Repeat Offender: Krakatoa Kills Again,
22 December 2018

History of Destruction

The infamous Krakatoa (Fig. 1) continues to live up to its legacy as one of the most volatile volcanoes on the planet. Its 1883 eruption is legendary for producing the largest explosion in historic times. The sound it made was heard 5000 km (3000 miles) away. Imagine hearing an explosion in Boston from San Francisco! The pressure wave of the explosion circled the globe 7 times and was registered on barographs worldwide over the course of 5 days.

The blast was sparked by the instant flashing to steam of mega-tons of seawater that poured into the magma chamber feeding the eruption as the volcano collapsed into the sea. The event generated a series of tsunamis with run-up heights > 35 m, which claimed most of > 36,000 deaths locally resulting from the eruption. Hundreds of settlements were swept away. Even more casualties globally are attributed to the eruption due to sulfur contamination of Earth's upper atmosphere from the violence of the explosion. The increase in sulfur dioxide blocked enough sunlight to cool Earth by an estimated 1.5 degrees C.

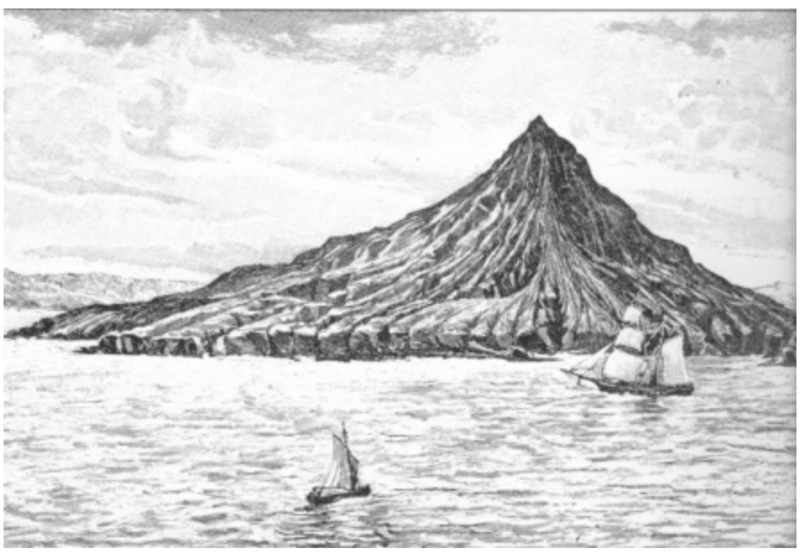


Fig. 1. Pre-1883 drawing of Krakatoa rising ominously over the busy shipping lanes of the Sunda Strait in Indonesia. Source: Wikipedia Creative Commons.

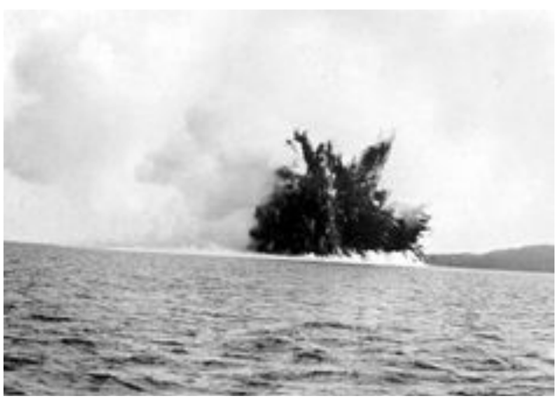
Near the eruption darkness continued for 3 days. When it cleared the survivors witnessed that most of Krakatoa was gone. Only a few remnants of its ~918 meter summit was visible, the most prominent of which is Rakata Island (Fig. 1).

Fig. 2. Remnants of Krakatoa remaining after the 1883 sector collapse and explosion. Rakata Island is on the left. Barely visible to the right are low lying remnants of what existed before (red dashed line)

Fig. 3. Large Coral block ripped form offshore and carried onto the coastal plain in West Java by 1883 ~30 meter tsunami from collapse and explosion of Krakatoa.
Source: Wikipedia.

The Restless Child
Anak (child) Krakatoa was born 45 years after the cataclysmic 1883 eruption. Rumblings under the sea spit ash and poured lava flows that eventually grew into a new island in 1930. By 1960 Anak Krakatoa had grown to a height of 166 meters and was averaging an episodic growth rate of 5 meters per year. It has erupted 59 of the past 100 years.

A.



B.

Fig. 4 A) Birth of Anak Krakatoa in 1927. B) Anak Krakatoa in 2017 showering its slopes with ash flows and volcanic bombs. Some of the bombs splash into the ocean. Photo from Indonesian Geophysical Survey (BMKG) and Smithsonian, respectively.

