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# A submarine landslide source for the devastating 1964 Chenega tsunami, southern Alaska

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ABSTRACT

During the 1964 Great Alaska earthquake ($M_w$ 9.2), several fjords, straits, and bays throughout southern Alaska experienced significant tsunami runup of localized, but unexplained origin. Dangerous Passage is a glacimarine fjord in western Prince William Sound, which experienced a tsunami that devastated the village of Chenega where 23 of 75 inhabitants were lost – the highest relative loss of any community during the earthquake. Previous studies suggested the source of the devastating tsunami was either from a local submarine landslide of unknown origin or from coseismic tectonic displacement. Here we present new observations from high-resolution multibeam bathymetry and seismic reflection surveys conducted in the waters adjacent to the village of Chenega. The seabed morphology and substrate architecture reveal a large submarine landslide complex in water depths of 120–360 m. Analysis of bathymetric change between 1957 and 2014 indicates the upper 20–50 m ($\sim$0.7 km$^3$) of glacimarine sediment was destabilized and evacuated from the steep face of a submerged moraine and an adjacent $\sim$21 km$^2$ perched sedimentary basin. Once mobilized, landslide debris poured over the steep, 130 m-high face of a deeper moraine and then blanketed the terminal basin ($\sim$465 m water depth) in $11 \pm 5$ m of sediment. These results, combined with inverse tsunami travel-time modeling, suggest that earthquake-triggered submarine landslides generated the tsunami that struck the village of Chenega roughly 4 min after shaking began. Unlike other tsunamigenic landslides observed in and around Prince William Sound in 1964, the failures in Dangerous Passage are not linked to an active submarine delta. The requisite environmental conditions needed to generate large submarine landslides in glacimarine fjords around the world may be more common than previously thought.

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## 1. Introduction

Several sets of destructive tsunami waves were generated during and immediately after the $M_w$ 9.2 Great Alaskan Earthquake of 1964. The devastation experienced throughout southern Alaska primarily resulted from two separate tsunami types. One was generated by the coseismic movement of the continental margin in the Gulf of Alaska, which produced long-period ocean waves that struck the Alaska coastline about 20 min after the earthquake began and propagated across the Pacific Ocean as far away as Antarctica (Plafker, 1969; Plafker et al., 1969). The second type consisted of trains of shorter period ocean waves generated locally within enclosed fjords and straits of Prince William Sound (PWS) and the Kenai Peninsula (Plafker et al., 1969; Von Huene and Cox, 1972). In many places, the local waves were catastrophic to nearshore communities and impacted the shorelines within minutes of the start of shaking. For example, the towns of Valdez, Seward and Whittier (Fig. 1; Table 1) are each located adjacent to shallow-water submerged delta fronts that failed during the earthquake. The resulting submarine landslides generated tsunami waves and significant wave runup, which severely damaged coastal infrastructure and collectively caused 54 fatalities (Haeussler et al., 2014; Parsons et al., 2014; Plafker et al., 1969; Reimnitz and Marshall, 1965; Suleimani et al., 2011; Von Huene and Cox, 1972; Wilson and Tørum, 1972). Local tsunamis were also observed in

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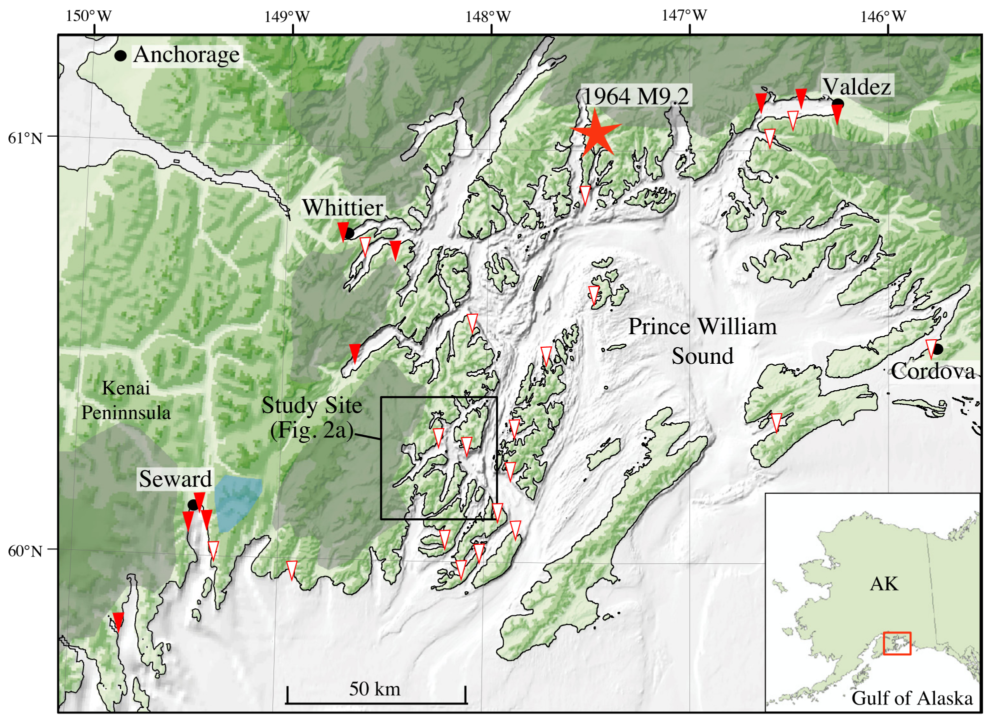


