

Surviving a Tsunami—Lessons from Chile, Hawaii, and Japan

Circular 1187

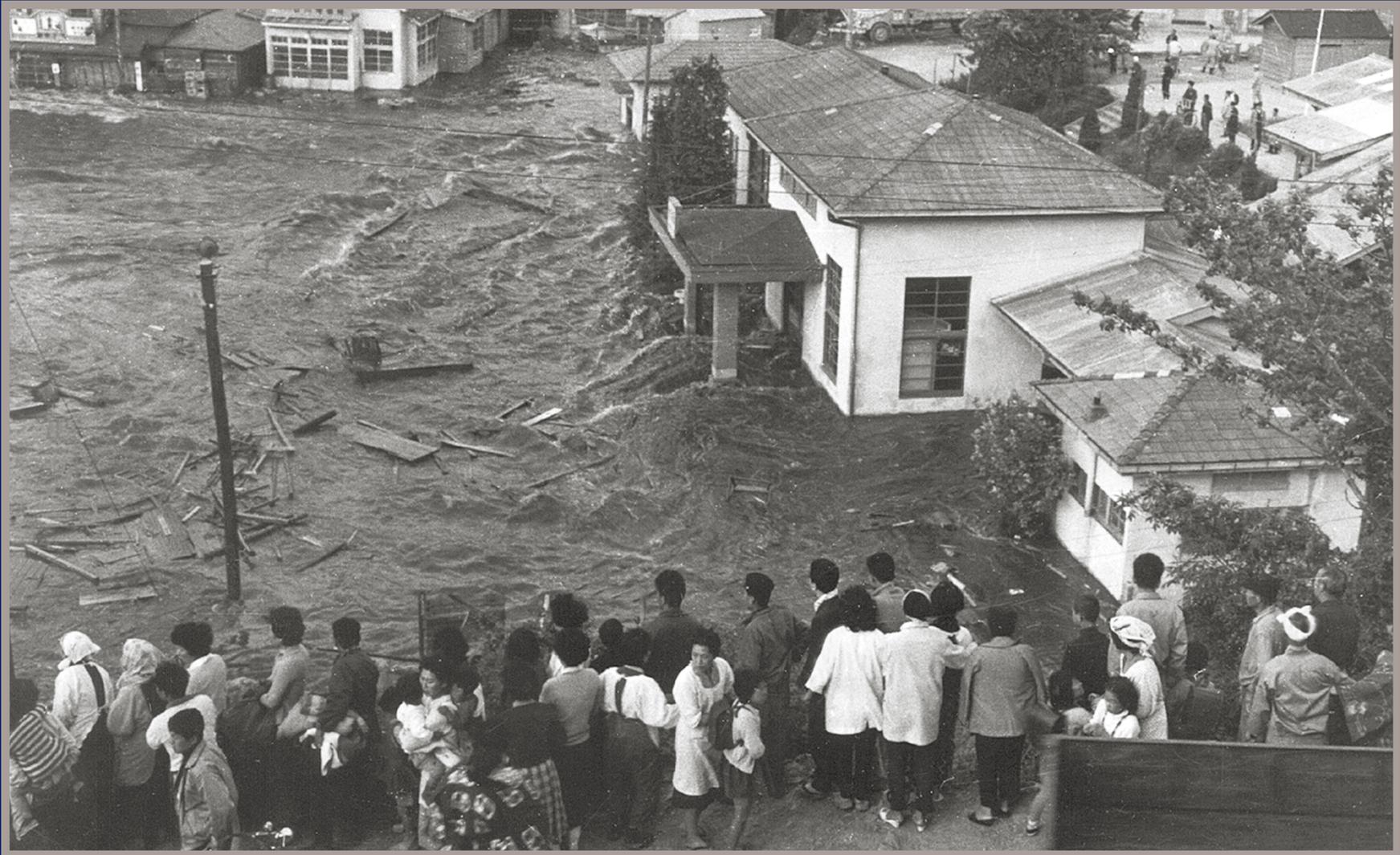


Photo on front cover: Seen safely from high ground, a wave of the 1960 Chilean tsunami pours into Onagawa, Japan.



Photo at left: Aftermath of the 1960 Chilean tsunami in Hilo, Hawaii, where the tsunami caused 61 deaths.

U.S. Department of the Interior
U.S. Geological Survey

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Compiled by Brian F. Atwater, Marco Cisternas V., Joanne Bourgeois, Walter C. Dudley, James W. Hendley II, and Peter H. Stauffer

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Actions that saved lives, and actions that cost lives, as recounted by eyewitnesses to the tsunami from the largest earthquake ever measured—the magnitude 9.5 earthquake in Chile on May 22, 1960.

U.S. Department of the Interior

Bruce Babbitt, Secretary

U.S. Geological Survey

Charles G. Groat, Director

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Surviving a Tsunami—Lessons From Chile, Hawaii, and Japan

Compiled by Brian F. Atwater, Marco Cisternas V.¹, Joanne Bourgeois², Walter C. Dudley³, James W. Hendley II, and Peter H.

Introduction

This book contains true stories that illustrate how to survive—and how not to survive—a tsunami. It is meant for people who live, work, or play along coasts that tsunamis may strike. Such coasts surround most of the Pacific Ocean but also include other areas, such as the shores of the Caribbean, eastern Canada, and the Mediterranean.

Although many people call tsunamis “tidal waves,” they are not related to tides but are rather a series of waves, or “wave trains,” usually caused by earthquakes. Tsunamis have also been caused by the eruption of some coastal and island volcanoes, submarine landslides, and oceanic impacts of large meteorites. Tsunami waves can become more than 30 feet high as they come into shore and can rush miles inland across low-lying areas.

The stories in this book were selected from interviews with people who survived a Pacific Ocean tsunami in 1960. Many of these people, including the nurse at right, contended with the waves near their source, along the coast of Chile. Others faced the tsunami many hours later in Hawaii and Japan. Most of the interviews were done decades later in the 1980’s and 1990’s.

The stories provide a mixed bag of lessons about tsunami survival. Some illustrate actions that reliably saved lives—heeding natural warnings, abandoning belongings, and going promptly to high ground and staying there until the tsunami is really over. Others describe taking refuge in buildings or trees or floating on debris—tactics that had mixed results and can be recommended only as desperate acts.

Palmira Estrada, a nurse who survived the 1960 tsunami in Maullín, Chile, talks with interviewer Marco Cisternas in 1989. Behind them stands a hospital that was evacuated during the tsunami. The waters of the tsunami washed against the building.

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³Pacific Tsunami Museum, P.O. Box 806, Hilo, HI 96721.



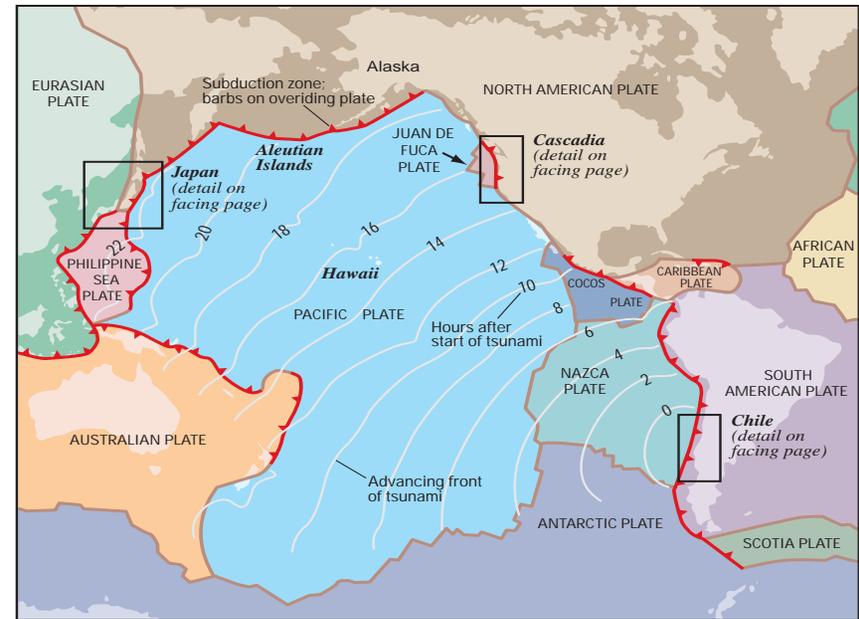
The 1960 Tsunami and the Earthquake in Chile That Caused It

Most of the events described in this book were caused by a series of waves widely known as the “1960 Chilean tsunami.” The tsunami was a result of the largest earthquake ever measured (magnitude 9.5). This quake occurred along the coast of Chile on May 22, 1960.

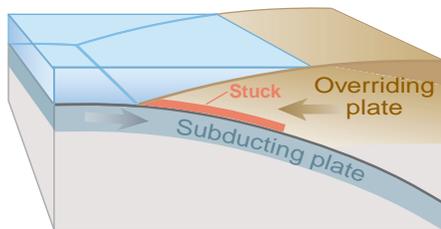
In Chile, the earthquake and the tsunami that followed took more than 2,000 lives and caused property damage estimated at \$550 million (1960 dollars). From Chile the tsunami radiated outward, killing 61 people in Hawaii and 122 in Japan.

The 1960 Chile earthquake ruptured a fault zone along which a slab of sea floor is descending, or “subducting,” beneath the adjacent South American Continent. Such “subduction zones” are formed where two of the tectonic plates that make up the Earth’s outer shell meet. Earthquakes occur when the fault ruptures, suddenly releasing built-up energy. During the 1960 Chile earthquake, the western margin of the South American Plate lurched as much as 60 feet relative to the subducting Nazca Plate, in an area 600 miles long and more than 100 miles wide.

The 1960 Chilean tsunami radiated outward from a subduction zone along the coast of Chile. Its waves reached Hawaii in 15 hours and Japan in 22 hours.

