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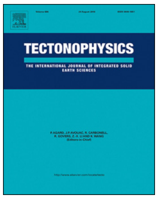

Crustal earthquakes in the Cook Inlet and Susitna region of southern Alaska

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ABSTRACT

Several large ($M \geq 6$) earthquakes have occurred in the vicinity of Anchorage, Alaska, within the past century. The presence of the underlying subducting Pacific plate makes it difficult to determine the origin of these older earthquakes as either crustal, slab, or the subduction plate interface. We perform a seismological study of historical and modern earthquakes within the Cook Inlet and Susitna region, west of Anchorage. We first estimate hypocenters for historical large earthquakes in order to assess their likelihood of origin as crustal, slab, or plate interface. We then examine modern crustal seismicity to better understand the style of faulting and the location of active structures, including within (and beneath) the Cook Inlet and Susitna basins. We perform double-couple moment tensor inversions using high frequency body waves (1–10 Hz) for small to moderate ($M \geq 2.5$) crustal earthquakes (depth $\leq$ 30 km) occurring from 2007 to 2017. Our misfit function combines both waveforms differences as well as first-motion polarities in order to obtain reliable moment tensor solutions. The three focus regions—Beluga, upper Cook Inlet, and Susitna—exhibit predominantly thrust mechanisms for crustal earthquakes, indicating an overall compressive regime within the crust that is approximately consistent with the direction of plate convergence. Mechanisms within upper Cook Inlet have strike directions aligned with active anticlines previously identified in Cook Inlet from active-source seismic data. Our catalog of moment tensors is helpful for identifying and characterizing subsurface faults from seismic lineaments and from faults inferred from subsurface images from active-source seismic data.

1. Introduction

Modern tectonic activity in south-central Alaska is governed primarily by the northwestern subduction of the Pacific plate beneath the North America plate (Fig. 1). This setting is one of the most seismically active regions in the world, having produced the $M_{\mathrm{w}}9.2$ 1964 earthquake. It includes pervasive earthquakes in the subducting slab, down to depths of 200 km, as well as crustal seismicity spanning a broad zone of intraplate deformation (Fig. 2) (Page et al., 1991; Bird, 2003). Many of the earthquakes—both large and small—are not clearly associated with any faults that appear on published surface geological maps. With improved locations of earthquakes and determination of the style of faulting from these earthquakes, we can better characterize the extent, and activity, of faults in the region. Here, we perform a seismological study of a tectonically complex region of south-central Alaska to improve our understanding of active tectonics and seismic hazards in the region.

The Pacific plate subducts to the northwest under south-central Alaska (Fig. 1a). Attached to the Pacific plate to the east is the Yakutat microplate, identified as an oceanic plateau, that is colliding and subducting beneath Alaska (Plafker et al., 1978; Eberhart-Phillips et al., 2006; Christeson et al., 2010). The subducting Pacific/Yakutat plate is interpreted to be responsible for the extremely shallow angle of subduction ($< 5^{\circ}$), far inland, as well as for the noteworthy lack of volcanism in the Susitna basin and Talkeetna Mountains, in a magmatic gap between the Aleutian volcanic arc on the west and the Wrangell volcanic field on the east (Fig. 1a) (Eberhart-Phillips et al., 2006; Rondenay et al., 2010).

We focus on a lowlands region marked by the presence of two major sedimentary basins (Figs. 1b and 3): the Cook Inlet basin south of the Castle Mountain fault, and the Susitna basin north of the fault (Fig. 1b). We refer to this region, which is outlined in Fig. 1b, as the Cook Inlet and Susitna region. The Susitna basin and the smaller, Peters Hill (or Yentna) basin (Haeussler, 2008; Haeussler et al., 2017b), are within the Susitna lowlands, which is outlined in Fig. 1b by Kirschner (1988). The Susitna lowlands and the Cook Inlet basin (Fig. 3) are surrounded by mountains (Fig. 1b): the Talkeetna Mountains to the east, the Alaska Range to the northwest, the Tordrillo Mountains to the west, and the Kenai Mountains to the south.

