# Chapter 32
# New Imaging of Submarine Landslides from the 1964 Earthquake Near Whittier, Alaska, and a Comparison to Failures in Other Alaskan Fjords

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**Abstract** The 1964 Alaska $M_w$9.2 earthquake triggered numerous submarine slope failures in fjords of southern Alaska. These failures generated local tsunamis, such as at Whittier, where they inundated the town within 4 min of the beginning of shaking. Run-up was up to 32 m, with 13 casualties. We collected new multibeam bathymetry and high-resolution sparker seismic data in Passage Canal, and we examined bathymetry changes before and after the earthquake. The data reveal the debris flow deposit from the 1964 landslides, which covers the western 5 km of the fjord bottom. Individual blocks in the flow are up to 145-m wide and 25-m tall. Bathymetry changes show the mass transfer deposits originated from the fjord head and Whittier Creek deltas and had a volume of about 42 million $m^3$. The 1964 deposit has an average thickness of ~5.4 m. Beyond the debris flow, the failures likely deposited a ~4.6-m thick megaturbidite in a distal basin. We have studied the 1964 submarine landslides in three fjords. All involved failure of the fjord-head delta. All failures eroded basin-floor sediments and incorporated them as they travelled. All the failures deposited blocks, but their size and travel distances varied greatly. We find a correlation between maximum block size and maximum tsunami run-up regardless of the volume of the slides. Lastly, the fjord's margins were influenced by increased supply of glacial sediments during the little ice age, which along with a long interseismic interval (~900 years) may have caused the 1964 earthquake to produce particularly numerous and large submarine landslides.

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S. Krastel et al. (eds.), *Submarine Mass Movements and Their Consequences*, Advances in Natural and Technological Hazards Research 37, DOI 10.1007/978-3-319-00972-8_32,
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**Keywords** Submarine landslide • 1964 Alaska earthquake • Fjord • Tsunami • Little ice age

## 32.1 Introduction

The 1964 Alaska $M_w$9.2 earthquake remains the second largest event ever recorded. In Alaska, 106 of 122 deaths from the earthquake were related to tsunamis, and 85 of these 106 deaths were associated with submarine landslide generated tsunamis (Fig. 32.1; NGDC tsunami database). Local submarine landslide-triggered tsunamis

