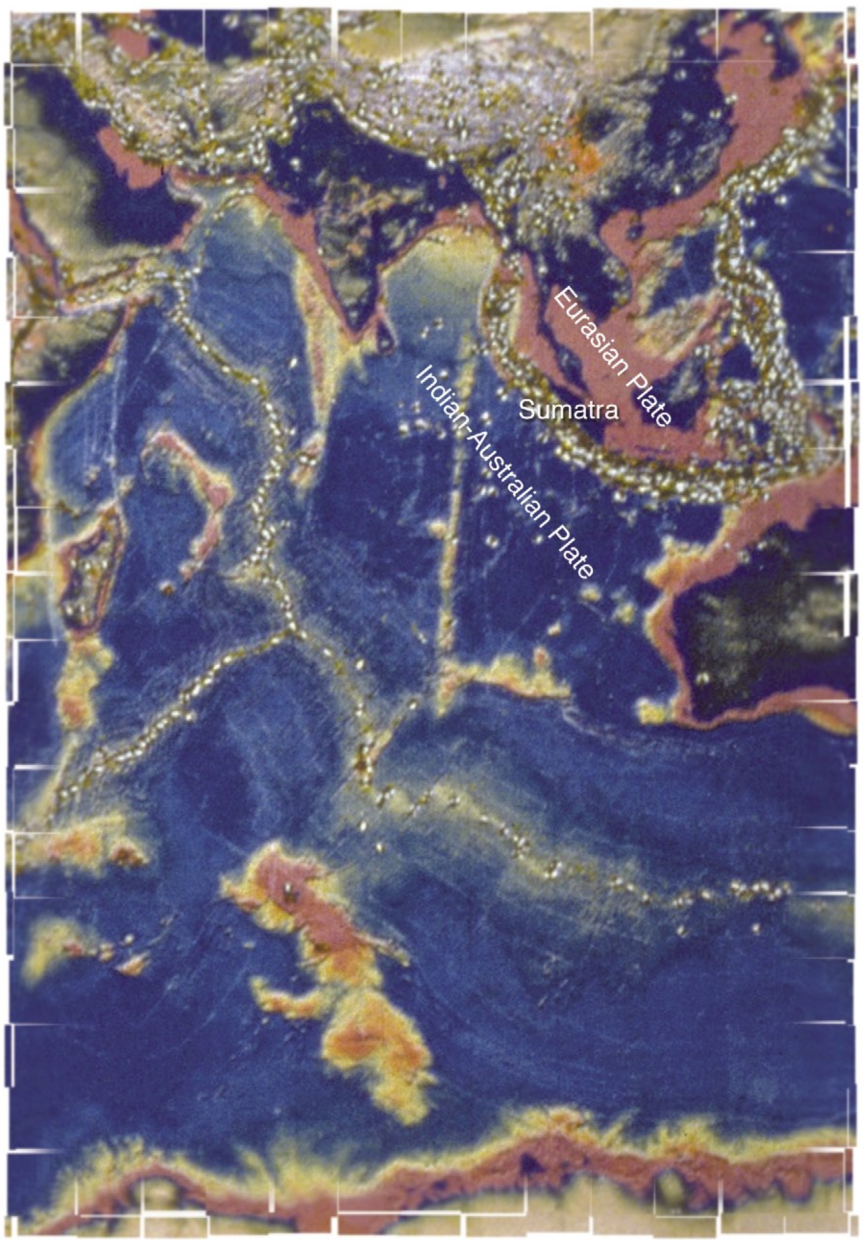
The Great Sumatra Quake

by Mark Wheeler



Geologist Kerry Sieh was at home on Christmas Day, 2004, working on his laptop, when word first came via e-mail that a magnitude (M) 8.5 earthquake had struck the Indonesian island of Sumatra. Normally, when scientists like Sieh hear about big earthquakes, the initial reactions are the human one, concern about people, along with that of the "science nerd," as he puts it—a lot of excitement, a lot of new data to eyeball, and the chance "to connect to big Earth processes." But with this earthquake, which ultimately proved to be one of the largest ever recorded, at a probable magnitude (M) of 9.3, Sieh didn't have the typical reaction of a geologist.

