Where the First Wave Arrives in Minutes

Indonesian Lessons on Surviving Tsunamis Near Their Sources

FRONT COVER Video scenes from Banda Aceh, December 26, 2004. All but the last were shot in Simpang Lima, at the tsunami's feather edge almost 3 km from the sea (p. iii).

Scene

1-4 **Crowds gather and an ambulance passes in front of a department store collapsed by the Aceh-Andaman earthquake, which occurred close to 8:00 a.m. (timeline, p. 4). Little more than the store's facade remains upright (scene 1; side view, p. 7).**

5-8 **Close to 9:00 a.m., people begin fleeing on a street that is still dry. They have heard that the sea is coming. The water follows. Children can run through it at first.**

9-11 **Household objects congest the growing flood.**

12 **A survivor receives help.**

Credits, p. 22

Published in 2010 by United Nations Educational, Scientific and Cultural Organization (UNESCO), for its Intergovernmental Oceanographic Commission (IOC), 7 Place de Fontenoy, 75 352 Paris 07 SP, France

Produced by Jakarta Tsunami Information Centre (JTIC), UNESCO/IOC, UNESCO Office Jakarta, Jalan Galuh (II) No. 5, Kebayoran Baru, Jakarta 12110, Indonesia. www.jtic.org

Supersedes "Surviving a tsunami — Lessons from Aceh and southern Java, Indonesia," 2009. Based on "Selamat dari bencana tsunami," 2009 (IOC Brochure 2009-1)

First printing 2010 for UNESCO/IOC - NOAA International Tsunami Information Centre, Honolulu, Hawaii

When citing this booklet please include its IOC series and number, IOC Brochure 2010-4 (or IOC/BRO/2010/4), and designate UNESCO/IOC as its publisher. In addition, consider using each compiler's names in full because none is a family name (citation style for reference 14, p. 26).

This booklet in pdf format may be downloaded free of charge at http://www.jtic.org/en/info-sources/jtic-info-sources/publications.html?download=1317%3Awhere-the-first-wave-arrives-in-minutes. Also posted there are the booklet's diagrams in their native cdr format and as pdf files.

Where the First Wave Arrives in Minutes

Indonesian Lessons on Surviving Tsunamis Near Their Sources

Public knowledge, natural warnings, and evacuation strategies
that helped people live through fast-arriving tsunamis in Aceh and southern Java

Compiled by Eko Yulianto[1], Fauzi Kusmayanto[1], Nandang Supriyatna[1], and Mohammad Dirhamsyah[2]

Adapted by Brian F. Atwater[3], Eko Yulianto, and Ardito M. Kodijat[4]

United Nations Educational, Scientific and Cultural Organization
Intergovernmental Oceanographic Commission
IOC Brochure 2010-4

[1] Lembaga Ilmu Pengetahuan Indonesia (Indonesian Institute of Sciences), Bandung
[2] Universitas Syiah Kuala, Banda Aceh
[3] United States Geological Survey, Seattle
[4] United Nations Educational, Scientific and Cultural Organization, Jakarta

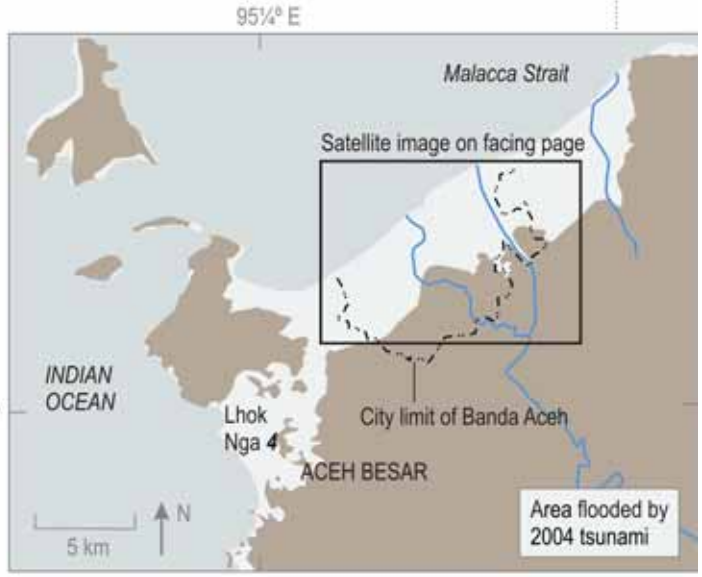
Index Maps

Number in ***bold italics*** denotes booklet page where place is mentioned.

Indonesia and vicinity

Nanggroe Aceh Darussalam (Aceh Province)

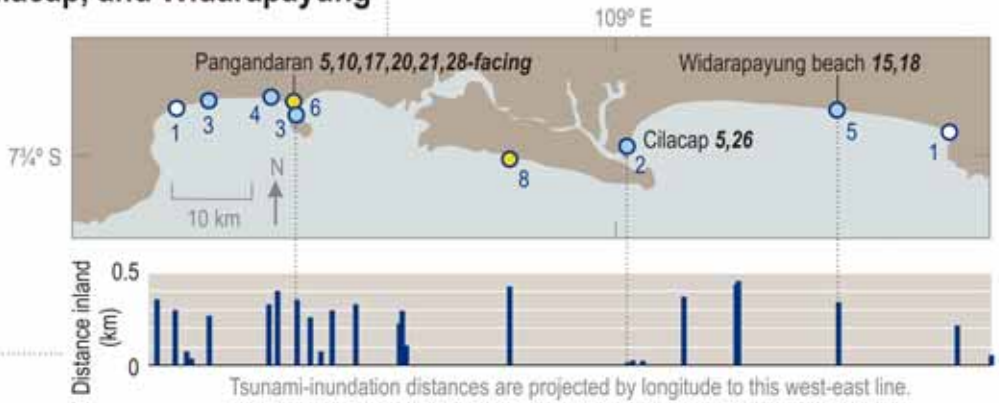
Northern Aceh Province



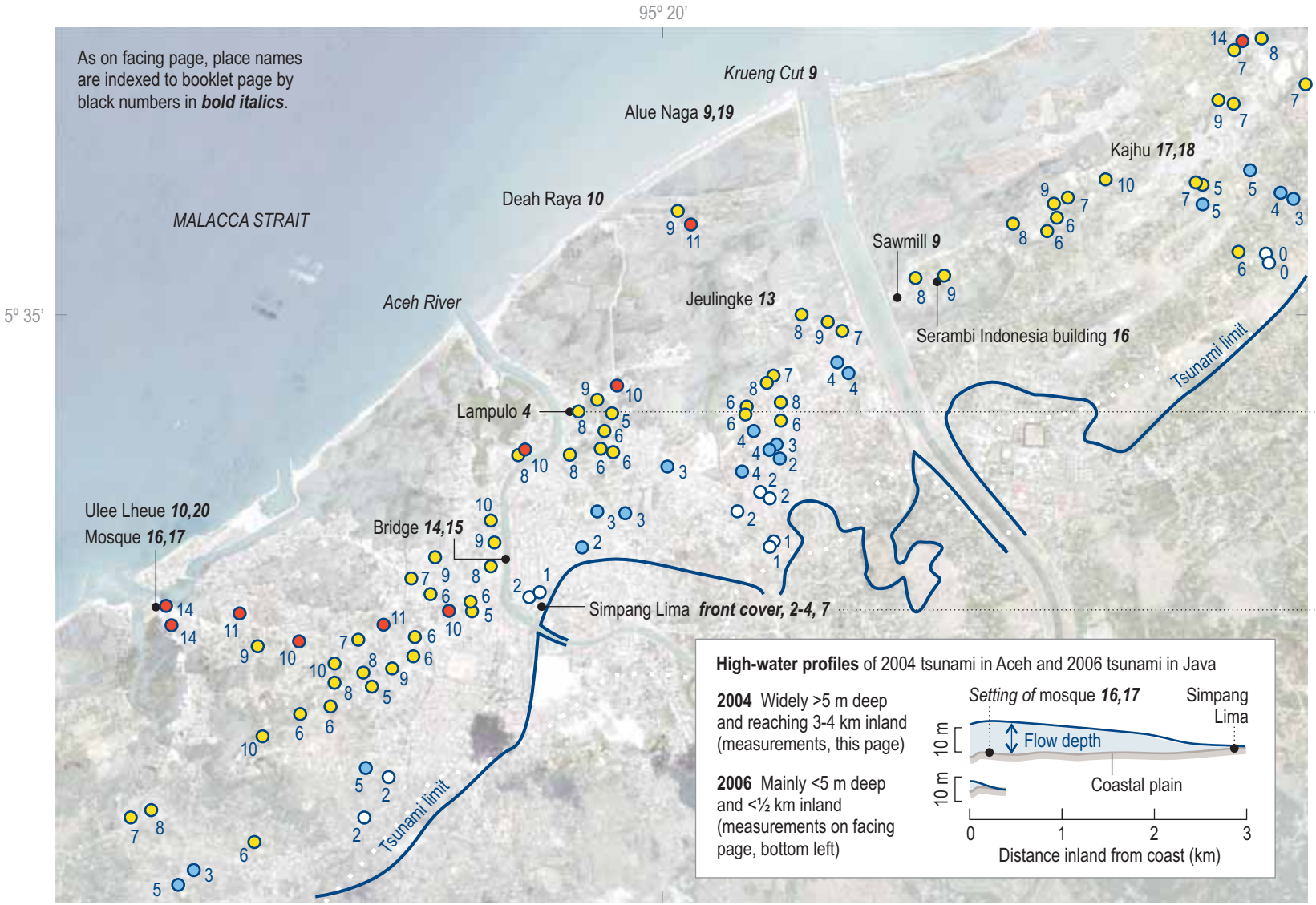
Pangandaran, Cilacap, and Widarapayung

2006 tsunami

Numbers in blue give maximum flow depths, in meters; dots color-coded by depth range (key, upper right on facing page). Maximum depth attained close to beach (profile, lower right on facing page). Water ran less than 0.5 km inland (distances graphed here).



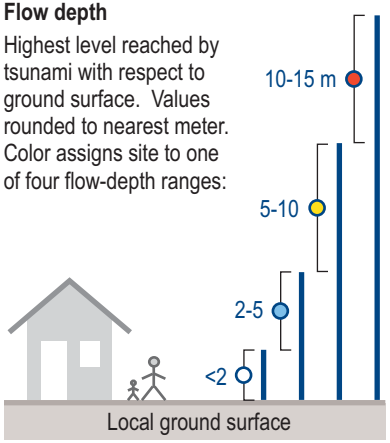
Banda Aceh and vicinity



Digital Globe image from Google Earth, taken June 22, 2004

Flow depth

Highest level reached by tsunami with respect to ground surface. Values rounded to nearest meter. Color assigns site to one of four flow-depth ranges:



Black dot in Lampulo locates evidence that the tsunami first flooded this area 45-50 minutes after start of earthquake. The evidence consists of the times on two stopped clocks, believed disabled by the tsunami, that had been hung 2-3 m above a house floor (timeline, page ***4***).

Black dot at Simpang Lima is centered on white monument in scenes 5, 6, and 10 of ***front cover.*** That monument is 150 m northeast of the collapsed Pante Pirak department store shown in scenes 1-3 and on page ***7***.

Data sources cited on page ***23***.

Contents

Introduction

THIS BOOKLET draws public-safety lessons from recent Indonesian experience with fast-arriving tsunamis. Initially prepared for Indonesian readers, it is adapted here for international use.

Most tsunamis in Indonesia arrive fast because they begin within or just outside the nation's archipelago. An earthquake, volcano, or landslide sets off a train of ocean waves that reaches the nearest Indonesian shores in an hour or less.