The Collapse of Anak Krakatoa
By 2016, when I first set foot on 'the child', her summit was around 400 meters above sea level (Fig. 3). The expedition to the island focused on searching for evidence of instabilities in the volcanic edifice. Several students and faculty from the WAVES project joined the expedition. We landed on the east side of the smoking volcano, which is perched on older deposits from the 1883 eruption (Figs. 2 and 3). Vegetation had established itself there and sheltered some huge monitor lizards that scurried through bushes.

The volcanic edifice was perched on the rim of the caldera formed during the 1883 eruption. The SW slope was steeply inclined (~30 degrees) directly into the sea and toward the deep hole left by previous explosions. The part of the volcano we climbed in 2016 had been built during the early emergence of the island and was much less steep. It was littered with fine pyroclastic material cratered by huge volcanic bombs (Fig. 5).

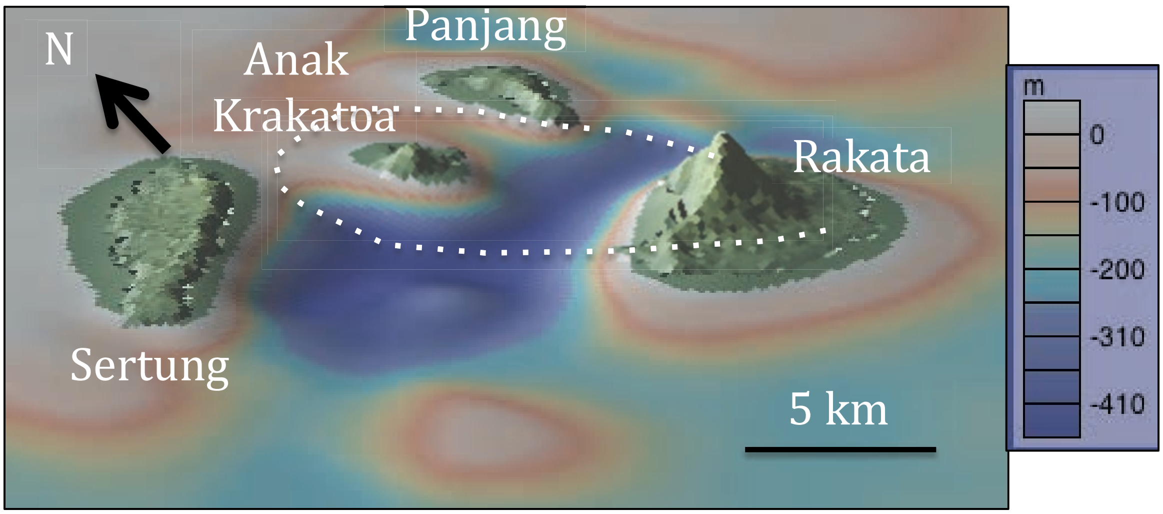


Fig. 5. Physiographic map of the Krakatoa Archipelago. Key to ocean depths on the right. Sertung, Panjung and the lower parts of Rakata outline the caldera of a massive explosive eruption in 416 CE of the mother of Krakatoa. The low area is the crater formed by that eruption. Krakatoa grew out of the 416 CE caldera and formed an island outlined by the dotted circle. The 1883 eruption blew most of the island of Krakatoa away, leaving its southern slope partly intact (Rakata Island). Anak Krakatoa rose from the crater left by the 1883 eruption and is perched on the SW edge of its caldera rim. Its steep SW face collapsed into the deep crater in December of 2018.

A paper published in 2012 warned that renewed activity of Anak Krakatoa could result in collapse of the SW slope of volcano into the sea (Giachetti et al., 2012). From numerical models these authors simulated the collapse and concluded:

"A hypothetical 0.280 km^3 flank collapse directed southwestwards would trigger an initial wave 43 m in height that would reach the islands of Sertung, Panjang and Rakata in less than 1 min, with amplitudes from 15 to 30 m. These waves would be potentially dangerous for the many small tourist boats circulating in, and around, the Krakatoa Archipelago. The waves would then propagate in a radial manner from the impact region and across the Sunda Strait, at an average speed of 80–110 km h^{-1}. The tsunami would reach the cities located on the western coast of Java (e.g. Merak, Anyer and Carita.) 35–45 min after the onset of collapse, with a maximum amplitude from 1.5 (Merak and Panimbang) to 3.4 m (Labuhan)."