This one was all personal.

Sieh has been studying Indonesia for more than a decade. To get to the remote places in the field where he and his colleagues go, they travel by boat, helicopter, horse, and their feet, often wading through water and trampling through jungle. Because there are few hotels, when they aren't sleeping on their boat they politely knock on the doors of villagers, explain what they're doing, and commonly end up eating meals and sleeping in the homes of people Sieh now considers friends.

In the hours following the first report, Sieh stayed glued to his computer screen, trying to e-mail people he knew in Indonesia—no luck. As he examined the pattern of aftershocks, he became increasingly concerned. The longer the rupture zone, the greater the magnitude, and the 1,300-kilometer-long band of aftershocks hinted that the fault had broken for a much greater distance than originally reported—even the revision to M 8.9 a few hours later seemed a bit too small. Still, regardless of which side of 9 the magnitude was on, an earthquake of that size strongly implied tsunamis. That's when Sieh really began to worry. "It was emotional for me when I started realizing people I held near and dear might be dead, or their property and livelihoods lost," he says. (The temblor, and the massive tsunamis it generated, resulted in

300,000 dead or missing Indonesians.)

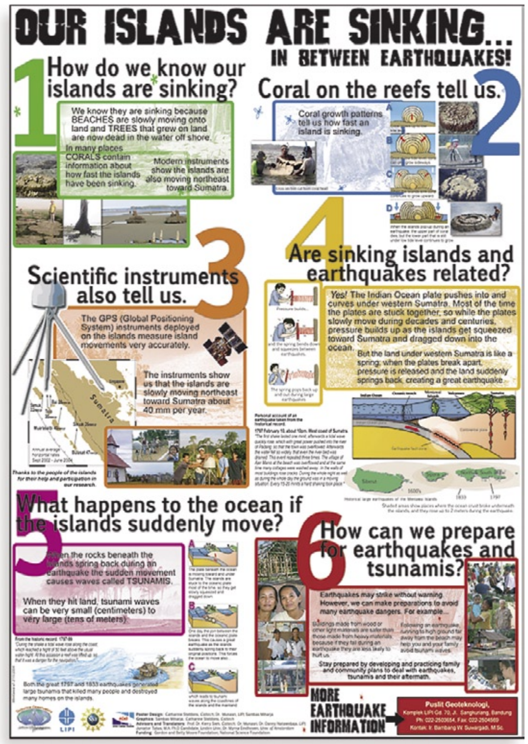
It took the next couple of weeks before he learned that the tsunamis that hit the areas where he was working were only a meter or so high, and that no one he knew died. But that hasn't stopped him from worrying. Sieh's research focuses on a different segment of the fault, several hundred kilometers from December's epicenter. Historically, earthquakes along this segment have struck with regularity, often in clusters, and his research had revealed the time was fast approaching for another large one. And when the fault finally breaks from the strain that's slowly been accumulating, it will break big time, with big, damaging earthquakes, probably followed by big, damaging tsunamis.

Last summer, Sieh and his colleagues traveled from village to village on several islands off Sumatra's west coast, handing out brochures and posters, educating the locals about the danger sleeping right under their feet, and advising them on what they can do to avoid a tsunami should a big earthquake strike (the advice can be boiled down to "run like hell—uphill"). In the months following the December quake, he has watched with growing concern as hundreds of aftershocks have marched south toward his segment of the fault. They included a large, M 8.7 earthquake just a few hundred kilometers away on March 28, followed on April 10 by two strong M 6.7 and 6.5 quakes that occurred right in his segment. They may be aftershocks or, worse, foreshocks of the big one he knows is coming, "sometime in the lives of your children," as he put it to the Indonesians he spoke to. The prospects of a giant earthquake like the one in December would be very bad news for the denizens of Padang, a coastal city of about one million that lies 200 kilometers due east of this segment. Padang has not been damaged from the recent quakes, but it is being shaken repeatedly. And it could be next.