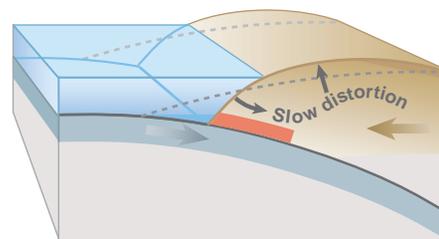


TSUNAMI—A SERIES OF WAVES, OR “WAVE TRAINS,” USUALLY TRIGGERED BY AN EARTHQUAKE



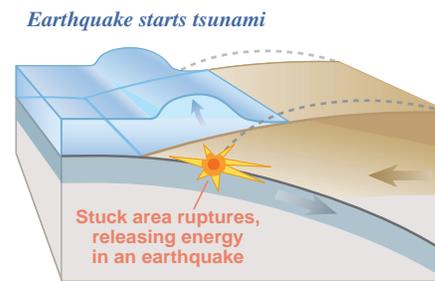
Vertical Slice Through a Subduction Zone

One of the many tectonic plates that make up Earth’s outer shell descends, or “subducts,” under an adjacent plate. This kind of boundary between plates is called a “subduction zone.” When the plates move suddenly in an area where they are usually stuck, an earthquake happens.



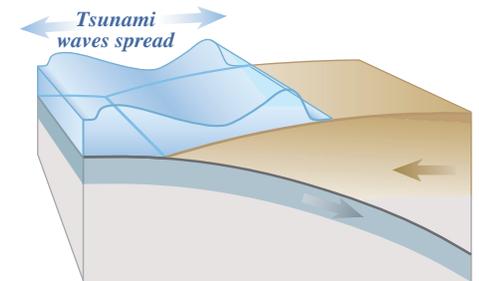
A. Between Earthquakes

Stuck to the subducting plate, the overriding plate gets squeezed. Its leading edge is dragged down, while an area behind bulges upward. This movement goes on for decades or centuries, slowly building up stress.



B. During an Earthquake

An earthquake along a subduction zone happens when the leading edge of the overriding plate breaks free and springs seaward, raising the sea floor and the water above it. This uplift starts a tsunami. Meanwhile, the bulge behind the leading edge collapses, thinning the plate and lowering coastal areas.



C. Minutes Later

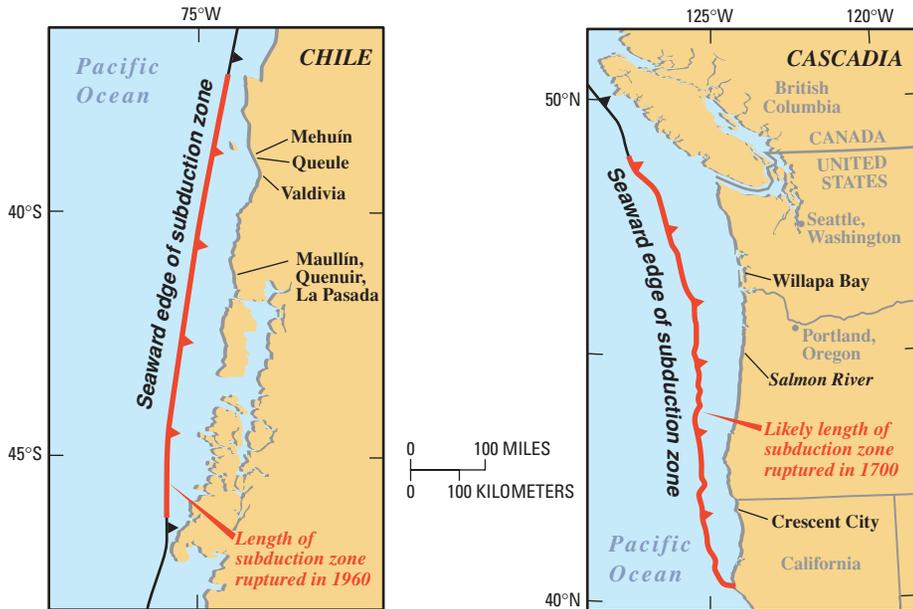
Part of the tsunami races toward nearby land, growing taller as it comes in to shore. Another part heads across the ocean toward distant shores.

Similar Tsunamis, Similar Strategies for Survival

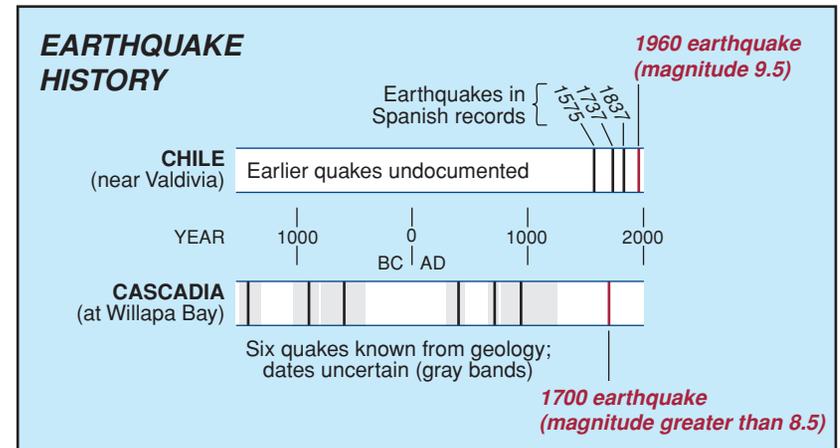
Some areas around the margin of the Pacific Ocean are located near subduction zones similar to the one that produced the 1960 Chile earthquake and its tsunami. One of these areas is Cascadia—southern British Columbia, Washington, Oregon, and northern California.

Recently, it has been discovered that the Cascadia Subduction Zone, like the subduction zone off Chile, has a history of producing earthquakes that triggered tsunamis. The most recent of these earthquakes, in 1700, set off a tsunami that struck Japan with waves about as big as those of the 1960 Chilean tsunami in Japan. However, modern Cascadia has had little experience with tsunamis and almost no experience with tsunamis generated close to home. Because of this, people in Cascadia need to look elsewhere for guidance about tsunami survival.

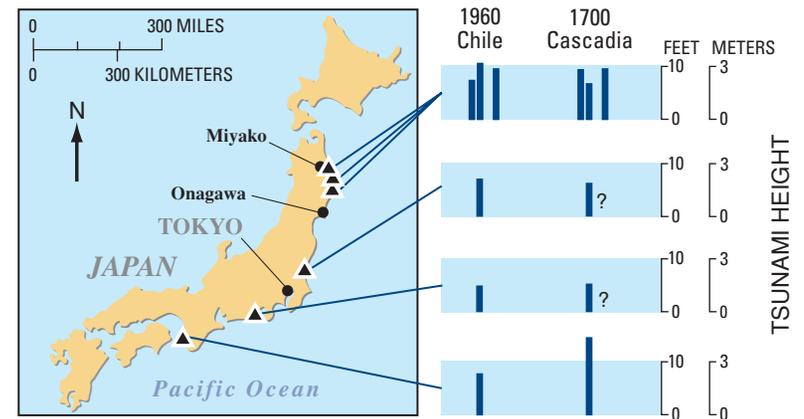
Perhaps the most basic guidance for people in Cascadia comes from the account on the following page. Many people in Cascadia may think that “The Big One”—an earthquake of magnitude 9—will kill them before its tsunami rolls in. So, why bother to prepare for such a tsunami? In the account, all the people in and near the town of Maullín, Chile, survived the biggest earthquake ever measured. The deaths in the area came later, during the tsunami that followed the quake.



Both the 1960 Chile earthquake and the 1700 Cascadia earthquake were caused by sudden ruptures of long segments of subduction zones. Each of these quakes generated a tsunami that not only struck nearby coastal areas but also caused damage in coastal areas as far away as Japan.



Long times between earthquakes can erase memories of how to survive their tsunamis. The region of the 1960 Chile earthquake had gone without such a quake since 1837. Except for Native American legends, memory of the 1700 Cascadia earthquake is limited to written records of its tsunami in Japan.



As shown by wave heights observed in Japan, subduction-zone earthquakes in Chile and Cascadia have caused tsunamis that were large even after crossing the Pacific Ocean.

Many Will Survive the Earthquake

In coastal areas, the largest subduction zone earthquake may kill fewer people than the tsunami that follows.

José Argomedo survived the 1960 Chile earthquake, which he initially mistook for nuclear war. Mr. Argomedo was 22 years old and living on a farm outside Maullín, Chile, where he got news of the world from his radio. Early in May 1960, the big news was the tension between the United States and the Soviet Union—a Soviet missile had downed an American spy plane.

On May 18, the Soviet leader, Nikita Khrushchev, suggested treating the United States like a cat that had stolen cream.

