THE Orphan Tsunami OF 1700

JAPANESE CLUES TO A PARENT EARTHQUAKE IN NORTH AMERICA

SECOND EDITION
Front cover
A simulated tsunami reaches Japan ten hours after its start along the Pacific coast of North America (p. 74-75).

Back cover
Sailboats skirt a pine-covered spit where Japanese villagers puzzled over a tsunami of remote origin in 1700 (p. 76-79). At the nearby castle, the word tsunami received its earliest known use in 1612 (p. 41). Map, from 1687, courtesy of East Asian Library, University of California, Berkeley.
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みなしご元禄津波
A merchant's notebook, in an entry for January 1700, tells of a tsunami that lacked an associated earthquake in Japan. The shaking occurred instead along the northwest coast of North America. A French map compiled in 1720 shows what Europeans then knew of those shores.

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Quote from Moriai-ke “Nikki kakitome chō” (p. 50-52). Map by Guillaume Del’Isle, from University of Washington Libraries, Special Collections Division (p. 2, 5).
The Orphan Tsunami of 1700
みなしご元禄津波

Japanese clues to a parent earthquake in North America
親地震は北米西海岸にいた

Second edition
第2版

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THE SUBTITLE, “Oya-jishin wa Hokubei nishi kaigan ni ita,” means, “The parent earthquake was along the west coast of North America.”

JAPANESE CITIZENS’ NAMES appear in customary order, family name first. For clarity, the authors’ family names contain small capital letters on the title page, pages 110-111, and the back cover.

TO WRITE JAPANESE WORDS in Roman letters we use a variant of the Hepburn system. The vowel sounds resemble those in Spanish: a resembles the first vowel in “mama,” e the final vowel in “Santa Fé,” i the second vowel in “police,” o the first vowel in “José,” and u the first vowel in “uno.” The combination ei prolongs the e sound, as does ii for i.

Prolonged o and u take macrons (ö, ü) except in internationalized words (Tokyo = Tōkyō). The n is pronounced n before b or p (Nambu, Sumpu) as it is in English (imbalance, empower). Additional changes in sound at the junctures between syllables or words are footnoted on pages 38, 52, 60, 68, and 78. A slight pause precedes a doubled consonant (yokka).

JAMES CURTIS HEPBURN (1815-1911), an American missionary, devised the system now employed widely, in modified form, to transcribe Japanese sounds into Roman letters. The standard dictionary by Nelson and Haig (1997) uses the Hepburn system. We hyphenate most counters (as in niji-kken, p. 39) but follow Nelson and Haig in closing compounds for the day counter ka (yōka, yokka).

“ORPHAN TSUNAMI” is probably a modern term of North American origin.
This book tells the scientific detective story of a giant earthquake and its trans-Pacific tsunami.

Part 1 illustrates geologic signs of enormous earthquakes and tsunamis at Cascadia, along the Pacific coast of North America from British Columbia to California.

Part 2 presents old Japanese writings about a tsunami of mysterious origin that caused flooding and damage in January 1700 from Kuwagasaki in the north to Tanabe in the south.

Part 3 links this orphan tsunami to a Cascadia earthquake and to seismic hazards in the western United States and Canada.
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謝辞
著者紹介
文献
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2015年の後書き
The Orphan Tsunami of 1700
みなし ご元禄津波
THE PACIFIC OCEAN TSUNAMI of 2011 arose from sudden displacement of the ocean floor off the northeast coast of Japan, during an earthquake of magnitude 9. The earthquake shook Japanese shores where the tsunami soon took thousands of lives. The tsunami also fanned out across the Pacific toward shores where the shaking had not been felt. Those far-traveled waves caused concern on the west coast of North America, but the losses there were comparatively light.

This book tells of a tsunami in 1700 that crossed the Pacific in the reverse direction. It began when the ground shook and the ocean floor lurched in the Cascadia region of western North America. It soon swelled bays and river mouths along the region's outer coast. It also crossed the Pacific to Japan, where no perceived earthquake forewarned of its approach. Flooding and damage on Japanese shores, though minor overall, were recorded in writing by samurai, merchants, and peasants. Nearly three centuries later, this written history in Japan would be matched with natural and oral history in Cascadia, and the combination would clarify earthquake and tsunami hazards in western North America.

The 1700 tsunami is reconstructed in these pages from clues in North America and Japan. The book exhibits this far-flung evidence, describes how it came to light, and explains how it was pieced together. The presented findings are unchanged from the first edition, which appeared a decade ago. New to the second edition is an afterword about an unusual North American precaution against a tsunami like the one in 1700.

Brian F. Atwater and David K. Yamaguchi
Seattle
August 2015
Still-uncharted shores in North America were home to a giant earthquake and its tsunami in the year 1700, two decades before France’s royal geographer compiled this map. In North America, the catastrophe left traces on the landscape and probably in the oral histories of native people. Across the Pacific, the tsunami entered Japan’s written history as a sea flood without local cause. Three centuries later, the combined clues would reveal that the North American earthquake probably attained magnitude 9.
OUTSIDERS SCARCELY KNEW of northwestern North America in the year 1700. Leading European geographers of the time left that part of the map blank. Not until 1741 would Russians land in Alaska. From there to Oregon’s Cape Blanco, the coast would remain uncharted until Spanish and English expeditions of the 1770s.

Across the Pacific Ocean in Japan, unusual seas ran ashore in 1700. People wrote of the effects: flooded fields, wrecked houses, a fire, a shipwreck, evacuation, fright. Having felt no earthquake beforehand, some writers called the flooding a “high tide” and most resisted calling it a tsunami. None could have known that a seismic shift on a North American fault had set off a train of trans-Pacific waves. Far from its parent earthquake, the tsunami of 1700 was an orphan.

The 1700 tsunami in Japan would remain an orphan for nearly three hundred years. The North American fault at its source would go unnoticed until the last decades of the 20th century. Today the fault is charted, and an earthquake on it is regarded as the orphan’s parent. This kinship gives the earthquake an exact date (January 26, 1700) and an estimated size (magnitude 8.7-9.2) that spur precautions against future earthquakes and tsunamis in the United States and Canada.

THE INDIAN OCEAN TSUNAMI of December 26, 2004, reminded the world of what an earthquake of magnitude 9 can do. Earth rarely provides such reminders; only three 20th-century earthquakes reached or exceeded magnitude 9.0 worldwide.

The Indian Ocean disaster, by affecting areas from southeast Asia to Africa, raised concern about earthquake and tsunami hazards around the planet. The disaster reminded North Americans of such hazards not only in Alaska, struck in 1964 by an earthquake of magnitude 9.2, but also at Cascadia—the region west of the Cascade Range from southern British Columbia to northern California.

Cascadia is home to a gently inclined boundary between two of the moving tectonic plates that make up Earth’s outer shell. The shallow, mostly offshore part of the boundary is the fault that ruptured in 1700. What losses will Cascadia sustain the next time it breaks? A scenario printed in 2005, several months after the Indian Ocean disaster, gives an idea of what to expect.

The scenario begins with an earthquake of magnitude 9.0. Strong shaking lasts for minutes along the Pacific coast in British Columbia, Washington, Oregon, and California. The main coastal highway, U.S. 101, becomes largely impassable, and landslides “sever highway travel between the coast and inland areas.” Thus isolated, coastal residents “have to do much of the work of rescuing those trapped in the rubble.”
The expected damage extends inland to Vancouver, Seattle, and Portland. In this urban corridor, “utilities and transportation lines in some areas could be disrupted, perhaps for months.” Damage to tall buildings “could lead to significant fatalities in downtown areas.”

These risks used to be unthinkable. Cascadia has no written records of homemade earthquakes larger than magnitude 7.5, nor of trans-oceanic tsunamis generated in its backyard. However, the region does have geologic records of great earthquakes—shocks of magnitude 8 or larger—and of tsunamis they spawned. It is the most recent of these Cascadia tsunamis that entered written history in Japan.

RECOGNIZING A HAZARD is just the first step toward dealing with it. Next, the hazard must be defined well enough for practical precautions to be devised and put into effect.

Discoveries about the orphan tsunami of 1700 helped drive this process at Cascadia. Earth science in North America revealed earthquake and tsunami hazards that Japanese history sharply defined. The findings spurred precautionary steps like the mapping of areas that future Cascadia tsunamis may flood and the posting of evacuation signs. The safeguards also include teaching schoolchildren the basics of tsunami survival: If you feel a strong earthquake, run to high ground. If the sea recedes strangely, run to high ground. If a tsunami ensues, stay on high ground; its first wave probably won’t be the last—or the highest.

If only such precautions could have been taken around the Indian Ocean before its 2004 disaster. Most of the victims experienced the earthquake, which was felt even in Thailand and Sri Lanka. Many saw the sea withdraw before the first damaging wave. Some thought the first wave would be the last. Almost everyone was surprised by the earthquake’s magnitude and by the tsunami’s height and reach. The 2004 earthquake and tsunami were outsize events with hardly any known precedent in the Indian Ocean’s past.

IN THIS BOOK we use the past to help warn of outsize earthquakes and tsunamis of the future. We assemble clues from both sides of the Pacific to establish precedent for a giant Cascadia earthquake and its tsunami. We tell the detective story behind some of the recent precautions against earthquakes and tsunamis in western North America.

Five of us were among the detectives. Ueda and Tsuji identified, verified, and correlated several of the Japanese accounts of an orphan tsunami from 1700. Satake recognized this tsunami’s probable link to North American geology and estimated the parent earthquake’s size. Atwater discovered some of that geology and Yamaguchi led in dating it, with tree rings, to a 10-month window that contains the orphan tsunami’s time.
The discoveries thrilled and astonished us—and they still do. But they also bring to mind the Indian Ocean disaster. How many actual orphans did the tsunami of 1700 create?

SIGNS OF CATASTROPHE in 1700 can still be seen in sediments and trees of northwestern North America and in archives of shogunal Japan. Having been privileged to examine these clues, we try to tell the story through them.

The Japanese archives tell of the 1700 tsunami in the words of magistrates, merchants, and peasants. We reproduce each account in full and, guided by linguist Musumi-Rokkaku, state its literal meaning in English. We also explore how each account came to be written and preserved, and how earthquake historians learned of it. Today’s North American precautions against earthquakes and tsunamis are founded, in part, on these minutiae of Japanese history.

THE MAP on the frontispiece and page 2, “Hemisphere occidental,” was compiled in 1720 and published in 1724 by Guillaume Del’Isle, then France’s foremost cartographer (Portinaro and Knirsch, 1987, p. 314; French, 1999, p. 353-354). Del’Isle began publishing maps in 1700, gained a reputation for accuracy, and was appointed royal mapmaker—Premier Géographe du Roi—in 1718. University of Washington Libraries, Special Collections, UW23622z.

EARLIER MAPS that leave northwestern North America blank include “Nova totius terrarum orbis tabula” by Frederick de Wit, 1665; “Novissima totius terrarum orbis tabula” by John Seller, ca. 1673; de Wit’s “Totius Americae descriptio,” 1690, and “A new map of America” by Edgar Wells, 1700 (Portinaro and Knirsch, 1987, p. 186-209). Hayes (1999) chronicles the European discovery of northwestern North America by presenting the explorers’ maps.

FAMILIAR WESTERNERS OF 1700 include Antonio Vivaldi, Johann Sebastian Bach, George Frederic Handel; Daniel Defoe, Jonathan Swift, Alexander Pope; Issac Newton, Gottfried Wilhelm von Leibniz, Jakob Bernoulli, Edmond Halley, Gabriel Daniel Farenheit; John Locke, Voltaire, Montesquieu; Rob Roy, William “Captain” Kidd; and Peter the Great. Charles Perrault’s “Little Red Riding Hood” appeared in 1697. In 1700 London was Europe’s largest city with a population of 550,000. In England’s North American colonies, residents of Boston then numbered 7,000, and New York was a town of 5,000. The school later renamed Yale University opened in 1702. Benjamin Franklin was born six years after the 1700 earthquake. Sources: Pascoe (1991), Garrath (1993), and Williams (1999).

“A MAGNITUDE 9.0 EARTHQUAKE SCENARIO” was prepared by a panel of scientists, engineers, and officials from government and industry, the Cascadia Region Earthquake Workgroup (2005). The scenario does not include numerical estimates of losses of life or property.

THE 2004 SUMATRA-ANDAMAN EARTHQUAKE was felt, at low intensity, in Sri Lanka, peninsular India, Myanmar, Malaysia, and Thailand. Estimates of the earthquake’s moment magnitude range from 9.0 (for seismic waves of 300-second period) to 9.3 (including waves of periods >500 seconds). By the criteria used to estimate the size of the 20th century’s largest earthquakes (graph, p. 98), the 2004 Sumatra-Andaman earthquake attained magnitude 9.0 (Lay and others, 2005). THE INDIAN OCEAN has a written history of dozens of tsunamis since the middle of the 18th century (http://www.ngdc.noaa.gov/spotlight/tsunami/tsunami.html). One of the largest of these was generated in 1833 during an earthquake of estimated magnitude 8.8-9.2 along the west coast of Sumatra (Zachariasen and others, 1999). Its rupture area lies a few hundred kilometers south of the southern end of the 2004 break. Northern parts of the 2004 rupture are the most likely sources of earthquakes of magnitude 8 in 1847, 1881, and 1941 (p. 101). A tsunami in the Bay of Bengal is known to have accompanied the earthquake of 1881 (Bilham and others, 2005, p. 304).

A TSUNAMI-SURVIVAL GUIDE by Atwater and others (1999) mentions Pacific and Atlantic hazards but not the Indian Ocean.

DOCUMENTARIES on findings central to this book include:
“The quake hunters”
http://www.films.com/d/10444

“The next megquake”
http://www.globalnetproductions.com/products.html

“Uncasing evidence of a tsunami in the Pacific Northwest”
Spruce cannot live where barnacles and rockweed cling. Trees like these, killed by tidal submergence, fueled discoveries in the late 1980s and early 1990s about earthquake hazards at Cascadia.

Willapa Bay at low tide, 4 km north of Oysterville, Washington, 1990. The striped handle is 0.5 m long. A man digs behind stumps at upper right.
THROUGH MOST OF THE 20TH CENTURY, North America’s Cascadia region was thought incapable of generating earthquakes larger than magnitude 7.5. Any tsunami striking the region’s coasts would come from afar, leaving hours for warning and evacuation. Yet by century’s end, Cascadia had its own recognized source of earthquakes of magnitude 8 to 9 and of tsunamis that would reach its shores in a few tens of minutes.

That recognition began in the early 1980s. Earth scientists were then beginning to debate Cascadia’s potential for great earthquakes—shocks of magnitude 8 or higher. Despite hints from oral histories of native peoples, there seemed no way to learn whether great earthquakes had ever struck the region.

Fortunately, the earthquakes had written their own history. They wrote it most clearly in the ways that great earthquakes of the 1960s in Chile and Alaska wrote theirs—by dropping coasts a meter or two, by sending sand-laden sea water surging across the freshly lowered land, and by causing shaken land to crack.

Those geologic records soon gave Cascadia a recognized history of great earthquakes. In the late 1980s, at bays and river mouths along Cascadia’s Pacific coast, researchers found the buried remains of marshes and forests that subsidence had changed into tidal mudflats. They also found that the burial began with sand delivered by tsunami or erupted in response to shaking. In a few places they even found the hearths of native people who had used the land before its submergence and burial.

But researchers quickly reached an impasse in this attempt to define, from events recorded geologically, Cascadia’s earthquake and tsunami hazards. How great an earthquake should a school or hospital be designed to withstand? How large a tsunami should govern evacuation plans on the coast? There seemed no way to know whether Cascadia’s plate-boundary fault can unzip all at once, in a giant earthquake of magnitude 9, or whether it must break piecemeal, in series of lesser shocks.
Earthquake potential 地震の可能性
Can Cascadia do what other subduction zones have done?

CASCADIA’S CONVERGING PLATES pose a triple seismic threat. The subducted Juan de Fuca Plate contains sources of earthquakes as large as magnitude 7. Large earthquakes can also radiate from faults in the overriding North America Plate. And the enormous fault that forms the boundary between the plates can produce great earthquakes, of magnitude 8 or 9.

This current picture began taking form in the 1960s, when early ideas about continental drift and seafloor spreading came together as the theory of plate tectonics. The Juan de Fuca Plate was identified as a remnant of a larger tectonic plate that had mostly disappeared beneath North America during 150 million years of subduction.

By the early 1980s, geophysicists had shown that the Juan de Fuca Plate continues to subduct at an average rate of 4 meters per century. But there was no consensus on how the plates move past one another. The plate boundary lacked a recognized history of earthquakes, even at the shallow depths where the rocks might be cool and brittle enough to break (pink in block diagram and map, right).

An earthquake in 1985 provided disturbing images of what can happen when such a plate boundary fails. On September 19th of that year, a subduction earthquake of magnitude 8 generated seismic waves that devastated Mexico City, 400 km from the earthquake source (facing page, top). More than 300 modern buildings collapsed or were damaged beyond repair, 10,000 lives were lost, and another 300,000 persons were left homeless. Could a great Cascadia earthquake have similar effects at inland cities like Vancouver, Seattle, and Portland?

Though few Earth scientists were then taking the idea seriously, some broached the possibility of a Cascadia earthquake of magnitude 9. Cascadia looked like it might have as much source area as the 1964 Alaska earthquake, of magnitude 9.2 (compare the Cascadia and Alaska maps on these two pages). It was even possible to imagine a Cascadia earthquake as large as the 1960 Chile mainshock, the 20th century’s largest earthquake at magnitude 9.5.

THE THEORY OF PLATE TECTONICS holds that Earth’s outer shell consists of moving plates composed of crust and rigid upper mantle (Sullivan, 1991; Oreskes, 2003). Riddihough (1984) used seafloor magnetic anomalies, first mapped by Raff and Mason (1961), to reconstruct the past 7 million years of convergence between the Juan de Fuca and North America Plates. Tanya Atwater’s animations of these and other plate motions can be downloaded at http://emvc.geol.ucsb.edu/

EARTHQUAKE SOURCES (fault rupture areas) inferred from aftershocks for Mexico (UNAM Seismology Group, 1986) and Alaska (Plafker, 1969, p. 6) and from aftershocks and land-level changes for Chile (Cifuentes, 1989, p. 676).

PHOTOS from the Karl V. Steinbrugge collection, National Information Service for Earthquake Engineering, University of California, Berkeley. Photographers: Karl Steinbrugge, Rodolfo Schald (Valdivia), and anonymous (Portage).
Tsunami potential 津波の可能性
Is Cascadia further threatened by its own Pacific tsunamis?

THE POTENTIAL for a great Cascadia earthquake carries with it the threat of an ensuing tsunami. And the tsunami that follows a great subduction earthquake often does more harm than the earthquake itself.

The giant Chilean earthquake of 1960, for instance, left many houses standing above the earthquake source (Valdivia photo, previous page). But the tsunami that followed erased entire villages, including Queule (above). In total, the 1960 tsunami took an estimated 1,000 lives in Chile. It also claimed 61 in Hawaii and 138 in Japan.

You can make a tsunami in a bathtub by sweeping your hand through the water. During a great subduction earthquake, the role of the hand is played by a moving tectonic plate. The plate displaces water from beneath by warping the sea floor (below). It is this tectonic warping, not the seismic shaking, that acts as the hand in the tub.

MAKING A TSUNAMI

OVERALL, a tectonic plate descends, or "subducts," beneath an adjoining plate. But it does so in a stick-slip fashion.

BETWEEN EARTQUAKES the plates slide freely at great depth, where hot and ductile. But at shallow depth, where cool and brittle, they stick together. Slowly squeezed, the overriding plate thickens.

DURING AN EARTHQUAKE the leading edge of the overriding plate breaks free, springing seaward and upward. Behind, the plate stretches; its surface falls. The vertical displacements set off a tsunami.
Such sea-floor deformation during the 1964 Alaska earthquake generated a tsunami that reached Cascadia’s shores four hours later. Warnings had been issued, and the tsunami had lost height by spreading out as it radiated toward far reaches of the Pacific Rim. Even so, the Alaskan waves swept four children off an Oregon beach and killed another dozen persons in northern California.


**Downwarped coast**

THE PLATE MOTION that drives a tsunami can also lower a coast (cartoons, opposite). When fault slip during the 1960 earthquake stretched the overriding South America plate, the Earth’s surface fell throughout a belt 1,000 km long (map, right). In Queule, near the axis of the downwarp, the entire landscape dropped 2 meters. Hence tides cover former riverbanks in the postearthquake photo above.

Similar coastal subsidence accompanied the 1964 Alaska earthquake (p. 14) and several earthquakes in southwest Japan (p. 91). Coastal subsidence accordingly provides pivotal evidence for the past occurrence of great Cascadia earthquakes—clues Earth scientists began using in the late 1980s (p. 16).
Flood stories 洪水の言伝え

Cascadia’s own tsunamis may have entered Native American lore.

OLD WRITINGS FROM CASCADIA offer few hints that the region’s subduction zone produces great earthquakes or tsunamis. Such events are unknown from the records of early explorers like Bruno de Hezeta y Dudagogiia, who mapped the mouth of Washington’s Quinault River in 1775; James Cook, who named Cape Flattery a few years later; and George Vancouver, who surveyed Puget Sound, Grays Harbor, and the lower Columbia River in the early 1790s. The Lewis and Clark Expedition recorded no signs of Pacific coast earthquakes or tsunamis while exploring that river in 1805 and 1806.

The oral traditions of Cascadia’s native peoples, however, tell of flooding from the sea. The example at right, one of the first written, comes from James Swan’s diary for a rainy Tuesday in January 1864 at Neah Bay, Washington Territory, home of the Makah tribe. Swan’s informant, Billy Balch, was a Makah leader.

Balch recounts a sea flood in the “not very remote” past. It began by submerging the lowland between Neah Bay and the Pacific Ocean. Next, the water receded for four days. Rising again “without any swell” the sea covered all but the highest ground on both sides of the Strait of Juan de Fuca. It dispersed tribes, stranded canoes in trees, and caused “numerous” deaths. “The same thing happened” at Quileute, 50 km south of Neah Bay.

Balch mentions no earthquake. Did the sea flood have a remote origin, like the tsunami from Alaska in 1964? Or did a tsunami of nearby origin prove more memorable than the Cascadia earthquake that triggered it?

DIARY OF JAMES SWAN FOR JANUARY 12, 1864

Billy also related an interesting tradition. He says that “ankarty” but not “hias ankarty” that is at not a very remote period the water flowed from Neeah bay through the Waatch prairie, and Cape Flattery was an Island. That the water receded and left Neeah Bay dry for four days and became very warm. It then rose again without any swell or waves and submerged the whole of the cape and in fact the whole country except the mountains back of Clyoquot. As the water rose those who had canoes put their effects into them and floated off with the current which set strong to the north. Some drifted one way and some another and when the waters again resumed their accustomed level a portion of the tribe found themselves beyond Nootka where their descendants now reside and are known by the same name as the Makahs—or Quinaitchechat. Many canoes came down in the trees and were destroyed, and numerous lives were lost. The same thing happened at Quillehuyte and a portion of that tribe went off either in canoes or by land and formed the Chimakum tribe at Port Townsend.

There is no doubt in my mind of the truth of this tradition. The Waatch prairie shows conclusively that the waters of the ocean once flowed through it. And as this whole country shows marked evidence of volcanic influences there is every reason to believe that there was a gradual depression and subsequent upheaval of the earth’s crust which made the waters to rise and recede as the Indian stated.

The tradition respecting the Chimakums and Quillehuytes I have often heard before from both those tribes.

BILLY BALCH’S family history is recounted by Goodman and Swan (2003), who give his Makah name as Yelakub. JAMES G. SWAN (1818-1900) lived among Indians of Shoalwater (now Willapa) Bay in the early 1850s and among the Makah in the 1860s (McDonald, 1972). He wrote newspaper articles and books about these people and their land (Swan, 1857, 1870, 1971). He also penned two and a half million words in diaries that span forty years (Doig, 1980). The excerpt is from University of Washington Libraries, Special Collections, UW19484z and UW19485z.

MAP at right excerpted from “Makah Indian Reservation in Washington Territory by J.G. Swan, 1862” (National Archives and Records Administration, RG 75, #995). Shorelines probably based on mapping by the U.S. Coast Survey.

THE ORPHAN TSUNAMI OF 1700
Cascadia earthquake that triggered it? a tsunami of nearby origin prove more memorable than the remote origin, like the tsunami from Alaska in 1964? Or did 50 km south of Neah Bay.

"numerous" deaths. "The same thing happened" at Quileute, dispersed tribes, stranded canoes in trees, and caused highest ground on both sides of the Strait of Juan de Fuca. It began by submerging the lowland between Neah Bay and Balch, was a Makah leader. Swan's informant, Billy Balch, recounts a sea flood in the "not very remote" past. The oral traditions of Cascadia's native peoples, however, tell of flooding from the sea. The example at right, "ankarty" but not "hias ankarty" that is at not a very remote period the water flowed through the Waatch prairie, and Cape Flattery was an Island. That the water receded but left Neah Bay dry for four days and became very warm, it then rose again without any swell or waves and submerged the whole of the cape and in fact the whole country except the mountains back of Clayoquot. As the water rose those who had canoes put their effects into them and floated off with the current which set strong to the north. Some drifted one way and some another, and when the waters again receded they accented level a portion of the tribe found themselves beyond. The same when they discovered more inside and are known by the same name as the makers, or Quinaitchechat, many canoes came down in the trees and were destroyed and numerous lives were lost. The same thing happened at Quillehuyte and a portion of that tribe went off either in canoes or by land and formed the Chemakum tribe of just Pendaut.

There is no doubt in my mind of the truth of this tradition. The writers of learning have concluded that the waters of the ocean once flowed through it, out as this whole country, show marked evidence of volcanic influences, there is every reason to believe that there was a gradual depression and subsequent upheaval of the earth's crust which made the water to rise and recede in the Indian states. The tradition respecting the Chemakum, and Quillehuyte, I have often heard before from both those tribes.
Alaskan analog アラスカの例

Ghost forests and a buried soil naturally record the 1964 earthquake.

SOME EARTHQUAKES write their own history. In a classic example, the giant Alaska earthquake of March 27, 1964, was accompanied by regional subsidence that lowered vegetated land into Cook Inlet. The results remain easy to see at Portage, near the axis of the earthquake’s downwarp. Trees stand dead because the land subsided 1.5 meters during the earthquake—far enough to admit tides into former meadows, willow thickets, cottonwood groves, and stands of Sitka spruce. Tides brought in silt and sand that buried this former landscape in the first decade after the earthquake.

Like the Portage garage, opposite, the spruce victims were falling by 1998. Their stumps, however, remain in growth position, entombed by the tidal silt. These serve as natural archives of the 1964 earthquake—and as a guide to identifying signatures of past great earthquakes at Cascadia.

TIDAL FLOODING A FEW WEEKS AFTER EARTHQUAKE, TWENTYMILE RIVER

Airphoto from U.S. Army, Mohawk series M-64-82. Probably taken during high tide of April 14, 1964 — 18 days after the March 27 earthquake.

The tectonic component of the subsidence near Portage amounted to 1.5-1.7 m (Plafker, 1969, plate 1). The railroad grade settled another 1 m, on average, in response to seismic shaking (McCulloch and Bonilla, 1970, p. 81). The subsidence at Portage created intertidal space that the silt and sand filled (Ovenshine and others, 1976). Much of the fill dates from the first months after the earthquake, when individual high tides left layers as much as 2 cm thick (opposite, Atwater and others, 2001b). The deposition was speeded by a 10-m tide range and ample sources of sediment (Bartsch-Winkler, 1988).
Unearthed earthquakes

GHOST FOREST AT PORTAGE GARAGE

By lowering land into a bay or river mouth, subsidence during an earthquake produces a lasting record of the earthquake’s occurrence.

TIDAL SILT AND SAND ABOVE BURIED SOIL, TWENTYMILE RIVER

- Ground surface in 1998
- Sand and silt of one high tide, probably April 1964
- By lowering land into a bay or river mouth, subsidence during an earthquake produces a lasting record of the earthquake’s occurrence.

Land subsides during earthquake (p. 10)

Before earthquake  Several months after earthquake  Several decades after earthquake

Soil  Tide  Silt

Buried soil

Few trunks still standing

Shrubs cover land rebuilt by tidal silt (example below)

High tide covers recently subsided land

10 cm

Unearthed earthquakes
Sunken shores 海岸の沈降
Land occasionally drops along Cascadia’s Pacific coast.