Opposite page: Earthquakes (white dots) mark the boundaries of Earth's tectonic plates. Sumatra lies along the border of the Indian-Australian and Eurasian plates. (Map prepared by Don Anderson, MS '58, PhD '62, Crafoord laureate and McMillan Professor of Geophysics, Emeritus, and David Sandwell, UC San Diego.)

So what do you tell these people? "In the lives of their children" could mean 70 years from now, or it could mean tomorrow. People in Padang are already terrified from all the shaking, and fearful of tsunamis. It's simple and doable to tell people living in small villages to run uphill in the event of a giant earthquake, but in a city of one million? Even if a tsunami warning system was in place—

Right: These *Porites* coral heads off the west coast of the island of Simeulue were uplifted about 90 centimeters by the December 26 earthquake.



The poster distributed by Sieh and colleagues was printed in English, Indonesian, and Mentawai.

and one isn't—how fast and how far can that many people run, Sieh asks, if they have a 15-minute head start, which is the maximum likely notice if such a warning system was installed? Imagine the panic. Imagine the deaths. Simply put, he says, Padang is another disaster waiting to happen, one that could be as terrible as Banda Aceh, and it is a big challenge to do anything about it.

Sieh, Caltech's Sharp Professor of Geology, is a founder of the field of paleoseismology, the study of prehistoric earthquakes. His PhD thesis (Stanford, 1977) was a history of the displacement of California's San Andreas fault over the last 10,000 years. (The San Andreas is a strike-slip fault, meaning that its two sides slip horizontally past each other during an earthquake. The Sumatran earthquake, on the other hand, was on a thrust fault, where the two sides of the fault move more or less vertically.) While he has conducted research on faults both near and far-flung—the Red River fault in China and the Chelungpu fault in Taiwan, the Denali fault in Alaska, numerous faults under Los Angeles, and, of course, Sumatra—the San Andreas had dominated his work until the 1990s. In fact, his most recent paper on it, published in 2004, showed that about 95 percent of the slippage on the San Andreas occurs in rare but big earth-

Two coral victims of the great Sumatran earthquake. Far left: A *Pocilopora.* Left: A *Meliopora.*

quakes. This is bad news for Angelenos who had been hoping that the stresses might be relieved by many small earthquakes instead.

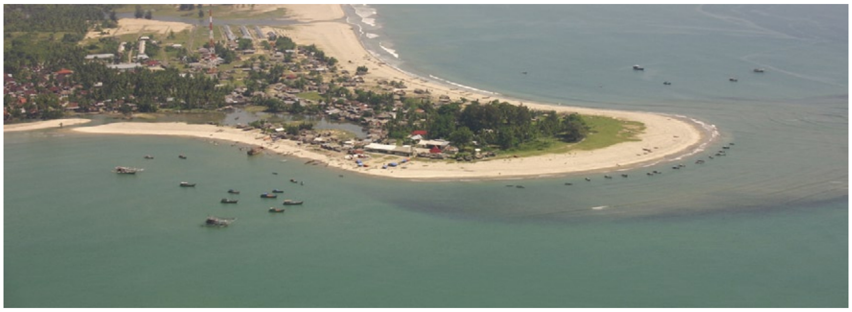
But for as much as he's learned about the San Andreas, it remains frustratingly enigmatic—running through several major urban areas, it is, to put it simply, a geologic mess. "We still do not understand why earthquakes have occurred on the fault with such great irregularity," he says, although he has a couple of suspicions. One is that, given that California is riddled by faults, a nearby one may break and give a kind of geologic "belly punch," as he puts it, to the San Andreas. This may change the stress level, "causing it to fail sooner—or later," he says. Or, by the very nature of it being a fault, "you can have something fundamental about the nature of a crack. If you drive at a crack from the sides it can be irregular spatially, in terms of how much it slips, and also irregular in terms of time—how long until it will slip."

