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Scientists Use Sound Waves to Probe Earthquake Hazards in the Puget Sound Area

"Geological evidence for past great earthquakes is clear, but basic information about regional earthquake processes is lacking. Knowing more about the structures underlying the region should give a clearer picture of the places most susceptible to violent shaking, landslides, and structural damage during earthquakes. City planners will have a rational basis for allocating scarce resources for such things as strengthening bridges, schools, and hospitals."—**Michael A. Fisher, U.S. Geological Survey**

Emerging evidence shows that damaging earthquakes of magnitude 8 or greater could strike the Pacific Northwest, a region that stretches from northern California through Oregon and Washington into British Columbia, Canada. This region includes large population centers such as Portland, Seattle, and Vancouver, Canada. To study the earthquake threat in and around Seattle, the U.S. Geological Survey (USGS) and eight cooperating institutions launched SHIPS—Seismic Hazards Investigation in Puget Sound. SHIPS scientists are using sound waves to probe sediment and rock layers beneath the Puget Sound area. The faults and other features they uncover will help them determine where the worst earthquake damage is likely to occur.

University of Washington's Research Vessel *Thomas G. Thompson* towed an array of airguns (to left of photo) through Puget Sound beside downtown Seattle in March 1998. Bursts of sound from the airguns bounced off rock layers deep beneath the earth's surface. Returning echoes built up a picture of the rock layers and faults that cut them. These data will be combined with on-land SHIPS data collected in September 1999 to create a complete three-dimensional view of the sediment and rock layers beneath the Seattle area. (Photograph by David L. Carver, U.S. Geological Survey)

Around 1860, a naturalist on a railroad survey noted many dead trunks of Western Redcedar standing along the shores of Willapa Bay on the southern Washington coast. More than a hundred years later, in the late 1980's, scientists discovered what killed the trees. Their roots had been submerged in saltwater when forested land dropped below sea level during a great earthquake (magnitude 8 or more) about 300 years ago. With that discovery came the realization that a great earthquake could strike the region again.

Pacific Northwest Quakes

The Pacific Northwest sits atop the Cascadia subduction zone, where two great slabs of the Earth's crust—called tectonic plates—are converging. The Juan de Fuca plate on the west, made up of dense oceanic crust, is shoving eastward beneath the North American plate, made of lighter, continental crust.

The grinding of plates past each other in subduction zones sometimes generates deep earthquakes—originating tens of kilometers beneath the earth's surface. Subduction-zone earthquakes can be huge; the magnitude 9.2 earthquake that struck Alaska in 1964 is an example. Until recently, scientists considered the Cascadia subduction zone to be moving smoothly and unlikely to generate big earthquakes. But by the late 1980's, evidence such as drowned forests, tsunami deposits, and sediments liquefied by shaking showed that the Cascadia subduction zone had produced great earthquakes in the past and could do so again. Added to that was evidence in the Puget Sound area for past large earthquakes generated on faults near the surface, such as the Seattle fault (see map and figure on back page). These discoveries inspired the U.S. Geological Survey (USGS) and other institutions to study the Pacific Northwest more intently, to assist decision makers in assessing and mitigating earthquake hazards there.

Experiments in Puget Sound

Earth scientists from the USGS and eight cooperating institutions (see list on back page) are currently conducting a study called SHIPS, or Seismic Hazards Investigation in Puget Sound.

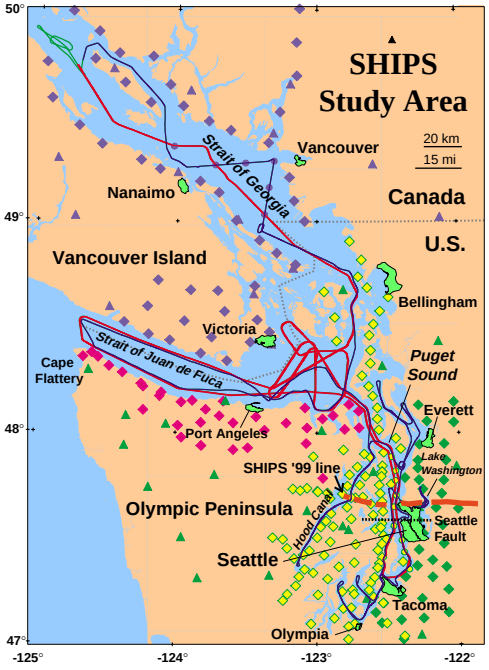
Though scientists cannot yet predict *when* earthquakes will strike, they can determine *where* earthquakes will strike and where the shaking will be most violent. To this end, SHIPS scientists are using sound waves to build up images of the sediment

and rock layers that lie beneath the Puget Sound area. The data will reveal (1) how faults and rock layers are arranged beneath the region, and (2) how earthquake waves will change speed and direction as they travel through the layers. Using these data, scientists will construct computer simulations of the effects of strong earthquake shaking on the Puget Sound area.