IT WAS ONLY A MATTER OF TIME before someone would recognize Portage look-alikes at Cascadia. In the late 1980s, spurred by controversy about Cascadia’s great-earthquake potential, geologists checked bays and river mouths along Cascadia’s Pacific coast. At nearly every one they found evidence that land had dropped.

These signs of subsidence include ghost forests—groves of weather-beaten trunks that stand in tidal marshes of southern Washington. First documented in the early 1850s, they are composed entirely of western red cedar, a long-lived conifer known for rot-resistant wood.

More common are victim trees preserved only as stumps beneath the marshes. Thousands of such stumps can be seen in banks of tidal streams in southern Washington (example opposite), hundreds more at estuaries in Oregon and northern California. The main victim is Sitka spruce—the species whose rotting trunks were falling at Portage in the fourth decade after their deaths in 1964 (p. 15).

Most common of all are the buried remains of tidal marshes. In streambanks and sediment cores, muddy tidal deposits abruptly overlie peaty marsh soils.

THE LOWERING OF LAND by Cascadia earthquakes has been inferred in dozens of reports. Recent examples include details from Oregon (Kelsey and others, 2002; Witter and others, 2003; Nelson and others, 2004) and Washington (Atwater and others, 2004) and a regional compilation (Leonard and others, 2004).

IN THE UPPER PHOTO, spruce saplings live high on the tallest of the dead trees. First documented in the early 1850s, they are composed entirely of western red cedar, a long-lived conifer known for rot-resistant wood.

More common are victim trees preserved only as stumps beneath the marshes. Thousands of such stumps can be seen in banks of tidal streams in southern Washington (example opposite), hundreds more at estuaries in Oregon and northern California. The main victim is Sitka spruce—the species whose rotting trunks were falling at Portage in the fourth decade after their deaths in 1964 (p. 15).

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JAMES GRAHAM COOPER (1830-1902), wintered at Shoalwater (now Willapa) Bay in 1853-1854, while serving as naturalist for a railway survey. He described the bay’s ghost forests of western red cedar to illustrate the wood’s durability. He inferred that the trees had spent their lives “above high-water level, groves of this and other species still flourishing down to the very edge of inundation” (Cooper, 1860, p. 26). As to what killed the trees, Cooper proposed gradual sinking into quicksand. Now it is clear that the land dropped suddenly (evidence opposite), and that subsidence resulted from stretching of solid rock (right cartoon, p. 10).
### Whodunit

**WHAT ALLOWED TIDES to kill forests and bury marshes along Cascadia’s Pacific coast?** At first, in the late 1980s, geologists couldn’t rule out gradual rise of the sea. But soon they convicted abrupt fall of the land that was accompanied by tsunami and shaking (p. 18 and 20), and which happened in the same decades at different places along a shared fault (p. 24).

Sudden subsidence provides a simple explanation for tree rings like those at right. The rings record the final decades of life for a Sitka spruce killed by postearthquake submergence at Willapa Bay, like the one in the photo above. Wide to the end, the rings suggest that the tree was healthy right up to the time of its death. The rings show no sign of lengthy suffering from gradual drowning and salt-water poisoning from a drawn-out sea-level rise.

Sudden lowering of land also explains remarkable preservation of buried marsh soils at Cascadia. Some of the soils retain delicate remains of plants that had been living on them at the time of submergence. Tidal-flat mud above such soils entombed herbaceous leaves and stems, in growth position, before they had time to rot. Such leaves and stems decay in a few years on modern marshes. Their preservation in tidal-flat mud above buried marsh soils implies that the change from marsh to tidal flat took a few years at most.

### Unearthed earthquakes

Though hundreds of trees succumbed to postearthquake submergence at Portage in 1964 (p. 14-15), some of those immersed in fresh water managed to live a few months beyond the March 27 earthquake. Their bark adjoins light-colored early wood from the 1964 growing season. Not imagining such survival, Atwater and Yamaguchi (1991) misinterpreted incomplete outer rings at Cascadia as evidence for sudden submergence during a growing season, between May and September. The trees in question are spruce that died from the Cascadia earthquake now dated to January 1700. As at Portage, some of the submerged spruce survived into the next growing season or later (Jacoby and others, 1995).
**Sand sheets 地層中の砂層**

Tsunamis overran newly dropped land along Cascadia’s Pacific coast.

**SIGNS OF CASCADIA TSUNAMIS**

WHILE MAPPING Cascadia’s signs of sudden subsidence, geologists in the 1980s and 1990s found associated evidence for tsunamis. That evidence consists of sand sheets beside bays and river mouths (dots on map, left). The sand came from the sea; it tapers inland and contains the microscopic siliceous shells of marine diatoms. Beside muddy bays the sand alternates with layers of mud (photos below) that probably settled out in lulls between individual waves in a tsunami wave train (modern example, opposite).

At most sites, the sand arrived just before tidal mud began covering a freshly subsided soil (cartoons below). Neither a storm nor a tsunami of remote origin explains this coincidence with subsidence. The simplest explanation is a tsunami from an earthquake in which a tectonic plate, in a seismic shift, abruptly displaces the sea while lowering the adjoining coast. The resulting tsunami then overruns the lowered land (cartoon, p. 10).

**SAND SHEETS** from tsunamis of great Cascadia earthquakes have been identified along Cascadia’s Pacific coast (compilation by Peters and others, 2003) and at northern Puget Sound (Williams and others, 2005). Some cover archaeological sites (p. 20-21) and the floors of coastal lakes (Hutchinson and others, 1997). Constituents include microscopic marine fossils (Hemphill-Haley, 1996). Sand sheets in British Columbia record Alaskan waves of 1964 in addition to the 1700 Cascadia event (Clague and others, 2000).

A SMALL TSUNAMI on April 25-26, 1992, in northern California, provides further evidence that the Cascadia subduction zone generates tsunamis of its own. The parent earthquake, of magnitude 7.1, probably broke the Cascadia plate boundary near its southern end. The tsunami crested 0.5 m above tides at Crescent City, where it lasted eight hours (Oppenheimer and others, 1993).
Unearthed earthquakes

Chilean counterparts

THE TSUNAMI associated with the giant 1960 Chile earthquake deposited sand in Chile. The deposit was noted soon afterward at several northern sites. Additional examples were documented decades later near Maullín, where tsunami sand had settled on subsided pastures.

Likewise in Japan, on the far side of the Pacific, the 1960 tsunami deposited sand onshore. For example, it coated plains beside Miyako Bay with alternating layers of sand and silt. The layers probably represent several of the dozens of 1960 tsunami waves recorded by the Miyako tide gauge. Those waves were numerous because, like the Cascadia tsunamis simulated on pages 37, 74-75, and 103, the 1960 Chile tsunami reflected off shorelines and resonated in bays.

In Chile

TSUNAMI DEPOSIT NEAR MAULLÍN

WAVE TRAIN AT TALCAHUANO TIDE GAUGE

TSUNAMI SOURCE

SAND SHEETS were noted by Wright and Mella (1963, p. 1371, 1372, 1389) and, near Maullín, by Cisternas and others (2005). Tide-gauge data redrawn from Sievers and others (1963, sheet 3). Tsunami source inferred from land-level changes mapped by Pfafker and Savage (1970).

In Japan

TSUNAMI DEPOSIT BESIDE MIYAKO BAY

WAVE TRAIN AT MIYAKO TIDE GAUGE

TSUNAMI HEIGHTS BESIDE MIYAKO BAY (location, p. 51)

Onshore limit of 1960 tsunami (p. 56)

G.M.T., Greenwich Mean Time

AT MIYAKO BAY the 1960 tsunami deposits contain microscopic marine fossils (Omuki and others, 1961) in addition to the multiple layers illustrated above (redrawn from Kitamura and others, 1961b). Details on the marigram, p. 46; sources for the mapped tsunami heights, p. 55.
In harm’s way  危険地域
Earthquake-induced submergence ruined Cascadia campsites.

IN A YUROK MYTH recorded a century ago, Thunder wants people to have enough to eat. He thinks they will if prairies can be made into ocean. He asks Earthquake for help. Earthquake runs about, land sinks, and prairies become ocean teeming with salmon, seals, and whales.

In cruel reality, native people paid a price for whatever they gained when Cascadia’s great earthquakes changed tidal prairies into shallow arms of the sea. First they faced horrific tsunamis, like the one implied by the story of a sea flood that swept canoes into trees (p. 12). Survivors then watched tides relentlessly cover their subsided, bayside fishing camps.

Several archaeological sites tell wordlessly of the waves and tides that overran them. Each lies buried beneath tidal mud. Some are also coated with tsunami sand. In the 1980s and 1990s, geologists noticed them while studying buried soils in the banks of tidal streams (examples below and opposite).

Most of the archaeological sites stand out for their broken stones. The estuaries’ muddy banks rarely contain sand, much less stones. But native peoples brought in pebbles and cobbles. They baked them in hearths, then used them to heat water in woven baskets and wooden boxes. Thermally shocked, the stones shattered.

Did a tsunami put out the campfires? None of the identified sites tells a story so dramatic. And something else must have driven people from the fishing camp on the facing page. Probably it was abandoned a century or two before the earthquake that sank it.

---

FORMER FIRE PITS, OREGON

<table>
<thead>
<tr>
<th>Before earthquake</th>
<th>Minutes to hours after earthquake</th>
<th>Decades to centuries later</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil darkened and thickened by charcoal and refuse</td>
<td>Sand-laden tsunami</td>
<td>Hearths buried</td>
</tr>
<tr>
<td>Dune sand</td>
<td>Tidal marsh</td>
<td>Tsunami sand</td>
</tr>
<tr>
<td>Hearths</td>
<td>Tidal mud</td>
<td>Soil amended by refuse</td>
</tr>
<tr>
<td>Salmon River, site 35LNC64</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

FIRE-MODIFIED ROCK, WASHINGTON

- Entirely angular pieces
- Unmodified pebbles and cobbles
- Broken pebbles and cobbles

---

Campsites ruined by a great Cascadia earthquake
- Covered by tsunami sand and tidal mud
- Covered by tidal mud only

- Residence of Yukon teller of “How the prairie became ocean”

---

ANN OF ESPEU, of the Yurok tribe, recounted “How the prairie became ocean” to the ethnographer Alfred L. Kroeber (1876-1960) between 1900 and 1908 (Kroeber, 1976, p. 460).
A weaver’s fate

WHAT BECAME OF THE MAKER of the woven object at right?

In 1991, before salvage by an archaeologist, the weaving protruded from an eroding tidal bank of Oregon’s Nehalem River. It rested on the lowest centimeter of tidal mud that covers a buried marsh soil. Its radiocarbon age matches the time when the marsh changed into a tidal flat. Did the tsunami from a great Cascadia earthquake snatch the weaving from a coastal village? Did the weaver survive?

A PIECE OF THE WEAVING gave a radiocarbon age (173 ± 44 14C yr B.P.; GX-17835) statistically indistinguishable from the mean of 16 ages on stems and leaf bases found rooted in the soil and entombed in the overlying mud (179 ± 15 14C yr B.P.; Nelson and others, 1995; graphed on our p. 25).

ABANDONED FISHING CAMP, WASHINGTON

A FENCE IN WATER, a fishing weir blocks fish or directs them into traps. Dozens of prehistoric examples have been reported from the coast between southeast Alaska and northern California (Moss and Erlandson, 1998). The weirs above jut into the tidal Willapa River on the bank opposite downtown South Bend (site 45PC103, Atwater and Hemphill-Haley, 1997, p. 69-71 and figs. 29, 30).

Two fishing weirs, exposed at very low tides at Willapa Bay, Washington, probably predate the 1700 Cascadia earthquake. A bark-bearing stave dates to 1400-1650. In the adjoining bank, archaeologically sterile soil records a time when the site lay abandoned. This soil separates a culturally darkened soil from the earthquake’s signature—the abrupt upward change to distinctly laminated mud that postearthquake tides laid on subsided land.
**Currents and cracks 水中土石流と液状化**

Cascadia earthquakes avalanched sea-floor mud and quickened coastal sand.

DID THE EARTH QUAKE while land subsided and tsunamis began along Cascadia’s Pacific coast? This key question went unanswered until the early 1990s, when two lines of evidence pointed to seismic shaking.

First, shaking offshore was shown to explain bottom-hugging muddy flows (turbidity currents) that repeatedly descended submarine channels (cartoon below).

Second and crucially, shaking onshore was found to have accompanied the coastal subsidence. The shaking liquefied loose, wet sand, turning it to quicksand. Water expelled from the liquefied sand erupted through cracks onto freshly subsided land (right). Today, these conduits are easy to spot because water plucks sand grains from the cracks more easily than it scours the sticky mud beside them.

**EVIDENCE FOR SHAKEING**

1. River delivers sediment to the sea.
2. Sediment settles on the continental shelf.
3. An earthquake shakes the continental shelf and slope.
4. Shaken sediment descends submarine canyons as turbidity currents.
5. Turbidity currents merge where tributaries meet. Resulting deposits are visible in sediment cores.

ON TURBIDITE EVIDENCE for great Cascadia earthquakes, see Adams (1990; source of the above cartoon) and Goldfinger and others (2003).

LIQUEFACTION during the 1700 Cascadia earthquake produced sand dikes along the Columbia River. These were discovered in the early 1990s by Stephen Obermeier (Petersen, 1997; Obermeier and Dickenson, 2000). Probably correlative intrusions were later found at Grays Harbor (right) and at Sixes River, Oregon (Kelsey and others, 2002, p. 310-312). The 1964 Alaska earthquake generated dikes near Portage (cracks in photo, p. 14; Walsh and others, 1995).

SHAKING LEAVES A DEEP-SEA DEPOSIT

1. Estuary where sand liquefied when land suddenly subsided.
2. Grays Harbor.
3. Columbia River.
4. Sixes River.

**SHAKING YIELDS A SAND-FILLED CRACK**

- **Before earthquake**
  - Tidal marsh rests on loose, wet sand
  - Sand liquefies, land cracks, and pressurized slurry spurts into crack.
- **During earthquake**
  - Sand intrusion records past shaking.
  - Land subsides.
- **Centuries after earthquake**
  - Sand intrusion in coastal sediments.
  - Exhumed marsh soil.
  - Top of crack from shaking.

A sand dike—a vertical sand-filled crack—rises to the top of a marsh soil, seen above in a natural low-tide outcrop. In the plan view at right, the dike cuts sharply across the mud.

Johns River, Grays Harbor (p. 103). In lower photo, the grooves in the mud are from scraping tool.
Strength of shaking

TO DESIGN A SCHOOL to withstand a great Cascadia earthquake, an engineer needs to know what shaking to expect. Researchers have sought guidance from records of past shaking at Cascadia, thus far with little success.

To estimate ancient ground motions, a logical first step is to identify sand that an earthquake liquefied. The sand’s resistance to liquefaction can then be measured, and the results compared with those from sand that did or did not liquefy at known levels of shaking.

However, sand that liquefies can look just the same as it did before. It can retain its original sedimentary layers after expelling the water that drives intrusions. In the photo below, a sill and offshooting dikes show that sand liquefied somewhere below them. How can that source sand be identified, so that its resistance to liquefaction can guide the design of schools that resist earthquakes?

PEAK SURFACE ACCELERATIONS of 0.15-0.35 g were inferred from the localized absence of near-surface sand dikes along the Columbia River 35-60 km inland from the Pacific coast (Obermeier and Dickenson, 2000). Deeper liquefaction features, like those at upper right, cast doubt on these proposed upper bounds (Atwater and others, 2001a; Takada and Atwater, 2004).

DURING LIQUEFACTION, sand sheared by shaking loses strength through an increase in pore-water pressure that decreases grain-to-grain contact. Partial collapse of the grain structure then drives much of the water out. However, where the expelled water escapes diffusely, the primary sedimentary layers in liquefied sand can remain nearly intact (Lowe, 1975; Owen, 1987; Liu and Qiao, 1984).

ADDED TINTS highlight the intrusions and mud bed in the slice photo.
Magnitude 9？マグニチュード9？
Geologists reach an impasse on Cascadia’s potential for a giant earthquake.

MAXIMUM EARTHQUAKE SIZE remained a big unknown for Cascadia through the early 1990s.

By then, geologists had identified signs of earthquake-induced subsidence, and attending tsunamis, at estuaries from southern British Columbia to northern California. They knew that nearly all sites had dropped most recently within the past 400 or 500 years, and that the southern Washington coast subsided in the decades after A.D. 1680 (box, below).

These findings spurred a radiocarbon experiment designed to detect coastwise differences—if any—in the time of earthquake-induced subsidence. Any such differences would limit earthquake size by limiting fault-rupture length.

The experiment ended up denying neither the giant-earthquake hypothesis nor its serial alternative (opposite). The most exact of the ages show that trees nearly 700 km apart, in southern Washington and northern California, died from earthquake-induced subsidence during the same few decades. Either a single giant earthquake or a swift series of merely great earthquakes could have done the job.

But the experiment succeeded in narrowing the time window for Cascadia’s most recent giant earthquake, or great-earthquake series, to the period 1695-1720. And unbeknown to the experimenters, an orphan tsunami in 1700 had long been puzzling earthquake historians in Japan.

### Natural clocks

<table>
<thead>
<tr>
<th>MATERIAL DATED (and year first measured)</th>
<th>AGE OF MATERIAL RELATIVE TO TIME OF EARTHQUAKE</th>
<th>METHOD (and typical uncertainty)</th>
<th>EVENTUAL COASTWISE EXTENT</th>
<th>TIME WINDOWS FOR MOST RECENT GREAT EARTHQUAKE as inferred by 1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat and other plant remains in or above buried soil (1986)</td>
<td>Commonly decades or centuries older, or decades younger</td>
<td>Conventional radiocarbon (± 50 °C yr)</td>
<td>Most estuaries, southern B.C. to northern Calif.</td>
<td>1650</td>
</tr>
<tr>
<td>Rings of weather-beaten trunks of western red cedar killed by postearthquake tides (1988)</td>
<td>Outermost preserved ring older by intervals unknown until 1996, when the trees’ final rings were dated in bark-bearing roots (p. 96)</td>
<td>Ring-width pattern matching to calendar year (p. 97)</td>
<td>Four estuaries in southern Washington</td>
<td>1800</td>
</tr>
<tr>
<td>Rings of bark-bearing roots of Sitka spruce killed by postearthquake tides (1990)</td>
<td>Typically older by amounts known, to within a few years, from counts of annual rings</td>
<td>High-precision radiocarbon (± 10-15 °C yr)</td>
<td>Four estuaries (facing page)</td>
<td>1700</td>
</tr>
<tr>
<td>Leaves and stems of herbaceous plants killed by postearthquake tides (1993)</td>
<td>Older by a decade or two at most for woody stems of perennials; by a few years at most for leaves</td>
<td>AMS radiocarbon (± 50 °C yr)</td>
<td>Seven estuaries (facing page)</td>
<td></td>
</tr>
</tbody>
</table>

For examples of differences in geological and analytical precision, see Atwater and Hemphill-Haley (1997, p. 84 [soil Y] versus p. 89).

±, standard deviation reported by lab. °C yr, radiocarbon years (graphed, opposite). AMS, accelerator mass-spectrometry, used to date small samples.
Unearthed earthquakes

**HYPOTHESES: ALL AT ONCE OR A PIECE AT A TIME?**

- Giant earthquake, M 9
- Series of lesser events, M 8+

**INCONCLUSIVE TEST: DEATH AT THE SAME TIME?**

The remains of earthquake-killed plants yielded ages that are neither statistically different nor necessarily the same within each of the three groups color-coded below.

---

**Uncommonly exact**

**RADIOCARBON AGES** rarely pin down the time of an event. To narrow the time of Cascadia’s most recent giant earthquake (or serial great earthquakes) to 1695-1720, isotopists and geologists pushed radiocarbon precision to its limits. They took advantage of quirks in the radiocarbon timescale, and they maximized geological and analytical precision in sampling and measurement.

Radiocarbon time has been called rubberband time. It stretches and shrinks because radioactive carbon is produced in Earth’s atmosphere by cosmic rays whose flux waxes and wanes. Trees use radiocarbon as part of the atmospheric carbon dioxide from which they make their annual rings. Tree rings thus yield radiocarbon ages that wiggles from straight-line equivalence of radiocarbon and calendar time. One of the tallest jags spans most of the century before A.D. 1700 (graph at right).

The dating to 1695-1720 relied on finding this tall jag in the annual rings of earthquake-killed spruce. Ring counts adjust for the time lag between the dated rings and the tree-killing earthquake. The radiocarbon ages themselves, like those that define the calibration curve, were measured at uncommon precision on cellulose whose carbon the trees took from the atmosphere by photosynthesis shortly before the dated rings formed.

Sample selection was guided by red-cedar evidence that the earthquake followed the 1680s (graph, left). This evidence, honed in the late 1990s (p. 96-97), would strengthen Cascadia’s link to a tsunami in Japan.
On the scenic spit at Miho, a village leader puzzled over a train of waves in January 1700 (p. 40, 78-79). Part 2

The orphan tsunami

A PACIFIC TSUNAMI flooded Japanese shores in January 1700. The waters drove villagers to high ground, damaged salt kilns and fishing shacks, drowned paddies and crops, ascended a castle moat, entered a government storehouse, washed away more than dozen buildings, and spread flames that consumed twenty more. Return flows contributed to a nautical accident that sank tons of rice and killed two sailors. Samurai magistrates issued rice to afflicted villagers and requested lumber for those left homeless. A village headman received no advance warning from an earthquake; he wondered what to call the waves (quote, opposite).

These glimpses of the 1700 tsunami in Japan survive in old documents written by samurai, merchants, and peasants. Several generations of Japanese researchers have combed such documents to learn about historical earthquakes and tsunamis. In 1943 an earthquake historian included two accounts of the flooding of 1700 in an anthology of old Japanese accounts of earthquakes and related phenomena. By the early 1990s the event had become Japan's best-documented tsunami of unknown origin.

Part 2 of this book contains a chapter for each of six main Japanese villages or towns from which the 1700 tsunami is known. Each chapter begins with a summary of main points, a geographical and historical introduction, and the content of the tsunami account itself. Other parts of the chapters explore related human and natural history. Concluding estimates of tsunami height reappear in Part 3 as clues for defining hazards in North America.
Part 2
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Preface

Europeans speculated on a large southern continent and on the shape of their maps. Those copies, and Ishikawa’s version as well, retained 16th-century origins. Unno (1994, p. 404-409) traces its roots to 16th-century Chinese copies of European maps. Merchants tracked goods and services in an economy driven by bustling cities. Peasants prepared documents for villages and a travel map of Japan (overleaf). Europe’s mapmakers also provided a market for required paperwork: the Tokugawa shogun, the Japanese national leader in Edo (now Tokyo). They also administered overleaf dates from 1694.

The accounts of the 1700 tsunami accordingly come late in the written history of Japan. The year belongs, accurately on page 26, in a village of 300 peasants, a farmer makes his living as a bureaucrat. Japan “sea to mountains.” Ishikawa issued its first edition in 1691, woodblock printed and hand colored. The version on denoted Holland, Japan’s sole European trading partner. The map serves as an encyclopedia, Nihon Koten Bungaku Daijiten Henshü I’inkai, (1983, p. 129). Ishikawa Tomonobu (or Ishikawa Ryüsen) is profiled in a Japanese literary tradition, humorous fiction, and published travel guides and courtesan evaluations. Like many of his contemporaries, including the short-story writer Ihara Saikaku and the playwright, published travel guides and courtesan evaluations. Ishikawa makes “Nihon kaisan” useful to the traveler by fitting his subject into a rectangular format and by filling margins with tourist information. Marginal tables give travel distances, domestic and international. Half the domestic table gives distances by land; the other half, distances by sea. Additional tables name the most important shrine in each county of each province. The lower left corner of the map provides an almanac on solstices, equinoxes, phases of the moon, and tides. Above it, signs of the Chinese zodiac denote twelve compass directions (p. 43).

The ukiyo artist further depicts cities, castles, highways, and a travel map of Japan (overleaf). Ishikawa's map depicts an ocean between the Japanese islands and the name of the daimyo himself. Roofs and their entourages, who journeyed to Edo every year or two for required attendance upon the shogun. A square or circle denotes Holland, Japan’s sole European trading partner. The map served as an illustration of the world’s peoples. The companion sheet contained portraits of the world’s peoples. Just off the Tökaidö, the pines of Miho beckon from a fisherman.
In Japan, the 1700 tsunami reached a society ready to write about it.

THE YEAR 1700, though almost a century earlier than the first written records from northwestern North America, comes late in the written history of Japan. The year belongs, moreover, to an era of Japanese stability, bureaucracy, and literacy that promoted record-keeping.

That era began with national pacification early in the 17th century. By 1700, the country had known almost a century of peace for the first time in 500 years. Many in its military class were making their livings as bureaucrats. Samurai did paperwork for the Tokugawa shogun, the national leader in Edo (now Tokyo). They also administered the hinterlands as vassals of regional land barons, the daimyo.

Reading and writing extended beyond this ruling elite to commoners urban and rural. Booksellers offered poetry, short stories, cookbooks, farm manuals, and children’s textbooks. Merchants tracked goods and services in an economy driven by bustling cities. Peasants prepared documents for villages they headed.

The accounts of the 1700 tsunami accordingly come from representatives of three social classes. The writers were military men employed by daimyo domains (p. 44, 70), merchants in business and local government (p. 53, 85), and peasants serving as village officials (p. 70, 77).

PERIOD MAPS open windows into the society in which those samurai, merchants, and peasants wrote. Such maps help introduce each of the six chapters in this part of the book. As a further introduction to a bygone time and place, consider the career of a commercial mapmaker and two of the products he sold: a decorative map of the world (opposite) and a travel map of Japan (overleaf).

Ishikawa Tomonobu wrote and drew in the decades around 1700. In addition to making maps, he illustrated calendars and novellas, composed linked-verse poetry and humorous fiction, and published travel guides and courteous evaluations. Like many of his contemporaries, including the short-story writer Ihara Saikaku and the playwright Chikamatsu Monzaemon (p. 63), Ishikawa worked in a tradition, ukiyo, or floating world, that focused on daily life and its fleeting pleasures.

Ishikawa’s world map, descended from 16th-century European compilations, was modeled on 17th-century Japanese surveyors’ certificates. The map served as an interior decoration hung lengthwise, east to the top. A companion sheet contained portraits of the world’s peoples.

The map depicts an ocean between the Japanese islands from the Americas. Japanese phonetic symbols identify America and Peru. Chinese characters for “The Red Haired” denote Holland, Japan’s sole European trading partner between 1639 and 1854.


Ishikawa makes “Nihon kaisan” useful to the traveler by fitting his subject into a rectangular format and by filling margins with tourist information. Marginal tables give travel distances, domestic and international. Half the domestic table gives distances by land; the other half, distances by sea. Additional tables name the most important shrine in each county of each province. The lower left corner of the map provides an almanac on solstices, equinoxes, phases of the moon, and tides. Above it, signs of the Chinese zodiac denote twelve compass directions (p. 43).

Frequent travelers in Ishikawa’s Japan included daimyo and their entourages, who journeyed to Edo every year or two for required attendance upon the shogun. A square or circle on the travel map represents each daimyo domain. An adjoining label gives a measure of daimyo status—the domain’s official valuation in terms of rice yield (p. 71)—and the name of the daimyo himself.

The ukiyo artist further depicts cities, castles, highways, fishermen, merchant marines, and urban samurai. Roofs represent the urban sprawl of the shogun’s capital, Edo, its population soon to surpass one million. The Tōkaidō, or Eastern Sea Road, wends its way toward Kyoto, the imperial capital since A.D. 794. Fifty-three-way stations await travelers seeking overnight accommodations.

Just off the Tōkaidō, the pines of Miho beckon from a floating-world island. On a peninsula rendered more accurately on page 26, in a village of 300 peasants, a farmer or fisherman will soon write the most vivid and inquisitive of Japan’s accounts of the orphan tsunami of 1700 (p. 78-79).
Ezo (now Hokkaido) was then held mostly by Ainu, a native people.

Land area distorted artfully at right

Compass (p. 43)

Solstices, equinoxes, zodiac, moons, tides

International distances
Holland, 12,500 n (see footnote, p. 29)

Domestic distances by major roads, such as the Tōkaidō (right), and by sea

Temples and shrines listed by kuni (ancient province) and gun (county)
Mount Fuji

Province boundary
(shown more exactly on official map, next page).