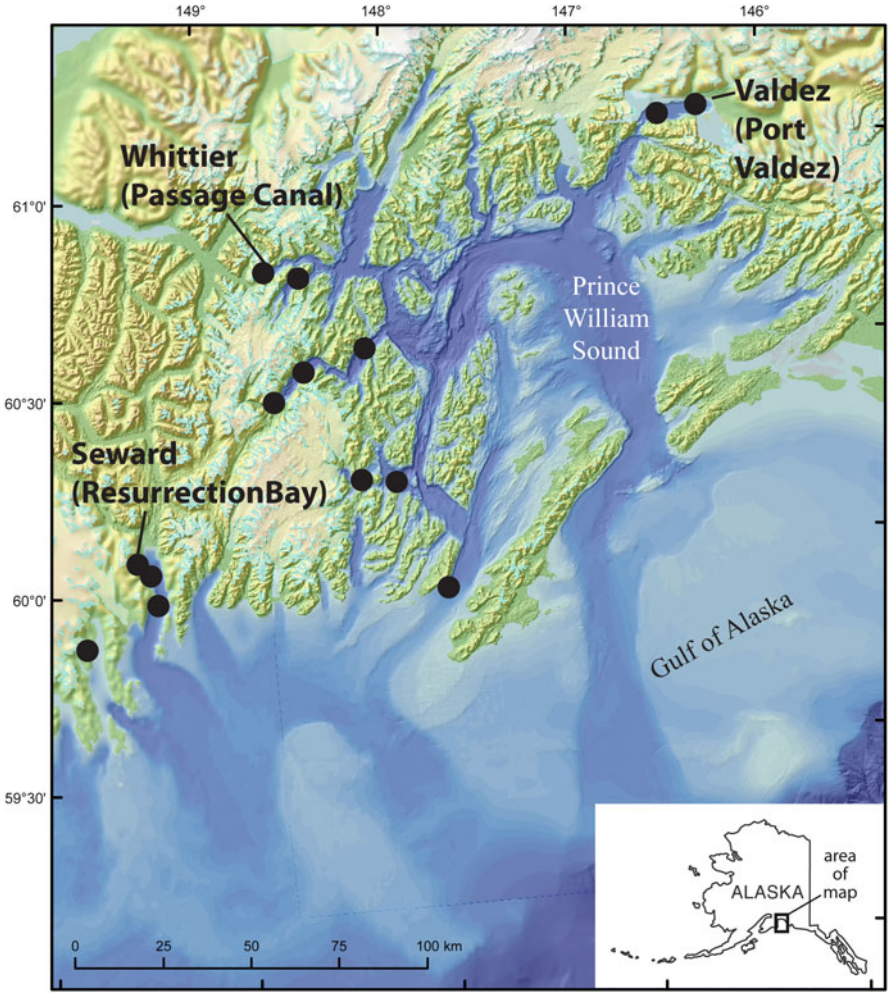



**Fig. 32.1** Overview bathymetric and topographic map of the southern Alaska margin. *Black circles* show the locations we infer submarine landslides from data of Plafker et al. (1969) and our observations. Town names are listed with adjacent water body names in *parentheses*

were the biggest single cause of deaths in this earthquake. This is in contrast to other great megathrust earthquakes, where most casualties come from the tectonic tsunami.

Here we provide the first geologic examination of submarine landsliding in Passage Canal, since pioneering work completed soon after the 1964 earthquake (Fig. 32.1; Kachadoorian 1965; Wilson and Tørum 1972). Tsunami inundation maps were recently produced for this area, based on hypothetical source scenarios (Nicolsky et al. 2011a). Our new data could be used to benchmark tsunami models and validate scenarios. Whittier, Alaska, is a small (population 223) port town on the southern edge of Passage Canal, which is a fjord in western Prince William Sound (Fig. 32.1). The town is built on the Whittier Creek alluvial fan at the edge of the fjord. Whittier was, and remains, an unusual community in that the majority of the residents live(d) in a 14-story building, which lies about 450-m inland. Between this apartment building and the shoreline lies the industrial part of town with the port and harbor facilities, ferry dock, and railroad yard. The fjord ends about 2 km west of town, where two streams empty into Passage Canal and construct the fjord head delta.

There was about 4 min of strong, sustained, ground shaking in Whittier during the 1964 earthquake. Plafker (1969) determined that Whittier and all of Passage Canal subsided about 1.6 m during the event.

At least three waves inundated Whittier soon after the earthquake (Kachadoorian 1965). About a minute after shaking began, a large glassy wave formed in the middle of Passage Canal. This wave had a height of ~8 m above the sea level, but did not cause any damage. About a minute later, a muddy 12-m-high breaking wave inundated the port and railroad facilities. About 45 s later, a smaller third wave hit the town. The waves caused extensive destruction and 13 fatalities.

After the earthquake, Kachadoorian (1965) documented the tsunami run-up, changes in bathymetry along three profiles, and showed that failure of the fjord-head delta and the Whittier Creek fan generated the local tsunami.

## 32.2 Data and Methods

In the summer of 2011, we collected multibeam bathymetry and sparker seismic data in Passage Canal. We also examined bathymetry changes between a 1948 survey and our survey. Our goals were to better map the location and characteristics of the landslides, and to compare them to submarine landslides near Seward and Valdez (Fig. 32.1; Lee et al. 2006, 2007; Haeussler et al. 2007; Ryan et al. 2010).

