Chapter XXX
The Generation of Tsunamis

David R. Tappin
British Geological Survey, Environmental Science Centre, Keyworth, UK

1 INTRODUCTION

Tsunamis are gravity-driven water waves, generated at the water/air interface from a vertical perturbation of the water column, usually from seabed movement. They are generated mainly along convergent margins and predominantly from undersea earthquakes. Build-up of stress along these margins, generated by outward "push" from rock intruded into the crust along oceanic ridges and gravitational "pull" along convergent margins from oceanic crust descending into the mantle, results in earthquake (seismic) rupture. The rupture uplifts the seabed and the overlying water column, thereby generating a tsunami. A number of recent catastrophic earthquake tsunamis include the Indian Ocean event in 2004, where over 230,000 people died, and Japan event in March 2011, which killed 19,000 people. These suggest that major tsunamis are now more common than before, but over the longer timescales this is not supported by statistical evidence (Ben-Naim, Daub, and Johnson, 2013). Tsunami is a Japanese word (in kanji = 津波, which translates into harbor ('tsu') and wave ('nami')). It derives from the first indication of a tsunami wave approaching the coast sometimes being a "whirlpool" effect within a harbor.

2 PERSPECTIVE

Here, we consider tsunamis from their different generating mechanisms, with "generation" including all processes from initial wave generation through propagation to final onland run-up. Since 1998, when a submarine landslide was proven to have generated a tsunami 15 m high that killed 2200 people (Tappin, Watts, and Grilli, 2008), there has been an increased realization that not only earthquakes generate destructive tsunamis. In addition, there are also different earthquake rupture mechanisms that generate different magnitude tsunamis. Recent events have resulted in major advances in understanding of how tsunamis are generated.

3 WHAT ARE TSUNAMIS?

Tsunamis are quite different from wind waves, generated by the frictional effect of wind acting on the sea surface, because they are caused by vertical seabed movement. The movement results in a wave at the sea surface that, by gravitational attraction, collapses and travels (propagates) outward (Figure 1). Apart from earthquakes other, "bottom up," tsunami generation mechanisms include submarine and subaerial landslides and volcanic eruptions, including caldera collapse and pyroclastic flows entering the sea.

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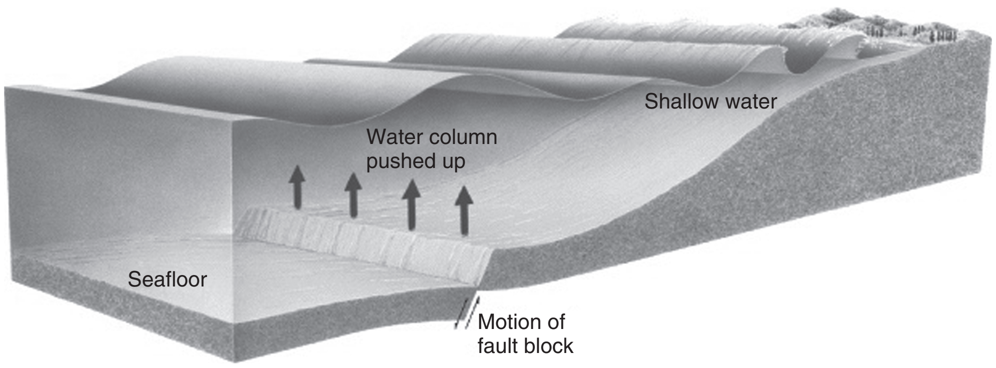

Figure 1. Tsunami generation, propagation, and run-up from a hypothetical earthquake generated event. Vertical elevation of the seabed travels up through the water column and creates a surface wave that travels out with low elevation that increases as the wave approaches the shore.

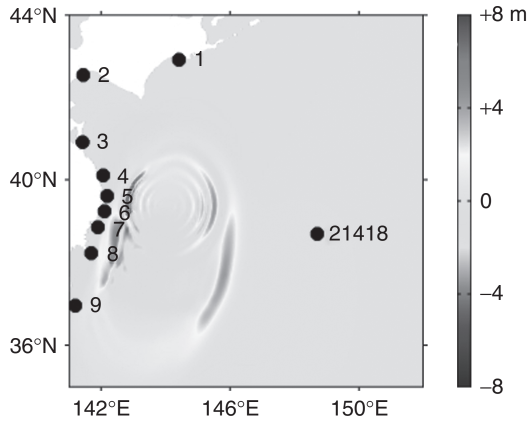

Figure 2. Comparison of tsunami wave surface elevations from the earthquake and submarine landslide generated 15 min after the Japan, 2011 earthquake. The earthquake tsunami (to the south) is almost linear compared to the circular wave train from the submarine landslide (to the north). Note the highly dispersive nature of waves generated by the landslide source, as compared to the longer wavelength, long-crested, non-dispersive, earthquake-generated tsunami waves. Labeled black dots mark the locations of offshore tsunami buoys. (Reproduced from Tappin *et al*. (2014). © Elsevier, 2014.)

Tsunamis are also generated from bolide impacts and rapid pressure changes that accompany storms—termed *meteotsunamis*, but these are "top-down" mechanisms, with the tsunamis generated at the sea surface.