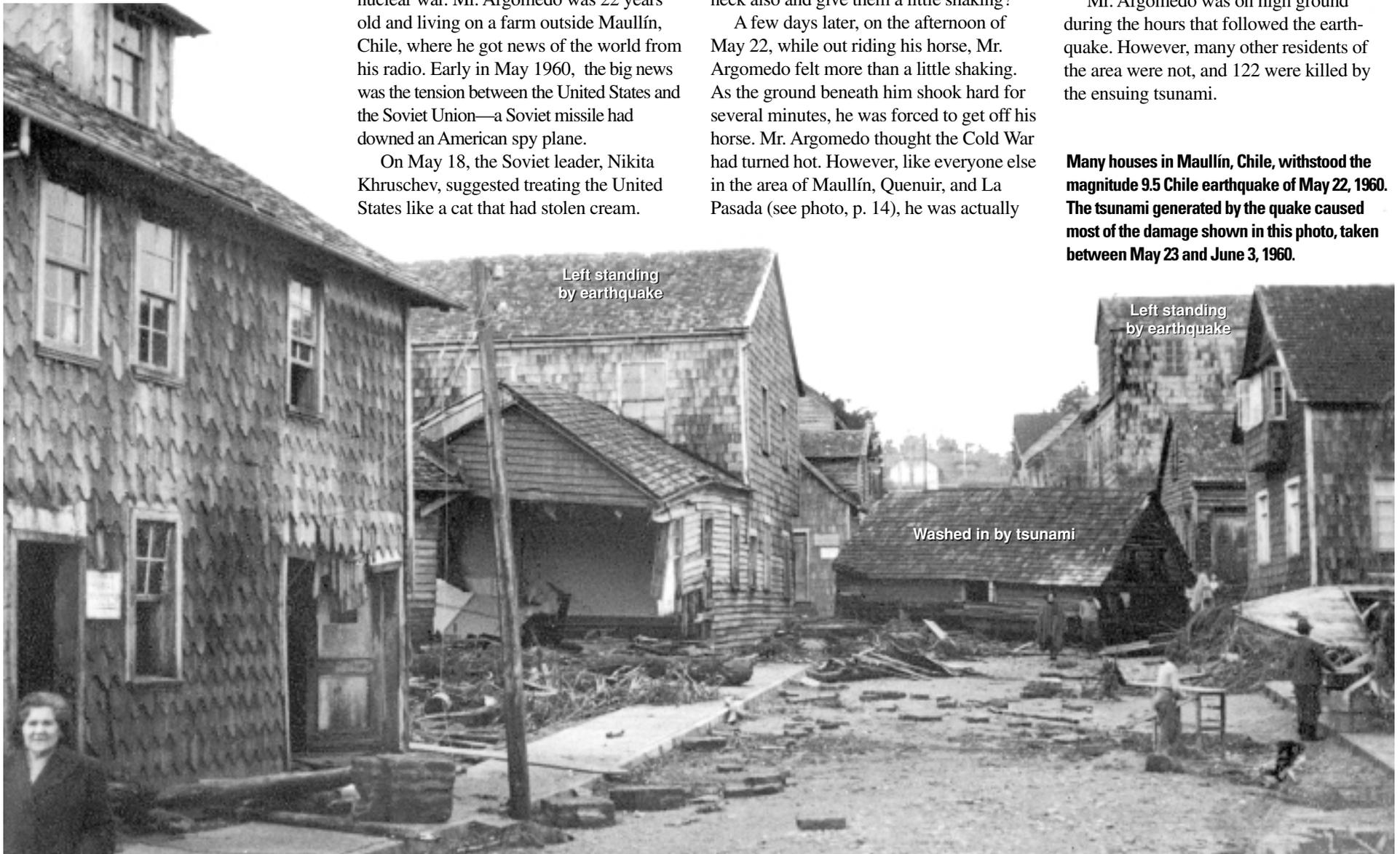
“Wouldn’t it be better,” he said, “to take the American aggressors by the scruff of the neck also and give them a little shaking?”

A few days later, on the afternoon of May 22, while out riding his horse, Mr. Argomedo felt more than a little shaking. As the ground beneath him shook hard for several minutes, he was forced to get off his horse. Mr. Argomedo thought the Cold War had turned hot. However, like everyone else in the area of Maullín, Quenuir, and La Pasada (see photo, p. 14), he was actually

living through a magnitude 9.5 earthquake, the largest ever measured.

Mr. Argomedo was on high ground during the hours that followed the earthquake. However, many other residents of the area were not, and 122 were killed by the ensuing tsunami.

Many houses in Maullín, Chile, withstood the magnitude 9.5 Chile earthquake of May 22, 1960. The tsunami generated by the quake caused most of the damage shown in this photo, taken between May 23 and June 3, 1960.



Heed Natural Warnings

An earthquake may serve as a warning that a tsunami is coming, and so may a rapid fall or rise in coastal waters.

On Sunday, May 22, 1960, Jovita Riquelme took her 5-year-old daughter to Mass in Queule, Chile (see map, p. 3). During Mass, the priest talked about earthquakes. A swarm of quakes as large as magnitude 8 had occurred 100 miles to the north the previous day.

Later that Sunday, the magnitude 9.5 mainshock of the 1960 Chile earthquake rocked the region. After the shaking ended, many people from Queule decided

to head to nearby hills. From their stories it is not known why they chose to do this, but their only known warning was the minutes of shaking or, perhaps, changes in the level of the Río Queule or the nearby Pacific Ocean (see also stories on p. 8, 10, 11).

Heeding natural warnings by going to high ground probably saved hundreds of lives in Queule. However, Mrs. Riquelme's family remained at their

house on low ground near the Río Queule. The tsunami that followed the earthquake caught the Riquelme family there. During the confusion caused by the waves, Mrs. Riquelme lost her daughter, and her husband was badly injured. Her husband died of his injuries, and the body of her daughter was found 3 days after the tsunami.

Not far from Queule, Vitalia Llanquimán lived outside the village of

Mehuín. Soon after the earthquake shaking stopped, a man on horseback told her that the sea had receded from shore. At first, Mrs. Llanquimán was not alarmed by this news, but her husband took it as a warning that the sea, when it came back, might surge inland. Carrying their two youngest children, the couple hurried up a nearby hill, where they safely remained during the tsunami.



Though a mile from the sea, most of Queule, Chile, was overrun and washed away by the tsunami that followed the 1960 Chile earthquake. Many residents of Queule fled to the safety of high ground soon after the earthquake, but Jovita Riquelme lost her daughter and husband to the tsunami because the family remained at their house on low ground near the



Río Queule. From the height of debris tangled in the branches of trees that remained standing after the 1960 tsunami, Wolfgang Weischet, then a geographer at the Universidad Austral de Chile in nearby Valdivia, estimated that water from the tsunami was as much as 13 feet deep in Queule. Mr. Weischet took these before and after photos.

Heed Official Warnings

Play it safe, even if warnings seem ambiguous or you think the danger has passed.

There was plenty of time for evacuation in Hilo, Hawaii, as the Chilean tsunami raced across the Pacific Ocean on May 22, 1960. At 6:47 p.m. Hawaiian time, the U.S. Coast and Geodetic Survey issued an official warning that waves were expected to reach Hilo at about midnight. Around 8:30 p.m., coastal sirens in Hilo sounded and continued to sound intermittently for 20 minutes.

When the first wave, only a few feet high, arrived just after midnight, hundreds of people were still at home on low ground in Hilo. Others, thinking that the danger had passed, returned to Hilo before

the highest wave of the tsunami struck at 1:04 a.m. on May 23 (see diagram on facing page). One of those who came back too soon was 16-year-old Carol Brown.

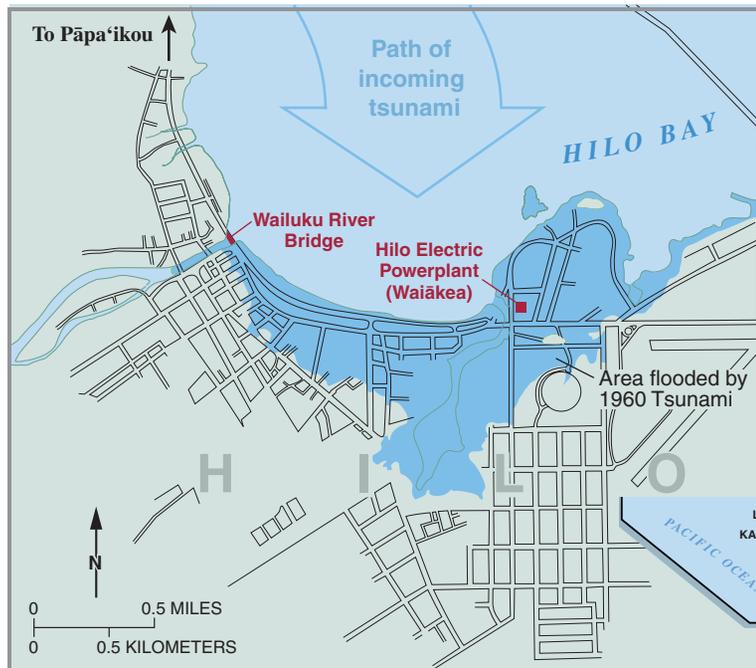
Carol was at her family's house on low ground in Hilo when the warning sirens sounded. Carol's parents took valuables to a relative's house in Pāpa'ikou, a few miles northwest of Hilo, while Carol and her brother Ernest checked on a niece who was babysitting outside of town.

Later, Carol and Ernest returned to Hilo after hearing on the radio that tsunami waves had already come into town and were only 7 feet high. On the way back,

they met a police officer who told them that the danger had passed. Carol and Ernest went to a sister's house in a low part of town. Around 1:00 a.m., they began to hear a low rumbling noise that soon became louder and was accompanied by sounds of crashing and crunching. Moments later, a wall of water hit the house, floating it off its foundation. When the house came to rest, Hilo was dark because the powerplant had been knocked out by the same wave.

Carol and her family survived the 1960 Chilean tsunami without serious injury. However, 61 other people in Hilo died

and another 282 were badly hurt. These losses occurred, in part, because the warning sirens in Hilo on the evening of May 22, 1960, were interpreted differently by different people. Although nearly everyone heard the sirens, only about a third of them thought it was a signal to evacuate without further notice. Most thought it was only a preliminary warning to be followed later by an evacuation signal. Others in Hilo were unsure of how seriously to take the warnings, because several previous alerts had been followed by tsunamis that did little damage.



In Hilo, Hawaii (see map at left), the 1960 Chilean tsunami left 61 people dead and 282 seriously injured. Although warning sirens sounded more than 3 hours before the first waves arrived, the meaning of these signals was not clear. Among those who evacuated in response to the sirens was 16-year-old Carol Brown. However, after hearing that the first waves were small and that the danger had passed, many people, including Carol and her brother Ernest, returned to homes in Hilo, only to be caught by the largest wave of the tsunami. The photo at right shows Carol Brown (wearing the white dress) and members of her family in Pāpa'ikou shortly after the 1960 tsunami.



Expect Many Waves

The next wave may be bigger, and the tsunami may last for hours.

Just after 10 p.m. on May 22, 1960, seismologist Jerry Eaton and four companions assembled at the U.S. Geological Survey's Hawaiian Volcano Observatory on the Island of Hawai'i. Gathering cameras, notebooks, flashlights, and steel measuring tapes, they piled into a Ford station wagon for the 30-mile ride down to Hilo. There they hoped to measure the 1960 Chilean tsunami, which was expected to arrive at about midnight.

The men had good reason to measure this tsunami. Hawai'i had been struck in the past by deadly tsunamis, including ones from Chile in 1837 and 1877 and one from

the Aleutian Islands in 1946 that in Hilo alone killed 98 people. Measurements of past tsunamis are commonly used to help identify areas at risk from future tsunamis. Measurements had been made in Hawaii of Aleutian tsunamis, but little was known about the heights of tsunamis from Chile.

