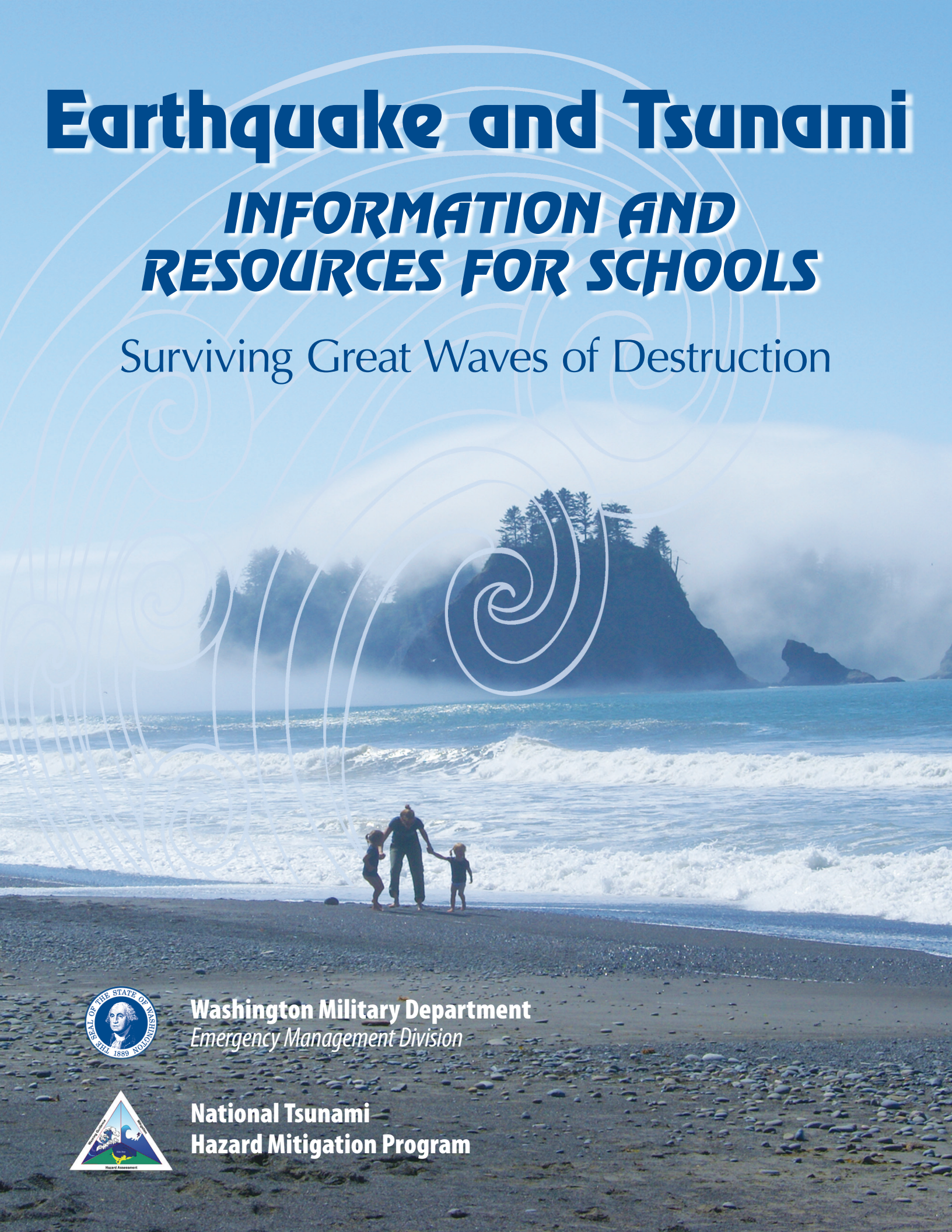
# Earthquake and Tsunami

## INFORMATION AND RESOURCES FOR SCHOOLS

Surviving Great Waves of Destruction




**Washington Military Department**
*Emergency Management Division*

**National Tsunami Hazard Mitigation Program**

# Earthquake and Tsunami Information and Resources for Schools

## *Surviving Great Waves of Destruction*

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## Publication design

Lee Doyle, Communication By Design

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# Introduction

This publication provides fundamental information about Washington's vulnerability to earthquakes and tsunamis.

Earthquakes have impacted Washington State in the past, and they will again in the future. Damaging earthquakes have occurred in Washington in 1949 (Olympia M6.8), 1965 (SeaTac M6.5) and 2001 (Nisqually M6.8). Each caused billions of dollars in damage and impacted people, property, the environment and our economy.

Since 1900, more than 100 tsunamis have impacted the Pacific U.S. states and territories. These U.S. tsunami events have killed 392 people and caused over $1.6 billion in damages. They include the fifth and sixth largest earthquakes ever recorded. With your help, we can reduce the loss of life from the next tsunami that strikes our shores.

Washington's coastal residents are particularly at risk from either an eastern Aleutian Island Subduction Zone tsunami or a Cascadia Subduction Zone earthquake and tsunami. A tsunami generated off our coast from a Cascadia Subduction Zone earthquake will arrive on Washington shores in 30 minutes or less with maximum force. People will be preoccupied with major damage from the earthquake. The tsunami waves will reach shore before they are registered clearly at the nearest detection buoy, and they will also reach people on the beach or low lying areas sooner than a tsunami warning center's message can warn them.

More lives will be saved through education about earthquakes and tsunamis than through man-made warning systems. As illustrated in the 2009 American Samoa Tsunami, the mayor of Amenave in American Samoa had attended tsunami awareness training and was taught natural warning signs. When he felt the ground shaking from the earthquake, he knew that his people must head to high ground immediately before the tsunami struck. He grabbed his bullhorn and ran through the village notifying people to evacuate immediately. Because of his actions, most villager's lives were saved, even though their community was completely destroyed.

# Background information for teachers

Tsunamis are caused by shallow undersea earthquakes, landslides, volcanic eruptions and meteor impacts. In Washington state, earthquake and landslides are the most probable causes of tsunamis.