There are three phases of a tsunami: (i) initial wave generation, (ii) propagation (travel) across the ocean and, (iii) finally, onland incursion or run-up (wave elevation at the coast) when the tsunami strikes and then flows across land (Figure 1). When the source mechanism is large enough, the incursion of the tsunami onto the land can be extensive (kilometer) and enormously destructive (e.g., the Indian Ocean tsunami of 2004 and Japan tsunami in 2011).

The initial elevation wave of the tsunami is dependent on the source mechanism. Large earthquakes generate tsunamis with initial wave elevations of 10–20 m along hundreds of kilometers of seabed—for example, the Indian Ocean rupture was 1300 km long. Landslides have the potential to generate initial wave elevations of hundreds and potentially thousands of meters, but the area of wave elevation is much smaller. With landslides, the maximum initial wave elevation is limited only by the ocean depth. A further difference between tsunamis from earthquakes and landslides is that at source the initial wave at the former is linear whereas at the latter the wave is circular as the landslide acts as a point source (Figure 2).

After initiation, the tsunami wave elevation from all mechanisms decreases as it travels outward from the source. Tsunamis are shallow-water waves, defined as having extremely long wavelengths (of hundreds of kilometers) in comparison to oceanic water depths of kilometers. Shallow-water waves travel at velocities given by $c = \sqrt{gh}$, where c is the celerity, g the gravity (=9.8 m/s^2), and h the water depth. Thus, tsunamis travel at very high velocities (160–250 m/s to 600–900 km/h) and have very long wavelengths (hundreds of kilometers) (Figure 3b, lower). These velocities compare to wind waves of about 15 m/s (50 km/h). The deeper the water is, the faster the tsunami travels (Figure 3a). In the deep ocean, a tsunami wave may be insignificant (less than a meter in elevation) and hardly noticeable, unlike storm waves that may be terrifically destructive, for example, freak waves, tens of meters high.

The controls of water depth and seabed morphology on velocity thus determine tsunami direction of travel (Figure 4). A notable aspect of tsunami travel is that the energy is within the whole water column, which results (from the combination with seabed morphology/water depth) in the control on velocity from seabed friction.

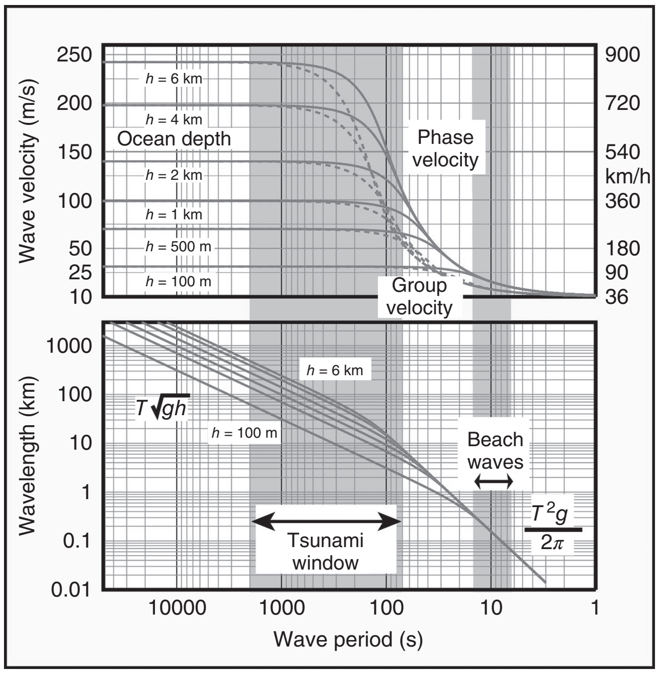

Figure 3. Relationship between tsunami wave period and wave velocity (a) and wavelength (b). Phase velocity $c(\omega)$ (solid lines) and group velocity $u(\omega)$ (dashed lines) of tsunami waves on a flat earth covered by oceans of 100 m to 6 km depth. Wavelength associated with each wave period. The "tsunami window" is marked. (Reproduced from Ward (2010). © Springer, 2010.)

The rate at which a wave loses its energy is inversely proportional to its wavelength, thus tsunamis not only propagate at high speeds but also travel great, transoceanic, distances with limited energy loss. Tsunami travel distance (as with initial wave height) is again dependent on the source mechanism; earthquake tsunamis travel much farther than tsunamis generated from submarine landslides, explained by dispersion, or frequency dispersion, which results in different wavelengths traveling at different phase and wave speeds (Figure 3). The farther the wave travels from its source, the greater the dispersion will be, hence the development of the numerous waves (wave trains) that characterize tsunamis.

Dispersion is particularly common in nonearthquake tsunamis because of their higher frequency content, and these are waves with periods on the steepest part of the graph, the tsunami window in Figure 3a. Even dominantly low frequency earthquake tsunamis, however, may be dispersive in the far field (Kirby *et al*., 2013).

When a tsunami leaves the deep ocean, it slows as water depths decrease (through the increasing effect of bottom friction), although the energy flux remains almost constant. Through conservation of energy, as the tsunami slows down, its height increases (termed *shoaling*) given by $(h_s/h_d) = \{H_d/H_S\}^{1/4}$ where h_s and h_d are wave heights in shallow and deep water and H_s and H_d are the depths of the shallow and deep water. A tsunami with a height of 1 m in the open ocean where the water depth is 4000 m would have an increased wave height of 4–5 m in a water depth of 10 m. Offshore seabed morphology has a significant control in focusing and defocusing the tsunami, which may appear as a series of breaking waves.

