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Krakatau

KRAKATAU, earlier misnamed Krakatoa, an island the size of Manhattan located midway in the Sunda Strait between Sumatra and Java, came to an end on Monday morning, August 27, 1883. It was dismembered by a series of powerful volcanic eruptions. The most violent occurred at 10:02 A.M., blowing upward like the shaped explosion of a large nuclear bomb, with an estimated force equivalent to 100–150 megatons of TNT. The airwave it created traveled at the speed of sound around the world, reaching the opposite end of the earth near Bogotá, Colombia, nineteen hours later, whereupon it bounced back to Krakatau and then back and forth for seven recorded passages over the earth's surface. The audible sounds, resembling the distant cannonade of a ship in distress, carried southward across Australia to Perth, northward to Singapore, and westward 4,600 kilometers to Rodriguez Island in the Indian Ocean, the longest distance traveled by any airborne sound in recorded history.

As the island collapsed into the subterranean chamber emptied by the eruption, the sea rushed in to fill the newly formed caldera. A column of magma, rock, and ash rose 5 kilometers into the air, then fell earthward, thrusting the sea outward in a tsunami 40 meters in height. The great tidal waves, resembling black hills when first sighted on the horizon, fell upon the shores of Java and Sumatra, washing away entire towns and killing 40,000 people. The segments traversing the channels and reaching the open sea continued on as spreading waves around the world. The waves were still a meter high when they came ashore in Ceylon, now Sri Lanka, where they drowned one person, their last casualty. Thirty-two hours after the explosion, they rolled in to Le Havre, France, reduced at last to centimeter-high swells.

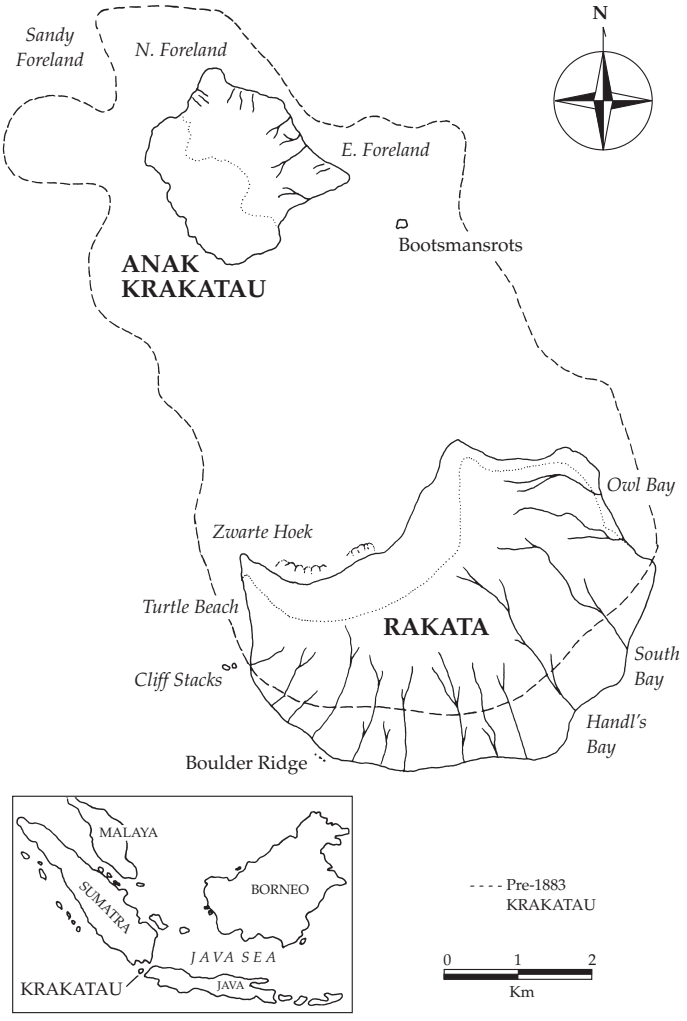
The eruptions lifted more than 18 cubic kilometers of rock and other material into the air. Most of this tephra, as it is called by geologists, quickly rained back down onto the surface, but a residue of sulfuric-acid aerosol and dust boiled upward as high

as 50 kilometers and diffused through the stratosphere around the world, where for several years it created brilliant red sunsets and "Bishop's rings," opalescent coronas surrounding the sun.