## Understanding tsunamis

Tsunamis are a series of long period waves typically generated during an earthquake by sudden displacement of the sea floor or lake bed. As demonstrated by the March 2011 Tohoku Earthquake and Tsunami, it caused vast death and destruction without regard for political boundaries. Tsunamis are particularly dangerous close to their sources, where, for example, the first tsunami wave struck the Japanese coast within 10 minutes after the tsunami began and where the earthquake already created havoc. 9 hours after the earthquake, the tsunami hit coastal communities in Northern California causing evacuations and millions of dollars and damages to coastal infrastructure.

A tsunami is not one wave, but a series of waves. The time between successive wave crests is usually tens of minutes apart and continues arriving for many hours. The first wave is almost never the largest. For instance, in a modeled Cascadia Subduction Zone the largest wave arriving in Westport is the first wave which arrives in 30 minutes. However, the same modeled event shows the largest wave inundating Aberdeen to be the fourth wave. The first wave to strike Crescent City, CA, following the 1964 Alaska earthquake was 9 feet above the tide level; the second was 6 feet above tide; the third was about 11 feet above the tide level; and the fourth, most damaging wave was more than 16 feet above the tide level. The third and fourth waves killed 11 people. Estimates of the damage range from $47 million to $97 million (2004 dollars). The same tsunami destroyed property in many areas along the Pacific coast from Alaska to California. In Washington, the largest wave entered Willapa Bay about 12 hours after the first one; the tsunami caused $640,000 (2004 dollars) in damage.

## How a tsunami behaves in deep and shallow water

In deep water, on the open ocean, tsunamis cause no damage and are hardly noticed. In the open ocean they can travel at 300 – 700 MPH, however, as the tsunami wave approaches shore from the open ocean the wave energy is transferred from wave speed to wave height. The wave can travel as low as 30 MPH and reach a wave height up to 100 feet – a person cannot out run a tsunami. Videos and photos from the December 2004 Indian Ocean Tsunami captured the first arrivals of the tsunami that immediately flooded inland causing unexpected tourists and residents to be swept off their feet where they drowned quickly or thrown against buildings, trees or debris. Never underestimate the power of a tsunami regardless how small it is!

## Distant tsunamis generated in the Pacific Basin

Subduction zones are largely located along the volcanic mountain chains that make up the "Ring of Fire". They can generate tsunamis that sweep through the entire Pacific basin causing a tsunami risk to Washington coastal communities within 2 or more hours. For example, the Chile February 27, 2010 Tsunami first wave arrived in Port Angeles after 17 hours 20 minutes and at La Push 16 hours and 20 minutes.

While only one distant tsunami has caused major damage (1964 Alaska Earthquake), strong currents accompanying a tsunami threaten the maritime industry as well as individuals in and around the water. The 2010 Chile Tsunami and 2011 Japanese Tsunami created strong currents causing marinas and beaches to be closed along the Washington coast. Distant events give the West Coast/Alaska Tsunami Warning Center in Palmer, Alaska, time to issue official tsunami messages, based on sea level data and gives state and local officials decision making information on what actions need to be taken (example: evacuation or close beaches and marinas/ports). Critical warning information will be sent over the All Hazard Alert Broadcasting System, the NOAA Weather Radio, radio and TV or other local means to communicate to the public on what action they should take.

## Cascadia Subduction Zone Earthquake – Washington's local tsunami source

However, a local event from a Cascadia Subduction Zone earthquake will cause very strong ground shaking lasting minutes causing damage to the built environment and potential immediate flooding by land changes that followed by tsunamis. A wave as high as 30 feet could reach outer coastal communities within 30 minutes or less (Wave arrival time based on modeling and inundation mapping data and identified in the perspective community tsunami brochure). Because the tsunami will strike before an official warning can be sent out, the public must know the natural warning signs of a tsunami. In the event of a Cascadia Subduction Zone, the strong ground shaking, land and sea level changes and a loud roar sounding like an airplane or train are cues to head to high ground immediately. Evacuation on foot may be the only option as debris, down power lines, etc., from the earthquake and flooding from land changes will increase the time it takes to get to an evacuation assembly area or high ground. Understanding these signs saved thousands of lives during the 2004 Indian Ocean Tsunami, 2009 South Pacific Tsunami in America Samoa the 2010 Chile Tsunami, and the 2011 Japanese Tsunami. If immediate action is taken, these important warning signs can give the public time to escape the damages of a tsunami.

## Earthquakes in Washington state

Below are examples of tsunami sources that have impacted our Washington communities.

- **1964 Alaska Earthquake**
  This was the largest and best-recorded historical tsunami on the Washington coast. Tsunami wave heights generally were greatest on the south coast and smaller on the north coast; additionally, the tsunami was recorded inland in the Strait of Juan de Fuca (Friday Harbor), Puget Sound (Seattle), and the Columbia River (Vancouver). Damages included debris deposits throughout the region, minor damage in Ilwaco, damage to two bridges on State Highway 109, a house and smaller buildings being lifted off foundations in Pacific Beach (the house was a total loss), and damage to the Highway 101 bridge over the Bone River near Bay Center.

- **1700 Cascadia Subduction Zone Earthquake**
  The Cascadia Subduction Zone earthquake generated a tsunami that overran Native American fishing camps and left behind telltale sheets of sand on marshes and in lakes along the southern part of the outer coast. During this earthquake much of the land on Washington's outer coast subsided, or fell, by about five feet. A Cascadia Subduction Zone Earthquake is considered a worst-case scenario for Washington coastal communities.

- **Seattle Fault Earthquake between years 900 and 930 AD**
  The earthquake raised shores of central Puget Sound by 20 feet between the Duwamish River and Bremerton. The uplift, by also including the floor of Puget Sound, created a tsunami. In Seattle, the tsunami washed across West Point, where it deposited a sheet of sand. Farther north, it deposited a sand sheet at Cultus Bay on southern Whidbey Island and along tributaries of the Snohomish River between Everett and Marysville.

## Landslides in Washington also cause tsunamis

- **1949 Puget Sound Tsunami**
  A small landslide-generated an 8-foot tsunami that struck the Point Defiance shoreline in the Tacoma Narrows on April 16, three days after a M7.1 earthquake weakened the hillside.

