10

Epilogue

This book began with five stories that were based upon legends and historical records of tsunami. These stories formed the basis of subsequent description and discussion about tsunami in the text. It is perhaps appropriate to end this book with five stories that foreshadow or prophesy about the nature of tsunami events in the near future. Each of these stories centers upon one of the underrated aspects about tsunami dealing either with their mechanism of formation or location; for example, the Indian Ocean Tsunami of December 26, 2004 (Figure 10.1).

FIVE STORIES

1 An unsuspected earthquake

Charleston—dances, southern nights, earthquakes—is home to the event that everyone ignores but that crops up in spreadsheets and internet databases as one of the worst earthquakes in U.S. history. The city lies in a broad embayment along the southeast coast (Figure 10.2). The earthquake of August 31, 1886 was considered a rarity, a whim, an isolated stochastic perturbation of the restless Earth, but never a harbinger of things to come. In 1886, the earthquake began as a barely perceptible tremor at 9:51 PM and grew to a sound like a heavy metal body rolling over gravel and then into a roar. It was felt over an area of 5 million km^2, as far away as New York City, Milwaukee in the Midwest, Havana, and Bermuda. Seven additional shocks followed during the next 24 hours. The earthquake's recurrence interval was evaluated as once in a millennium, maybe twice. The warning signs of a similar event in the future were always present—1903, 1907, 1912, 1914, 1924, 1945, 1952, 1959, 1960, 1964, and 1967. The epicenter for the March 12, 1960 event was off the coast of South Carolina. Further tremors occurred throughout the 1970s and then nothing—not until that July 4 weekend in the early part of the 21st century.

Figure 10.1. The western coast of the Indonesian province of Aceh devastated by the December 26, 2004 tsunami. The tsunami totally obliterated all buildings and infilled rice paddies with mud and debris. Note the trim line on the backing mountains. The height of the wave was at least 10 m above sea level at this location. No one living on this coastal plain survived. *Source:* Defence Australia, Image 20050126cpa8267338_034 *http://www.defence.gov.au/optsunami assist/images/gallery/310105/index.htm* © Commonwealth of Australia.

It began as a low rumble around 10:00 AM. Some describe it as a locomotive coming in from the ocean. The ground shook so violently that five- to nine-story buildings immediately collapsed. The shaking went on forever—10 seconds, 30 seconds, a minute, two. Puffs of sand issued from hundreds of sand fountains on the beaches along the coastline before they slowly sank into the Atlantic Ocean. Some of the lagoonal sediments also lost their bearing strength, and houses and apartments built during the housing boom of the late 20th century sank at weird angles into the substratum. It was a catastrophic earthquake, and within 30 minutes the region was affected by many aftershocks registering a surface wave magnitude over 7.0. Silently, 200 km offshore, turbidity currents slithered off the edge of the continental shelf and into the abyss. Hundreds merged into tens and then into one stream of immense proportions. Anyone who had been diving at these depths would have noticed the strong undertow and, more importantly, the slow oscillatory rotation that was taking place throughout the water column. A tsunami was being generated, fed by a myriad of streams of coalescing debris on the seabed and propagating shoreward.

Ninety minutes later the water withdrew from over 200 km of coastline, from Brunswick, Georgia, in the south to Wilmington, North Carolina, in the north. Water flowed out of estuaries, leaving peats exposed above sea level for the first time in thousands of years. Boats drifted on their anchors; some broke free and surged into

