DANGER ZONES

Some of the most powerful earthquakes emanate from remote ocean-floor faults. Geophysicists are now laying networks of sensors to keep tabs on these hidden killers.

BY NAOMI LUBICK

Japanese seismologists have been worried about a sea-floor fault for years. The Nankai trough off the nation's southeast coast has produced some of the most devastating earthquakes in Japanese history and is considered ripe for another. So, earlier this year, researchers went out in the ship *KAIYO* to install underwater seismic observatories that should reveal more about the fault and provide seconds of warning when the next big quake hits. In March, the ship was just depositing a batch of the sensors when the massive Tohoku-Oki earthquake broke a completely different fault, 800 kilometres to the northeast, triggering a tsunami that crippled coastal communities.

Seismologists had not thought that the Japan trench off the Tohoku coast was capable of generating such giant earthquakes, in part because they did not have enough devices on the sea floor to catch signs of the building stress. The same dearth of data exists elsewhere, wherever one tectonic plate rams into another and slides beneath it. Such subduction zones generate the planet's most powerful earthquakes, including the biggest ever recorded, a magnitude-9.5 monster off the coast of Chile in 1960. In 2004, a subduction-zone quake off the Indonesian island of Sumatra triggered a tsunami that killed more than 230,000 people. And researchers forecast that a subduction zone bordering the north-western coast of the United States is building towards a magnitude-9 shock that could happen within the next century.

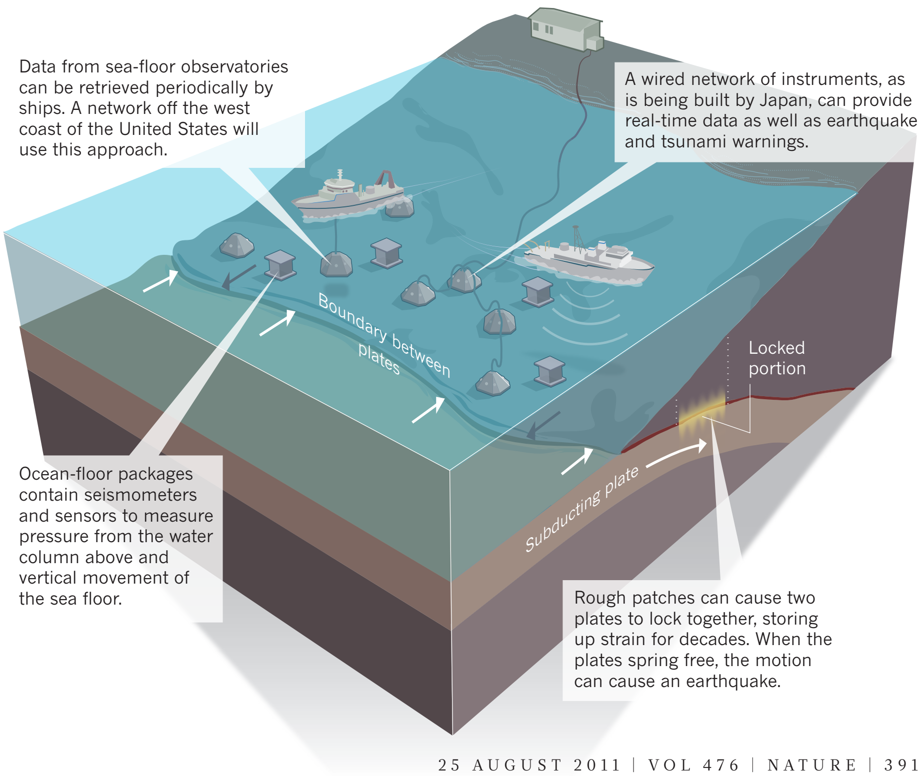
The trouble for seismologists is that these major faults sit hundreds of kilometres from land and buried by thousands of metres of water, where it is difficult to place and maintain observatories equipped with the seismometers, global-positioning-system units and other instruments that can reveal the structure of the faults and detect changes such as warping of the crust.

Japan has just 50 observatories offshore to watch its sea-floor faults, compared with more than 8,700 on land. Other nations are even less prepared, with few or no sensors on the sea floor, where the most dangerous parts of subduction zones lie. Instead, they rely on measurements taken by stations on land — which provide a distant and muffled reading, much like that obtained by a cardiologist who places a stethoscope over a patient's shoe in a fruitless attempt to monitor the heart.

Researchers are now trying to get much closer to the action. The Japanese effort to wire up the Nankai trough is the most

SENSORS ON THE SEA FLOOR

To learn more about subduction zones — regions where one tectonic plate slips beneath another, and sources of giant earthquakes — geophysicists are installing monitoring equipment on the ocean floor.



ambitious project so far, but the United States and Canada have programmes to monitor the Cascadia subduction zone, which runs from northern California to British Columbia (see 'Sensors on the sea floor'). With better data, geophysicists hope to improve their understanding of how subduction zones work and possibly identify signs of impending disasters.

"Without ocean-bottom measurements, we're always guessing," says Emma Hill, a geodesist at the Earth Observatory of Singapore who is studying quake risks off Indonesia.