We collected high-resolution bathymetric data for the westernmost 14 km of Passage Canal (Fig. 32.2). In total, we obtained 25 $km^2$ of multibeam data with a Reson 7111 system. Sound velocity casts were collected at six locations to improve depth calculations. In the survey area, we covered all areas deeper than about 20 m. Data processing removed noise and artifacts, and we produced a final DEM at a 5-m

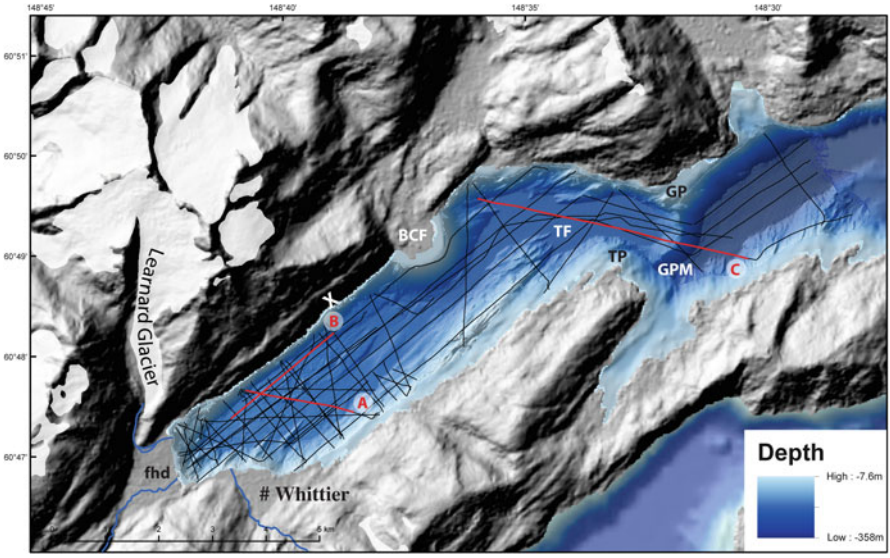



**Fig. 32.2** Combined topography and bathymetry of the Passage Canal and Whittier area. *Black lines* are high-resolution seismic tracklines. Tracklines in *red*, labeled A, B, C, are shown in Fig. 32.3. Location X is where Nicolsky et al. (2011b) found evidence for cracking in bedrock indicating rockfall potential. *GP* Gradual Point, *GPM* Gradual Point moraine, *TP* Trinity Point, *TF* Trinity flats, *BCF* Billings Creek fan, *fhd* fjord-head delta

grid spacing. A 1995 NOAA conventional survey (H-10655) was combined with our final multibeam DEM to produce a combined DEM (Fig. 32.2).

For high-resolution seismic imaging, we used a single-channel streamer and a SIG 2Mille 50-tip mini-sparker as the source. The sparker was operated at a power of 500 J with a frequency range of 160 Hz to 1.5 kHz and a shot spacing of about 2.4 m. We collected about 168 km of data (Fig. 32.2) and found coherent reflections up to about 90 m below the sea bottom (Fig. 32.3). After data collection, a spectral shaping filter was applied to sharpen the seismic wavelet, then a coherency filter and automatic gain control were applied to produce the final image.

For examining bathymetric changes, we compared the depths from our survey to those of a 1948 NOAA survey (H-7161 with depths recorded in fathoms). We digitized more than 6,000 soundings from the smooth sheet, which averaged 93-m apart. As the entire area subsided about 1.6 m in 1964, the 1948 data were lowered this amount. The 2011 survey was then subtracted from the 1948 survey to show areas of depth changes.

The subsequent bathymetry difference map (Fig. 32.4) has some errors. As navigational accuracy was low in 1948, we discount most difference values on the fjord walls. The flat areas both east and west of the Gradual Point moraine are good locations to compare values as the effects of navigational errors are minimized. We refer to the basin west of the moraine as Trinity flats. It is possible a ~4-m-thick turbidite was deposited here in 1964, which we discuss later. Thus, we either

expect no depth change or a shallowing by about 4 m. Instead, we find depths are approximately 2.5–4.0 m deeper, and east of the moraine, depths are about 9 m deeper. A uniform water velocity of 800 fathoms/s (that is 1,463 m/s) was used for soundings in the 1948 survey, which would result in only a 1 m discrepancy from our values, so the source of the error remains unknown. The smaller error west of the moraine is consistent with the ~4 m thick turbidite hypothesis. Thus, the difference map is probably not accurate to <10 m in the deep fjord.