And getting data from the San Andreas is a hassle. For one thing, it's labor-intensive and expensive—"you need to bring in a big diesel backhoe on a flatbed truck to excavate a trench that's about a meter wide and about 5 meters deep, then you have to put up shoring to support the walls," says Sieh. "You have to find the right site where the layers are accumulating at the right rate, that has carbon you can date, and then it takes a couple of months to get reliable analysis from a lab." Because all living things contain radioactive carbon-14 that begins to decay at the time of death, and scientists know what that rate of decay is, measuring the remaining level of C-14 in a sample of say, peat, gives the date when it died, give or take 50 years or so. "The problem, though, is that material can blow or fall in and get caught in a layer and fool you," says Sieh. "So with all these limitations, around 1990 I came to the realization I was going to be an old man before I figured this thing out, and I may not be able to figure it out at all in my lifetime."

"All I could think about was damn, if the San Andreas fault just had some coral, we could do some really good dating."

Then three things happened, roughly around the same time: two Caltech colleagues developed a new dating technique, Sieh read an article about coral, and he got invited to Sumatra. The dating method uses uranium found in corals. Uranium is brought up from the earth's deep interior in igneous (volcanic) rocks, and then leaches out into the environment. It's everywhere. And it decays at a known rate—uranium-238 decays to uranium-234, which decays to thorium-230, which eventually decays to lead-206, which, finally, is stable. "All the daughter products decay at different rates down to lead," says Sieh. "And as they decay, certain ratios exist between the daughter products. And if we can figure the ratio between the two, we can determine the age of a 500-year-old sample to within two years." Which is exactly what Caltech's Gerald Wasserburg, Crafoord laureate and MacArthur Professor of Geology and Geophysics (now emeritus), and graduate student Larry Edwards (PhD '88), now a professor at the University of Minnesota, did. "So as I was learning about this method all I could think about was damn, if the San Andreas fault just had some coral, we could do some really good dating," says Sieh.

Next, early in 1991, Yehuda Bock, a colleague at the Scripps Institution of Oceanography, had a project to measure strain accumulation along the Sumatran plate boundary. He was also trying to figure out how fast the Sumatran fault, which runs down the backbone of the island, was slipping over the millennia. Since it, like the San Andreas, was a strike-slip fault, he turned to Sieh. "So off I went to Indonesia for a week, charging around the mountains looking at this fault," says Sieh. Back in Jakarta for a little R & R, he was catching

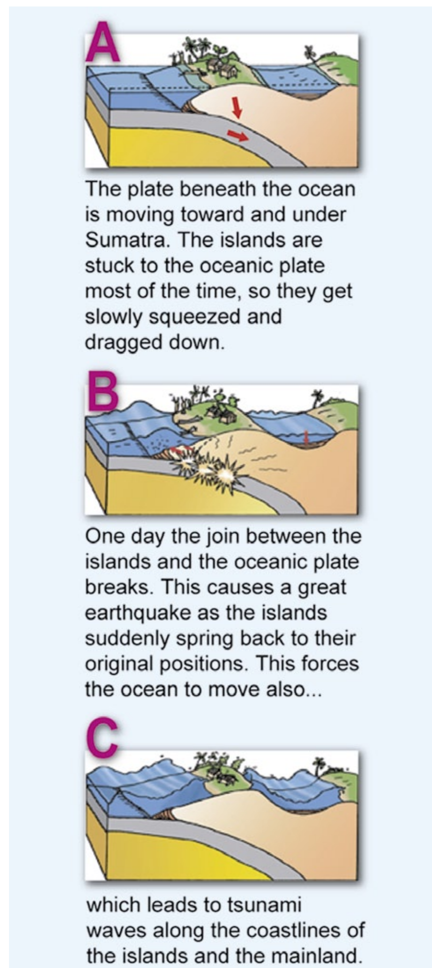


Is this town, which sits on a promontory near Padang, a disaster waiting to happen?