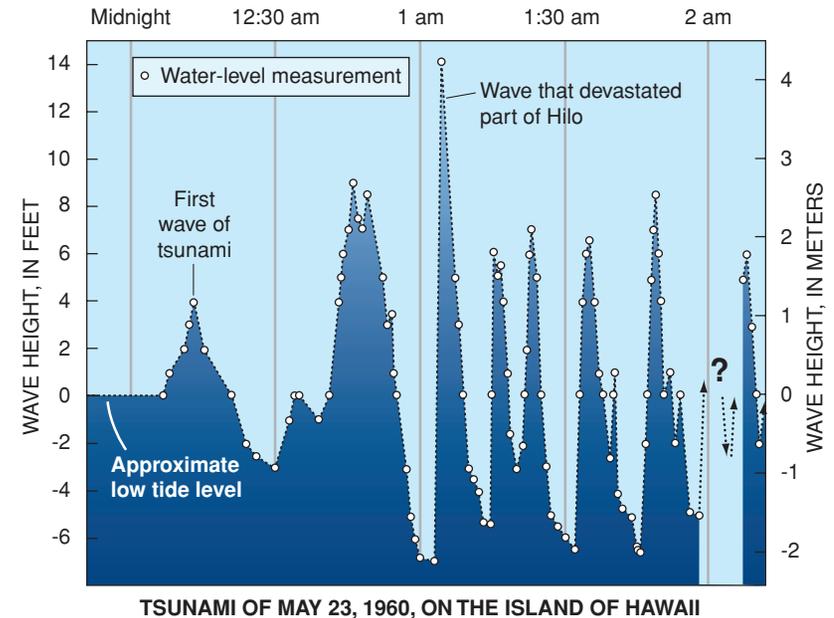
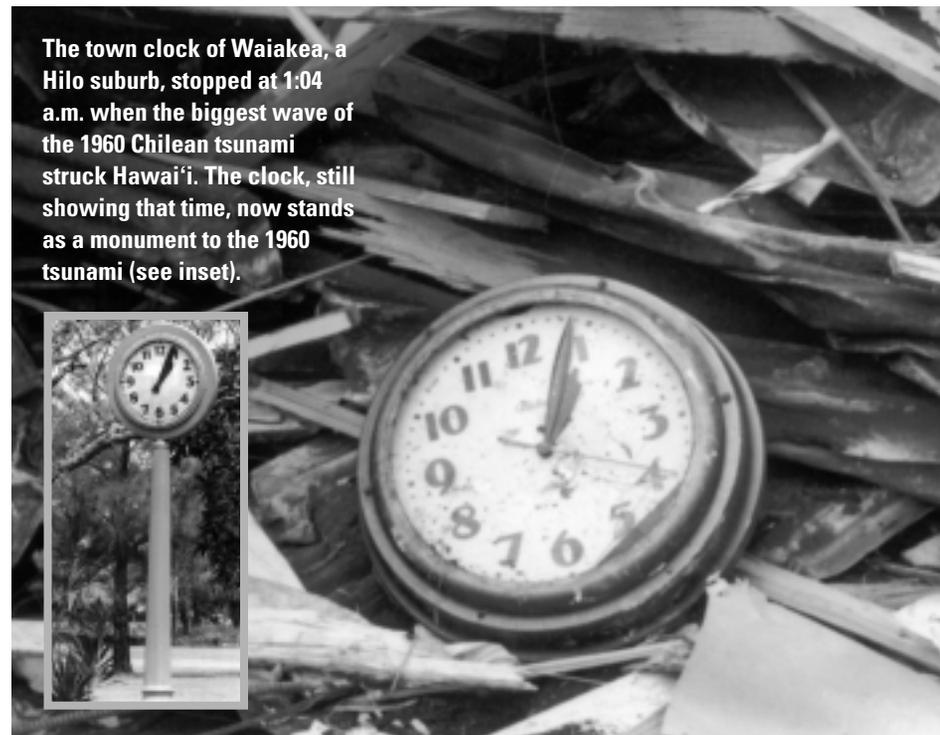
In Hilo, Mr. Eaton and his companions stopped to clear their plans with the police and then drove to the Wailuku River Bridge, on the shore of Hilo Bay (see map on facing page). They knew that the 1946 Aleutian tsunami had destroyed the bridge there. The men set up an observation post on the new bridge and began measuring

the water level beneath it. Just in case, they also planned their own evacuation route, a short sprint to high ground.

Just after midnight, the water under the bridge rose to 4 feet above normal—the first wave of the tsunami had arrived. At 12:46 a.m., the second wave washed under the bridge at a level 9 feet above normal. By 1:00 a.m., the water beneath the bridge had dropped to 7 feet below normal. Mr. Eaton recalls that they then heard an ominous noise, a faint rumble like a distant train, that came from the darkness far out in Hilo Bay. Two minutes later, they began to see the source of the

noise, a pale wall of tumbling water, caught in the dim lights of Hilo. The wave grew in height as it moved steadily toward the city, and the noise became deafening.

By 1:04 a.m., the men on the bridge realized that they should run the few hundred feet to high ground. Turning around, they watched the 20-foot-high, nearly vertical front of the wave hit the bridge, and water splashed high into the air. After this wave had passed and they thought it was safe, Mr. Eaton and his companions returned to the bridge and continued to record the water level during several more waves of the tsunami (see diagram below).



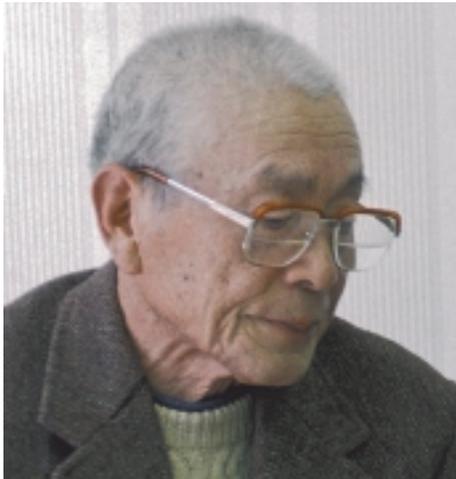
The 1960 Chile earthquake produced a series of tsunami waves that crossed the Pacific Ocean. This record shows measurements of water levels beneath the Wailuku River Bridge made by seismologist Jerry Eaton and his companions during the first few hours of the tsunami in Hilo, Hawaii.

Head for High Ground and Stay There

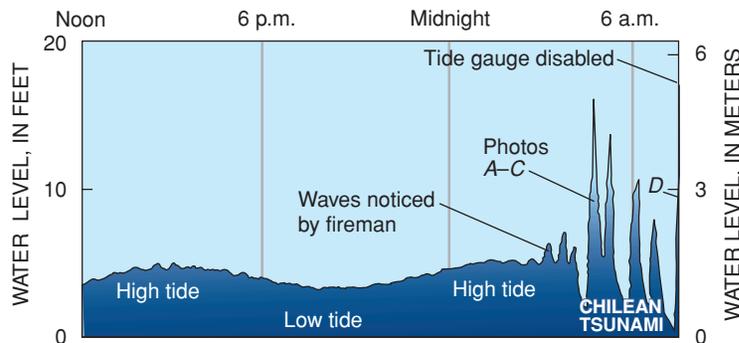
Move uphill or at least inland, away from the coast.

Going to high ground and staying there helped save lives during the 1960 Chilean tsunami, not only in Chile but also in Onagawa, Japan (see map, p. 3). Damaging waves in Onagawa, some of which carried battering rams of floating wood, reached heights of 14 feet. Such waves kept arriving for several hours. Elsewhere, in Japan the tsunami killed

122 people, but in Onagawa no one died, probably because many people there went to high ground. Some arrived there by 4:45 a.m., as the first large wave entered town. They had been alerted by fireman Kimura Kunio. Mr. Kimura, on early morning watch beside the town's harbor, had noticed unusual motion of the water.

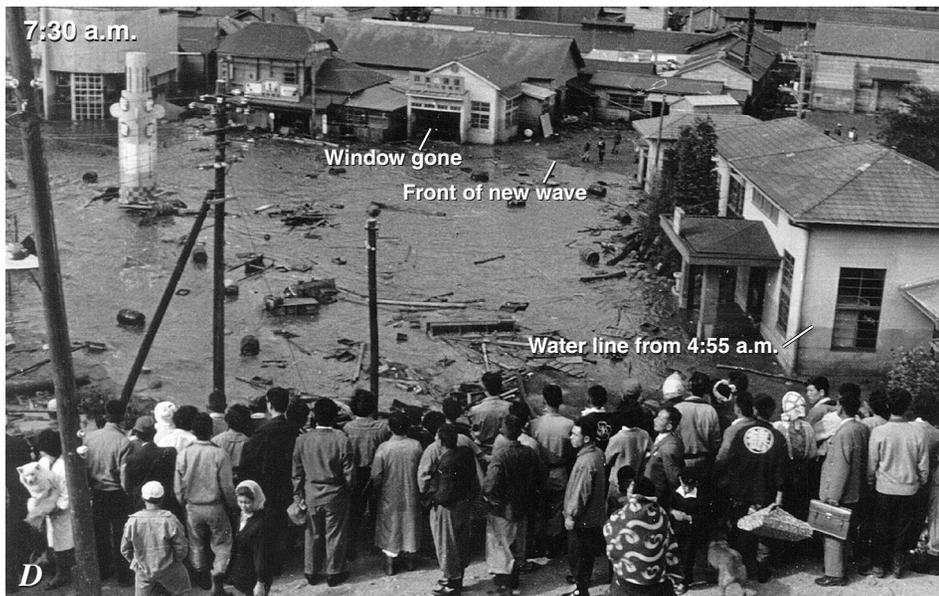


Endō Fukuei (left, in 1999) recalls the fireman's warning that spurred citizens of Onagawa, Japan, toward high ground as the 1960 Chilean tsunami reached the town's harbor. Some residents gathered on a hillside as the first large wave poured into town (photos A-C at right). Almost 3 hours later, crowds remained on this hillside as another wave arrived (D). Waves shown in the photos were recorded by a tide gauge in the Onagawa harbor (see below).