Fast-arriving waves account for most tsunami deaths worldwide. They threaten coasts near tsunami sources, most of which are on the Pacific Rim, beside parts of the Indian Ocean, in the Mediterranean and Caribbean Seas, and at volcanic islands. The waves afford little lead time for the delivery of official tsunami warning, and they commonly begin with an earthquake or volcanic eruption that can cut phone service, electric power, and roads. They tend to be bigger than the same tsunami on distant shores reached hours later.

This booklet draws on eyewitness accounts of tsunamis that arrived in an hour or less. Such fast-arriving tsunamis threaten many coasts, particularly those that adjoin subduction zones (global distribution, above; see also p. 3 and 23). In the photo, Eko Yulianto interviews a survivor of one such tsunami in Lampon, Java.

Many of the lessons in this booklet are based on experiences of eyewitnesses to two fast-arriving tsunamis: the enormous waves that took an estimated 160,000 lives in Aceh on December 26, 2004; and lesser waves that left some 700 dead on the south coast of Java on July 17, 2006. The booklet's compilers interviewed some of the eyewitnesses, and they obtained other accounts from published sources.

The lessons, outlined on the facing page, have three main themes. Several kinds of knowledge provide **The Earliest Warnings** of tsunami hazard, during the decades before a tsunami begins. Among **Warnings of a Tsunami Underway**, earthquake shaking provides the most immediate natural signal to go to high ground. This reaction, in turn, is among the nine survival tactics under **Evacuation Strategies**.


6
PUMA

The Earliest Warnings

Understanding Why Tsunamis Happen to Us

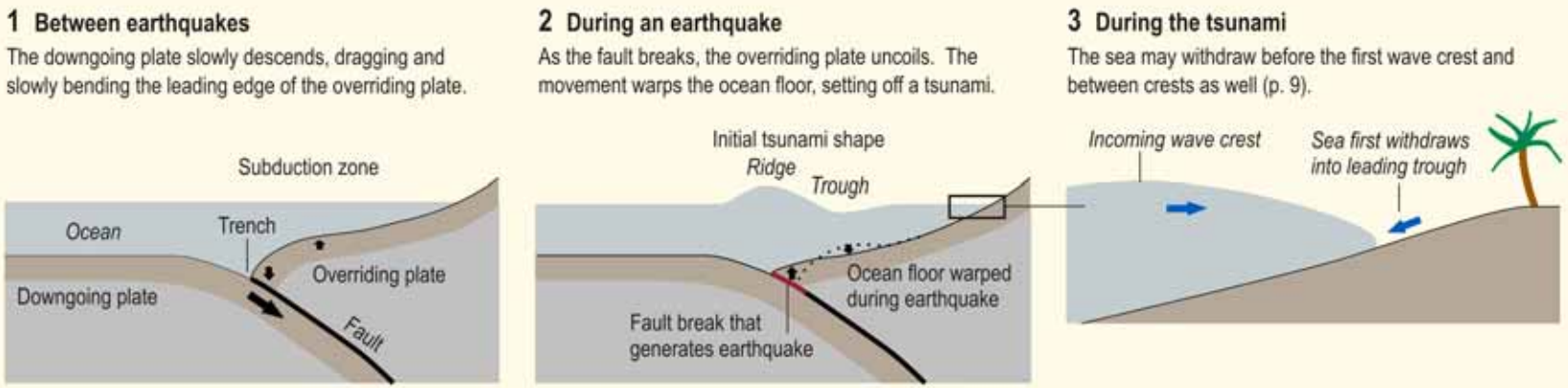
TSUNAMI WARNING begins decades before the tsunami does. It takes time to build scientific and public knowledge of tsunami risk. Can tsunamis damage a coastal community? If so, how often can they be expected to occur, and how much harm can they cause? In Indonesia these questions lead to a more basic one: Why do tsunamis happen to us? Here are two of the explanations offered in Indonesia:

1. It is by God's will that we find ourselves on an Earth that both sustains and endangers us. Rocks yield minerals, oil, gas, and coal. Soils enriched by beautiful volcanoes nourish plants that feed and delight. Surrounding seas provide fish and ports. But these same lands and waters are also rich in natural hazards. Tsunamis, along with earthquakes, volcanoes, and landslides, are not punishments from God, but rather are part of God's gift to contemplate.

2. Most tsunamis result from plate tectonics—the motion of rock slabs that form our planet's outer shell. Most tsunamis originate near a sloping boundary between tectonic plates, where one plate descends, or subducts, beneath another. Subduction yields the fault ruptures that set off most tsunamis. The plates themselves are moving about as fast as our fingernails grow (arrows on map, p. 23). The motion, monitored by orbiting satellites, shows no sign of stopping.

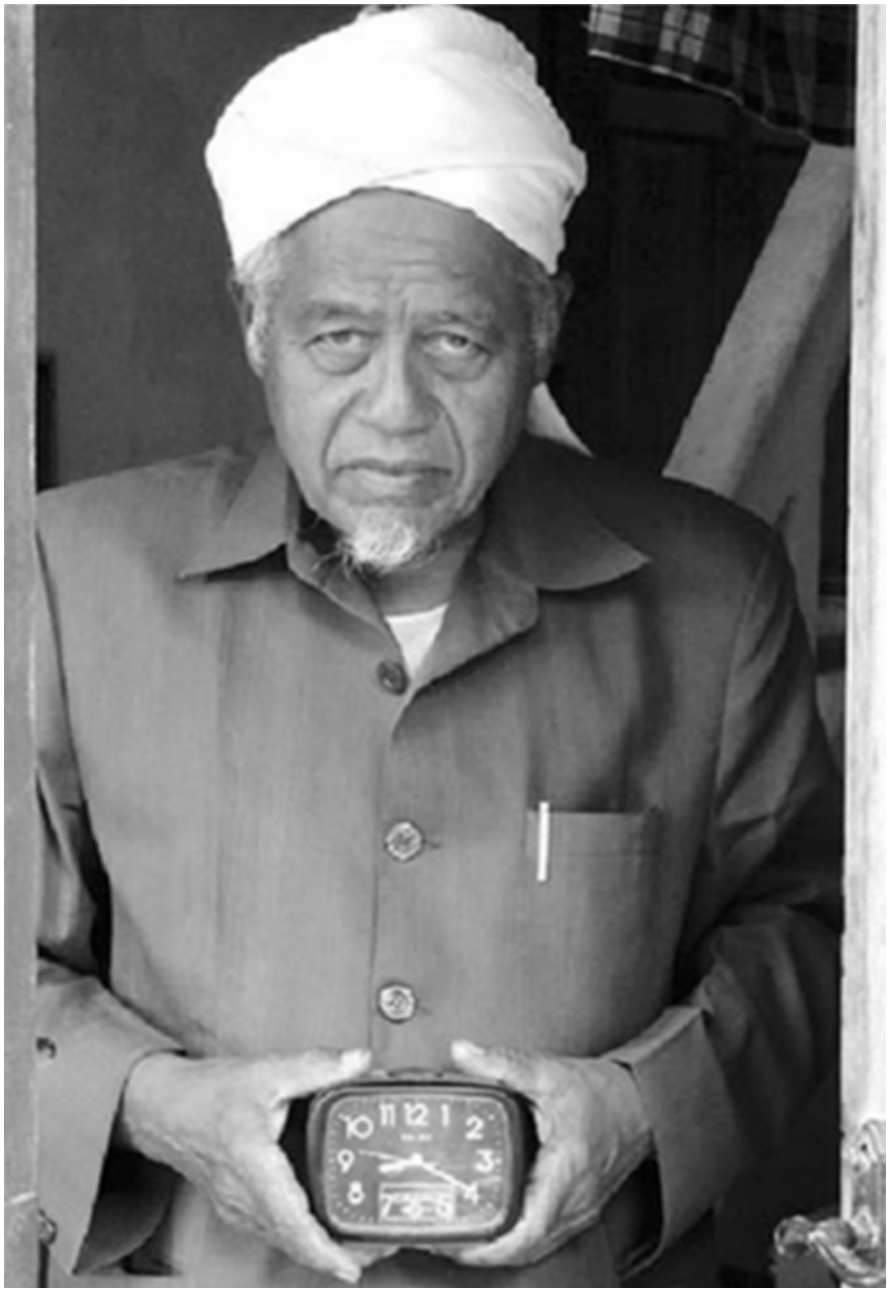
A Tsunami Explained by Subduction

Most tsunamis begin with warping of the ocean floor during an earthquake. A fault break raises the ocean floor near a trench and lowers it closer to shore. The tsunami then begins as a ridge and trough at the ocean surface. The sea withdraws from the shore where the trough arrives first.



The 2004 tsunami in Simpang Lima, Banda Aceh, 9:14 a.m.

Fast-Arriving Waves Tend to Pose the Greatest Threat

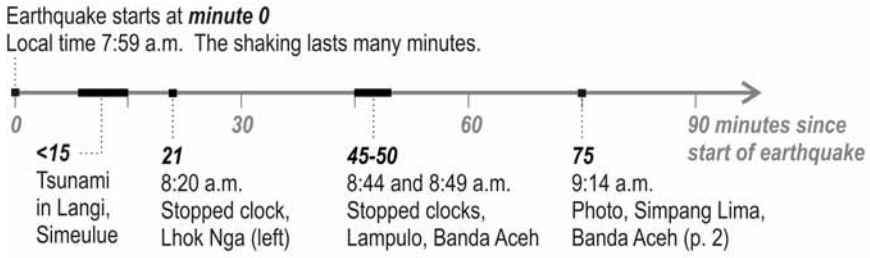


THE 2004 TSUNAMI arrived soonest and with maximum force in on the shores nearest its source. Near Banda Aceh it came ashore within 20 minutes (clock, left; timeline, below). In parts of that city it ran 5-10 m deep (yellow dots, p. iii). It followed an earthquake that had knocked people off their feet and had brought down buildings (scenes 1-6, front cover; photo, p. 7).

This combination of short lead time, large waves, and prior damage helps explain why fast-arriving waves account for most tsunami deaths worldwide. It also helps explain why Indonesia leads the world in tsunami losses.

The Indonesian archipelago accounts for two-thirds of global tsunami fatalities since the year 1800. Even without the estimated 160,000 deaths in Aceh in 2004 and the 36,000 deaths from waves set off by 1883 eruptions of Krakatau, Indonesian tsunami fatalities since 1800 rival the total from Japan and exceed the sum for South America.

Today, millions of Indonesians are vulnerable to fast-arriving tsunamis. Many have no other place to live. Some feel that if a tsunami will cause their death, that is their destiny. Although most have probably heard that they can survive a tsunami by going to high ground in the event of an earthquake, some lack easy access to high ground. Similar challanges face many other countries where a tsunami can arrive in minutes.



Tsunamis since 1800 have taken more lives in Indonesia than anywhere else, in part because the waves arrive quickly. Imam Abu Abdul Rhaffar holds a clock believed stopped by the tsunami in Lhok Nga (left). The time is a little more than 20 minutes after the start of the 2004 Aceh-Andaman earthquake (above).

The Earth May Remember What People Forget

PAST TSUNAMIS can provide the earliest warnings of future ones. This forewarning usually depends, however, on written or oral records that may span too little time to include a rare tsunami, like the one in 2004, that takes centuries to repeat. Geological records, though usually incomplete themselves, can help clarify and extend an area's tsunami history.

Over 100 tsunamis are known from the last four centuries of Indonesia's written history. On average in the last decade and a half, a tsunami happened somewhere in the archipelago every other year. Yet the time between tsunamis at any one place commonly spans decades or even centuries. Such long times between successive tsunamis contributed to the recent tsunami losses in Aceh and southern Java.