During onland incursion, tsunamis slow further due to (i) wave energy being reflected offshore and (ii) shoreward-propagating wave energy being dissipated through bottom friction and turbulence (Figure 5). Tsunamis, however, still retain tremendous amounts of energy and can be very destructive. They have great erosive power, stripping beaches of sand, undermining trees and other coastal vegetation, and crushing homes and other coastal infrastructure. They can inundate and flood kilometers inland. Tsunamis may reach major elevations (termed *run-up height*) above sea level of tens of meters. Depending on whether the first part of a tsunami to reach the shore is a crest or a trough, the tsunami may appear as a rising or falling tide.

4 EARTHQUAKE TSUNAMIS

Tsunami magnitude generally scales to earthquake magnitude, except for "tsunami earthquakes," where a tsunami is much larger than earthquake magnitude would predict (Kanamori, 1972). Satake and Tanioka (1999) identify three types of earthquakes: (i) at the plate interface (interplate), (ii) earthquakes at the outer rise, within the subducting slab or overlying crust (intraplate events), and (iii) tsunami earthquakes (Figure 6). The most common earthquake is termed *interplate*, where it ruptures along the boundary between the overriding and underthrusting plates. The geometry of the fault rupture is significant in tsunami generation, for example, where slip is along a fault that splays off the interplate boundary rupturing the accretionary prism.

4.1 Earthquake controls

Tsunami generation from earthquakes is dependent on magnitude (termed *moment*), depth, and the type of fault rupture. Earthquake size is the primary control on tsunami elevation in the far field, but closer to the source mechanism, a greater variability in tsunami elevation is attributable to variations in water depth, the combination of higher slip and lower shear modulus at shallow depth, and rupture complexity in the form of heterogeneous slip distribution patterns (Geist, 1999). Earthquake depth is important because the deeper the event, the broader the area uplifted,

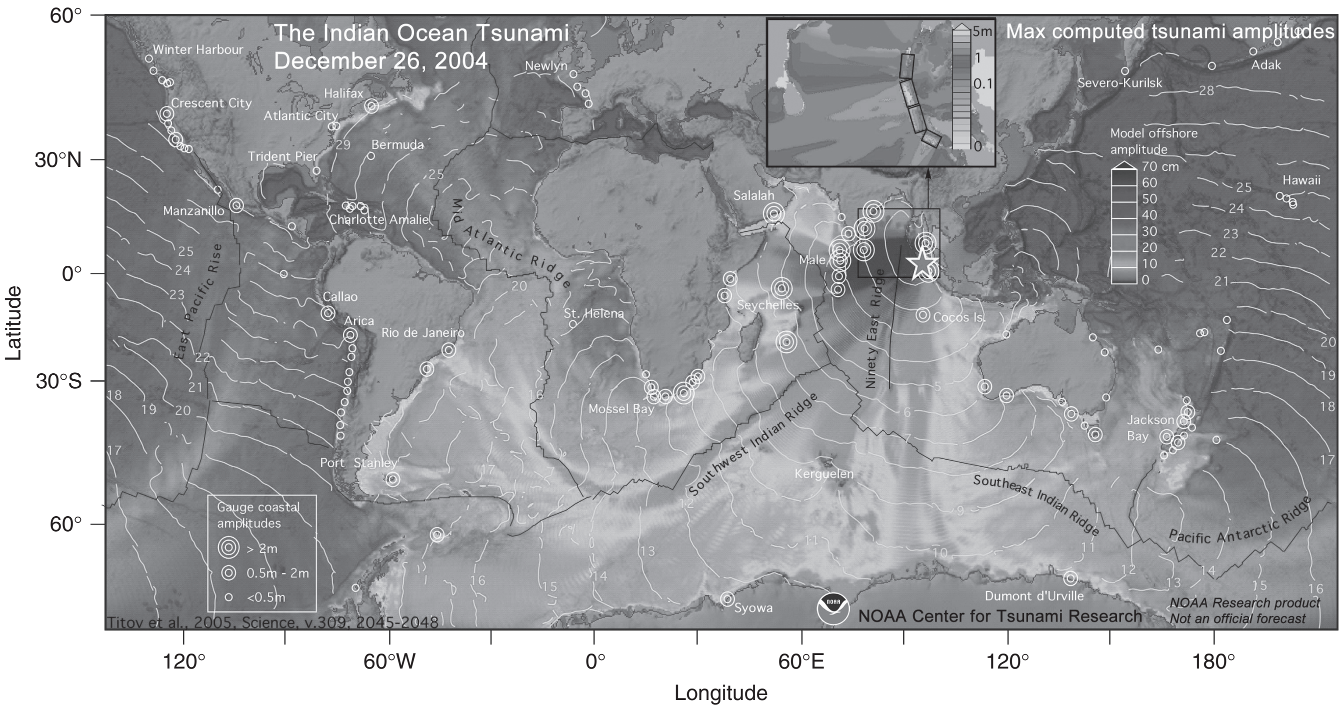

Figure 4. The control on tsunami travel from seabed morphology, from the Indian Ocean tsunami of 2004. Maximum computed tsunami amplitudes around the globe. Note how the tsunami tends to track the midocean ridges, especially the Southwest Indian Ridge. (Reproduced with permission from the NOAA Center for Tsunami Research. © 2015.)

