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Thermochronology in southeast Alaska and southwest Yukon: Implications for North American Plate response to terrane accretion

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ABSTRACT

This study presents the first comprehensive dataset of low-temperature thermochronology from 43 bedrock samples collected north of the active Yakutat–North American plate boundary. Our apatite and zircon (U–Th)/He and fission-track data reveal the cooling history of the inboard Wrangellia Composite Terrane that is dominated by rapid cooling after Late Jurassic to Early Cretaceous arc magmatism followed by very little cooling and exhumation until today. Deformation resulting in rock exhumation due to the collision of the Yakutat microplate is spatially very limited (20–30 km) and is concentrated mainly in the Chugach–Prince William Terrane and rocks near the Border Ranges Fault. Focused exhumation from greater depths of ca. 10 km with very high rates (>5 km/Myr) is localized at the syntaxis region, starting ca. 10 Ma and shifted south through time. The rapid exhumation rates are explained by the development of strong feedbacks between tectonically driven surface uplift and erosion, which started already before glaciation of the area. The shift in the location towards the south is a consequence of continuous readjusting between tectonics and climate, which is changing on local and global scales since the Late Miocene.

1. Introduction

Terrane accretion and subduction are fundamental processes that modify plate margins and result in the expansion of continental crust, the classic example being the western North American margin. The St. Elias Mountains located at the border region of Alaska (USA), Yukon, and British Columbia (Canada) are a key location for studying geologic processes that formed western North America, including arc accretion and spreading-ridge subduction. Moreover, it is a prime study location for an ongoing indentation of a plate corner, resulting in a structurally complex plate boundary transitioning from transform to convergence (Bruhn et al., 2012; Koons et al., 2010). The high-latitude (60–61°N) and coastal position resulted in heavy glaciation that makes the St. Elias Mountains a natural laboratory for studying the interplay between tectonics and climate-driven surface processes (Enkelmann et al., 2009, 2010, 2015). Most research effort has been concentrated on the coastal side of the St. Elias Mountains (southeast Alaska), but only few thermochronology data have been reported from the heavily glaciated northern side (Canada) (O'Sullivan and Currie, 1996; Spotila and Berger, 2010). As a consequence, many unknowns exist including the spatio-temporal pattern of initial uplift and erosion, structural accommodation of crustal shortening over time, and strain transfer inboard of the plate boundary.

Low-temperature thermochronology is an effective tool to study orogenic evolution through deciphering timing, rates, and spatial patterns of rock exhumation. Previous zircon and apatite fission-track (ZFT and AFT, respectively) thermochronology studies on modern glacio-fluvial detritus revealed that rocks underneath the large glaciers covering the region of the indenting Yakutat plate corner (the St. Elias syntaxis) exhume much more rapidly ($\sim$5 km/Myr) in comparison to the surrounding area ($<$1 km/Myr) (Enkelmann et al., 2009, 2010; Falkowski et al., 2014), and that this localization of rapid exhumation migrated from the north to the south over the past $\sim$10 Myr (Enkelmann et al., 2015; Falkowski and Enkelmann, 2016). While detrital samples are essential to detect exhumation patterns from a large glaciated area, bedrock samples allow obtaining a cooling record from multi-phase analyses of samples from known *xyz*-coordinates.

We collected 43 bedrock samples from the northern St. Elias Mountains (southwest Yukon) and present a total of 126 new thermochronometric ages from ZFT, AFT, and zircon and apatite

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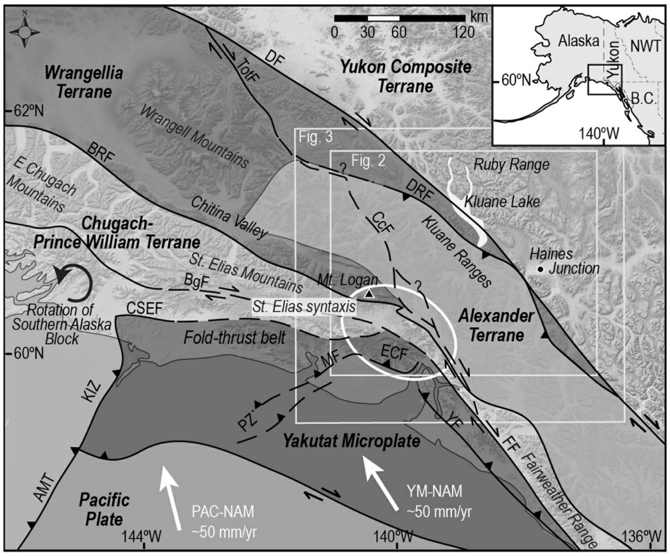

Fig. 1. Terrane and tectonic map of southeast Alaska and southwest Yukon. DF: Denali Fault, TotF: Totschunda Fault, DRF: Duke River Fault, CcF: Connector Fault, BRF: Border Ranges Fault, BgF: Bagley Fault, ECF: Esker Creek Fault, MF: Malaspina Fault, YF: Yakutat Fault, FF: Fairweather Fault, KIZ: Kayak Island Zone, AMT: Aleutian Megathrust, PZ: Pamplona Zone, YM: Yakutat microplate, NAM: North American Plate, PAC: Pacific Plate, NWT: Northwest Territories, B.C.: British Columbia.

(U–Th)/He (ZHe and AHe, respectively) analyses reflecting upper-crustal cooling through ∼250–60 °C (e.g., Brandon et al., 1998; Farley, 2000; Reiners, 2005). We show that rocks of the Wrangellia Composite Terrane (WCT) of the northern St. Elias Mountains mainly record rapid cooling after late Mesozoic arc magmatism, followed by very limited exhumation since the mid-Cretaceous. The ongoing collision of the Yakutat plate corner that started in the mid-Miocene had only a spatially very limited effect inboard of the plate boundary (<30 km).