**Fig. 1.** Shaded relief map of Prince William Sound and surrounding region. Triangles are documented locations of high wave runup during the 1964 Great Alaskan Earthquake (red star marks the epicenter). Observed runup linked to a submarine landslide is filled red; runup of unexplained origin is filled white (following Fig. 2 of Nicolsky et al., 2013); runup observations are from Plafker et al. (1969). Gray shaded regions are locations of large ice fields and active glaciation (e.g., Wiles et al., 1999). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

**Table 1**
Sites of documented landslide-induced tsunami runup.

| Location | Fatalities | Max runup (m) | Landslide volume ($km^3$) | References |
|---|---|---|---|---|
| Whittier | 13 | 32 | 0.04 | Haeussler et al. (2014), Plafker et al. (1969) |
| Valdez | 33 | 67 | 0.4–1.0 | Lee et al. (2007), Parsons et al. (2014), Plafker et al. (1969) |
| Seward | 13 | 12 | 0.2 | Haeussler et al. (2007), Plafker et al. (1969), Wilson and Tørum (1972) |
| Chenega | 23 | 21 | 0.1–0.7 | This study, Plafker et al. (1969) |

many other places in and around PWS (white triangles in Fig. 1), but the specific source mechanisms remain unknown (Plafker et al., 1969; Von Huene and Cox, 1972; Nicolsky et al., 2013). The importance of delineating the sources of these events is highlighted by the fact that a total of 82 lives were claimed in 1964 by local tsunamis, but also because many high-latitude commercial ports and coastal communities are located along glacimarine fjords. Most documented landslides in fjord settings occur in relatively shallow water along submerged delta fronts, depositional environments known to be prone to failure during earthquakes and other transient sources of shear stress (e.g., Aarseth et al., 1989; Hampton et al., 1996; L'Heureux et al., 2010; Lastras et al., 2013; St-Onge et al., 2004; Syvitski and Schafer, 1996; Prior et al., 1982, 1986; Reimnitz and Marshall, 1965). Nevertheless, most fjords lack the data needed to systematically evaluate the potential hazards.

One of the most devastating, but poorly understood local tsunamis of 1964 struck the native village of Chenega in western PWS (Fig. 2). Waves virtually destroyed the village, and 23 of 75 inhabitants lost their lives (KPIX-TV, 1964; Plafker et al., 1969). Surviving residents were temporarily relocated to other townships until 1984 when 'New' Chenega was reestablished in Sawmill Bay, ~20 km to the south of the original site (Nicolsky and Koehler, 2014). Although eyewitnesses helped document the sequence of events at Chenega in 1964 (Plafker et al., 1969), the specific source of the destructive waves remains heretofore unknown. We present new interpretations of the tsunami source based on high-resolution marine geophysical data acquired in the waters near Chenega. Our results help constrain tsunami hazards across southern Alaska and provide new insights into submarine landslide occurrence and associated tsunami generation in glacimarine fjords.

## 2. Background

Dangerous Passage is one of several glacially eroded fjords that extends westward of Knight Island Passage and contains a series of smaller elongate tributary fjords, including Icy Bay, Whale Bay, Jackpot Bay and Nassau Fjord (Fig. 2a). Late Pleistocene glaciers retreated from PWS into the headland fjords around 10,000 yr B.P. (Barclay et al., 2009). The most recent major ice advance in southern Alaska occurred during the late Little Ice Age (LIA; Barclay et al., 2009), in which many of the ice margins advanced to their Holocene maxima (Calkin et al., 2001). Princeton Glacier, located to the west of Nassau Bay, is thought to have merged with Chenega and Tigertail glaciers during the LIA and advanced to the mouth of Nassau Bay, before retreating back to the fjord head in the late 1800s (Wiles et al., 1999). The heads of Nassau Bay and Icy Bay still contain tidewater glaciers. Several rudimentary (by today's standards) bathymetric surveys of Dangerous Passage and surrounding inlets were conducted since 1950, but there has been no detailed marine geological study of this area.