

**Record: 1**

**Title:** UNCHARTED TERRITORY.

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**Source:** Science News; 4/1/2006, Vol. 169 Issue 13, p202-204, 3p, 1 diagram, 2 color

**Document Type:** Article

**Subject Terms:** MID-ocean ridges  
GEOMORPHOLOGY  
REGOLITH  
MAGMAS  
ROCKS, Igneous

**Geographic Terms:** ARCTIC Ocean

**Abstract:** The article reports that new clues to crust's formation have been found on ultraslow ridges. The surprising discovery of mantle rocks indicated that Gakkel Ridge is one of only two places known on the planet where the tectonic plates that make up Earth's hard outer crust slide apart and expose large slabs of the mantle on the seafloor. Henry Dick of the Woods Hole Oceanographic Institution (WHOI) in Massachusetts was the cochief of the Healy expedition which studied the Arctic Ocean Gakkel Ridge. The other site is the 8,800-km-long Southwest Indian Ridge (SWIR).

**Lexile:** 1170

**Full Text Word Count:** 2422

**ISSN:** 00368423

**Accession Number:** 20386042

**Database:** Middle Search Plus

## UNCHARTED TERRITORY

### Ultraslow ridges hold new clues to crust's formation

At the top of the world in the late summer of 2001, the U.S. Coast Guard's icebreaker Healy carved a slow path through the ice-covered Arctic Ocean. On board, marine geologist Henry Dick sent dredge after dredge through the ice to the seafloor, searching for telltale rocks that would help shed light on how Earth's crust forms. "People said, 'You'll never get a single rock off the seafloor,'" Dick says. "They said, 'You can't dredge in the ice.'" But in fact, Dick's team collected more than 200 rocks-many of which turned out to be pieces of Earth's mantle.

Under the ice and 2 kilometers of water was a 1,800-km-long underwater mountain range known as the Gakkel Ridge. The Healy's expedition, conducted in tandem with the German icebreaker Polarstern, was the first exploration to that Arctic ridge to attempt to collect geological samples.

The surprising discovery of mantle rocks indicated that Gakkel Ridge is one of only two places known on the planet where the tectonic plates that make up Earth's hard outer crust slide apart and expose large slabs of the mantle on the seafloor. That mantle is normally buried under 6 km of crustal rock.

The other site, the 8,800-km-long Southwest Indian Ridge (SWIR), is on the far side of the world. Like the Gakkel Ridge, the SWIR is utterly remote. It's located beneath treacherous high seas.

Oceanographers are only now beginning to explore these areas in detail. They have already made surprising geological finds, including the exposed mantle. They've also uncovered evidence at both ridges of hydrothermal vents, fissures in the seafloor through which circulating, magma-heated seawater escapes. Researchers say that these two ridges may represent a new class of tectonic boundary, called an ultraslow-spreading ridge. The finding offers scientists the chance to explore new ideas about how Earth's crust forms and to study the rich ecosystems spawned by the vents.

### LAYER CAKE

For 3 decades, oceanographers have been studying the undersea creation of crust, Earth's outermost layer. Still, "we don't understand the crust at all well," Dick says. "We know more about the moon than the ocean floor."

The theory of plate tectonics is a blueprint for Earth's surface as it is continuously recycled. The crust is broken into plates that rest on a warm, soft layer in the mantle, the material that reaches all the way to Earth's core. Driven by heat from that underlying mantle, the plates shift, collide, and move apart. Where the plates pull away from each other, the crust is thinner and magma from the interior of the planet rises in response to lessened pressure from overlying rock. Much of the rising magma collects and solidifies in a reservoir below the surface, but when enough pressure builds up, it erupts as lava through thousands of volcanoes on the seafloor, where it ultimately cools and forms new crust.

This endless cycle of thinning crust, rising magma, and erupting lava occurs along the mid-ocean ridge system, a 55,000-km-long volcanic mountain chain that includes both Gakkel Ridge and SWIR. The system, divided by fault lines called transform faults that lie perpendicular to the ridge, circles the planet like a seam on a baseball.

Midocean ridges are classified into two groups: fast- and slow-spreading. Each group has characteristic geological features. At fast-spreading ridges, such as the East Pacific Rise, the plates move apart at a rate of 100 to 200 millimeters per year and are rapidly supplied with hot magma. These ridges are narrow with a tentlike shape, formed by sheets of lava flowing from a hot, buoyant central peak.

Slow-spreading ridges, such as the Mid-Atlantic Ridge, move at less than 55 mm per year and have a slower magma supply. Their topography is broader and rougher, with wide, deep rift valleys forming along the axis of the ridge.

Traditionally, scientists have envisioned most of the under ocean crust as a layer cake of three rock types. The layers correspond to different chemical stages of the magma as it emerges where the plates split and cool. Together, the layers provide a 6-to-7-km-thick covering over Earth's mantle.