Suruga province
contained seven gun 七郡, or counties.

Sumpu castle, site of earliest known writing of “tsunami” (p. 41)

Tōkaidō, the “Eastern Sea Road,” connected imperial Kyoto and shogunal Edo.

One of 53 way stations.

Miho 三佛, source of an account of the 1700 tsunami (p. 76-79)

The orphan tsunami

Edo 東京, the Tokugawa shoguns’ capital. Population approaching one million in 1700 (p. 61). Became Tokyo in 1868.

“NIHON KAISAN CHÔRIKU ZU” by Ishikawa Tomonobu (p. 29), 1694 edition (Akioka, 1997, p. 214), fills a sheet nearly 1.7 m by 1.2 m. Walter (1994, p. 194) likens the geographic distortion to that in a subway map. Courtesy of East Asian Library, University of California, Berkeley. More excerpts, p. 43, 70-72.

The orphan tsunami
The orphan tsunami flooded sites along nearly 1000 kilometers of Japan’s Pacific coast.
PLACES FLOODED by the 1700 tsunami in Japan include Kuwagasaki, Tsugaruishi, Ötsuchi, Miho, and Tanabe. Some of the accounts mention damage in additional villages. In one account, the tsunami takes the form of rough seas that initiate a nautical accident near Nakaminato. The writers represent three of their society’s four main classes: the bushi, or samurai; farmers and other peasants; and merchants (p. 53).

The main accounts grace the next two pages. We parse them, from north to south, in the six chapters that follow.

<table>
<thead>
<tr>
<th>PLACE</th>
<th>OTHER SITES</th>
<th>WRITERS</th>
<th>LOSSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuwagasaki</td>
<td>p. 36-49</td>
<td>The tsunami account</td>
<td>13 houses</td>
</tr>
<tr>
<td></td>
<td>Adjoined Miyako, where Morioka-han had a district office. Nearly 300 houses</td>
<td>originated in Miyako. It was delivered inland to Morioka, where it entered administrative records of Morioka-han.</td>
<td>destroyed by flooding, 20 more by a concurrent fire</td>
</tr>
<tr>
<td>Tsugaruishi</td>
<td>p. 50-57</td>
<td>The writer describes losses along the nearby bayshore and mentions, as hearsay, the flooding and fire in Kuwagasaki.</td>
<td>Houses destroyed by flooding along bayshore near Tsugaruishi</td>
</tr>
<tr>
<td>Ötsuchi</td>
<td>p. 58-65</td>
<td>The tsunami account</td>
<td>Damaged:</td>
</tr>
<tr>
<td></td>
<td>Like Miyako, headquarters of an administrative district of Morioka-han</td>
<td>originated in Ötsuchi. A summary survived there, as do details in administrative records in Morioka. Losses were said to have been reported to Edo.</td>
<td>2 buildings</td>
</tr>
<tr>
<td></td>
<td>Transfer cargo between seagoing ships and river boats that plied inland waterways to Edo</td>
<td>officials of Ötsushi and Isahama village</td>
<td>2 buildings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Magistrates in Miyako and scribes in Morioka castle</td>
<td>paddles and fields</td>
</tr>
<tr>
<td>Nakaminato</td>
<td>p. 66-75</td>
<td>The account focuses on a shipwreck in rocks offshore of Isahama village, nearby. The cargo originated in Nakamura-han. Officials of Mito-han investigated.</td>
<td>Two sailors killed and nearly 30 tons of rice sunk in an accident caused mainly by a storm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The account remained in Miho, where it was later included in an anthology of headmen’s writings.</td>
<td>Rice paddies and wheat crops lost in Atonoura, Mera, Mikonohama, and Shinjō</td>
</tr>
<tr>
<td>Miho</td>
<td>p. 76-83</td>
<td>The boat’s crew and officials of Isahama village</td>
<td>Government storehouse flooded in Shinjō</td>
</tr>
<tr>
<td></td>
<td>Picturesque place near the Tōkaidō. Population 300</td>
<td>officials of Mito-han</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Officals of Mito-han</td>
<td></td>
</tr>
<tr>
<td>Tanabe</td>
<td>p. 84-92</td>
<td>Village headman</td>
<td>No damage reported</td>
</tr>
<tr>
<td></td>
<td>Capitol of a sector of Wakayama-han. Population no less than 2600</td>
<td>Mayor of Tanabe, also serving as district mayor of surrounding villages</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rice paddies and wheat crops lost in Atonoura, Mera, Mikonohama, and Shinjō. Government storehouse flooded in Shinjō</td>
<td></td>
</tr>
</tbody>
</table>

The orphan tsunami
Primary sources 根本史料

EACH ACCOUNT BEGINS at its upper right. The columns read from top to bottom and from right to left (headnote, p. 39). The account reappears with transliteration and translation on the pages identified in italics below the document title.

Each title is enclosed by quotation marks (『』 in Japanese). Most are names shared by other documents; “Zassho,” for instance, means “Miscellaneous records.” To make such titles unique we add, outside quotation marks, the name of the family (-ke) or daimyo domain (-han) that produced or preserved the document.
THE ORPHAN TSUNAMI

KUWAGASAKI
錫ヶ崎
Morioka-han
“Zassho” 盛岡藩
『雑書』 p. 60

TSUGARUISHI
津軽石
Moriai-ke
“Nikki kakitome chō” 盛合家
『日記書留帳』 p. 52

NAKAMINATO
那珂湊
Öuchi-ke
“Go-yōdome” 大内家
『御用留』 p. 68-69

ÖTSUCHI
大槌
Morioka-han
“Zassho” 盛岡藩
『雑書』 p. 38-39

EACH ACCOUNT BEGINS at its upper right. The columns read from top to bottom and from right to left (headnote, p. 39). The account reappears with transliteration and translation on the pages identified in italics below the document title. Each title is enclosed by quotation marks ( in Japanese). Most are names shared by other documents; “Zassho,” for instance, means “Miscellaneous records.” To make such titles unique we add, outside quotation marks, the name of the family (-ke) or daimyo domain (-han) that produced or preserved the document.
**Kuwagasaki 鍬ヶ崎**

The port of Kuwagasaki was administered from Miyako by district magistrates of a feudal domain, Morioka-han. Administrative records in a volume of Morioka-han “Zassho,” compiled by samurai in the domain’s castle, mention the 1700 tsunami in Kuwagasaki.

KUWAGASAKI had 281 houses a decade or two before 1700 (Takeuchi, 1985a, p. 321, citing Morioka-han “Zassho” for the years 1681-1691). It was then a major port for Morioka-han, as recounted by Iwamoto (1970, p. 116, 119) and implied by a shipping route on the shogunal map from 1702 (null red line, p. 33).

THE ABOVE VIEW of the village and its surroundings comes from a 1739 map of the Miyako district (p. 44). The tax office arose beside the port in 1701. Its map label reads jūhun no ichi o-yakuya (“ten-percent office”) because Morioka-han levied a ten-percent tax on non-agricultural goods (Hanley and Yamamura, 1977, p. 129; Iwamoto, 1970, p. 49).
Main points
A nighttime flood and ensuing fires destroyed one tenth of the houses in Kuwagasaki. In response, officials issued food and sought wood for emergency shelters (p. 38-39). An account of these events, probably written in 1700, calls the flood a “tsunami”—a term used in no other account of the 1700 tsunami in Japan (p. 40-41). The reported hour of the tsunami in Kuwagasaki, identical to that reported from Otsuchi, 30 km to the south, pinpoints the 1700 Cascadia earthquake to the North American evening of January 26, 1700 (p. 42-43). A regional government run by samurai produced the main account of the 1700 tsunami in Kuwagasaki (p. 44-45).

People went to high ground during the 1700 tsunami, as they did centuries later during the tsunami from Chile in 1960 (p. 46-47).

Waves of the 1700 tsunami directly destroyed 13 houses in Kuwagasaki. The damage in Japan helps define the size of the 1700 earthquake (p. 48-49).

Setting
From the nation’s capital in Edo, later renamed Tokyo, the Tokugawa shoguns and their retainers ruled Japan between 1603 and 1867, the Edo period. Under their authority, the Nambu clan controlled much of the northeast part of the nation’s main island, Honshu.

The Nambu domain, Morioka-han, included several coastal districts. One of these districts was administered from Miyako. The village of Kuwagasaki, 1 km east of Miyako, adjoined the district’s main harbor. The village contained close to 300 houses in 1700.

Other tsunamis
Tsunamis of nearby origin caused deaths in Kuwagasaki in 1611, 1896, and 1933. A lesser near-source tsunami, in 1677, swept away five houses, flooded rice paddies, and damaged salt-evaporation kilns.

Aside from the 1700 event, no tsunami of remote origin is known to have damaged Edo-period Kuwagasaki. The 1960 Chile tsunami entered 14 houses but destroyed none (p. 49).

Documents
Morioka-han “Zassho,” an administrative diary compiled in Morioka castle, contains the main account of the 1700 tsunami in Kuwagasaki. The news originated with district magistrates in Miyako. Their report reached Morioka six days after the tsunami (p. 44).

An independent report of the tsunami, dispatched from Otsuchi, reached Morioka a day later (p. 60). A merchant’s account of the 1700 tsunami in Tsugaruishi mentions, as hearsay, the house fires in Kuwagasaki (p. 52, columns 3-5).

MEASURED HEIGHTS of the 1952 and later tsunamis are from The Central Meteorological Observatory (1953, p. 20-22, 46), The Committee for Field Investigation of the Chilean Tsunami of 1960 (1961, p. 178), Unoki and Tsuchiya (1961, p. 258), and Kajiru and others (1968, p. 1370). The 1964 Alaska tsunami, not shown, crested 0.14 m above tide (map, p. 95). The graphed heights of most of the earlier tsunamis were inferred from descriptions of flooding and damage (Hatori, 1995, p. 60; Tsuji and Ueda, 1995, p. 96-97; Usami, 1996, p. 189; pages 48-49 of this report). The 1611 tsunami caused about 100 deaths in Miyako and Kuwagasaki (Hatori, 1995, p. 64; Tsuji and Ueda, 1995, p. 96). In Kuwagasaki alone, the 1896 tsunami killed 125 (Yamashita, 1997, p. 113) and the 1933 tsunami, 24 (Usami, 1996, p. 189).

THE SIMULATED WAVES are those from sea-floor deformation during a magnitude-9 earthquake at the Cascadia subduction zone (p. 98). The wave train lasts more than a day (p. 74-75), like the gauged Chilean tsunami of 1960 (p. 19). The modeled earthquake occurs about 9 p.m. local time on January 26, 1700 (p. 43). Diagram from Satake and others (2003).
TWELVE CURSIVE COLUMNS in Morioka-han “Zassho” provide an official description of the 1700 tsunami and its aftermath in Kuwagasaki. The tsunami arrived at night (column 2). Villagers fled to high ground (2-3). The water destroyed 13 houses outright (4) and set off a fire that burned 20 more (3). In response, magistrates in nearby Miyako issued rice to 159 persons (6-7) and sought wood for shelters (8-9). They kept others in the han government informed of these emergency efforts (9-12).

The columns contain symbols of Chinese origin (kanji) and a few, simpler symbols from Japanese syllabaries (kana). The writer applied these symbols with a brush. In gray we

1. go-ginmigata from, honorific go-ginmigata o-

2. suika flood and fire

3. hito people

4. wa as for, kega injury

5. nite because of, ni to, o-tasukemai relief rice

6. monodomo villagers

7. tsukamatsu- zu sôrô did not receive, kudassaretaki want to be provided,

8. o-metsuke chû officials

9. yoshi it was reported, yoshi môshi .kîari request was made.

10. sôdan sôrô consulted, made to, môshiageru petitioned.

11. Yamaya Yamaya San’emon San’emon

12. tsukamatsuri tashì to want to build, o-kuramai stipend rice

NOTES. LIKE THE COLUMNS, BEGIN AT RIGHT ON THE FACING PAGE.

The columns proceed from right to left. Matter already mentioned therefore appears “at right” (9, 11, 12). Verbs end sentences, some of which are punctuated further by “ink breaths,” where bold lines of a newly inked brush start the next sentence (clear example: これを, column 9). Nouns follow all their modifiers; prepositions follow their objects.

NOTES. Column 1, Miyako o-daikansho no uchi—In the district administered from the Miyako magistrates’ office (p. 44; office location, p. 36, 49).
1. o-daikansho—Honorific o- here and in 7-11.
2. kokonotsu-doki—Around midnight (p. 43).
3. monodomo—Commoners.
4. yamayama—More than one hill (yama).
The orphan tsunami—Kuwagasaki

The orphan tsunami—Kuwagasaki
Words for waves 「津波」を表すことば

In each primary account, the orphan tsunami has a different alias.

Sudden slip on a submarine fault initiates a typical tsunami while also setting off an earthquake (cartoon, opposite; see also p. 10, 99). Feeling no precursory earthquake (p. 54), several Japanese writers called the 1700 tsunami a high tide. Only the writer of the Kuwagasaki account uses 津波 tsunami without questioning the term.

**Tsunami** 津波

A tsunami flooded Kuwagasaki at midnight on January 27-28, 1700, according to the entry in Morioka-han “Zassho” for February 2, 1700. The writer, inland at Morioka (p. 44), was probably paraphrasing a report from coastal magistrates in Miyako. He wrote tsunami with the same pair of symbols used today: 津 tsu (harbor) and 波 nami (waves).

**High tide** 大潮

“High tide” denotes the 1700 tsunami in Tsugaruishi. The symbols mean “big” (大 dō) and “salt” or “tide” (日本の shio); in context, they connote “high tide.” The report states that the flooding was not associated with a felt earthquake.

**High waves** 浪高久

Nami takaku held a rice boat offshore Nakaminato on January 28, 1700. The waves were probably described as such by the crew; 浪高久 appears in a petition from the captain. At right, the version in a probably 18th-century copy of an accident certificate issued February 12, 1700.

**Tsunami? 徒奈三？**

The headman of Miho village puzzled over what to call the waves in 1700. He described them as “high water” (mizu takaku) and as “something like high tides” (michishio nado no yōi). He knew and used the term tsunami (which he wrote phonetically) but expressed wonder as to why no preceding earthquake was felt in his village or nearby.

**Unusual seas** あびき

A Tanabe municipal record from 1700 introduces the tsunami as あびき abiki—unusual seas from tides, storms, winds, or tsunami. The same record also calls the tsunami a “tide” (潮 shio). This shio contains a radical for morning, while the one for Ōtsuchi contains “evening”—in accord with times when the tsunami was first noticed (p. 43).
The first “tsunami”

AN OFFICIAL DIARY from 1612 contains what is probably the earliest extant example of 津波 tsunami. The writer was an aide to Tokugawa Ieyasu (1542-1616), the first of 15 shoguns to rule Japan from Edo. The document, “Sumpuki,” provides a record of Ieyasu's years at Sumpu, near Miho (p. 76), in the last decade of his life.

A tsunami spawned off northeast Honshu took thousands of lives there on December 2, 1611. Among the dead were 100 persons in Miyako, 150 in Tsugaruishi, and 800 in Ötsuchi. In height the 1611 waves rivaled those of Japan’s most disastrous tsunami, which caused 22,000 fatalities in northeast Honshu in 1896.

The tsunami entry in “Sumpuki,” written in January 1612, begins by noting a gift from Date Masamune (1566-1636), daimyo of Sendai-han. From northeast Honshu Masamune has sent hatsu tara, the season’s first cod. Aides then tell of the 1611 disaster. A so-called tsunami (yo ni tsunami to yu'u) has drowned 5,000 people in the territory of Masamune and 3,000 persons and horses (jimba) in the Nambu clan’s domain (Morioka-han) and in adjoining Tsugaru. Along with this news comes a story about a samurai who survived the tsunami by faithfully serving his daimyo:

Masamune wants fish. Two samurai receive the order. They round up fishermen. The fishermen balk because the sea has a strange color and the skies look ominous. One of the samurai insists on obeying the daimyo’s order. All set out in a boat. Soon it meets the tsunami, which drives it inland into the crown of a pine tree. The waves also sweep away entire villages along the shore. Later, after the water recedes, the men clamber down from the tree. Scanning the shore, they realize that they too would have been swept away had they not gone fishing for Masamune. The two samurai return to Masamune, who bestows a gift upon the one who had insisted on following orders.

The story, as recounted in “Sumpuki,” concludes with a moral voiced by Ieyasu: If you follow orders, you may escape disaster and receive gifts.
Converting time 時間の換算
The orphan tsunami came ashore in Japan on January 27 and 28, 1700.

TWO CALENDARS date the 1700 tsunami in Morioka-han “Zassho.” The year was the twelfth of the Genroku era—one of 35 eras in the period of Tokugawa rule from Edo. Genroku 12 was also a “Year of the Rabbit” in a 60-year zodiacal cycle of Chinese origin.

By either name, the year lasted 384 days; it contained a leap month, between the 9th and 10th month. Each month started on the new moon and lasted 29 or 30 days. The usual 12-month sum came to 354 days—eleven days short of a solar year. Therefore a leap month was inserted every few years, as happened in Genroku 12.

The 1700 tsunami came ashore on the 8th and 9th days of the 12th month of Genroku 12. This final month of Genroku 12 coincides with January and February of 1700. In the Julian calendar, the 1700 tsunami in Japan spans January 17 and 18; in the Gregorian calendar, adopted by Spain in 1582 and England in 1752, the equivalents are January 27 and 28.

**JAPANESE ERAS**

The orphan tsunami came ashore in Japan on January 27 and 28, 1700.

**YEARS ON “ZASSHO” COVER**

<table>
<thead>
<tr>
<th>Genroku era (1688-1704)</th>
<th>Edo period (1603-1867)</th>
<th>Meiji era</th>
<th>Heisei era</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.D. 1600</td>
<td>1700</td>
<td>1800</td>
<td>1900</td>
</tr>
</tbody>
</table>

**JAPANESE YEARS AND MONTHS**

Genroku 12 (leap year; 384 days)

30-day month  29-day month

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>u9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
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</tbody>
</table>

Rabbit Year waves of Genroku 12, 12th month, 8th and 9th days

<table>
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<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
</tr>
</tbody>
</table>

Uru‘u kugatsu (leap Ninth Month)

Genroku 13 (354 days)

- Winter solstice: Genroku 12.11.1 = December 21, 1699 Gregorian

**CHINESE SIXTY-YEAR CYCLE**

<table>
<thead>
<tr>
<th>JIKKAN</th>
<th>CELESTIAL STEM Element</th>
<th>JUNI-SHI EARTHY BRANCH Brother</th>
</tr>
</thead>
<tbody>
<tr>
<td>kino</td>
<td>wood</td>
<td>mouse</td>
</tr>
<tr>
<td>kinoto</td>
<td>wood</td>
<td>ushi</td>
</tr>
<tr>
<td>hino</td>
<td>fire</td>
<td>tiger</td>
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<tr>
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<td>fire</td>
<td>u</td>
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<tr>
<td>tsuchinoto</td>
<td>earth</td>
<td>fourth zodiac sign: rabbit</td>
</tr>
<tr>
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**JAPANESE MONTHS**

1699 Gregorian (365 days)

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1700 Gregorian (365 days)

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1699 Julian (365 days)

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1700 Julian (366 days)

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Morioka-han “Zassho” records the tsunami’s midnight arrival at Kuwagasaki and Otsuchi as the hour of nine on the 8th day (p. 39, columns 1 and 2):

The writer here refers to traditional Japanese timekeeping that divided a day into in two series of six parts. These “hours,” each 120 minutes on average, were counted down, starting at midnight and again at noon, from nine to four:

Because the traditional numbered day began at dawn, the 1700 tsunami’s midnight arrival in Kuwagasaki and Otsuchi refers unambiguously to the 8th day. In Tsugaruishi the flooding reportedly began on the 8th and continued to the 9th. At Nakaminato and Miho, unusual seas were first noticed on the 9th day, in the first hours after dawn. The Tanabe account says “since about dawn of the 8th day”—either near the start of the 8th day or, interpreted for agreement with the other reports, near the start of the 9th.

The 1700 tsunami probably originated in the Cascadia region of North America in response to warping of the seafloor during an earthquake (p. 94, 99). From there, crossing the Pacific Ocean at jetliner speed, the tsunami front needed about ten hours to reach northern Honshu—the arrival simulated on the front cover and on page 75.

Suppose a Cascadia earthquake therefore preceded Kuwagasaki’s midnight waves by ten hours. Also allow for a 105-degree difference in longitude (a 17-hour difference in modern time zones). Then the earthquake’s local time becomes 9 p.m. Cascadia time on Tuesday, January 26, 1700:

The timelines above show how Satake and others (1996, 2003) dated the 1700 Cascadia earthquake to about 9 p.m. of January 26. The earthquake may have occurred a few hours earlier if the midnight flooding in Kuwagasaki and Otsuchi was from large waves that lagged the tsunami front. Such a lag, between one and two hours long, appears in a simulation of the 1700 tsunami at Kuwagasaki (p. 37) and in Japanese tide-gauge records of the 1960 Chile tsunami (p. 46, 73).

Because a tsunami’s speed in the deep ocean depends solely on ocean depth, a tsunami from Cascadia should take about as much time to reach Japan as does a tsunami that follows a similar path in the reverse direction. Tsunamis from northern Honshu in 1896 and 1933 reached California in 11 hours. Similarly, tsunamis from southern Honshu in 1854 and 1946 reached California in 12-13 hours (box, p. 91; Lander and others, 1993, p. 120, 126, 130, 178).

Twelve hours or more is the likely duration of the 1700 tsunami in Japan. A single train of waves most simply explains the overlap among reported tsunami times (graph at left; p. 72-73). A long train appears in simulations of the 1700 tsunami (snapshots, p. 74-75; graph, p. 37). The 1960 tsunami excited Japanese harbors for days (p. 46, 73).

The Traditional Hour of Six coincided with the beginning of dawn and the end of dusk. Its time therefore varied with season, longitude, and latitude. Tsuji and others (1998, p. 9) reckoned that Genroku 12.12.9 dawned in Miho at 6:13 a.m. and in Tanabe ten minutes later.
Military men in a castle town documented their peacetime rule of a feudal domain.

**MORIOKA-HAN “ZASSHO”**

*MORIOKA-HAN “ZASSHO”* was kept in Morioka castle until 1874, when the castle was torn down and the “Zassho” volumes entered a storehouse of the Nambu clan. A typeset version has been prepared by Morioka-shi Kyöiku I'inkai (1986-2001). On the han’s history and administration see Mori (1972), Hosoi (1988), and Hanley and Yamamura (1977). The HEADNOTE dates to six days after the tsunami’s midnight arrival in administration see Mori (1972), Hosoi (1988), and Hanley and Yamamura (1977). The HEADNOTE dates to six days after the tsunami’s midnight arrival in administration see Mori (1972), Hosoi (1988), and Hanley and Yamamura (1977). The year Genroku 12 appears on the volume cover (p. 42); the month is introduced on an interior page.

**THE SENIOR MINISTERS**, named in full in the year’s first “Zassho” entry, were among seven karô who served Nambu Yukinobu (opposite) between 1693 and 1702 (Hoshikawa and Maezawa, 1984-1985; Yoshida and Oikawa, 1983-1992). Nakano Hiroyasu (ca. 1658-1745) served as Kichibe’e in 1690-1713. He inherited the post as an adopted son of the preceding karô Kichibe’e. Kita Yoshihisa(?!) (1670-1732) succeeded his own father as Kyûbe’e in 1696. He held that post for seven years and later returned to it, after the death of his son, for another six. Urushido Shigetada (1640-1709), born in Edo, was Jinzaemon in 1691-1700.

**“ZASSHO” EARTHQUAKES**

Morioka-han “Zassho” abounds in incidental facts. Headnotes summarize daily weather, which we use to confirm an error in the orphan tsunami’s dating (p. 52-53) and to rule out storms as the cause of flooding (p. 72). Graphed above are the yearly number of days when “Zassho” scribes noted an earthquake or earthquakes. The years 1650-1700 included 366 such earthquake days.

Official papers of Morioka-han also include large picture maps (ōezu). The one being unfolded below, from 1739, shows one of the domain’s 33 administrative districts. The maps aid in envisioning the bygone villages and fields that were flooded in 1700 (p. 36, 50, 56, 58).

**DISTRIBUTIONS OF MORIOKA-HAN**

**PICTURE MAP OF MIYAKO DISTRICT, 1739**

**MORIOKA**

- han, feudal domain
- machi, castle town
- shi, modern city

**EARTHQUAKES** recorded in Morioka-han “Zassho” were tabulated by the Ofunato City Museum in a well-attributed list of earthquakes and tsunamis in northeast Honshu (Ofunato Shintoshitsu Hakubutsukan, 1990). The graph above is compiled from pages 9-29 of that list, in the manner described by Satake (2002). The peak of 30 earthquake days in 1677 results from aftershocks of the earthquake whose tsunami washed away five houses in Kuwagasaki and flooded the main street in Ütsuchi (p. 37, 59).

The scribes of Morioka-han “Zassho” resided in Morioka-machi, a castle town zoned by class. As samurai, they probably lived nearer the castle than did artisans and merchants—commoners whose neighborhoods ringed the town. A census in 1700 identified 14,209 commoners in Morioka-machi, out of a total of 343,499 in Morioka-han.

The scribes worked in the ninomaru, an administrative center that adjoined the keep of Morioka castle. They may have trained at a military school just north of the castle grounds.

IN CASTLE TOWNS of Edo-period Japan, samurai typically resided nearest the castle (Sakudō, 1990, p. 149). The census figures come from Mori (1963, p. 641-643, 688-692); the 1736 map, from Mori-ishi Chūō Kōminkan (1998, p. 2); the 1770 map, from a visitors pamphlet for Morioka-ishi Chūō Kōminkan. Nagaoka (1986, p. 81-82) locates the school, Han go-shinmaru go-keikojo, which probably began as a military institute for the sons of high-ranking samurai.

Scribes in Morioka castle and district magistrates in Miyako served the Nambu clan. The Nambu wrested control over the region while Japan was emerging from centuries of civil war. Nambu rule then continued for more than 250 years under Tokugawa shoguns, throughout the Edo period.

This Nambu authority initially depended on Toyotomi Hideyoshi, who gained hegemony over Japan’s warlords in the 1580s and 1590s. In July 1590, Hideyoshi granted much of northeast Honshu to Nambu Nobunao on condition that he survey taxable land and subjugate its owners. Nobunao faced a farmer’s rebellion a few months later and an attempted coup the following March. Hideyoshi sent an army to his aid in August 1591.

Morioka castle, begun under Nobunao in 1598, became the domain’s headquarters in the 1630s. By then, power had passed from Hideyoshi to the Tokugawa shogunate, and Nambu retainers were attending to peace-time administration. Their successors, under the daimyo Nambu Yukinobu, documented the 1700 tsunami.

DAIMYOS

Scribers in Morioka castle and district magistrates in Miyako served the Nambu clan. The Nambu wrested control over the region while Japan was emerging from centuries of civil war. Nambu rule then continued for more than 250 years under Tokugawa shoguns, throughout the Edo period.

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Nambu family crest
A pair of cranes symbolizes the clan that controlled Morioka-han throughout the Edo period.

PORTRAITS AND CREST courtesy of Moriooka-ishi Chūō Kōminkan. Totman (1993, chap. 4) outlines pacification under Hideyoshi and Ieyasu. Han were reorganized into today’s prefectures after 1871 (Beasley, 1982, p. 126).
High ground 高台へ

In 1700, Japanese villagers used a timeless tactic for surviving tsunamis.

1700 tsunami
A curling wave chases a fleeing figure on roadside signs in Washington, Oregon, and California. In Sumatra in 2004, how many lives would such signs have saved?

In Japan in 1700, tsunami-savvy villagers fled to high ground during a tsunami that originated not far from where the North America signs stand. Going to hills probably prevented casualties at Kuwagasaki; all its villagers escaped injury despite a sea flood that destroyed 13 houses and set off a fire that burned 20 more. Miho’s headman advised the elderly and children to go to a shrine on the area’s highest ground.