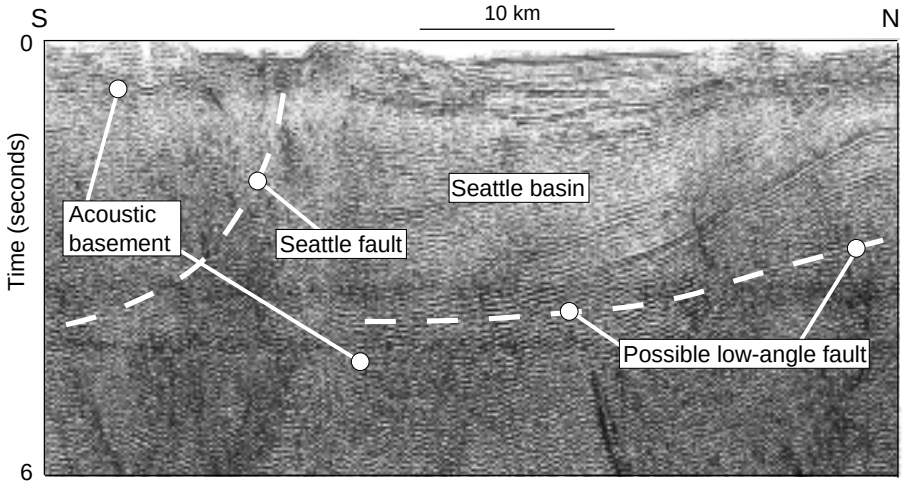
Phase I—SHIPS on Water

The first phase of SHIPS was conducted from March 10 to March 24, 1998, on research vessels cruising Puget Sound, the Strait of Juan de Fuca, Strait of Georgia, Hood Canal, and Lake Washington (see map, below). Airguns towed behind the University of Washington's Research Vessel *Thomas G. Thompson* produced bursts of sound energy that traveled deep into sediment and rock layers beneath the region. Returning sound waves were recorded by more than 300 seismographs (see map). Special precautions were taken to be sure that the sound waves did not harm marine mammals (see inset, lower right).

Among the results are vertical slices through the earth's crust revealing details of fault structures that could cause earthquakes (see example, upper right).



Locations of SHIPS seismic recording instruments. Heavy red east-west line in lower right is where about 1,000 temporary seismographs will record SHIPS data in September 1999. Lines in waterways show where towed airguns were fired in March 1998. Dots are locations of temporary and permanent seismographs used to record returning airgun echoes in March 1998.



This vertical slice of the earth's crust below Seattle was created from data collected during the March 1998 SHIPS cruise. Labels show scientists' preliminary interpretation of the data. Acoustic basement is hard bedrock. In this image, it floors the Seattle basin, a deep depression filled with sedimentary deposits that might amplify earthquake shaking. Forming the south wall of the basin is the Seattle fault, which is thought to have generated at least one large earthquake and associated tsunamis about 1,000 years ago. The subducted part of the Juan de Fuca plate lies about 50 kilometers (30 miles) beneath the top of this image.

Phase II—SHIPS on Land

The second phase of SHIPS will be conducted in September 1999. To complement the data collected from the waterways, SHIPS scientists will conduct an experiment along an east-west line on land. Seismic waves will be generated by explosions in deep boreholes. These holes will be placed in open fields so that the waves will not damage structures or natural features. Echoes from the explosions will be recorded by about 1,000 seismographs placed at 100-meter (110-yard) intervals along the 100-kilometer (60-mile) east-west line (see heavy red line, lower part of map at left). The combined SHIPS data, from water and land, will provide a complete three-dimensional view of the Seattle basin, allowing researchers to construct computer models of how strong earthquake shaking will affect the basin.

Cooperating Institutions:

In the United States:

University of Washington
Oregon State University
University of Texas at El Paso
Dept. of Natural Resources, State of Washington

In Canada:

Geological Survey of Canada
University of Victoria
University of British Columbia
Dalhousie University

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Protecting Marine Life from Underwater Research Sound

Although loud, low-frequency sound waves have been used for decades in underwater research, there has recently been heightened concern about their effects on marine life—especially marine mammals. The USGS worked with the National Marine Fisheries Service and the Cascadia Research Collective, a non-profit research organization, to minimize negative effects of SHIPS airgun sounds during the March 1998 cruise. About a dozen biologists took part in the cruise to watch for marine mammals, request shutdown of airguns if marine mammals were sighted near agreed-upon safety zones, measure sound levels at various distances from the airgun array, and monitor mammal behavior. The airguns were shut down quickly (on five occasions) when mammals were observed near or considered likely to enter the safety zones. The sound measurements and behavior observations will help researchers modify safety zones to better fit various species.