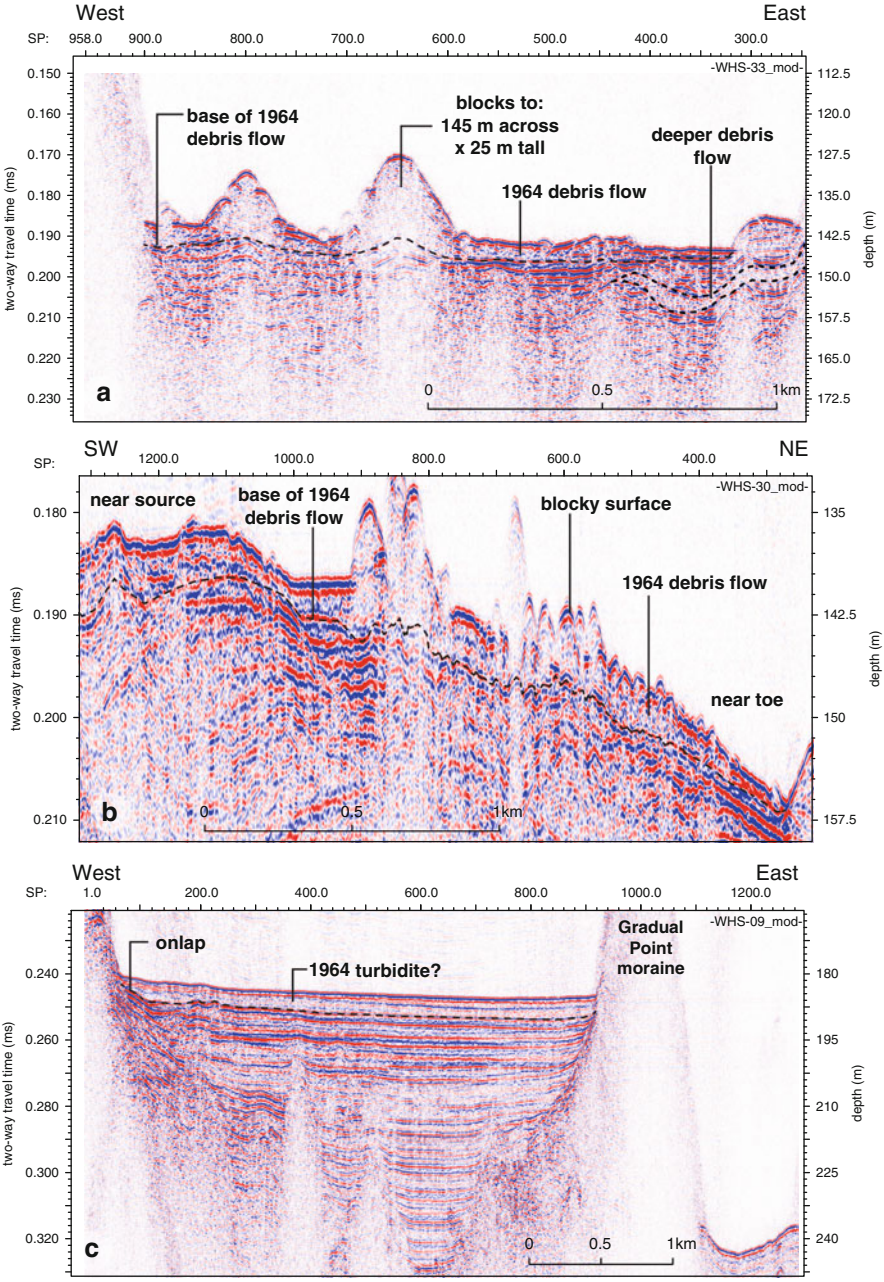
## 32.3 Results and Interpretations

The bathymetry data reveal the Holocene geologic processes at work (Fig. 32.2). Glacial scouring emphasizes the NW-SE strike of bedding. At the west end of the fjord, the lumpy character of the bottom shows blocks from the 1964 failures. This region extends about 5 km down the fjord center (Figs. 32.2 and 32.4). The Billings Creek fan is the next major feature, which shows small rills and gullies typical of fans. There are no indications of failures on the fan on the bathymetry or seismic data. We identify a submerged moraine south of Gradual Point with a shallowest depth of 141 m. West of the Gradual Point moraine is the Trinity flats basin. Nicolsky et al. (2011b) showed evidence of an incipient subaerial rock fall on the north shore of Passage Canal (point X on Fig. 32.2), and the authors model potential tsunami impact at Whittier. No evidence of rock fall is observed on the fjord bottom at this location.

High-resolution seismic reflection data show the base of the 1964 submarine landslide deposit (Fig. 32.3). We consider the seismic data in two parts divided by the Billings Creek fan. These areas have different characteristics at all stratigraphic levels, and the relationship between the two is obscured by channelization along the southern margin of the fan.

At the west end of the fjord, the uppermost seismic-stratigraphic unit consists of a hummocky, acoustically transparent facies with low-amplitude internal reflections (Fig. 32.3A, B). This unit correlates with the geomorphic expression of a blocky debris flow, and we conclude this is the mass transfer deposit (MTD) triggered by the 1964 earthquake. This deposit is typically 2- to 8-m thick, assuming a velocity of 1,500 m/s. Truncations of reflectors at the base of this unit indicate it was eroding as it flowed. Blocks within the deposit are up to 25-m tall and 145-m long. They have a velocity pull up beneath, indicating they consist of relatively high velocity material, possibly till. We infer a volume of about 20 million $m^3$ based on mapping the deposit with the seismic reflection data.

