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Not My Fault: The Tonga eruption and tsunami: more unusual than first suspected

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One week has passed since the eruption of Hunga Tonga-Hunga Ha'apai that spawned last Saturday's tsunami alert around the Pacific. Even in the early hours, it was clearly unusual. A week later, the emerging evidence is a more groundbreaking event than we initially thought.

Almost no one knew about this volcano before last week. It is a mere speck of land on Google Earth, barely over 2 miles wide and less than 400 feet above sea level, the top first emerging above the ocean in 2015. But that small surface appearance belies a much larger edifice beneath the water, extending 6500 feet down to the sea floor.

The volcano has been growing for centuries, but only noticed in 2009 when steam and ash erupted several thousand feet into the air. That was small potatoes compared to the January 14th blast. Initial estimates put the plume height as 12 miles but more recent studies (https://www.bbc.com/news/science-environment-60088413) suggest 35 miles, extending to the top of the stratosphere. This is the highest volcanic plume ever observed, exceeding the 1991 eruption of Mt. Pinatubo in the Philippines by 15 miles.

To get that high, the volcanic ejecta needed a tremendous boost and the volcano likely got it from two sources. The first is gas in the molten material (magma) beneath the surface. Like a bottle of beer, pressure keeps the gas in solution as long as it is buried. But near the surface, pressure is reduced, and the gas explodes out. The second source is seawater. Recent volcanic activity probably created fractures allowing water to contact the rising magma. When seawater contacts magma, it flashes to steam. Geysers are a small-scale version of the process. The more water that comes into magma contact, the bigger the steam blast.

This explosion produced a very loud noise. The blast was described like thunder in Fiji 430 miles away. In Anchorage, 6000 miles distant, it was heard as loud bangs. The Alaska Volcano Observatory's infrasound (low frequency, below human perceptibility) detected a signal consistent with the Tonga eruption for more than two hours. Other infrasound sites observed the sound wave circling the globe as many as four times.

How does the Tonga eruption compare to a nuclear bomb? That depends on the size of the nuke. I've seen reports that it released the energy equivalent of 10 megatons of TNT, making it larger than the largest underground nuclear test ever conducted (Cannikin 1971, 5 megatons) but smaller than Tsar Bomba, the ~55-megaton atmospheric test in 1961. The jury is still out on the exact number, and further analysis could move it closer to Bomba in size.

It is still unclear just how large an eruption the January 15th event was. Volcanologists use the Volcano Explosivity Index (VEI) as a qualitative measure of eruption size. Fluid eruptions like those on Hawaii rate VEIs of 1. Most eruptions of Mt. Etna in Sicily have VEIs around 3. The 1991 eruption of Pinatubo with a VEI of 5 is the largest and most explosive eruption of my lifetime. Two factors figure into VEI - how high the ejecta reached, and the total volume of material erupted. We've got a pretty good estimate of the height of last week's eruption, but it is tricky to measure volume.

When great eruptions occur on land, scientists estimate volume from isopach maps contouring the thickness of ash and other explosive debris. The Tonga eruption was in the ocean and the volcanic products are spread out on the sea surface and sea floor. In coming months, submarine investigations will scan the ocean bottom to estimate how much of the pre-eruption structure was blown away, but for now, volume estimates are speculative. We do know that the most intense part of the eruption was brief, lasting on the order of minutes rather than hours or days. That could mean a stronger initial blast but smaller VEI than Pinatubo.

The blast appears to have played a role in the tsunami. This was an unusual tsunami and is why it took so long for the alert bulletins to be issued along our coast. The Pacific Tsunami Warning Center (PTWC) in Hawaii was aware of the eruption soon after it occurred. PTWC issued a tsunami threat message to nations in the SW Pacific only two hours afterwards announcing a tsunami was possible within 600 miles of the volcano.

As the tsunami traveled across the Pacific, it was recorded on tide gauges and deep ocean pressure sensors and the signal was unlike anything the PTWC staff had seen before. The first wave arrivals were coming in too early, and the signals were larger than expected. It wasn't until the tsunami had arrived in Hawaii that the National Tsunami Warning Center realized there was a threat to the US West Coast and Alaska, and we began to receive alert updates.

The speed of a tsunami in the ocean is well understood and depends only on the depth of the sea floor. Using an average depth for the Pacific, a tsunami travels at roughly 450 to 500 miles per hour, about the speed of a jet airplane. But the first tsunami signals at many locations in the Pacific were 'premature' and corresponded to over 700 miles per hour. That value turns out to be the speed of sound in the atmosphere.

Even odder are the tsunami signals detected in the Atlantic and in the Mediterranean Sea. The times don't match what it would take to travel around the tip of South America. They do appear to match a sound wave traveling across Central America and triggering an ocean disturbance once the land has passed.

The Hunga-Tonga-Hunga-Ha'apai eruption and tsunami is providing the best ever data set to understand the complex coupling between earth's atmosphere and ocean. It is an exciting time to be an earth scientist.

For more on the emerging picture of the shockwave, see https://www.nature.com/articles/d41586-022-00127-1 , and https://www.severe-weather.eu/news/tonga-volcano-massive-eruption-explosion-stratosphere-usa-tsunami-shockwave-fa/.

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