FAULTY UNDERSTANDING

Subduction zones are the recycling centres in the theory of plate tectonics, which describes the movement of the great oceanic and continental plates that make up Earth's brittle outer shell. When two plates collide, the cold, dense ocean crust sinks, and the plate with more-buoyant, crustal rock rides up over it. But the cartoon-like model — a conveyer belt with slabs of ocean rock diving beneath sheet-like continents above — is an overly simplified picture. "It's going to be complex," says Hill. "And we're still modelling it as a nice smooth plane."

Geophysicists want to know the details of what goes on where the two plates grind against each other. They suspect that the plates somehow become locked together, perhaps when seamounts or other rough features on the subducting plate catch on the underside of the upper plate. After many decades or centuries, the plates then spring free in a mammoth megathrust earthquake. In the case of the March earthquake in Japan, researchers had suspected that the boundary between the two plates was locked, but did not appreciate the risk because they lacked knowledge about the structure of the subduction zone and how stress was accumulating there.

They were more worried about the Nankai trough area, which has a 70% chance of producing a magnitude-8 quake in the next 30 years, according to Japan's official hazard forecast. As part of the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET), geophysicists will create a network of 20 underwater observatories in the region of the trough where earthquakes are thought to originate. The DONET project, started in 2006 and to be completed this year, ran to some ¥6.3 billion (US$82 million), excluding ship time.

The observatories contain seismometers that record vibrations emanating from quakes within the subduction zone as well as seismic waves from tremors across the globe — all of which should help to illuminate the geometry of the interface between the upper and lower plates. Pressure sensors track warping of the crust by measuring changes in the weight of the water column above. Telecommunications-grade cables connect the observatories with land stations, so researchers have access to the sensor data in real time.

Yoshiyuki Kaneda, who is leading the DONET project for the Japan Agency for Marine-Earth Science and Technology, hopes that the observatories will capture a whole earthquake cycle — from the build up of stress to the release during a great earthquake, followed by the gradual reaccumulation of stress. Researchers hope to learn, for example, how major earthquakes start and what kind of activity precedes them.

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When a big quake does come, the DONET observatories should be close enough to provide early warning to Osaka, Tokyo and other cities that could soon be hit by devastating seismic waves. The pressure sensors can also give advance notice of a tsunami racing toward the coast.

WESTERN WORRIES

US researchers have seismic worries of their own, focused on the Cascadia region. Great tremors and tsunamis have hit there before, and more than 300 years have passed since the last one. "The seismic hazard from the Cascadian subduction zone is profound," says Maya Tolstoy of Columbia University's Lamont-Doherty Earth Observatory in New York.

Tolstoy is one of the principal investigators in the Cascadia Initiative, a four-year-long programme that is installing temporary observation posts to learn about the behaviour of the massive offshore fault. Last month, the team began deploying the first of 60 such observatories on the sea floor that will enhance an existing network onshore. The project is funded in part by US$5 million from the American Recovery and Reinvestment Act of 2009, with support from the US National Science Foundation.

Each ocean-floor device, which costs $60,000–80,000, contains a pressure gauge and a seismometer the size of a soup can, housed in a pressure case with levelling systems and protected from currents and fishing gear by a steel hood. These observatories will not be connected by cable to the mainland. Instead, researchers will retrieve each sensor and download its data once a year before moving it to a new spot. By pinpointing where earthquakes occur in the subduction zone, data from the Cascadia Initiative will help to resolve the location and structure of the interface between the plates — such as how rough it is and which areas remain locked, says Richard Allen of the University of California, Berkeley.

The sea-floor observations should also help to decipher unusual seismic signals that have been recorded by land-based seismometers in the Cascadia area. The land sensors picked up swarms of tiny quakes occurring roughly every 12–14 months (N. I. Gershenzon *et al. Geophys. Res. Lett.* **38,** L01309; 2011) as well as seismic events that unfold so slowly that nobody can feel the shaking, even though they release substantial amounts of energy. Researchers suspect that the signals reflect activity within the subduction zone, perhaps layers within the plates moving separately or fluids migrating deep under the surface — and hope that recordings from the offshore sensors will help them to come up with an explanation. The sensors might also be able to detect changes in the locked parts of the subduction zone.

The United States is also teaming up with Canada to install long-term sea-floor observation posts in the Cascadia area as part of the Neptune project, which will collect a wide variety of biological, oceanographic and seismic data both for basic research and for potential early warnings of hazards such as algal blooms or earthquakes. Canada is spending Can$143 million (US$145 million) on its part of the effort, and last year finished installing a system that includes three seismic stations, five sea-floor pressure recorders and other instruments, connected by an 800-kilometre loop of cable that transmits information to a land station. Budget problems delayed the US portion of Neptune, which began laying cable this summer for observatories to be established over the next few years.

Because installing hundreds of kilometres of fibre-optic cable is expensive, researchers are working to develop autonomous seafaring robots that are able to collect the data. One proposed project would pair wave-powered robots developed by Liquid Robotics in Sunnyvale, California, with stand-alone sea-floor sensors.

As readings pour in from the various networks of offshore sensors, researchers hope they can finally gain a more sophisticated understanding of subduction zones and the hazards they hold. Such ocean-bottom observations are "going to be the story of the next few years", says Hill. Although some projects were in the works before the March earthquake, that catastrophe has added urgency to the research. "Because of Japan," says Hill, "people's minds are on this right now." ■

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