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Crustal deformation due to Alaska–Yakutat collision

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ABSTRACT

The region of Alaska and adjacent northwest Canada is tectonically active and is subjected to multiple tectonic processes including plate subduction and terrane accretion. These tectonic processes and the forces originating thereof are responsible for high seismicity in the region and deformation of the crust. In the present-day tectonic setting, the Yakutat terrane is obliquely colliding with Alaska along the Aleutian Trench. Also, flat subduction due to under thrusting of a thickened crust, probably of oceanic affinity, is contributing to the tectonic evolution of this region in a basal traction collision style. This study uses the 2D, planform, thin-viscous-sheet model to investigate the effect of the Yakutat terrane colliding with Alaska and adjacent northwest Canada. Along with the obliquity and velocity of convergence, the lateral strength heterogeneities in the crust are considered in this investigation. The results of the numerical model are constrained with the observed topography and stress orientation in Alaska. It is shown that the Alaska–Yakutat collision is producing asymmetric deformation of the crust with respect to the normal to the collision boundary and that lateral strength heterogeneities contribute significantly to the deformation of the crust. Also, the influence of this collision can be observed up to a distance of ~700 km inland from the collision boundary.

1. Introduction

The Alaska region has a complex history of evolution that includes multiple terrane accretion, ridge subduction, rifting and oblique convergence (Plafker and Berg, 1994; Plafker, 2003; Bradley et al., 2003; Roeske et al., 2003; Sisson et al., 2003). In the present-day tectonic setting, Alaska and adjacent northwest Canada are being affected by more than one tectonic process. There is the collision between the Yakutat terrane and Alaska, subduction of the Pacific plate beneath Alaska under the Aleutian trench (see Fig. 1), lateral movement along the Queen Charlotte transform system and opening of the North Atlantic ocean (Lane, 1998; Bruhn et al., 2004). The crustal deformation in Alaska and adjacent northwest Canada is the result of all these activities compounded by the elements of previous tectonic events. In order to have a proper understanding of the crustal deformation in this region, it is important that the influence of the tectonic forces originating from the various present-day tectonic processes be investigated separately and then collectively.

Along the Aleutian Trench, the Yakutat terrane is obliquely colliding with Alaska (see Fig. 2) and is the major process affecting most of the deformation and earthquake distribution in Alaska and adjacent northwest Canada (Mazzotti and Hyndman, 2002; Pavlis et al., 2004). The Yakutat terrane was excised from western Canada during the middle Cenozoic and moved north along the Queen Charlotte transform fault where it has been colliding with Alaska since the Miocene (Plafker et al., 1994). Approximately half of the Yakutat terrane has subducted under Alaska and the remaining part is unsubducted because it is composed of lighter Mesozoic transitional crust (Plafker, 1987; Plafker et al., 1994). The subduction angle is about 10° but becomes sub-horizontal further down dip (Brocher et al., 1994), acquiring the overall shape of a flat subduction which extends 400 km under Alaska from the trench (Gutscher et al., 2000; Gutscher and Peacock, 2003).

Geodetic measurements on parts of the Yakutat terrane (e.g., Sauber et al., 1997) indicate a range in the direction of convergence varying from N22°W to N35°W (see Fig. 10 in Bruhn et al., 2004). The estimated convergence rate varies from 45 to 50 mm/year (Fletcher and Freymueller, 1999). However, lower convergence rates have also been observed in geodetic measurements by Sauber et al. (1997). The global plate motion model NUVEL1A of DeMets et al. (1994) predicts a convergence rate of 50 mm/year, similar to the geodetic measurements but the estimated direction of convergence is only N11°W (Fletcher and Freymueller, 1999). Also, study of the velocity field in central Alaska using Global Positioning System (GPS) (Sauber et al., 1997) indicates velocities of 38 mm/year close to the coast decreasing to 2–5 mm/year at the Denali Fault (Fig. 2A).

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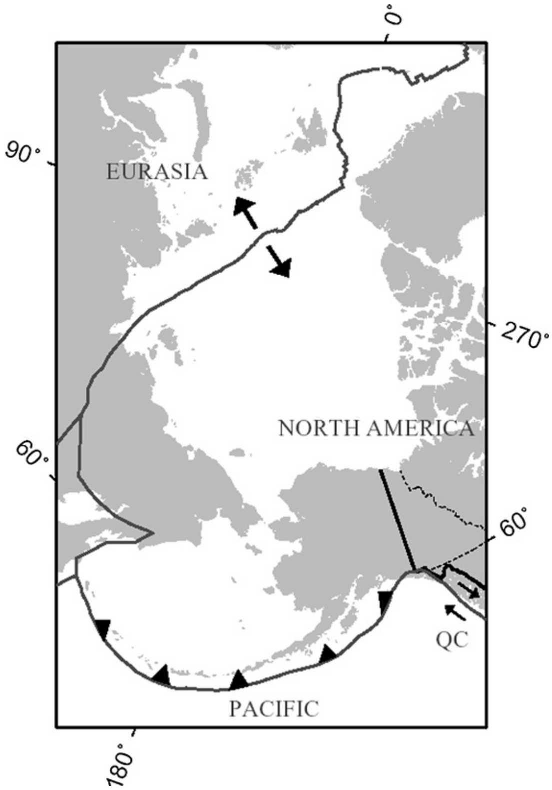

Fig. 1. Plate boundaries around Alaska and adjacent northwest Canada. QC = Queen Charlotte transform fault. Plate boundary locations obtained from Bird (2003).