- **1894 Commencement Bay Tsunami**
  A submarine landslide in the delta of the Puyallup River in Commencement Bay, Tacoma, caused a tsunami. The tsunami carried away a railroad track and roadway, resulting in two deaths.

- **Early 1800s Camano Head Tsunami**
  According to tribal accounts, the landslide sounded like thunder, buried a small village and created a large volume of dust. The tsunami washed over the barrier beach at Hat Island, destroying homes or encampments and drowning many people.

## How do you know a tsunami is approaching?

If you feel strong ground shaking, notice a change in land or sea level, or a loud roar like a train or airplane, follow the tsunami evacuation route immediately to higher ground and to an evacuation assembly area. DO NOT wait for a tsunami warning to be announced. Stay away from rivers and streams that lead to the ocean just as you would a tsunami. If the earthquake has damaged roads and power lines and resulted in significant debris, do not try to follow the evacuation routes out.

## What to do when a tsunami occurs?

- If you can't evacuate inland and there are no high structures nearby, then you should find the tallest, sturdy structure and climb up and cling to it until the wave passes. In some cases, this might only be a strong tree or utility pole. If you're swept up by a tsunami, look for something to help you stay afloat, and to protect you from dangerous floating debris like houses, cars, and trees. If you are on the beach and unable to get to high ground, go inland as far as you can.
  - Reinforced concrete buildings are stronger than wood frame buildings.
  - Look for a structure that is farther back from the beach and on higher ground.
  - Debris that is drifting in tsunami waves (such as cars, trees, logs and chunks from damaged buildings) can be destructive to all standing buildings.
  - Avoid hazardous material sites, if possible.
- If you are in school and you hear there is a tsunami warning, you follow the advice of school administration and your local emergency and law enforcement authorities.
- If you are at home and hear there is a tsunami warning over your community All Hazard Alert Broadcasting System, TV, radio or NOAA Weather Radio, you should make sure your entire family is aware of the warning. Your family should follow instructions given by local authority and evacuate your house if you live in a tsunami hazard zone. Move in an orderly, calm and safe manner to the tsunami evacuation assembly area or to any place outside of the tsunami hazard zone.
- In some locations, high ground may not exist, or tsunamis triggered by local events may not allow sufficient warning time to evacuate to high ground. The only solution is to evacuate in place, meaning vertical evacuation into the upper levels of structures.
- Return to the tsunami hazard zone only after emergency officials say it is safe. This will be done through an "All Clear" message.

## What you can do to protect yourself from a tsunami

- Have a NOAA Weather Radio.
- Know the tsunami hazard for your community or location.
- Have a copy of the community's Tsunami Evacuation map/brochure.
- Know the evacuation routes and assembly area locations.
- Have a family emergency plan, and plan where each family member would go for any emergency event.
- Practice the plan, and improve it on a regular basis.
- Have a pre-packed emergency supply kit and take it with you. Don't expect to have shelter, food and water available at the tsunami evacuation assembly area.
- If you are on a ship or in a boat, do not return to port if you are at sea and a tsunami warning or advisory has been issued for your area. Tsunami wave activity is imperceptible in the open ocean, but tsunamis can cause rapid changes in the water level and dangerous currents in harbors and ports.

# Remember

### If you live near or visit the coast and you feel an earthquake:

- When you feel the earth shake – drop, cover, and hold on to something sturdy until the earthquake is over.
- Grab your 3-day emergency supply kit.
- Evacuate on foot if at all possible. The roads may be damaged and traffic may be jammed up.
- Do not wait for an official warning – do not pack or delay in any way.
- Move quickly inland to high ground and away from low-lying coastal areas.
- Do not return to the tsunami hazard zone until the "All Clear" is issued by local officials
- Listen to your NOAA Weather Radio or your local radio station for information on shelter locations and emergency broadcasts
- Be alert for aftershocks

# Unit 1

## Earthquakes: A common cause of tsunamis

Facts about earthquakes, a common cause of tsunamis

Defining earthquakes

Subduction zone earthquakes

Subduction

Location of subduction zones

The “Ring of Fire”

Key points to remember

Online learning resources

# Facts About Earthquakes: A common cause of tsunamis

The world's greatest land mountain range is the Himalaya-Karakoram. It contains 96 of the world's 109 peaks of over 7,317m (24,000 ft). The longest range is the Andes of South America, which is 7,564km (4700 mi) in length. Both were created by the movement of tectonic plates.

*Earthquake Facts, USGS*

Subduction is a geological process in which one edge of a crustal plate is forced downward into the mantle below another plate. When an earthquake occurs, the sudden motion raises the seafloor and the water above it, and a tsunami might be created.

Many subduction zone earthquakes occur between the Pacific plate and the North American plate, commonly referred to as the "Pacific Ring of Fire" of which Washington is part.

The largest earthquakes occur along subduction zones, which historically include the 1964 Alaska Earthquake, 2010 Chile Earthquake, and the 2011 Tohoku Earthquake. Each of these earthquakes generated tsunamis, and some resulted in the death of people in the Pacific basin.

## Defining Earthquakes

An earthquake is a natural phenomenon like rain. Earthquakes have occurred for billions of years. Descriptions as old as recorded history show the significant effects they have had on people's lives. Long before there were scientific theories for the cause of earthquakes, people living along the coast in the Pacific Northwest and around the world created folklore to explain them.

In simple terms, think of the surface of Earth as pieces of a puzzle, called tectonic plates, that make up the upper crust of the earth. These plates constantly shift apart, push against one another, and slide under or over each other. This constant motion of Earth's surface creates pressure between the plates. Sudden release of that tension between plates is called earthquakes. The result of earthquakes on Earth's surface sometimes breaks the surface layer, sometimes crunches it up into mountainous terrain. During a major earthquake, one often can see the ground moving and shaking.