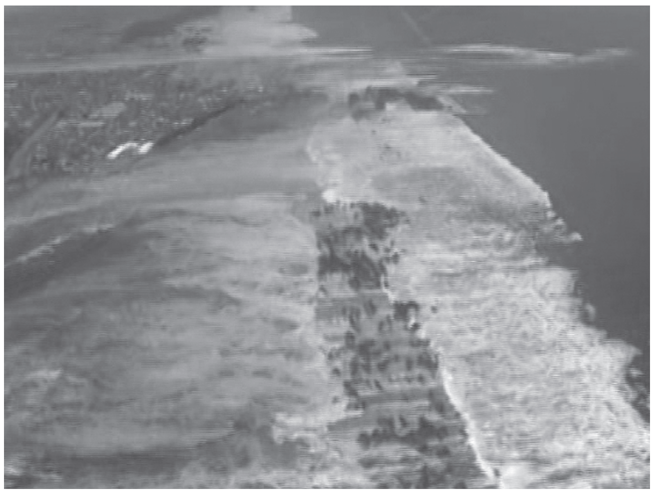

Figure 5. Turbulence of tsunami flowing across the coast at Yuriage—Japan tsunami. (Snapshot of video image -Reproduced with permission from the Japanese Coast Guard.)

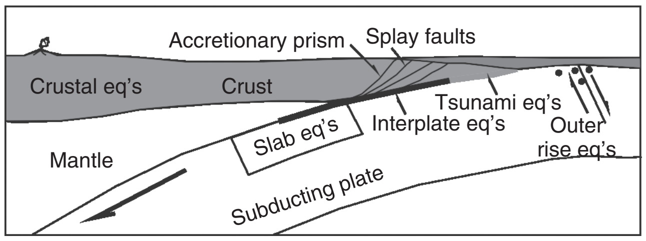

Figure 6. Schematic cross-section of a subduction zone. "Typical" interplate earthquakes occur at the seismogenic boundary between the subducting and overlying plates. Intraplate earthquakes include outer-rise events, slab events, and crustal earthquakes. The source region of "tsunami earthquakes" is beneath the most trenchward part of the accretionary wedge. (Reproduced from Satake and Tanioka (1999). © Springer, 1999.)

with a consequent reduction (conservation of energy) in vertical uplift.

A minimum earthquake magnitude of M_w 7 is required to generate a noticeable tsunami, but a significant tsunami (apart from generation by tsunami earthquakes) that would result in an initial wave of several meters requires upward of M_w 8 (Ward, 2010). The Indian Ocean tsunami of 2004, from an M_w 9.1 event, generated tsunamis with local run-ups of up to 30 m. The vertical component fault rupture is another major control; for example, differences in tsunami generation from interplate and splay faults (Figure 6) are due to the former being located in deeper water farther offshore and with rupture at a shallower dip, compared to the latter where rupture is closer to shore and with a steeper fault angle

(Heidarzadeh, 2011). A tsunami from a splay fault closer to shore results in an earlier wave impact and a higher initial wave (because of steeper fault dip).

Tsunamigenic earthquakes are generated within the seismogenic zone where brittle fracture takes place within rocks hard enough (well lithified) to allow stress build-up from the induced pressure as plates collide. The depth range of typical interplate earthquakes is between 10 and 40 km. At shallower depths, rocks are less well consolidated and formed of relatively soft sediments; because they are less rigid, stress build-up is not as great as within the seismogenic zone. At depths below the seismogenic zone, rock begins to soften because of increasingly high temperatures and pressures and mineral transformations, thus here there is a reduced likelihood of large earthquakes (although earthquakes take place at depths of hundreds of kilometers).

4.2 Tsunami generation

Earthquake rupture takes place at kilometers per second, resulting in uplift of the overlying water column and collapse of the sea surface. The rise time of the sea surface is slow compared to the velocity of the earthquake, thus tsunami modeling is based on an instantaneous input of energy. Earthquake rupture is usually characterized by uplift of the outer part of the convergent margin or seismic zone and subsidence toward land. This characteristic is explained by the outer parts of the overriding plate being dragged down and/or compressed, during interseismic periods, and when rupture takes place springing upward or forward, with subsidence along the more landward parts of the margin. This mechanism explains why the tsunami wave generated from earthquake rupture is positive in seaward direction and negative toward land.

4.3 Intraplate tsunamigenic earthquakes; outer-rise, crustal, and slab events

Outer-rise events are caused by the flexuring of the oceanic plate as it bends before subducting under the overriding plate, with the bending causing brittle fracture in the hard basaltic rock; ruptures are thus from normal faulting. Major tsunamis include those of 1933, off the north Honshu Island, Japan when 3000 people died and in 2009, in the southwest Pacific, between Samoa and Tonga, when a tsunami from an earthquake doublet of outer-rise and interplate events killed over 200 people (Satake, 2010).

