis

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Summary

The Richardson Mountains are a Late Cretaceous–Cenozoic fold-thrust belt located along the eastern margin of the Northern Cordillera, east of the Brooks Range and north of the Mackenzie Mountains (Fig. 1). Cordilleran deformation initiated in the latest Cretaceous and peaked during the Paleocene–early Eocene. Late Cenozoic deformation and associated exhumation is recorded in the Brooks Range at ~25 Ma (e.g. O'Sullivan, 1996; O'Sullivan et al., 1993; Peapples et al., 1997; O'Sullivan and Wallace, 2002), and in the Mackenzie Mountains at 33–20 Ma (Enkelmann et al., 2019). However, there is no record of post-Cordilleran deformation in the Richardson Mountains. We investigated the low-temperature history of rocks collected across the northern Richardson Mountains to constrain the timing and magnitude of rock exhumation. Thermal history modeling of the apatite (U-Th-Sm)/He (AHe) data suggests that rapid exhumational cooling occurred during Cordilleran orogenesis in the Paleocene–early Eocene (>65–50 Ma) and renewed exhumation occurred in the late Eocene–early Oligocene (40–30 Ma). An implication of these findings is that Late Cenozoic deformation in the northern Richardson Mountains preceded that of the Brooks Range and Mackenzie Mountains. We investigated plate kinematic relationships and found that the timing of deformation along the margin of the Cordillera may relate to the absolute motion of the North American Plate with respect to structural trends.

Method

Apatite and zircon (U-Th-Sm)/He analysis is used to constrain the timing and amount of exhumation driven by tectonic and surface processes. Helium (^{4}He) is produced by alpha decay of radioactive ^{238}U, ^{235}U, ^{232}Th, and ^{147}Sm. The ^{4}He diffuses out of the grain at high temperatures and accumulates over time at lower temperatures. Helium retention progressively increases during cooling through a range of temperatures known as the Partial Retention Zone (PRZ). The PRZ is ~40–85°C for apatite (Wolf et al., 1998; Shuster et al., 2006) and ~130–200°C for zircon (Guenthner et al., 2013). The temperature sensitivity differs for individual grains depending on factors such as grain size, radiation damage, and thermal history (Flowers et al. 2009; Guenthner et al., 2013). The (U-Th-Sm)/He analysis was conducted at the Geo- and Thermochronology Lab at the University of Calgary. For each sample, we packaged 3–6 grains individually into niobium tubes, selecting grains that are euhedral, unbroken, and inclusion-free. The encased grains were heated with a laser to extract ^{4}He, which was measured with a quadrupole mass spectrometer. Parent nuclides were measured by isotope dilution inductively coupled plasma mass spectrometry (ID-ICP-MS).

Results and Modeling

This study yields 88 new apatite (U-Th-Sm)/He (AHe) dates from 19 Proterozoic–Paleocene rocks and 10 new zircon (U-Th)/He (ZHe) dates from two Jurassic rocks. The AHe dates are younger than the stratigraphic ages, indicative of thermal resetting and burial to temperatures generally above ~80°C. Conversely, the ZHe dates are older than the stratigraphic age, which indicates burial was insufficient to reset the grains and temperatures were below ~160°C since deposition. The AHe dates range from 300–16 Ma but most dates (65%) range 56–24 Ma. Numerical modeling using the program HeFTy (v.1.9.3; Ketcham, 2005) suggests that this AHe date dispersion is likely caused by variable pre-depositional (i.e. source rock) thermal histories of the grains. The radiation damage that accumulated prior to burial heating may have caused some of the grains to be especially helium-retentive and yield anomalously old dates (Shuster et al., 2006; Fox et al., 2019). We further exploited the dispersion to determine that burial temperatures were probably within ~70–90°C for most of our samples. We used the inverse thermal history modelling mode of HeFTy to derive possible post-depositional cooling histories that are consistent with the measured AHe data. Among our samples we found three groups of cooling histories: the five samples of Group 1 show accelerated cooling initiating at >65–50 Ma, which compares well with previous studies (O'Sullivan and Lane, 1997); the 11 samples of Group 2 show a previously unrecognized phase of rapid cooling between 40–30 Ma; and the three samples of Group 3 are similar to the previous two groups, except that these samples may have resided within the PRZ until as late as 15 Ma. Cooling slowed and rocks were at near-surface temperatures (<40°C) since the early–middle Miocene.

Discussion and Conclusions

Our modelling indicates that a minimum 1–2 km of exhumation occurred during late Eocene–early Oligocene time, suggesting that the northern Richardson Mountains continued to deform after the Paleocene–early Eocene phase of Cordilleran orogenesis. Additionally, the results imply that Late Cenozoic deformation was asynchronous along the margin of the Northern Cordillera between the Brooks Range, Richardson Mountains, and Mackenzie Mountains, which raises questions about possible driving mechanisms. We explored plate kinematic relationships using GPlates (v2.2; Müller et al., 2018) and hypothesize that the most recent phase of exhumation in each of these mountain belts relates primarily to changes in absolute plate motion of the North American Plate as opposed to interactions along the plate boundary in southern Alaska. Measurable exhumation occurred along the eastern margin of the Northern Cordillera during periods of increased plate velocity, particularly when absolute plate motion was at high angle to pre-existing structures. This relationship may account for the difference in the timing of exhumation between regions with north–northeast-trending structures that deformed at 40–30 Ma (Richardson Mountains), and regions with west- and northwest-trending structures where deformation is recorded primarily at ~25 Ma and 33–20 Ma (northeastern Brooks Range and Mackenzie Mountains, respectively).

Figure 1. Generalized tectonic setting map of northwestern North America showing locations of thermal history studies along the margin of the Northern Cordillera. The studies are numbered west-to-east and are listed in the sidebar. The red box shows the location of the study area. Abbreviations: BM, British Mountains; BnM, Barn Mountains; NEB, Northeastern Brooks Range.

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