Thus, most of the deformation due to accretion and subduction of the Yakutat terrane is to the south of the Denali Fault.

The topography of the coastal mountains in southern Alaska (e.g., Saint Elias, Wrangell and Chugach) is the consequence of the interplay between tectonic and geomorphic processes: the collision and subduction of the Yakutat terrane is responsible for the thickening and uplift of the overlying crust whereas glacial erosion has the opposite effect. For example, the rapid uplift of the Saint Elias Mountains (Fig. 2A) during the last 10 million years is linked to the interaction of the continental crust of eastern Yakutat with the subduction zone (Bruhn et al., 2004; Pavlis et al., 2004). This process was initiated at ca. 10 Ma and intensified during the last 5 million years (Pavlis et al., 2004; White et al., 1997).

The evolution of coastal mountains in Alaska is recorded by sediments that were removed by erosion from the mountains and deposited in the offshore basins (Gulick et al., 2004). For example, the thick Yakataga Formation, that covers the continental margin of southern Alaska, records the tectonic history from late Miocene to Recent (Zellers, 1995; Lagoe and Zellers, 1996). Based on the sediment record, Lagoe and Zellers (1996) suggested that the time of tectonic uplift in southern Alaska began in the late Miocene (~10 Ma).

Limited studies have been done to understand how plate boundary forces and the presence of various structural elements in Alaska have affected its evolution. The numerical model of Alaska's neotectonics by Bird (1996) suggested that the Chugach and Wrangell mountains absorbed two thirds of the convergence between the Yakutat terrane and Alaska. Also, the northeast directed compression in Canada is due to the strike normal component of the motion along the Queen Charlotte and Fairweather faults (Bird, 1996). Such a compression direction is consistent with the N20° ± 10°E crustal movement observed by Mazzotti and Hyndman (2002) through GPS surveys. On the basis of numerical modeling, with topography as a constraint, Mazzotti and Hyndman (2002) proposed that

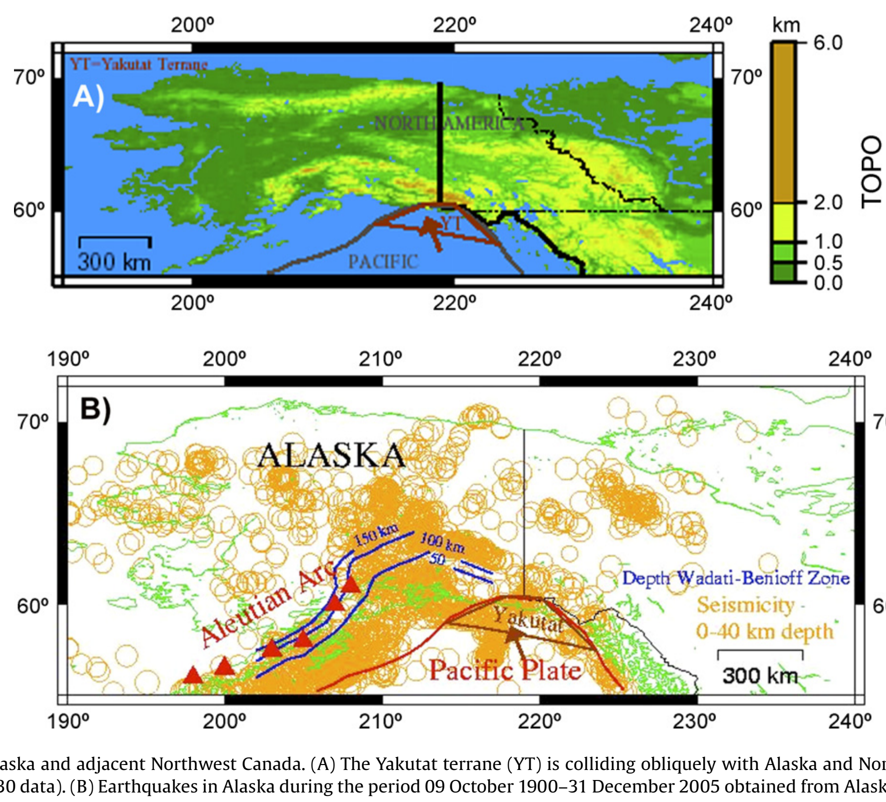

Fig. 2. Seismotectonics of Alaska and adjacent Northwest Canada. (A) The Yakutat terrane (YT) is colliding obliquely with Alaska and Northwest Canada giving rise to the topography (based on Gtopo30 data). (B) Earthquakes in Alaska during the period 09 October 1900–31 December 2005 obtained from Alaska Earthquake Information Center (AEIC). Size of circles scaled to the magnitude of earthquakes. Noticeable is the concentration of earthquakes in front of the Yakutat block and along the convergent boundary.