Deep mission: Japan takes aim at the source of megaquakes

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Even in port, it's easy to see how the research vessel Chikyu got its nickname. From the waterline to the top of its drilling derrick, the vessel also known as "Godzilla-Maru" towers nearly 30 stories tall.

It's longer than two football fields.

A helicopter landing pad juts over the bow. The two midship cranes are powerful enough to hoist a Boeing 787.

The Japanese government spent more than $500 million to build this monster of a ship with one goal in mind: to decipher the inner workings of a fault capable of unleashing a disaster far worse than the 2011 Tohoku earthquake and tsunami.

In 2016, Japan hopes to complete a nine-year mission to drill into the heart of the Nankai Trough, a 500-mile-long fault that threatens some of the country's most populous areas.

The borehole will extend more than three miles into the Earth's crust, shattering the record for scientific drilling in the ocean.

Only Japan would bankroll such complex and costly seismic research. In a country rattled by more than a thousand sizable earthquakes every year, no threat is more pressing.

But the results unearthed by Chikyu will also be relevant to the U.S.

Pacific Northwest, where an offshore fault called the Cascadia Subduction Zone stretches from Vancouver Island to Northern California.

"Cascadia and Nankai are so strikingly similar, we call them sister subduction zones," said Kelin Wang of the Geological Survey of Canada. "By studying Nankai, we North Americans will benefit, too."

Subduction zones, where an oceanic plate dives - or subducts - under a continental plate, are responsible for the world's most powerful earthquakes and tsunamis.

But subduction zones are much tougher to study than landlocked faults. The boundaries where the plates collide are almost always miles offshore, under thousands of feet of water.

Japan has installed seismometers and other sensors on the seafloor to detect small earthquakes and monitor how the plates warp as strain builds. But even those instruments provide only a superficial view.

"Earthquakes don't happen on the surface," said Harold Tobin, co-chief scientist for the drilling project, called the Nankai Trough Seismogenic Zone Experiment. "They happen kilometers down in the Earth."

Chikyu was designed to go deep, penetrating the portion of the fault where megaquakes are born. Called the seismogenic zone, it's the region where rocks that are normally locked suddenly jerk past each other in what scientists call a megathrust quake.

(There's no danger the drilling will trigger an earthquake, Tobin said. No fluid is injected into the rock, and the foot-wide hole is too tiny to affect the stress levels in such an enormous structure.)

By extracting cores from the fault, researchers will be able to analyze the rock itself, said Nobu Eguchi, program manager for science operations at Japan's Center for Deep Earth Exploration (CDEX). "Nobody has ever seen this material before."

Properties like stiffness, strength, mineral composition and fluid content are all crucial to understanding how plates become locked and what happens when the pressure reaches the breaking point.

"One of the key things people are working on is essentially trying to reproduce fault-zone conditions in the laboratory using material that is cored from the fault rock itself," said Pennsylvania State University geologist Demian Saffer, part of the Chikyu science team.

When the deepest borehole is finished, scientists will install instruments to continuously measure motion on the fault, the accumulation of strain and changes in the rock due to tectonic forces. "Those are things you can't measure unless you have sensors in the rock," Saffer said.

Scientists hope the instruments will capture the run-up to the next big quake. If so, that data might help identify warning signs that precede a rupture.

The search for such precursors has so far been futile, but researchers are only beginning to look on - and under - the seafloor, Tobin said. There's some evidence that the Tohoku quake was triggered by slow slip that pushed the fault over its edge. It's not clear how common or significant the phenomenon will be, but the best way to monitor such subtle motion is with borehole instruments as close to the action as possible, Tobin said.

Saffer and Japanese scientists have already installed one set of instruments in a half-mile-deep borehole drilled by Chikyu, part of a series of 15 holes of varying depths along the Nankai Trough.

Historic records show quakes of about magnitude 8 strike on the fault every 90 to 200 years. The most recent ruptured adjacent segments in 1944 and 1946, killing nearly 3,000 people.

Japan's population has increased significantly since then, and studies warn that 320,000 people could perish in a worst-case scenario. That's more than 10 times the toll from the Tohoku quake and tsunami, which struck on a different subduction zone.