1960 tsunami
As a precaution against the incoming tsunami from Chile, local police and firemen began evacuating low-lying parts of Kuwagasaki at 4:05 a.m. on May 24, 1960. This action anticipated, by an hour, a tsunami warning from the regional headquarters of the Japan Meteorological Agency, in Sendai. The local officials used tips like these, which weather observers received at JMA’s station in Kuwagasaki:

3:30....Chilean tsunami in Hawaii (source: radio news)
3:40....Surge at Norinowaki (fishermen’s association)
3:49....High water in Ōtsuchi (town officials)
3:55....High water near Kuwagasaki (local resident)

Soon after 4:13 sunrise, with the local evacuation underway, JMA observers in Kuwagasaki saw the sea withdraw. By then, they had received a further inquiry from the fishermen’s association and official calls from Miyako and Yamada. By 4:30, the sea had flooded a pier in Kuwagasaki and a wave had been reported from Tarō.

Forerunner waves prompted the 3:40 report from Norinowaki. Such advance notice of the 1960 Chile tsunami registered on 27 Japanese tide gauges. Did forerunners similarly warn of the 1700 Cascadia tsunami in Japan?

MIYAKO WEATHER STATION in 1960 stood on low ground in Kuwagasaki (map, p. 49). The station report is in Japan Meteorological Agency (JMA) (1961, p 232-233). JMA Sendai had authority to issue a warning; JMA Miyako did not.

THE MARIGRAM was recorded by the Miyako tide gauge, Kuwagasaki (JMA, 1961, p. 271; map, p. 49). There, 1960 mean sea level stood 0.1 m above a national vertical datum, TP (Tokyo Peil). Though the marigram shows the tsunami cresting 1.2 m above TP (JMA, 1961, p. 34), a high-water line 2.4 m above TP was observed on a warehouse near the gauge (p. 49). For details on forerunner waves of the 1960 tsunami, see Nakamura and Watanabe (1961); on damping of tsunamis by tide gauges, Satake and others (1988).

THE ORPHAN TSUNAMI OF 1700
1854 tsunami
Hamaguchi Gohei, a village elder, knows “all the traditions of the coast.” One autumn evening, high above the seaside village that he heads, the old man feels an earthquake “not strong enough to frighten anybody.” Soon the sea withdraws in a “monstrous ebb.” As unknowing villagers flock to the beach, Gohei torches his rice harvest—“most of his invested capital.” The villagers rush uphill to fight the fire. Their headman’s selfless ruse has saved them from a tsunami.

As “Inamura no hi” (“The rice-sheaf fire”), this story first appeared in a Japanese grade-school reader in 1937 (p. 113) and later appeared in video (p. 115-121). As “The Wave,” an American children’s book, the tale similarly became a video sent to hundreds of schools in the 1990s for tsunami education in British Columbia, Washington, Oregon, and California. As public art inscribed in stone in Seattle, a “true story” tells of “an old farmer in Japan who saved an entire village from destruction by a tidal wave.”

The story, timeless as a cautionary tale about natural tsunami warnings, originated in 1897 as “A living god” by Lafcadio Hearn. Hearn blended two 19th-century disasters: Honshu’s giant waves of 1896 (p. 41), whose parent earthquake was weak; and a tsunami evacuation a half century earlier in the southwest Honshu village of Hiro. On the night of December 24, 1854, 34-year-old Hamaguchi Goryō lit rice-straw fires in Hiro during a tsunami that shortly followed a violent earthquake of estimated magnitude 8.5. Lost that night in Hiro were 36 lives and 158 of 374 houses. Goryō himself nearly drowned.

Hamaguchi Goryō’s rice-straw fires in Hiro village beckoned villagers well-rehearsed in seeking high ground. As a precaution against tsunamis, Hiro had already evacuated twice in 1854—after earthquakes on July 9 and December 23. Goryō’s beacons on December 24, depicted below, are said to have guided nine persons to safety.

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The painting above, courtesy of Yōgen temple in Hirogawa, portrays Goryō’s fires as numerous and widely dispersed in rice paddies being covered by the tsunami of December 24, 1854. The artist, Furuta Shōemon (also known as Furuta Eisho), witnessed the tsunami in adjoining Yuasa village (Shimizu, 2003).


“Inamura no Hi” remained, until 1947, in a national reader for students 10-11 years old (p. 113). Nakai Tsunezō, a grade-school teacher, wrote this adaptation. Hodges (1964) similarly made “A living god” into “The wave.” Ellen Ziegler, with a 1987 grant from the Seattle Arts Commission, inscribed the tale on tablets fronting Jefferson Park fire station.
Tsunami size 津波の高さ

Kuwagasaki’s losses in 1700 suggest a tsunami several meters high.

WRITTEN RECORDS of flooding and damage by the 1700 tsunami imply tsunami heights in the range 2-5 m in Japan. The heights, graphed in blue below, are central to the conclusion that the Cascadia subduction zone can produce earthquakes of magnitude 9 (p. 98-99).

The height estimates vary with assumptions about the recorded damage and flooding, illustrated for Kuwagasaki in the cartoons at right. In an estimate that is probably low (A), the 1700 tsunami crested 2½ m high when it destroyed 13 houses in Kuwagasaki. The estimate increases to 3 m under moderate assumptions (B), and it reaches 4 m if it includes a generous assumption about land-level changes since 1700 (C; p. 65).

Summary of tsunami heights, 1700 and 1960

ON TSUNAMI HEIGHTS in 1700, see also pages 56-57, 64-65, 82-83, and 88-91. A and B, “low” and “medium” height estimates of Satake and others (2003); C, estimate by Tsuji and others (1998). TP, datum near sea level (p. 46, footnote).

AT THE MIYAKO GAUGE, high tide averaged 0.6 m above mean sea level for the years 1954-1959; the highest tide in 1937-1995 was 1.0 m above 1995 mean sea level (Japan Meteorological Agency, 1960, p. 402; 1996, p. 253).

WHERE THEY DESTROYED wooden Edo-period houses in Japan, tsunamis commonly ran at least 1.0-1.5 m deep (Tsuji, 1987).

Estimates of 1700 tsunami height in Kuwagasaki

REPORTED DAMAGE

13 houses

waves by

sorob were destroyed

ASSUMPTIONS

Flow depth Tsunami flowed 1.0-1.5 m deep where it destroyed houses (1.0 m assumed in A, 1.5 m in B, 1.0-1.5 m in C).

Freeboard To escape storm waves—and perhaps with the 1677 tsunami in mind (p. 37)—villagers built their houses at least 0.5 m above highest astronomical tide (0.5 m in A, 0.6 m in B).

Tide zone The highest astronomical tide in 1700 was 0.7 m above mean sea level, by analogy with modern tides in Kuwagasaki Harbor (Miyako gauge; location on facing page). Used in A and B.

Tide stage Tide stood 0.2 m below mean sea level when houses were destroyed (A, B, and C; supporting details, p. 83).

Modern ground The ground surface, surveyed in 1971-1995, was 1.4-1.9 m above TP in probable area of 1700 destruction (C).

Subsidence Relative to the sea, land at Kuwagasaki has subsided about 1 m since 1700 (C, p. 65).
**1960 tsunami**

In Japan, the 1700 tsunami probably attained about the same size as the 1960 tsunami (summary graph, opposite)—the trans-Pacific waves that began in Chile (p. 10-11, 19).

In Kuwagasaki, where the 1700 tsunami probably reached heights of 2-3 m, the 1960 tsunami crested about 2 m high. The range of 1960 heights is 1.8-2.3 m above a datum near mean sea level (map, below). This range corresponds to 1.7-2.2 m above tide because the 1960 tsunami crested when the tide was about 0.1 m above this datum (p. 46, tide-gauge record). The 1960 tsunami in Kuwagasaki wetted floors of 14 houses without destroying any buildings. In the photo at right, shallow flooding by the tsunami has littered a street with empty petroleum barrels.

**Tsunami height and earthquake size**

IN RELATING TSUNAMI DAMAGE in Japan to earthquake size at Cascadia, we assume that the height of a far-traveled tsunami increases with the size of the parent earthquake. The graphs at right show this tendency among 14 subduction-zone earthquakes of magnitude 8.1-9.5 between 1933 and 1974 (p. 98). Below, a similar trend among tide-gauged tsunamis at Crescent City, California.

**EFFECTS OF SHALLOW FLOODING IN 1960**

VIEW northward from tip of arrow on map below. At left, in a grocery, the 1960 tsunami crested about 0.3 m above a street-level floor (Atwater and others, 1999, p. 9). Photo from Japan Meteorological Agency (1961, p. 351).
Tsugaruishi 津軽石

The south end of Miyako Bay, 7 km from Kuwagasaki, flanked Edo-period villages near the mouth of a river known for its salmon. The largest village, Tsugaruishi, adjoined the river 1 km upstream from the bay.

Moriai-ke "Nikki kakitome chō," a Tsugaruishi family’s notebook for the years 1696-1703, mentions the 1700 tsunami as high water that swept away houses along the bayshore, went inland to Inarinoshita and Kubota Crossing, and reportedly caused a related fire in Kuwagasaki. "Nikki" further states that there was no accompanying earthquake.

Entries about

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<th>Heavy snow</th>
<th>Tsunami (p. 52)</th>
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<td>Both events misdated by exactly one month (p. 53)</td>
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UPPER VIEWS from the 1739 map of Miyako-dōri (unfolding, p. 44). Scale varies from place to place on the map, as does perspective shown by brown rooftops and red shrine gates (additional examples, p. 36, 56).
Main points
High water at the south end of Miyako Bay washed away houses and entered Tsugaruishi village, 1 km inland. The same event set off a fire that burned “about 21 houses” in Kuwagasaki (p. 52; compare p. 39, col. 3). The flooding happened without an earthquake (p. 54). The water went upvalley to “Kubota Crossing”—perhaps as far as did the 1960 Chile tsunami, which ran 2 km inland from the south shore of Miyako Bay. Therefore the 1700 tsunami may have attained heights like those of the 1960 tsunami—about 5 m at the bayshore (p. 56-57). The Tsugaruishi account originated with a merchant family that built a local financial empire in the 18th century (p. 53).

Setting
Tsugaruishi village, today as in 1700, occupies alluvial fans 1 km south of Miyako Bay. East of the village a farmed plain extends northward to a pine-covered beach ridge near Akamae. Pines also bordered this part of Miyako Bay in 1739 (detail, opposite; mapped also on p. 56).

Edo-period Tsugaruishi belonged to the Miyako district of Morioka-han (p. 44). In the 1680s the village contained 183 houses—about 100 fewer than Kuwagasaki.

Other tsunamis
Tsunamis from earthquakes along the coast of northeast Honshu took lives at the south end of Miyako Bay in 1611, 1896, and 1933. A lesser near-source tsunami in 1677 swept away 13 houses in Kanahama and ten houses in Akamae while damaging 70 hectares of rice paddies near Tsugaruishi.

The 1960 Chile tsunami resonated in Miyako Bay. Just 2 m high along the Pacific coast, the waves rose inside the bay and crested about 5 m high at its south end (p. 55). From there the waters ran past Norinowaki and Tsugaruishi to a limit 2 km inland (p. 56).

Documents
Earthquake researchers learned of the 1700 tsunami in Tsugaruishi through a 1983 transcription by a noted regional historian, Mori Kahei. In 1993 they quoted this transcription in the earthquake anthology “Shinshū Nihon jishin shiryō” (p. 62, 123).

In 2004 we viewed Mori’s source document in the home of the Moriai family of Tsugaruishi (home interior, p. 53). That source is a Moriai family notebook for the years 1696-1703 (opposite). Because of a copyist’s error, the notebook dates both the orphan tsunami and a subsequent snowstorm exactly one month early (p. 52-53)

THE 17TH-CENTURY STATISTICS on Tsugaruishi can be found in Iwamoto (1970, p. 11) and Takeuchi (1985a, p. 507).

THE 1960 CHILE TSUNAMI

1960 CHILE TSUNAMI

Roofs of Norinowaki, weighted against typhoons


THE 1960 PHOTO, from Japan Meteorological Agency (1961, p. 339), shows a view east-northeast from the site plotted on page 56. The Akamae pines, in which people served the 1960 tsunami, are probably similar in location to the pines shown in the picture map from 1739 (facing page).
A “DIARY MEMO NOTEBOOK” of Tsugaruishi’s Moriai family recounts flooding at the south end of Miyako Bay, relates it to a nearby fire, and notes the lack of an earthquake.

The water swept away houses along the bayshore and went as far inland as Kubota Crossing (columns 1-2). It caused panic in Tsugaruishi by reaching Inarinoshita, an area below Inari shrine (3). The related fire, in Kuwagasaki, destroyed about 21 houses according to hearsay (3-5). The account’s author probably suspected a tsunami, for he noted that no earthquake accompanied the event (4-5).

THE ORPHAN TSUNAMI OF 1700

5, migi no tōri (as at right)—Refers to material stated previously, in a column to the right (as in columns 9, 11, and 12 on p. 38).

5, nijūi-kken hodo (approximately 21 houses)—The houses that burned in Kuwagasaki (p. 39, column 3). Reported as hearsay.

Formal language—mōshi sōrō (2, 4), mairi sōrō (3), goza sōrō (3-5), tsukamatsurazu (5).

Sound change at word juncture—mura-jū for mura-chū (3), nijūi-kken for nijūichi-ken (5).

1, basho ni yori—Not fully translated. Literally, “depending on the place.”

2, ie nado—The nado (“and so on”) makes the ie plural: “houses.”

2, Norinowaki 法之崎—Village (maps, p. 51, 56). Probably includes the area of the houses in the foreground of the photo on p. 51. In transcribing Moriai-ke “Nikki kakitome chō,” Mori (1983, p. 161) read nori 法 as nori 乗, “to ride,” and he inserted a comma after this. Thus in Mori’s transcription, salt water “rode” to Kubota Crossing.

- NOTES. Column 1, jūichi-gatsu (11th month)—A mistake in copying jūnigi-gatsu (12th month). The writer repeated this mistake for a heavy snow that fell ten days after the orphan tsunami (facing page). This snowfall is securely dated in Morioka-han “Zassho” and in Hachinohe-han “Han niki.” In the latter, the heavy snow was noted independently by the metsukesho (inspection bureau) and by its kanjōsho (finance office) (Hachinohe Konomojo Benkyō-kai, 1994, p. 203).
Human error 写しまちがい

A Tsugaruishi writer miswrote the orphan tsunami’s month.

ONE LUNAR MONTH separates two reported dates for a fire that destroyed some 20 houses in Kuwagasaki during a sea flood late in the year Genroku 12. Morioka-han “Zassho” dates this unusual event to the 8th day of the 12th month (p. 39, column 1); “Nikki kakitome chō,” to the 8th and 9th days of the 11th month (p. 52, column 1; excerpt, right).

Errors in compiling “Nikki” probably explain this discrepancy and an adjoining one. The next entry in “Nikki kakitome chō” (p. 50), nominally for the 18th day of the 11th month, tells of heavy snow (right). Morioka-han “Zassho,” however, reports fair skies on that day and snow exactly one month later. Similarly in Hachinohe, snow fell not on 11/18 but heavily on 12/18 (first footnote, opposite). Miswriting the month of this storm, the “Nikki” compiler similarly misdated the orphan tsunami.

Social status 士農工商

A merchant family that chronicled the orphan tsunami later attained samurai rank.

THE FOUNDING WARRIORS of Edo-period Japan decreed a hereditary social order that ranked samurai above farmers, farmers above artisans, and nearly everyone above merchants. However, the samurai-led governments commonly ran up debts (p. 61), which some daimyo domains partly covered by selling samurai status to merchants. Thus in 1774 Morioka-han issued, to a prosperous merchant family from Tsugaruishi, a license that elevated them to samurai with the surname Moriai.

The family’s commercial ascent began in the 1680s with loans secured by land and fishing rights. Holdings grew as borrowers failed to repay. By 1776 the Moriai held timber and shipping interests in Kuwagasaki and sake breweries in Miyako and Ōtsuchi.

The family’s first samurai, Moriai Chūzaemon, reviewed records from this era of financial growth. He assembled in 1777 most of the transactions graphed at right. In that same year he annotated “Nikki kakitome chō,” a “diary memo notebook” that probably originated with his grandfather, Mitsutatsu, who headed the family between 1690 and 1730.

A MORIAI ANCESTOR. Wakasa, held property in Tsugaruishi in 1625. His descendants purchased for 410 ryō, in 1774, samurai status that included an annual stipend of 50 koku and official use of the family name Moriai. Iwamoto (1970, p. 98-130) describes this purchase and tabulates the family’s financial records; in a later book (1979) he relates additional Moriai history. One ryō (cash) would buy about 1 koku (180 liters) of dry hulled rice (p. 71).

Errors in compiling “Nikki” probably explain this discrepancy and an adjoining one. The next entry in “Nikki kakitome chō” (p. 50), nominally for the 18th day of the 11th month, tells of heavy snow (right). Morioka-han “Zassho,” however, reports fair skies on that day and snow exactly one month later. Similarly in Hachinohe, snow fell not on 11/18 but heavily on 12/18 (first footnote, opposite). Miswriting the month of this storm, the “Nikki” compiler similarly misdated the orphan tsunami.

A Moriai ancestor owns property in Tsugaruishi, 1625

Family buys 50-koku samurai license

A Moriai ancestor owns property in Tsugaruishi, 1625

Family buys 50-koku samurai license

Moriai Mitsunori headed the main branch of the Moriai family in 2004. His ancestors tracked their gains in lands and fishing rights, below.

EIGHTEENTH-CENTURY ENTREPRENEURS paid cash to Morioka-han for “samurai status and often the rights to conduct their commerce on a restrictive basis.” In 1783 “the domain issued a ‘price list’ for the various ranks of samurai status and privileges... [T]he right to wear swords and use a surname was 50 ryō; a promotion...to a bona-fide samurai was considerably more expensive at 620 ryō” (Hanley and Yamamura, 1977, p. 140).
Foreign waves 外国からの津波
Occasionally, a tsunami that damages Japan comes from afar.

NO EARTHQUAKE WARNED of the 1700 tsunami in Japan. No account mentions associated shaking, and two accounts note the lack of seismic warning (right).

Such orphan waves intrigued Ninomiya Saburo of the weather station in Miyako (p. 46). Soon after the 1960 Chile tsunami he matched three Edo-period tsunamis with South American earthquakes—from 1687, 1730, and 1751. Ninomiya found no parent for the 1700 tsunami. It would remain an orphan until the 1990s (p. 93-94).

Foreign tsunamis in Japan

Earliest domestic tsunami in Japanese written history, November 26, 684 (Julian calendar)

<table>
<thead>
<tr>
<th>YEAR A.D.</th>
<th>Wave trains of unknown, probably distant source, in both cases recorded near Nakaminato</th>
<th>Tsunamis linked to distant earthquakes</th>
</tr>
</thead>
<tbody>
<tr>
<td>799</td>
<td></td>
<td>1500</td>
</tr>
<tr>
<td>1420</td>
<td></td>
<td>1600</td>
</tr>
<tr>
<td>500</td>
<td></td>
<td>1700</td>
</tr>
<tr>
<td>1000</td>
<td></td>
<td>1751</td>
</tr>
<tr>
<td>1500</td>
<td></td>
<td>1837</td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td>1877</td>
</tr>
<tr>
<td></td>
<td>Early period (1603-1867)</td>
<td>1922, 1960</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1952, 1964</td>
</tr>
</tbody>
</table>

1586 Peru | Known in Japan from southern Sanriku coast only.                                                                                             |
1687 Peru | At least 12 waves as much as 0.5 m high in Shigama. Also known from Ryūkyū Islands (location map, lower left). |
1700 Cascadia | Reported from sites along 900 km of Honshu coast. Included at least seven waves and spanned parts of two days. |
1730 Chile | Flooded fields in Rikuzen and on Oshika Peninsula.                                                                                           |
1751 Chile | In Otsuchi, contained seven waves and flooded house floors. In Shinjō, flooded rice fields during part of a morning.                          |
1837 Chile | Damaged rice paddies and salt works along coast between Ōfunato and Sendai (map, p. 81). Unreported from other parts of Japan but crested as high as 6 m in Hilo, Hawaii. |
1952 Kamchatka | Spawned by third-largest earthquake of the 20th century (M 8.8-9.0; size graphed, p. 98). Crested 1-3 m high in northern Honshu. Did not exceed 1.0 m on tide gauges (map, p. 95); however, the Miyako gauge apparently damped the 1960 Chile tsunami (footnote, p. 46). |
1964 Alaska | From the second-largest earthquake of 20th century (M 9.2). Maximum tide-gauged height in Japan 75 cm, at Ōfunato (p. 95). Tsunami small in Japan relative to earthquake size because its waves went mainly southeastward (arrow, map at far left). |

Quotes at top from pages 52 and 78.


Japan’s 684 tsunamis, according to the ancient chronicle “Nihonshoki” (or “Nihonshoki”), was “an overflowing rush of sea-water” that sank “many of the ships used for conveying tribute” (Aston, 1972, p. 366).
Few of Japan’s foreign tsunamis rival the 1700 event. In its documented Asian extent, it exceeds all other foreign tsunamis before 1868 with the exception of the South American waves of 1687 and 1751.

Japan’s most ruinous foreign tsunami originated with the largest earthquake ever measured—the 1960 Chile shock of magnitude 9.5 (p. 10-11). The waves took nearly 24 hours to reach Japan. The largest waves arrived a few hours after high tide in northern Honshu and at high tide to the south (p. 46, 83). They widely reached heights of 2-4 m and, where amplified in bays, locally crested at 5-6 m (map below). The waves caused 52 fatalities in Ōfunato (above and p. 81) and 71 deaths elsewhere in northeast Honshu. None of these losses occurred in areas of documented flooding in 1700.

**1960 Chile tsunami**

1960 tsunami (p. 56) 0 5 km

**HEIGHT OF 1960 TSUNAMI IN HONSHU AND SHIKOKU**

- 5-6 m
- 4-5
- 3-4
- 2-3
- 1-2
- 0-1

**RECORDED SITE OF 1700 TSUNAMI**

Kuwagasaki
Tsugaruishi
Ōtsuchi
Ōfunato

**INCREASE IN 1960 TSUNAMI HEIGHT IN MIYAKO BAY BETWEEN KUWAGASAKI AND TSUGARUISHI**

IN POST-TSUNAMI SURVEYS, Japanese teams made hundreds of height measurements of the 1960 Chile tsunami. Most were compiled in books by the Japan Meteorological Agency (1961) and by The Committee for Field Investigation of the Chilean Tsunami of 1960 (1961)—sources for the overview map at left and most details above. The height estimate for Tsugaruishi is based on tsunami limits identified by eyewitnesses interviewed in 1999 (p. 56-57).
**Tsunami size 津波の高さ**

The 1700 tsunami probably grew to heights of five meters in Miyako Bay.

**EVIDENCE FROM "NIKKI KAKITOME CHÔ"**

AS IT SWEPT AWAY HOUSES between Kanahama and Akamae, the 1700 tsunami rose more than 2 m above the ambient tide (estimate A). Its reported limits at Kubota Crossing and Inarinoshita imply greater heights (B and C), especially by analogy with the 1960 Chile tsunami. The 1960 tsunami went 2 km up the Tsugarushi River (map below), entered Tsugarushi village (photo in C, opposite). Because the 1700 tsunami probably did likewise (quotes at left), it probably attained heights like those in 1960—about 5 m along the bay shore (B).

**SETTING OF THE 1700 TSUNAMI, AND OBSERVED LIMITS AND HEIGHTS OF THE 1960 TSUNAMI**

![Map of Miyako Bay and Tsugarushi River](image)


BASE MAPS from Kokudo Chiriin (Geographical Survey Institute), Miyako and Tsugarushi 1:25,000, 1996, and Rikuchu Sokuryôbu, Miyako 1:50,000, 1916.
The 1700 tsunami probably grew to heights of five meters in Miyako Bay.

ASSUMPTIONS
Flow depth  Tsunami crested 1 m deep where it destroyed houses.
Freeboard  To avoid flooding during storm tides—and perhaps with the 1677 tsunami in recent memory (p. 51)—villagers sited their houses no less than 0.5 m above highest astronomical tide.
Tide zone  The highest astronomical tide in 1700 was 0.7 m above mean sea level, by analogy with modern tides recorded in Kuwagasaki Harbor (footnote, p. 48).
Tide stage  No correction attempted because “Nikki” gives dates of flooding but not its time.

B  More realistic height inferred from inundation to Kubota Crossing

ASSUMPTIONS
Kubota Crossing  Denotes a ferry where the area’s main Edo-period road intersected the Tsugaruishi River. Two such crossings appear on the picture map from 1739 (far left). The one nearer Miyako Bay coincides with the 1960 tsunami’s upriver limit, as judged from points shared with later maps (linked, facing page). “Kubota Hill” is the local name for high ground that overlooks this area, 2 km inland from the bay.
1960 analogy  If the 1700 and 1960 tsunamis had similar inland limits, they probably reached similar heights at the south shore of Miyako Bay. On that shore the 1960 tsunami crested at 4.5-5.5 m.
Inland decline  Both tsunamis probably decreased inland in maximum height. The 1960 maximum probably descended from 5.5 m at the bay to 3.5 m at Inarinoshita, where the water crested about 1.5 m deep on land 2 m above TP (likely site shown in photo below). Relative to TP, the 1960 maximum also descended landward at Ōtsuchi and Shinjō (p. 65, 89).

C  Height inferred from inundation to Inarinoshita, adjusted for tectonic subsidence

ASSUMPTIONS
Modern ground  Inarinoshita, now Inarigashita, refers to the area at right. (This area lies below, shita, a hill between Tsugaruishi and Norinowaki on which a shrine to Inari, a Shinto god, has stood since 1635 or earlier.) Flat ground in the photo is 2.0 m above TP.
Subsidence  Relative to the sea, about 1 m since 1700 (see p. 65)
Tide stage  0.2 m below 1700 mean sea level (p. 83)

Height C from Tsuji and others (1998). Tsugaruishi fishermen went to “Inari Hill” in 1635 for divination of the year’s catch (Iwamoto, 1970, p. 21). Morai Miya, interviewed in 1999 (p. 107), identified a 1960 high-water line near the site at right, for which a modern municipal map gives a height of 2 m TP.

The 1700 tsunami probably flooded the site of the Tsugaruishi neighborhood now known as Inarigashita. Here, the 1960 tsunami flowed about 1.5 m deep and destroyed a house.
In Ötsuchi, the district magistrates' office. To the southwest, smoke rises from kilns. On a tax map probably made in 1730, Ötsuchi's houses line a road between bayside paddies and the district magistrates' office. To the southwest, smoke rises from kilns.

Ötsuchi magistrates stationed here, in a government office building (ô-yakuya 郡役屋), sent a report on the 1700 tsunami to Morioka castle. A later Ötsuchi magistrate prepared a summary from which a Japanese earthquake historian would learn of the 1700 tsunami by 1943 (p. 62).

The kilns may mark the area of salt evaporators reportedly damaged by the 1700 tsunami. Notes below kilns identify recipients of rice-tax revenues.

Ötsuchi's main street probably escaped flooding by the 1700 tsunami and also by the 1960 tsunami. Lining the street were neighborhoods named for their market days. The 1677 tsunami, of nearby source, entered 20 houses in the eighth-day neighborhood, Yôkamachi.

The 1700 tsunami killed no person or horse in Ötsuchi, and also by the 1960 tsunami. Lining the Ötsuchi district of Morioka-han. Houses flanked both sides of the street. In a side valley stood Ötsuchi stretched along a road between two river mouths.

THE PICTURE MAP, conserved at Morioka-shi Chûö Kôminkan (p. 44), is probably tied to tax records from about 1730, according to Konishi Hiroaki, the Kôminkan documents librarian (interviewed 1999). Text beside kilns describes division of 74 koku (about 13,000 liters) of rice among Morioka-han (21 koku) and three samurai (17, 6, and 29 koku). In the fourth-day neighborhood (四日町 Yôkamachi), market days ended in four (4th day, 14th day, 24th day); likewise in the eighth-day neighborhood (八日町 Yôkamachi), markets were open on the 8th, 18th, and 28th.

Main points
The sea invaded Ōtsuchi the same date and hour as it did 30 km to the north, in Kuwagasaki (p. 43, 72). The flooding damaged paddies, two houses, and two salt-evaporation kilns (p. 60). This damage, though small, was reported to Edo, perhaps to help justify financial relief from the Tokugawa shogunate (p. 61). An earthquake historian included this flooding in an earthquake catalog issued in 1943 (p. 62).
The flooding in 1700 probably stopped short of Ōtsuchi’s main Edo-period street. The 1751 Chile tsunami reportedly crossed this street, but the 1960 Chile tsunami did not (p. 64).
Because of puzzling regional subsidence, places covered by the 1700 tsunami in Ōtsuchi may now stand a meter lower, relative to the sea, than they did in 1700 (p. 65).

