Signs of ancient megatsunami could portend modern hazard

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Geologists think that the eastern slope of Fogo volcano crashed into the sea some 65,000 to 124,000 years ago, leaving a giant scar where a new volcano can be seen growing in this satellite image. Credit: NASA

Scientists working off west Africa in the Cape Verde Islands have found evidence that the sudden collapse of a volcano there tens of thousands of years ago generated an ocean tsunami that dwarfed anything ever seen by humans. The researchers say an 800-foot wave engulfed an island more than 30 miles away. The study could revive a simmering controversy over whether sudden giant collapses present a realistic hazard today around volcanic islands, or even along more distant continental coasts. The study appears today in the journal *Science Advances*.

"Our point is that flank collapses can happen extremely fast and catastrophically, and therefore are capable of triggering giant tsunamis," said lead author Ricardo Ramalho, who did the research as a postdoctoral associate at Columbia University's Lamont-Doherty Earth Observatory, where he is now an adjunct scientist. "They probably don't happen very often. But we need to take this into account when we think about the hazard potential of these kinds of volcanic features."

The apparent collapse occurred some 73,000 years ago at the Fogo volcano, one of the world's largest and most active island volcanoes. Nowadays, it towers 2,829 meters (9,300 feet) above sea level, and erupts about every 20 years, most recently last fall. Santiago Island, where the wave apparently hit, is now home to some 250,000 people.

There is no dispute that volcanic flanks present a hazard; at least eight smaller collapses have occurred in Alaska, Japan and elsewhere in the last several hundred years, and some have generated deadly tsunamis. But many scientists doubt whether big volcanoes can collapse with the

suddenness that the new study suggests. Rather, they envision landslides coming in gradual stages, generating multiple, smaller tsunamis. A 2011 French study also looked at the Fogo collapse, suggesting that it took place somewhere between 124,000-65,000 years ago; but that study says it involved more than one landslide. The French researchers estimate that the resulting multiple waves would have reached only 45 feet—even at that, enough to do plenty of harm today.

A handful of previous other studies have proposed much larger prehistoric collapses and resulting megatsunamis, in the Hawaiian islands, at Italy's Mt. Etna, and the Indian Ocean's Reunion Island. But critics have said these examples are too few and the evidence too thin. The new study adds a new possible example; it says the estimated 160 cubic kilometers (40 cubic miles) of rock that Fogo lost during the collapse was dropped all at once, resulting in the 800-foot wave. By comparison, the biggest known recent tsunamis, which devastated the Indian Ocean's coasts in 2004 and eastern Japan in 2011, reached only about 100 feet. (Like most other well documented tsunamis, these were generated by movements of undersea earthquake faults—not volcanic collapses.)

On a clear day, from these cliffs in northern Santiago island, it is possible to see a silhouette of Fogo, nearly 40 miles away. The geologists on this ridge believe that a tsunami generated by Fogo's sudden collapse generated a wave that swept the spot where they are standing. Credit: Kim Martineau/Lamont-Doherty Earth Observatory

Santiago Island lies 55 kilometers (34 miles) from Fogo. Several years ago, Ramalho and colleagues were working on Santiago when they spotted unusual boulders lying as far as 2,000 feet inland and nearly 650 feet above sea level. Some are as big as delivery vans, and they are utterly unlike the young volcanic terrain on which they lie. Rather, they match marine-type rocks that ring the island's shoreline: limestones, conglomerates and submarine basalts. Some weigh up to 770 tons. The only realistic explanation the scientists could come up with: A gigantic

wave must have ripped them from the shoreline and lofted them up. They derived the size of the wave by calculating the energy it would have taken to accomplish this feat.

To date the event, in the lab Ramalho and Lamont-Doherty geochemist Gisela Winckler measured isotopes of the element helium embedded near the boulders' surfaces. Such isotopes change depending on how long a rock has been lying in the open, exposed to cosmic rays. The analyses centered around 73,000 years—well within the earlier French estimate of a smaller event. The analysis "provides the link between the collapse and impact, which you can make only if you have both dates," said Winckler.