Below the 1964 deposit, we observe reflectors that we interpret as mostly background fjord sedimentation (Fig. 32.3). Blocks in the 1964 deposit make it difficult to better image the lower strata. Nonetheless, the reflectors usually parallel the bottom and pinch and swell slightly. There are acoustically transparent regions, but these do not have lateral continuity beyond a few hundred meters (Fig. 32.3A). These likely represent sediments deposited in small debris flows off the fjord-head


West
East
SP: 958.0 900.0 800.0 700.0 600.0 500.0 400.0 300.0
-WHS-33_mod-
base of 1964 debris flow
blocks to: 145 m across x 25 m tall
deeper debris flow
1964 debris flow
two-way travel time (ms)
depth (m)
a
0 0.5 1km
SW
NE
SP: 1200.0 1000.0 800.0 600.0 400.0
-WHS-30_mod-
near source
base of 1964 debris flow
blocky surface
1964 debris flow
near toe
b
0 0.5 1km
West
East
SP: 1.0 200.0 400.0 600.0 800.0 1000.0 1200.0
-WHS-09_mod-
onlap
1964 turbidite?
Gradual Point moraine
c
0 0.5 1km

delta or Whittier Creek. We have not been able to confidently trace seismic-stratigraphic packages from line to line. We see no evidence for large-scale MTDs beneath the 1964 deposit.

East of the Billings Creek fan, beneath the Trinity flats, the uppermost deposit is possibly a turbidite from the 1964 earthquake (Fig. 32.3C). The uppermost 0.005 s TWT (~4 m) is a coherent seismic stratigraphic unit with low amplitude and 1 or 2 weak internal reflectors. It locally shows onlap, and has a volume of about 14 million $m^3$. Given the large 1964 debris flow at the west end of the fjord, it is reasonable to expect that a turbidite developed and travelled farther eastward. The stratigraphic position, onlap, acoustic properties, and setting are consistent with a turbidite generated in 1964.