In Aceh, as elsewhere around the Indian Ocean, the 2004 tsunami seemed without precedent. Geological evidence for its predecessors had yet to be reported (the Thai example, below left, was discovered in 2007). The waves in 2004 thus took most people by surprise.

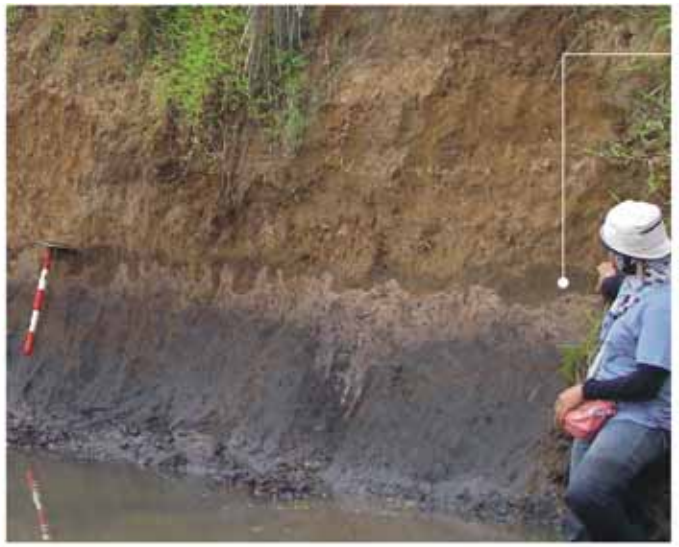
Similarly in Java, the 2006 tsunami came as a surprise to many in Pangandaran and Cilacap. Its most recent predecessor occurred 85 years earlier, in 1921. Whether Java is subject to tsunamis as great as Aceh's remains to be learned (below right).

On most coasts, a damaging tsunami happens so rarely that people forget about the hazard. Earth's own extended memory of tsunami history can help them remember.

2,500-year record in Thailand
The light-colored layers, made of sand, represent the 2004 tsunami and three of its predecessors:

The dark layers are soils that represent times between tsunamis.

Swale 0.5 km inland, Phra Thong Island, Thailand



Clue from the past in Java
This layer of dark sand probably represents a tsunami several centuries ago. The inferred tsunami's size and source remain to be determined, as do its potential links to Java's written history.

Bank of tidal Cikambulan River, Pangandaran

How Grandparents and Graves Kept Memories Alive

Beach Boat stranded by 2004 tsunami Shelter over Ulama's grave

KNOWING ABOUT A PREVIOUS TSUNAMI helped save thousands from the 2004 tsunami on Simeulue Island, off the Aceh coast. The 2004 tsunami reached Simeulue within a few tens of minutes. The islanders received no tsunami advisory from radios, sirens, cell phones, or tsunami-warning centers. Yet among the island's mainly coastal population of 78,000, just seven people died. What saved lives was a combination of natural and traditional defenses: the island's coastal hills and the islanders' knowledge of when to run to them.

Islanders had passed along this knowledge by telling of *smong*—a local term that covers a three-part sequence: earthquake shaking, withdrawal of the sea beyond the usual low tide, and returning waters that rush inland. Smong can be traced to a tsunami in 1907 through the memories of old people like the woman at left, who learned of that tsunami from her parents. Interviews in 2006 showed islanders familiar with tangible evidence from 1907: coral boulders in rice paddies, victims' graves, and stones transported from the foundation of a mosque. They also knew of religious leaders' graves that the 1907 tsunami had left unharmed (example, below left).

Smong stories most commonly passed from grandparent to grandchild. Elders would tell of smong at family gatherings after dinner. The stories taught good behavior by illustrating a kind of disaster that bad behavior can attract. The smong of 1907 was sure to be mentioned after any small earthquake as an example of what a bigger earthquake can do. The teller often concluded with guidance like this: "If the ground rumbles and if the sea withdraws soon after, run to the hills before the sea rushes ashore."

Tsunami history and cultural heritage mix at Simeulue Island, where only seven died from the 2004 tsunami. The history gets handed down by people like Pi Dawan (photographed in 2006 with a great-grandson in Labuan Bajo). Her parents had told her of the 1907 tsunami, tangible reminders of which include the grave of an early religious leader, Tengku Di Ujung (left, in Latak Ayah). Many knew Tengku's grave not only because he had spread Islam on the island but also because the tombstone had survived the 1907 tsunami. It remains standing today, having survived the 2004 tsunami as well.

Warnings of a Tsunami Underway

If the Earth Shakes, a Tsunami May Soon Follow

AN EARTHQUAKE usually shakes the coasts that its tsunami will strike soonest and hardest. The shaking provides a natural warning to go to high ground or inland, or to seek refuge high in buildings or trees.

At Simeulue it has become almost routine to run to the hills whenever a strong earthquake is felt. The islanders especially take this precaution at night, when they cannot easily confirm a smong by watching from high ground for its next sign, recession of the sea. At Simeulue, a strong earthquake is sufficient reason to expect a tsunami (facing page).

By contrast in mainland Aceh, few heeded the giant 2004 earthquake as a tsunami warning. The shaking could not have gone unnoticed, for it damaged buildings, knocked people off their feet, and was said to have lasted ten minutes. When it was over, many people went outdoors, fearing further damage from aftershocks. Some gathered at buildings that had collapsed (photo, right; scenes 2 and 3, front cover). Others just carried on with what they had been doing. A few even followed a receding river 2 km to the sea (story, p. 9). Meanwhile the tsunami was approaching. It followed the earthquake by 15-20 minutes on mainland Acehnese coasts and by 45-50 minutes in Lampulo, 1.5 km seaward from the scene at right (timeline, p. 4).

Some Indonesian earthquakes, however, scarcely shake the nearby coasts their tsunamis will soon strike. Such gentle earthquakes sent deadly tsunamis to southern Java in 1994 and 2006. The 1994 tsunami took 238 lives in the east (survivor, p. 1), the 2006 tsunami about twice that number in the west (estimates, p. 23). They had the stealth of a tsunami in 1896 that killed 22,000 people in Japan, that country's greatest tsunami disaster.

Earthquake shaking provided a natural tsunami warning that was widely heeded on Simeulue Island (facing page) but not in Banda Aceh. The shaking brought down the Pante Pirak department store (right)—a collapse that surpassed most other earthquake damage in Banda Aceh, and which drew onlookers in the hour before the tsunami chased people from the area (front cover).

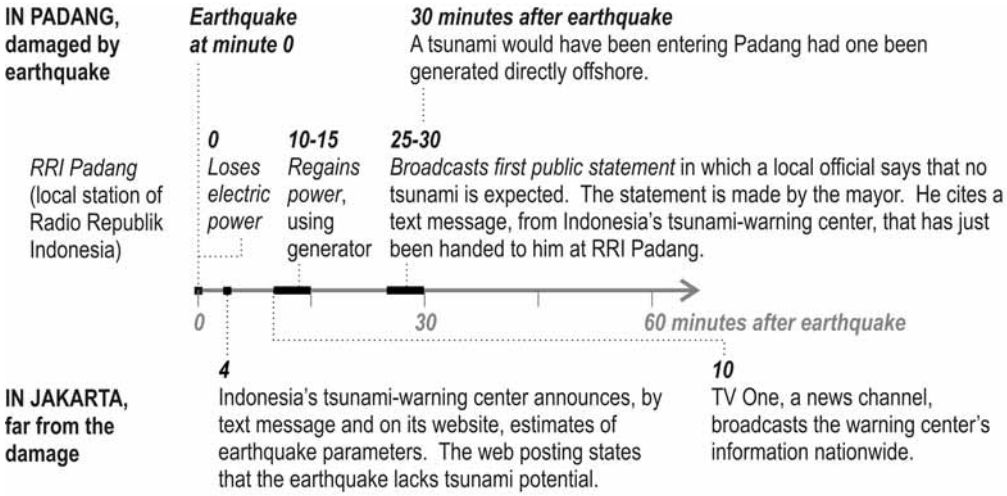
The Tsunami May Arrive Before Official Guidance Can

SHOULD A PERSON WAIT for official evacuation orders after feeling a large earthquake on a coast that is subject to fast-arriving tsunamis? Tsunami-warning centers now need just a few minutes to figure out whether an earthquake has probably set off a tsunami. The centers relay this determination to officials and the media, and they post it on the Internet as well. However, tens of additional minutes may pass before people in harm's way receive official information on whether to evacuate. By then, a fast-arriving tsunami may already be coming ashore.

In Padang, Sumatra, where a tsunami can arrive in 30 minutes, it has become city policy that upon feeling a strong earthquake, people near the coast should evacuate without waiting for official guidance. With self-evacuation underway, officials can reinforce or cancel it on the basis of information from Indonesia's tsunami-warning center.

In September 2009 that policy was reinforced by a strong earthquake in Padang that failed to generate a tsunami. The National Tsunami Warning Center, in Jakarta, took just four minutes to determine and announce that the earthquake, because of its 70-km depth, lacked tsunami potential. However, the public in Padang did not begin to receive this news for another 20-25 minutes. The delay resulted from the earthquake, which had cut power and communications while taking nearly 400 lives in the city.

Padang's Operations Control Center had managed to receive the Tsunami Warning Center's announcement just 5 minutes after the earthquake. After September 2009 the Control Center was given the city's mandate to order and cancel tsunami evacuations and to disseminate this guidance. As a precaution, however, the city maintains its policy that citizens should rely first on felt shaking, and secondarily on official guidance that may follow.



An earthquake without a tsunami reinforced a Sumatran city's policy that upon feeling a strong earthquake, people in its tsunami-prone areas should evacuate without waiting for official guidance. The earthquake took place September 30, 2009 near Padang, where several hundred thousand people live in tsunami-evacuation areas. Indonesia's tsunami-warning center quickly announced that the earthquake was too deep to set off a tsunami. But most people in Padang had trouble receiving this news because of earthquake damage to electric-power grids, cellphone networks, and radio stations. At right, the jammed evacuation and a timeline for the mayor's decision to cancel it.

The Sea May Withdraw Shortly Before It Attacks

A FELT EARTHQUAKE usually surpasses all other natural warnings of an impending tsunami in speed and reliability (p. 7). However, if the shaking is weak, as it was on the south coast of Java in 2006, later cues to evacuate may come into play. The most common of these is a wave trough that may precede the first wave crest (diagram, p. 3). The trough causes the sea to go out, and it may also cause river mouths to drain.

Those in Banda Aceh who saw the water go out include Katiman (right), who lost a leg and his wife to the tsunami. He and coworkers headed down Krueng Cut soon after the earthquake threw them to the ground at a sawmill 2 km from the sea. They followed the river to its mouth near Alue Naga beach. Along the way they saw fish stranded, first on the exposed bed of the river and later at the beach, where a tsunami crest would catch them.

Many people in Padang knew to expect initial withdrawal of the sea in the event of a tsunami from the strong earthquake of September 30, 2009 (facing page). Some of these people flocked to the beach, unsure whether to evacuate in response to the earthquake alone. This response used up much of the time they would have needed to flee a tsunami had one been generated. It also jammed up evacuation routes.

Receding Sea

In this satellite image, the sea withdraws from a Sri Lankan coast between waves of the 2004 tsunami. Waters of an earlier wave are draining through gashes in the beach. Two streams run hundreds of meters across the exposed sea floor. Eddies swirl near the sea's receding edge.