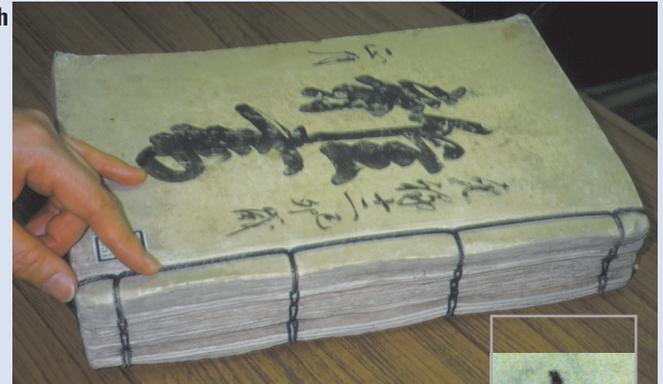


Tide-Gauge Record for May 23 and 24, 1960, at Onagawa, Japan





In Miyako, Japan, north of Onagawa (see map, p. 3), people went to high ground to escape the 1700 Cascadia tsunami (see p. 3, 15, 16). Their flight is reported in this book of government records from 1700. The same records say that in Miyako this tsunami destroyed 13 houses, set off a fire that burned 20 more, and caused authorities to issue rice to 159 people. At right, the character for “high ground” in the entry about the 1700 tsunami.



People in Miyako, Japan, also went to high ground to escape the 1960 Chilean tsunami. Takanohashi Go (right), outside his family’s grocery store in 1999, recalls the 1960 tsunami with fireman Yamazaki Toshio. As a middle-school student, Mr. Takanohashi ran uphill and escaped the tsunami’s waves as they reached the store.

Abandon Belongings

Save your life, not your possessions.

Like everyone else in Maullín, Chile, Ramón Atala survived the 1960 Chile earthquake. However, he lost his life while trying to save something from the tsunami that followed.

Mr. Atala was Maullín's most prosperous merchant. Outside of town, he owned a barn and a plantation of Monterey pine. In town, he owned a pier and at least one large building and also had private quarters in a waterfront warehouse.

According to Nabih Soza, a fellow merchant, Mr. Atala entered this warehouse between the first and second waves of the tsunami that struck Maullín. Mr. Atala was probably trapped in the warehouse when the second wave of the tsu-

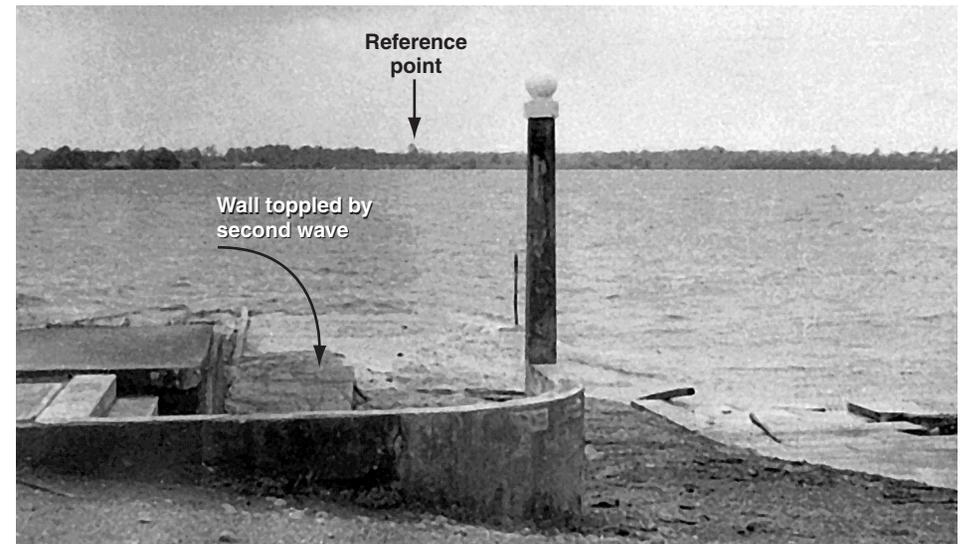
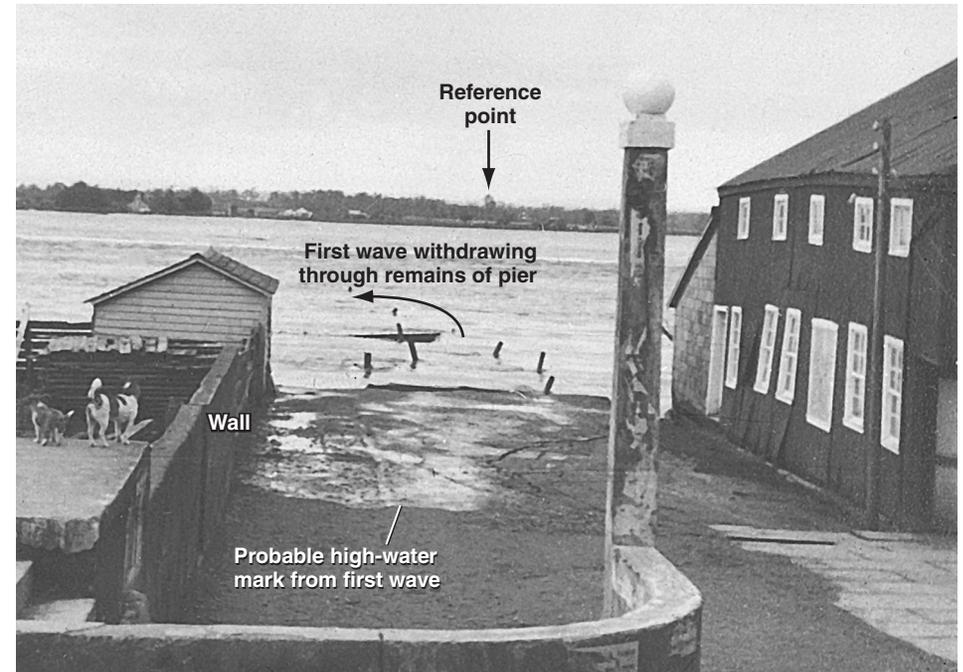
nami washed the building away. His son, Eduardo, said that afterward his father was among the missing and that his body was never found.

Some residents of the town say that Mr. Atala was briefly restrained outside the warehouse by his wife, who grabbed his hair before he finally broke away. Many in the town, spinning a cautionary tale about a wealthy man, say he entered the warehouse to rescue money.

Even as Mr. Atala was being carried off by the second wave, his barn outside of Maullín was providing a refuge for some 20 people, saving their lives from the tsunami (see story, p.12).



Nabih Soza, at his store in 1989, remembers Ramón Atala, a fellow merchant in Maullín, Chile. Mr. Atala entered a warehouse in the town between the first and second waves of the 1960 Chilean tsunami. Photographs taken during the tsunami show the warehouse as the first wave withdrew (top) and a similar view after the second wave washed the warehouse away (bottom).



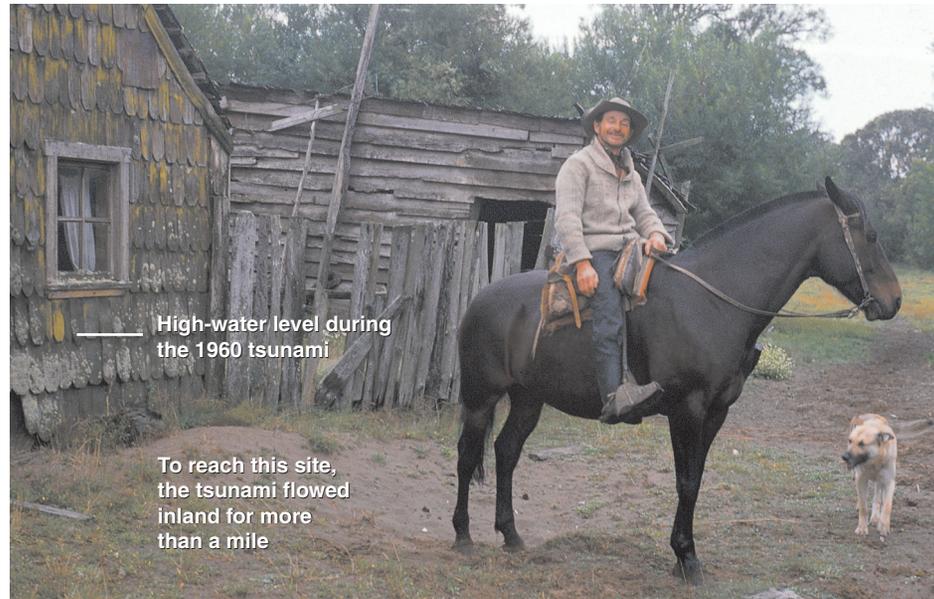
Don't Count on the Roads

When fleeing a tsunami caused by a nearby earthquake, you may find roads broken or blocked.

Minutes after the 1960 Chile earthquake, René Maldonado rode his horse on the road from Maullín, Chile (see locations on photo, p. 14). During the ride, Mr. Maldonado's horse had to jump newly formed cracks in the road. The weakened road was soon severed by the waves of the tsunami that followed the earthquake, leaving channels too wide even for a horse to jump.

Not all people in the area fleeing the earthquake and the tsunami were as lucky as Mr. Maldonado. Some had their routes of escape severed by tsunami waves (see story, p. 12).

Shaking from the 1960 earthquake not only damaged roads but also caused landslides. In addition to blocking roads, landslides caused by the quake dammed the Río San Pedro in the foothills of the Andes about 40 miles east of the city of Valdivia, Chile. Later failure of this landslide dam unleashed a flood that covered parts of the city (see map, p. 3).



High-water level during the 1960 tsunami

To reach this site, the tsunami flowed inland for more than a mile

The 1960 Chile earthquake cracked a road near Maullín, Chile, used minutes later by René Maldonado. This road was soon cut by the waves of the tsunami that followed the quake. At left, Mr. Maldonado poses on horseback in 1989 beside his 1960 home. Below, a photo from 1960 shows a quay in Valdivia, Chile, that was broken when shaking from the earthquake caused land to spread toward the adjacent river.



Go to an Upper Floor or Roof of a Building

Only if trapped and unable to reach high ground, go to an upper story of a sturdy building or get on its roof.

The family of José Navarro, farming on a low peninsula near Maullín, Chile, had only one quick route to high ground after the 1960 Chile earthquake. The route was eastward along an unpaved road, across a bridge over a tidal stream, to uplands called Chuyaquén. Although a neighbor quickly took that route, the Navarro family stayed in their home, beside another tidal stream (see photo at lower right).