## Subduction Zone Earthquakes

Sometimes plates run into each other, or slide under each other. The interaction of the two plates is called a subduction zone, or ocean trench. Subduction plates cause the largest earthquakes, such as the 1964 Alaska Earthquake, 2010 Chile Earthquake and 2011 Tohoku Earthquake. Each of those earthquakes generated tsunamis that killed thousands of people in the Pacific basin.

These types of earthquakes cause volcanoes, sometimes forcing the ground upward into huge mountain chains, such as the Cascade Mountain Range. The Cascade Range is a major mountain range of western North America, extending from southern British Columbia through Washington and Oregon to northern California. The Cascade Mountain Range in Washington state includes five active volcanoes.

The earliest recorded evidence of an earthquake has been traced back to 1831 BC in the Shandong province of China, but there is a fairly complete record starting in 780 BC during the Zhou Dynasty in China.

*Earthquake Facts, USGS*

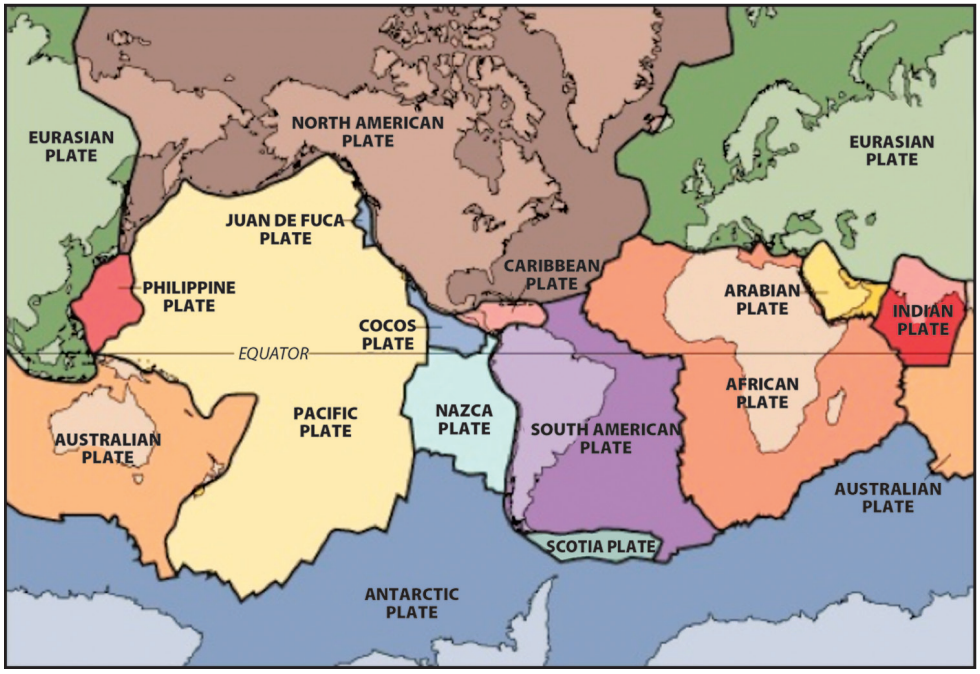



Illustration 1. **Earth's Tectonic Plates.** Earth is made up of a dozen or so major tectonic plates and several minor plates. These tectonic plates are constantly on the move. The fastest plate races along at about 6 inches per year, while the slowest plates crawl at less than 1 inch per year. (USGS)

## Subduction

Subduction is a geological process in which one edge of a crustal plate is forced downward into the mantle below another plate. For example, the Juan de Fuca plate descends beneath the North America, this process is known as subduction. Accumulated energy raises the seafloor (and the water above it) and a tsunami can be created.

## Location of Subduction Zones

There are certain parts of the Earth where subduction zone earthquakes are common. The majority of earthquakes occur along the Earth's plate boundaries, which carry the continents and the ocean floor. They occur most between the Pacific plate and the North American. These two plates are commonly referred to as the Pacific Ring of Fire, of which Washington is a part.

In 1907 a large earthquake and tsunami hit Simeulue Island, Sumatra, Indonesia, destroying villages, and killing more than half the population. The tsunami left boulders far inland, clearly showing the strength of tsunami waves. Through oral histories, this local knowledge, has been passed down through many generations. In 2004, when the M9.3 earthquake and devastating Indian Ocean tsunami occurred about 50 km offshore, officially only seven persons out of a population of about 78,000 on Simulue Island lost their lives. The community had learned what to do when the earth shakes.