The bathymetry difference map shows redistribution of sediment during the 1964 earthquake (Fig. 32.4). The primary features of the map are an increase in depth up to 80 m at the west end of the fjord and off Whittier, and the deposition of the block field and debris flow in the area north of Whittier. This conclusion is the same as that of Kachadoorian (1965), who did 2D bathymetry differencing in this area and found broadly similar results. Based on differencing just the source regions, we calculate the volume of failed sediment was approximately 42 million $m^3$. This volume is greater than the calculated volume of the deposit from the seismic data (32 million $m^3$ ($32 = 20 + 14$ million $m^3$)), and moreover, we found evidence of erosion at the base of the debris flow, which indicates the deposit volume should be greater than the source region volume. This leads us to infer that there are errors in one of these two numbers, possibly related to incorrect mapping of flow margins or bathymetry on the older survey.

## 32.4 Discussion and Comparison

The new data provide a clear picture of the submarine landslide deposit generated in the 1964 earthquake. Simply, the fjord head delta and the Whittier Creek delta failed, and the landslide material slid eastward up to 5 km. A large turbidite was likely generated and deposited farther eastward across the Trinity flats. We can compare the characteristics of this slide and fjord to Port Valdez and Resurrection Bay where there were also submarine landslides in 1964.

**Fig. 32.3** Seismic reflection profiles showing features of the 1964 mass transfer deposit. Location of profiles shown on Fig. 32.3. Horizontal scale is shot points, vertical scale is two-way travel time in seconds. 0.01 s TWT is approximately 8 m. (**A**) Line (WHS-33) across the largest blocks in the area north of Whittier. (**B**) Line (WHS-30) shows the main debris flow deposit from near the source region on the left to the distal end of the debris flow to the right. (**C**) Profile (WHS-09) across the Trinity flats and the Broad Point moraine that shows the nature of sedimentation beneath this basin. The uppermost ~4 m may be a turbidite generated in 1964. It onlaps older sediments at the west end of the profile. Older deposits may also contain turbidites