Kalutara, southwest Sri Lanka. Image from DigitalGlobe's Quickbird satellite

The Sea May Boom

INCOMING WAVES announced themselves by booming like cannons during the 2004 tsunami in Aceh and during the 2006 tsunami at Pangandaran.

In Aceh, those who heard such sounds include Harianto (story, p. 12), Mochtar (p. 16), Sharla Emilda Binti Muhammad, and Emirza. Sharla, onshore along west coast in Alue Ambang, thought she was hearing artillery fire from a conflict that had been going on for 28 years, since her childhood. Emirza, in his boat off Ulee Lheue (p. 20), may have observed a real source of these loud, resonant sounds. From the crest of a wave Emirza glimpsed the exposed floor of the sea. The sound of an explosion filled his ears as the water collapsed.

A loud noise noticed at Pangandaran had a somewhat different cause. There, several people reported hearing the sound of an explosion when a tsunami wave ran into limestone cliffs.

Birds May Flee

A DISASTER can elicit stories in which cats or dogs, or snakes or elephants, sense pending trouble before people do. Flocks of birds, which tsunami sounds may have frightened, commonly figure in accounts of the 2004 tsunami in Aceh.

The morning of 26 December 2004, Brigadier General Suroyo Gino headed eastward from Banda Aceh toward the port of Malahayati in Krueng Raya. There he was to attend a farewell ceremony for 700 soldiers of Battalion 744 Kupang, who were that day finishing their tour of duty. On the way he saw a flock of white birds flying towards Banda Aceh. He turned back toward Banda Aceh, thinking this unusual sight a warning of something bad. By then he was inland, out of harm's way. The soldiers of Battalion 744 Kupang also survived because they had not yet boarded their ship and were able to run to safety.

That same morning Surya Darma bin Abdul Manaf of Banda Aceh was at work in his *perahu*, a wooden canoe, a half kilometer off Deah Raya. He was pulling up fish traps he had set the day before. When rocked by a wave that felt unusual, he thought that an earthquake had just occurred. A couple of minutes later he saw a flock of cranes fly out of mangroves and head towards the hills, as if being pursued. Figuring something more was about to happen, he abandoned his fish traps and paddled the perahu to shore. As he was preparing to pull crab traps from a pond, a wave roared into the mangroves. He took refuge in a nearby tree, which withstood the first wave but was swept away by the second. Surya survived by clinging to a jerry-can that kept him afloat until the current carried him towards another tree, where he stayed through the rest of the tsunami.

Booms heard in Aceh during the 2004 tsunami sounded like artillery from the area's military conflict that the tsunami helped to end. At left, uniformed soldiers from the national army mingle with the tsunami's wounded.

Evacuation Strategies

Run to the Hills

A SHORT DISTANCE from the shore to the high ground makes "run to the hills" the standard procedure for tsunami evacuation at Simeulue (p. 6). In mainland Aceh, many of the residents of Krueng Sabee, had the similar good fortune of being a few hundred meters from the hills. The family of Harianto bin Leginem, 18, used these hills as a refuge from the 2004 tsunami, which Harianto himself barely survived.

At the time of the earthquake Harianto had been at work in a quarry, where he counted trucks exiting with loads of rock. During or soon after the earthquake, he and his coworkers fled the quarry for fear of rockfalls. They returned to work but soon fled again upon hearing a loud boom, which was followed by four more. The workers dropped their tools and ran for home.

As Harianto made his way home he saw fishing boats rocking in the sea and a giant wave closing in on the shore. He soon crossed paths with his younger brother and niece, who were walking slowly towards a hill. He shouted at them, throwing stones to make them run to safety. Then he continued to the family's house.

Finding that everyone had already fled to the hill, Harianto decided to follow. But he could not find his older brother or the brother's children there. So he ran back to his brother's house only to learn that they had already fled to another hill.

Harianto headed toward his brother's hill but now he was too late; the tsunami was already lapping against it. The second floor of the brother's house provided refuge but not for long. Wounded by debris in the water, Harianto clung to a mattress as the tsunami carried it out to sea. A fishing boat returned him to his family eight hours later.

Elsewhere in mainland Aceh the landscape commonly poses greater challenges than those faced by Harianto's family. To reach high ground during the 2004 tsunami, many of the mainland residents needed to cross a kilometer or more of low ground that the tsunami would largely overrun. The steepness of some of the adjacent hills makes them hard to climb.

High ground provides ready refuge near Naibos, on Simeulue Island. In the story at left, a mainland hill keeps a young man safe so long as he stays there.

Abandon Belongings

ONE OF SIMEULUE'S seven tsunami victims was a 60-year-old man who used the 2004 earthquake as a tsunami warning and evacuated promptly, only to take a chance on retrieving things he had left behind.

The man, Lasamin, was a life-long resident of Sinabang who felt the ground shake strongly on December 26, 2004. Schooled in smong (p. 6), he and his wife got on their motorcycle and sped towards the hills. They reached high ground without incident.

As waters of the first wave receded, Lasamin told his wife he was going to retrieve documents in their house. Perhaps he doubted that the sea would come in again, or maybe he believed that if it did, he could outrace it on his motorbike. Whatever was going through his mind, he headed back toward the tsunami.

On the way he met his young friend Sukran (right). He asked him to come along, and Sukran agreed. An incoming wave soon toppled the motorbike and flung Lasamin to the asphalt. Sukran survived by swimming to and climbing a nearby tree, but Lasamin was later found dead.

Though Sukran survived an attempt to retrieve belongings during the 2004 tsunami on Simeulue Island, the friend he was helping was not so lucky.

Stay out of Cars

Bukhari bin Abdullah, left, lost his wife and a child when the tsunami trapped them inside an automobile. Above, a car mangled by tsunami in Banda Aceh.

AN AUTOMOBILE can endanger its occupants and others if used for evacuation from a fast-arriving tsunami. The earthquake minutes before is likely to have severed the road with fissures or blocked it with landslides. Even without such damage, the roads can become clogged by people on foot or on motorbikes (photo, p. 8). Cars may injure these people, add to the congestion, or both. Moreover, the tsunami itself may trap motorists inside their cars, as in these family tragedies in Banda Aceh.

When Bukhari bin Abdullah, 45, in Alue Naga, heard people shouting that the seawater was rising, he ordered his wife and one of their sons into the family car. He drove them a few hundred meters before a wave turned it upside down and dumped it into a river. Bukhari managed to escape through a broken window, then stayed afloat by hanging on to a tire. But his wife and son remained trapped with the car, sinking with it to the river bottom.

Two kilometers inland in Jeulingke, 57-year-old Sujiman bin Abdullah also heard shouts that the sea was rising. Parked outside his house was his younger brother's car. He and his wife and their children got in. The car could barely move among the throngs of people on the road. An incoming wave 6 m high, sounding like the roar of an approaching aircraft, slammed into the car. The car began to fill with tsunami water. Sujiman tried to break open the doors and windows but was unable to do so. Meanwhile the water inside the car rose toward the ceiling. Sujiman and his wife managed to escape but one of their children drowned inside the car.

Beware of Rivers and Bridges

A LOWLAND RIVER can be highway for a tsunami. Its channel admits the incoming water more readily than do the walls of houses and the limbs and leaves of mangroves. Buildings beside the river tend to be swept away before those farther from the river banks.

In Aceh, people were surviving the 2004 tsunami by clinging to or riding atop debris it was carrying, only to get crushed when the debris piled up against bridges.

On the south coast of Java, Suwardi witnessed the deadly assistance that a river gave to the 2006 tsunami near Widarapayung beach. The beach adjoins a swale, parallel to the coast, that a sandy ridge separates from the sea. The swale contains a sluggish stream flanked by fields of rice, fruit, and vegetables.

Suwardi was working one of these fields at the time of the 2006 tsunami. He did not notice the weak earthquake beforehand, and he had no chance to see a wave looming on the horizon because the sandy ridge blocked his view of the sea. When the tsunami took him by surprise it came from two directions—from across the ridge and from the river. He avoided getting swept away by pressing his feet against a stout coconut tree and by clutching, with his hands, a smaller tree beside it (reenactment, right). From this position, with the water rising to his nose, Suwardi watched the tsunami rush from the river into other farmed fields, where it carried people away.

The incoming 2004 tsunami drove the remains of houses and entire boats into a bridge over the Aceh River (left). In this area, 1 km seaward from scenes on the front cover, the tsunami crested 6-8 m above the ground surface (flow depths, p. iii). On the south coast of Java, Suwardi (right) shows how he braced himself against fast-flowing water from a stream that the 2006 tsunami had engorged.

Climb a Tall Building

A BUILDING may offer refuge for people who cannot escape a tsunami by going to high ground.

Four people survived the 2004 tsunami in Mesjid Baiturrahim, the seaside mosque at left. Its reinforced concrete, though battered on the seaward side by water-borne debris, kept the building standing in an area otherwise demolished. The tsunami here, a neighborhood in Ulee Lheue, reportedly crested 14 m above ground level.

Another 52 people survived the 2004 tsunami in the Serambi Indonesia building, Kajhu (right). In this area, 2 km from the sea, the water would crest 6-10 m above ground and continue inland for another 1 km (p. iii). Debris in the tsunami's second wave rattled the building but failed to bring it down. Most of the 52 went to the second floor. Among them were Mochtar A.R., Hasbi, Ibrahim, and Rohani. Mochtar had heard three explosions just before seeing a wall of black water on the horizon. The first wave to reach him ran only knee deep but flowed fast. Children screamed with delight at having water to play in. Mochtar and Hasbi ordered them to run to the building—home of a daily newspaper, the *Harian Serambi Indonesia*.

The 2004 tsunami drove people high into buildings that saved some of their lives. Four people survived in the mosque at left, even though the tsunami removed railings, pushed in walls and windows, peeled off green roof tiles, and demolished the second-floor roof on the building's seaward side. At right, a newspaper building provided refuge for 52 people including Rohani (left), Hasbi, Ibrahim, and Mochtar (back row, right) and Rohani's children, Magdalena, Muhajirin, and Intan (front). They pose in front of the building's landward side.

Consider Water Towers

The 2006 Java tsunami destroyed 2,000 buildings but spared most water towers. The weak earthquake that spawned the tsunami left the towers standing. An hour later, the tsunami passed harmlessly between their legs at the same time as it was destroying adjacent houses. Such towers, if equipped with steps or ladders, may allow vertical evacuation. In the example above, near Pangadaran, the man stands on the floor of a washed-away house.

Climb a Tree

PEOPLE CAUGHT IN A TSUNAMI sometimes survive it by reaching and climbing trees. Some steer themselves toward the nearest tree, while others have the good fortune to drift there by accident. Once in a tree, many people manage to hang on for the tsunami's duration (stories below and p. 10, 12).

Like so many others in the vicinity of Banda Aceh, Wardiyah could not help but notice the 2004 earthquake. Although her house in Kajhu stood 300 m from the shore, she heard none of booms reported by others (p. 10). She did, however, hear a sound like the roaring of a wind just before the tsunami washed over her. She was carried inland by the first wave, then out to sea by its backwash. Along the way she managed to grab a piece of wood that helped keep her afloat. The next wave moved her back onshore to a place near a kedondong fruit tree (right). There she found herself standing in water just knee deep. But soon more water surged in, carrying her closer to the tree. She grabbed a branch and climbed to the tree top. Fearful of more waves she stayed in the tree several hours longer, along with a man who had also taken refuge there.