Setting
Nestled between hills and bayside paddies, Edo-period Ōtsuchi stretched along a road between two river mouths. Houses flanked both sides of the street. In a side valley stood the office of a magistrate, or magistrates, who administered the Ōtsuchi district of Morioka-han.

Documents
Morioka-han “Zassho” provides the main account of the 1700 tsunami in Ōtsuchi. Like the entry about the tsunami in Kuwagasaki (p. 36), it is based on a report from coastal magistrates (p. 44). The report from Ōtsuchi probably reached Morioka castle the day after the report on Kuwagasaki arrived from Miyako (p. 60).

The 1700 tsunami killed no person or horse in Ōtsuchi, according to “Ōtsuchi kokon daidenki,” a chronological record of the Ōtsuchi magistrates’ office. A secondary source, “Daidenki” contains material from 1596 to 1796 that was compiled and edited in Ōtsuchi by Ogawa Magobei Yoshiyasu (1735-1820). The oldest surviving version was copied from Ogawa’s compilation. The compiler or the copyist wrote the 1700 tsunami’s month and hour but neglected its day. Before earthquake historians found the “Zassho” account, this omission in “Daidenki” obscured the link between the 1700 tsunami in Ōtsuchi and the flooding of similar character in Tanabe (p. 62).

Other tsunamis
Tsunamis generated off northeast Honshu devastated Ōtsuchi in 1611, 1896, and 1933. Deaths from the 1611 waves totaled about 800 in Ōtsuchi and vicinity. In the town of Ōtsuchi alone, the 1896 and 1933 tsunamis took 600 and 61 lives, respectively. An inscription on the back of a memorial stone, above, further states that the town lost more than 600 houses to each of these latter tsunamis.

Lesser near-source tsunamis reached heights of several meters in Ōtsuchi in 1677, 1793, 1856, and 1968. The 1677 tsunami covered the floor in 20 of 60 houses in the Yōkamachi neighborhood along the town’s main street.

Among tsunamis of remote origin, 1751 Chile may have reached the farthest into Ōtsuchi. It entered both the Yokamachi and Yōkamachi neighborhoods, flooding a dozen houses. The 1960 Chile tsunami approached 4 m in height along the bayshore south of town. Its crest descended onshore to the tsunami’s limit near the 2 m topographic contour, seaward of the main Edo-period street (p. 64-65).

NOTABLE TSUNAMIS IN ŌTSUCHI SINCE 1600

TSUNAMI MEMORIAL mapped on page 65.
HIGH WATER came to the small port of Ötsuchi at a time equivalent to midnight (column 1; clock, p. 43). Damaged were rice paddies and vegetable fields seaward of Ötsuchi’s main street (2). In addition, the Ötsuchi magistrate’s office learned of damage to two houses and two salt kilns (2-3). All this news was forwarded to Edo (4).

Ötsuchi magistrates (to the daikan). In hason tsukamatsuri sōro yoshi, the magistrates offer the news to their own superiors in Morioka (to the karō Kichibe’e, Kyūbe’e, and Jinzaemon, p. 44).

3. migi—Mentioned in a previous column, at right.
4. Edo e mōshiage sōro—Officials in Morioka forwarded the news to the domain’s officials in Edo. See facing page.

4. e—Pronounced and written as e, signifies “to.” Sound change at word juncture—doki for toki (1), dōri for tōri (2), gama for kama (3).

COLUMNS 1 and 3-4, Minami Hei—Mutsu province (labeled, p. 32), contained 54 counties, or gun (Suruga province contained seven, p. 31). Morioka-han administered Hei-gun as two districts, Miyako-dōri in the north and Ötsuchi-dōri in the south (map, p. 44) on February 2, 1700 (p. 40, 42). The Ötsuchi report came a day later, as dated by its headnote, above. Neither report took more than seven days to reach Morioka.

NOTES. Columns 1 and 3-4, Minami Hei—Mutsu province (labeled, p. 32), contained 54 counties, or gun (Suruga province contained seven, p. 31). Morioka-han administered Hei-gun as two districts, Miyako-dōri in the north and Ötsuchi-dōri in the south (map, p. 44).

1. ura—Small port; unlike Miyako, lacks shipping route on shogunal map from 1702 (red line, p. 33).
2. ōshio—Parsed on page 40.
3. mōshiage—Probably refers to the neighborhoods yōka-machi and yokka-machi (p. 58).
SEVERAL REPORTS of the 1700 tsunami make their immediate purpose clear. Magistrates justify an allocation of rice and a request for wood in Kuwagasaki. Other magistrates certify the sinking of 28 tons of rice off Nakaminato. A headman wonders about stealth waves in Mihi. A mayor in Tanabe expresses concern about the flooding of a nearby storehouse that belongs to a branch of Japan’s ruling Tokugawa family.

Left unstated, in column 4 at left, is why samurai in Morioka castle forwarded to Edo—the shogun’s bustling capital—details on small losses from a natural disturbance to a remote shore. We speculate that officials of Morioka-han kept track of natural disasters in hopes of financial relief from the Tokugawa shogunate.

Morioka-han spent heavily to comply with Tokugawa edicts. Through most of the Edo period, the shogunate required daimyo—some 260 land barons, including the distant Nambu governor of Morioka-han—to reside alternate years in Edo. This required residence consumed over half the tax income of Morioka-han. The Nambu governor would journey between Morioka and Edo, 546 km by road, with a showy entourage of some 250 persons and 100 horses. While in Edo, he would reside in a mansion near the shogun’s castle (map, lower right).

The shogunate allowed Morioka-han to cancel this journey after poor harvests in 1695. Reportedly starving that year were 34,000 people—ten percent of the domain’s population. The domain’s next famine, in progress at the time of the 1700 tsunami, resulted from frost and rain during the 1699 growing season. The domain’s records state that 27,186 people suffered from hunger that year. Such circumstances may have spurred domain officials to document natural disasters as minor as the 1700 tsunami in Ötsuchi.
Modern recognition of the 1700 tsunami in Japan began with a teacher’s mimeographed anthology of historical earthquakes.

MUSHA KINKICHI (1891-1962), an educator and geographer, collected accounts of historical earthquakes on behalf of the Earthquake Research Institute in Tokyo. He began this work in 1928 and continued it into the 1940s.

Because his mandate included events possibly related to earthquakes, Musha noted reports of high water at Ôtsuchi and Tanabe from the year 1700. Musha summarized them side-by-side in a collection brought out first as a wartime mimeograph and printed later as one of the green hardbound volumes at right.


The Musha and “Shinshū shiryō” anthologies together identify 45,698 Japanese earthquakes from the years A.D. 416 to 1872. Most date from the Edo period (1603-1867), when record-keeping first flourished outside the nation’s capitals (graphs, facing page). Coincidence with the Edo period thus helped the 1700 tsunami enter written history.

DURING THE FIREBOMBING of Tokyo in 1945, the manuscript for Musha’s 1949 volume awaited war’s end in a galvanized box 3 m underground. Musha worked for the military geology branch of the U.S. occupation forces from 1949 to 1960. His collection of earthquake accounts built on previous work, much of it by Tayama Minoru, who issued a two-volume anthology in 1904 (Usami, 1979a, b). USAMI (1996) summarizes descriptions of more than 300 earthquakes that struck Japan between 416 and 1872. A parallel summary for tsunamis was compiled by Watanabe (1998). Tsuji and others (1998, p. 2-4) trace the origins of accounts of the 1700 tsunami.

A PREFECTURAL FISHERIES ASSOCIATION published the Nakaminato account in a volume edited by Ôuchi (1943).

THE COLUMNS OF JAPANESE TEXT above are excerpted from Mombushō Shinsai Yobō Hyōgikai (1943, p. 23; see also page 112). The photo of Musha Kinkichi, undated, was provided by his family through Matsuo'ura Ritsuko.
THE CULTURAL PEAK of the Edo period is known as Genroku 元禄, the era name for 1688-1704 (p. 42). The Genroku society that kept prodigious records also produced literary innovations, popular titles, and scholarly tomes.

Genroku innovations include haiku—poems of seventeen syllables in three unrhymed lines. These were refined and popularized by Matsuo Bashō (1644-1694). In a posthumous collection he tells how to focus verse so brief: “You should put into words the light in which you see something before it vanishes from your mind.”

Bashō’s contemporary, Ihara Saikaku (1642-1693), introduced realistic description of the lives of urban merchants and samurai. His novels and collections of short stories include “The life of an amorous man” (1682), “Five amorous women” (1686), “The great mirror of love between men” (1687), “The Japanese family storehouse” (1688), and “Reckonings that carry men through the world” (1692).

The playwright Chikamatsu Monzaemon (1653-1725) popularized puppet theater and wrote dance dramas (kabuki) as well. Some of his works treat turmoil in the houses of land barons; others, beginning in 1703, tell of lovers driven to suicide by social obligation and financial difficulty.

Genroku publishers issued thousands of commercial books. A book-dealers’ catalog from 1696, in 674 pages, listed 7,800 titles. The books in print included how-to manuals for home use by the young. “Onna chōhōki” (1692) instructed young women; “Otoko chōhōki” (1693), for young men, provided lessons on calligraphy, Chinese and Japanese poetry, tea ceremony, and letter writing. “Shōbai ōrai” (“Merchants’ manual,” ca. 1694) exhorted merchants’ children to practice writing and arithmetic “from infancy.” “Nōgyō zensho” (“Encyclopedia of farming,” 1697) advised peasants to “lay up stores of money and grain” as precautions against “the very great risk of dying of starvation in bad years.”


The shogun throughout the Genroku era, Tokugawa Tsunayoshi (1646-1709), was more scholar than soldier. He is said to have lectured on the “Yiching,” an ancient Chinese book of wisdom and divination, no fewer than 240 times between 1693 and 1700.

“Honchō tsuban” (“General history of our State”), completed by 1680, filled 310 volumes. Attributed to the founder of a competing historical project, “Dai-Nihon shi” (“The history of greater Japan”): “In writing one must be true to fact, and the facts must be presented as exhaustively as possible. An excess of detail is preferable to excessive brevity.”

The 1700 tsunami crested several meters high at the edge of Ötsuchi Bay.

### 1700 tsunami

**EVIDENCE, HEIGHTS A AND B**

<table>
<thead>
<tr>
<th>ryōshi no fishermen's</th>
</tr>
</thead>
<tbody>
<tr>
<td>tokoro place</td>
</tr>
<tr>
<td>ni-ken two houses</td>
</tr>
<tr>
<td>shiogama salt kilns</td>
</tr>
<tr>
<td>ni-kō two sets</td>
</tr>
<tr>
<td>hason damaged</td>
</tr>
<tr>
<td>sonsu were damaged</td>
</tr>
</tbody>
</table>

**INFERRED HEIGHT OF TSUNAMI AT BAY SHORE, IN METERS**

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**EVIDENCE, HEIGHTS B AND C**

<table>
<thead>
<tr>
<th>machiya commercial district</th>
</tr>
</thead>
<tbody>
<tr>
<td>uradōri back street,</td>
</tr>
<tr>
<td>tahata paddies and fields</td>
</tr>
</tbody>
</table>

WHILE DAMAGING BUILDINGS AND KILNS near the bay shore in front of Ötsuchi or nearby, the 1700 tsunami approached or exceeded 2 m above tide (A).

Maximum tsunami heights of 3-4 m are likely if, like the 1960 Chile tsunami, the 1700 tsunami descended inland to a limit near Ötsuchi’s Edo-period street (first option in B). The 1960 tsunami crested 3.6-4.0 m at the bay shore but stopped short of the 2-m contour a few hundreds meters inland (top map, facing page). Independently, maximum tsunami heights of 3-4 m in 1700 can be estimated by assuming that Ötsuchi has subsided 1-2 m since 1700 (C and second option in B).

The 1700 tsunami probably crested lower in Ötsuchi than did the 1677 and 1751 tsunamis, for these flooded houses along the town’s main street (p. 59). Unlike estimate B, the published height for the 1677 tsunami in Ötsuchi (2.8 m) lacks correction for an onshore decrease in tsunami height; and unlike estimate C, it neglects land subsidence since 1677.

Land-level changes since 1700

THE DESCENDING PACIFIC PLATE dragged land downward along the Japan Trench through the last half of the 20th century. If such subsidence persisted through the last 300 years, northern sites flooded by the 1700 tsunami stood 1.0-1.5 m higher than now—as assumed in the C estimates on pages 48, 57, and 64. The assumption is doubtful because (1) 20th-century sea-level rise explains part of the apparent subsidence, (2) stability prevailed at Ayukawa early in the 20th century, and (3) long-term uplift has raised the region’s coast in the past 125,000 years.

The coast farther south has a history of cyclic land-level changes related to historical subduction earthquakes on the Nankai Trough (p. 91).

TIDE-GAUGED TRENDS, LAND LEVEL RELATIVE TO THE SEA

- Hachinohe
- Miyako
- Kamaishi
- Ofunato
- Shimizu
- Wakayama
- Shirahama

- 0.5 m relative subsidence
- Ayukawa
- 1900
- Yearly mean level
- Record complete
- Record incomplete
- Mean subsidence rate (mm/yr)
- 4.8

SUBDUCTION ZONES

- Inland limit of 1960 tsunami
- Estimates differ between sources “a” and “b”
- a
- b

Height of 1960 tsunami
- 3.9 a
- 2.8 b

Topography mapped in 1975
- 2-m contour
- Elevation 1.2 m in former rice paddy

All heights in meters above TP, a datum near mean sea level

- a, Omote and Komaki (1961); b, Ötsuchi-chō Kyōiku Ginkai (1961)
- Base map from Kokudo Chiri’in (Geographical Survey Institute), Ötsuchi 1:25,000 quadrangle, 1996. Contour interval 10 m.

The orphan tsunami—Ötsuchi

The descending Pacific plate dragged land downward along the Japan Trench through the last half of the 20th century. If such subsidence persisted through the last 300 years, northern sites flooded by the 1700 tsunami stood 1.0-1.5 m higher than now—as assumed in the C estimates on pages 48, 57, and 64. The assumption is doubtful because (1) 20th-century sea-level rise explains part of the apparent subsidence, (2) stability prevailed at Ayukawa early in the 20th century, and (3) long-term uplift has raised the region’s coast in the past 125,000 years.

The coast farther south has a history of cyclic land-level changes related to historical subduction earthquakes on the Nankai Trough (p. 91).

TIDE-GAUGED TRENDS, LAND LEVEL RELATIVE TO THE SEA

- Hachinohe
- Miyako
- Kamaishi
- Ofunato
- Shimizu
- Wakayama
- Shirahama

- 0.5 m relative subsidence
- Ayukawa
- 1900
- Yearly mean level
- Record complete
- Record incomplete
- Mean subsidence rate (mm/yr)
- 4.8

SUBDUCTION ZONES

- Inland limit of 1960 tsunami
- Estimates differ between sources “a” and “b”
- a
- b

Height of 1960 tsunami
- 3.9 a
- 2.8 b

Topography mapped in 1975
- 2-m contour
- Elevation 1.2 m in former rice paddy

All heights in meters above TP, a datum near mean sea level

- a, Omote and Komaki (1961); b, Ötsuchi-chō Kyōiku Ginkai (1961)
- Base map from Kokudo Chiri’in (Geographical Survey Institute), Ötsuchi 1:25,000 quadrangle, 1996. Contour interval 10 m.

The orphan tsunami—Ötsuchi
At Nakaminato, pictured above in 1842, seagoing boats unloaded Edo-bound cargo that continued to the shogun's capital on inland waterways.

Ouchi-ke “Go-yōdome,” a family’s collection of documents on shipwrecks, describes the loss of 28 metric tons of rice from a boat that drifted into rocks at Isohama on January 28, 1700. In 2004 a local historian, Satō Tsugio, compared two writings of the boat captain’s name. Ouchi Yoshikuni (left) represented the family.

THE PICTURE MAP of Nakaminato, above, was made by Watari Kizaemon in Tenpo 13 (1842) and published in Ansei 4 (1857). Map courtesy of the city office of Hitachinaka, Ibaraki Prefecture.

Ouchi-ke “Go-yōdome,” a single volume of 1,390 pages, contains writing from many hands. One hand, probably no earlier than 1735, compiled all the material on wrecks between 1700 and 1735, according to Satō Tsugio, an authority on Mito-han documents. The volume’s entire contents, along with reports on 14 other Edo-period shipwrecks, have been printed by Nakaminato Shishi Hensan I’inkai (1993). In this modern volume the 1700 wreck is number 55, pages 81-83.

THE MAPS OPPOSITE are derived from modern sources. The middle map is from Kawana (1984, p. 6, 20) and Kaizuka and others (2000, p. 21). The lowest map is from 1:25,000-scale maps by Kokudo Chiri’in (“Hitachinaka” 1999; “Isohama” 2001) except for the former entrance to Naka River, which is from a 1:200,000-scale map by Rikuchi Sokuryōbu, 1885 (Meiji 18).

THE RICE BOAT went aground at “Hakoiso” (p. 69, column 6). The place name denotes the shore south of the Naka River mouth on a map from 1845 (Tempō 15). The rocks in the photo at right include a group called “Hakoiso” on a fishers’ sketch map from Ōrai in 2004.
Main points
High waves on the morning of January 28, 1700, prevented a boat from entering the river-mouth port of Nakaminato. A storm that evening drove the boat to a rocky shore near Isohama village (map, lower right). Lost were all the boat’s cargo—28 metric tons of rice—and two of the crew (p. 68-69, 71).

Officials of Mito-han certified the losses in response to a petition (p. 70). The certificate and petition were copied into a family’s collection of documents about Edo-period wrecks near Nakaminato (opposite).

The morning high waves probably represent ordinary ocean swells that were opposed at the river mouth by the ebb currents of a long-lasting tsunami (p. 72-75).

Setting
The river mouth at Nakaminato afforded access to inland waterways that conveyed cargo to metropolitan Edo (p. 31, 61). The waterways followed valleys that the sea covered 6,000 years ago. A prehistoric people, the Jomon, fringed this former sea with piles of clam shells (dots, right).

To reach Nakaminato, Edo-period sailors threaded a rocky constriction north of a sand spit (lower map at right, picture map at left). Additional rocks awaited boats that drifted south toward Isohama, a name that means “rocky beach” (photo below).

Nakaminato served as the main port in Mito-han. The rice boat came from another domain, Nakamura-han (upper map). The lost rice belonged to the Nakamura daimyo. Villagers from Isohama towed the wreck for salvage but failed to recover any of the rice.

Documents
The boat captain, two local villagers, and two other men petitioned local officials to certify the accident. The petition and the resulting certificate make up “Ura shōmon no koto” (ura, port; shōmon, certificate; p. 70-71). A headnote states that 470 bails of rice were lost. Next, a narrative explains the loss in the words of headmen from Isohama village. The certificate concludes with a signed statement by representatives of the senior ministers of Mito-han.

The earliest extant copy appears in a family volume, Ōuchi-ke “Go-yōdome” (go-yō, official business; tome, records). The volume (opposite) contains documents on 131 shipwrecks near Nakaminato between 1670 and 1832.

Rocks break fair-weather surf near former Isohama.
A BOAT LADEN WITH RICE—470 bales belonging to the daimyo of Nakamura-han—approached the Mito-han port of Nakaminato around 8 a.m. (columns 1-2). High waves held the boat offshore, where the crew cast anchor (3). Still offshore that evening, the crew bailed half the rice during an evening storm (4-5). But the storm broke the anchor lines and drove the boat to a rocky shore near Isohama village (5-6). Two of the crew perished (7).

Afterwards, villagers from Isohama and Nakaminato collected and returned, to surviving crew, articles that had

Subject marker wa written as ha (1, 6); object marker o as wo (7).

Sound change at word juncture: dóryō for tōryō (1), doki for toki (2), gaikari for kakari (3).


Honorific language: o-in terms for rice (1, 6, 13), and government offices and titles (11, 12); on-in on-kōri (11), on-ide (12), and on-idaishi (13); go-in go-dōryō (1). Formal sóró (3, 5, 7, 8, 9, 10, 11, 13, 14), mōsu (6). Humble tsukamatsuri (3, 9, 10).

6, Hakoiso—hako, box; iso, rock (note, p. 66; photo, p. 67).

7, yoshi...motte—Reported by the captain, Kambē’e, through the Isohama villager, Gon’emon.

Kambē’e is also the likely source of the second-hand information marked by yoshi in column 5.
washed ashore (8-9). Officials of Mito-han, from a district magistrate’s office, oversaw a fruitless attempt to find the rice bales (11-14) and certified the accident (14).

The full document, reproduced on the next two pages, contains this narrative as part of a certificate issued to two samurai of unstated affiliation. The narrative’s authors, all from Isohama, were a pair of boat headmen, Hei’emon and Rokuzu’emon; the village headman, Sakubei; and two village assistant headmen, Heisaku and Jiza’emon.

2, toryō Nakanominato—Mito-han’s Nakanominato. 4-5, お-nami...uchini—The crew jettisoned cargo in hopes of saving the ship. 5, tōson chinoi—The boat drifted to the area of Isohama, home of the narrative’s authors and of two of the certificate’s petitioners, Kichirōemon and Gon’emon (p. 70).

1, tsumitate—The rice was loaded onto a boat. 1-2, saru nanuka ni—On the most recent 7th day before the headnote date (24th day, 12th month, Genroku 12; p. 70). Similarly, ど kokonuka in column 2 means the most recent 9th day. 2 and 4, itsutsudoki—About 8 o’clock in the morning (column 2) or evening (4); see page 46.

NOTES. Column 1, migi...o-kome—The rice mentioned previously; itemized, p. 71.
1. Sōma Danjō sama—Sōma Masatane served as 5th daimyo of Nakamura-han in 1679-1702.
1. go-doryō Ukedo-hama—Ukedo-hama (literally, Ukedo Beach) was the southernmost of four ports in Nakamura-han (Satō, 1988, p. 167).
Like a police report on a car crash, a harbor certificate verified the shipwreck. OBLIGATIONS AWAITED the captain who lost cargo at sea while bound for the Morioka-han port of Kuwagasaki. On arrival he was to inform port officials of the loss. He would then petition them for a port certificate, *ura shōmon*, that could absolve his crew of responsibility while clearing the way for insurance claims.

Similarly in the Mito-han port of Nakaminato, the shipwreck started by the 1700 tsunami resulted in a petition and certificate (below). The petitioners included not just the captain but also villagers from Nakaminato and Isohama, along with two men we call samurai because they have family names. They addressed their joint petition to officials of Mito-han and Isohama village. In response, village headmen affirmed the accident and han officials, having made an inspection of their own, issued the certificate.

As copied into Ōuchi-ke “Go-yōdome,” this *ura shōmon* contains both the petition and the certificate. Each mentions the “high waves” we ascribe to the 1700 tsunami (p. 73).

<table>
<thead>
<tr>
<th>Petitioners</th>
<th>Certification by Mito-han</th>
<th>Date, equivalent to February 12, 1700</th>
<th>Document title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samurai</td>
<td>Migi no tōri</td>
<td>Genroku jüninen u</td>
<td><em>ura Port shōmon no koto certificate</em></td>
</tr>
<tr>
<td>Peasants</td>
<td>ware ware tachiai</td>
<td>Genroku jünigatsu</td>
<td></td>
</tr>
<tr>
<td>Villagers</td>
<td>utsu tame hiki mōshi</td>
<td>12th month</td>
<td></td>
</tr>
<tr>
<td>Captain</td>
<td>soraie for salvage</td>
<td>nijüyokka</td>
<td></td>
</tr>
<tr>
<td></td>
<td>towed</td>
<td>24th day</td>
<td></td>
</tr>
<tr>
<td>Mito-han officials</td>
<td>domo despite</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>o-kome</td>
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<td>rice</td>
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<td>i-ppyö mo</td>
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</tr>
<tr>
<td></td>
<td>not even one bale</td>
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</tr>
</tbody>
</table>

**Narrative** (p. 68-69)  
**Loss** (opposite)  

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**Mito-han officials**  
Kobayashi and Suzuki, on behalf of senior ministers (kārō) Okazawa and Ayuzawa, endorsed the village officials’ account by appending the certification at right.

---

**Captain Kambe’s** hailed from Ukedo, Nakamura-han (p. 67). His boat may have resembled the bale-laden one below.
The certificate begins by itemizing the loss of 470 bales of rice (right). Those bales probably looked like the ones that burly men fill, cinch, lift, and carry in the Hokusai sketches below. Each bale, with a volume of one hyō (i-ppyō), probably weighed close to 60 kilograms (130 pounds).

Two and a half bales made up one koku. A unit of volume, the koku measured such quantities as the capacity of freighters. But it also measured wealth and status—the amount of rice granted annually to a samurai (the 50-koku stipend of the former merchant, Moriai Chūzaemon, p. 53), and the officially expected agricultural yields that ranked daimyo domains (examples, below right).


BOAT AND YIELDS from “Nihon kaisan chōrīku zu,” 1694 (p. 30-31), courtesy of the East Asian Library, University of California, Berkeley.

Fair-weather waves 好天下の高波
The 1700 tsunami in Japan began without a storm but may have continued into one.

THE SUN WAS SHINING from Morioka to Wakayama the day before the 1700 tsunami approached Japan (the 7th day, below). On the 8th day, as the tsunami crossed the Pacific (p. 74-75), skies remained fair over Morioka and Wakayama while snow fell in Edo. Rain or snow fell widely on the 9th day before the 1700 tsunami approached Japan (the 7th day, Kyoto). Edo.

Most of these weather observations come from diaries.

Weather observations

7TH DAY

8TH DAY

9TH DAY

Weather observers

LOCATION DIARY AND WRITER

a Morioka “Morioka-han zassho” Administrators of Morioka-han (p. 44, 60).
b Nikkō “Shake gobansho nikki” Officials of shrine for the grave of Tokugawa Ieyasu (shogun, p. 41).
c Edo “Gokokuji nikki” Buddhist monks.
d Edo “Sakakibara-ke Edo hantei nikki” Officials at an Edo mansion of the Sakakibara family, which then ruled Murakami-han. Diary started 1651, continued to 1866; 553 volumes. For map of Edo mansions of daimyo like the Sakakibara, see pages 61 and 106.
f Nagoya “Ômu rôchû ki” Asahi Bunzaemon Shigeaki, floor-mat manager (tatami bugyō) of Nagoya castle. The castle was headquarters of one of the three main branches of the Tokugawa family. As the caged parrot (Ômu rôchû) in the book’s title, Asahi says he wrote exactly what he heard.
g Kyoto “Kinsumi-kyô ki” Shigenoi Kinsumi, court aristocrat and scholar.
h Kyoto “Kinmichi ki” Ōgimachi Kinmichi, court aristocrat and Shinto scholar.
i Kyoto “Tokudaiji hinami” Tokudaiji Közen, court aristocrat.
j Kyoto “Sadamoto-kyô ki” Nonomiya Sadamoto, court aristocrat and scholar.
k Wakayama “Miura-ke nikki” Miura-family head serving as a karô (senior minister, p. 44) of Wakayama-han.

Some are official journals—from castle towns, a shrine, a temple, and Edo mansions (p. 61). Others were kept by court aristocrats in the imperial capital, Kyoto.

Among narratives of the 1700 tsunami, only the Nakaminato rice-boat story mentions weather—a storm that arrived 12 hours after the crew first encountered “high waves” as they tried to enter port.

WEATHER OBSERVATIONS are lacking from Nikkō on the 7th and 8th days, and from Nagoya on the 7th day. Observations differ in Edo on the 8th day, in Kyoto on the 8th and 9th days. All were first compiled in Tsuji and others (1998, p. 8), where Ueda mislocated observation g in Ise (80 km south of Nagoya).

e—All Korean trade sanctioned by the Tokugawa shogunate passed through Tsushima-han (Totman, 1989, p. 76-77).

JAPAN’S WINTER STORMS “cause ship disasters as well as damage along the coast due to wind waves” (Arakawa and Taga, 1969, p. 128). They are not typhoons, which instead hit Japan in summer and fall (p. 83).
**Waves raised by an opposing current**

The morning “high waves” that held the rice boat offshore probably originated as incoming ocean swells that met river-mouth backwash of a long-lasting tsunami.