Tsunami expert Bill McGuire, a professor emeritus at University College London who was not involved in the research, said the study "provides robust evidence of megatsunami formation [and] confirms that when volcanoes collapse, they can do so extremely rapidly." Based on his own work, McGuire s says that such megatsunamis probably come only once every 10,000 years. "Nonetheless," he said, "the scale of such events, as the Fogo study testifies, and their potentially devastating impact, makes them a clear and serious hazard in ocean basins that host active volcanoes."

Ramalho cautions that the study should not be taken as a red flag that another big collapse is imminent here or elsewhere. "It doesn't mean every collapse happens catastrophically," he said. "But it's maybe not as rare as we thought."

In the early 2000s, other researchers started publishing evidence that the Cape Verdes could generate large tsunamis. Others have argued that Spain's Canary Islands have already done so. Simon Day, a senior researcher at University College London has sparked repeated controversy by warning that any future eruption of the Canary Islands'

active Cumbre Vieja volcano could set off a flank collapse that might form an initial wave 3,000 feet high. This, he says, could erase more than nearby islands. Such a wave might still be 300 feet high when it reached west Africa an hour or so later he says, and would still be 150 feet high along the coasts of North and South America. So far, such studies have raised mainly tsunamis of publicity, and vigorous objections from other scientists that such events are improbable. A 2013 study of deep-sea sediments by the United Kingdom's National Oceanography Centre suggests that the Canaries have probably mostly seen gradual collapses.

The tsunami generated by Fogo's collapse apparently swept boulders like this one from the shoreline up into the highlands of Santiago island. Here, a researcher chisels out a sample. Credit: Ricardo Ramalho

Part of the controversy hangs not only on the physics of the collapses themselves, but on how efficiently resulting waves could travel. In 1792, part of Japan's Mount Unzen collapsed, hitting a series of nearby bays with waves as high as 300 feet, and killing some 15,000 people. On July 9, 1958, an earthquake shook 90 million tons of rock into Alaska's isolated Lituya Bay; this created an astounding 1,724-foot-high wave, the largest ever recorded. Two fishermen who happened to be in their boat that day were carried clear over a nearby forest; miraculously, they survived.

These events, however, occurred in confined spaces. In the open ocean, waves created by landslides are generally thought to lose energy quickly, and thus to pose mainly a regional hazard. However, this is based largely on modeling, not real-world experience, so no one really knows how fast a killer wave might decay into a harmless ripple. In any case, most scientists are more concerned with tsunamis generated by undersea earthquakes, which are more common. When seabed faults slip, as they did in 2004 and 2011, they shove massive amounts of water upward. In deep water, this shows up as a mere swell at the surface; but when the swell reaches shallower coastal areas, its energy concentrates into in a smaller volume of water, and it rears up dramatically. The 2004 Indian Ocean earthquake and tsunami killed 230,000 people in 14 countries; the 2011 Tohoku event killed nearly 20,000 in Japan, and has caused a long-term nuclear disaster.

James Hunt, a tsunami expert at the United Kingdom's National Oceanography Centre who was not involved in the study, said the research makes it clear that "even modest landslides could produce high-amplitude anomalous tsunami waves on opposing island coastlines." The question, he said, "is whether these translate into hazardous events in the far field, which is debatable."

When Fogo erupted last year, Ramalho and other geologists rushed in to

observe. Lava flows (since calmed down) displaced some 1,200 people, and destroyed buildings including a new volcano visitors' center. "Right now, people in Cape Verde have a lot more to worry about, like rebuilding their livelihoods after the last eruption," said Ramalho. "But Fogo may collapse again one day, so we need to be vigilant."

More information: Hazard Potential of Volcanic Flank Collapses Raised by New Megatsunami Evidence, DOI: 10.1126/sciadv.1500456 , advances.sciencemag.org/content/1/9/e1500456

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