some sun at a public swimming pool ("instead of the one at my hotel, where it's all rich Westerners; I like to be in the 'stream of life' of the local folk, watching the kids and the parents"). That's when it hit him. He had brought along a paper about corals by another colleague, Fred Taylor, from the University of Texas. Taylor described measuring how much the earth had risen during an earthquake by looking at coral heads that had been raised out of the water, had died, and were now growing at a lower level. "That's when I had one of those rare moments in my scientific career—a chill up my spine, a true eureka moment," says Sieh. "I realized that if I could find a warm, low-latitude (where coral would exist), big subduction zone, one that's unaffected by neighboring faults, like the San Andreas is, I could do a clean paleoseismic history that might inform us about future earthquakes." He realized he was sunning himself directly on top of just such a zone, one that had been relatively unexplored by other scientists—"It's tucked away in a corner of the world that just doesn't have a lot of scientific traffic," as he's said in the past.

Sumatra, the largest island in Indonesia and the sixth largest in the world, doesn't just have a double whammy in terms of tectonics, but multiple whammies. There is the Sumatran fault Sieh worked on, and there are volcanoes running the island's length. Last April, during a time of frequent aftershocks, Mount Talang, located about 40 kilometers east of Padang, spewed ash 500 meters into the air, adding to the misery of people already terrified about earthquakes and tsunamis. (Western Sumatra is also home to Toba Lake, which fills a 100-kilometer-long caldera that formed 73,000 years ago atop Toba volcano. Fortunately, it's still asleep.) Then there's the boundary between the Indian-Australian and Eurasian plates, which runs 5,500 kilometers beginning near Myanmar, curving past Sumatra, then heading toward Australia. This source of Indonesia's recent woes lies about 200 kilometers off Sumatra's west coast, where the plates collide five kilometers beneath the Indian Ocean at what geologists refer to variously as the Sumatran trench or Sunda trench. It's here that the Indian-Australian plate begins to subduct—slide beneath—the Eurasian plate, and into the earth's interior. And it's not going down easily. The two plates move in a jerky fashion, remaining locked together in a tight embrace for centuries until a sudden slip of a few meters occurs, generating a large earthquake. When one plate slides under another, it's called a thrust fault. But this fault is so large it is commonly referred to as a megathrust.

A small necklace of islands sits on the Eurasian plate, right on top of the megathrust. Because the two plates are locked, these islands are slowly being pulled down by the subducting Indian-Australian plate, only to rebound when the plates move freely during earthquakes—resetting the clock, as



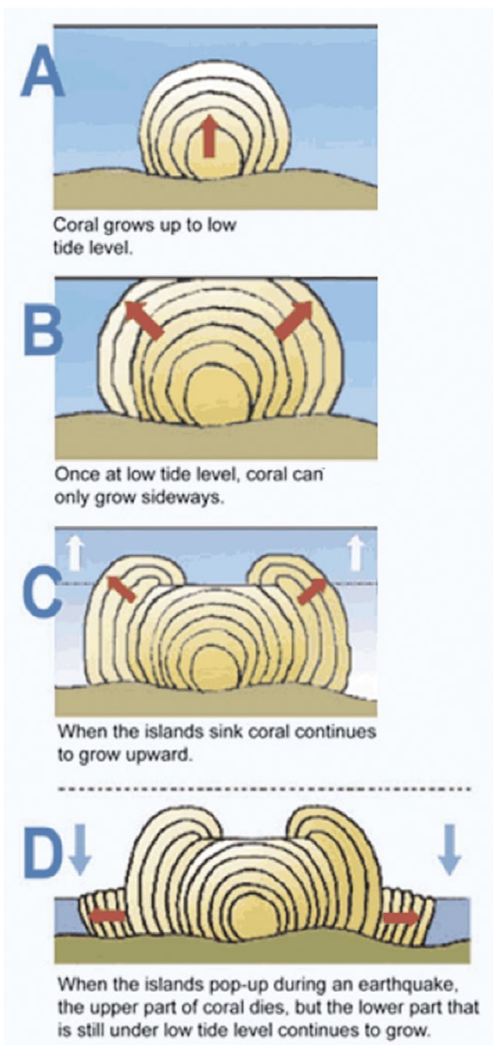
This panel from the poster shows why the offshore islands are slowly sinking, and why their rebound during earthquakes causes tsunamis.