Back on Krakatau the scene was apocalyptic. Throughout the daylight hours the whole world seemed about to end for those close enough to witness the explosions. At the climactic moment of 10:02 the American barque *W. H. Besse* was proceeding toward the straits 84 kilometers east northeast of Krakatau. The first officer jotted in his logbook that "terrific reports" were heard, followed by

> a heavy black cloud rising up from the direction of Krakatoa Island, the barometer fell an inch at one jump, suddenly rising and falling an inch at a time, called all hands, furled all sails securely, which was scarcely done before the squall struck the ship with terrific force; let go port anchor and all the chain in the locker, wind increasing to a hurricane; let go starboard anchor, it had gradually been growing dark since 9 A.M. and by the time the squall struck us, it was darker than any night I ever saw; this was midnight at noon, a heavy shower of ashes came with the squall, the air being so thick it was difficult to breathe, also noticed a strong smell of sulfur, all hands expecting to be suffocated; the terrible noises from the volcano, the sky filled with forked lightning, running in all directions and making the darkness more intense than ever; the howling of the wind through the rigging formed one of the wildest and most awful scenes imaginable, one that will never be forgotten by any one on board, all expecting that the last days of the earth had come; the water was running by us in the direction of the volcano at the rate of 12 miles per hour, at 4 P.M. wind moderating, the explosions had nearly ceased, the shower of ashes was not so heavy; so was enabled to see our way around the decks; the ship was covered with tons of fine ashes resembling pumice stone, it stuck to the sails, rigging and masts like glue.

In the following weeks, the Sunda Strait returned to outward normality, but with an altered geography. The center of Krakatau had been replaced by an undersea crater 7 kilometers long and 270 meters deep. Only a remnant at the southern end still rose from the sea. It was covered by a layer of obsidian-laced pumice 40 meters or more thick and heated to somewhere



Old Krakatau was destroyed by a volcanic eruption in 1883, leaving only Rakata, a lifeless remnant, at the southern end. Anak Krakatau emerged from the sea as a volcanic cone in 1930.

between 300° and 850°C, enough at the upper range to melt lead. All traces of life had, of course, been extinguished.

Rakata, the ash-covered mountain of old Krakatau, survived as a sterile island. But life quickly enveloped it again. In a sense, the spinning reel of biological history halted, then reversed, like a motion picture run backward, as living organisms began to return to Rakata. Biologists quickly grasped the unique opportunity that Rakata afforded: to watch the assembly of a tropical ecosystem from the very beginning. Would the organisms be different from those that had existed before? Would a rain forest eventually cover the island again?

The first search for life on Rakata was conducted by a French expedition in May 1884, nine months after the explosions. The main cliff was eroding rapidly, and rocks still rolled down the sides incessantly, stirring clouds of dust and emitting a continuous noise "like the rattling of distant musketry." Some of the stones whirled through the air, ricocheting down the sides of the ravines and splashing into the sea. What appeared to be mist in the distance turned close up into clouds of dust stirred by the falling debris. The crew and expedition members eventually found a safe landing site and fanned out to learn what they could. After searching for organisms in particular, the ship's naturalist wrote that "notwithstanding all my researches, I was not able to observe any symptom of animal life. I only discovered one microscopic spider—only one; this strange pioneer of the renovation was busy spinning its web."

A baby spider? How could a tiny wingless creature reach the empty island so quickly? Arachnologists know that a majority of species "balloon" at some point in their life cycle. The spider stands on the edge of a leaf or some other exposed spot and lets out a thread of silk from the spinnerets at the posterior tip of its abdomen. As the strand grows it catches an air current and stretches downwind, like the string of a kite. The spider spins more and more of the silk until the thread exerts a strong pull on its body. Then it releases its grip on the surface and soars upward. Not just pinhead-sized babies but large spiders can occasionally reach thousands of meters of altitude and travel hundreds of kilometers before settling to the ground to start a new life. Either that or land on the water and die. The voyagers have no control over their own descent.