The Cook Inlet and Susitna region spans the western margin of the

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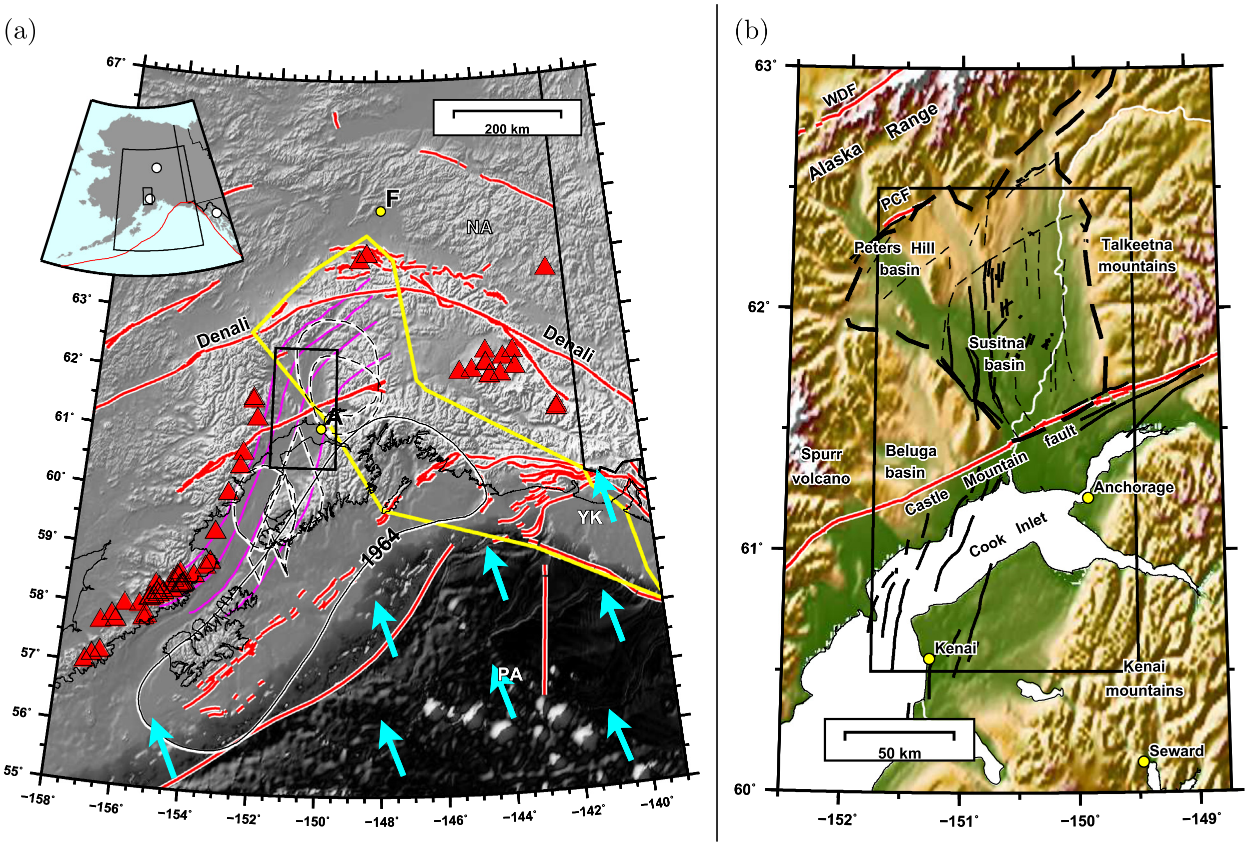