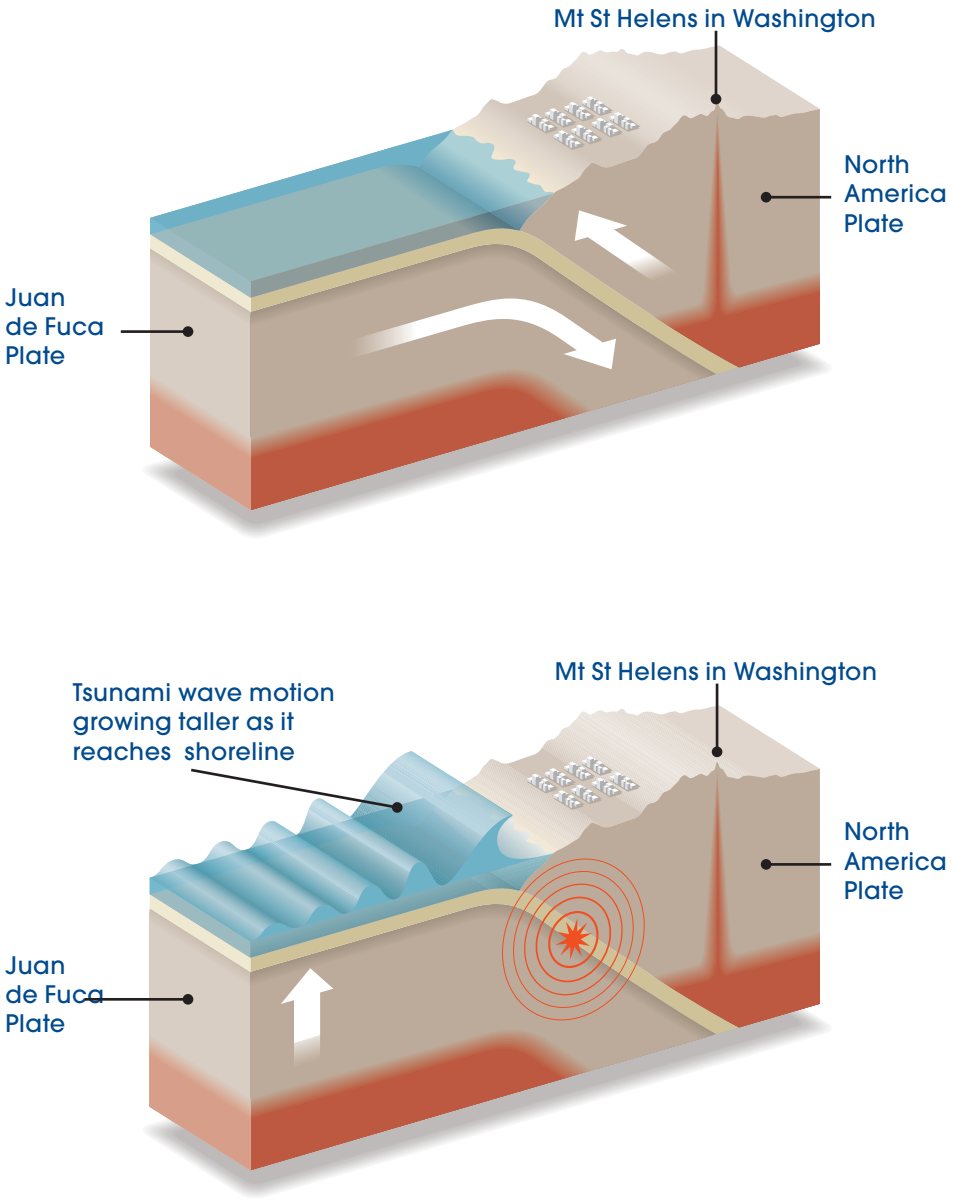



Illustration 2. **Tsunami**. When two plates collide, the released energy may force an upward motion of water, causing waves on the ocean surface. As those waves travel towards land, they can grow to dangerous heights. That wave action is called a tsunami.

Illustration 3. **Active Volcanoes, Plate Tectonics and the "Ring of Fire"**


Due to the various tsunami sources along the "Ring of Fire", distant source tsunamis are more frequent than local source tsunamis.

## The "Ring of Fire"

Scientists cannot accurately predict when or where an earthquake will occur. The majority of the earthquakes and volcanic eruptions occur along plate boundaries such as the boundary between the Pacific Plate and the North American plate. One of the most active plate boundaries where earthquakes and eruptions are frequent, for example, is around the massive Pacific Plate commonly referred to as the Pacific "Ring of Fire", illustrated in the map above.

Earthquakes are relatively brief, but their effects range far and wide. Aftershocks may spread over days or even months. The impact of the quake may be felt hundred of miles from its epicenter. A severe quake may trigger a chain of events, such as landslides, fires, floods, and pollution, that extend the damage and add to the panic and the casualties.

Even near the epicenter of a disastrous quake, much of the damage that occurs is due to secondary events. An earthquake may trigger landslides, fires, floods, chemical spills, and the release of nuclear wastes and other dangerous wastes. It may cause train wrecks and collisions of other vehicles. Power sources and water supplies may fail.

Earthquakes on the ocean bottom may result in the up- or down-shifting of large blocks of the crust. Such motion can generate a special kind of ocean wave called a tsunami. A series of these waves may travel at speeds up to 800 km/hr in the deep ocean, where they are too small to be seen. But when they reach land, they mount to heights of tens of meters and break against the shore and its buildings. Low coastal areas can be flooded, and much loss of life can result.

There is no such thing as "earthquake weather." Statistically, there is an equal distribution of earthquakes in cold weather, hot weather, rainy weather, and moderate temperatures. Furthermore, there is no physical way that the weather could affect the forces several miles beneath the surface of the earth. The changes in barometric pressure in the atmosphere are very small compared to the forces in the crust, and the effect of the barometric pressure does not reach beneath the soil.

*Earthquake Facts, USGS*

# Key Points to Remember

Subduction is a geological process in which one edge of a crustal plate is forced downward into the mantle below another plate. This motion raises the seafloor, and the water above it, and a tsunami can be created

Most subduction zone earthquakes occur between the Pacific plate and the North American plate, commonly referred to as the Pacific Ring of Fire, of which Washington is a part.

The largest earthquakes occur along subduction zones, such as the 1964 Alaska Earthquake, 2010 Chile Earthquake and 2011 Tohoku Earthquake. All of those earthquakes generated tsunamis and killed thousands of people in the Pacific basin.

## Online Learning Resources

### WASHINGTON STATE HAZARD MITIGATION PLAN

**Earthquake Hazard Profiles**
www.emd.wa.gov/plans/documents/ehmp_5.4_earthquake.pdf

**U.S. Geological Survey**
www.usgs.gov

**Pacific Northwest Seismic Network**
www.ess.washington.edu/SEIS/PNSN

**Washington Department of Natural Resources**
www.dnr.wa.gov/researchscience/topics/geologichazardsmapping/pages/earthquakes.aspx

# Unit 2

## Understanding Washington's Earthquake Sources

Facts about Washington's earthquakes sources

Understanding Washington's earthquake sources

Cascadia earthquake sources

How we know about the 1700 Cascadia earthquake and tsunami

Tsunami and land-level changes

Sand deposits

Tribal oral history

Key points to remember

Online learning resources

# Facts About Washington's Earthquakes Sources

With over 1,000 earthquakes recorded each year, Washington is ranked number two at risk from earthquakes based on U.S. populations.

Washington coastal communities are at greatest risk from a local earthquake generated by the Cascadia Subduction Zone.

In Puget Sound communities, the Seattle Fault poses a great risk for a local damaging earthquake and tsunami.

Native American oral history and historic written materials and records provide scientific data on the 1700 Cascadia Subduction Zone earthquake and tsunami.