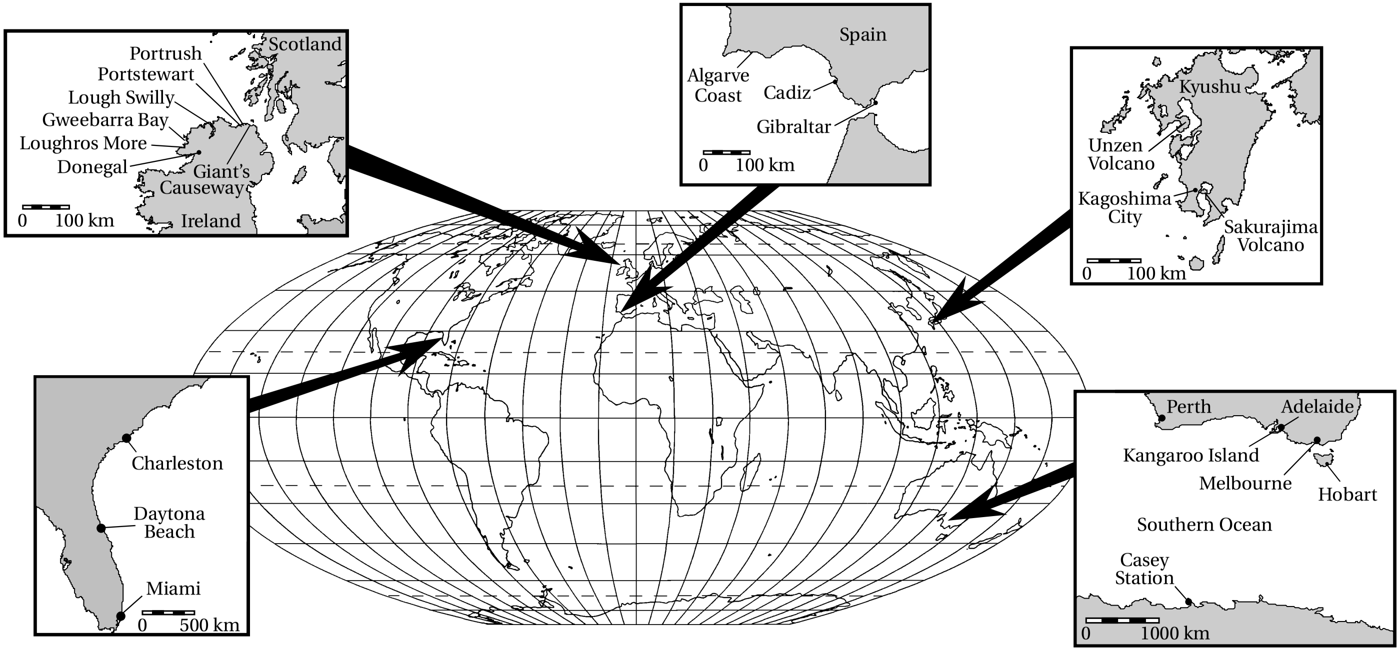

Figure 10.2. Location map of scenarios for future tsunami events

the Atlantic through tidal inlets. Then the sea came back. It was preceded by a change in wind ever so slight. A hump on the horizon grew into a wave, and then a wall began to form closer to shore. The sound became deafening, like hundreds of jet planes landing at once along the whole coast. The drifting boats became ballistic missiles, dragged upright on their anchors and then shot into the air like champagne corks at the millennium celebrations, as they broke free. The wave was 15 m high when it reached the coastline directly off Charleston, 6 m high opposite Savannah, and 8 m high northwards along the barrier islands leading to Cape Hatteras. Not since the Great Lisbon Earthquake of November 1, 1755 had the Atlantic Ocean experienced such a big wave. The wave raced over barriers, through tidal inlets, and 40 km up estuaries. When it appeared that the full force of the wave was expended, a second and then a third wave roared into the coast, obliterating all surviving signs of human occupation. Within half an hour the waves spread outwards from Charleston and began to rise in amplitude along the Florida coast. Because the coastline southward swept into the Atlantic, the wave grew in amplitude towards Daytona Beach, Cape Canaveral, West Palm Beach, Fort Lauderdale, and Miami. The beach ridges on promontories along the coast were eroded and then laid down again as bedforms under the swamping waves. Houseboats, yachts, tourists sunbathing on beaches all were inundated without any warning. Ten minutes after the first wave had obliterated the coast, a single curt message was issued by the National Weather Service.

> This is a tsunami information message, no action required . . .
> An earthquake, preliminary magnitude 8.2, occurred at 1458 UTC
> 4 Jul 2011, located near latitude 32 N longitude 79 W in the
> vicinity of Charleston S Carolina.
>
> Evaluation: no destructive Atlantic-wide tsunami threat exists.
>
> This will be the only bulletin issued unless additional information
> becomes available.