Fig. 6. Approaching Anak Krakatoa in 2016. It is visible as the smoking peak rising slightly above the horizon on the right. Rakatan is the large island to the left, Sertung is the low lying island in the distance.

Fig. 7. Photo of the southern slope of Anak Krakatoa (July 2014), which had grown to an elevation of 400 meters (1300 ft.) since 1930. Note dense forest thriving near the beach where tourist boats land.

Fig. 8. Measuring a volcanic bomb ejected from Anak Krakatoa that cratered its slope in 2016.

Fig. 9. 2016 WAVES Expedition climbing the south slope of Anak Krakatoa. The volcano grew from this point toward the SW, which is where the much steeper part of the edifice (smoking) is visible in the distance.

Fig. 10. 2016 WAVES expedition near the summit of Anak Krakatoa, which no longer exists.

The Beginning of the End

Violent eruptions shook Anak Krakatoa from October to December 2018, eventually engulfing the entire island (Figs. 11-12). These eruptions destabilized the volcanic construct as forecast by Giachetti et al. (2012).

Fig. 11. Aerial photo of SW slope of Anak Krakatoa 2 days before it collapsed on 22 Dec. 2018. Yellow arrow indicates approximate location of the where the landslide broke (see Fig. 12 and 14). Red arrows show direction of collapse of the bulk of the volcano into the deep crater formed in 1883 (see Fig. 5). Photo from Tempo News.

On the night of 22 December it happened - the steep SW slope of Anak Krakatoa collapsed into the deep sea of the former crater of the 1883 eruption (Fig. 5). Two catastrophic events followed: first, mega-tons of seawater were displaced by the landslide to send a tsunami outward from the site (see waves radiating away from the collapsed island in Fig. 14); and second, the water rushed back into the new opening of the volcano furnace, flashed into steam and exploded (Fig. 12). This event blew what was left of Anak Krakatoa apart.

In February of 2019 I was able to gain access to the Cucu Krakatoa to compare it with what we observed in 2016 and document damage on the nearby coastlines of the tsunami (Figs. 14-18).

Fig. 12. An aerial view looking east at the birth of Cucu Krakatoa on 23 December 2018, the day after Anak Krakatoa collapsed. Steam-assisted explosions give birth to a new crater in the void Anak Krakatoa collapsed into. Yellow arrow points at the scar from its landslide (see Fig. 11 for reference). The scar is no longer visible due to burial under the new volcano of Cucu Krakatoa. Photo from Indonesia's Natural Resources Conservancy Agency.

Fig. 13. The steam-assisted (phreatomagmatic) eruption of Anak Krakatoa on 28 Dec 2018 after it had collapsed. Photo taken from west Java as in Fig. 2. Rakata Island is obscured by the ash. Photo by Ed Wray/Getty Images.

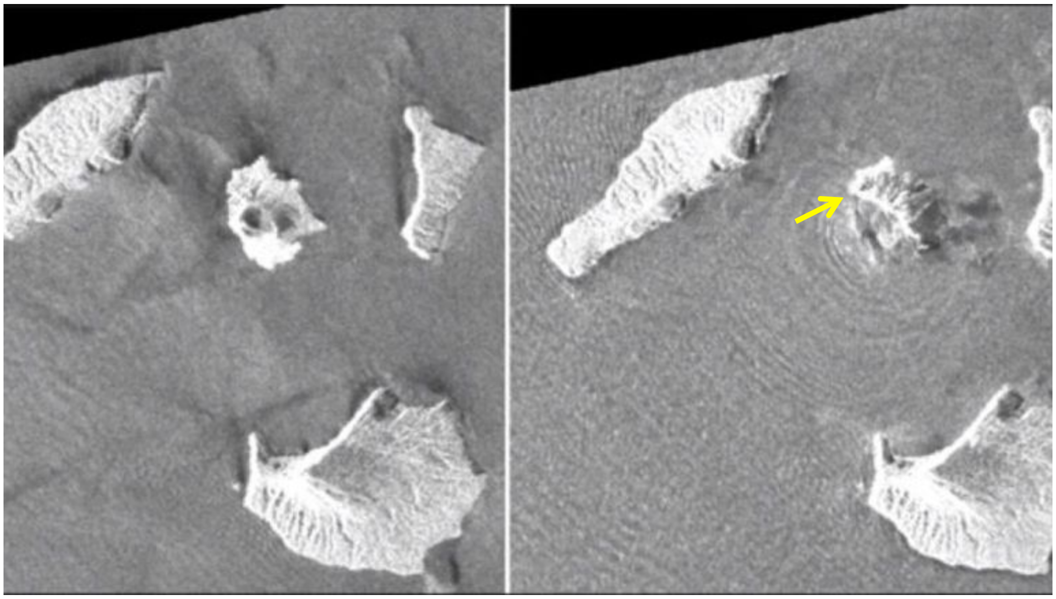


Fig. 14. Satellite images of before and after the 22 Dec. 2018 collapse of Anak Krakatoa. Yellow arrow points to landslide scar seen in Fig. 12. Images from AP/JAXA/Geospatial Authority of Japan/Gizmodo.