Major tsunamis from earthquakes within the crust of the overriding plate are quite rare and include the Flores Island event of 1992, when over 2000 people died (Imamura *et al*., 1995). Tsunamis from earthquakes in the subducting slab are common but as these are often beneath land, their potential to generate tsunamis is limited.

4.4 Tsunami earthquakes

Tsunami earthquakes are recognized by their deficiency in high frequency seismic radiation, very long earthquake rupture duration, and shallow slip along the plate interface; characteristics are attributed to either (i) slip through low strength sediments at the shallow end of the seismogenic zone or (ii) by an absence of soft sediments along the trench. Where low strength sediments are the cause, the anomalous tsunamis are attributed to the dominant low frequency component of the earthquake; sediment absence results in rupture propagation to the seabed. Their identification was based on the 1946 Aleutian and 1896 Sanriku events.

4.5 Recent ideas on earthquake tsunamis

Until the Indian Ocean tsunami of 2004, it was believed that great earthquakes (greater than M_w 9) were only generated along certain convergent margins, where subducting crust was young and convergence rapid (Figure 7) (Ruff and Kanamori, 1980). Both Indian Ocean and the Japan events resulted in a major reappraisal of this understanding, with analysis of more recent data sets and improved understanding of plate motions and velocities revealing that great earthquakes may take place along any subduction zone (McCaffrey, 2007; Stein and Okal, 2007). In addition, it was realized that the (human) time scales over which earthquake frequencies were being assessed were far too short and that longer time periods were required, which could be based on geological data, from sediments deposited as a tsunami inundates the land.

The identification of tsunami earthquakes has been complicated by the recognition that submarine landslides along convergent margins also generate significant tsunamis. For example, the tsunami earthquakes on which the original identification was based (e.g., the 1946 Aleutian event), may now be associated with submarine landslides that generated the local tsunami (Fryer, Watts, and Pratson, 2004), although this possibility was also suggested in the original 1972 paper. The evidence for a submarine landslide component of the 2011 Japan tsunami that is located in the same region as the 1896, Sanriku, also suggests that this latter event may be associated with a submarine landslide (Tappin *et al*., 2014).

5 LANDSLIDE TSUNAMIS

Tsunamis from landslides have been recognized for some time (Gutenberg, 1939) and are generated from both

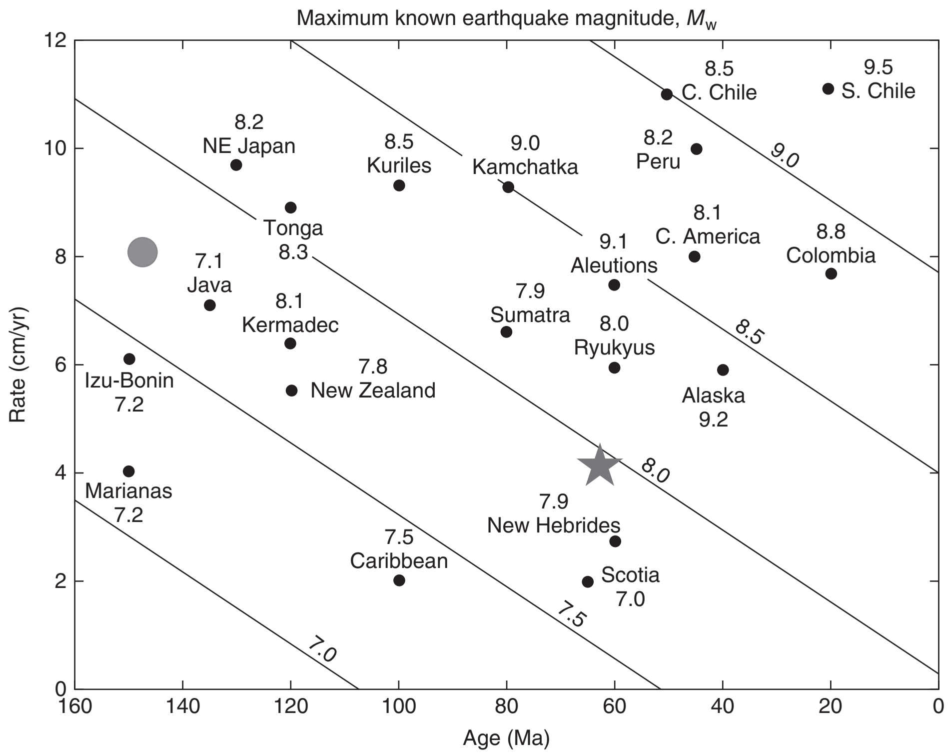

Figure 7. Peak subduction zone earthquake magnitude as a function of oceanic plate age and convergence rate. The Indian Ocean 2004 (star) and Japan 2011 earthquakes (large circle) showed that the proposed relationship between rate of plate convergence and age of oceanic crust in the generation of earthquakes was wrong, as both were M_w 9 and not located where convergent rates were fast and oceanic crust was young. (Reproduced from Ruff and Kanamori (1980). © Elsevier, 1980.)

subaerial and submarine mechanisms. One of the most devastating tsunamis from a subaerial landslide was at Scilla, Italy in 1783 when a rockslide generated a tsunami 16 m high that killed 1500 people. The most amazing subaerial event was in 1958 in Lituya Bay, Alaska, where an earthquake of M_w 8.1 triggered a landslide volume of 30×10^6 m^3 that generated a maximum run-up of 524 m measured from the stripping of trees on the adjacent shoreline (Ward and Day, 2010). Other significant events include the Vajont (Italy) reservoir collapse in 1963, where 2000 people died, and Spirit Lake, 1980, with the flank collapse of Mount St Helens volcano.