2. Background

Since the Late Cretaceous the western North American margin has been characterized by rapid, oblique subduction of oceanic crust and transpressional deformation manifested in large-scale strike-slip faults such as the Denali and Border Ranges faults (Fig. 1; e.g., Pavlis and Roeske, 2007). The study area comprises mainly the WCT, which finalized accretion to the former North American margin (Yukon Composite Terrane (YCT); Fig. 1) in the mid-Cretaceous, and was afterwards displaced northwestward by ca. 400 km along the Denali Fault (Lowey, 1998). Continued subduction at the southern margin of the WCT resulted in the accretionary complex of the mostly Late Cretaceous–Eocene Chugach–Prince William Terrane (CPWT) that was displaced north along the Border Ranges Fault (e.g., Pavlis and Roeske, 2007; Garver and Davidson, 2015). Subduction style changed in the Paleocene with the introduction of increasingly younger, buoyant oceanic crust and a spreading-ridge subduction that affected the south Alaskan margin diachronously ca. 62–47 Ma and resulted in near-trench plutonism (Sanak–Baranof suite) and the formation of the Chugach Metamorphic Complex (e.g., Bradley et al., 1993; Sisson et al., 2003; Gasser et al., 2012). Afterwards, normal subduction briefly resumed before subduction of the Yakutat microplate began (e.g., Plafker et al., 1994; Finzel et al., 2011). The Yakutat microplate is a 15–30 km thick, wedge-shaped oceanic plateau that has been translated northward along the Fairweather–Queen Charlotte dextral transform (Fig. 1; Christeson et al., 2010). Since at least 30 Ma southern Alaska is dominated by the Yakutat subduction that results in deformation and mountain building above the downgoing flat slab (e.g. Finzel et al., 2011), and at the plate boundary (e.g., Enkelmann et al., 2010; Falkowski and Enkelmann, 2016).

2.1. Geologic setting of the study area

Six samples were collected from north of the Denali Fault (Fig. 2), of which four are granitic rocks intruded into the YCT and two are metasedimentary rocks from a former flysch basin with WCT affinity (Dezadeash Formation) that is now smeared along the dextral Denali Fault. The YCT is made up of several terranes of continental margin sequences and in the study area it is characterized by intrusions of the Late Cretaceous–early Eocene Kluane Arc and associated metamorphic rocks (e.g., Erdmer and Mortensen, 1993). These rocks are part of the Coast Plutonic Complex, which is more widespread in British Columbia (∼175–45 Ma; Erdmer and Mortensen, 1993; Gehrels et al., 2009). The southern YCT and northern WCT margins experienced deformation and metamorphism along their entire lengths associated with the mid-Cretaceous final accretion of the WCT (e.g., Csejtey et al., 1982; Gehrels et al., 1991).

South of the Denali Fault, intraoceanic Cambrian–Late Triassic arc–backarc basin assemblages and Upper Triassic greenstone and limestone of the Wrangellia and Alexander terranes form the basement of the WCT in the study area (Fig. 2; e.g., Nokleberg et al., 1994). Subduction at the southern margin of the WCT resulted in several Jurassic–Cretaceous, northward propagating magmatic arcs that are reflected by two plutonic suites in the study area, from which most of the samples were collected: the 160–130 Ma St. Elias Suite (Chitina Arc) and the 120–105 Ma Kluane Ranges Suite (Chisana Arc) (Fig. 2; Dodds and Campbell, 1988). Overall, the existing chronometric data show that the cooling record of the WCT is controlled by Late Jurassic–Early Cretaceous arc magmatism (Fig. 2) and Early Cretaceous shortening and uplift within the Chitina thrust belt (Trop and Ridgway, 2007). Crystallization and higher-temperature cooling ages (biotite, hornblende K–Ar and $^{40}Ar/^{39}Ar$) document the emplacement of lower Cenozoic intrusions and associated metamorphism, or Wrangell lava emplacement (Fig. 2; e.g., Dodds and Campbell, 1988; Farrar et al., 1988; Richter et al., 1990). The CPWT south of the Border Ranges Fault represents mostly Late Cretaceous–Eocene volcaniclastic accretionary sediments and is characterized by the Eocene amphibolite- to greenschist-facies Chugach Metamorphic Complex and ∼55–50 Ma Sanak–Baranof intrusions (e.g., Gasser et al., 2012).

3. Methods

3.1. Analytical techniques

Apatite and zircon grain separation was performed using standard mineral separation procedures. For AHe and ZHe analysis, euhedral and inclusion-free apatite and zircon grains were picked under a Leica stereomicroscope. Grain dimensions were measured for alpha-ejection correction (Farley et al., 1996) and grains were packaged in niobium tubes for single-grain analyses of zircons and single- or multi-grain analyses of apatites (Supplementary Information Tables S1 and S2). Helium degassing and measurement was performed using the Patterson Instruments extraction line at the University of Tübingen. Uranium, thorium, and samarium relative abundances were measured at the Element2 HR-ICP-MS of the University of Arizona.

For fission-track analysis apatite grains were mounted in epoxy resin, ground and polished, and etched with 5.5 molar nitric acid for 20 s to expose fossil fission tracks. Zircons were mounted in Teflon® and etched in a NaOH:KOH eutectic melt for 9–30 h at 228 °C, depending on age and uranium content (Garver, 2003). AFT