REBECCA WALSH DELL

PHYSICAL OCEANOGRAPHY

Powerful Currents in Deep-Sea Gorges

What energy drives these currents in hundreds of seafloor ‘Grand Canyons’?

On my first major research cruise, the ship was hit by a hurricane. On the second, the weather was even worse. In one particularly nasty storm, I remember standing braced on the ship’s bridge late at night, watching bolts of lightning light up the world.

Each one revealed waves taller than the ship extending to the horizon in every direction. We bobbed haplessly among them. At a time like that, it’s hard not to feel philosophical about the power of nature.

In a very different context, the power of nature is something I spend a lot of my time thinking about. Energy—where it comes from, what form it takes, how it is transformed—is central to my work as a graduate student at Woods Hole Oceanographic Institution. In my case, it is the energy that controls currents in the deep ocean and ultimately influences the ocean’s global circulation.

I research the way the shape of the

The seafloor is filled with thousands of deep canyons, where powerful currents appear to be flowing uphill along the canyon floors. These currents could play a major role in driving global ocean circulation.

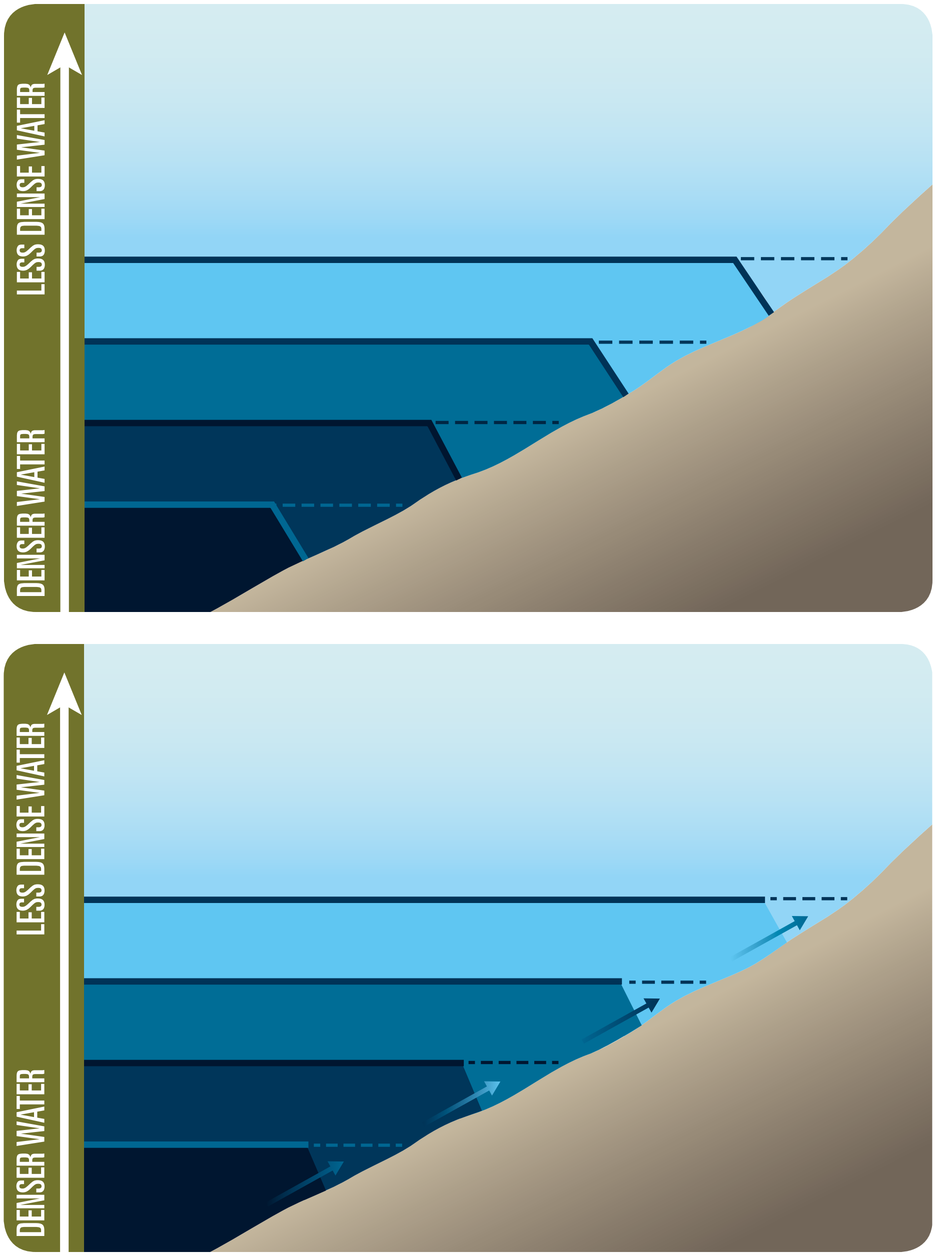
ocean floor affects the ocean's circulation. More particularly, I explore the fundamental physics that transforms energy, drives currents, and mixes up water masses in the deep ocean. It turns out that features of the undersea landscape might play a big and previously unknown role.