Top: Kerry Sieh. Bottom left: Danny Natawidjaja in the helicopter. Bottom right: John Galetzka.

it were. The islands allow easy access to the coral heads Sieh needs to study. All in all, he says, "It is just a perfect, natural laboratory, a bonanza for science." Sieh looks at a segment of the megathrust that runs from the equator to about four degrees south latitude. He collaborates with a number of colleagues, most often Danny Natawidjaja and Bambang Suwargadi from the Indonesian Institute of Science (Natawidjaja, MS '98, PhD '03, is his former graduate student), and Caltech staffer John Galetzka, who spends virtually all of his time in the field, taking coral samples and installing, repairing, and downloading data from the Global Positioning System (GPS) stations that precisely measure any tectonic movement. All of them serve as science ambassadors to the locals, who wonder why these crazy Westerners ask permission to chop up a coral, hack a circle in their farmland or the nearby jungle to install some bizarre-looking machine, or pay money to sleep on their floor.

Over the course of the last decade, Sieh has primarily relied on the heads of *Porites* coral. Specimens of this bowler-hat-shaped coral (Remember the hat worn by Oddjob in the 007 movie *Goldfinger*?) can be large enough to stand on, and can weigh tons. Growing in annual bands much like tree rings, the long-lived corals serve as "nature's seismometers," as Sieh puts it, recording, to within centimeters, sea-level changes caused by uplift and submergence of the earth. "The coral grows right up to the sea surface, then flattens out like a plate and begins to grow out to the sides," says Sieh. "So each time the island sinks, raising sea level, the coral grows higher; when the island is uplifted and the sea level drops, the coral is raised out of the water and dies." The coral is cut into slabs with a waterproof chainsaw, and the samples sent off to Larry Edwards's lab in Minnesota for uranium dating. (For an animation of the coral's growth and die-off, see: http://www.gps.caltech.edu/~danny/research/coralanimation_gif.gif.)

The GPS station at the airport in Sinabang, the capital of Simeulue Island, close to the epicenter of the December quake, showed that the entire island lurched 2.33 meters to the southwest, while its northwestern shore rose 1.65 meters. This is what commonly happens with Sumatra's offshore islands, says Sieh: "a long-term trend toward submersion



Right: Another panel shows how *Porites* corals record sea-level changes. Far right: The top of this newly emerged *Porites* microatoll off the northern tip of Simeulue shows that the head was submerging in the years before the earthquake.

This uplifted reef is on the westernmost tip of Simeulue, looking roughly south. The original shoreline is the thin, beige strip of sand where the vegetation ends.

and tilt." Most of the network's GPS stations have to be visited in person to download their data, but they are slowly being upgraded to communicate by satellite. That way, Sieh will get readings within hours in the comfort of his Caltech office—no more anxiously waiting days or weeks.

When Sieh hustled to Sumatra after Christmas (ironically, on a long-planned trip), he described the area of uplift in an e-mail (see http://today.caltech.edu/gps/sieh/): "Even though [we've] been studying ancient evidence of the slow sinking and fast emergence of the Sumatran coral reefs, we were astonished to find ourselves walking through a pristine marine ecosystem, missing only its multitude of colors, its fish, and its water. Corals of every shape and size rested lifeless on the reef platform—branching corals, massive corals, staghorn corals, fire corals, brain corals, whorls, fans. And here and there a poor crab. Even though the tsunami had raged across the reef, there was scant evidence of any breakage of the delicate whorls and dendritic corals that crunched beneath our feet. But a fishing boat in the trees beyond the shoreline and an overturned, two-ton, umbrella-shaped *Porites* coral head were testimony to the power of the tsunami. The scene was the marine equivalent of a village on the flank of a volcano after the passage of a nuée ardente (a destructive 'glowing cloud')—life quick-frozen in place at the moment of death."