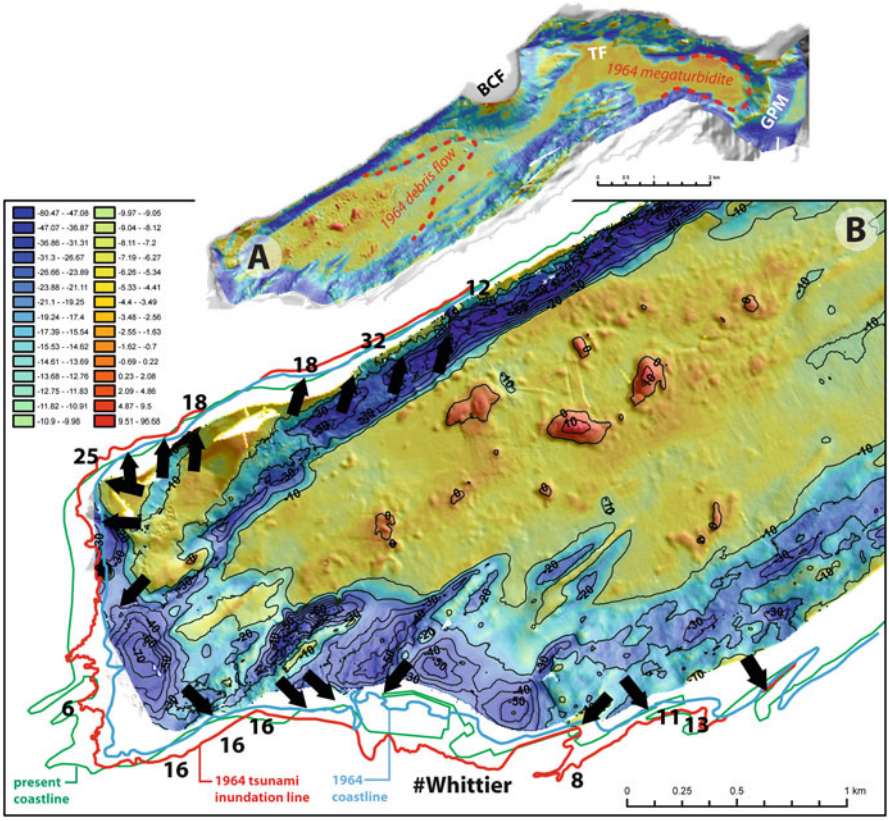



**Fig. 32.4** Bathymetry difference, in meters, draped onto shaded relief image of Passage Canal. Note zero depth change color is *orange*. Older bathymetric survey is from 1948, our multibeam survey was in 2011. *Cool* colors indicate deeper values in 2012, *warm* colors indicate shallower depths in 2011. (**A**) Overview map of entire area of multibeam survey. *BCF* billings creek fan, *TF* trinity flats, *GPM* Gradual Point moraine. *Dashed red lines* show the limits of the 1964 debris flow, and the 1964 megaturbidite deposit. (**B**) Detail map of west end of Passage Canal near Whittier, which also shows the coastline and inundation line, tsunami runup directions (*arrows*) and heights, in meters (Data from Kachadoorian 1965)

At Port Valdez, the Shoup Bay moraine failed (Ryan et al. 2010). Blocks are up to 40-m tall and 400-m wide, extend 25 m below the sea floor, and the nearby tsunami run-up reached 67 m. In Passage Canal, the blocks are up to 25-m tall and 145-m wide, and extend ∼5 m below the sea floor. Nearby tsunami run-up (Fig. 32.4) reached 32 m. The blocks may be composed of till, because a little ice age moraine is located on the modern shoreline adjacent to material that failed in 1964. The lack of seismic penetration and the velocity pull up beneath the blocks is consistent with blocks composed of till. In Resurrection Bay, the maximum block size off Seward was 12-m tall and 75-m across. Maximum tsunami runup was 12 m. The blocks were likely composed of sand and gravel. Although the nature of the failed material

varies, and likely influences block size and the ability of the blocks to remain intact, we find a correlation between the size of landslide blocks and maximum runup. Blocks may be more important than slide volume for generating tsunamis in some circumstances.

There are similarities and differences in the failures we have studied. All the landslides have evidence of erosion at their bases. Thus the landslide volume increased as the landslide progressed, leaving a larger deposit than the initial failure. Fan deltas almost always fail. In Resurrection Bay, every fan failed in the 1964 earthquake (Haeussler et al. 2007), and the Whittier Creek fan failed in Passage Canal. It is remarkable there is no evidence of failure of the Billings Creek fan. There is cryptic evidence of pre-1964 slides in Passage Canal, as described previously. Both Resurrection Bay and Port Valdez have clear evidence for pre-1964 slides, with Port Valdez showing five older failures (Ryan et al. 2010).

The little ice age (LIA) probably had a significant influence on the size of the submarine landslides in the 1964 earthquake. The little ice age consisted of multiple advances of glaciers, with three main pulses of expansion: 1180–1320 AD, 1540–1720 AD, closely followed by 1810–1880 AD (Barclay et al. 2009), all of which post-dated the last major megathrust earthquake around 900 years ago (Carver and Plafker 2008). These glacial advances transported additional sediment to the margins of these fjords, which then failed in 1964. Port Valdez has the clearest link to LIA advances, in that the Shoup Bay moraine was likely built during the LIA (Post and Viens 1994). At Resurrection Bay the relationship is less clear as there are no moraines near the waters edge. Nonetheless, it seems likely the fjord-head delta and the fan deltas built out during the LIA with increased sediment supply. The same arguments can be made for Passage Canal. Moreover, the Learnard Glacier (Fig. 32.2) extended to the shoreline at LIA time, and possibly generated diamicts that favored the generation of large cohesive blocks during failures.

**Acknowledgements** We thank Captain Greg Snedgen of the RV Alaskan Gyre for support during data collection. We thank Jasper Moernaut and Jean-Sébastien L'Heureux for reviews of the manuscript.

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