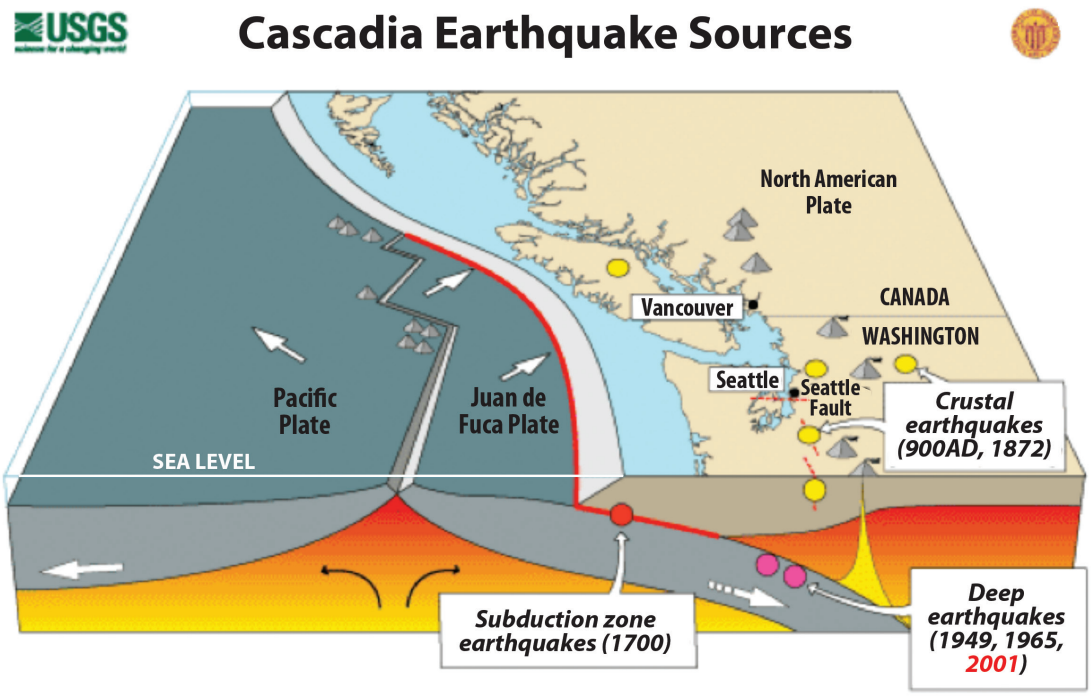
## Understanding Washington's Earthquake Sources

In studies conducted by the Federal Emergency Management Administration (FEMA), Washington is ranked number two in the nation for earthquakes based on at-risk populations. Washington averages over 1,000 earthquakes a year, and while only a few have caused major damage to date, it is only a matter of time before our population will experience a massive earthquake generated by the Cascadia Subduction Zone or one of our crustal faults, such as the Seattle Fault. Through education and preparedness actions citizens can be better prepared and know the appropriate actions to take when a major earthquake occurs. The following examples describe the sources of earthquakes in Washington.

It is estimated that there are 500,000 detectable earthquakes in the world each year. 100,000 of those can be felt, and 100 of them cause damage.