2 An unassuming earthquake

Cádiz on the southwest coast of Spain is the last place in the world that should be struck by an earthquake (Figure 10.2). Actually the earthquake wasn't centered here but offshore along the extension of the plate boundary that had given rise to the Great Lisbon Earthquake of November 1. 1755. The earthquake wasn't big. It only had a magnitude of 7.0, maybe a little more. Hardly anyone in the city felt it, which was unusual because it was siesta time and if an earthquake were going to be noticed at all, it would be noticed while people were resting. Some of the fishermen were suspicious. For the past two weeks they had seen dead fish floating offshore, and one had even reported seeing the ocean bubbling around his boat. It wasn't a good day at all. It was gray and drizzly, and the horizon was bumpy from the heavy swell running along the coast after the storm of the past two days. Even that storm was unusual. It probably had something to do with greenhouse warming.

One or two of the fishermen wandered down to the breakwall and casually scanned the ocean as they talked about their run of bad luck. The bumps had moved. They were closer to shore now and appeared to be growing in height. They were! Within 30 seconds a coherent wall of water formed and increased to a height of 10 m before it slammed into the coastline. There was no time for the fishermen to flee. They were picked up by the wave and swept into the harbor. The wave washed across the adjacent beach, splashed against the 15-story hotels and apartments that lined the backshore, and squeezed between the buildings and into the streets behind. North of the beach, it ran into the bay and along the harbor foreshores. Docks were swamped, and boats were picked up and ripped from their moorings or sunk on the spot. The wave surged across the bay and up the Guadelete River. Within 10 minutes, another wave struck the coast and finally a third came ashore. It was all over in 30 minutes. One of the most picturesque cities on the Spanish west coast had just experienced a tsunami earthquake, which supposedly only occurs in the Pacific Ocean.

3 A submarine landslide

The signs were ominous. There were the small earthquakes with surface wave magnitudes registering 3–4. They had increased in frequency to the extent that the Norwegian government instituted tsunami evacuation drills in the major cities along the coast—at Bergen, Stavenger, and more than a dozen smaller communities. The Storegga slides had occurred here more than 7,000 years ago, but the cause of the slides and their resulting tsunami were still a heated point of debate. The devolved government in Scotland took particular note of the events because the most widespread evidence of the tsunami from the third Storegga slide existed along its east coast. The debate went no further because geological events were not political ones and Scotland didn't count any more. Everyone was wrong. What wasn't noticed were the smaller earthquakes along the continental shelf edge off the coast of Ireland. While the Storegga coast off Norway had been the source for 3 major submarine slides, 11 others had occurred over the same timespan along the steep continental slope off the coast of northwestern Europe. At least seven of these had occurred along the coast of Ireland within a few hundred kilometers of the coast.

At 4:58 AM on that Sunday morning in April, the shelf slope finally succumbed to the enormous pressures that had been building up over the last 5,000 years of higher sea levels during the Holocene. The triggering earthquake was minor, and because it was a Sunday, the whole event went relatively unnoticed. Surveys afterwards found it difficult finding anyone who had felt the earthquake; however, everyone had stories to tell of the consequences. Slowly the tsunami from the slide built up, and within two hours the first communities along the west coast of County Donegal were witnessing its effects. Headlands along 350 km of rugged coastline were swamped, while flat pocket beaches in sheltered embayments were completely eroded. The wave was amplified by funneling in embayments such as Loughros More and Gweebarra Bays, and into Lough Swilly running down to Letterkenny (Figure 10.2). Here the wave reared from 8 m along the open coast to over 15 m inside embayments. The tsunami had its most dramatic effect to the east. Where the shelf shallowed and the coastlines of Ireland and Scotland came closer together, the wave not only maintained its height but also underwent amplification. At the Giant's Causeway on the northern tip of Ulster, it broke again over the knob of basalt columns and deepened the canyon that formed the toothbrush-shaped headland. Bedrock-sculpturing effects were unmistakable along the whole of the coast of Northern Ireland.

