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Active tectonics around the Yakutat indentor: New geomorphological constraints on the eastern Denali, Totschunda and Duke River Faults

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ABSTRACT

The Yakutat collision in SE Alaska – SW Yukon is an outstanding example of indentor tectonics. The impinging Yakutat block strongly controls the pattern of deformation inland. However, the relationship between this collision system and inherited tectonic structures such as the Denali, Totschunda, and Duke River Faults remains debated. A detailed geomorphological analysis, based on high-resolution imagery, digital elevation models, field observations, and cosmogenic nuclide dating, allow us to estimate new slip rates along these active structures. Our results show a vertical motion of 0.9 ± 0.3 mm/yr along the whole eastern Denali Fault, while the dextral component of the fault tapers to less than 1 mm/yr ∼80 km south of the Denali–Totschunda junction. In contrast, the Totschunda Fault accommodates 14.6 ± 2.7 mm/yr of right-lateral strike-slip along its central section ∼100 km south of the junction. Further south, preliminary observations suggest a slip rate comprised between 3.5 and 6.5 mm/yr along the westernmost part of the Duke River thrust fault. Our results highlight the complex partitioning of deformation inland of the Yakutat collision, where the role and slip rate of the main faults vary significantly over distances of ∼100 km or less. We propose a schematic model of present-day tectonics that suggests ongoing partitioning and reorganization of deformation between major inherited structures, relay zones, and regions of distributed deformation, in response to the radial stress and strain pattern around the Yakutat collision eastern syntaxis.

1. Introduction and tectonic setting

The Yakutat collision zone is an outstanding example of continental indentor tectonics (Fig. 1). At the transition between subduction and strike-slip plate boundaries, the thickened oceanic crust of the Yakutat block (carried by the Pacific plate) collides with the North America plate at ∼50 mm/yr, at the border between Alaska and the Yukon Territory (Bruns, 1983; Pavlis et al., 2004). This collision results in a strong partitioning of the deformation, with ∼13 mm/yr block-like WNW-ward motion of southern Alaska (Elliott et al., 2013; Mériaux et al., 2009) and diffuse inland deformation with shortening rates of 6–10 mm/yr north and east of the syntaxis (Leonard et al., 2008; Marechal et al., 2015). Inland, the Denali Fault is clearly defined as a right-lateral strike-slip structure (e.g., Plafker et al., 1994). The Mw = 7.9 earthquake, which occurred along its central part in 2002 and propagated onto the Totschunda Fault (Haeussler et al., 2004), raises the question of the slip rate evolution along the Denali Fault from its central segment to its eastern segment.

Fault slip data, regional kinematics, and strain analyses indicate a lateral eastward decrease of the Denali Fault slip rate from 12–14 mm/yr on its central part to 6–10 mm/yr at the junction with the Totschunda Fault, which accommodates the remaining 5–7 mm/yr (Matmon et al., 2006; Mériaux et al., 2009; Bemis et al., 2015). Further south, near the Alaska border and into Yukon Territory, Richter and Matson (1971) did not recognize any evidence of activity in the geomorphology along the eastern Denali Fault. However, Seitz et al. (2010) documented paleo-earthquakes and estimated ∼3 mm/yr horizontal slip rate from offset mounds along the Kluane Lake section (Fig. 1). South of Kluane Lake, GPS data show 2.0 ± 0.9 mm/yr of dextral motion along the eastern Denali Fault, while a 5–10 mm/yr NE–SW shortening rate is estimated across the region comprising the eastern Denali and Duke

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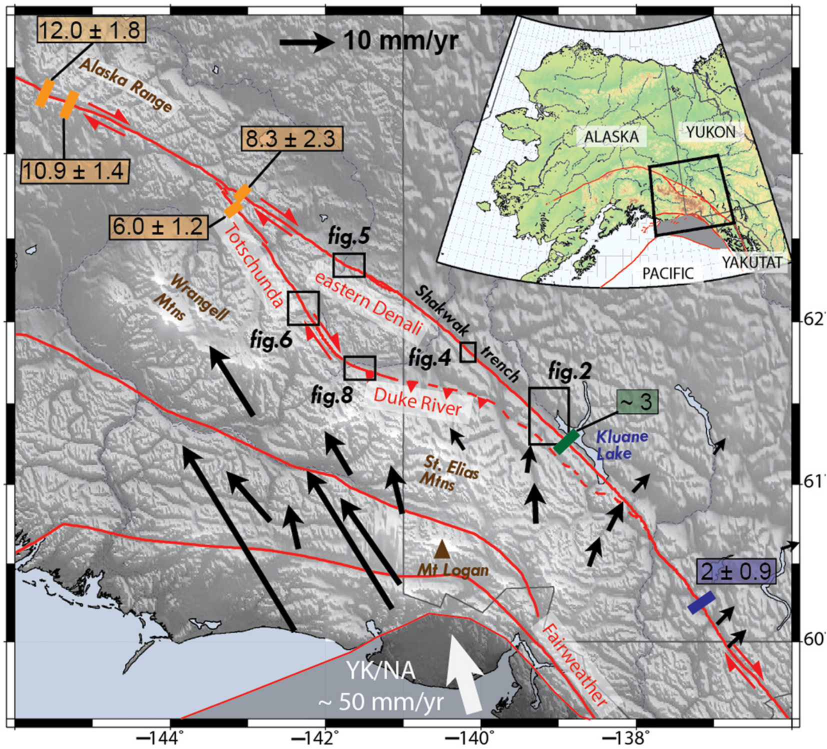