After the M 8.7 March earthquake, John Galetzka noted, in an e-mail, "At Lahewa on the north coast of Nias Island there was no tsunami, only intense shaking. Thirty-two people died from building collapses and fires that swept through the town. The harbor rose about two to two-and-a-half meters due to tectonic uplift."

Sieh notes that the 8.7 quake extended to near the equator. He suspects the fault could have broken even further, but was stopped by an "aseismic zone." This is a piece of the fault next to his area of study that has more elastic properties than his study zone, allowing stress to build up much more slowly. And while an M 8.7 should be strong enough to generate tsunamis, this one generated only very slight ones. The reasons aren't yet clear, but the March quake occurred under relatively shallow water, so there may just have been less to displace.

On Tello, a tiny island on the equator near the epicenter of the March earthquake, Galetzka found a dead GPS unit. Apparently, people had grown suspicious of it. "Since no earthquakes had occurred in their lifetimes before the machine was put in, they figured the GPS was to blame," he says. "So they cut its wires!" He told the full story in an e-mail: "As we were trying to repair the vandalized station, the situation could have easily tipped into chaos had it not been for some cool heads there to keep things calm. At one point we were even told to stop repairing the station. Later that night there was a community meeting called by the district supervisor to try to dispel the

A typical GPS installation. The gray dome on the tripod in the background houses the GPS unit proper, and the open cabinet under the solar panel contains the electronics.

These old, now-flooded rice paddies are near the nothern tip of Simeulue. They apparently re-surfaced after the earthquake.

numerous rumors about our GPS station and other things regarding giant earthquakes and tsunamis. My colleagues, Bambang Suwargadi and Imam Suprihanto, gave an excellent oral presentation and answered questions from the audience. Because satellite telemetry has been re-established to the Tello station, we'll soon know if the citizens believe us or not."

Between earthquakes, says Sieh, the islands are slowly being dragged under water at a rate of about a half an inch a year. "The villagers know this," he says. "They can see their boardwalks and harbors sinking." On a helicopter survey of the islands after the December quake, he was intrigued when he spotted what appeared to be rice paddies on the northern tip of Simeulue Island where none had been before. He believes the newly emerged paddies had been slowly flooded by the ocean, only to reappear after the quake. Along the fault in Sieh's study area, the Indian-Australian plate is cool, not very dense, and locked against the Eurasian plate. As the plate subducts, it becomes hotter, more gooey, and denser. "So as the lower part sinks down," he says, "it stretches and pulls on the upper part; that's what's pulling the islands down. And eventually, it's going to snap."

Snap indeed. This particular segment has been resisting now for about 200 years. Sieh's coral evidence shows that large earthquakes occur regularly—often in pairs—every 200 to 230 years. His research shows that clusters of quakes occurred in the 1300s and 1500s, and one in 1797 (M 8.2), and 1833 (M 8.7), all probably accompanied by tsunamis. In fact, he has an historical account, recently translated from the Dutch, of tsunamis inundating Padang in 1797 and 1833. "It describes a 150-ton boat that was picked up and carried through the city, just mowing down houses as it went," he says. "So our inkling is that these earthquakes are roughly periodic." Given the 200- to 230-year average, this suggests another quake is coming due. "It's a quandary," he says. "We have better information about the recurrence history of this section of the subduction zone than nearly any other subduction zone in the world," yet science can't say with any certainty what, exactly, is going to happen tomorrow. "That's why I tell the local people that another earthquake will occur sometime in the lifetime of their kids." It could be 70 years from now—or it could be tomorrow.

After the December earthquake, Sieh and other geologists thought it likely that the segments of the Sunda megathrust immediately to the south would be closer to failure. The pattern of aftershocks that followed confirmed this opinion, and, sure enough, in March the M 8.7 quake struck. Debate continues as to whether this quake was an aftershock or a new earthquake in its own right, but the point, says Sieh, "is this earthquake, like the earlier one, is one of the few great earthquakes of the past 40 years." The approximate 300-kilometer length of its rupture is a very significant piece of the fault, although the December 2004 quake ruptured more than 1,000 kilometers. "Many of us wondered if the December earthquake would trigger another significant event," says Sieh. "Nature has now answered that question." Adding to the woes of the

Top: This picture of Lahewa harbor on the north coast of the island of Nias was taken at high tide on February 15. Bottom: This photo, taken at low tide on April 24, shows another 2 to 2.5 meters of uplift as a result of the March 28 earthquake. The yellow line approximates the new high-tide mark.