Ballooning spiders are members of what ecologists, with the accidental felicity that sometimes pops out of Greek and Latin sources, have delightfully called the aeolian plankton. In ordinary parlance, plankton is the vast swarm of algae and small animals carried passively by water currents; aeolian refers to the wind. The creatures composing the aeolian plankton are devoted almost entirely to long-distance dispersal. You can see some of it forming over lawns and bushes on a quiet summer afternoon, as aphids use their feeble wings to rise just high enough to catch the wind and be carried away. A rain of planktonic bacteria, fungus spores, small seeds, insects, spiders, and other small creatures falls continuously on most parts of the earth's land surface. It is sparse and hard to detect moment by moment, but it mounts up to large numbers over a period of weeks and months. This is how most of the species colonized the seared and smothered remnant of Krakatau.

The potential of the planktonic invasion has been documented by Ian Thornton and a team of Australian and Indonesian biologists who visited the Krakatau area in the 1980s. While studying Rakata they also visited Anak Krakatau ("Child of Krakatau"), a small island that emerged in 1930 from volcanic activity along the submerged northern rim of the old Krakatau caldera. On its ash-covered lava flows they placed traps made from white plastic containers filled with seawater. This part of the surface of Anak Krakatau dated from localized volcanic activity from 1960 to 1981 and was nearly sterile, resembling the condition on Rakata soon after the larger island's violent formation. During ten days the traps caught a surprising variety of windborne arthropods. The specimens collected, sorted, and identified included a total of 72 species of spiders, springtails, crickets, earwigs, barklice, hemipterous bugs, moths, flies, beetles, and wasps.

There are other ways to cross the water gaps separating Rakata from nearby islands and the Javan and Sumatran coasts. The large semiaquatic monitor lizard *Varanus salvator* probably swam over. It was present no later than 1899, feasting on the crabs that crawl along the shore. Another long-distance swimmer was the reticulated python, a giant snake reaching up to 8 meters in length. Probably all of the birds crossed over by powered flight. But only a small percentage of the species

of Java and Sumatra were represented because it is a fact, curiously, that many forest species refuse to cross water gaps even when the nearest island is in full view. Bats, straying off course, made the Rakata landfall. Winged insects of larger size, especially butterflies and dragonflies, probably also traveled under their own power. Under similar conditions in the Florida Keys, I have watched such insects fly easily from one small island to another, as though they were moving about over meadows instead of salt water.

Rafting is a much less common but still important means of transport. Logs, branches, sometimes entire trees fall into rivers and bays and are carried out to sea, complete with microorganisms, insects, snakes, frogs, and occasional rodents and other small mammals living on them at the moment of departure. Blocks of pumice from old volcanic islands, riddled with enough closed air spaces to keep them afloat, also serve as rafts.

Once in a great while a violent storm turns larger animals such as lizards or frogs into aeolian debris, tearing them loose from their perches and propelling them to distant shores. Waterspouts pick up fish and transport them live to nearby lakes and streams.

Swelling the migration further, organisms carry other organisms with them. Most animals are miniature arks laden with parasites. They also transport accidental hitchhikers in soil clinging to the skin, including bacteria and protozoans of immense variety, fungal spores, nematode worms, tardigrades, mites, and feather lice. Seeds of some species of herbs and trees pass live through the guts of birds, to be deposited later in feces, which serves as instant fertilizer. A few arthropods practice what biologists call phoresy, deliberate hitchhiking on larger animals. Pseudoscorpions, tiny replicas of true scorpions but lacking stings, use their lobster-like claws to seize the hairs of dragonflies and other large winged insects, then ride these magic carpets for long distances.

The colonists poured relentlessly into Rakata from all directions. A 100-meter-high electrified fence encircling the island could not have stopped them. Airborne organisms would still have tumbled in from above to spawn a rich ecosystem. But the largely happenstance nature of colonization means that flora and fauna did not return to Rakata in a smooth textbook

manner, with plants growing to sylvan thickness, then herbivores proliferating, and finally carnivores prowling. The surveys made on Rakata and later on Anak Krakatau disclosed a far more haphazard buildup, with some species inexplicably going extinct and others flourishing when seemingly they should have quickly disappeared. Spiders and flightless carnivorous crickets persisted almost miraculously on bare pumice fields; they fed on a thin diet of insects landing in the aeolian debris. Large lizards and some of the birds lived on beach crabs, which subsisted in turn on dead marine plants and animals washed ashore by waves. (The original name of Krakatau was Karkata, or Sanskrit for "crab"; Rakata also means crab in the old Javanese language.) Thus animal diversity was not wholly dependent on vegetation. And for its part vegetation grew up in patches, alternately spreading and retreating across the island to create an irregular mosaic.

