Comment

Tsunami

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It began at the bottom of the ocean, off the west coast of Indonesia. From there it spread outward, silently, invisible under the surface of the water. When it came ashore, in forty countries, some as far as 4,000 miles from where it started, it killed upwards of 150,000 people. There have been deadlier catastrophes - the earthquake in China in the mid-1970s killed a quarter of a million in that country, and the cyclone that devastated Bangladesh in the decade before that is thought to have caused half a million deaths - but none that involved so many different nations scattered across so much of the earth's surface. The tsunami spawned by the magnitude 9.0 earthquake of 26 December 2004 was perhaps the first truly global natural disaster in modern history: a third of the world's countries were directly affected. The worldwide scope of the destruction reminds us of something that genomics is also starting to make clear: that we are all truly one people, that national and racial differences are artificial and insignificant compared to the common bond of our humanity. Despite all our technological prowess and environmental hubris, we also have yet another grim reminder that Nature, not Man, is still boss of this planet.

The word 'tsunami' comes from the Japanese words for harbor (tsu) and wave (nami). It refers to a series of giant undersea waves that travel at high velocity for very long distances, and that crest when they hit a shoreline in the form of a devastating surge, sometimes as much as 30 meters high. Tsunamis are often called 'tidal waves' but that's a misnomer: the phenomenon has nothing to do with the tides. It has its origins, like everything else that involves the earth's surface, in plate tectonics.

It is hard to imagine that the theory of plate tectonics, which is at the heart of all modern geological science, is only a hundred years old and was not widely accepted until the 1970s. Schoolchildren had noticed for hundreds of years that the facing shapes of South America and Africa could be fitted neatly together like pieces of a jigsaw puzzle to make a single entity (Francis Bacon had noticed it in 1620 but drew no conclusion), but it wasn't until 1908 that the amateur American geologist Frank Bursley Taylor proposed that the continents had once slid around and that this motion might have thrust up the world's mountain chains. His theory was taken up by the German planetary astronomer-turned-meteorologist Alfred Wegener, who in 1912 proposed that all the world's continents had once been part of a single giant landmass he called Pangaea, which had split apart in a process of lateral motion that was still continuing. Traditional geologists attacked both Wegener and his ideas viciously, and it wasn't until the decade after his death (he froze to death on a scientific expedition in Greenland in 1930) that the great English geologist Arthur Holmes provided an explanation for how Wegener's motion could occur. In a textbook published in 1944 he speculated that heat caused by the decay of radioactive elements in the earth's crust could produce powerful convection currents that could slide the continents around on the earth's surface. He has probably as good a claim as anyone to be the father of the modern view of continental drift, although, curiously, he often expressed skepticism about his own theory. Harry Hess, a Princeton University geologist, figured out in the 1950s that there were two large plates of land under the floor of the Atlantic Ocean and that their relative motion was responsible for the topography and geology of the seafloor. Finally, in 1963, Cambridge University geophysicist Drummond Matthews and his graduate student Fred Vine used magnetic readings to prove that the seafloor and the continents were in motion. (Canadian geologist Lawrence Morley came up with the same result at the same time but his paper was rejected by the *Journal of Geophysical Research*.) J. Tuzo Wilson of Toronto showed at about the same time how plate tectonics could explain the behavior of the ocean floor at mid-ocean ridges. Still, even in the 1970s, many textbooks of geology continued to dismiss plate tectonics as physically impossible.

Today we know that the surface of the earth is composed of about a dozen large plates and almost two dozen smaller

The Great Wave off the Coast of Kanagawa. From *Thirty-six Views of Mount Fuji* by Katsushika Hokusai (1823-1829); woodcut, 10 x 15 inches. From the Metropolitan Museum of Art, New York, USA [http://www.moma.org].

ones, all moving in different directions. Where they grind against one another (regions geologists call 'subduction zones'), the tremendous force can be released either slowly and steadily, giving rise to thermally active regions like Iceland, or sporadically and violently, giving rise to earthquakes and volcanic eruptions. That is what happened on 27 August 1883, when subduction along the Java Trench, where the Indo-Australian plate is moving under the Indonesian Island chain, caused the explosive eruption of the volcano on the Indonesian island of Krakatoa that in turn generated waves that reached 41 meters in height, destroying 165 coastal towns and villages along the Sunda Strait between the islands of Java and Sumatra and killing 36,417 people. (Hollywood made a movie about this great disaster in 1969: *Krakatoa, East of Java*. In case you are ever tempted to equate Hollywood productions with history, let me point out that Krakatoa is west of Java.) That is probably what happened in 1648 B.C., when the entire Minoan civilization on the island of Crete was wiped out, in a single day, as the result of a tsunami created by the explosive eruption of the volcano on Santorini.