Some minutes after the earthquake, the Navarro family saw the waters of the

stream recede. Never before had they seen so much of the streambed exposed. By then, the first wave of the tsunami that followed the quake was approaching but still out of view to the west (see locations on photo, p.14).

Only when they saw a low wall of water less than a mile away did the Navarros head for high ground. The family needed to cover half a mile just to reach the bridge that their neighbor had used. They got far enough to see the first tsunami wave destroy it in front of them.

As the first wave receded, they looked for something to climb. Nothing near them stood more than a few feet high, except for their 9-year-old apple trees and several windbreaks of cypress. Three quarters of a mile to the south, however, was a barn. This was among the properties of Ramón Atala, who was about to be carried away by the second wave in Maullín (see story, p. 10).

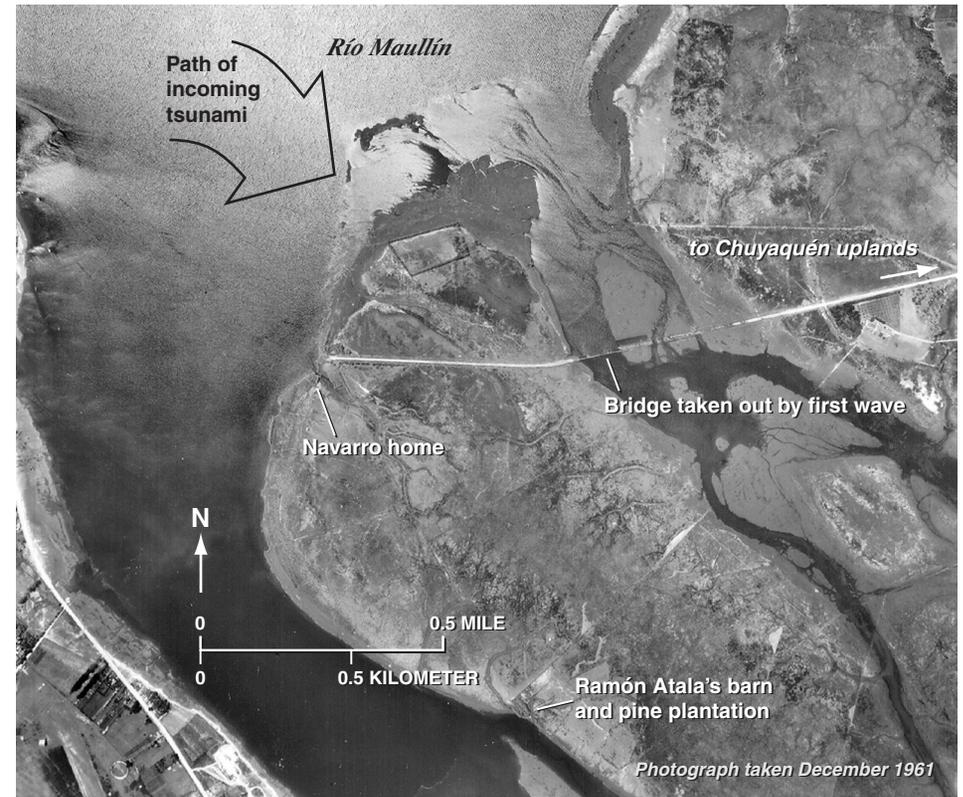
Although Mr. Navarro's wife and children headed for the barn, Mr. Navarro did not go with them. He thought he'd retrieve

a few things from the family house. However, when he heard shouts from the direction of Maullín, he took them as a warning of a second wave and went directly to the barn.

The second wave reached the barn just as Mr. Navarro joined his family there. Along with 14 others, the Navarro family spent the night in the loft of Ramón Atala's barn, safe above the tsunami waters that ran beneath them.



Mrs. and Mr. Navarro, joined by a daughter, stand for a 1989 photo on the porch of their post-tsunami home on high ground near Maullín, Chile. The 1960 Chilean tsunami destroyed their former home, which was located on low ground by a tidal stream. Photo at right shows reference points for their flight to safety during the first two waves of the tsunami.



Climb a Tree

As a last resort, climb up a strong tree if trapped on low ground.

At least a dozen people near Maullín, Chile, survived the 1960 Chilean tsunami by climbing trees (see locations on photo, p. 14). However, others perished when the trees they climbed were toppled by the tsunami (see story, p. 14).

Ramón Ramírez, 15 years old at the time of the tsunami, survived by climbing into the branches of a cypress tree (photo at right) on a plain west of Maullín. While Mr. Ramírez stayed safely in the cypress, the waters of the tsunami swirled about the tree. The water crested at 15 feet above sea level, reaching several feet above the tree's base.

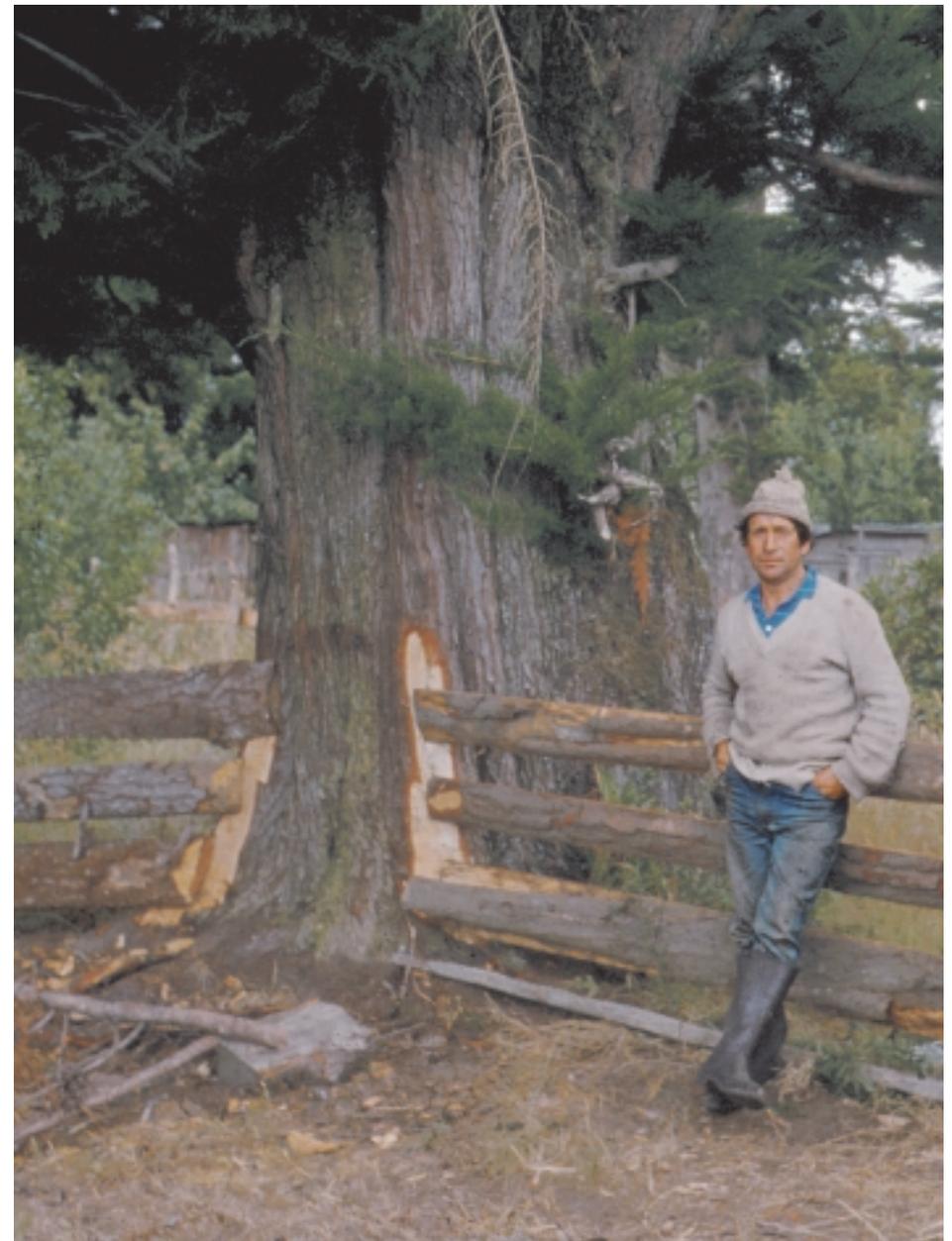
In nearby Quenuir, at the mouth of the Río Maullín, Estalino Hernández climbed

an arrayán tree to escape the tsunami's waves. While he clung to the tree, the waters of the tsunami rose to his waist. Not far away, the onrushing water covered land 30 feet above sea level. Although Mr. Hernández survived the tsunami, he lost his 13-year-old son to the waves. Quenuir had 104 other victims, most of whom took to boats just after the earthquake and were caught by the first wave of the tsunami.

Inland from Quenuir, a pregnant María Vera and eight others climbed a peta tree on a low plain north of the Río Maullín (photo below). Throughout the night, water surged beneath them, scouring sandy ground nearby.



María Vera, pregnant and over a half mile from high ground, escaped the 1960 Chilean tsunami by climbing a peta tree outside of Quenuir, Chile. Ramón Ramírez (at right, in 1989) stands beside the cypress tree in which he safely stayed while the waters of the tsunami swirled about its base.



Climb onto Something that Floats

If swept up by a tsunami, look for something to use as a raft.

Nelly Gallardo survived the tsunami that followed the 1960 Chile earthquake by clinging to a log. The earthquake struck while she was digging for clams on the shore more than 4 miles west of Maullín, Chile. Soon after the shaking from the quake stopped, she walked about 100 yards inland to a house that was more than half a mile from the nearest high ground. The next thing Ms. Gallardo recalls is floating on a tree trunk. She

clung to this trunk until the next morning. For a time she heard a man's voice crying for help—his body was found later. At daybreak she was more than a mile from where the tsunami had swept her up. The tsunami included many waves, but Ms. Gallardo recalls only the one that set her adrift.