Uplift is not the only thing changing the coastline—this beach is moving inland, rather than seaward. Natawidjaja (on the left of the group) is standing where the grass used to end before the December 26 earthquake. The locals say that this erosion has taken place since the tsunami, not during it.

Indonesian people is the danger that the portion of the San Andreas-like Sumatran fault nearest to the December quake has been put under increasing strain as well. It runs right through the already devastated Banda Aceh area and down Sumatra's backbone.

So what will become of the Indonesian people? Do they face an existence of recurring devastation, especially those that live in large cities like Padang? With the destruction, the deaths, and the aftershocks that continue to hammer Sumatra, Sieh says many people in Padang are in a near-constant state of panic. Galetzka was in the city in mid-April when the two 6-plus aftershocks struck. They even scared him. "I was really thinking those weren't aftershocks, but foreshocks of the larger quake that's coming," he says. "It was a very unsettling experience." Many Indonesians now understand—having learned the hard way—that they live on top of one of the most violent seismic zones in the world. On some of the smaller islands, Galetzka reports, people have taken steps to reduce their risks, establishing new communities in the interior on higher ground. And they've made escape routes from the villages near the sea. Others are less reassured. In April, Sieh was hearing from friends that many people on the offshore islands were convinced they were about to sink; ferries to the mainland were running full every day.

Residents of Padang know earthquakes will come, but they don't know what to do. About 10 percent, estimates Sieh, are not waiting for their government to advise them. They've "voted with their feet," he says, leaving behind homes and jobs to flee into the hills or south to Jakarta. Sieh shared an e-mail from an Indonesian friend in Padang: "May be you have heared about earthquake at nias, north sumatra, and you know kerry many people and TV inform that tsunamies will come to Padang in this month. it's true kerry? but now I'm afraid if it's become because my parents don't want to leave from here, they don't believe what I and people say, I've tried to persuade them. . . ." Sieh wrote back, "No one knows if the big earthquake and tsunami will come to Padang soon. It could be tomorrow or it could be in 30 years. No one knows, so you should not believe anyone who says that they know it will happen soon. Where do your parents live in Padang? If they live close to the beach, then perhaps they should think about moving farther away."

Sieh is not optimistic. Because of his outreach efforts last summer, the media wanted to talk to the geologist who had "predicted" a large earthquake was imminent. "Reporters asked me if Indonesia will do anything, and I said I was skeptical," says Sieh. "Then they asked if this was because Indonesia is a third world country, and I said no, it's because they're human." He pointed out how long it's taken Los Angeles to retrofit buildings and bridges. He noted that after an earthquake people stockpile food, water, and flashlights with fresh batteries. Then the water gets used, the food goes bad, and the batteries die as the memory of the earthquake fades. There *are* things Indonesia could do—begin moving Padang's city center several kilometers back from the shoreline, and turn that into parkland, he suggests; construct buildings with first floors whose walls will break away in the event of a tsunami, allowing the water to pass through. (Instead, Padang recently built a new marketplace—a gathering place for people!—mere feet from the waterfront.)

Meanwhile, Sieh will continue, and possibly expand, his own efforts at educational outreach, but hopes to find a nonprofit organization and possibly a funding "angel" that will take over. "It's a terrific place to be from a scientific standpoint, but from a humanitarian point of view, it's an odd place to be in as a scientist," he says. "I never expected this would become a component of my work. But I guess that's what science in the public interest is all about." □

PICTURE CREDITS:
25-31 – Kerry Sieh; 25 – Catharine Stebbins; 27, 28 – Sambas Miharja; 30 – John Galetzka