Fig. 1. (a) Active tectonic setting of the Aleutian–Alaskan subduction zone, south-central Alaska. The rectangle in the middle shows the main study region. Cyan arrows shows the plate vectors for the subducting Pacific plate (PA) under the North American plate (NA) (Bird, 2003). Red lines denote active faults (Koehler et al., 2012). Magenta curves are the 40 km, 60 km, 80 km, and 100 km contours of the subduction interface, i.e.„ the top of the Pacific plate (Li et al., 2013). Yellow bounded region denotes the surface and subsurface extent of the Yakutat block (YK) (Eberhart-Phillips et al., 2006). Red triangles represent active volcanoes. Black dashed lines are inferred slow slip events from various sources (Ohta et al., 2006; Wei et al., 2012; Fu and Freymueller, 2013; Li et al., 2016). Also marked is the aftershock zone of the 1964 M_w9.2 earthquake. Labeled cities: Anchorage (A) and Fairbanks (F). (b) Physiographic map of the Cook Inlet and Susitna region, south-central Alaska. Active faults are plotted in red and include Castle Mountain, Pass Creek (PCF), and the western Denali fault (WDF) at upper left (Koehler et al., 2012). Cook Inlet sedimentary basin underlies Cook Inlet and the western Kenai Peninsula (Shellenbaum et al., 2010) (Fig. 3). North of the Castle Mountain fault are three sedimentary basins: Beluga, Susitna, and Peters Hill. Active folds in Cook Inlet basin (Koehler et al., 2012) are marked in black. Other faults in Susitna basin also marked in black are obtained from Haeussler et al. (2017b) and Shah et al. (2015) (Fig. S1). The thick black dashed line denotes the boundary of Susitna lowlands Kirschner (1988). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Pacific/Yakutat plate (Fig. 1a) and contains several notable tectonic elements. Contours of the depth to the top of the subducting Pacific plate (i.e., the subduction interface) (Li et al., 2013) show a clear kink from a westward-dipping slab to a northwestern-dipping slab (Ratchkovski and Hansen, 2002) (Fig. 1a). The subduction interface ranges from a depth of 40 km in the southeast, beneath the Kenai Peninsula, to a depth of 100 km in the northwest, beneath the Alaska Range. The southeast corner of the region also marks the approximate downdip extent of the 1964 M_w9.2 earthquake (Fig. 1a) (Davies et al., 1981; Ichinose et al., 2007). Slow slip and tectonic tremor have been identified on the deeper sections of the subduction interface, from about 40 km to 80 km (Ohta et al., 2006; Wei et al., 2012; Fu and Freymueller, 2013; Li et al., 2016). The crustal thickness inferred from receiver functions is ~30 km in the northern region (Veenstra et al., 2006), implying that these deeper slow slip events would arise from contact with subcrustal mantle.

The dynamics of underlying subduction provide context for characterizing crustal structures and crustal earthquakes, which are the target of this study. Within the Cook Inlet and Susitna region are two active faults in the publication of Koehler et al. (2012): the Pass Creek fault and the Castle Mountain fault. The earliest description of the Pass Creek fault (PCF) appears in Capps (1913), who reported "over 2000 feet" (p. 31) of displacement across the fault. Using interferometric synthetic aperture radar (IFSAR) elevation data, Haeussler et al. (2017b) inferred the PCF to be a northwest dipping normal fault and that it "appears likely that the scarp is a result of at least several surface-rupturing earthquakes" (p. 1471). They estimated the fault has a slip-rate of ~0.5 mm/yr and has the potential of producing a M6.9 ± 0.3 earthquake if the complete 37 km of the fault plane ruptured. Koehler and Carver (2018) discussed a possible interpretation for the Pass Creek fault as "north-directed backthrusting and hanging wall extension above a blind, north-dipping master thrust" (p. 23).

The Castle Mountain–Lake Clark fault system extends 500 km from Lake Clark in the southwest to the Talkeetna Mountains in the northeast (Grantz, 1966). The fault has been interpreted as a right-lateral strike-slip fault based on geological features (Grantz, 1966; Haeussler and Saltus, 2004; Trop et al., 2005; Willis et al., 2007; Haeussler and Saltus, 2011). Two modern earthquakes, each well-recorded by regional stations, provide support for the Castle Mountain fault—or at least the eastern portion—as a right-lateral strike-slip fault. These earthquakes occurred just east of the Cook Inlet and Susitna region, as 1984-08-14 M_w5.8 (depth 15 km) and 1996-11-11 M_l4.6 (depth 17 km). A detailed study of the 1984 earthquake was presented in Lahr et al. (1986); this was the largest earthquake on the Castle Mountain–Lake Clark fault system within the past 40 years (Dziewonski et al., 1981; Ekström et al.,