The 2006 tsunami found Teguh Sutarno on Widarapayung beach, where he was collecting little clams to feed to his ducks. It was the season for this type of beach clam. Seeing something like a large swell on the horizon, he wondered what it could be. He waited, watching, until realizing it was a big wave. By then it was too late for an escape. The water first carried him into some bushes, where he remained until the second wave moved him to a group of tree stumps. During the third wave Teguh remembered hearing how people had survived the 2004 Aceh tsunami by climbing trees. He aimed for one of the many coconut trees nearby. Managing to reach and climb one, he held on while the tsunami flowed beneath him.

Two saved by trees: Wardiyah in front of the kedondong tree that she climbed during the 2004 tsunami in Banda Aceh; and Teguh Sutarno, who used a coconut palm during the 2006 tsunami near Cilacap.

Use a Floating Object as a Life Raft

MANY OF THE SURVIVORS in Aceh, though caught by the tsunami and not necessarily able to swim, saved themselves by clinging to lumber, tree trunks, mattresses, refrigerators, jerry-cans, plastic bottles, tires, and boats. Some drifted out to the sea with their makeshift floats, while others used them as ferries to trees or buildings. Many of those who survived had managed to climb atop the floating object; merely holding on to it exposed the floating person to injury or death by other debris.

On the morning of the Aceh tsunami, eleven-year-old Taha Yasin bin Ilyas was helping his father plant mangroves along the shore in the Alue Naga sector of Banda Aceh. When the shaking stopped he headed home, his father staying behind to chat with friends. Not long after reaching home Taha heard a thundering sound coming from the direction of the sea, followed by shouts that the sea was rising. Taha, his brother, and mother rushed out of the house and joined the throng on the road. A giant black wave closed in, swallowing all in its path.

This first wave carried Taha to a nearby tree. He clung to it but the next wave broke his grip. Taha found himself submerged beneath debris. He struggled to the surface, saw a pillow, and grabbed it. A third wave left him adrift in the open sea.

At this point Taha gain an additional float—a book. Noticing Arabic script he lost all fear. He was still clutching both the pillow and the book when he drifted ashore. He carried the book through the next ten days, until finding his father alive. He holds the book in a photo that accompanies his full story (p. 26).

Objects floating in the 2004 tsunami battered buildings and people but also, in some cases, served as life rafts. Eleven-year-old Taha, in the story at left, stayed afloat with a soggy pillow and a book (account in Indonesian, p. 26). Eighteen-year-old Harianto (p. 11), after being struck by a floating log, used a floating mattress that buoyed him and a friend's parent. Above, a mattress in tsunami debris of Banda Aceh.

If Offshore, Go Farther Out to Sea

AS A TSUNAMI APPROACHES SHORE its great speed and wavelength get converted into height. So it is not surprising that fishermen, already at sea when the 2004 and 2006 tsunamis bore down on them, found safety by going farther seaward. One of them, however, nearly fell victim to tsunami backwash and another lost a friend who had sought safety by going to shore.

Emirza survived most of the 2004 tsunami while off Banda Aceh's Ulee Lheue coast. Here, four waves caught Emirza's boat. He struggled to keep the bow pointed into the incoming waves, and all the while trying to get farther out to sea. Finally he reached calmer waters, where he waited before deciding to head home. But just before he reached the harbor a torrent from the land capsized the boat. Emirza survived by grasping an electric cable and climbing up a power pole.

Budiyono and a friend were fishing, each in his own boat, about five hundred metres off the shore at Pangandaran when the first wave of the 2006 tsunami loomed on the horizon. At first Budiyono did not see it because he was facing toward land. The friend noticed the wave, but by the time Budiyono noticed it the wave was fast approaching. The friend raced towards the coast. Budiyono headed out to sea, needing all his strength to fight the incoming waves. Budiyono survived but the friend who had turned back to land did not.

Emirza (left), rode out the largest waves of the 2004 tsunami by taking his fishing boat to deep water, though he struggled with tsunami backwash upon returning to Banda Aceh. Heading out to sea also helped Budiyono (right) endure the 2006 tsunami, which took the life of a fellow fisherman who had instead headed to shore.

Expect More than One Wave

THE FIRST WAVE of a tsunami is rarely the biggest and never the last. The 2004 tsunami reportedly contained five waves on Simeulue and perhaps twice that number in Banda Aceh. The 2006 tsunami included three consecutive waves a few minutes apart.

The 2004 tsunami returned again and again for forty-year-old Nurdin bin Ahmad of Peunaga Pasi. He and a companion, Amir bin Gam, were at a market when the giant earthquake struck. After strong shaking ended Nurdin and Amir headed toward home on a Honda motorbike. Along the way they saw houses and shops that the shaking had brought down or damaged. They were still a few kilometers from home when a chest-high wall of water knocked them over. The current swept Amir and the Honda into a coconut grove. Nurdin managed to stand up briefly but then he too was carried along. With the water still rising, he grabbed hold of a block of peat, larger than a person, and climbed on top of it. The block, also carrying a chicken, drifted towards a mangrove swamp and lodged in the trees.

Nurdin did not know that there were more waves to come. After an hour in the trees, he climbed down from the peat block into chest-deep water of the swamp. He started home, clambering over fallen trees as he went. But he had not gone far before another wave approached. He climbed a tree and stayed there until the waters receded. He hopped down and walked on a bit only to climb again when another wave approached. Only after three such ups and downs did he manage to reach a main road. And even then the wave train kept coming, sending him up a coconut tree for one final climb.

Multiple waves also reached Asep on the eastern shore at Pangandaran as he tried to save his boat from the 2006 tsunami. He and his brother, making a fishing platform a hundred meters offshore, felt the weak earthquake that seismologists recorded at 3:19 p.m. Soon they saw a wall of sea water approaching. They could see three waves, one after the other. When the first wave smashed into the fishing platform they jumped into their boat. Asep cut the mooring rope, started the engine, and turned the boat around in hopes of slicing through the oncoming waves. As they tried to head south into deep water they battled waves reflected from shores to their east and west. They also nearly ran out of fuel. Their battle went on about two hours, until they headed safely back to shore around six o'clock in the evening.

Asep and his brother, in a boat off Pangandaran, won a two-hour battle against multiple waves of the 2006 tsunami.

Notes

THIS BOOKLET contains eight eyewitness accounts adapted from a collection published by Aceh's archive office[5]: Katiman (p. 9), Sharla (p. 10), Surya (p. 10), Harianto (p. 11), Bukhari and Sujiman (p. 13), Nurdin (p. 21), and Taha (p. 19). Eko Yulianto further interviewed Katiman, Bukhari, and Sujiman. Another collection of dozens of essays and stories from Aceh[8] contains a fuller account from Brigadier General Suroyo (p. 10). The compilers also consulted a collection of newspaper accounts of the 2006 tsunami in southern Java[15]. The remaining accounts come from interviews by Eko Yulianto and Nandang Supriatna at Simeulue Island and mainland Aceh in 2005, 2006, 2007 and 2008, and in Pangandaran and Cilacap in 2006, 2007, and 2008.

Photo credits: Bedu Saini (p. 2), Franck Lavigne (p. 4), Patra Rina Dewi (p. 8), Herry Yogaswara (p. 12, back cover), Murat Saatcioglu (p. 16), Ardito Kodijat (p. 26), Badan Arsip Daerah Aceh (p. 7, 13, 14), Brian Atwater (p. 1, 5, 22, 27, facing 28), and Eko Yulianto (p. 6, 9, 11, 13, 15, 17, 18, 20, 21, 24). Scenes on front cover are from video footage by Yasman Yatif (scenes 1-11) and from a documentary by Kementerian Komunikasi dan Informasi, a national agency (scene 12)—all provided by Badan Arsip Daerah Aceh, the provincial archive agency.

The booklet evolved from several predecessors. It resembles, in purpose and format, a collection of eyewitness accounts of the 1960 Chilean tsunami[2]. UNESCO's "Selamat dari bencana tsunami"[14], in Indonesian, was published in 2008. An initial English adaptation,"Surviving a tsunami – Lessons from Aceh and southern Java", appeared in 2009. The further adaptation you are reading incorporates translations by Eko Yulianto; diagrams and endnotes by Brian Atwater, whose work on the booklet was supported in part under a Fulbright grant; design by Ardito Kodijat; initial editing by Sally E. Wellesly; and further editing by Brian, Ardito, Eko, and Mohammad Dirhamsyah in response to reviews from Marco Cisternas, Nate Wood, Irina Rafliana, Oakley Brooks, Pungky Utami, Veronica Cedillos, Delores Clark, Michael Hoppe, Laura Kong, Velly Asvaliantina, Joaquim Post, Lori Dengler, Patricia McCrory, and Jane Ciener.

Additional booklets on tsunamis and tsunami safety can be found at http://ioc3.unesco.org/itic/categories.php?category_no=75.

Legend in Java tells of an ocean queen, Nyi Roro Kidul, who captures men and women in waves she sends ashore. Similar stories are told as far west as the Mentawai Islands and eastward to Flores. At left, Roro Kidul drives a chariot on a canvas by Wasdi, who stands in his studio a stone's throw from the beach at Pelabuhanratu, the Port of the Queen.

Index maps (p. ii, iii)

DATA SOURCES: fault-rupture areas on p. ii, references 6 and 9; most of the flow depths on p. ii, reference 11 and field notes of Eko Yulianto; the inundation distances on p. ii, ftp://ftp.agu.org/apend/gl/2007gl029404; and all data on p. iii, reference 31 and www.tsunarisque.cnrs.fr.

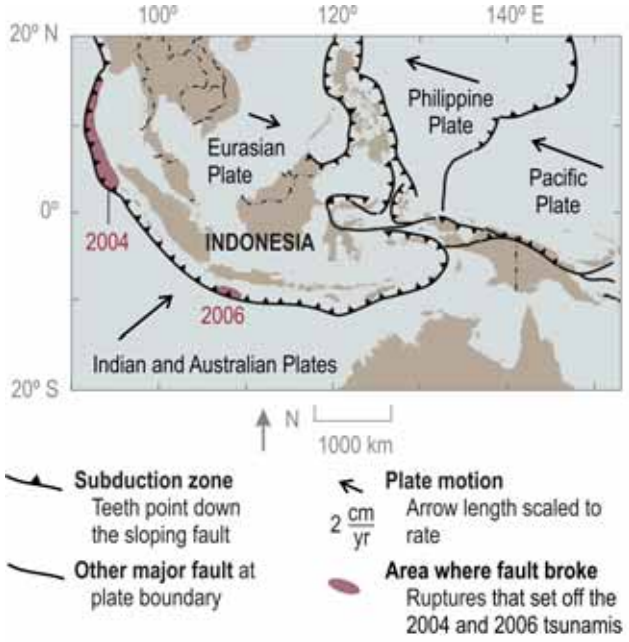
Introduction (p. 1)

ESTIMATES VARY on death tolls from the 2004 Indian Ocean tsunami. EM-DAT[58], an international database on disasters, reports 165,708 fatalities in Indonesia. The tsunami database maintained by the National Oceanic and Atmospheric Administration (NOAA)[12] gives a similar Indonesian total of 165,659. For the 2004 tsunami the NOAA database also lists fatalities from eleven other countries: Sri Lanka, 35,322; India, 18,045; Thailand, 11,029; Somalia, 289, Maldives, 108; Malaysia, 75; Myanmar, 61; Tanzania, 13; Seychelles, 3; Bangladesh, 2; and Kenya, 1. EM-DAT gives similar numbers except for India, 16,389, and Thailand, 8,345. Caveat: A global risk assessment published by the United Nations International Strategy for Disaster Reduction Secretariat (ISDR)[55], on its page [25], cautions against treating death tolls as exact, or even approximately correct, for disasters that preclude accurate counts.