Submarine landslide tsunamis have been recognized since the 1929 Grand Banks event, but only recently, with Papua New Guinea in 1998 where 2200 died has their real hazard been more widely appreciated. A major problem in investigating submarine landslides until the development of multibeam echo sounders (MBES) was our inability to map the seabed in high resolution. The development of MBES and their now widespread use allow the seabed to be mapped almost to the same resolution as on land. In addition, while the simulation of earthquake tsunamis is simplified by the almost instantaneous input of earthquake energy (compared to tsunami rise time) into the water column, the order-of-magnitude slower velocities of submarine landslides were a major obstacle in simulating tsunamis from this mechanism. Submarine landslides travel at tens of meters per second rather than the kilometer per second of earthquakes.

The events of Papua New Guinea and the Storegga landslide of Norway stimulated significant advances in modeling tsunamis from submarine landslides (Watts *et al*., 2005) (Figure 8). Tsunami generation from landslides is somewhat similar to earthquakes as there is a vertical displacement at seabed that propagates up through the water column to displace the sea surface (Figure 9). Unlike earthquakes, however, there is a significant horizontal motion that pushes the wave ahead. The relationship of the landslide to water depth is also important because of resonance effects.

Submarine landslide mechanisms are complex and variable; they range from slumps (such as PNG) that are relatively small volume and travel short distances to translational landslides (such as Storegga) that travel far (hundreds to thousands of kilometers). Per unit volume, however, slumps generate larger tsunamis. The elevation of the initial tsunami wave is mainly dependent on slide volume, water depth, and

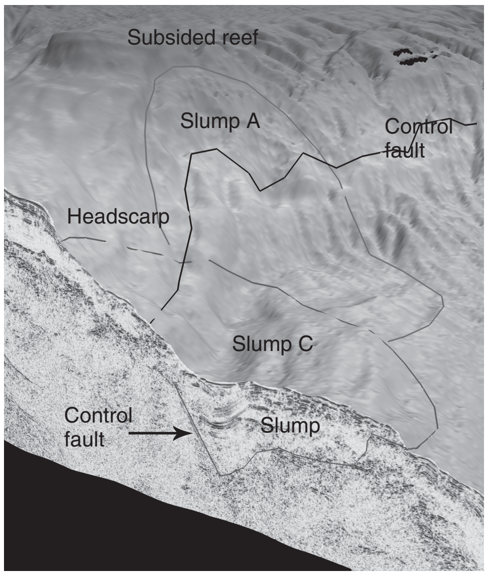

Figure 8. Cutaway 3-D image of the PNG slump showing the slump (C) surface and section (Slump) viewed from the northeast. Vertical exaggeration ×3. (Reproduced from Tappin, Watts, and Grilli (2008). © D. R. Tappin, P. Watts, and S. T. Grilli, 2009.)

the initial acceleration (Tappin, Watts, and Grilli, 2008). A further control is the location where failure initiates, from the top or the bottom. If the failure is from the bottom, the landslide could be "retrogressive" and fail sequentially (like a pack of cards) from the bottom up; because this failure mechanism is slower than failure from the top, the initial wave elevation is lower than a synchronous (instantaneous) failure because of the inherent slower velocity.

Theoretically, because submarine landslide slip could extend to the deepest water depths, the initial tsunami wave generated could be as elevated as the deepest ocean depth, and for larger landslide tsunamis the initial wave has been modeled at hundreds of meters. In addition, because landslide tsunamis are more dispersive than those from earthquakes, unless the landslide source is large volume (such as Storegga), they do not travel as far as earthquake generated events. Obviously, near source, the local run-ups could be much larger and, on the Hawaiian Islands, have been demonstrated to be at least 350 m elevation above sea level at the time of the event.

The controls on submarine landslide tsunami are complex and may be geographical and temporal; they are not well understood. Dominant environmental controls are from climate, with preconditioning of sediment as important as the final triggering, which may be from earthquakes, atmospheric and tidal changes, river discharge, and hypopycnal flow.

6 VOLCANIC TSUNAMIS

Volcanic flank collapse is similar to the landslide mechanisms described above. The most studied examples are from the Hawaiian and Canary islands (McMurtry *et al.*, 1999). Eruption-generated events are fewer, with the most devastating from Krakatau, 1883 (Francis and Self, 1983). Although the Krakatau tsunami was generated from the final cataclysmic eruption, the specific tsunami-generating mechanism is uncertain, with caldera collapse and pyroclastic flows (or a combination) being the most likely.