Concealed from our view, the bottom of the ocean is covered with mountains and canyons far larger and steeper than those on land. In the Atlantic, there are thousands of canyons as deep as the Grand Canyon. They line the eastern and western flanks of the Mid-Atlantic Ridge, a giant range of mountains that runs from Iceland nearly to Antarctica and covers about half the bottom of the Atlantic Ocean.

Mountains on land affect the flow of air in the atmosphere and have significant effects on the weather, and similarly, oceanographers know that

Jack Cook, WHOI

HOW CAN CURRENTS FLOW UPHILL AT THE SEAFLOOR?



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Water at the seafloor is stratified, with layers of progressively denser waters toward the bottom. When these layers collide with a slope, mixing occurs, and less dense waters end up at the same level as denser waters. Gravity then pushes the denser water to sink under the less dense water, driving a current flowing upward along the slope of the incline.

these mid-ocean ridges and canyons affect the ocean's circulation. But we don't really know how, because it's very difficult to get observations on the bottom of the ocean.

Three miles below the surface, our electronic sensors have to withstand water, salt, and extremely high pressures. Designing and building these sensors is like trying to make a mobile phone that would keep working if you dunked it in a puddle of salt water and then parked a semi-trailer truck on top of it—you can do it, but it's really expensive. Then you have to get the sensors out to the middle of the ocean and down to the depths, which is also costly. So our observations near the seafloor are sparse.

Strong currents flowing uphill

The observations we *do* have, though, are really exciting. In canyons at the bottom of the ocean, we see currents moving ten times faster than we had predicted and going in the opposite direction from what we would expect on land. On land, streams run down the sides of mountains toward the plains. In seafloor canyons, the currents run from the deep plains *up* the side of the Mid-Atlantic Ridge, toward the peaks of the mountains.

In addition, we see turbulence that's more than ten times stronger in the canyons than the average for the deep ocean. The water flowing down there has a lot more energy than we had expected. Where does the energy come from, and what does it mean for the rest of the ocean?

To try to understand these tumultuous canyon currents, I started by taking a close look at density variations in the seawater. The temperature and saltiness of seawater determine its density, and they are among the easiest things to measure in the ocean. Cold, salty water is denser than warm, fresh water and tends to sink beneath it.

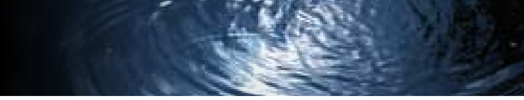
In seafloor canyons, we have observed that water in some places close to the bottom of the canyons is less dense than in other places at the same depth. Gravity pushes the more dense water toward the less dense water. This movement of water propels currents along the bottom of the canyons to flow up toward the ridge crest.

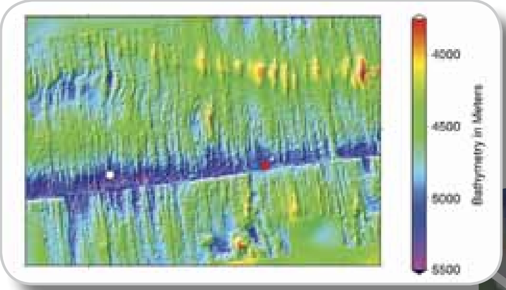
Mixing makes the ocean go

We can actually observe similar uphill flows in experiments in tanks in the laboratory. They happen any time we put a fluid with a varying density in a container whose bottom is not flat. These flows are driven by the *mixing* of water with different densities.

To understand how these mixing-driven currents might work in the ocean, I use models. Scientists use the term "model" a lot, and it can refer to a tank in laboratory, or mathematical equations, or a computer program that uses our understanding of a process to reproduce it. Or it could be just a picture in the mind of a scientist. A model is something that represents a system from the real world, but in a simplified form.