Fig. 15. The before and after of Anak Krakatoa looking north. Aerial photos from Øystein Lund Andersen (left) and Earthuncut TV (right).

Fig. 16. Left - Cucu Krakatoa in February 2019. Photo is looking west from around the same position as the pre-eruption photo in Fig. 8. The gullies carved into the 1 month old slopes of Cucu Krakatoa are deeply gullied and difficult to ascend. Right – should have brought my boots.

Fig. 17. The author looking SW from the new 100-meter summit of Cucu Krakatoa. The crater lake is where 415 meter high Anak Krakatoa formerly stood. Not sure what exactly is the cause of the pink water stirred up by the slide. Note the 20-25 meter vegetation high trim line from the tsunami that slammed into Sertung Island in the distance.

Fig. 18. On the east flank of Anak Krakatoa before (above) and after (below) the 2018 eruption. Note dead trees on Panjung Island in the distance. Also notice how much more landed was added to the east during the eruption. Climbing Cucu Krakatoa is very difficult due to the many gullies in the loose pyroclastic material.

Silent Tsunami

The tsunami generated by the collapse of Anak Krakatoa is known as a 'silent wave' because it was not caused by an earthquake (no ground shake warning). Also, the landslide happened at night, which made it difficult for anyone to see it was approaching. Over 1000 persons were killed by the tsunami. A YouTube video of a concert on the beach in West Java captured the tsunami crashing into the stage and shoving it and the band over the crowd (https://www.youtube.com/watch?v=2ERXCR86GU4).

The largest waves were those that struck the islands surrounding Anak Krakatoa. A 'trim line' where the tsunami ripped the vegetation from the shorelines of these islands is over 20 meters high in places (Figs. 17-20).

A.

B.

Fig. 19. Comparison of shoreline vegetation on Anak Krakatoa (foreground) and Rakatan Island (distance) before (A) and after (B) the Dec. 2018 volcano collapse tsunami. The photos are looking south from near the same location in 2016 (A) and 2019 (B). Red arrow is trim line along the shore, which decreases to the left further away from SW directed wave.

A.

B.

Fig. 19. Shoreline of Rakata (see Fig. 18) before (A) and after (B) tsunami. Notice the pumice (white fragments) mixed in with coarse-grained sand deposited by the tsunami that ripped away the vegetation and a small fishing camp. 5 persons died on this site.

Fig. 20. West Java coast. Large slab of coral that was ripped from offshore, turned upside down and carried onto coastal plain by the 22 Dec. 2018 tsunami. A local fisherman (left) confirmed what we suspected about the block. Fellow researchers Poliman (center) and Hanif (right).

Fig. 21. West Java coast. Shipping containers used as condominiums (inside lined with brick) scattered 200 meters inland by the tsunami.

Fig. 22. Fishing fleets damaged by the tsunami that struck Anyer in West Java. Over 2000 boats were damaged or destroyed. The economic impact of this disaster is still mounting.

Fig. 23. Refuge camp for the survivors from the villages swept away by the tsunami. Homes and businesses once occupied this site. Hundreds of people died here.

What Can We Do?

The catastrophic collapse and explosion of Anak Krakatoa, and the tsunami it spawned, was not as formidable as the 1883 eruption, but it claimed >1000 lives and injured and impacted thousands more. The only way to avoid such events is to maintain tidal gauges around Cucu Krakatoa. These gauges transmit real-time data about unusual wave activity (long wavelength tsunami waves) to a siren system. However, these types of technologies have been installed in Indonesia before and within a few years were in ill repair. Another problem is the sparcity of sirens compared to the number of coastal communities. In some places where sirens work no one knows what to do when they hear it due to lack of tsunami evacuation drills.

These issues are the focus of In Harm's Way, which is a non-profit organization dedicated to natural disaster reduction through preparedness. We have saved thousands of lives by identifying local, community-based solutions to building resilience to natural hazards. Our motto is, "an ounce of disaster prevention is better than tons of disaster relief." Have you given your ounce? Visit our website and see how: inharmswayhelp.org.