The 2006 tsunami probably took about 700 lives, all of them in Indonesia. Figures from Indonesia's Ministry of Health, tabulated in a 2007 analysis by geodesists from Indonesia and Japan[22], sum to 668 dead and 65 missing. Other estimated death tolls: 373 according to the NOAA database[12]; at least 600, according to a international post-tsunami survey team[16]; and 802 according to EM-DAT[58]. A total of 414 died in Pangandaran and vicinity, the area where most of the fatalities occurred, according to a detailed list provided by local authorities to a joint New Zealand – Indonesia post-tsunami survey[11].

Understanding Why Tsunamis Happen to Us (p. 3)

TECTONIC ORIGINS of Indonesian hazards are discussed in English-language reports that include a journal article on historical earthquakes in Sumatra and Java[40], documentation for maps that underpin seismic provisions of building codes[32], articles on West Sumatran earthquake history[38,48], an overview of tsunami hazards in Sumatra and Java[41], and a monograph on the 1883 Krakatau eruptions and the tsunamis they spawned[49]. A new book in Indonesian provides a well-illustrated overview of the country's earthquake and tsunami hazards[52]. Scientific journals provide frequent updates on Global Positioning System measurements of Indonesian plate motions[50], which include contortion of the eastern part of the archipelago[51] and extraordinary displacements that occurred during and soon after the giant 2004 Aceh-Andaman



earthquake[53]. The plate-tectonic map below is simplified from ones in references 50 and 51.

Often shown radiating from an earthquake epicenter, the 2004 Indian Ocean tsunami resulted instead from warping of the ocean floor in an area extending 1,500 km northward along the trench from northern Sumatra to the Andaman Islands and beyond[9]. This enormous rupture length, greater than any other in the last 100 years or more, helps explain why the 2004 Aceh-Andaman earthquake approaches the greatest earthquake recorded instrumentally, the giant Chilean mainshock of 1960, on the moment magnitude scale that seismologists now use to express earthquake size[29].

Fast-Arriving Waves Tend to Pose the Greatest Threat (p. 4)

DEATH TOLLS from Indonesia's tsunamis after 1600 were tabulated a decade ago by Indonesian and Japanese researchers[21]. The comparisons with fatalities in other parts of the world are based on figures in the NOAA database[12]. The travel times for the 2004 and 2006 tsunamis in Indonesia are from reports of post-tsunami surveys in mainland Aceh[7,31], on Simeulue Island[33], and in Java[16]. Stopped clocks and tsunami videos give evidence for a roughly 45-minute travel time in central Banda Aceh according to a French and Indonesian group that reconstructed the tsunami's chronology from comprehensive field observations[31]. The timeline is based on references 33 (Langi) and 31 (clocks), and on camera data provided by Bedu Saini, photojournalist with *Harian Serambi Indonesia*.

The ISDR report[55] ranks Indonesia first in number of people exposed to tsunamis. The report also places Indonesia among the six nations facing the greatest losses of life from the combination of tropical cyclones, floods, earthquakes, and landslides (the others are Bangladesh, China, Colombia, India, Myanmar). The report relates these risks of death not just to the natural hazards but also to population, standard of living, governance, environmental quality, and climate change.

According to a recent survey that draws on tsunami modeling and vulnerability assessments[41], "4.35 million Indonesians live in tsunami endangered areas on the southern coasts of Sumatra, Java and Bali and have between 20 and 150 min[utes] to reach a tsunami-safe area."

Sea-level gauges[35] and computer simulations[54] show how the 2004 tsunami spread across the Indian Ocean, continued into the Atlantic, and leaked into the Pacific. The tsunami registered on tide gauges as distant as Valparaíso (24 hours after the earthquake), Hilo (27 hours), Bermuda (28 hours), and Kodiak, Alaska (39 hours). The 1946 Aleutian tsunami, which spurred the first efforts to provide advance warning of tsunamis generated on the Pacific Rim, took about 5 hours to

reach Hawaii[47]. The 1960 Chilean tsunami reached Hawaii in 15 hours[13] and Japan in just under a full day[2].

The Earth May Remember What People Forget (p. 5)

THE SAND BEDS in the Thai photo further suggest that a total of four Indian Ocean tsunamis like the one in 2004 have occurred since 2,500-2,800 years ago, for an average recurrence interval of 800-900 years or less[27]. Geologic evidence for predecessors to the 2004 tsunami has also been reported from Aceh Barat near Meulaboh[36] and from India in the Andaman and Nicobar Islands[43, 44] and south of Chennai[42]. The sand bed shown in the photo from Pangandaran has not yet been documented in scientific journals.

Multiple centuries typically separate back-to-back earthquakes recorded geologically at several other subduction zones including Sumatra[48], Cascadia[3, 19, 39], Hokkaido[37, 46,] and south-central Chile[10]. At these zones, steady motion of tectonic plates converging at centimeters per year produces the seismic slip that makes the zones' largest earthquakes. The steady motion, like money put in a savings account every payday, can take centuries to yield the average slip of 10-20 meters in a giant earthquake, of magnitude 9.

It is an open question whether earthquakes of magnitude 8 or larger can happen on the subduction zone that slants beneath Java[34]. This zone's largest earthquakes measured by seismology[6,40] yielded the tsunamis that reportedly took 238 lives in eastern Java in 1994 and about 700 in western Java in 2006. At moment magnitude 7.8 and 7.7, respectively, these earthquakes had less than 1/1000th the size of the 2004 earthquake, which attained a moment magnitude in the range 9.0-9.3; each whole number increase in the logarithmic scale of earthquake magnitude corresponds to a nearly 32-fold increase in seismic moment, a linear measure of earthquake size[28].

How Grandparents and Graves Kept Memories Alive (p. 6)

THE SAVING OF THOUSANDS of lives by Simeulue's tsunami traditions has been documented most fully in an Indonesian report also available in English[24]. A brief account of the evacuation of Langi appears in a collection of scientific and engineering papers on the 2004 tsunami[33]. The same collection contains an analysis by geologists and psychologists of natural warnings of the 2004 tsunami in Thailand[20].

In a widely known celebration of traditional knowledge about tsunamis, a Greek-American journalist fictionalized an evacuation by Japanese villagers who in real life were well-practiced in using an earthquake as their cue to go to high ground. In the journalist's dramatic retelling[23], none of them know to take this cue except for an elderly man steeped in traditional knowledge. Too far away to be heard, the man lures the clueless villagers to high ground by torching all of his freshly harvested rice. The earthquake that he notices is weak, like the real earthquake whose stealth tsunami killed 22,000 people in northeast Japan in 1896. The story, published soon after that disaster and known in Japanese as

In an interview in 2006, Sabri (left) of Lakuban, Simeulue, said he could still recall the 1907 tsunami.

"Inamura no hi" ("The rice-sheaf fire"), brought the word "tsunami" into the English language[4].

If The Earth Shakes, a Tsunami May Soon Follow (p. 7)

FEEBLE SHAKING like that from the 1994 and 2006 Java earthquakes poses a challenge for official tsunami warnings as well as for natural ones. Tsunami-warning centers make rapid estimates of earthquake size as a first clue to tsunami potential. Earthquake size is estimated most readily by measuring what a seismologist, Emile Okal, has called "treble notes" – the high-frequency waves that people feel. The 1994 and 2006 earthquakes, however, were dominated by "bass notes." For much the same reason that people scarcely felt these earthquakes, it is possible to underestimate their size by neglecting their low-frequency content. Seismologists have now come up with work-arounds[30, 56].

Indonesia officially inaugurated a national tsunami-warning system in November 2008. As with such systems in Japan and the United States[57], the initial cue is an undersea earthquake detected by seismometers (http://www.jtic.org/en/jtic/images/dlPDF/bha_budpar/The_Indonesian_Warning_Chain_V2.pdf). The seismic waves, by traveling tens of times faster than tsunami waves, make possible initial warning messages within several minutes. Water-level gauges on the coast and offshore are then to show whether a tsunami has been generated, after time lags under evaluation.

The Tsunami May Arrive Before Official Guidance Can (p. 8)

INTERVIEWS IN PADANG five to six weeks after the earthquake of September 30, 2009 yielded lessons on the roles of natural and official warnings in a city where an estimated 200,000 persons reside in areas subject to a fast arriving tsunami. These lessons are spelled out in a recent report[25] available at http://www.jtic.org/en/info-sources/other-tsunami-sources/publications.html?download=1314%3A30-minutes-in-the-city-of-padang.

Among 200 individuals interviewed, half evacuated in response to the earthquake alone, and four-fifths of these evacuees got underway in the first 15 minutes. But meanwhile, officials from government agencies and non-governmental organizations grappled with receiving and broadcasting information about the lack of tsunami threat. Outages of power and telephone service contributed to delays in notifying the public in Padang that the earthquake was unlikely to generate a tsunami. The report's authors found that in Padang, official information about the absence of a tsunami threat was largely unavailable to the public in the first 30 minutes after the earthquake.

Decentralized government in Indonesia gives local jurisdictions the authority to order and cancel tsunami

evacuations. Thus that authority resided with officials in Padang, not with the National Tsunami Warning Center.

The Sea May Withdraw Shortly Before It Attacks (p. 9)

THE INITIAL WITHDRAWAL in Aceh, uncommon to the west in peninsular India and Sri Lanka, resulted from the tsunami's initial shape: an elongate ridge a few meters high flanked on its east by a parallel trough[17]. This ridge and trough at the sea surface mimicked warping of the sea floor, a warping caused by the same fault slip that produced the earthquake itself (diagram, p. 2). The sea floor raised the sea surface where the leading part of the overriding tectonic plate ran up the rupture on the sloping fault plane. The sea floor lowered the sea surface where this sudden slip stretched, and consequently thinned, the trailing part of the overriding plate. The downwarp included the northwest coast of Aceh[31].

According to a post-tsunami survey in southern Sri Lanka[18], the 2004 tsunami began there with a positive wave about 1 m high. A later positive wave, or waves, far exceeded the first and attained a maximum measured height of nearly 4 m near the area shown on page 9.

The policy of not waiting for official guidance in Padang (p. 8) is geared toward earthquake-induced tsunamis that would originate near the Mentawai Islands. Human reminders of earthquakes in Mentawais include the verses below. The verses probably play on the similar sound of the Mentawai words for "grandfather" and "earthquake". The first version is in a northen dialect, the second in a southern one. Both are sung.

Teteu amusiat loga	Grandfather, the squirrel is chattering
Teteu katinambu leleu	Grandfather, noise comes from the hills
Teteu girisit nyau'nyau'	Grandfather, land is sliding
Amagolu' teteuta pelebuk	Angry our grandfather seashell
Arotadeake baikona	The Baiko tree is cut
Kuilak pai-pai gou'gou'	The Kuilak bird flaps its tail like a chicken
Lei-lei gou'gou'	The chicken's tail shivers
Barasita teteu	Here comes Grandfather
Lalaklak paguru sailet	Rumbling sound people hiding

Teteu amusiat loga	Earthquake the squirrel is chatteriing
Teteu girisit nyau'nyau'	Earthquake the landslide is roaring
Teteu katinambu leleu	Earthquake in the middle of the forest
Amagolu' teteuta Pelebuk	Grandfather Pelebu is angry
Aratadde ake baikona	The baikona tree is cut
Uilak pai-pai gou'gou'	The tail of the pai-pai bird is flapping
Uilak lei-lei gou'gou'	The tail of the chicken is flapping

THE NORTHERN VERSES and their literal meaning in English were told to Ardito Kodijat by Koen Meyers, Darmanto, and Hendrikus Napitupulu of UNESCO Jakarta. Darmanto and Hedrikus are stationed on South Siberut, one of the northern Mentawai Island. The southern verses and their translation into Indonesian were provided to Eko Yulianto by Jon Hendra of Limosua, on the southern Mentawai island of Pagai Selatan.

