Study of 2004 Tsunami Disaster Forces Rethinking of Theory of Giant Earthquakes

PASADENA, Calif.--The Sumatra-Andaman earthquake of December 26, 2004, was one of the worst natural disasters in recent memory, mostly on account of the devastating tsunami that followed it. A group of geologists and geophysicists, including scientists at the California Institute of Technology, has delineated the full dimensions of the fault rupture that caused the earthquake.

Their findings, reported in the March 2 issue of the journal Nature, suggest that previous ideas about where giant earthquakes are likely to occur need to be revised. Regions of the earth previously thought to be immune to such events may actually be at high risk of experiencing them.

Like all giant earthquakes, the 2004 event occurred on a subduction megathrust-in this case, the Sunda megathrust, a giant earthquake fault, along which the Indian and Australian tectonic plates are diving beneath the margin of southeast Asia. The fault surface that ruptured cannot be seen directly because it lies several kilometers deep in the Earth's crust, largely beneath the sea.

Nevertheless, the rupture of the fault caused movements at the surface as long-accumulating elastic strain was suddenly released. The researchers measured these surface motions by three different techniques. In one, they measured the shift in position of GPS stations whose locations had been accurately determined prior to the earthquake.

In the second method, they studied giant coral heads on island reefs: the top surfaces of these corals normally lie right at the water surface, so the presence of corals with tops above or below the water level indicated that the Earth's crust rose or fell by that amount during the earthquake.

Finally, the researchers compared satellite images of island lagoons and reefs taken before and after the earthquake: changes in the color of the seawater or reefs indicated a change in the water's depth and hence a rise or fall of the crust at that location.

On the basis of these measurements the researchers found that the 2004 earthquake was caused by rupture of a 1,600-kilometer-long stretch of the megathrust-by far the longest of any recorded earthquake. The breadth of the contact surface that ruptured ranged up to 150 kilometers. Over this huge contact area, the surfaces of the two plates slid against each other by up to 18 meters.

On the basis of these data, the researchers calculated that the so-called moment-magnitude of the earthquake (a measure of the total energy released) was 9.15, making it the third largest earthquake of the past 100 years and the largest yet recorded in the few decades of modern instrumentation.

"This earthquake didn't just break all the records, it also broke some of the rules," says Kerry Sieh, who is the Sharp Professor of Geology at Caltech and one of the authors of the Nature paper.

According to previous understanding, subduction megathrusts can only produce giant earthquakes if the oceanic plate is young and buoyant, so that it locks tightly against the overriding continental plate and resists rupture until an enormous amount of strain has accumulated.

Another commonly accepted idea is that the rate of relative motion between the colliding plates must be high for a giant earthquake to occur. Both these conditions are true off the southern coast of Chile, where the largest earthquake of the past century occurred in 1960. They are also true off the Pacific Northwest of the United States, where a giant earthquake occurred in 1700 and where another may occur before long.

But at the site of the 2004 Sumatra-Andaman earthquake the oceanic crust is old and dense, and the relative motion between the plates is quite slow. Yet another factor that should have lessened the likelihood of a giant earthquake in the Indian Ocean is the fact that the oceanic crust is being stretched by formation of a so-called back-arc basin off the continental margin.

"For all these reasons, received wisdom said that the giant 2004 earthquake should not have occurred," says Jean-Philippe Avouac, a Caltech professor of geology, who is also a contributor to the paper. "But it did, so received wisdom must be wrong. It may be, for example, that a slow rate of motion between the plates simply causes the giant earthquakes to occur less often, so we didn't happen to have seen any in recent times-until 2004."

Many subduction zones that were not considered to be at risk of causing giant earthquakes may need to be reassessed as a result of the 2004 disaster. "For example, the Ryukyu Islands between Taiwan and Japan are in an area where a large rupture would probably cause a tsunami that would kill a lot of people along the Chinese coast," says Sieh.

"And in the Caribbean, it could well be an error to assume that the entire subduction zone from Trinidad to Barbados and Puerto Rico is aseismic. The message of the 2004 earthquake to the world is that you shouldn't assume that your subduction zone, even though it's quiet, is incapable of generating great earthquakes."

According to Sieh, it's not that all subduction zones should now be assigned a high risk of giant earthquakes, but that better monitoring systems-networks of continuously recording GPS stations, for example-should be put in place to assess their seismic potential.

"For most subduction zones, a $1 million GPS system would be adequate," says Sieh. "This is a small price to pay to assess the level of hazard and to monitor subduction zones with the potential to produce a calamity like the Sumatra-Andaman earthquake and tsunami. Caltech's Tectonics Observatory has, for example, begun to monitor the northern coast of Chile, where a giant earthquake last occurred in 1877."

In addition to Sieh and Avouac, the other authors of the Nature paper are Cecep Subarya of the National Coordinating Agency for Surveys and Mapping in Cibinong, Indonesia; Mohamed Chlieh and Aron Meltzner, both of Caltech's Tectonics Observatory; Linette Prawirodirdjo and Yehuda Bock, both of the Scripps Institution of Oceanography; Danny Natawidjaja of the Indonesian Institute of Sciences; and Robert McCaffrey of Rensselaer Polytechnic Institute.

Contact: Robert Tindol (626) 395-3631 **tindol@caltech.edu**

Navigating Tools

Search for: in News Releases Search

Email us at **prmedia@caltech.edu** with comments, questions or suggestions.