That well-established model began to be questioned 8 years ago, when researchers exploring some sections of the slow-spreading Mid-Atlantic Ridge found small, widely dispersed areas of exposed mantle rock on the seafloor. The absence of the layer cake was surprising, says marine geologist Jian Lin, a colleague of Dick's at the Woods Hole Oceanographic Institution (WHOI) in Massachusetts.

The finding suggested a dearth of magma flow in those sections. It challenged the view that the ocean crust is ubiquitous. It also raised the possibility that different chemistries and mechanics of mantle and seafloor rocks might affect plate spreading.

At the Mid-Atlantic Ridge sites, geologists discovered a rock called serpentinite instead of the basalt found on the seafloor elsewhere. Seawater interacting with exposed mantle creates serpentinite, which is softer and mechanically weaker than basalt. Serpentinite is "very different in chemical composition, in mechanism, in biological character" from crustal rocks, Lin says.

Another long-standing question is how the perpendicular transform faults develop. All the small, exposed areas of mantle rock were found at the ends of ridge segments, near the transform faults. That result suggests that the faults may be important for magma channeling. But, Lin says, "we don't know the mechanism yet of how they are formed at all."

Perhaps, some researchers speculated, a ridge with an even lower magma supply than that at the exposed-mantle sites on the Mid-Atlantic Ridge might be the place to look for these answers.

### **SOMETHING NEW**

If scientists want to know what happens at a ridge when the rate of spreading drops close to zero, Gakkel Ridge is the best bet, says marine geochemist and Healy cochief scientist Charles Langmuir of Harvard University. Nearly 20,000 km, or one-third, of the total midocean-ridge system is likely to fall into the new, ultraslow category, and Gakkel Ridge is "the slowest-spreading major portion," he says. There are hypotheses about the mantle "that can be tested there and nowhere else," Langmuir proposes.

The Gakkel cruise, along with a series of voyages to the SWIR between 1997 and 2005, led researchers to the unexpected discovery that these ultraslow ridges were completely devoid of transform faults. Transform faults form only perpendicular to a ridge. Scientists had thought that the faults take up the stress between adjacent blocks of new seafloor and also fit together straight-edged ridge sections with curving plate boundaries. Researchers also thought that the faults might determine where the magma erupts along a ridge. Faults would create channels below the surface that focus magma into widely spaced volcanoes. But on the Gakkel, separate, scattered volcanoes were present even in the absence of faults, Langmuir says.

Instead of transform faults, an entirely new plate-boundary structure is linking the volcanoes on ultraslow-spreading ridges, Dick says. Between the volcanoes, the crust fractures and solid mantle rock rises up to the seafloor. These fractures and the mantle rock filling them extend from the ridge at various angles.

Another interesting feature of the ultraslow ridges is that they're much colder than even the slow-spreading ridges are. They ought to be brittle, Lin says, resulting in more earthquakes as the ridges strain to pull apart. But actually, there are fewer earthquakes recorded in the ultraslow-spreading areas. Perhaps earthquakes require transform faults, or the mechanically weak serpentinite might fill the cracks and lubricate the plates, says Lin.

He ponders the role of transform faults. "Are they not needed?" he wonders. "It's very exciting. When you are so close to the fundamental types of plate tectonics, your heart starts beating very fast."

## HOT SITES

Beyond the unusual seafloor surface, expeditions to both Gakkel and SWIR brought an additional surprising discovery: cloudy, warm patches in the water column that contain unusually high concentrations of minerals. These plumes are considered evidence of hydrothermal vents.

Until 2 decades ago, researchers had held that vents arise only on fast-spreading ridges, such as the East Pacific Rise, because slower-spreading ridges don't have enough heat. However, in 1985, a large hydrothermal vent field was discovered on the Mid-Atlantic Ridge. In early 2005, new vent fields turned up in slow-spreading parts of the ridge system in the Arctic and South Atlantic oceans.

These finds are "flying in the face of the consensus," says Peter Rona, a marine geologist at Rutgers University in New Brunswick, N.J.

Rona, along with his WHOI colleague Rob Reves-Sohn, organized one of three sessions dedicated to slow-spreading ridges and hydrothermal vents for the American Geophysical Union's December 2005 meeting. Just in the past 2 years, Rona says, research on hydrothermal vents at slow- and ultraslow-spreading ridges has taken off.

Although vents haven't been observed in an ultraslow-spreading area, scientists have dredged up bits of hydrothermal deposits from the seafloor. An international race is on to find the vents. "It's an area of hot research," Rona says.

The first sign that such vents might exist at ultraslow ridges came in 1996, when WHOI marine geochemist Chris German, then at the Southampton Oceanography Centre in England, found hydrothermal plumes at the SWIR. Though the data were scanty, they "proved the point that hydrothermal activity is there," German says.

Lin, with Dick and fellow WHOI scientist Hans Schouten, traveled to the SWIR in December 2000 and found more plumes along the ridge. The cruise "set new expectations," Dick says.