Unfortunately, the death toll was high. Unlike the Grand Banks tsunami of November 1929—which struck a similarly shaped but sparsely inhabited coastline—this tsunami hit a more densely populated coastline. University students at Coleraine living in the coastal communities of Portstewart and Portrush succumbed to the waves. The countryside around the towns of Gweedora and Donegal was particularly hard hit. The number of dead will never be known because rural marginalization along one of the most isolated coastlines in western Europe ensured that many victims had no community contacts and hence went missing without being noticed. Experts afterwards stated that the whole event was an abnormality. Meanwhile the offshore slopes continued to build up pressure.

4 A volcanic eruption

Sakurajima Volcano on the Island of Kyushu, Japan is not a well-known one (Figure 10.2). It was overshadowed farther north by Unzen on the Shimabara Peninsula, which during its eruption on May 21, 1792, caused a tsunami with a maximum run-up of 55 m. That wave killed over 14,000 people. Sakurajima had never had eruptions like this; however, people lived closer to it. About 7,000 people lived at the foot of the volcano and half a million people lived in Kagoshima City 10 km to the west. The oldest documented eruption had taken place in AD 764. Since then, five major eruptions had occurred—each generating pyroclastic ash and lava flows that had reached the ocean. On September 9, 1780, one of the ash flows had produced a 6 m high tsunami. Since 1955, Sakurajima had burst into life. That would not have been so bad, but the location of the volcano was dangerous. So was its height. Unlike many other explosive Japanese volcanoes, Sakurajima was high, rising to over 1,000 m above sea level. It also protruded like a hernia into Kagoshimawan Bay on the southern end of Kyushu Island. It was a disaster waiting to happen.

The eruptions since 1955 just seemed to go on and on. They were cyclic and intense, and should have warned authorities that all was not well. Towards autumn in the early part of the 21st century the seismic tremors and eruptions became more frequent. The local officials even thought about advertising the eruptions, because unlike others, these could be viewed from the relative safety of Kagoshima across the bay. On that sunny morning, with the latest eruption sending ash high into the sky towards the east, the unthinkable happened. One last major earthquake shook the region and the oversteepened slope of the volcano collapsed to the west. Before the slope could disintegrate into the ocean, the volcano blasted through its flank in the largest basal surge since Mt. St. Helens in May 1981. The severity of the situation became immediately apparent to all who were watching the eruption from the city.

The authorities and subsequent investigations could never define the main cause of death for the 20,000 people that died that day. To allay fears in other communities—such as those around Unzen Volcano to the north—the experts said that the wave was not a tsunami, that the water came from the volcano, that the death toll was due to the lateral pyroclastic flow, and that the blast was a freak of nature—never recorded before in the history of Japanese eruptions. Certainly part of the basal surge had spread across the ocean's surface and swept through the city. The melting of glass and metal in the path of the blast confirmed that. However, a few witnesses implicated a tsunami. The bank manager, who saw the eruption and then ducked into the vault and shut it, swore that the ash cloud had sunk below the ocean. He had paused in his retreat because he saw the ocean heaving erratically like a cat crawling under a carpet. Then farther down the bay there were the fishermen who actually saw the floor of the bay exposed in the 10 km gap between the base of the volcano and the city. One of them, before cutting the anchor of his boat and deciding to ride the wave out, said that the whole bay splashed in the air over the city. Certainly, there was plenty of evidence of water swamping the city. A camera attached to the internet, and updated every minute, even showed a fuzzy picture of a 50 m high wave in the last of its frames. While many said that the debris deposited in the city originated from the volcano, the presence of rounded boulders, marine mud, and shell left little doubt that the seabed had been swept clean. The final details of the disaster may never be known, but over subsequent years people slowly moved away from the foreshores of Kagoshimawan Bay and the waters surrounding Unzen Volcano farther to the north. The seas were perceived as being too dangerous.

