

Tsunamis' Toll Might Have Been Lessened

Experts Cite Lack of Warning System

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Yesterday's massive tsunamis were triggered when a plate of earth that was dug like a bulldozer blade into the ocean floor off the coast of western Indonesia broke through layers of rocky resistance and created a rupture hundreds of miles in length, geologists said.

Once the action was begun, rock would have torn apart like paper. The ocean floor collapsed in places and rose elsewhere, triggering massive upheavals of water. Unlike waves on the surface, a tsunami is an underwater wave whose effects are apparent only when it reaches shore, often hundreds or even thousands of miles away.

"The extent of this earthquake is on the order of the size of California," said Eddie Bernard, director of the Pacific Marine Environmental Laboratory, which is part of the National Oceanic and Atmospheric Administration. "You have the earth shooting up in some places 10, 15, 20 feet and creating underwater landslides."

The real tragedy, many experts acknowledged yesterday, is that thousands of lives in countries such as Sri Lanka, India and Thailand could have been saved if an early warning system similar to one that exists for the Pacific Ocean had been in place. U.S. officials said that they wanted to warn the countries but that there was no mechanism to do so.

The tsunamis' impact in the hardest-hit countries occurred about two hours after the underwater earthquake: If authorities had had the opportunity to move people even a few hundred yards inland, many people would have been saved, Bernard said.

"The idea is to get yourself high enough or far enough inland that the water is not strong enough to take you back to sea. About waist-deep water is where you lose control," he said.

One reason experts had not pushed hard for a warning system is that the risk along the shores of the Indian Ocean had long been underestimated. Most of the devastating tsunamis in the last century or more have occurred elsewhere.

"We have believed as a community that the Indian Ocean is fairly immune to tsunamis of the kind that took place," said **Costas Synolakis**, a professor of civil engineering at the University of Southern California. "The last tsunami that affected the Indian Ocean was in 1883. . . . The hazard was underestimated by a factor of 10."

Synolakis said he had opened discussions two weeks ago with officials in Hawaii at the Pacific Tsunami Warning Center about expanding the warning system to the Indian Ocean.

The geological cause of the earthquake is plain: Indonesia has long been plagued by earthquakes and the volcanoes that usually attend such massive fissures in the earth. Giant plates bearing India and Australia have been moving north for millenniums, colliding with the Eurasian landmass near Indonesia. As a result of the immense pressure that was built up, the southern plate is dug like a bulldozer blade under the northern plate.

"Most of the time, the plates are stuck together and nothing happens," said Lori Dengler, professor of geology at Humboldt State University in California. "But every several hundred years, we have a rupture that causes one side to move."

When that happened about 8 p.m. Eastern time Saturday, pressure that had accumulated for years or decades was released in an instant. As the earth convulsed, the ocean floor probably fell rapidly in some places and rose elsewhere along a fissure hundreds of miles in length, several experts said. Areas that collapsed saw tons of water plunge in, causing what is known as a depression wave. Elsewhere, the ocean floor reared up, causing water to be displaced -- an elevation wave. It is likely that both effects fed the tsunamis, experts said.

"Think of a kid's plastic swimming pool and sliding your hand underneath -- pushing up on the plastic," said John Ebel, a professor of geophysics at Boston College. "It would cause a wave to spread throughout the pool. That's what happens on the ocean floor after an earthquake."

Unlike wind-whipped waves on the ocean, which rarely cause much disturbance below the surface, a tsunami's energy is contained underwater. A ship in the deep ocean is unlikely to be affected by a tsunami.

But the effects become shockingly clear as a tsunami approaches shore and the waves rear up, said Kenneth Hudnut, a geophysicist at the U.S. Geological Survey in Pasadena, Calif. Depending on where the earthquake occurred, people often encounter the depression and elevation waves in the same sequence in which they were created.

"In many cases, people report the sea withdrew first and then the seafloor was exposed, and then the elevation wave comes in and hits the land," Synolakis said.

The energy released by a tsunami is enormous, and geologists said that measuring instruments would likely continue to pick up signals for about 24 hours all over the world. Although earthquake

aftershocks are common, new tsunamis are likely to be much smaller and localized, and might well not be noticed without sensitive measuring instruments.

Even without a sophisticated early warning system, experts said, just knowing about the nature of tsunamis could have saved lives. A rapidly receding shoreline is a warning that the elevation wave is about to strike -- people may have as long as 10 minutes to flee the ocean's edge, Synolakis said. Even fleeing when the sound of the approaching wave can be heard might save lives, Bernard said.

Fishing boats or sailboats in the ocean are likely to find greater safety by heading farther out to sea, Bernard added. A tsunami has less effect in deeper water.

"You can't stop these once they get going," he said. "The only thing that could have been done is evacuate the coastline.