Several accounts refer to the 1700 tsunami as a tide (p. 40). The Miho headman, for instance, reports that the water came in “something like a very high tide” about seven times between dawn and about 10 a.m. (“the hour of four”). The headman further notes that the water drained “with the speed of a big river” (p. 79, columns 3-4).

Such tide-like currents impressed eyewitnesses to the 1960 tsunami at Nakaminato. They estimated incoming velocities at 7 knots (about 3.5 meters per second) and described the outflow as even faster.

Strong ebb currents heighten incoming ocean waves on river-mouth bars. An Oregon boating manual warns, “If you are trapped outside a rough bar on an ebb tide, it is wise to lay to and wait” until a rising tide produces an inflowing current.

The 1700 tsunami probably produced strong ebb currents that heightened waves at 8 a.m. off Nakaminato. Such currents should not have resulted from the astronomical tide, which was rising at that hour from Kuwagasaki to Tanabe (p. 83). But the tsunami, at Miho, was then producing intermittent, swift outflow. Similar outflow from the port of Nakaminato probably raised the “high waves” that eventually led to the rice boat’s demise.

The tsunami likely continued raising river-mouth waves through the morning and perhaps into the early evening. It disturbed seas at Miho until noon (p. 79, columns 4-5). Together with the coming storm it may explain why the rice boat stayed off Nakaminato throughout the day.

An outsize tsunami can go on for 24 hours or more. The 1960 tsunami lasted that long (marigrams below and p. 46). Similarly in a computer model, the 1700 tsunami disturbs the Pacific Ocean for an entire day (next two pages).

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**Duration of tsunami wave trains in 1700 and 1960**

**QUOTES AT LEFT from Ōuchi-ke “Go-yōdome” (p. 69, col. 3) and “Mhiro-mura yōgi oboe” (p. 79, col. 4).**

**MARIGRAMS traced from The Committee for Field Investigation of the Chilean Tsunami of 1960 (1961, p. 364, 371). Gauge sites plotted on p. 67 (Nakaminato) and p. 82 (Shimizu, near Miho).**

**CURRENTS. Toba and Taka (1961, p. 309) summarize eyewitness accounts of currents at Nakaminato during the 1960 tsunami. The Oregon boating manual offers little comfort for the latter-day Kambei who becomes “trapped outside a rough bar with a southwester developing 40-knot or better winds... If possible, run to another port with more favorable bar conditions” (Oregon Sea Grant and Oregon State Marine Board, 1999, p. 8-9). On the bar off the mouth of the Columbia River (river location, p. 22), wave height oscillates at tidal periods and peaks during ebb currents, which at this bar commonly exceed 2 meters per second. During a five-day series of measurements, ebb currents raised incoming waves of 3 meters to heights as great as 7 meters (González, 1984).**

**WAVE PERIODS. During a typical wave of the 1960 tsunami at Nakaminato (above), the crest-to-trough fall in water level amounted to 1 meter and took an hour or two. In contrast, the port’s astronomical tides change water levels by no more than 1.8 m in six hours, as judged from extreme tides 20 km south of Nakaminato (at Kasahma; Maritime Safety Agency, 1998).**
Simulated waves 津波のシミュレーション

In a computer model, a long-lasting 1700 tsunami engulfs the Pacific.

In the deep ocean a tsunami’s waves have little height but great crest-to-crest length. As they enter shallow water the waves slow down and stack up. In the model above, the 1700 tsunami rarely rises more than 0.5 m as it crosses the Pacific but builds against Japanese shores to heights as great as 5 m (p. 99).
Simulated waves
In a computer model, a long-lasting 1700 tsunami engulfs the Pacific.

津波のシミュレーション
Japan
Hawaii
Cascadia

0 1 2 3 4 5
6 7 8 9 10
TIME SINCE EARTHQUAKE

TIME IN JAPAN
(~120-minute hours; p. 43)

The model depicts the tsunami from a Cascadia earthquake of magnitude 9.0 with a fault rupture 1,100 km long (p. 98-99; Satake and others, 2003).

ANIMATED VERSION of the model:
Miho village, on a sheltered shore of a pine-covered sand spit, was home to some 300 peasants in 1700. To their headman, the tsunami of that year resembled a series of brief high tides. He noted that the waves lacked a parent earthquake felt in Miho or nearby. His inquisitive eyewitness account survives in “Miho-mura yöji oboe,” a selection of headmen’s records probably compiled in the early 19th century. At right, the document and its possessor in 1999, hotel owner Endō Kunio.
Main points
While waves held the rice boat off Nakaminato (p. 73), the sea at Miho rose and fell repeatedly, like a swift series of tides (p. 78-80).
Wary of flooding, Miho’s headman advised villagers to flee (p. 46; 79, columns 6-7).
The lack of an associated earthquake puzzled the headman, who expected that an earthquake would precede a tsunami (p. 40; 54; 78, columns 12-14).
Like the 1960 tsunami, the 1700 tsunami at Miho was probably under 2 m in height and caused less flooding than did a storm of its era. The largest wave of the 1960 tsunami at Miho probably rode a higher tide than did the 1700 tsunami (p. 82-83).

Documents
Compiled in the 19th century from records of the village’s headmen, “Miho-mura yöji oboe” contains 71 entries on a wide range of topics. Three-quarters of these date from 1694 to 1730.
The 1700 tsunami appears twice in “Oboe”—as the main event in the account on the next two pages, and as a flashback in the entry below, which begins with an earthquake that devastated Edo in December 1703. The tsunami from this earthquake reminded the headman of Rabbit Year waves—doubtless those of Genroku 12 (p. 42). In both cases, the likely writer was either Gorōemon or Chūemon, the village’s headmen in 1698.

1703 EARTHQUAKE AND TSUNAMI

1700 TSUNAMI

"MIHO-MURA YŌJI OBOE” also recounts: 1697, Fire destroys 23 homes—40 percent of the village’s houses—when wind fans flames from the home of Zen’emon. Later, villagers dry a big catch of sardines and the shogunate orders a new map of the area (probably the 1702 map, opposite). 1698, Gorōemon and Chūemon, as shōfu (headmen) of Miho, sign a land survey that assesses Miho’s cropland at 54.2 koku (expected yield: 9,756 liters of rice, or its equivalent).

Tectonic setting and local tsunamis
Barely ten kilometers of continental crust separates Miho from the giant fault on which the Philippine Sea tectonic plate descends. Beneath Miho, this fault ruptured during an earthquake in 1854, and perhaps in 1707, but not in 1944. Efforts to predict earthquakes in Japan focus largely on the patch that failed to break in 1944—the Tokai gap.
The earthquakes of 1707 and 1854 produced tsunamis as much as 5 m high in Miho. Lesser tsunamis in Miho resulted from nearby earthquakes in 1605, 1703, and 1944.

NOTABLE TSUNAMIS IN MIHO SINCE 1600

ON HISTORICAL EARTHQUAKES near Miho and forecasts for the Tokai gap, see Ishibashi (1981). We traced the block diagram from his page 312.
THE TSUNAMI HEIGHTS are from Watanabe (1998, p. 71, 80, 93, and 133) for 1605 and 1707, and from Hatori (1976, p. 24) for 1854 and 1944.
THE MIHO HEADMAN describes the 1700 tsunami as having entered "something like a very high tide" (column 2). There were seven such waves between dawn and late morning (4). Each wave rose gradually and went out "with the speed of sending elders and children to the high ground of Miho, the MIHO HEADMAN describes the 1700 tsunami as of a big river" (3). The flooded area included a bayside grove of pines (maps, p. 76, 82).

Puzzled by the waves, the headman took the precaution of sending elders and children to the high ground of Miho, having entered "something like a very high tide" (column 2). Much later, the "Oboe" writer did not use dakuten. His kana can be read, out of context, as Eko (instead of Ego in 2), nato (instead of nado in 2, 10, 12), and shisumari (instead of shizmari in 12).

The “Oboe” writer used simple phonetic script (kana) instead of complex ideograms (kanji) for nado (2, 10-11, 12, 13), hodo (4, 6), kainakuro nari (5), naran in kikinaren (6) and in minarren (9), naru (6), shizumari (8), odo (10), suezue and kange (11), tame and sei (12), yota (12-13), bakari, tsuyoku, and oite (15). The “Oboe” script thus looks simpler than the kanji-rich columns of the other orphan-tsunami accounts (p. 34-35).
There were seven such waves between dawn and late morning. Puzzled by the waves, the headman took the precaution.

THE MIHO HEADMAN describes the 1700 tsunami as of a big river” (3). The flooded area included a bayside grove. (11). Sound change at word juncture—(9, 10, 14, 15).

Among surviving accounts of the 1700 tsunami, this one stands out as the testimony of an involved eyewitness who pondered a phenomenon beyond his life experience.

11. kangae—Written kangae.
12-13. mottomo... mono to möshi sóro—Further, it is said that an earthquake happens, a tsunami follows.
14. goza naku sóro—Written naku goza sóro.
14. soto hama—The beach facing the open sea.

NOTES. Columns 1-2, lenomae, Wada, and Ego—Place names in Miho (map, p. 82).
1 and 14, e—Pronounced and written e. Signifies “to” as does e in 7, where written he *. 
3 and 7, wa—Topic marker written ha ハ.
6. rönyaku—The elderly and children.
7. o-miya—Miho shrine (maps, p. 76, 82).

The orphan tsunami—Miho
A tsunami that resembles a tide may sweep away buildings.

TIDE-LIKE WAVES OF 1700 TSUNAMI

HOKUSAI’S WAVE MISUSED AS A TSUNAMI ICON

TOWERING, BREAKING WAVE dominates one of Hokusai’s “Thirty-six views of Mount Fuji.” Though an exaggerated wind wave, it has become an icon of tsunamis. Reproduced on the cover of a leading scientific journal, it represents a report on the 1700 tsunami in Japan. Adapted on a Japanese postage stamp, it commemorates diplomatic relations with a country known in Japan for its 1960 tsunami (below and opposite; see also p. 55). Simplified on American roadsides, it identifies tsunami-evacuation routes (p. 46).

The tide-like flows described by the Miho headman (quote, left) more nearly resemble a real tsunami. Tens of kilometers crest to crest, tsunami waves typically come ashore as relentlessly rising surges, like the ones captured in horrific videos from South and Southeast Asia in 2004.

The headman’s words bring to mind the 1960 Chile tsunami in Japan. It entered Onagawa as waves that neither towered nor broke (below). At Ofunato (opposite) its swift currents drove boats ashore (p. 55) while sweeping buildings off their foundations (opposite). Near Tsugaruishi and Tanabe it resembled a river in flood (photos, p. 51, 85). Such flooding probably explains the how the orphan tsunami of 1700 destroyed houses beside Miyako Bay (losses quoted, p. 48, 56).

1960 TSUNAMI AT ONAGAWA: FIRST LARGE WAVE...

...AND A LATER WAVE

“The INAPPROPRIATE ICON” is the late Doak Cox’s epithet for tsunami symbols that contain or mimic Hokusai’s wave. Towering breakers rarely signal a tsunami’s arrival (Lander and others, 1993, p. 2; Cox, 2001). The Nature cover spotlights the orphan-tsunami report by Satake and others (1996). For footage of the 2004 Indian Ocean tsunami, see http://www.waveofdestruction.org/videos/.

ONAGAWA PHOTOS, attributed to M. Kondō, are from a notebook stored at the Earthquake Research Institute, University of Tokyo. An alert fireman, noting water-level changes from forerunner waves, warned residents to go to high ground before 4:40 a.m. Everyone survived (Atwater and others, 1999, p. 8).
Selective history

THE DEVASTATION ABOVE, from the 1960 tsunami, contributed to 52 deaths in Öfunato. The 1700 tsunami surely came ashore here as well; the two tsunamis attained similar size elsewhere in Japan (p. 48). However, the orphan tsunami of 1700 is unknown from Öfunato, probably because of accidents of human history:

- Öfunato belonged to a domain, Sendai-han, that kept fewer administrative records than did Morioka-han.
- Magistrates reported the 1700 tsunami incompletely even in Morioka-han. They documented its effects close to their district offices in Miyako and Ötsuchi but neglected the damage or flooding 7 km to the south at Tsugaruishi (compare p. 38-39 with p. 52).
- The district office for Öfunato, at Imaizumi, was 10 km away on a different bay.
- Öfunato had less at risk in 1700. The area probably had little more than one-tenth its 1960 population. Few houses stood in 1700 on land the 1960 tsunami would rake.

ÖFUNATO also lacks records of the 1611 tsunami, which crested over 5 m high between Miyako and Sendai (p. 41). The village area had 1,217 residents in 1641 (Öfunato Shishi Henshu I’inkai, 1978, appendix, p. 378), versus 11,200 in 1960. An 1822 map shows paddies and salt ponds on low ground but houses solely on uplands (Kin’in, 1981, p. 22-23).
Tsunami size

At Miho, the far-traveled tsunamis of 1700 and 1960 were similarly small.

NO REPORTED DAMAGE resulted from the 1700 tsunami at Miho. To enter the pine grove, the tsunami probably rose a meter or two above ambient tide, which likely stood near mean sea level as the water repeatedly rose and fell (graphed tide curve, opposite). The 1960 tsunami similarly amounted to little at Miho, even though its largest wave coincided with a tide several tenths of a meter higher.

EVIDENCE FOR 1700
IN “MIHO-MURA YÔJI OBOE”

matsu no uchi
within pine groves
[at Ego]

TSUNAMI HEIGHT,
IN METERS AT BAY SHORE

Inferred
for 1960 tsunami

Measured, 1960 tsunami

1700 tsunami at Ego

A and B Height inferred with simplest assumptions

ASSUMPTIONS

Inland change in tsunami height None (A). Inland descent (B), by analogy with the 1960 tsunami at Otsuchi and Shinjô (p. 65, 89).

Flow depth In pines, 0.3 m (A) or 0.5 m (B).

Freeboard Storm-wave swash excluded pines from land less than 0.5 m above highest astronomical tides.

Tide zone Highest astronomical tides 0.8 m above mean sea level.

Tide stage At 1700 mean sea level during tsunami (facing page).

C Height depends greatly on net uplift since 1700

ASSUMPTIONS

Inland change in tsunami height None.

Tide stage 0.2 m below 1700 mean sea level (facing page).

Modern ground The area of the flooded pines is now about 1.6 m above TP (map, upper left).

Net uplift 0.1-0.8 m since 1700: coseismic uplift 0.0-0.7 m in 1707 and 1.4 m in 1854; interseismic subsidence 4.8 mm/yr (250-year extrapolation of Shimizu trend, p. 65).

LOWER MAP at left originated in 1893 with officials of Shizuoka prefecture, the modern regional jurisdiction to which Miho belongs (Hatori, 1976). The validity of height C, from Tsuji and others (1998), depends partly on the shoreline changes reconstructed on this map. Those changes demonstrate uplift at Shimizu but not necessarily at Miho. Ishibashi (1984, p. 107) estimated that the 1854 earthquake elevated Shimizu by about 3 m. Before the earthquake, ships of 1,000-koku (180,000 liter) capacity would pull into the dock. Afterward, the channel became too narrow and shallow for such use (Hatori, 1976).
Comparisons with storms
At Miho, the 1700 and 1960 tsunamis crested below storm surges of their eras. The 1700 tsunami caused less flooding or damage in Miho than did a typhoon in 1699. Similarly, the 1960 tsunami failed to enter houses that were flooded during a storm in 1974.

In September 1699, a typhoon advanced from Kyushu to northern Honshu. In Miho it caused greater flooding and damage than did the orphan tsunami four months later. The storm surge drove villagers through waist-deep water to Miho shrine. Two persons had to be rescued from the sea; another was reported missing. On returning to their houses, villagers found high-water marks 1-2 shaku (0.3-0.6 m) above floor level. Three homes lost everything but their support posts. Also damaged were rice paddies, some destroyed “forever” (eiare). One seventy-year-old farmer, Jōzō, said he had seen his Miho paddy flooded thirteen times in 41 years. Only one or two of those floods damaged his standing crop of rice as much as did the 1699 typhoon.

Likewise for elders in modern Miho, the flooding of record accompanied a storm, not a tsunami. A storm surge on July 7, 1974 flooded the bayside homes of the Mizuno and Ishino families, in the approximate area of the neighborhood called lenomae in 1700 (index map, opposite). Interviewed in 1999, elders of the two families recalled no other flooding of these homes, even though they lived there in 1960. The 1960 tsunami also failed to flood the home of Shiba Tsune, in nearby Wada. In her account, the water went no farther than the bayshore road in front of her house.

Adjustments for tides
When the 1700 tsunami was first noticed in Japan, the astronomical tide stood near mean sea level (left graphs below). The tsunami’s midnight arrival at Kuwagasaki and Ötsuchi coincided with a falling tide a few tenths of a meter below mean sea level. Dawn flooding at Miho and Tanabe occurred on the rising side of that low tide. Only later waves arrived with the tide above mean sea level.

In contrast, the 1960 tsunami crested during high tide (right graphs). Its largest wave nearly coincided with the peak of high tide at Miho and Tanabe. Near Miho at the Shimizu gage, the tide stood about 0.3 m above mean sea level. Because the 1960 tsunami at Miho did not exceed 1.6 m above mean sea level, it crested no more than 1.3 m above ambient tide.

TIDES The 1700 tsunami is unlikely to have piggybacked on a storm surge during its first 12 hours in Japan (p. 72). The tsunami coincided with neap tides—astronomical tides of smaller than average range (Mofjeld and others, 1997). The Pacific coast of Honshu has two daily high tides and two daily lows (Maritime Safety Agency, 1998). The mean tide range is 1-2 m. An individual tide sweeps southward, reaching Tanabe nearly 3 hours after leaving Kuwagasaki.

HEIGHT OF 1960 TSUNAMI IN MIHO In the record of the Shimizu tide gauge (p. 73), the first large wave of the 1960 tsunami crested 1.3 m above TP (The Committee for Field Investigation of the Chilean Tsunami of 1960, 1961, p. 194, 371). The Mizuno and Ishino homes occupy low ground near intersections 1.1-1.3 m above TP; while the Shiba home is founded a few tenths of a meter above a road 1.4 m above TP (map, opposite). TP (Tokyo Peil) is a datum near mean sea level.

TYPHOON OF SEPTEMBER 1699 An anthology like those by earthquake historians (p. 62) identifies more than ten historical accounts of this storm (Arakawa and others, 1961). Japan’s typhoon season runs from June to November and peaks in September. Storm surges account for much of the damage they cause (Arakawa and Taga, 1969, p. 129).
The castle town of Tanabe zoned large central lots for samurai and outlying neighborhoods for artisans, merchants, and foot soldiers. The town’s mayor, of the merchant family Tadokoro, resided 150 meters a limit of the 1700 tsunami: the landward end of a castle moat at Horidobashi.

Volumes of “Tanabe-machi daichō” form a set of official records for the years between 1585 and 1866. The Tadokoro family kept a parallel set of private records, “Mandaiki,” between 1471 and 1839. An account of the 1700 tsunami appears in both sets. Ōta Yūji, a Tanabe librarian, watched over “Daichō” in 1999 (right).

The picture map shows Tanabe-machi in the Hōei era (1704-1710). The map is a copy dated 1884, provided courtesy of Tanabe Municipal Library.

“TANABE-MACHI DAICHŌ,” temporarily at this library when the photo at right was taken, is ordinarily held at Tōkei shrine (location on picture map above and on index map opposite). Tanabe-shi Kyōiku I’inkai (1987-1991) edited a printed version.

“MANDAIKI” can be translated as “Diary of ten thousand generations.” Many of its extant volumes, including the one that covers A.D. 1700, were written in the same hand, according to librarian Ōta. In 1999 he told us that these volumes are probably copies prepared under the direction of Tanabe’s seventh Tadokoro mayor (born 1738, died 1818). A printed version of “Mandaiki” runs 10,200 pages (Andō and Wakayama-ken Tanabe-shi Kyōiku I’inkai, 1991-1994).
Main points
Unusual seas off Tanabe entered a government storehouse in Shinjō, ascended a castle moat as far as Horidobashi, and flooded farmland in Atonoura, Mikonohama, and Mera (p. 86).
This inundation probably began after the 1700 tsunami’s midnight arrival in Kuwagasaki (p. 43).
The tsunami probably crested 2-4 m above tide level as it crossed shores near Tanabe (p. 88-90). The flooded areas fell during subsequent earthquakes by perhaps 1 m more than they rose in between (p. 91).

Tanabe—town and district
Tanabe’s mayor served also as the district mayor (ōjōya) of nearby villages. In this dual capacity, a mayor with the family name Tadokoro supervised the writing of “Tanabe-machi daichō” in January 1700 from his family’s home in the merchant district north of Tanabe castle. There, he likely received news of the flooding in Shinjō through that village’s headman, Denbe’e. Perhaps he also saw the water reach Horidobashi, 150 m from his home.

Tanabe in 1700 had 2,600 residents, probably excluding its samurai and their families. Counted among the town’s commoners in 1725 were 257 fishermen, 38 fishmongers, 33 house builders, 25 innkeepers, 14 liquor merchants, 13 doctors, 3 makers of floor mats, 2 roofers, 1 stonemaster, 1 shipwright, 1 umbrella maker, and 1 merchant of palanquins (kago).

Shinjō in 1700 probably contained 185 houses and 240 outbuildings—structures lost to a tsunami of nearby origin in 1707 (p. 89).

Other tsunamis
As at Miho, the worst tsunamis in Tanabe originate along a plate-boundary fault off the Pacific coast of southwest Japan (p. 65, 77). An earthquake rupture 500 km long in 1707 produced a tsunami 3.5 m high in Tanabe and perhaps 8 m high in Shinjō. The fault broke again, piecemeal, in 1854 and again in the 1940s. The second of the 1854 earthquakes triggered the tsunami that led to the rice-sheaf fire in Hiro village, 40 km from Tanabe (p. 47). In Tanabe and vicinity, the 1960 tsunami from Chile crested about 3 m above ambient tide.

NOTABLE TSUNAMIS AT TANABE AND SHINJŌ SINCE 1600

**PLATE-TECTONIC SETTING**

- Upper edge of plate-boundary fault (p. 8, 65, 77)
- Rupture area of great earthquake on plate-boundary fault
- 1707—Areas 1 and 2 combined
- 1854—32 hours apart, area 1 first
- 1944 (1) and 1946 (2)—M 8.1, 8.1; smaller than 1854
- Known site of 1700 Cascadia tsunami

**TANABE AND VICINITY**

- Limit of 1700 tsunami in moat, at Horidobashi
- View in photo

**EARTHQUAKES AND TSUNAMIS**

Ando (1975) and Ishibashi (1981) estimated rupture areas of the 1707, 1854, 1944, and 1946 earthquakes. The Tanabe map is traced from Kokudo Chiriin (Geographical Survey Institute), Kii Shira-hama and Kii Tanabe 1:25,000, 1990 and 1996. Shinjō Köminkan, a community center, provided the above photo (location, p. 89). The tsunami heights are from Watanabe (1998, p. 71, 80, 96, and 136), Japan Meteorological Agency (1961, p. 192), Yoshinobu (1961), and our interpretation of a “Mandaiki” account of slight flooding in Shinjō during the 1751 tsunami (footnote, p. 54).

**TOWN AND DISTRICT**

Takeuchi (1985b, p. 658) lists commoners’ occupations and gives Tanabe’s population as 2,516 in Kanbun 7 (1667) and 2,720 in Kyōhō 10 (1725). The totals exclude children under nine. Kishi Akinori, a local historian, told us in 1999 about the Tadokoro mayors and the Shinjō headman.
Account in “Tanabe-machi daichō” 『田辺町大帳』の記述

SEAS ROSE STRANGELY near Tanabe around dawn of the 8th day (columns 1-2). The water entered a Tokugawa storehouse in Shinjō village and other buildings, too. In addition, the water damaged crops and fields in the Atonoura area of Shinjō. Within Tanabe itself, not far from the writer, the water ascended a castle moat as far as Horidobashi (3-4).

This account comes from the water-stained volume pictured at right.

3, shio—Composite symbol for “water” and “morning” (p. 40).
3, Shinjō Atonoura—An account from “Mandaiki,” from the year 1707, treats Atonoura as part of Shinjō village (Tokyo Daigaku Jishin Kenkyūsho, 1981, p. 326). Its passage on the 1700 tsunami mentions damage to fields not only in Atonoura but also in Hama (that is, Mikonohama) and Mera. See page 85 for an index map and page 84 for notes on “Mandaiki.”

possibilities include tide, storm, wind, and changes in atmospheric pressure, in addition to tsunami (p. 40; Hibiyama and Kajura, 1982; Yanuma and Tsuji, 1998).
2, go-kōgi—go, honorific; kōgi, public affairs (Berry, 1982, p. 158; Hall, 1991, p. 19). Refers here to the branch of the Tokugawa clan that ruled Wakayama-han, of which Tanabe was a part.
2, e—Pronounced e, written he, signifies “to.”

NOTES. Column 1, dō—Same year and month as in preceding entry.
1, uraura—Repeat symbol makes u plural.
The unusual seas occurred along more than one part of the coast near Tanabe.
1, e—Written e, means “into.”
1, abiki—The term refers to unusual seas without necessarily implying their cause. From usage that varies with region, and perhaps also with time,
Durable history

ACCOUNTS OF THE 1700 TSUNAMI were brushed onto washi. Strengthened by fibers of bark, washi has served as writing paper, screens, windows, lantern covers, and even clothing. Its use in Japan predates the 1700 tsunami by more than 1,000 years.

The tsunami accounts have survived water and bookworms. Water erased an edge of the account in “Tanabe-machi daichô” (above). Worms known as shimi (紙魚 paper fish) explored most of the source documents, including Morioka-han “Zassho” (below). Additional bookworms leaf through sturdy pages at right.

Bookworm passages perforate the volume of Morioka-han “Zassho” for the year Genroku 12 (above; entire volume, p. 42). Such trails also cross the map folds on page 32 and riddle the book cover on page 66. At upper right, earthquake historians devour durable documents in Tanabe.

TANABE LIBRARIAN Öta Yüji identified as kőyawashi the paper used by the Tadokoro mayor who copied “Mandaiki” in the late 1700’s or early 1800’s. This paper takes its name from manufacture in Köya, 60 km north of Tanabe.

IN MORIOKA, librarian Konishi Hiroaki surmised that the washi in “Morioka-han zassho” was imported from the south, for want of suitable fiber in northern Honshu.

Tsunami size near a storehouse

The 1700 tsunami probably reached heights of several meters in Shinjō.

CROSSING THE SHORE on its way to the government storehouse in Shinjō, the 1700 tsunami crested at least 2 m above tide (estimate A). A height of 4 m is reasonable if the storehouse stood on low ground at least half a kilometer inland, and if the tsunami height descended inland as it did in 1960 (B; heights in 1960 mapped on facing page).

The tsunami rose more than 5 m if the storehouse stood on high ground identified in Shinjō oral tradition (C). That tradition places a bygone government storehouse at the site in the photo below (map, opposite). However, this site was not necessarily the one flooded in 1700: Shinjō had more than one government storehouse in 1707, when a tsunami destroyed two of them (box, facing page).

**STOREHOUSE SITE IN SHINJŌ**

AT THE STOREHOUSE SITE in the photo above, the family of Matsuzaki Tomiji built a house early in the 20th century. Mr. Matsuzaki, born in 1926, told us in 1999 that he saw the 1960 tsunami stop short of this house and also the street fronting it. Mr. Matsuzaki also recalled being told that this street was crossed by the tsunami from the region’s great 1946 earthquake (p. 85).

ESTIMATE C is from Tsuji and others (1998). HEIGHT DATUMS. Tide tables of the Maritime Safety Agency (1998) list the highest astronomical tide at Tanabe as 1.04 m above mean sea level. TP is a datum near mean sea level.

**SUMMARY OF TSUNAMI HEIGHTS**

At edge of Mori Harbor, in meters above ambient tide. Inferred for 1700 (diagrams below), measured for 1960 (map opposite).

**ASSUMPTIONS**

Flow depth 0.3 m for storehouse with minimal foundation (A), 0.5 m for foundation typical of traditional storehouses in former samurai neighborhoods of Tanabe (B; storehouse photo, p. 108).

Freeboard To keep government rice above waves during storm surges, storehouse was sited 0.5 m (A) or 1.0 m (B) above highest astronomical tides.

Tide zone Highest astronomical tides were 1.0 m above mean sea level, the modern value for Tanabe listed in tide tables. Relevant to A and B only.