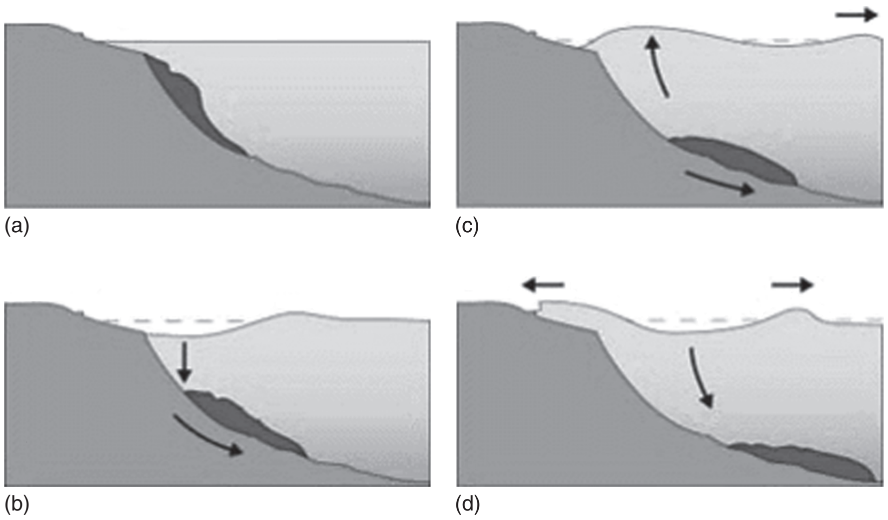

Figure 9. SMF failure and tsunami generation. (a) Prefailure, (b) initial slip and surface drag down above the rear of the SMF, (c) positive and negative wave generation, and (d) continued wave propagation.

Although simulation of the tsunami by an underwater explosion produces the recorded run-ups, there is no geological evidence that an explosion actually took place. Pyroclastic flows entering the sea are a complex mechanism as part of the flow sinks, part can act as a "bow wave," and part flows over the sea surface. Modeling of tsunamis from this mechanism is complex.

7 METEOTSUNAMIS

Meteotsunami are also shallow-water waves (like all tsunamis) but created by rapidly produced air pressure disturbances moving over the sea (Monserrat, Vilibić, and Rabinovich, 2006). In the open ocean, the disturbances generate waves that, as the water shallows (over the continental shelf) and as they approach the coast, are amplified by resonance. Resonance, for example, can result from the velocity of the wave being the same as shallow-water wave velocity in the water depths over which it is passing, thus the waves are "in phase" (Tappin *et al*., 2013). In the deep ocean, the elevation of a meteotsunami wave will remain low because the pressure wave and weather-induced surface wave velocities in the ocean will be out of phase (due to different velocities). As water depths decrease, the velocities come into phase and the meteotsunami wave elevation increases. Once generated, the meteotsunami wave traveling at the speed of the weather disturbance continues to be driven forward. In this respect, meteotsunamis are similar to submarine landslides. The meteorological disturbances that source meteotsunamis may be atmospheric gravity waves, active frontal passages, and downdrafts or squall lines from convective activity. The initial atmospheric pressure change results in a corresponding sea surface elevation of a few centimeters; for example, a 1 mbar change in atmospheric pressure would result in a sea level perturbation of approximately 1 cm. During resonance, the atmospheric disturbance propagating over the ocean surface is able to generate significant long ocean waves by the continuous pumping of energy into these waves (Monserrat, Vilibić, and Rabinovich, 2006). The most likely resonances are those of Proudman (1929), Greenspan (Raichlen, 1966), and shelf resonance (Rabinovich, 1993). On approaching land, the waves can be several meters high. Meteotsunamis are common in the Mediterranean, Adriatic, and off Japan.

