Influences on landslide tsunamigenesis and propagation

Landslide volume is a primary control on tsunamigenesis; important factors also include failure initial acceleration, velocity and duration, density, viscosity, slope angle, displacement relative to area, retrogressive behaviour, and water depth (Fine et al. 2003; Trifunac and Todorovska 2003; Harbitz et al. 2006). During tsunami propagation, the bearing of coastal sites relative to the direction of slide motion will determine the most affected areas. Other factors that influence the trade-off between attenuation (radial spreading and/or dispersion) and amplification over the tsunami’s travel path include distance, bottom friction, nearshore bathymetry, and resonance effects in inlets, as well as the position of the failure on the continental slope (Harbitz et al. 2006; Geist et al. 2009). Thus, complex modelling is required to assess the potential tsunamigenic impact of submarine failures at coastal sites; observations from the 1929 event are also useful.

Failure Styles

On the Atlantic continental slope three main styles of sediment failure occur (Piper 2005); each is likely the result of different trigger mechanisms and/or preconditioning to failure. (1) Glaciogenic sediments in trough-mouth fans are thought to result from very high-viscosity (glacial till) non-tsunamigenic debris flows during meltwater discharge from parent ice streams; such flows are not expected at the present day (Tripsanas and Piper 2008). (2) A few large deep-seated failures have been identified (e.g., Hopedale-Makkovik failure complex, Deptuck et al. 2007; Shelburne mass-transport deposit, Mosher et al. 2010; Fig. 1). These deposits represent catastrophic slides (on décollements up to hundreds of metres below the surface) that undoubtedly produced large tsunamis; however, with very long recurrence intervals their probabilistic contribution to the tsunami hazard of the east coast is negligible. (3) Most failures are shallow and retrogressive, similar to the 1929 Grand Banks event. Small failures (up to ~10 km³) are common on steep slopes, e.g., canyon walls, but large, potentially tsunamigenic slides occur on lower angle slopes (2-6° regional gradient; Piper et al. 2003; Twichell et al. 2009), generally by retrogression from local steeper areas where failure may be initiated relatively easily by strong ground shaking (ten Brink et al. 2009; Piper et al. 2011). The Scotian slope (except for canyon walls etc) is stable under static conditions (Mosher et al. 1994). Failure would require elevated pore pressure and/or earthquake shaking; factors such as shallow salt deformation, seaward-dipping faults, and the presence of gas-charged sediments, may play a role in pre-conditioning the slope (e.g., Giles et al. 2010).
Modelling of selected slides

Tsunami modelling of selected slides on the Atlantic margin provides some insight into the threshold size for damaging tsunamigenic failures. Geist et al. (2009) modelled the Currituck slide (offshore northern Carolina); for slide volumes of 57, 108 and 165 km³, coastal runup is ~3 ± 1, ~4 ± 2 and ~6 ± 3 m, respectively. The largest volume is similar to the Grand Banks slide, which resulted in a larger maximum runup (13 m; Fine et al. 2005) due to resonance amplification (Murty 1977). At Cape Fear (also offshore northern Carolina), for slide volumes of ~8 and 60 km³, Hornbach et al. (2007) modelled respective maximum wave amplitudes at 100 m depth of 0.7 and > 2 m (for 50 km along strike). Mosher et al. (2010) simulated a tsunami resulting from a deep-seated slump-debris flow on the western Scotian Slope comparable in scale to the Pliocene Shelburne mass-transport deposit (location in Fig. 1; volume ≥ 862 km³; thickness ~130-450 m). Two scenarios were tested for their impact on Halifax, Nova Scotia, located ~200 km from the source across the shelf. (1) A 117 km³ slump results in a 13-m maximum wave amplitude at Halifax; (2) a simultaneous 862 km³ slump and debris flow leads to a 25 m wave. However, the use of instantaneous vertical displacements may have overestimated the amplitudes.

Observations from the 1929 Grand Banks landslide tsunami

The 1929 Grand Banks landslide, triggered by an $M_{7.2}$ earthquake beneath the continental slope (Fig. 1), involved 150-200 km³ of sediment. The most damaging waves of the resulting tsunami travelled ~250 km directly north across the continental shelf, orthogonal from the slide headwall, to devastate the Burin Peninsula; Halibut Channel likely played a significant role in directing tsunami energy from the site of greatest sediment failure. Severe damage occurred in over 40 communities along a ~75-km stretch of coastline (white line in Fig. 1), with loss of life in six communities (Berninghausen 1968; Ruffman and Hann 2006). Minor damage occurred on the coasts of Nova Scotia and Newfoundland, from the Burin Peninsula up to ~425 km to the southwest and up to ~160 km to the east (Berninghausen 1968); the Bonavista area (northeastern Newfoundland) was also slightly affected (Ruffman 2006). Wave amplitudes on the Burin Peninsula are estimated at 3-8 m, with up to 13 m runup, highest at the heads of long bays (e.g., Fine et al. 2005). Reported runups were ~0.6 m at Canso and 1.5 m at Sydney, Nova Scotia, respectively ~425 and 330 km southwest of the Burin Peninsula; a ~1.25 m amplitude (peak-to-trough) was recorded by the Halifax tide gauge, ~640 km from Burin (Fine et al. 2005). Small tsunami waves were recorded as far away as South Carolina, the Antilles, Azores, and Portugal (Berninghausen 1968; Ruffman and Hann 2006).

These observations suggest that a tsunami generated by a 1929-type landslide could result in runup exceeding 1.5 m along a stretch of coastline up to ~700 km or more in length (~100 km for severe damage, with minor damage possible for ~300 km on either side). Tsunamis resulting from smaller landslides closer to the damage threshold are expected to affect a considerably shorter length of coastline.
References


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Fig. 1 SE Canadian continental margin. White star: 1929 M 7.2 epicentre; associated white line: along-slope extent of the Grand Banks landslide (thicker line for section with greatest volume, e.g., Mosher and Piper 2007). White line along Burin Peninsula (BP) coast: extent of most severe tsunami damage in 1929. AP: Avalon Peninsula; CGFZ: Charlie Gibbs Fracture Zone; MTD: mass-transport deposit