Tide stage When storehouse flooded at or before dawn, tide stood 0.3 m below 1700 mean sea level (p. 83). Used in all estimates.

Inland decline Tsunami crest descended inland in 1700 as much as it did in 1960 (map on facing page). B only.

Net subsidence 1.0 m since 1960 (p. 91). C only.

Modern ground The storehouse site now stands 4.1 m above TP (photo at left; map and airphoto on facing page). C only.
The orphan tsunami—Tanabe

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1960 TSUNAMI HEIGHTS. The heights plotted above, at left, are from a regional report by the Japan Meteorological Agency (1961, p. 192); at right, from a local survey by Shinjō headed by a schoolteacher, Yoshinobu Eiji. Mr. Yoshinobu sought comparisons with the 1946 tsunami, whose heights he had previously surveyed with a hand level. After the 1960 tsunami, Tanabe’s mayor provided him with the services of Fujino Fumitada, a licensed surveyor, and Otani Yasuzō, an assistant to Mr. Fujino. Mr. Yoshinobu pointed them to the points he had measured in 1946, as well as to levels reached by the Chilean tsunami. The men surveyed for three days. Their findings appear on pages 20 and 23 of Yoshinobu’s report (which also describes the building of a breakwater at the entrance to Mori Harbor in 1965). Okamoto Yoshishiko of Tanabe’s city office provided us with a copy of the report and with the airphoto above. The lower photo comes from a collection at Shinjō Kōminkan (a community center), courtesy of Kashiwagi Tamio.

1960 TSUNAMI DAMAGE. Except for the south shore of Miyako Bay (p. 51), no recorded site of the 1700 tsunami in Japan suffered more damage from the 1960 tsunami than did the area around Mori Harbor. The area’s losses, compiled by Wakayama Prefecture and reported by the Japan Meteorological Agency (1961, p. 193), totaled 1.66 million yen (U.S. $2,700 in 1960, or $16,900 adjusted for inflation to 2003; http://www.bls.gov/cpi/).

Confounding clue from 1707

BOTH TADOKORO ACCOUNTS of the 1700 tsunami mention the flooding of one o-kura, or government storehouse, in Shinjō. Oral tradition in Shinjō places a government storehouse on high ground in a neighborhood called o-kura yashiki (government-storehouse district; photo on facing page). But the storehouse flooded in 1700 and that remembered by tradition are not necessarily the same, as shown by an account of the 1707 tsunami in Shinjō.

The great Hōei era earthquake and tsunami of October 28, 1707 devastated Shinjō. Losses there, reported in Tadokoro documents, included 185 houses, 196 sheds, 40 cattle shelters, and five private storehouses (kura). The losses also included two o-kura—two government storehouses. Which, if either, did the 1700 tsunami enter? Which corresponds to the storehouse in Shinjō’s oral tradition?

ADDITIONAL LOSSES IN 1707. The great Hōei-era earthquake and tsunami of October 28, 1707 devastated Tanabe as well. In that castle town, 24 persons died, 138 houses and 75 storehouses collapsed, 154 houses and 6 storehouses were washed away, and 119 houses suffered severe damage (taiba). Among the houses destroyed was that of the Tadokoro mayor (location, p. 84, 90). Left standing, but entered by the water, was the family’s adjacent storehouse that likely held “Tanabe-machi daichō” (p. 86) and “Mandai.” Salt water soaked the Tadokoro records; these dried the following week.

**Tsunami size near Tanabe Bay**

Of modest height, the 1700 tsunami flooded bayside fields but not the mayor’s house.

SIMPLE ASSUMPTIONS about reported damage to fields and crops yield bayshore heights up to 3 m for the 1700 tsunami near Tanabe (A and B). In Tanabe proper, near the home of the Tadokoro mayor, the water ascended a castle moat without reportedly overtopping its rim. Perhaps, as assumed in C, the tsunami approached the moat rim in the area of the motorcycle at lower right.

**TSUNAMI HEIGHT, IN METERS ABOVE AMBIENT TIDE**

<table>
<thead>
<tr>
<th></th>
<th>Measured 3.3 m above TP, with tide probably 0.8 m above TP, along the Aizu River 0.3 km west of Horidobashi (tide stage, p. 83).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td>Inferred from plausible heights of flooded fields</td>
</tr>
<tr>
<td>Flow depth</td>
<td>1700 tsunami</td>
</tr>
<tr>
<td>Tide zone</td>
<td>Mean sea level in 1700</td>
</tr>
<tr>
<td>Tide stage</td>
<td>3 m Total</td>
</tr>
<tr>
<td>1.6 m</td>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Inferred from speculative height of flooding in moat at Horidobashi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow depth</td>
<td>Grain</td>
</tr>
<tr>
<td>Tide zone</td>
<td>Mean sea level in 1700</td>
</tr>
<tr>
<td>Tide stage</td>
<td>3 m Total</td>
</tr>
<tr>
<td>3 m</td>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Moat rim in 1700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net subsidence</td>
<td>Horidobashi</td>
</tr>
<tr>
<td>Modern ground</td>
<td>Land level</td>
</tr>
<tr>
<td>3.3 m</td>
<td>Total</td>
</tr>
</tbody>
</table>

**ASSUMPTIONS**

- **Flow depth** At least 0.3 m to damage grain (A); higher at shore (B).
- **Freeboard** Kept fields above waves during most storm surges (B).
- **Tide zone** Highest astronomical tides 1.0 m above mean sea level, as listed for Tanabe in modern tide tables (A and B; datum, p. 88).
- **Tide stage** When fields and moat flooded, tide stood 0.3 m below 1700 mean sea level (p. 83). Used in all estimates.
- **Net subsidence** 1.0 m since 1700 (facing page). Used in C only.
- **Modern ground** Tsunami approached level of moat rim, now an intersection about 2 m above TP (C; photo, right).

Estimate C from Tsuji and others (1998). TP, a datum near mean sea level.

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**FLOODING DESCRIBED IN TADOKORO DOCUMENTS**

**FIELDS IN VILLAGES**

- denchi rice paddies
- mugisaku wheat crops
- habō lost

**MOAT IN TANABE**

- kokomoto Close to me,
- horidobashi Horidobashi
- made as far as
- shio iro morning tide entered.

On the picture map from 1704-1711 (p. 84), the former moat is labeled *sendai hori aito* (moat in preceding generation). The neighborhood in the photo is known today as Horidobashi. Officials of the General Affairs Section, City of Tanabe, showed us the location of the Tadokoro lot.
**Sawtooth cycles 地震サイクル**

Tanabe sinks during great earthquakes and probably rises between them.

GREAT SUBDUCTION EARTHQUAKES lower land at Tanabe. The subsidence probably punctuates cycles that plot like sawteeth (below). The cycles result from stick-slip subduction (p. 10), as do the land-level changes at Chile, Alaska, and Cascadia (p. 11, 14-25). The cycles’ net effect at Tanabe adds 1 m of inferred tsunami height in estimate C (opposite). At Tanabe since 1700, subsidence during earthquakes probably exceeded the area’s gradual uplift.

**COASTAL LAND-LEVEL CHANGE DURING EARTHQUAKES ALONG THE NANKAI TROUGH**

**INFERRED CYCLES OF LAND-LEVEL CHANGE AT TANABE**

SUBSIDENCE ESTIMATES for the earthquakes in 1707, 1854, and 1946 are from Usami (1996, p. 303). Tanabe subsided about 0.4 m during the 1946 earthquake according to a comparison of geodetic benchmarks leveled before and after the event (Thatcher, 1984, p. 3090).

**Firsts**

INSTRUMENTAL RECORDS of confirmed tsunamis begin with a pair of Japanese wave trains that registered on tide gauges in Oregon and California on December 23 and 25, 1854.

The December 23 tsunami, originating off Miho (p. 77), in turn yielded pioneering estimates of Pacific Ocean depths. Its wave train was noticed on a San Diego marigram by the gauges’ installer, William P. Trowbridge. Suspecting a submarine earthquake, Trowbridge notified Alexander Dallas Bache, head of the U.S. Coast Survey. Months later, Bache learned that an earthquake and tsunami had struck southwest Japan about 9 a.m. local time on December 23, 1854. Bache combined this news with the marigrams and with wave physics to estimate the average ocean depth between Shimoda (location, p. 77) and San Francisco. His estimate, 4.1-4.6 km, scarcely differs from today’s, 4.7 km.

The second wave train originated on December 24, Japan time, off Tanabe (map, above). Its effects in Hiro village, 35 km northwest of Tanabe, inspired the story that brought “tsunami” into the English language (p. 47).

**TSUNAMI RECORDS**

Marking each year’s growing season, the annual rings of western red cedar in Washington State strengthen the link between the January 1700 tsunami in Japan and a great earthquake at Cascadia. In this earthquake victim’s root, a complete ring from 1699 forms the smooth outer edge at right. The tree lived through August or September of 1699 but died before May 1700, when the next growing season began (p. 96-97).

IN JAPAN

1603 Edo becomes shogun’s capital
1612 Earliest known writing of 津波 (p. 41)
1644 Earliest volume of Morioka-han “Zasho” (p. 44)

Tree PX-782, South Fork Palix River, Willapa Bay
A TRANS-PACIFIC REUNION took place in 1996. Orphaned for nearly 300 years, the 1700 tsunami in Japan was reunited, on the pages of a scientific journal, with an earthquake and tsunami in North America (p. 94-95). The orphan dated the earthquake to the evening of January 26, 1700 (p. 42-43) and gave its approximate size as magnitude 9.

Today the 1700 tsunami is securely linked to a giant North American earthquake. The tie was strengthened in 1997 by tree-ring dating that narrowed the time window for a great Cascadia earthquake to the months between August 1699 and May 1700 (opposite; p. 96-97). The earthquake’s enormity was confirmed in 2003 through improved estimates of the orphan tsunami’s size and from computer simulations of Cascadia earthquakes and of the tsunami itself (p. 98-99). The tsunami’s written record in Japan has become clearer, too, with discovery in 1998 of the Miho headman’s account, authentification in 2002 of the Nakaminato shipwreck certificate, and explanation in 2004 of a discordant date from Tsugaruishi (p. 62).

The fault that broke in 1700 has been reloading for future Cascadia earthquakes. If the fault behaves as it has the last few thousand years, the earthquakes will happen sporadically at intervals ranging from a few centuries to a millenium (p. 100-101). Sometimes the fault may break along its entire length; at other times it may break piecemeal.

Today, public officials are taking steps to prepare coastal communities for Cascadia tsunamis, and engineers are using new seismic-hazard maps that allow for shaking from Cascadia earthquakes as large as magnitude 9 (p. 102-105). The story of the orphan tsunami of 1700 continues through these public-safety efforts.
By elimination 消去法によって
No other place rivals Cascadia as the orphan tsunami’s source.

MIHO’S HEADMAN WONDERED what made the 1700 tsunami (p. 78, columns 9-16). That mystery grew as 20th-century historians collected accounts of its orphan waves from Kuwagasaki to Tanabe (p. 54, 62). Geologic clues in North America, summarized in Part 1, show that the tsunami could have originated at the Cascadia subduction zone. But might the waves’ real source lie elsewhere?

There is no reason to believe that the 1700 tsunami began in the seas directly off Japan. No precursory earthquake was felt along the Japan Trench at Tsugaruishi or along the Nankai Trough at Miho (p. 54). Nor did the tsunami coincide with a Japanese storm (p. 72).

Other potential sources around the Pacific Rim conflict with the tsunami’s year or height. South American catalogs give sources for tsunamis recorded in Japan in 1687, 1730, and 1751, but not for any tsunami in 1700 (p. 54). The 20th century’s third-largest earthquake, in Kamchatka, produced a tsunami in Japan with heights of a few meters in the north but less than 1 m in the south (graph, right; map, opposite). The 1964 Alaska tsunami, from the century’s second-largest earthquake, radiated mainly off the long side of the area of a sea-floor uplift—southeastward, away from Japan—and therefore crested no more than 1 m high in Japan. An eastern Indonesian tsunami in 1996 amounted to little in Japan except on tips of southern peninsulas.

A CASCADIA SOURCE for Japan’s orphan tsunami of 1700 was proposed by Satake and others (1996). Kerr (1995) and Kanamori and Heaton (1996) commented on the breakthrough.

SPANISH AMERICA in 1700 included the Pacific coast from Peru to central Chile (Haring, 1963)—sources of the tsunamis recorded in Japan in 1586, 1687, 1730, and 1751 (p. 54). Spaniards described 19 tsunami-causing earthquakes in Peru and Chile between 1650 and 1750 (Lomnitz, 1970; Lockridge, 1985). Among these, the event closest to 1700 was one that damaged northern Chile in 1705. In Mexico, shaking on June 30, 1700 was recorded both on the Pacific coast and inland, and other tremors were recorded inland on September 29, 1699 and on March 30, 1700 (Garcia and Suárez, 1996, p. 106).
Alaskan ancestors

EVIDENCE AGAINST an Alaskan source for the 1700 tsunami includes not just the modest size of the 1964 Alaska tsunami in Japan but also the geologic history of pre-1964 Alaska earthquakes.

The immediate predecessor of the 1964 Alaska earthquake predates 1700 by 400 years or more. At upper Cook Inlet, where a buried soil marks land subsidence from 1964 (p. 14-15), an underlying buried soil dates the penultimate subsidence event to A.D. 1000-1200 (below). Similarly at the Copper River delta, uplifted in 1964, the penultimate uplift occurred about 1100-1300.

FOR FURTHER CONTRAST with the 1960 Chile tsunami, compare both these maps with the ones on page 55. The Kamchatka tsunami heights are from The Central Meteorological Observatory (1953, p. 39, 45-58); the Alaskan data, from Hatori (1965).

TP, a vertical datum near mean sea level.

ON PREDECESSORS to the 1964 Alaska earthquake, see Combellick (1991), Plafker and others (1992), and Hamilton and Shennan (2005).

THE PHOTOS show the shore of Turnagain Arm at Girdwood. Lower image courtesy of Ian Shennan.
Tree-ring tests 年輪のテスト

A great Cascadia earthquake killed red-cedar trees between August 1699 and May 1700.

IN 1996, soon after Japanese researchers assigned a Cascadia earthquake to January 1700, North Americans sought to test the date. Radiocarbon had already been pushed to its limits in dating the death of earthquake-killed trees as exactly as 1695-1720 (p. 24-25). But there remained the possibility of dating, to the year and growing season, the trees’ final months of growth.

That work had begun in 1987 with sampling of the red-cedar trunks standing in tidal wetlands of four Washington estuaries (photos, p. 16, 24; red diamonds, right). The victims contain a climatic bar code: year-to-year variation in the width of their annual rings. They share the code with old trees that safely witnessed the earthquake from high ground (cartoon, opposite). Witnesses felled by loggers in 1987 give the year for each bar in the code. Matching of the ring-width patterns thus yields dates for the victims’ rings.

Dating a victims’ year of death, however, requires samples that preserve the tree’s final ring. The samples dated in the 1980s came instead from weather-beaten trunks. So in the summer of 1996, to ask trees whether they died from an earthquake in January 1700, geologists unearthed bark-bearing roots attached to the already-dated trunks. Tree-ring scientists then checked the ring-pattern match between root and trunk. The work yielded, for each of eight trees, a final-ring date. In all but one case, the tree died after completing the 1699 growing season and before the start of the next—in the window between August 1699 and May 1700.

As a further test, tree-ring scientists dated the onset of stress in Sitka spruce that barely survived post-earthquake tides (yellow triangles). The trees endured the submergence by sprouting roots into the new, higher ground. Several dozen such survivors remained in southern Washington and northern Oregon in the early 1990s. In half of them the width or anatomy of annual rings changed in 1700-1710 (examples in box, opposite).

RİNG-WIDTH PATTERNS were matched to date the ring next to bark in the roots of eight red cedar (Yamaguchi and others, 1997; Jacoby and others, 1997). Seven of these trees died between the 1699 and 1700 growing seasons; the other survived until 1708. The ring-width measurements from the trunks of witnesses and victims are archived at ftp://ftp.ncdc.noaa.gov/pub/data/paleo/treering as rwl files wa129 through wa133. STRESS IN SURVIVING SPRUCE was documented by Jacoby and others (1997). Aside from a few dozen survivors, living spruce of Washington’s tidal forests postdate 1700. Most of the trees postdate 1750 because of a lag in colonizing lands that brackish tides were rebuilding (Benson and others, 2001).
A great Cascadia earthquake killed red-cedar trees between August 1699 and May 1700. Tree-ring tests on surviving trees determined that they shared the year August 1699, the year for each bar in the code. Matching of the ring-width measurements from the trunks of western red cedar树木 with the ring-width patterns of western red cedar trees that safely witnessed the earthquake from high ground established the year 1700. Most of the trees postdate 1750.

Tree-ring tests for A.D. 993–1986 (Yamaguchi and others, 1997). Victim tree is PX-782, a stump along the South Fork Palix River (entire cross-section of root, p. 92). Survivor data is from Jacoby and others (1997).

ON TREE-RING DATING see Stokes and Smiley (1968), Fritts (1976), and Schweingruber (1988). Witness is red cedar from land above the reach of post-earthquake tides, at Long Island—from one of 19 used to make a master bar code data is from Jacoby and others (1997).
Magnitude 9 マグニチュード 9

The 1700 Cascadia earthquake probably attained a magnitude between 8.7 and 9.2.

A MAGNITUDE OF 9 makes an earthquake unusually enormous. Only two twentieth-century earthquakes surpassed M 9.0 (left). In several minutes, an earthquake of M 9.0 radiates as much energy as the United States consumes in a month, or twice the energy a hurricane’s winds would release if they blew nonstop for a month (middle graph).

The 1700 Cascadia earthquake probably was such a giant. It likely broke at least 1,000 kilometers of the boundary between the subducting Juan de Fuca Plate and the overriding North America Plate—a rupture about as long as California, or about the length of Japan’s main island, Honshu (lower left). On the seaward half of the rupture, the plates probably lurched past one another by about 20 meters. The magnitude was probably in the range M 8.7-9.2.

These estimates depend, in part, on assumptions about what fault area broke during the 1700 earthquake. By the assumptions in red at right, the break extends about 1,100 km coastwise and averages nearly 100 km in width. The fullest seismic slip takes place offshore, where the break is shallow (dark). Onshore the slip diminishes toward depths where the fault is too warm for brittle failure (light).

This picture has gained support from orbiting satellites of the Global Positioning System. GPS measurements help define mostly offshore areas where the downgoing Juan de Fuca Plate is currently coupled with the overriding North America Plate. Farther inland, the plates episodically creep a few centimeters past one another (green).

Resulting estimates of fault-rupture areas provide a starting point for simulating, by computer, the sea-floor displacement that triggered the 1700 tsunami. Offshore the sea floor rises several meters as the North America Plate lurches up the inclined fault. Near the coast, the seafloor and the adjacent land fall as much as two meters as this plate stretches (cartoons, p. 10). The simulated deformation varies with the rupture width and the slip amount—two of the main contributors to earthquake size.

Additional simulations track the resulting tsunami across the Pacific Ocean (p. 74-75). The modeled tsunami heights in Japan can then be compared with the heights estimated from damage and flooding by the orphan tsunami (bar graph, opposite). The comparisons rule out a Cascadia parent of M 8.0-8.5, whose tsunami would not likely exceed 1 m high in Japan. Instead, the inferred combinations of rupture area and seismic slip correspond to Cascadia earthquakes of M 8.7-9.2, with the best fit at M 9.0.

MAGNITUDE 8.7-9.2 explains three sets of reconstructed tsunami heights in Japan (p. 48), six assumed rupture areas at Cascadia, and various amounts of seismic slip in each of these rupture areas (Satame and others, 2003). The rupture depicted on the facing page is among three found consistent with geologic evidence for coastal subsidence like that on pages 16 and 17. The range M 8.7-9.2 excludes errors from ignoring bottom friction in computing the tsunami’s advance through shallow water off Japan.
Rupture and deformation from a hypothetical 1700 earthquake

Modern motions that help define the rupture area in 1700

Modeled Japanese tsunami heights for the earthquake, compared with heights inferred from flooding and damage

The orphan's parent
**Muddy forecast** 泥から森へ
How will history repeat itself at Cascadia?

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The earthquake timeline applies to Grays Harbor, Willapa Bay, and the Columbia River estuary (location map, p. 96). The gray bars span 95-percent confidence intervals from radiocarbon dating reported by Atwater and others (2004). The pictured outcrop adjoins site JR-1 of Shennan and others (1996). The intervals between great Cascadia earthquakes. Writings from China’s Shang dynasty—inscribed into cattle scapulas and turtle shells—date to 1200-1050 B.C. (Keightley, 1978, p. 228). Early examples of Chinese characters written in Japan date to the 5th century A.D. (Seeley, 2000, p. 4-6, 16-25). Japanese phonetic symbols became commonplace by early in the 11th century (Seeley, 2000, p. 76).
THE NEXT GREAT CASCADIA EARTHQUAKE is inevitable. The Cascadia plate boundary has repeatedly broken in great earthquakes during past millenia (summary graphs, below). Since 1700 the fault has been accumulating strain that future earthquakes will release (p. 99).

That next earthquake may have already happened by the time you read this, or it may come lifetimes later. Cascadia makes earthquakes on an irregular schedule.

In the example of irregularity at left, a low-tide outcrop in Washington displays buried soils from each of five great earthquakes of the past 3,000 years. Another buried soil lies below low tide, and still another is too poorly preserved to form a visible ledge.

The full sequence tells of seven earthquakes from the past 3,500 years. The six intervals between them average about 500 years but range from a few centuries to a millennium. The two longest intervals are marked by extensive remains of forests. Trees from the more recent of these long intervals enabled demanding tests of correlation with the January 1700 tsunami in Japan (p. 96-97).

During Cascadia’s next great earthquake, will the plate boundary rupture along its full length, as in 1700, or will it break one piece at a time? Either behavior would be consistent with geologic records of great Cascadia earthquakes. Piecemeal rupture can’t be ruled out (p. 24-25), especially if Cascadia behaves like subduction zones where successive earthquakes differ in size (box, below).

For now it is prudent to assume, simplistically, that the next great Cascadia earthquake has a one-in-ten chance of occurring in the next 50 years, and that it may attain magnitude 9 (p. 102-105). The one-in-ten odds follow from an average interval of 500 years if the fault lacks memory of when it last broke. The magnitude-9 assumption leaves a margin of safety in case of lesser events.

### AVERAGE INTERVALS BETWEEN GREAT CASCADIA EARTHQUAKES

<table>
<thead>
<tr>
<th>Inferred earthquakes</th>
<th>Number</th>
<th>Age range</th>
<th>Average recurrence interval</th>
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<tr>
<td></td>
<td>2</td>
<td>4-6</td>
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<td>0-6</td>
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<td>10-12</td>
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<td>13</td>
<td>13-15</td>
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**SOURCE OF ESTIMATES**

- Clague and Bobrowsky (1994)
- Adams (1990)
- Atwater and others (2004)
- Darienzo and Peterson (1995)
- Witter and others (2003)
- Kelsey and others (2005)
- Kelsey and others (2002)
- Clarke and Carver (1992)
- Petersen and others (2002)

Versatile faults

A SUBDUCTION ZONE that breaks in a long rupture may also rupture in shorter pieces. At Japan’s Nankai Trough, the rupture area of a single earthquake in 1707 slipped next in a pair of lesser earthquakes in 1854 and again in two parts in the 1940s (map, p. 85). Similarly in South America and South Asia, single earthquake ruptures have spanned the areas of multiple, smaller breaks. Variable rupture can be expected at Cascadia as well.

Japan, Ando (1975); Colombia-Ecuador, Kanamori and McNally (1982); Sumatra-Andaman, Bilham and others (2005).
PLANS FOR FLEEING TSUNAMIS in North America have been shaped by the Japanese accounts of the 1700 tsunami. The accounts, along with Native American traditions, have spurred such planning by providing eyewitness evidence for a giant Cascadia tsunami. Moreover, because the Japanese accounts suggest a Cascadia earthquake of magnitude 9, they provide a basis for evacuation signs and maps, such as those at right. Since 1997, tsunami mapping at Cascadia has been based on computer modeling of a Cascadia earthquake of M 9.1. The modelers chose this magnitude to resemble the one inferred, in 1996, from heights of the 1700 tsunami in Japan.

Since 1997, tsunami modeling has identified inundation-prone areas in cities and towns along Washington’s outer coast and on parts of the Oregon coast (index map, facing page). Evacuation maps based on the modeling serve most of the U.S. mainland population at risk from a great Cascadia tsunami. That at-risk population exceeded 150,000 year-round residents in the year 2000, as judged from census totals for areas within 1 km (0.6 mi) of tidewater.

The tsunami mapping helpscitizens and public officials identify areas of probable danger and of probable safety. The evacuation map for Gearhart, for example, shows where to assemble on high ground. The inundation map for Grays Harbor, opposite, similarly identifies a likely island of safety above a simulated tsunami in Westport. Farther inland at Aberdeen, the map depicts inundation that could turn logs into battering rams.

The models fit geologic evidence for the 1700 tsunami. The areas of computed inundation commonly contain sand sheets from the flooding in 1700. Sequences of computed water levels, such as those graphed opposite, show multiple waves like those recorded by tide gauges (p. 19, 49, 73) and by sediment layers (p. 18-19).

In simulations, the model tsunami has the advantage of overrunning freshly subsided land—land lowered as much as 1.5 meters (5 feet) during the parent earthquake. This is the subsidence anticipated on page 10, inferred from geology on pages 16-17, dated to 1700 or thereabouts on pages 24-25 and 96-97, and computed for a model rupture on page 99. The coast’s subsidence during an earthquake increases the hazard from the ensuing tsunami.

THE FIRST MAPS of hazards from a Cascadia tsunami showed potential inundation in northern California. They were based on a computer model in which a hypothetical wave is 10 m high in offshore waters 50 m deep (Bernard and others, 1994; Toppozada and others, 1995). OREGON’S LEGISLATURE soon mandated tsunami-inundation mapping of their entire coast. Under Senate Bill 379, passed in 1995 and implemented as Oregon Revised Statutes 455.446 and 455.447, new schools, hospitals, fire stations, and police stations shall not be constructed in areas subject to flooding by tsunamis, except where no alternative sites exist (http://www.leg.state.or.us/ors/455.html).
ELEMENTS OF TSUNAMI RISK FOR A CASCADIA EARTHQUAKE LIKE THAT OF 1700

HAZARD MAPS were prepared by Priest and others (1997; 1998; 1999a,b; 2000b; 2002) and by Walsh and others (2000; 2002a,b; 2003a,b; 2004). Their state-by-state index is at http://www.pmel.noaa.gov/tsunami/time/.

COASTAL POPULATION, tallied from U.S. Census data for the year 2000, is listed by jurisdiction at http://www.pmel.noaa.gov/tsunami/time/workshop/population.shtml. We round the figures down to the nearest 5000 (left) or 100 (below).

HAZARD POTENTIALLY INCREASED BY LOWERING OF LAND DURING EARTHQUAKE

EXAMPLE FOR GRAYS HARBOR, WASHINGTON

COMPUTED WAVES

LOG YARD AND HOMES IN HAZARD ZONE

GRAYS HARBOR HAZARD MAP and wave-train simulations, from Walsh and others (2000), are based on computer modeling of an assumed earthquake rupture 1,050 km long and, on average, 70 km wide (Myers and others, 1999; Priest and others, 2000a). The seismic slip is uniform along the length of this hypothetical rupture. Tide stage is held steady near mean tide level. Not depicted is the slightly greater tsunami modeled for a rupture that includes a patch of greater-than-average slip off Washington (asperity model of Walsh and others, 2000). PHOTO from Washington Department of Ecology digital coastal atlas (http://apps.ecy.wa.gov/website/coastal_atlas/viewer.htm), image 02081033_578.
Seismic waves

Tall buildings await Cascadia’s next great earthquake.

THE URBAN CORRIDOR between Vancouver, British Columbia, and Eugene, Oregon, can expect minutes of shaking from a great Cascadia earthquake. The shaking poses less of a threat to the region’s traditional wood-framed houses than to larger structures that are slender and flexible. Tall buildings, long bridges, and steel aqueducts sway most readily at periods of a second or more. Great earthquakes excel in exciting such long-period motion. A common result, seen in 1985 in Mexico City, is damaging resonance between the ground and the long-period structures founded on it.