And that is what happened on 26 December 2004, when the Indian plate slid underneath the Burma plate (a subduction zone), driving a 600-mile long piece of the earth's crust 20 to 50 feet upwards on the floor of the Indian Ocean. This sudden rise in the seafloor displaced an enormous volume of water - exactly as if the ocean were a swimming pool and someone had just dropped a large block of concrete into it. The displacement spread outward in all directions, like the ripples that would spread from that block. But because the event occurred underwater, the displacement traveled underwater until it encountered the sharply rising seafloor on the edge of an island or continent. When the undersea waves hit this obstacle, they were pushed straight up, compressed into walls of water that surged over the landmass.

The speed of a tsunami depends on the square of the depth of the ocean: the deeper the water, the faster the displacement travels. The Indonesian tsunami formed in deep water, which meant that the wave velocity reached upwards of 800 km/h, the speed of a commercial jet aircraft. When they encounter the shallow depths of a coastline the speed of tsunami waves slows to perhaps 45 km/h, still fast enough to do tremendous damage. At top speed it took the tsunami less than 7 hours to cross the Indian Ocean and reach the east coast of Africa, where the waves came ashore in Somalia and killed 150 people who cannot possibly have understood that the power that was destroying them had been spawned more than 3,000 miles away.

Like the ripples from that dropped block of concrete, a tsunami is actually a series of waves, usually spaced about 15-20 minutes apart, with troughs in between them. To the observer on shore, the approach of a tsunami often begins with a rapid receding of the shoreline, much further out than normal. This is followed, 8-10 minutes later, by the first wave, which surges onto the shore, often traveling a half a mile or more inland. As the cycle repeats, the first wave recedes, carrying anything loose back out to sea. Then the next wave hits. In Thailand, Sri Lanka and Indonesia, where the worst damage occurred, many people who survived the impact of the first wave were swept out to sea as it receded, or were killed by one of the surges that followed. But what fascinates me the most about tsunamis is that, until they reach land, they are practically unnoticeable on the surface of the ocean. Their amplitude in deep water is often only a meter or less. An ocean liner or a fishing vessel would pass right over them, completely unaware that underneath it a force was racing onward that, when it surfaced, could obliterate an entire country.

I've been thinking a lot about that sort of thing recently, because it seems to me that it's a pretty good metaphor for what is going on in science. I started writing this column because I believed that genomics was like a tsunami: a force that, when it crested, would change everything, and I wanted to have an excuse to think about what that would mean. The true impact of the genomics revolution is only starting to be apparent now, and it's very different from what it was predicted to be when the Human Genome Project began in the late 1980s. It has not had a significant impact on human health yet - the disease genes that have been discovered have generally come from specific individual research programs, and pharmacogenomics has initially focused on polymorphisms in genes that were already identified before the human genome was sequenced. Genomics has produced technology, such as cDNA microarrays and mass spectroscopy-based proteomics, that is likely to play a major role in diagnostics in the near future, but not necessarily in treatment. No, the major effects, which are now rolling across biology like a series of waves, are cultural.

Because of genomics, data gathering and analysis is now valued highly - in some instances above hypothesis-driven research. Because of genomics, targeted big science projects, such as structural genomics, that aim to produce easily appreciated results (usually in the form of large amounts of data), are consuming a large chunk of funding that would otherwise go to individual investigator-initiated basic research. Because of genomics, there is a perception in some quarters that when you have analyzed something you have understood it; mathematical modeling of biological processes is beginning to become a substitute for experimental probing. Because of genomics, a kind of mysticism is creeping back into biology: we use terms, like 'systems biology' and 'emergent properties', that have echoes of vitalism in them - almost as though we are starting to believe that we cannot explain the behavior of living systems in terms of the physics and chemistry of their component parts. We can argue about whether this is good or bad for our field. We can argue about how we should react to it. But we cannot ignore it. None of this could have been appreciated in 1990. It was all moving beneath the surface, moving rapidly and inexorably and now it is upon us. Until the next tsunami comes along, genomics, like molecular biology before it, will change our scientific world whether we like it or not.

So one of the lessons I take from what happened on 26 December is the folly of believing that things will remain as they are today. We go about our lives and our careers unaware of the great forces that move, unseen, beneath the usual tide of events. Until they crest they are almost undetectable, so we don't talk about them or plan for them. And once they do crest, they can change our careers and our lives in a very short time. It would seem that, of all the qualities we need to survive and thrive in an unpredictable world, flexibility - adaptability if you will - might just be the most valuable. The other lesson is a practical one. If you're standing on shore, looking out at what seems to be a perfectly calm ocean, and you suddenly see the shoreline receding rapidly, exposing the sea bottom much farther out than usual, turn around and run like hell away from the water. You need to get a half mile inland; a mile would be better. You have, if you're lucky, maybe 10 minutes.