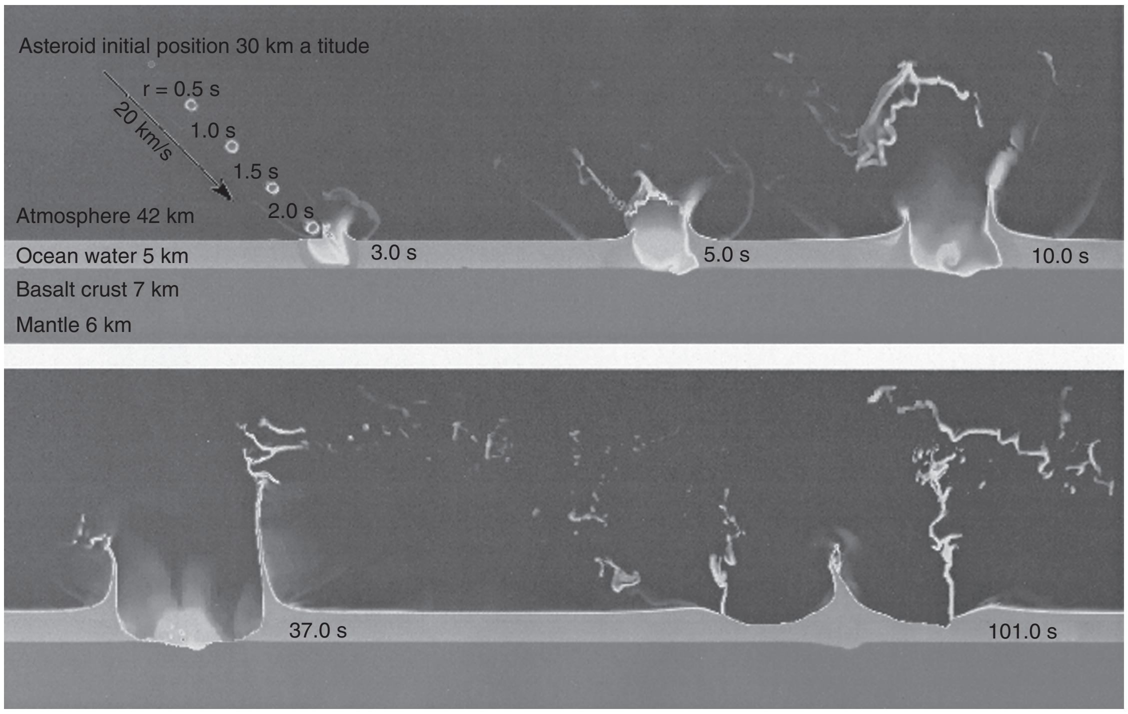

Figure 10. Montage of nine separate images from the 3-D run of the impact of a 1-km iron bolide at an angle of 45° with an ocean of 5-km depth. These are density raster graphics in a two-dimensional slice in the vertical plane containing the asteroid trajectory. Note the initial asymmetry and its disappearance in time. (Reproduced from Gisler, Weaver, and Gittings (2011). © The Tsunami Society, 2003.)

8 EXTRATERRESTRIAL (BOLIDE) IMPACTS

Contrary to received opinion, there is little evidence for tsunamis directly generated from asteroid impacts; modeling confirms that they do not generate tsunamis that lead to global events (Figure 10). Bolide impacts are not like geological tsunamis, because the tsunamis are disorderly and chaotic and have shorter wavelengths and lower velocities (Gisler, Weaver, and Gittings, 2011). There is little evidence for impacts in ocean basins, largely because of their young age, which because of tectonic erosion is rarely not greater than 200 million years. Tsunami deposits on land attributed to impacts are rare, with most examples reported from the Pacific coast of South America, and with their interpretations controversial. Impact craters are only found on continental shelves as in the deep ocean, the water absorbs the energy of impact so a very large event is necessary to make a deep seabed crater. The Eltanin impact in the southwest Pacific is identified by its associated sediments, not an impact crater. The tsunamis generated from most the famous impact, Chicxulub, off Mexico, were almost certainly from large-scale slope failures triggered by impact-generated earthquakes• (Dypvik and Jansa, 2003).

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GLOSSARY

Bolide	Any generic large crater-forming impacting body.
Convergent Margin	In plate tectonics, a deforming region where two (or more) tectonic plates collide.
Dispersive	In water refers to frequency dispersion where waves of different wavelengths travel at different phase speeds.
Earthquake	A shaking of the Earth's surface resulting from the sudden release of energy in the earth's crust.
Meteotsunami	Is a tsunami-like wave of meteorological (atmosphere and air pressure related) origin.
Runup	Water that a tsunami pushes onto land above the regular sea level.
Submarine Landslide	Movement of sediment down a seabed slope.
Tsunami	Is a large water wave or waves caused by displacement from an earthquake, landslide, eruption, or meteoric disturbance.
Volcano	A vent in the Earth's crust through which lava, steam, ashes, and so on are expelled.

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Abstract: Tsunamis are gravity-driven water waves. Most are generated by vertical displacement of the seabed that propagates through the water column to the sea surface. The resulting elevated surface wave collapses through gravity and then propagates outward from the source. Dispersion of the initial wave generates a multiple wave train. Tsunamis are mainly (~80%) generated by earthquakes, but other mechanisms include subaerial and submarine landslides and volcanic collapse and eruption. Other, less frequent, tsunami mechanisms include bolide (asteroid) impact and weather events (meteotsunamis), but these are generated at the water surface, respectively, from external impact and from wind friction.

The magnitude of a tsunamigenic earthquake has the main control on the tsunami, although "tsunami" earthquakes generate tsunamis much larger than expected from their earthquake source magnitude. Tsunamigenic earthquake mechanisms include interplate boundary rupture, splay faulting, and intraplate rupture. Landslide tsunami mechanisms include slumps and translational failures that may be initiated from either the bottom or the top. Landslide volume, water depth, and initial acceleration are the main controls on tsunami magnitude, although other factors such as the failure mechanism and the location of initiation are influential.

There are three main aspects of a tsunami; (i) initial wave generation, (ii) propagation, and (iii) onland run-up. Initial wave generation from earthquakes is mainly from seabed vertical displacement, and a rule of thumb suggests that in most instances the maximum initial wave elevation is up to twice this. The maximum initial wave elevation from a landslide tsunami is theoretically determined by the ocean depth and thus could be thousands of meters.

Local tsunami run-up elevations vary with source mechanism and vary considerably. Although dependent on local bathymetry and topography, these are likely to be more elevated and focused from submarine landslides than from earthquakes. The different mechanisms generate different tsunami wave frequencies; these determine travel distances, with the low frequency tsunamis from earthquakes traveling much farther than tsunamis from landslides, which are much higher frequency. Final onland run-up is mainly dependent on source mechanism as well as local offshore bathymetry and coastal topography.

Keywords: tsunami; earthquake; submarine landslide; volcanoes; bolide; meteotsunami; dispersive; run-up; convergent margin

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