Off the U.S. coast, the 700-mile-long Cascadia fault hasn't ripped as frequently as the Nankai fault - but the quakes can be more powerful. Geologic records reveal a history of magnitude 9 megaquakes and tsunamis every 500 years, on average. But some were separated by as little as two centuries - and the last was more than 300 years ago.

Scientists don't know as much about the mechanics of the Cascadia fault, partly because there's been so little offshore drilling in the Northwest.

Beginning in the early 1990s, several shallow boreholes - up to about 1,000 feet - were sunk off British Columbia, Washington and Oregon. A few are still being employed as simple pressure gauges to measure motion of the seafloor. Next year, scientists will install a tiltmeter and other sensors in an existing borehole near the subduction zone.

But those projects only scratch the surface.

On land, the deepest seismic borehole extends about two miles into the San Andreas Fault. Scientists retrieved cores and installed sensors. But the instruments failed within weeks under the harsh conditions deep inside the Earth.

Chikyu has encountered its share of challenges as well, said Sean Toczko, a Virginia native who helps coordinate missions. During stomach-churning storms, crews have to pull up the drill pipe so it won't snap off, he said. Even when the weather is good, holding the ship stationary requires constant adjustment via a computerized thruster system that reads signals from GPS satellites.

Chikyu is pushing the boundary for scientific drilling, penetrating zones of fractured rock where even oil companies have little experience, Toczko said.

It might seem surprising that so many Americans work on a ship owned by the Japan Agency for Marine-Earth Science and Technology. But the effort is truly international, Toczko said.

Most of the ship's crew and many researchers are Japanese, but scientists from around the world are part of the team. Many of the drillers are Scottish veterans of North Sea oil rigs.

Chikyu is the first research ship to employ techniques from the oil industry, like the use of an outer pipe called a riser to stabilize the main drill pipe and prevent the hole from collapsing.

Drill bosses use joysticks to guide the pipe through miles of water and hit a tiny bull's-eye on the seafloor. One scientist likened it to threading a needle on the floor from shoulder height.

The atmosphere on the ship is most electric when the crew is extracting cores, said Eguchi, the CDEX program manager. Scientists form an assembly line and work around the clock to run the rock through a series of scans and tests. "The lab is equipped with the type of sophisticated instruments you normally only see in a university," he said.

In January, Chikyu reached a depth of 1.8 miles - but not without difficulty. The borehole kept collapsing, and operators are still looking for solutions, Eguchi said.

They hope to resume drilling in early 2016. Between science missions, the ship contracts out for oil and gas exploration to offset operating costs as high as $400,000 a day.

The cores already collected are yielding some unexpected insights.

In one area surprisingly close to the surface, researchers found signs that the frictional force from a past quake heated a thin band of rock to nearly 600 degrees.

A rapid-response mission to drill into the fault that ruptured in 2011 revealed a slippery layer of clay that also ripped all the way to the surface, explaining why the ocean floor lurched 160 feet and triggered such a massive tsunami.

The results raise questions about whether parts of the Cascadia Subduction Zone might be equally slippery and capable of generating bigger tsunamis than expected.

"We need to study our fault-zone material more carefully," Wang said. "Our knowledge is quite limited because we don't have this type of drilling."

Scientists hope to use a U.S. ship to drill shallow scientific boreholes off the Northwest coast - both for rock collection and instrumentation. But that vessel is booked for the next four years.

In the meantime, researchers are using indirect methods to probe the fault. Temporary arrays of ocean-bottom seismometers have been recording the location of tiny quakes. And scientists recently compiled subsurface pictures by bouncing acoustic signals off the seafloor and measuring how the sound waves penetrate and ricochet.

That's the kind of information necessary to guide future research drilling in the region, Tobin said.

"We know the structure on a big scale, but the kind of detail you need for a scientific drilling project is a whole different ballgame."

Once those gaps are filled in, a Chikyu mission to Cascadia would make a lot of sense - if funding is available, Tobin said. Japan is already considering proposals to send the vessel to subduction zones off Costa Rica and New Zealand.

"I'm an optimist," Tobin said. "I think Cascadia has a great chance of being a future Chikyu project."