The roof of her family house served as a life raft for Armanda Cubate, her 4-year-old nephew Nelson, and five others. The

house, on low ground west of Maullín, withstood the 1960 earthquake. The house also withstood the first two waves of the tsunami that followed the quake, but the third wave swept it away. This wave also toppled a nearby tree that Ms. Cubate's father had climbed to escape the tsunami. Both he and Ms. Cubate's mother drowned in the tsunami. Survivors on the roof later pulled the mother's body from the water.

As marked on this 1944 photo of the mouth of the Río Maullín, Chile, the 1960 Chilean tsunami flowed 2 miles inland from the beach at right foreground. In much of this flooded area, the tsunami reached a height of 15 feet above sea level. After being swept up by the tsunami, Nelly Gallardo floated on a log and Armanda Cubate floated on a roof until the next morning (see far right in photo). They survived the tsunami, but 15 other people near them died.



Expect the Waves to Leave Debris

A tsunami will leave behind sand, the remains of houses, and bodies.

El maremoto fue tan grande que hasta los muertos sacó de sus tumbas (“The tsunami was so big that it even took the dead from their graves”). This saying comes from Quenuir, Chile, a village at the mouth of the Río Maullín (see locations on photo, p. 14). The tsunami that followed the 1960 Chile earthquake killed 105 people from Quenuir—a quarter of the village’s population. In addition to this loss of the living, Quenuir lost many of its dead. The village cemetery was located on sandy ground that the tsunami washed away. Debris from the cemetery came to rest more than 3

miles upriver. There, just outside La Pasada, Tulio Ruiz found crosses and a full casket.

The 1960 tsunami also deposited sand along the Río Maullín, some of it on land owned by Juan Vera. He and his wife, María Silva, lived on low ground 2 miles east of Maullín. The 1960 earthquake found Mrs. Silva at home and her husband on a nearby hillside. Their house collapsed, but Mrs. Silva escaped and soon joined her husband on high ground. Together they watched the tsunami overrun their fields and carry away the remains of their house. The next day, Mr.

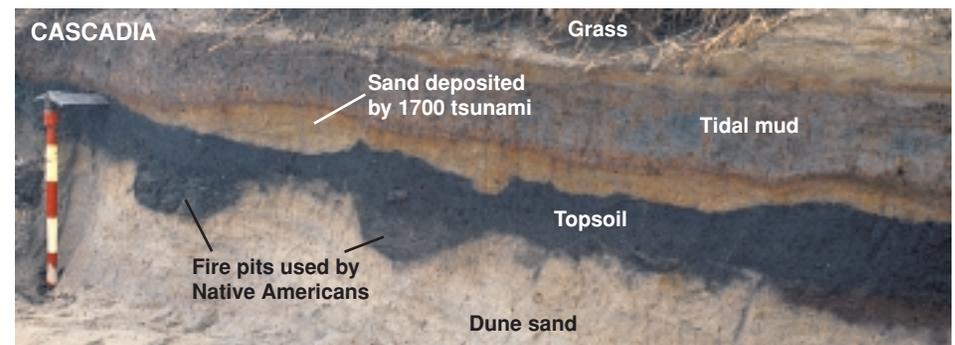
Vera found a layer of sand several inches thick on much of the land the tsunami had overrun.

Many houses were carried inland by the 1960 tsunami. After fleeing to high ground near Queule, more than 100 miles north of Maullín (see map, p. 3, and photos, p. 5), Filberto Henríquez saw houses floating away from the town. He recalls that some of the houses, with their stoves still smoking, looked like ships. Remains of houses from Queule ended up as much as a mile inland (according to a report by Wolfgang Weischet; see p. 5), but Margarita Liempi’s house was

deposited intact; even her drinking glasses were unbroken.

At Mehuín, near Queule, Jacinto Reyes buried some of the tsunami victims. Among them were the parents of two girls who were found in blackberry bushes, scratched but alive. Not all the tsunami victims were found quickly. About 10 days after the tsunami, Mr. Reyes happened upon bodies stuck in sand and being eaten by birds.

The 1960 Chilean tsunami deposited a sand layer on fields owned by Juan Vera near Maullín, Chile. When this picture of Mr. Vera was taken in 1989, the sand layer was still visible in a streambank (upper right photo). A similar sand layer from the 1700 Cascadia tsunami covers the remains of a Native American fishing camp exposed in a bank of Oregon’s Salmon River (lower right photo; see map, p. 3, for location).



Expect Quakes to Lower Coastal Land

A large earthquake can leave nearby coastal areas lowered, allowing tidal water to flood them.

The 1960 Chile earthquake not only triggered a tsunami that killed Ramón Atala (see story, p. 10), it also changed his Monterey pine plantation outside of Maullín, Chile, into a salt marsh (see photo at right). The pines, grown for timber, covered low ground around Mr. Atala's barn (see story, p. 12). During the earthquake, this land was lowered. Because tides were then able to inundate the plantation, the ground became too wet and salty for the trees to survive.

What happened to Mr. Atala's plantation happened at many places along Chile's coast. When a 600-mile-long

stretch of the South American tectonic plate was thinned during the 1960 earthquake, nearby land was lowered as much as 8 feet (see diagram B, p. 2). The sea was then able to cover coastal pastures, farms, and forests.

Coastal areas were also lowered and submerged in Cascadia after the 1700 Cascadia earthquake (see p. 3, 15). These areas include the Native American fishing camp shown on page 15. After being inundated by the 1700 tsunami, this fishing camp became a tidal flat or a tidal marsh.

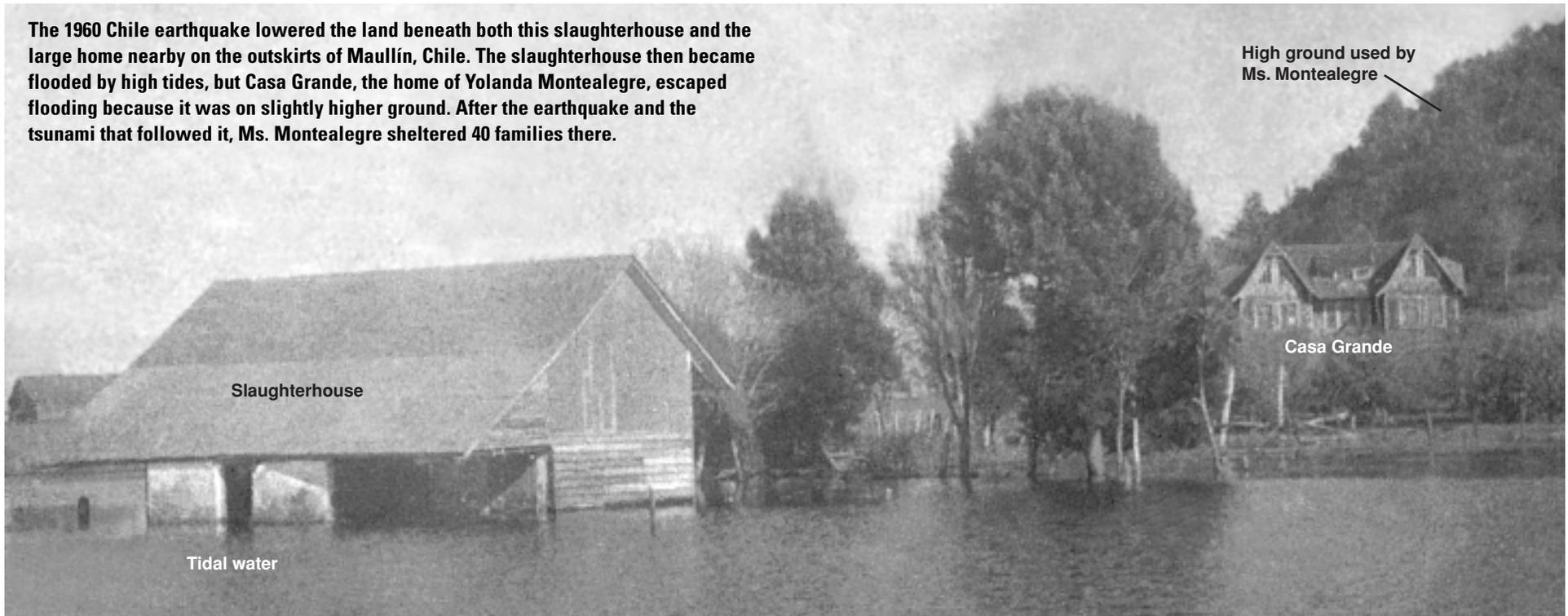


Expect Company

Shelter your neighbors.

In the first weeks after the 1960 Chile earthquake and tsunami, Yolanda Montealegre provided shelter for 40 families in Casa Grande, her large home on the outskirts of Maullín, Chile (see locations on photo, p. 14). Ms. Montealegre left her house minutes after the earthquake and reached high ground in time to watch the arrival of the second wave of the tsunami that followed the quake. The next morning, she found Casa Grande in good shape, its ground floor dry. The families she soon took in were among the estimated 1 million Chileans left temporarily homeless by the earthquake and tsunami.

The 1960 Chile earthquake lowered the land beneath both this slaughterhouse and the large home nearby on the outskirts of Maullín, Chile. The slaughterhouse then became flooded by high tides, but Casa Grande, the home of Yolanda Montealegre, escaped flooding because it was on slightly higher ground. After the earthquake and the tsunami that followed it, Ms. Montealegre sheltered 40 families there.



Credits and Sources

People Interviewed

[Listed alphabetically by father's last name. Numerals give age in 1960, omitted if age not recorded. Bold type denotes people named in this booklet or shown in one of its photographs.]