An earthquake and tsunami on February 10, 1797, begin the documentary history of earthquakes and tsunamis off West Sumatra[21, 40]. Natural records found in corals have helped to clarify and extend this history; the corals show the size and extent of the ruptures on the subduction thrust beneath the Mentawai Islands[38] while telling also of earlier breaks on this fault[48].

Climb a Tall Building (p. 16-17)

A RECONNAISSANCE STUDY of structures damaged in Banda Aceh blamed tsunami-related damage on water pressure from the tsunami and on the impact of debris that the water carried. The report[45] concluded that "the damaging effects of the tsunami were most pronounced in unreinforced masonry walls, nonengineering reinforced concrete buildings, and low-rise timber-framed buildings". Regarding the city's mosques, the same report described them as supported by circular columns of high-quality reinforced concrete that resisted seismic loads. These columns limited the damage that the mosques sustained before the tsunami attacked them. Figure 26 of reference 45 gives additional views of the Mesjid Baiturrahim, which post-tsunami repairs have reshaped. Tenku Imum told Muhammad Dirhamsyah, in 2010, that four persons survived the 2004 tsunami in this mosque.

Recommended designs for vertical evacuation structures in the United States are intended to allow a tsunami to pass through ground floors without damage to supporting columns, braces, or walls[1].

A government report on property damage, issued two weeks after the 2006 tsunami, states that the tsunami destroyed 1,986 buildings. These included hotels, residential and government buildings. The report is quoted in reference 22.

References Cited

1. Applied Technology Council. Guidelines for design of structures for vertical evacuation from tsunamis. FEMA Report P 646, 159 p. (2008). http://www.atcouncil.org/pdfs/FEMAP646.pdf
2. Atwater, B. F., Cisternas, M., Bourgeois, J., Dudley, W. C., Hendley, J. W., I.I. & Stauffer, P. H. Surviving a tsunami—lessons from Chile, Hawaii, and Japan. U.S. Geological Survey Circular 1187. 18 p. (1999, rev. 2005) http://pubs.usgs.gov/circ/c1187/. Available in Spanish as Sobreviviendo a un tsunami: lecciones de Chile, Hawaii y Japón. U.S. Geological Survey Circular 1118. 18 p. (2001, rev. 2006) http://pubs.usgs.gov/circ/c1218/.
3. Atwater, B. F. & Hemphill-Haley, E. Recurrence intervals for great earthquakes of the past 3,500 years at northeastern Willapa Bay, Washington. U.S. Geological Survey Professional Paper 1576. 108 p. (1997).
4. Atwater, B. F., Musumi-Rokkaku, S., Satake, K., Tsuji, Y., Ueda, K. & Yamaguchi, D. K. The orphan tsunami of 1700; Japanese clues to a parent earthquake in North America. U. S. Geological Survey Professional Paper 1707. 133 p. (2005). http://pubs.usgs.gov/pp/pp1707/
5. Badan Arsip Provinsi Naggroe Aceh Darussalam [Archive Office, Province of Naggroe Aceh Darussalam]. Tsunami dan kisah mereka [Tsunami and survivors' stories from Aceh]. (2005).
6. Bilek, S. L. & Engdahl, E. R. Rupture characterization and aftershock relocations for the 1994 and 2006 tsunami earthquakes in the Java subduction zone. Geophysical Research Letters 34, L20311. doi 1029/2007GL031357 (2007).
7. Borrero, J. C., Synolakis, C. & Fritz, H. Northern Sumatra field survey after the December 2004 great Sumatra earthquake and Indian Ocean tsunami. Earthquake Spectra 22, S93-S104 (2006).
8. Cahanar, P. Bencana Gempa dan Tsunami [Earthquake and Tsunami Disaster]. 562 p. (Penerbit Buku Kompas, Jakarta, 2005).
9. Chlieh, M., Avouac, J., Hjorleifsdottir, V., Song, T. A., Ji, C., Sieh, K., Sladen, A., Hebert, H., Prawirodirdjo, L., Bock, Y. & Galetzka, J. Coseismic slip and afterslip of the great Mw 9.15 Sumatra-Andaman earthquake of 2004. Bulletin of the Seismological Society of America 97, S152-S173. doi 10.1785/0120050631 (2007).
10. Cisternas, M., Atwater, B. F., Torrejon, F., Sawai, Y., Machuca, G., Lagos, M., Eipert, A., Youlton, C., Salgado, I., Kamataki, T., Shishikura, M., Rajendran, C. P., Malik, J. K., Rizal, Y. & Husni, M. Predecessors of the giant 1960 Chile earthquake. Nature 437, 404-407. doi 10.1038/nature03943 (2005).
11. Cousins, W. J., Power, W. L., Palmer, N. G., Reese, S., Iwan Tejakusuma & Saleh Nugrahadi. South Java tsunami of 17th July 2006, reconnaissance report. GNS Science Consultancy Report 2006/333. 42 p. (Institute of Geological and Nuclear Sciences Limited, Lower Hutt, New Zealand, 2006).
12. NOAA/WDC historical tsunami database. http://www.ngdc.noaa.gov/hazard/tsu_db.shtml.
13. Eaton, J. P., Richter, D. H. & Ault, W. U. The tsunami of May 23, 1960, on the Island of Hawaii. Seismological Society of America Bulletin 51, 135-157 (1961).
14. Eko Yulianto, Fauzi Kusmayanto, Nandang Supriyatna & Muhammad Dirhamsyah. Selamat dari bencana tsunami; pembelajaran dari tsunami Aceh dan Pangandaran [Safe from tsunami disaster; lessons from the Aceh and Pangandaran tsunamis]. IOC Brochure 2009-1. 20 p. (Jakarta Tsunami Information Centre, Jakarta, 2009). http://www.jtic.org/en/info-sources/jtic-info-sources/publications.html?download=1316%3Aselamat-dari-bencana-tsunami
15. Enton Suprihyatna Sind & Taufik Abriansyah. Tsunami Pangandaran bencana di pesisir selatan Jawa Barat [Pangandaran tsunami disaster on the south coast of West Java]. 234 p. (Semenanjung, Bandung, 2007).
16. Fritz, H. M., Kongko, W., Moore, A., McAdoo, B., Goff, J., Harbitz, C., Uslu, B., Kalligeris, N., Suteja, D., Kalsum, K., Titov, V., Gusman, A., Latief, H., Santoso, E., Sujoko, S., Djulkarnaen, D., Sunendar, H. & Synolakis, C. Extreme runup from the 17 July 2006 Java tsunami. Geophysical Research Letters 34, L12602. doi 10.1029/2007GLO29404 (2007).
17. Fujii, Y. & Satake, K. Tsunami source of the 2004 Sumatra-Andaman earthquake inferred from tide gauge and satellite data. Bulletin of the Seismological Society of America 97, S192-S207 (2007).
18. Goff, J., Liu, P. L.-F., Higman, B., Morton, R., Jaffe, B. E., Fernando, H., Lynett, P., Fritz, H., Synolakis, C., & Fernando, S. Sri Lanka field survey after the December 2004 Indian Ocean tsunami. Earthquake Spectra 22 (S3), S155–S172 (2006).
19. Goldfinger, C., Grijalva, K., Burgmann, R., Morey, A. E., Johnson, J. E., Nelson, C. H., Gutierrez-

An anthology published by the provincial archive office of Nanggroe Aceh Darussalam, cited at left as reference 5, tells survivors' stories more fully than space in this booklet allows. Above, part the story from Taha Yasin bin Ilyas (p. 19), who stayed afloat with a soggy pillow and with a book in Arabic that he clutches in the testimonial photo. Not identified by him as al-Qur'an, this book probably consists of Islamic lessons.

Pastor, J., Ericsson, A., Karabanov, E., Chaytor, J. D., Patton, J. & Gracia, E. Late Holocene rupture of the northern San Andreas Fault and possible stress linkage to the Cascadia Subduction Zone. Bulletin of the Seismological Society of America 98, 861-889. doi 10.1785/0120060411 (2008).
20. Gregg, C. E., Houghton, B. F., Paton, D., Lachman, R., Lachman, J., Johnston, D. & Wonbusarakum, S. Human warning signs of tsunamis: human sensory experience and response to the 2004 great Sumatra earthquake and tsunami in Thailand. Earthquake Spectra 22, S671-S691 (2006).
21. Hamzah Latief, Nanang T. Puspito & Imamura, F. Tsunami catalog and zones in Indonesia. Journal of Natural Disaster Science 22, 25-43 (2000).
22. Hasanuddin Z. Abidin & Kato, T. Why many victims: lessons from the July 2006 south Java tsunami earthquake? Asia Oceania Geosciences Society abstract SE19-A0002, 13 p. (2007). http://www.asiaoceania.org/society/public.asp?bg=abstract&page=absList07/absList.asp
23. Hearn, L. Gleanings in Buddha-fields; sutides of hand and soul in the Far East. 296 p. (Houghton, Mifflin, Boston, 1897).
24. Herry Yogaswara & Eko Yulianto. Smong, pengetahuan lokal Pulau Simeulue: sejarah dan kesinambungannya [Smong: Local knowledge at Simeulue Island; history and its transmission from one generation to the next] 69 p. (Lembaga Ilmu Pengetahuan Indonesia; United Nations Educational, Scientific, and Cultural Organization; and International Strategy for Disaster Reduction, Jakarta, 2006). English translation at http://www.jtic.org/en/info-sources/jtic-info-sources/publications.html?download=1315%3Asmong-pengetahuan-lokal-pulau-simeulue
25. Hoppe, M., & Hari Setiyo Mahadiko. 30 Minutes in the City of Padang: Lessons for tsunami preparedness and early warning from the earthquake on September 30, 2009. Capacity building in local communities, working document no. 25, 26 p. (German-Indonesian Cooperation for a Tsunami Early Warning System, GTZ-International Services, Jakarta, 2010). http://www.jtic.org/en/info-sources/other-tsunami-sources/publications.html?download=1314%3A30-minutes-in-the-city-of-padang
26. Iemura, H., Mulyo Harris Pradono, Agussalim bin Husen, Thantawi Jauhari & Sugimoto, M. Construction of tsunami memorial poles for hazard data dissemination and education, in Kato, T., ed., Symposium on giant earthquakes and tsunamis, p. 249-254. (Earthquake Research Institute, University of Tokyo, Tokyo, 2008).

During a search for tsunami geology like that shown on page 5, Priyobudi of Indonesia's tsunami-warning center interviews residents near Cilacap. References 11 and 16 describe some of the effects of the 2006 tsunami on this part of the south coast of Java, and reference 6 explores how the tsunami was generated.