*Earthquake Facts, USGS*

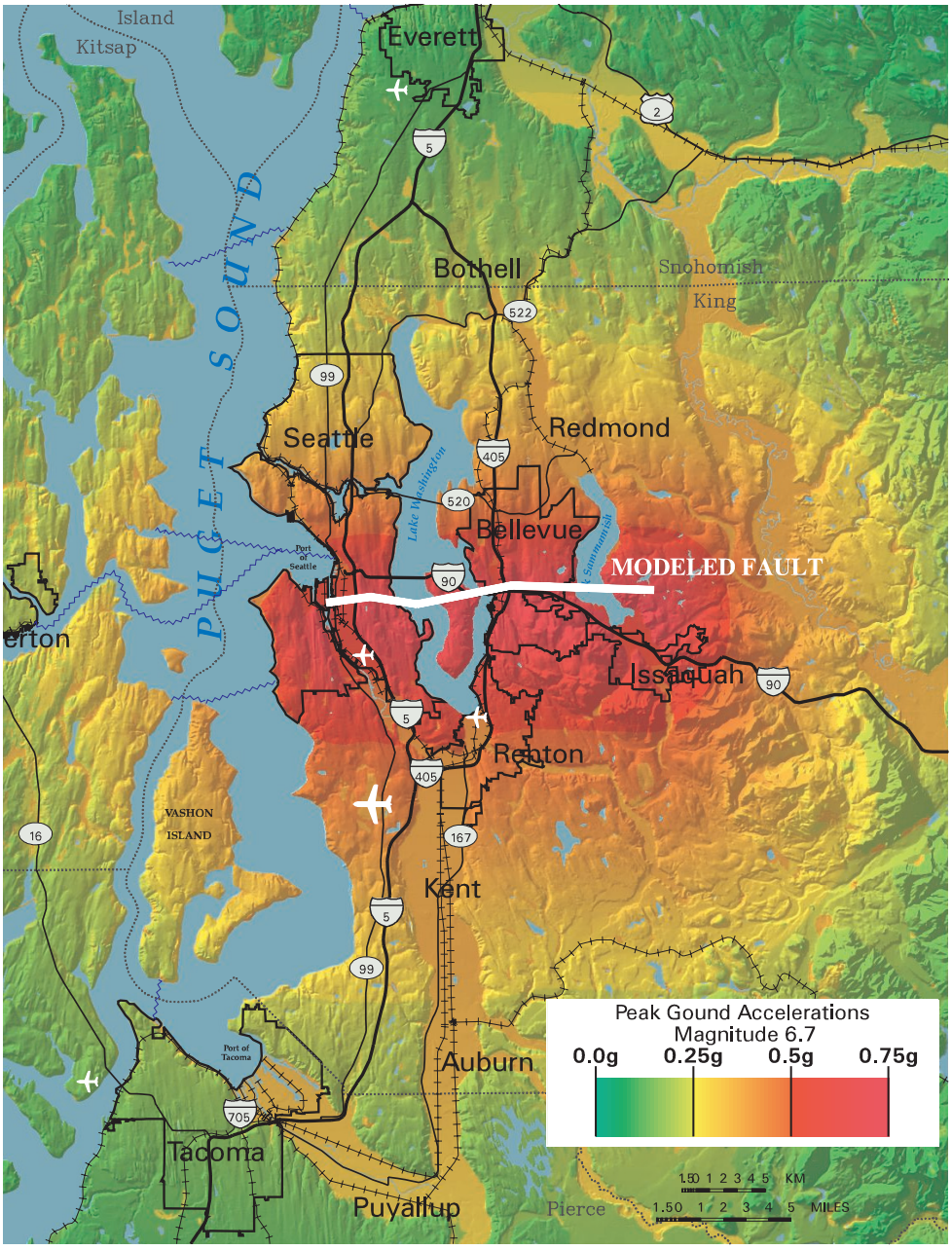
Illustration 4




| Source | Affected Area | Max. Size | Recurrence |
|---|---|---|---|
| Subduction Zone | W. WA, OR, CA | M 9 | 500-600 yr |
| Deep Juan de Fuca plate | W. WA, OR | M 7+ | 30-50 yr |
| Crustal faults | WA, OR, CA | M 7+ | Hundreds of years |

■ Cascadia subduction zone is the long fault boundary between the North American and Juan de Fuca plates. The zone stretches from northern Vancouver Island to Northern California and has produced great-magnitude earthquakes that have generated tsunamis at least six times in the past 3,500 years. The most recent occurred on the evening of January 26, 1700. During this earthquake and that of its predecessors, much of the land on Washington's outer coast subsided, or fell, by about five feet. Such lowering of the land caused flooding of coastal low-lying areas and killing western red cedar forests and other vegetation.

■ As the Juan de Fuca plate slides beneath North America, the plate begins to bend more steeply into the earth. The area near this bend is the second source zone, usually called the deep zone. This is the most frequent source of damaging earthquakes for Puget Sound; the 1949 Olympia Earthquake and 2001 Nisqually earthquake were in this source zone.




Graphic / US Geological Survey

Illustration 5. Seattle Fault showing peak ground accelerations using soils map.

The 2001 Nisqually earthquake was centered about 10 miles northeast of Olympia. One person died, more than 700 people were injured, and various estimates place damage at between $1 billion and $4 billion.

■ The Earth's shallow crustal faults are closer to the surface in many parts of the state, and can produce intense, localized ground shaking. Although there are numerous examples of shallow earthquakes, the 1872 earthquake near Lake Chelan was the state's most widely felt shallow earthquake. However, the majority of our population lives in Puget Sound. The Seattle Fault poses a threat to people and the built environment. A scenario for a magnitude 6.7 earthquake on the Seattle fault indicated such an event would probably result in more than 1,600 deaths, injure more than 24,000 people, the complete destruction of about 9,700 buildings, severe damage to more than 29,000 buildings, restricted use to about 154,500 buildings, and an estimated property damage and economic loss of about $33 billion dollars.

## ■ How we know about the 1700 Cascadia Subduction Zone Earthquake/Tsunami

Many times there are no written records or they are insufficient to accurately assess the tsunami hazard. For example, tsunami deposits allow geologists to expand the record of tsunamis, improving hazard assessment. Oral and written records also complement modern science and technology in identifying hazardous events. Along with modern scientific tsunami numerical modeling, oral and written records provide information for communities to determine their level of risk. Local knowledge can also supplement scientific data and help educate the population about impending hazards. Consequently, lives may be saved by oral history and written records.

Below are examples of evidence that support scientific investigation of the 1700 Cascadia Subduction Zone Earthquake and Tsunami on our coastal communities.

The subduction zone earthquakes can produce massive destruction, as shown in this aerial view of the 2011 Japan earthquake.

During the 2001 Nisqually 6.8 deep earthquake, land dropped along Deschutes Parkway in downtown Olympia, WA.

The first "pendulum seismoscope" to measure the shaking of the ground during an earthquake was developed in 1751, and it wasn't until 1855 that faults were recognized as the source of earthquakes.

*Earthquake Facts, USGS*

A dead forest along the Copalis River in Western Washington. Photo / Brian Atwater, U.S. Geological Survey

## Tsunami and Land-Level Changes

Pictured to the left is a dead forest along the Copalis River, about a mile upstream from the Highway 109 Bridge. The dead trees in this picture are western red cedars, and are very resistant to rot once they die. How did these trees die? They were killed by drowning with salt water. During the 1700 earthquake, imagine these trees covered with thick, green branches. Then, during the earthquake, the ground along the Copalis River suddenly drops, and salt water rushes in. The trees slowly die from the salt water. Some 300 years later, a paleoseismologist matches the tree rings of a dead tree and compares it to some of the long-lived cedar trees along the coast. That match tells the paleoseismologist that the tree died during the winter of 1699-1700. This is the evidence that a significant Cascadia Subduction Zone earthquake occurred about 1700.

A seiche (pronounced SAYSH) is a temporary disturbance in the water level of an enclosed, or partially enclosed body of water, such as a lake or swimming pool. It is "an internal wave oscillating in a body of water" or, in other words, it is the sloshing of the water in any body of water, caused by the ground shaking in an earthquake, or changes in atmospheric pressure. It may continue for a few moments or hours, long after the generating force is gone.

*Earthquake Facts, USGS*

## Sand Deposits

Tsunami deposits allow geologists to expand the record of tsunamis, improving hazard assessment. Water from a tsunami can deposit sand, cobbles, boulders and debris from offshore beaches over coastal lowlands. These deposits can be preserved in the geologic record giving evidence of past tsunamis to help assess the tsunami hazard for a community.

Similar to the killing and burial of the Copalis River trees, tide flat mud covers and buried tsunami sands. At Niawaikum River, the bottom is forest peat, then tsunami sand, then marine mud. Frequency and magnitude, two primary factors in tsunami hazard assessment, can be estimated through tsunami deposits. Where more than one tsunami deposit or subsided ground surface is preserved, the possibility is presented to determine earthquake or tsunami recurrence. The tsunami deposit can tell the minimum distance inland and run up as well as the minimum current needed to move the sediment. So it helps us understand the range of current strength and inundation.