Mauñín, Quenuir, and La Pasada, Chile

Ricardo Aguila (34), Juan Reinaldo Aguila R. (36), Carlos Andrade (12), **José Argomedo Hernández (22)**, José Norberto Asencio Cárcamo (45), Elisa Asencio Téllez (19), **Eduardo Atala B. (42)**, Reinaldo Cárcamo (52), Hernán Cárcamo Gómez (33), Víctor Chávez Villegas (56), **Armanda Cubate (38)**, Nelson H. Cubate O. (4), **Palmira Estrada Estrada (27)**, **Nelly Gallardo (23)**, René García Silva (39), Hermógenes Gómez Rival, Adelina Gómez Rival (44), Feliza del Rosario Hernández Paredes (39), **Estalino Hernández (54)**, Gaspar Hernández, Tulio Hernández, René Leichtle Krebs (43), **René Maldonado (30)**, Alejandrino Mancilla, Antonio Segundo Mancilla (22), Bernarda Mancilla S. (23), **Yolanda Montealegre Mücke (40)**, Rodrigo Morales, Fidel Navarro (50), Oscar Navarro Navarro (34), **José Miguel Navarro Silva (44)**, Enoc Ojeda (20), José B. Ojeda Muñoz (40), Julia Paredes Toledo (54), **Ramón Ramírez Solís (15)**, Braulio Reyes, Jorge Ruiz (34), **Tulio C. Ruiz (23)**, José Rupertino Sánchez Gallardo (15), René Serón (36), **María Isolina Silva (29)**, Domitila Solís (50), Pedro Soto Soto (62), **Nabih Soza (23)**, Gastón

Exequiel Toledo Arria (22), José Elizardo Torralbo (27), **María Vera (42)**, Guillermina Vera Mansilla (39), and **Juan Vera Mancilla (34)**, father of Angela Vera Reyes.

Mehuín and Queule, Chile

Erna Espinosa, Elsira Flores, **Filberto Henríquez Jaramillo (32)**, Hernán Liempí (11), **Margarita Liempí (18)**, **Vitalia Llanquimán**, Señor and Señora Moraga, Gilberto Nahuelpán Liempí (25), **Jovita Riquelme (45)**, Daniel Nahuelpán Rumillanca (32), Alberto Perón Antilco (23), **Jacinto Reyes Reyes (54)**, Alejandro Villagrán Rojas (25), Andrea of Mehuín, Erasmo of Mehuín (23), and Diodema of Mehuín (35).

Onagawa and Miyako, Japan

Endō Fukuei (40), Kimura Tsuneo (28), Moriai Miya (40), Moriai Mutsuhara (22), **Takanohashi Gō (12)**, Yamasaki Nori (26), and **Yamazaki Toshio**.

Hilo, Hawaii

Carol D. Brown (16) and **Jerry P. Eaton (33)**.

Book Preparation

Interviews (C, Chile; J, Japan)

Brian Atwater (C, J), Joanne Bourgeois (C), José Ulloa Cortés (C), Marco A. Cisternas Vega (C), Héctor Jiménez Núñez (C), Marcelo López Bermedo (C), Musumi Satoko (J), Mary Ann Reinhart (C), Adriana Sandoval Lagos (C), Tsuji Yoshinobu (J), Ueda Kazue (J), and David K. Yamaguchi (J).

Interviews (Hawaii)

Adapted from stories of tsunami survivors in *Tsunami!* by Walter C. Dudley and Min Lee, 1998 (University of Hawaii Press), and supplemented with 1999 interviews done by Walter C. Dudley, Peter H. Stauffer, and James W. Hendley II.

Photographs taken before 1989

Fuerza Aérea de Chile, Servicio Aerofotogramétrico (p.12, image 16019), Griffin (1984) (inside back cover), Ilustre Municipalidad de Mauñín (p. 4, 10, 16), Pacific Tsunami Museum (p. 6, 7, inside front cover), Saint-Amand (1963) (p. 5, 11), University of Tokyo (p. 8, 9), and U.S. Defense Mapping Agency (p. 13, image 503-333; p. 14, image 552.R.13).

Critical reviews

Sally Atwater, Jan Bono, Steven R. Brantley, Eddie Bernard, Gary Brown, George Crawford, Lori Dengler, Rich Eisner, Stephanie Fritts, Eric Geist, Helen Gibbons, Frank Gonzolez, Dick Hagemeyer, T.J. Harmon, Imamura Fumihiko, Chris Jonientz-Trisler, Hal Mofjeld, Alan Nelson, Dave Oppenheimer, Jim Phipps, George Priest, Barbara Thurman, Vasily Titov, and John Vollmer.

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For Additional Information

1960 Chilean earthquake and tsunami

Dudley, W.C., and Lee, M., 1998, *Tsunami!*: University of Hawaii Press, 362 p.
Eaton, J.P., Richter, D.H., and Ault, W.U., 1961, The tsunami of May 23, 1960, on the Island of Hawaii: Seismological Society of America Bulletin, v. 51, no. 2, p. 135-157.
Griffin, Wallace, 1984, Crescent City's dark disaster: Crescent City Printing Co., 188 p.
Japan Meteorological Agency, 1961, The report on the tsunami of the Chilean earthquake, 1960: Japan Meteorological Agency Technical Report 8, 389 p.
Lachman, R., Tatsuoka, M., and Bonk, W.J., 1961, Human behavior during the tsunami of May 1960: Science, v. 133, p. 1405-1409.

Lomnitz, C., 1970, Major earthquakes and tsunamis in Chile during the period 1535 to 1955: *Geologische Rundschau*, v. 59, p. 938-960.

Plafker, G., and Savage, J.C., 1970, Mechanism of the Chilean earthquakes of May 21 and 22, 1960: *Geological Society of America Bulletin*, v. 81, p. 1001-1030.

Saint-Amand, P., ed., 1963, Special issue—oceanographic, geologic, and engineering studies of the Chilean earthquakes of May 1960: *Seismological Society of America Bulletin*, v. 53, no. 6, p. 1123-1436.

Shepard, F.P., MacDonald, G.A., and Cox, D.C., 1950, The tsunami of April 1, 1946: *Scripps Institution of Oceanography Bulletin*, v. 5, p. 391-528.

The Committee for Field Investigation of the Chilean Tsunami of 1960, 1961, Report on the Chilean tsunami of May 24, 1960, as observed along the coast of Japan: Tokyo, Maruzen Co., 397 p.

1700 Cascadia earthquake and tsunami

Atwater, B.F., and Hemphill-Haley, E., 1997, Recurrence intervals for great

earthquakes of the past 3,500 years at northeastern Willapa Bay, Washington: U.S. Geological Survey Professional Paper 1576, 108 p.

Atwater, B.F., Yelin, T.S., Weaver, C.S., and Hendley, J.W., II, 1995, Averting surprises in the Pacific Northwest: U.S. Geological Survey Fact Sheet 111-95, 2 p.

Clague, J.J., 1997, Evidence for large earthquakes at the Cascadia subduction zone: *Reviews of Geophysics*, v. 35, p. 439-460.

Satake, K., Shimazaki, K., Tsuji, Y., and Veda, K., 1996, Time and size of a giant earthquake in Cascadia inferred from Japanese tsunami record of January 1700: *Nature*, v. 379, p. 246-249.

Tsuji, Y., Ueda, K., and Satake, K., 1998, Japanese tsunami records from the January 1700 earthquake in the Cascadia subduction zone: *Zishin*, v. 51, p. 1-17 [in Japanese with English abstract, figures, and figure captions].

Yamaguchi, D.K., Atwater, B.F., Bunker, D.E., Benson, B.E., and Reid, M.S., 1997, Tree-ring dating the 1700

Cascadia earthquake: *Nature*, v. 389, p. 922-923; correction in v. 390, p. 352.

Other sources

In the comparison of tsunami heights in Japan (p. 3), heights for the 1960 tsunami are known to the nearest foot or better. They come from reports by the Japan Meteorological Agency (1961) and the Committee for Field Investigation of the Chilean Tsunami of 1960 (1961), and from reconnaissance near Miyako, Japan, in 1999 by Brian Atwater and David Yamaguchi. The comparison with 1700 is not adjusted for changes in land level between 1700 and 1960; correction for these changes would increase most of the 1700 heights by several feet (Tsuji and others, 1998).

Nikita Khrushchev (p. 4) was referring to the U-2 mission of Francis Gary Powers. His remarks come from a news conference after cancellation of a summit meeting with Dwight Eisenhower in Paris. A partial transcript was printed in the *New York Times* of May 19, 1960. East-West tension was still the lead story on May 23, but on that day the front page of the *Times*

also carried an initial wire-service account of the May 22, 1960, Chile earthquake and tsunami. The tsunami remained front-page news on May 24 and May 25—second only to stories about U.S. and Soviet spying and a U.S. missile-detection satellite—as tsunami losses were reported from Hawaii and Japan.

Tsunami heights and deaths on page 14 come from interviews and surveys done in 1988 and 1989. The heights are rounded to the nearest 5 feet, but some points precisely identified by survivors were surveyed to the nearest foot. The figure of 105 fatalities from Quenuir comes from René Serón. As a civil servant in 1960, Mr. Serón kept records of births, deaths, and other official matters in Quenuir. In 1989, he recalled that the pre-tsunami town had about 50 houses, a church, a cemetery, and 400 to 450 inhabitants.

Tsunami-hazard information on the World Wide Web

<http://www.pmel.noaa.gov/tsunami-hazard/>



Waterfront area in Crescent City, California, flooded by the 1960 Chilean tsunami. Here, the tsunami caused more than \$30,000 in damage, including the sinking of two boats. However, damage was much more severe 600 miles to the south in the Los Angeles area, where the tsunami killed one person and caused from \$500,000 to \$1,000,000 in damage, including the sinking of 30 boats.

In interviews several decades later, people in Chile, Hawaii, and Japan recall the tsunami triggered by a magnitude-9.5 earthquake that struck Chile in 1960.

Their accounts contain lessons on tsunami survival:

- **Many Will Survive the Earthquake**
- **Heed Natural Warnings**
- **Heed Official Warnings**
- **Expect Many Waves**
- **Head for High Ground and Stay There**
- **Abandon Belongings**
- **Don't Count on the Roads**
- **Go to an Upper Floor or Roof of a Building**
- **Climb a Tree**
- **Climb onto Something that Floats**
- **Expect the Waves to Leave Debris**
- **Expect Quakes to Lower Coastal Land**
- **Expect Company**

A blue rectangular sign with rounded corners. At the top, the text "TSUNAMI HAZARD ZONE" is written in white, bold, uppercase letters. Below the text is a white silhouette of a person running up a hill, with a large wave crashing behind them. At the bottom of the sign, the text "IN CASE OF EARTHQUAKE, GO TO HIGH GROUND OR INLAND" is written in white, bold, uppercase letters.

TSUNAMI HAZARD ZONE

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