27. Jankaew, K., Atwater, B. F., Sawai, Y., Choowong, M., Charoentitirat, T., Martin, M. E. & Prendergast, A. Medieval forewarning of the 2004 Indian Ocean tsunami in Thailand. Nature 455, 1228-1231. doi doi 10.1038/nature07373 (2008).
28. Kanamori, H. The energy release in great earthquakes. Journal of Geophysical Research 82, 2981-2987 (1977).
29. Kanamori, H. Lessons from the 2004 Sumatra-Andaman earthquake. Philosophical Transactions - Royal Society. Mathematical, Physical and Engineering Sciences 364, 1927-1945. doi 10.1098/rsta.2006.1806 (2006).
30. Kanamori, H. & Rivera, L. Source inversion of W phase; speeding up seismic tsunami warning. Geophysical Journal International 175, 222-238. doi 10.1111/j.1365-246X.2008.03887.x (2008).
31. Lavigne, F., Paris, R., Grancher, D., Wassmer, P., Brunstein, D., Vautier, F., Leone, F., Flohic, F., De Coster, B., Gunawan, T., Gomez, C., Setiawan, A., Rino Cahyadi & Fachrizal. Reconstruction of Tsunami Inland Propagation on December 26, 2004 in Banda Aceh, Indonesia, through Field Investigations. Pure and Applied Geophysics 166, 259-281 (2009).
32. Masyhur Irsyam, Donny T. Dangkua, Hendriyawan, Drajat Hoedajanto, Bigman M. Hutapea, Engkon K. Kertapati, Boen, T. & Petersen, M. D. Proposed seismic hazard maps of Sumatra and Java islands and microzonation study of Jakarta city, Indonesia. Journal Journal of Earth System Science 117, Supplement 2, 865-878. doi 10.1007/s12040-008-0073-3 (2008).
33. McAdoo, B. G., Dengler, L., Prasetya, G. & Titov, V. Smong: How an oral history saved thousands on Indonesia's Simeulue Island during the December 2004 and March 2005 tsunamis. Earthquake Spectra 22, S661-S669 (2006).
34. McCaffrey, R. Global frequency of magnitude 9 earthquakes. Geology 36, 263-266. doi 10.1130/G24402A.1 (2008).
35. Merrifield, M. A., Firing, Y. L., Aarup, T., Agricole, W., Brundrit, G., Chang-Seng, D., Farre, R., Kilonsky, B., Knight, W., Kong, L., Magori, C., Manurung, P., McCreery, C., Mitchell, W., Pillay, S., Schindele, F., Shillington, F., Testut, L., Wijeratne, E. M. S., Caldwell, P., Jardin, J., Nakahara, S., Porter, F. Y. & Turetsky, N. Tide gauge observations of the Indian Ocean tsunami, December 26, 2004. Geophysical Research Letters 32, doi 10.1029/2005GL022610 (2005).
36. Monecke, K., Finger, W., Klarer, D., Kongko, W., McAdoo, B., Moore, A. L. & Sudrajat, S. U. A 1,000-year sediment record of tsunami recurrence in northern Sumatra. Nature 455, 1232-1234. doi 10.1038nature07374 (2008).
37. Nanayama, F., Satake, K., Furukawa, R., Shimokawa, K., Atwater, B. F., Shigeno, K. & Yamaki, S. Unusually large earthquakes inferred from tsunami deposits along the Kuril Trench. Nature 424, 660-663. doi 10.1038/nature 01864 (2003).

38. Natawidjaja, D. H., Sieh, K., Chlieh, M., Galetzka, J., Suwargadi, B. W., Cheng, H., Edwards, R. L., Avouac, J. & Ward, S. N. Source parameters of the great Sumatran megathrust earthquakes of 1797 and 1833 inferred from coral microatolls. Journal of Geophysical Research 111, doi 10.1029/2005JB004025 (2006).
39. Nelson, A. R., Kelsey, H. M. & Witter, R. C. Great earthquakes of variable magnitude at the Cascadia subduction zone. Quaternary Research 65, 354-365. doi 10.1016/j.yqres.2006.02.009 (2006).
40. Newcomb, K. R. & McCann, W. R. Seismic history and seismotectonics of the Sunda Arc. Journal of Geophysical Research 92, 421-439. 10.1029/JB092iB01p00421 (1987).
41. Post, J., Wegscheider, S., Mück, M., Zosseder, K., Kiefl, R., Steinmetz, T., & Strunz, G. Assessment of human immediate response capability related to tsunami threats in Indonesia at a sub-national scale. Natural Hazards and Earth System Science 9, 1075-1086. www.nat-hazards-earth-syst-sci.net/9/1075/2009/ (2009).
42. Rajendran, C. P., Rajendran, K., Machado, T., Satyamurthy, T., Aravazhi, P. & Jaiswal, M. Evidence of ancient sea surges at the Mamallapuram coast of India and implications for previous Indian Ocean tsunami events. Current Science 91, 1242-1247 (2006).
43. Rajendran, C. P., Rajendran, K., Anu, R., Earnest, A., Machado, T., Mohan, P. M. & Freymueller, J. T. Crustal deformation and seismic history associated with the 2004 Indian Ocean earthquake; a perspective from the Andaman-Nicobar islands. Bulletin of the Seismological Society of America 97, S174-S191. doi 10.1785/0120050630 (2007).
44. Rajendran, K., Rajendran, C. P., Earnest, A., Ravi Prasad, G. V., Dutta, K., Ray, D. K. & Anu, R. Age estimates of coastal terraces in the Andaman and Nicobar Islands and their tectonic implications. Tectonophysics 455, 53-60 (2008).
45. Saatcioglu, M., Ghobarah, A. & Nistor, I. Performance of structures in Indonesia during the December 2004 great Sumatra earthquake and Indian Ocean tsunami. Earthquake Spectra 22, S295-S319 (2006).
46. Sawai, Y., Kamataki, T., Shishikura, M., Nasu, H., Okamura, Y., Satake, K., Thomson, K. H., Matsumoto, D., Fujii, Y., Komatsubara, J. & Aung, T. T. Aperiodic recurrence of geologically recorded tsunamis during the past 5500 years in eastern Hokkaido, Japan. Journal of Geophysical Research 114 (2009).
47. Shepard, F. P., Macdonald, G. A. & Cox, D. C. The tsunami of April 1, 1946 [Hawaii]. Scripps Institute of Oceanography Bulletin 5, 391-528 (1950).
48. Sieh, K., Natawidjaja, D. H., Meltzner, A. J., Shen, C., Cheng, H., Li, K., Suwargadi, B. W., Galetzka, J., Philibosian, B. & Edwards, R. L. Earthquake supercycles inferred from sea-level changes recorded in the corals of west Sumatra. Science 322, 1674-1678. doi 10.1126/science.1163589 (2008).
49. Simkin, T. & Fiske, R. S. Krakatau 1883; the volcanic eruption and its effects (Smithsonian Institution Press, Washington, DC, 1983).
50. Simons, W. J. F., Socquet, A., Vigny, C., Ambrosius, B. A. C., Haji Abu, S., Prothong, C., Subarya, C., Sarsito, D. A., Matheussen, S., Morgan, P. & Spakman, W. A decade of GPS in Southeast Asia; resolving Sundaland motion and boundaries. Journal of Geophysical Research 112, B06420. doi 10.1029/2005JB003868 (2007).
51. Socquet, A., Simons, W., Vigny, C., McCaffrey, R., Subarya, C., Sarsito, D., Ambrosius, B. & Spakman, W. Microblock rotations and fault coupling in SE Asia triple junction (Sulawesi, Indonesia) from GPS and earthquake slip vector data. Journal of Geophysical Research 111. doi 10.1029/2005JB003963 (2006).
52. Subandonon Diposaptono & Budiman. Hidup akrab dengan gempa dan tsunami [Living closely with earthquakes and tsunamis]. 383 p. (Buku Ilmiah Populer, Bogor, 2008).
53. Subarya, C., Chlieh, M., Prawirodirdjo, L., Avouac, J., Bock, Y., Sieh, K., Meltzner, A. J., Natawidjaja, D. H. & McCaffrey, R. Plate-boundary deformation associated with the great Sumatra–Andaman earthquake. Nature 440, 46-51 (2006).
54. Titov, V., Rabinovich, A. B., Mofjeld, H. O., Thomson, R. E. & Gonzalez, F. I. The global reach of the 26 December 2004 Sumatra tsunami. Science 309, 2045-2048. doi 10.1126/science.1114576 (2005).
55. United Nations International Strategy for Disaster Reduction Secretariat. 2009 Global assessment report on disaster risk reduction: risk and poverty in a changing climate. 207 p. (2009). http://www.preventionweb.net/english/hyogo/gar/report/index.php?id=9413&pid:34&pil:1.
56. Weinstein, S. A. & Okal, E. A. The mantle wave magnitude Mm and the slowness parameter THETA: five years of rea-time use in the context of tsunami warning. Bulletin of the Seismological Society of America 95, 779-799 (2005).
57. Whitmore, P., Benz, H., Bolton, M., Crawford, G., Dengler, L., Fryer, G., Goltz, J., Hansen, R., Kryzanowski, K., Malone, S., Oppenheimer, D., Petty, E., Rogers, G. & Wilson, J. NOAA/West Coast and Alaska Tsunami Warning Center Pacific Ocean response criteria. Science of Tsunami Hazards 27, 1-21 (2008).
58. World Health Organization Collaborating Centre for Research on the Epidemiology of Disasters (CRED). Emergency Events Database (EM-DAT): the OFDA/CRED international disaster database. http://www.emdat.be/

The 2006 tsunami near Pangandaran caught Uus and his daughter, Piara, then one month old. In an interview three years later he sketches the tsunami with Piara's help.

THE JAKARTA TSUNAMI INFORMATION CENTRE, this booklet's producer, develops and provides information to reduce suffering and loss of life from tsunamis. It focuses its efforts on Southeast Asia as a regional complement to the UNESCO/IOC - NOAA International Tsunami Information Centre.

JTIC strives to promote tsunami preparedness through educational materials, this booklet being one of many examples. A comprehensive website, www.jtic.org, allows free download of dozens of tsunami-education materials developed by JTIC and others. The Centre makes some of these materials available in print.

JTIC was founded in 2006 in response to the Indian Ocean tsunami of December 26, 2004. In its first two and one-half years it was supported by the Canadian International Development Agency. Today it is an arm of the Intergovernmental Oceanographic Commission (IOC), which in turn is part of the United Nations Educational, Scientific Cultural Organization (UNESCO).

JTIC does not issue tsunami warnings but does provide information about how tsunami warnings are made and how to respond to them. Inquiries are always welcome.

Jakarta Tsunami Information Center
UNESCO Office Jakarta
Jl. Galuh II No. 5, Kegayoran Baru
Jakarta 12110, Indonesia
+62-21-7399-818
a.kodijat@unesco.org
www.jtic.org

A TSUNAMI NEAR ITS SOURCE can start coming ashore less than an hour after the natural warning of a felt earthquake. This booklet draws survival lessons from eyewitness accounts of two such tsunamis in Indonesia. The booklet is intended for people who live, work, or vacation on shores where fast-arriving tsunamis may strike. Such shores border parts of all the world's oceans and account for most tsunami deaths worldwide.

A student in Langi, on Simeulue Island off northern Sumatra, pairs national and local words for earthquake and tsunami during a school lesson in 2006. A year and a half earlier the 2004 Indian Ocean tsunami swept Langi's houses off their foundations. The tsunami reportedly arrived there in the first quarter-hour after the earthquake during which it began. Yet Langi, like most other villages on Simeulue Island, suffered no fatalities. The islanders have a well-remembered history of tsunamis, and they have a tradition of using earthquakes as natural warnings to go to high ground. **See page 6.**

Published by the United Nations Educational, Scientific and Cultural Organization through its Intergovernmental Oceanographic Commission during the IOC's 50th year

Produced by the Jakarta Tsunami Information Centre with contributions from
Lembaga Ilmu Pengetahuan Indonesia
Universitas Syiah Kuala
United States Geological Survey
American Indonesian Exchange Foundation
International Tsunami Information Centre
Canadian International Development Agency

United Nations Educational, Scientific and Cultural Organization
Organisation des Nations Unies pour l'éducation, la science et la culture
Intergovernmental Oceanographic Commission
Commission océanographique intergouvernementale
50 1960-2010

ISBN 978-979-19957-9-5