If the fauna and flora came back chaotically, they also came back fast. In the fall of 1884, a little more than a year after the eruption, biologists encountered a few shoots of grass, probably *Imperata* and *Saccharum*. In 1886 there were fifteen species of grasses and shrubs, in 1897 forty-nine, and in 1928 nearly three hundred. Vegetation dominated by *Ipomoea* spread along the shores. At the same time grassland dotted with *Casuarina* pines gave way here and there to richer pioneer stands of trees and shrubs. In 1919 W. M. Docters van Leeuwen, from the Botanical Gardens at Buitenzorg, found forest patches surrounded by nearly continuous grassland. Ten years later he found the reverse: forest now clothed the entire island and was choking out the last of the grassland patches. Today Rakata is covered completely by tropical Asian rain forest typical in outward appearance. Yet the process of colonization is far from complete. Not a single tree species characterizing the deep, primary forests on Java and Sumatra has made it back. Another hundred years or more may be needed for investment by a forest fully comparable to that of old, undisturbed Indonesian islands of the same size.

Some insects, spiders, and vertebrates aside, the earliest colonists of most kinds of animals died on Rakata soon after arrival. But as the vegetation expanded and the forest matured, increasing numbers of species took hold. At the time of the Thornton

expeditions of 1984–85, the inhabitants included thirty species of land birds, nine bats, the Indonesian field rat, the ubiquitous black rat, and nine reptiles, including two geckos and *Varanus salvator*, the monitor lizard. The reticulated python, recorded as recently as 1933, was not present in 1984–85. A large host of invertebrate species, more than six hundred in all, lived on the island. They included a terrestrial flatworm, nematode worms, snails, scorpions, spiders, pseudoscorpions, centipedes, cockroaches, termites, barklice, cicadas, ants, beetles, moths, and butterflies. Also present were microscopic rotifers and tardigrades and a rich medley of bacteria.

A first look at the reconstituted flora and fauna of Rakata, in other words Krakatau a century after the apocalypse, gives the impression of life on a typical small Indonesian island. But the community of species remains in a highly fluid state. The number of resident bird species may now be approaching an equilibrium, the rise having slowed markedly since 1919 to settle close to thirty. Thirty is also about the number on other islands of Indonesia of similar size. At the same time, the *composition* of the bird species is less stable. New species have been arriving, and earlier ones have been declining to extinction. Owls and flycatchers arrived after 1919, for example while several old residents such as the bulbul (*Pycnonotus aurigaster*) and gray-backed shrike (*Lanius schach*) disappeared. Reptiles appear to be at or close to a similar dynamic equilibrium. So are cockroaches, nymphalid butterflies, and dragonflies. Flightless mammals, represented solely by the two kinds of rats, are clearly not. Nor are plants, ants, or snails. Most of the other invertebrates are still too poorly explored on Rakata over sufficiently long periods of time to judge their status, but in general the overall number of species appears to be still rising.

Rakata, along with Panjang and Sertung, and other islands of the Krakatau archipelago blasted and pumice-coated by the 1883 explosion, have within the span of a century rewoven a semblance of the communities that existed before, and the diversity of life has largely returned. The question remains as to whether endemic species, those found only on the archipelago prior to 1883, were destroyed by the explosion. We can never be sure because the islands were too poorly explored by naturalists before Krakatau came so dramatically to the world's attention

in 1883. It seems unlikely that endemic species ever existed. The islands are so small that the natural turnover of species may have been too fast to allow evolution to attain the creation of new species, even without volcanic episodes.

In fact the archipelago has suffered turbulence that destroyed or at least badly damaged its fauna and flora every few centuries. According to Javanese legend, the volcano Kapi erupted violently in the Sunda Strait in 416 A.D.: "At last the mountain Kapi with a tremendous roar burst into pieces and sunk into the deepest of the earth. The water of the sea rose and inundated the land." A series of smaller eruptions, burning at least part of the forest, occurred during 1680 and 1681.

Today you can sail close by the islands without guessing their violent history, unless Anak Krakatau happens to be smoldering that day. The thick green forest offers testimony to the ingenuity and resilience of life. Ordinary volcanic eruptions are not enough, then, to break the crucible of life.