Despite its inland location, the urban corridor from Vancouver to Eugene lies within range of damaging ground motions from great Cascadia earthquakes. Long-period waves from subduction earthquakes can travel hundreds of kilometers inland without losing much of their punch. In addition, the waves can get trapped and amplified in sedimentary basins like those beneath Seattle and Tacoma.

Only recently did these threats become certain enough to affect building design. Among Cascadia’s nearly 900 high-rises, more than half were completed by 1990 (graph). Not until 1994 did building codes in Washington and Oregon begin to reflect the great-earthquake threat. Even then, designers of newer structures faced a moving target as the credible size of a Cascadia earthquake rose to M 9 (p. 98-99), and as newly found urban faults augmented the hazard (block diagram).

The prospect of great Cascadia earthquakes influences the mapping of earthquake hazards in the western United States, especially for ground motions of long period. According to the maps at right, plate-boundary ruptures at Cascadia contribute to the hazard of long-period seismic shaking across Washington, Oregon, and northern California, particularly in the western parts of those states.

OLD SEATTLE BUILDINGS from lithograph at University of Washington Libraries, Special Collections, UW347. Tall-building tallies from http://www.emporis.info/en/. In the block diagram, geologic boundaries are based on interpretations by Parsons and others (1998) and Brocher and others (2003).

ON INLAND EARTHQUAKE SOURCES in the North America crust, see Bucknam and others (1992), Johnson and others (2001), Nelson and others (2003), and Sherrod and others (2004). On earthquakes within the underlying Juan de Fuca Plate, see Frankel and others (2002a) and Atkinson and Casey (2003).

TALL BUILDINGS SWAY at fundamental periods of 1-6 seconds (Building Seismic Safety Council, 2001, p. 106). The 1985 Michoacan earthquake of M 8.0 caused inordinate damage to Mexico City high rises with fundamental periods of 1 second, at a distance 400 km from this subduction earthquake’s source (p. 9; see also Scawthorn and Celebi, 1987).

BY LASTING A MINUTE OR MORE, a great Cascadia earthquake would likely cause more damage than would shaking of similar strength in a briefer earthquake (Tremblay, 1998).

STRONG SHAKING has been measured for earthquakes up to M 8.3 (Atkinson and Boore, 2003); ground motions for M 9 are extrapolations (Heaton and Hartzell, 1989). Beneath Seattle, a sedimentary basin several kilometers deep amplifies weak shaking at periods of 1-5 seconds (Pratt and others, 2003).

THE UNIFORM BUILDING CODE extended its seismic zone 3, for high hazard, throughout western Washington and western Oregon in 1994 (Atwater and others, 1995). FOR ADDITIONAL INFORMATION on ground-shaking hazards at Cascadia, see Yeats (2004), Ballantyne and others (2005), and Cascadia Region Earthquake Workgroup (2005).
LONG-PERIOD SHAKING: WHERE AND HOW MUCH DO GREAT CASCADIA EARTHQUAKES CONTRIBUTE TO THE HAZARD?

Main Source of Seismic Waves of 1 Cycle per Second

Great-Earthquake Contribution to 1-Second Hazard

THE MAPS ABOVE are derived from the 2002 version of national maps of earthquake shaking hazards in the United States (Frankel and others, 2002b; maps at http://eqhazmaps.usgs.gov/). The national maps show the combined effect of hundreds of earthquake sources (such as the sources cartooned opposite). Companion maps and graphs deaggregate the shaking to show contributions from the individual sources (Harmsen and others, 2003). The deaggregations above were provided by Stephen C. Harmsen.

ASSUMPTIONS ABOUT CASCADIA earthquakes built into the national maps:
- Either the earthquakes attain M 9 with ruptures about 1,000 km long, or they are limited to M 8.3 ruptures 250 km long. These end-member scenarios were introduced in previous national hazard maps (Frankel and others, 1996, p. 16-17).
- M 9 is as plausible as M 8.3. “For 2002, we assigned a weight of 0.5 for each scenario... For 1996, the weights were 0.67 for the M 8.3 scenario and 0.33 for the M 9.0 scenario. Since 1996, the M 9.0 scenario has gained credibility” (Frankel, and others, 2002b, p. 11).
- At a given place along the subduction zone, the mean recurrence interval for great earthquakes (either M 8.3 or M 9) is 520 years and the median interval 440 years. If the probability of earthquake occurrence does not vary with time within a recurrence interval, the resulting probability of either kind of event is about 10 percent in 50 years (Peterson and others, 2002, p. 2163-2164).
- IN CANADA, great Cascadia earthquakes contribute to the hazard mapped for the proposed 2005 edition of the national building code. The assumed earthquake size is M 8.2, on the premise that only a nearby part of an M 9 rupture, comparable in size to a M 8.2 rupture, governs a site’s shaking hazard (Adams and Atkinson, 2003, p. 260).

Shaking-hazard maps of the United States and Canada, including those above, do not yet reflect the long duration expected of great Cascadia earthquakes. An earthquake of M 9 would last several times longer than the largest earthquake expected of inland faults in the urban corridor. Engineers are beginning to grapple with how to design for shaking so prolonged.

It was a lack of seismic shaking that perplexed the Miho headman as he contemplated the orphan tsunami of 1700 (p. 54, 78-79). He or a later compiler recommended keeping the event in mind (right). Today, solved by geologic links to a distant earthquake, the headman’s puzzle serves as a reminder to guard against infrequent earthquakes and tsunamis of extraordinary size.
Acknowledgments 謝辞

Libraries in Berkeley, Morioka, Seattle, Tanabe, and Tokyo made available, for use in this book, maps that aid in visualizing the bygone world of the orphan tsunami of 1700. The example above—from the collection of the East Asian Library of the University of California, Berkeley—shows moats and samurai neighborhoods spiraling around the castle grounds of Edo in 1684. The white box outlines an area of daimyo mansions (enlarged view, p. 61).

WHERE JAPANESE WRITERS recorded the 1700 tsunami, dozens of people helped us explore questions central to this book: Who wrote the original accounts of the flooding and damage? Why were these accounts written and how were they preserved? Which passages contain errors in copying? Where are the places described as flooded? Were these same places reached by the 1960 tsunami as well?

In Morioka, Konishi Hiroaki granted access to the Moriake-han documents reproduced on pages 36, 38-39, 44-45, 58, and 60. He provided clues on how Moriake-han “Zassho” was compiled, documentation on senior ministers named there, and likely dates for the early 18th-century maps of Miyakodōri and Ōtsuchi-dōri (p. 36, 44, 58). He serves as librarian of the Documents Office, Morioka City Central Community Center (Kyōdo Shiryō Shitsu, Morioka-shi Chūō Kōminkan).

On the coast in modern Miyako city, Yamazaki Toshiro and Sasaki Tsutomu identified places inundated by the 1960 tsunami in Kuwagasaki and Tsugaruishi (photos, p. 49 and 51). In 1999, Mr. Yamazaki was fire chief and Mr. Sasaki one of his deputies at the Central Fire Station of the Miyako Unified Fire District (Miyako-chiku Kōki Kumiiai Gyōsei, Shōbōsho Honbu). Shuto Nobuo of Iwate Prefectural University provided an introduction to Mr. Yamazaki and a walking tour of Kuwagasaki’s tsunami-prone districts. Kishi Shōichi, a historian for Miyako city, shared his knowledge of Miyako’s Edo-period governance. His successor, Kariya Yūichirō, helped us interpret and photograph Moriai-ke “Nikki kaktome chō.”

In Tsugaruishi, Moriai Mitsunori granted access to his family’s notebook, Moriai-ke “Nikki kaktome chō.” He and his mother welcomed three of us into the family home (p. 53). Iwamoto Yoshiteru, an authority on the area’s Edo-period economy (books, p. 116), provided guidance on obscure place names of Tsugaruishi (p. 50, 51, 56).

Morikoshi Ryō of Hachinohe helped Ueda identify copyist’s errors in Moriai-ke “Nikki kaktome chō” by providing a transcription, in printed Japanese, of official records of Hachinohe-han, its “Han Nikki” (footnoted, p. 52). Mr. Morikoshi leads Hachinohe Konomono Benkyō-kai, a group that studies historical documents and which made the transcription of Hachinohe “Han Nikki.”

Moriai Mutsuharu, a retired schoolteacher in Tsugaruishi, adopted Atwater and Yamaguchi for a day of interviewing his fellow villagers about the 1960 tsunami (sites marked by blue and yellow dots, p. 56). Those who identified inundation limits include Yonezawa Takui (in color photo, p. 57, upper right) and Moriai Miya (photo, below).

In Ōtsuchi, Maeda Zenji, Fujimoto Toshiaki, and Kamata Seizō provided guidance on Edo-period neighborhoods. They also shared the town’s collection of photographs and maps showing sites inundated by the 1960 tsunami. When interviewed in 1999, Mr. Maeda headed Ōtsuchi’s Historical Preservation Council (Ōtsuchi-chō Bunzakai Hogo Shingikai), while Messrs. Fujimoto and Kamata served as assistant director and archaeologist, respectively, in the town’s office of continuing education (Ōtsuchi-chō Kyōiku Iinkai, Shkai Kyōkka).

Ogawa Kaori journeyed to Ōfunato to learn about that city’s devastation by the 1960 tsunami and its lack of writings on the 1700 tsunami (p. 81). She also checked for written records in Sendai. In Ōfunato she received help from Satō Etsuro of Ōfunato city, Shirato Yutaka and Kin’no Ryōichi of Ōfunato Museum, and Honda Fumito of nearby Rikuzentakada city.

Town officials, local historians, and private citizens of Hitachinaka (formerly Nakaminato) twice received visitors interested in tsunami evidence from Ōuchi-ke “Go-yōdome.” The hosts included Kawasaki Osamu, Onizawa Yōichi, Onizawa Yasuhiro, Saitō Arata, Satō Tsugio, and, from the family that conserves the document, Ōuchi Yoshikuni. Town officials permitted photographs of the volume and of a picture map (p. 66-70).

In Miho, Endō Kunio kindly met with three North Americans to share with them “Miho yōji oboe” and how he came to possess it (p. 76). Mr. Endō’s daughter, Mayumi, arranged a later gathering with two local historians, Endō Shōji and Watanabe Yasuhiro. She also provided copies of books on “Oboe” by Endō Shōji and others (p. 115).

Nagao Toshiyasu of Tokai University joined two of us in Miho for interviews of witnesses to the 1960 tsunami and 1974 storm: Shiba Tsune, Mizuno Teruko, and a lady in the Ishino family (p. 82-83). Moriguchi Osamu, of the central fire office of Shimizu city, arranged for an interview with another witness to the 1960 tsunami, Aoki Yukio.

Officials and residents of Tanabe welcomed us repeatedly for visits that included informative discussions with Kishi Akinori, a local historian, and field trips guided by
members of the city’s general affairs office: its directors, Yamasaki Kiyohiro and Okamoto Yoshihiko, and staffers Urabe Shunji and Shin’ya Jun. Ota Yüji, librarian with the municipal library, granted access to Tadokoro documents and shared his views of their history (p. 84–87). Hashimoto Kuniko and Minakata Fumie provided a tour of a Tanabe storehouse (photo, below left). In Shinjō, Matsuzaiki Tomiji welcomed visitors to a storehouse site (p. 88) and Kashiwagi Tomio provided photos of the 1960 tsunami (p. 89).

Not far from Tanabe, in Hirogawa, Shimizu Izao gave three North Americans an enthusiastic, full-day field trip on Hamaguchi Goryō and his response to the 1854 tsunami that devastated Hiro-mura (photo, below right). At the time of that field trip, Mr. Shimizu was continuing education specialist at the town’s community center, Hirogawa-chō Chūō Kōminkan. Tsumura Kenshiro, formerly of Hirogawa, further advised us on Goryō and “Inamura no hi.” The picture on page 47 was taken by him and is reproduced with permission of the painting’s owner, Yōgen Temple.

IN FORMER EDO, Watanabe Tokie of the Earthquake Research Institute (ERI), University of Tokyo, set up some of the rural visits. Murakami Yoshikane, while a graduate student at ERI, provided a speedy drive to northeast Japan. Kato Teruyuki of ERI advised us on tide-gauge data. Hirata Sakura and Kikuchi Ryōichi of Meiji University allowed us to examine maps of Japan and Suruga province from 1702 (p. 32, 76). Ota Yoko, formerly of Yokohama National University, helped us interpret the picture maps of Morioka-han (p. 36, 44, 58), the inland waterways between Nakaminato and Edo (p. 67), and land-level changes in northeast Japan (p. 65). She also arranged for an Edo mansion for Atwater and his family; and Joel Muraoka provided Tokyo lodging for Yōmaguchi.

In nearby Tsukuba, Okada Masami and Tanioka Yūichirō of the Meteorological Research Institute, Japan Meteorological Agency, checked tidal measurements and datums. Odagiri Satoko, of the Geographical Survey Institute, provided old topographic maps. Staff of the Active Fault Research Center, a part of the National Institute of Advanced Industrial Science and Technology, extended countless courtesies to Atwater. These included telephone interviews and trip planning by Isoda Hisako, guidance on Japanese history and language from Horikawa Haruo and Nanayama Futoshi, and bibliographic work by Satō Nobue. Dr. Horikawa photographed the monument on page 45; Ms. Satō, the anthologies on pages 62 and 123. Azuma Takashi led the visits to Hitachinaka and to the shogunal maps at Meiji University (p. 32, 76).

Atwater’s contributions to the book were made possible, in part, by several visits to Japan. During the longest of these, for nearly a year, his travel and living expenses were covered by Japanese government fellowships from the Center for Global Partnership, ERI, the Science and Technology Agency, and the Geological Survey of Japan. Persons who made these fellowships possible include Usui Akira and Ozaki Hiromi of the Geological Survey of Japan; Satō Hiroshi, Shimazaki Kunihiko, and Murakami Tomoko of ERI; and Ruth Reid and Rebecca Barnhart, and Jack Medlin of the U.S. Geological Survey (USGS).

Matsuda Izumi welcomed Atwater to her first-year Japanese language course at the University of Washington. Yōmaguchi drew on Japanese language training that includes a summer program in 1976 (sponsored by Sumitomo Bank) and immersion during an appointment at the Hokkaido Research Center of the Forestry and Forest Products Research Institute from 1994 to 1996 (supported by Japan’s Science and Technology Agency).

THE NORTH AMERICAN PARENT for Japan’s orphan tsunami of 1700 became known through the work of a great many people. The principals include Hiroo Kanamori of the California Institute of Technology; Tom Heaton and Alan Nelson of the USGS; and Minze Stuiver of the University of Washington.

The Nuclear Regulatory Commission underwrote the radiocarbon dating of trees and herbs killed by tidal submergence from the 1700 earthquake (p. 24–25). In Minze Stuiver’s lab, Philip Wilkinson analyzed the spruce samples.

Unsung heroes of the earthquake’s tree-ring dating include Boyd Benson, Lori Davis, John Shulene, Karl Wegmann, and Marco Cisternas, all of whom helped dig out and sample the stumps of earthquake-killed red cedar.

Pierre Saint-Amand provided sharp prints of the Chilean photos on pages 10 and 11. The Alaskan airphoto on page 14 comes from the collection of A. Thomas Ovenshine and Susan Bartsch-Winkler, formerly of the USGS. Ian Shennan supplied one of the more recent Alaskan images on page 95.
THIS BOOK began in 1999 as a manuscript too large for its initially intended outlet, a volume of papers on subduction zones. Andō Masataka—who twenty years earlier published a seminal paper on Cascadia’s great-earthquake potential—released Atwater from a promise to contribute to that volume.

Critical review began that year with Andrew Moore, then at Tohoku University, and Ruth Ludwin, University of Washington. Ebara Masaharu of the Historiographical Institute, University of Tokyo, corrected subsequent transliterations and translations of the Edo-period documents. Later drafts were reviewed in full by Emile Okal of Northwestern University; Ruth Pelz of the Burke Museum, Seattle; Yoko Ota; and Ruth Kirk, Kip Ault, Eric Blackford, and an anonymous reader on behalf of University of Washington Press. Suggestions from the anonymous reader spurred reorganization of the book and expansion of its chapters on the Cascadia subduction zone. Additional reviews were provided by Patricia Atwater, Lori Dengler, Adriana Erickson, Ned Field, Harumi Kato, Hayakawa Yukio, Hal Mojfield, Joel Muraoka, Yoshiko Sorensen, and Vasily Titov. Pauline Curiel and Satō Nobue printed and circulated the reviewers’ copies.


The reference list includes titles located by Keiko Yokota-Carter, the Japanese-language specialist at the East Asia Library, University of Washington. Inoue Megumi, Nakamura Noriyuki, and Ekida Fusae, bilingual graduate students from Japan, translated reference materials and romanized bibliographic citations. Additional translations were provided by Tajima Maiko and Harada Shino. Annalie Eipert helped compile the references.

The book’s design is based on a USGS pamphlet by Peter Ward, Robert Page, Laurie Hodgson, and Jeff Troll, and on examples presented by Edward Tufte. Susan Mayfield and Sara Boore of the USGS provided guidance on color, fonts, and layout; Boore also prepared the block diagrams adapted on page 10. Ed Mulligan and Lorien Freeman, University of Washington, helped us mock up pages by providing computer-network connections and maintaining a color printer.

The USGS granted Atwater freedom to devote several years to the book. Michael Blanpied, Nancy Rountree, Peter Stauffer, and Jane Cienner helped set aside USGS funds for editing and printing. Ruth Kirk initiated discussions, with Michael Duckworth and Pat Soden, that led to joint publication by University of Washington Press.

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- Meiji University Library, Tokyo—p. 32-33, 76
- Morioka City Central Community Center, Documents Office—p. 36, 44, 45, 49, 50, 58
- Ofunato city—p. 81, 133
- Sendai Museum—p. 127
- Shinjō Community Center—p. 85, 89
- Tanabe Municipal Library—p. 84, 90
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- University of California, Berkeley, National Information Service for Earthquake Engineering—p. 9
- University of Washington Libraries, Special Collections—frontispiece and p. 2, 13, 104, 129
- Yōgen temple, Hiogawa—p. 47


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The Nuclear Regulatory Commission, reviewing the design of this power plant, supported carbon-14 dating of Cascadia earthquakes (p. 25).

Satsop, Washington (location map, p. 96).

Boyd Benson, in an Oregon tidal swamp, checks the annual rings of a spruce survivor of the 1700 earthquake (p. 97).
THE STORY OF THE 1700 TSUNAMI draws on human history interpreted from old Japanese documents, on natural history inferred from North American sediments, trees, and native legends, and on mathematical modeling of tsunamis. The authors pooled their backgrounds in these and other fields. Below, as on the cover and title page, their names appear alphabetically.

**THE ORPHAN TSUNAMI OF 1700**

SATAKE Kenji 佐竹 健治 estimated sizes of the 1700 tsunami in Japan and the 1700 earthquake at Cascadia. He also tracked down primary sources for accounts of the 1700 tsunami in Tsugaruishi and Nakaminato. These contributions stem from his broad interest in subduction-zone earthquakes, which he studies with instrumental, written, and geological records, and with geophysical modeling. He holds B.S. and M.S. degrees in geophysics from Hokkaido University and a Ph.D. in geophysics from the University of Tokyo. He spent seven years in the United States, as a postdoctoral researcher at the California Institute of Technology and as an assistant professor at the University of Michigan. Since 1995 he has worked at the Geological Survey of Japan, where he is now deputy director of the Active Fault Research Center of the National Institute of Advanced Industrial Science and Technology. His field work in 2005 included post-tsunami surveys in Myanmar and Thailand. He chairs the tsunami commission of the International Union of Geodesy and Geophysics, serves on governmental committees that evaluate earthquake hazards in Japan, and edits “Rekishi Jishin,” the journal of Japan’s Society of Historical Earthquake Studies.

**TSUJI Yoshinobu 都司 嘉宣** identified places reached by the 1700 tsunami, computed tides for estimates of the tsunami’s height, and helped transliterate and translate the tsunami accounts. From the University of Tokyo he earned a B.S. in civil engineering, and M.S. and Ph.D. degrees in geophysics. His studies of Japan’s historical earthquakes and tsunamis began in the 1970s, when he worked for the National Research Center for Disaster Prevention. In 1987 he joined the faculty of the University of Tokyo’s Earthquake Research Institute. He subsequently participated in post-tsunami field surveys in Nicaragua and Papua New Guinea, and he led such surveys in 2005 in Aceh and Thailand. He has also investigated storm surges and tsunami-induced damage to buildings. His second languages include Korean, Chinese, Russian, English, and Fortran.

**BRIAN ATWATER Brian F. Atwater** conceived of the book and led in its preparation. To this work he brought over a decade of experience with geologic records of the 1700 earthquake and tsunami in North America. Through field work in 1999 he also contributed to size estimates for the 1700 tsunami in Japan. He holds B.S. and M.S. degrees in geology from Stanford University and a Ph.D. in geology from the University of Delaware. In thirty years with the U.S. Geological Survey he has studied bay and river geology in California, ice-age floods in Washington, and geologic records of earthquakes and tsunamis in the United States, Chile, and Japan. He lives in Seattle and is based at the University of Washington.

**MUSUMI-ROKKAKU Satoko 六角 聡子** guided the transliteration and translation of the tsunami accounts. She also contributed to interviews in northeast Japan and to historical background material. Her education includes a B.A. in Humanities at Tokyo’s International Christian University and an ensuing year as a Fulbright Fellow at the University of Chicago, where she did graduate work in Islamic cultural history and Arabic language. Since 1979 she has coordinated the United Nations University fellowship program for Asian food scientists while teaching at Tokyo’s Obirin University. She has served as an officer in the UNU Women’s Association and holds an honorary professorship at the Mongolian University of Science and Technology. Her travels have taken her to 33 countries.
UEDA Kazue 上田 和枝 discovered, transliterated, and translated accounts of the 1700 tsunami. She also confirmed the tsunami’s misdating in Moriai-ke "Nikki Kakitome-chō" (p. 53), investigated the historical context of the tsunami’s accounts, and interviewed witnesses to the 1960 tsunami. For over thirty years she has specialized in the written records of Japanese earthquakes. She entered that field eleven years after earning a B.A. in psychology at Tokyo Woman’s Christian College and joining the Earthquake Research Institute, University of Tokyo. The 21-volume, 16,812-page earthquake anthology, “Shinshū Nihon jishin shiryō” (p. 123), resulted largely from her efforts. These included some 300 visits to libraries, prominent families, government offices, temples, and shrines where she searched thousands of pages daily for accounts of earthquakes and tsunamis. Since retiring from the Earthquake Research Institute in 1998 she has remained active in meetings and publications on Japan’s historical earthquakes.

David K. YAMAGUCHI デイビッド・K・ヤマグチ relentlessly revised the entire book for presentation and content. He also contributed tree-ring dates, photographs, and bilingual interviews in Tsugaruishi, Miho, and Tanabe. A Seattle-born grandson of Japanese immigrants, he earned a B.S. in biology at Yale and a Ph.D. in forestry at the University of Washington. While a graduate student, he dated two eruptions of Mount St. Helens to 1479-1482 from the thin rings of trees damaged downwind. These findings led to a postdoctoral fellowship with the U.S. Geological Survey, where he dated volcanic debris flows by matching the ring-width patterns of entombed trees with those of living ones. During that fellowship he began the coastal tree-ring studies that helped identify Cascadia as the source of the orphan tsunami (p. 24, 96-97). Those studies progressed while he served on the research faculty of the University of Colorado and worked as a visiting scholar at the Forestry and Forest Products Research Institute, Hokkaido. Later he became a financial advisor at Merrill Lynch and a public-health statistician at the University of Washington's School of Dentistry. He now analyzes public-health data as a programmer at the Center for Health Studies, Group Health Cooperative, Seattle.
Two accounts of the 1700 tsunami were first published in Musha Kinkichi’s second volume of collected materials on Japanese historical earthquakes. The accounts, boxed above, are quoted on page 62. The volume is listed in the references by its corporate author, Mombushō Shinsai Yobō Hyōgikai.

Mombushō Shinsai Yobō Hyōgikai (1943, p. 25).
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When the tsunami comes ashore, every villager is standing safely on high ground.


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Accounts of the 1700 tsunami form part of the 21-volume, 16,812-page earthquake anthology, “Shinshū Nihon jishin shiryō” (p. 62). Two of the volumes are cited at the top of the facing page, under Tokyo Daigaku Jishin Kenkyūsho.

First volume, shelved at upper right, was published in 1981.

Fingered volume, published in 1993, contains accounts of the orphan tsunami of 1700.
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* Like the associated earthquakes (footnote, p. 126), these tsunamis are known by era and region. Complications: Hakuhō is obsolete as an era name, and the 1854 tsunami predate the Ansei era but are customarily assigned to it.
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A wave from Chile in 1960
approaches roofs of Ōfunato,
Japan (p. 81).

Courtesy of Ōfunato city
A SIMULATED TSUNAMI modeled on the one in 1700 floods nearly all of the peninsular town of Westport, Washington (p. 103). The area mapped as tsunami-prone includes the grounds of the town’s public schools, which stand on a low sandy plain between the Pacific Ocean and Grays Harbor.

A partial remedy was rising from that plain in 2015, as this book approached reprinting. Two years earlier, voters in Grays Harbor and Pacific Counties had approved a $13.8 million bond issue for school reconstruction. The measure provided for a tsunami haven—a rooftop platform with space for as many as a thousand persons.

The platform design combines resistance to earthquake shaking, safeguards against tsunami scour, and ample height. Reinforced concrete towers support the flat roof at its four corners. Piles are driven fifteen meters into the sand. The platform stands nine meters above ground, well above simulated water levels in an extreme scenario (diagrams, opposite).

This engineered refuge, North America’s first for tsunamis, has roots across the Pacific. Its design incorporates lessons from the catastrophic tsunami of March 2011. Its funding came about while memories of that disaster were fresh. Its necessity came to light, in large part, through matching of North American and Japanese clues to the transpacific tsunami of January 1700.

—Prepared by Brian Atwater and David Yamaguchi from information provided by Paula Akerlund, superintendent, Ocosta School District; Cale Ash, associate principal with Degenkolb Engineers in Seattle and engineer of record for the Ocosta project described here; Robert Butler, professor, University of Portland, and founder, Cascadia Earthscope Earthquake and Tsunami Education Program (CEETEP); Jon Harwood, science and math teacher, Ocosta secondary schools; John Schelling, earthquake, tsunami, and volcano programs manager, Emergency Management Division, Washington State Military Department; Beth Pratt-Sitaula, CEETEP program director; and Charles Wallace, deputy director, Grays Harbor County Department of Emergency Management.
The refuge design was guided by this tsunami simulation, which allows for subsidence during the earthquake (p. 14–17) and for erosion during the tsunami.

The four corner towers rose first (photo, July 2015). The completed tsunami refuge will span the flat roof of a gymnasium, with doors at ground level providing access through the corner towers (artist’s conception).
A puzzling tsunami entered Japanese history in January 1700. Samurai, merchants, and villagers wrote of minor flooding and damage. Some noted having felt no earthquake; they wondered what had set off the waves but had no way of knowing that the tsunami was spawned during an earthquake along the coast of northwestern North America. This orphan tsunami would not be linked to its parent earthquake until late in the twentieth century, through an extraordinary series of discoveries in both North America and Japan.

The Orphan Tsunami of 1700, now in its second edition, tells this scientific detective story through its North American and Japanese clues. The story underpins many of today’s precautions against earthquake and tsunami hazards in the Cascadia region of northwestern North America. The Japanese tsunami of March 2011 called attention to these hazards as a mirror image of the transpacific waves of January 1700.

“The relevance of this history to our present-day situation is underscored. This book about the ‘big one’ of long ago should be of special interest to all of us right now.”
—HISTORY LINK

“A meticulous and comprehensive piece of scholarship that both draws on the authors’ groundbreaking research and pulls together hundreds of references on the topic... The text is highly readable and requires no special expertise, only a scientific curiosity and a willingness to participate in the assembly of discovery.”
—OREGON HISTORICAL QUARTERLY

“Paddling around the salt marshes and tidal flats of Washington State, Atwater discovered evidence of earthquakes and giant waves of a magnitude that seemed, to many, inconceivable—until late last year, when a tsunami of similar power tore across the Indian Ocean killing more than 200,000.”
—TIME MAGAZINE, NAMING BRIAN ATWATER ONE OF THE WORLD’S 100 MOST INFLUENTIAL PEOPLE OF 2005