Illustration 6. Inundation Time Series

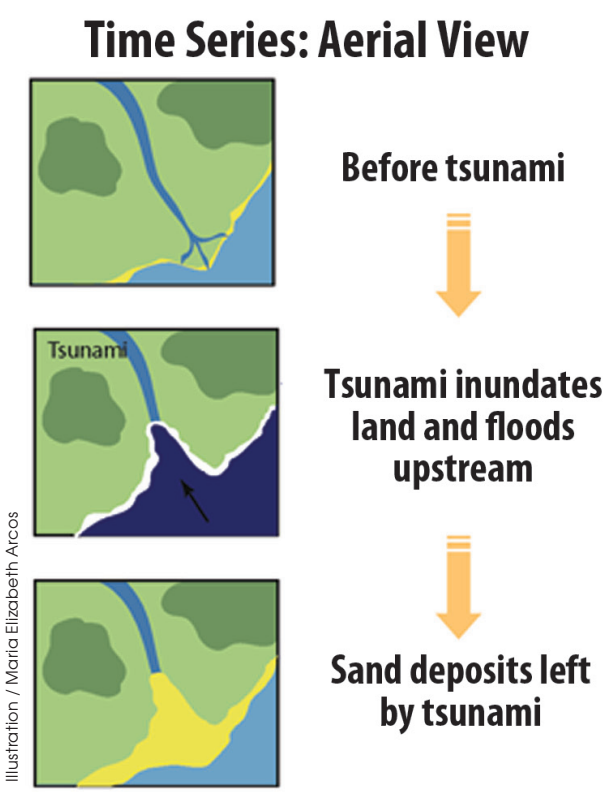
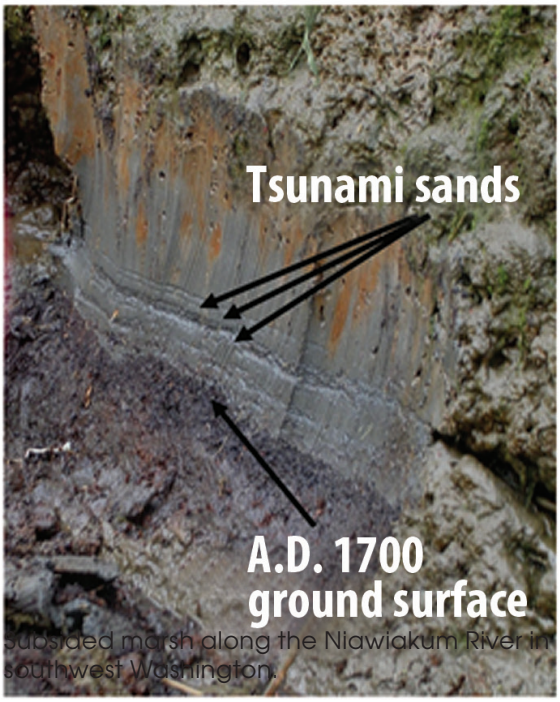



Illustration / Maria Elizabeth Arcos




Subsided marsh along the Niawiakum River in southwest Washington.

Photo / Tim Walsh, Washington DNR

## Tribal Oral History Tells of the 1700 Cascadia Earthquake and Tsunami

It was recognized as early as 350 BC by the Greek scientist Aristotle that soft ground shakes more than hard rock in an earthquake.

*Earthquake Facts, USGS*

Oral history has been used by many cultures throughout the world to educate and pass information from generation to generation. This tradition has been very helpful to complement scientific data and develop hazard assessment tools.

Oral traditions of Native Americans from Vancouver Island to Northern California tell of the earth shaking and the rising of the sea. For example, stories of the Hoh, Quileute and Makah Indians of the northwestern Olympic Peninsula relate the struggle between Thunderbird and Whale. Thunderbird is a bird of monstrous size, "... when he opens and shuts his eyes he makes lightning. The flapping of his wings makes the thunder and the great winds."

"Thunderbird ... soared from her dark hole in the mountains... far out over the placid waters and there poised herself high up in the air and waited for [Whale] to come to the surface of the water … the powerful bird darted and seized it. The great thunderbird finally carried the weighty animal to its nest in the lofty mountains, and there was the final and terrible contest fought."

Historic accounts of tsunami events from the Makah Tribe: "Among the signs of danger," the elders warn, "is long-lasting shaking moving from west to east, and sand that becomes so loose people walking on the beach sink into it. Elders tell the young they must run to high ground."

Researched by Ruth Ludwin, seismologist, Department of Earth and Space Sciences, University of Washington

"There were ... a shaking, jumping up and trembling of the earth beneath, and a rolling up of the great waters. The waters receded ... and ... again rose."

**INSTRUCTOR:** Show the video, *Run to High Ground*, a Native American story about tsunamis and earthquakes featuring storyteller Viola Riebe of the Hoh Tribe.

# Key Points to Remember

Subduction is a geological process in which one edge of a crustal plate is forced sideways and downward into the mantle below another plate. Accumulated energy raises the seafloor, and the water above it, and a tsunami can be created

Most subduction zone earthquakes occur between the Pacific plate and the North American plate, commonly referred to as the Pacific Ring of Fire, of which Washington is a part.

The largest earthquakes occur along subduction zones, such as the 1964 Alaska Earthquake, 2010 Chile Earthquake and 2011 Tohoku Earthquake. All have generated tsunamis, and some killed thousands of people in the Pacific basin.

## Additional online resources

**Atwater, Brian F., Musumi-Rokkaku Satoko, et al. (2005). The Orphan Tsunami of 1700. (No. 1707). Seattle, WA: U.S. Geological Survey.**
http://pubs.usgs.gov/pp/pp1707/

**Cascadia Subduction Zone Earthquakes: A magnitude 9.0 earthquake scenario, CREW, 2005**
www.CREW.org

**Thunderbird and Whale Stories**
www.pnsn.org/HIST_CAT/STORIES/legend.html