Fig. 1. Tectonic setting of the Yakutat collision. White arrow shows the Yakutat – North America convergence rate; black arrows show the GPS data (after Marechal et al., 2015); colored marks and rectangles identify fault slip rate estimates from previous studies (orange: Matmon et al., 2006; green: Seitz et al., 2010; blue: Marechal et al., 2015). Black frames show sites analyzed in this study. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

River Faults (Marechal et al., 2015). GPS data also suggest that the deformation within the Yakutat syntaxis is radiating from an indentor corner with velocities rotating clockwise from NW to NE around the syntaxis of the Yakutat indentor (Leonard et al., 2007; Marechal et al., 2015) (Fig. 1).

These GPS and geomorphological data raise the question of how the regional tectonics accommodates the distributed deformation field along the eastern Denali, Totschunda and Duke River Faults. In this paper, we present new constraints on the kinematics (sense of motion) and the slip rates along these three faults from a detailed geomorphological study. Our observations bring new insight into the present-day geodynamics of the Yakutat collision.

2. Morphotectonic analysis

2.1. Geomorphological setting

The fault system studied here (Fig. 1) is comprised of i) the eastern Denali Fault that runs along a major glacial valley (Shakwak Trench) extending between the USA/Canada border and Kluane Lake, ii) the Totschunda Fault that marks the NE flank of the Wrangell Mountains, and iii) the Duke River Fault that bounds the St. Elias Mountains to the north. This region is located at high latitudes (60–63.5° N) and high elevations (700–3500 m.a.s.l.) and was repeatedly covered with massive glaciers and icecaps from the Cordilleran Ice Sheet during the Quaternary (Duk-Rodkin et al., 2004). Paleoclimate studies relying on radiocarbon- and cosmogenic-dated glacial landforms and deposits establish a chronology of major and minor episodes of ice advance and retreat. Many studies provided age constraints for the region for the past 300 ka (e.g. Denton, 1974; Duk-Rodkin et al., 2004; Matmon et al., 2010; Kaufman et al., 2011; Turner et al., 2016). Overall, the maximum late Pleistocene glaciation occurred during MIS 4/3 (40–70 ka) and was followed by an intermediate episode at 25–30 ka. At 29.6 ± 0.46 kyr BP (MIS 3), the Macauley–Kluane glacier filled the Shakwak trench entirely and reached a maximum thickness of 300 ± 50 m; this marks the Last Glacial Maximum (LGM). Within the Shakwak trench, ice retreat is attested by similar landforms within the Kluane Lake area at 12.5 ± 0.2 ka BP and near the USA/Canada border at 11.0 ± 0.16 ka BP. Re-calibrating these two ages using OxCal 4.2 (Bronk Ramsay, 2008) and IntCal13 (Reimer et al., 2013) yields 14700 ± 300 cal yrs BP and 12950 ± 100 cal yrs BP, respectively.

2.2. Methodology

Our geomorphological study is based on the analysis of aerial photographs, satellite images, and digital elevation models at different resolutions (i.e. DEM from WorldDEM, IfSAR, Pleiades/High Elevation Aerial/Low Elevation Aerial photogrammetry, and field RTK (see Suppl. Material text S1)) that was complemented by field observations and measurements. These data allow us to determine offsets and therefore the kinematics along faults.

In terms of age constraints, we mainly use published data that are both the closest to our studied sites and correspond to the type of markers we analyze. We recalibrated radiocarbon dating of Denton (1974) using OxCal (Bronk-Ramsey, 2008) to constrain the age of the ice retreat in or near the main Shakwak Trench, whereas we use cosmogenic ^{10}Be ages obtained by Matmon et al. (2006) on stabilized moraines within the northern part of the Totschunda fault to constrain the age of ice retreat in this region. In summary, the age constraints for the LGM retreat are 11.9 ± 1.8 kyr BP along the Totschunda Fault, 12.9 ± 0.2 kyr BP along the Duke River Fault and 13.8 ± 0.9 kyr BP along the Denali Fault. The maximum extent of the late Pleistocene glaciation is dated to 27.5 ± 3.3 regionally (Matmon et al., 2010). Table 1 presents a summary and the locations of the ages used in this study. These age constraints combined with measured fault offsets are used to determine slip rates along faults. We also performed cosmogenic radionuclides analyses at two sites (Ramshole Creek and Washe Creek) along the