Then came the 2001 Gakkel cruise. Marine geochemist Hedy Edmonds of the University of Texas at Austin was invited on the off chance that evidence of hydrothermal vents would turn up. "The idea was that I would be really bored," she says.

She attached a sensor that recorded temperature, pressure, and optical backscatter-which detects suspended sediment-to each dredge line cast from the Healy. Of the dredge casts, 82 percent showed evidence of hydrothermal plumes (SN: 1/18/03, p. 37: Available to subscribers at <http://www.sciencenews.org/articles/20030118/fob6.asp>). The hydrothermal vent activity was "astounding," Edmonds says. "It got to be a joke halfway through the cruise."

In 2005, Lin returned to the SWIR as one of two U.S. scientists on the Chinese ship DaYangYiHao. He again detected hydrothermal plumes, including one that he calls particularly huge. "It's exciting because it's a very strong signal," Lin says.

Lacking the equipment to scour the seafloor, the researchers were unable to locate the vent. "But we are going back," he says.

Edmonds also plans to return to her site. "To me, the most exciting question is to go back and actually find [the vents]-and find out what's living there," she says.

## REMOTE SENSING

The challenge of locating those vents is driving the development of the next generation of remote equipment. "It's going into the unmapped jungle and finding out new things," Reves-Sohn says. "The real problem is [learning] how prevalent venting is on the seafloor. We make all these extrapolations based on some pretty heavy assumptions."

At the moment, there are two ways to directly investigate the seafloor. Manned submersibles such as WHOI's Alvin can take scientists down, but they are limited to 8-to-10-hour shifts. Furthermore, weather conditions on the surface frequently don't permit submersible use.

The other approach is to drop sensors that are connected to the ship by long tethers. "A lot of the technology we've been using up to now was deployed with wires from the surface ship," German says. That doesn't lend itself to prolonged, precise searches on the seafloor, he adds.

German and others are developing a new breed of robot, known as autonomous underwater vehicles, that isn't limited by wires and time (SN: 2/1/03, p. 75: Available to subscribers at <http://www.sciencenews.org/articles/20030201/bob9.asp>). One such vehicle, called the Autonomous Benthic Explorer (ABE), can be dropped into a plume, where it zooms around in the water column and maps a 5-km-square grid of the chemical signal. After constructing a second, more detailed grid of the region of highest mineral concentration, it can locate the source of the plume and dive down to the seafloor to take photographs. It's been used to locate and explore deep-sea vents on both the Mid-Atlantic Ridge and the East Pacific Rise but hasn't yet visited any ultraslow ridges.

Another obstacle to ocean exploration is money. There are few suitably equipped ships, and the cost of a scientific cruise can be prohibitive, particularly for scientists whose target sites require expensive icebreakers such as the Healy.

With the manned submersible Alvin, the unmanned ABE, and ongoing development of autonomous robots that can scan the seafloor in detail, the United States has the best tools, Reves-Sohn says. But "one of the stark realities is that it's going to be other countries that will discover a lot of vents. It would be nice if our country would get interested again in exploring the seafloor."

Under a budget crunch, U.S. oceanographers are looking to international and interdisciplinary collaboration to get back to sea, such as Lin's 2005 cruise to the SWIR, a collaboration between Chinese, German, and U.S. scientists. The 2007-2008 International Polar Year has plenty of prospects for cash-strapped geologists to piggyback on already-funded cruises, Lin says.

"The Arctic Ocean is an ideal case," he notes. "It's a wonderful opportunity for geologists and biologists to tag along and sample hydrothermal vents or map ocean ridges while [other researchers] do climate change and ice coring."

Overall, the new ridge-and hydrothermal-vent-discoveries have had something of a galvanizing impact on the global oceanography community. One bellwether is the excitement at the geology meeting last fall, where there was "a tremendous response" to the ridge sessions, Rona says.

There is still debate over whether designating a new, distinct class of ultraslow ridges simply provides intriguing new avenues for researchers to study how the crust forms or whether it introduces a textbook-rewriting paradigm shift.

Whatever the outcome, Dick asserts, "this is a significant change to plate tectonics theory."

DIAGRAM: SPLITTING APART -- This ultraslow-spreading ridge shares features with typical midocean ridges, such as upflows of molten magma that collect below the surface. At the ultraslow ridges, however, solid slabs of cooled mantle rock may rise directly to the seafloor.

PHOTO (COLOR): CUTTING THROUGH ICE -- The U.S. Coast Guard's icebreaker Healy carves a path through the icebergs above the Arctic's underwater Gakkel Ridge. On its first research mission, Healy found signs of a new type of ridge.

PHOTO (COLOR): SIGNS OF LIFE -- At hydrothermal vents such as this one along the slow-spreading Mid-Atlantic Ridge, hot, mineral-rich fluids build rock columns and sustain diverse life.

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By Carolyn Gramling

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