5 An asteroid impact with the ocean

It hurtled around the Sun as it had thousands of times before, spinning, dark, ominous, 65 million tonnes of stony conglomerate formed in the birth of the solar system 5 billion years ago. As it swung from behind the Sun it was silhouetted against a distant pale blue speck, the planet Earth, with which it would rendezvous ten weeks later. It should have missed the Earth, but this time round its orbit deviated ever so slightly because of the gravitational attraction of the Earth and the Moon. The asteroid's fate was sealed. It spun through the Earth's atmosphere at $25\,\mathrm{km\,s^{-1}}$ on a low southeast trajectory. It began to heat up, and just before striking the ocean, it fragmented covering an area four times larger than its original 250 m diameter. Along the south coast of Australia, late on a clear, warm summer's day, a few residents who happened to look south noticed a dull glow hanging over the horizon. Some even said that they could read by the light as night fell. Within seconds, the Australian Antarctic Division in Hobart lost contact with Casey Station in the Antarctic (Figure 10.2). Such blackouts were common, but this one was permanent. The crew on the supply ship standing off Casey never knew what hit them. It was all over within 10 seconds as the asteroid struck the ocean less than 100 km away in a blast equivalent to more than 3,000 megatons of TNT. In that interval, billions of tonnes of water were thrown at the speed of sound into the atmosphere and vaporized. The vapor—heated to 5,000°C—struck the ship and instantly incinerated it.

Within 10 minutes a tsunami had propagated away from the center of impact and was approaching the ice cap. When it reached shore the wave was almost 100 m high. It sloshed over the ice and then ran back into the ocean together with millions of tonnes of melted ice and water that had condensed out of the atmosphere. After five hours the lead wave from the tsunami generated by the impact had crossed the Southern Ocean and was approaching the first tide gauge of any note—Adelaide. This wave was followed by a larger one generated by the slosh from the ice cap. In the late evening, the wave approached Kangaroo Island, which protected the mouth of the Gulf of St. Vincent leading to the city. The waves surged over the rocky coastline as effortlessly as a previous tsunami that had wiped out Aboriginal culture on the island 500 years before. The island absorbed the brunt of the wave; however, the tsunami refracted around the ends of the island and ran in a crisscross fashion up the funnel-shaped Gulf. The wavelets increased in amplitude from 5 m to 10 m as they impinged upon the western shore of the mainland. The Adelaide tide gauge never registered a thing. It was instantly obliterated as waves surged up the Torrens River and through the Central Business District of the city. In the flatter coastal suburbs, successive waves smashed up to 2 km inland, leaving a mass of demolished houses and shops stacked up at the limit of run-up. The whole scene was broadcast live nationwide from the Goodyear Blimp hovering over the Adelaide Cricket Ground for the day–night match between Australia and India. Viewers sat stunned in front of their TV sets as the wave crashed through the outer stands of the cricket ground. In Melbourne, frantic activity could be seen in one or two houses as their occupants prepared to flee. Only they knew that the waves were minutes away from that city.

CONCLUDING COMMENTS

The above scenarios have been deliberately contrived to highlight the fact that, while earthquakes are commonly thought as the cause of tsunami, tsunami have many sources. None of the stories should be viewed as unbelievable. In fact, the tone, voice, and storyline of each deliberately match those of the historical accounts and legends presented in Chapter 1. If these concluding stories are perceived as tall tales, then the reader is likely to deny the magnitude of past historical events such as the tsunami generated by the Lisbon earthquake of 1755, by the volcanic eruption of Krakatau in 1883, or by the Sumatran earthquake of 2004. If the run-up heights of 40 m generated by these three events are trivialized, then bigger events in isolated parts of the globe are more likely to be ignored. We then are prone to mock the descriptions of tsunami present in ancient historical writings. Finally, we unashamedly convert history into legends and legends into myths. It is human nature to minimize hazards, and that is why tsunami are so underrated. Unlike any past civilization, Western Civilization is unique in its settlement of the shoreline and its development of great coastal cities. We develop ever-larger ports in harbors and along the open coast, establish retirement villages on coastal marshes and barrier islands, talk up the value of coastal real estate, and glamorize seaside holidays. Our civilization is so dependent upon the coastline and marine trade that it in turn plays down marine hazards. We then marvel at devastating hurricanes and attribute them to phenomena such as global warming, and farewell sporting seamen on ocean races who then die in storms that we term abnormal. The purpose of this textbook has been to make readers aware that tsunami are ubiquitous along our shorelines. The only guarantee or prediction is that they will happen again, sometime soon, on a coastline near you—on a reservoir, a lake, a sheltered sea, inside a coral barrier, in the lee of an island, or along an open coastline. Our present knowledge about marine hazards is biased. Tsunami are very much an underrated, widespread hazard. Any coast is at risk.