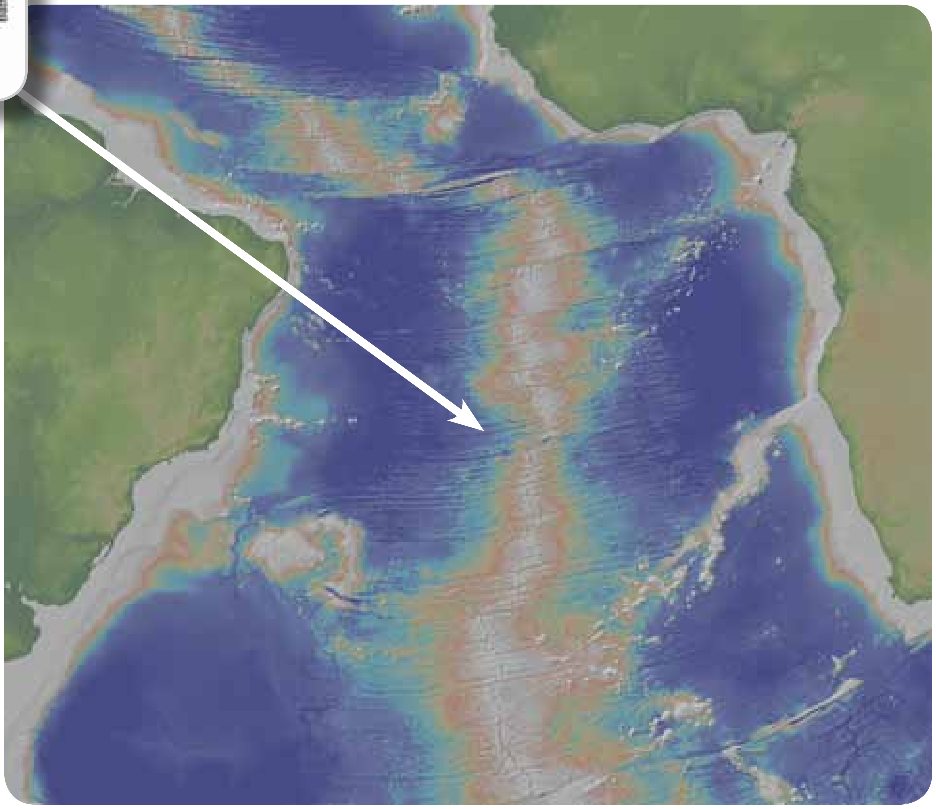
The ocean is too complicated to understand all at once, so a scientist might make a model that captures the most salient features of an aspect of the ocean's fluid dynamics, and try to understand that. Then the scientist can apply that understanding back to the real world in all its





John Toole, WHOI

The Mid-Atlantic Ridge undersea mountain range covers about half the floor of the Atlantic Ocean. Its flanks are lined with thousands of deep canyons like the one at left. Data from this canyon show a strong current flowing uphill along the canyon floor. Scientists think there are similar currents in many other seafloor canyons.



gory and beautiful complexity.

My models are a combination of mathematics and computer programs. I use both to simulate and examine the mechanisms driving the uphill currents observed in seafloor canyons and in the laboratory.

I suspect that the same mechanism we see operating in the laboratory might be what's driving the strong currents in the canyons on the bottom of the Atlantic Ocean: the mixing of water. Usually, we think of mixing as a process that dissipates energy—for example, the way that the coffee in your cup quickly comes to rest after you stop stirring. The flows we observe in the lab of waters with different densities have the opposite effect: Mixing *generates* kinetic energy, and the seemingly chaotic motions of mixing become organized into currents that flow uphill.

When you convert energy associated with the position of water—denser next to lighter—into motion, you are converting potential energy into kinetic energy. By combining waters of different densities, mixing can generate potential energy that is then available to be converted into kinetic energy. That's why oceanographers care so much about turbulence in the ocean: It is constantly transforming energy.

The mixing in seafloor canyons—which happens on scales of inches—is being organized by the topography into powerful currents that extend for hundreds of miles. Swirling eddies spur mixing of water masses with different densities, setting up density gradients and converting kinetic energy to potential and back again. The motions at the smallest scales are tied directly to motions happening on the largest scales. And once formed, these canyon currents can cause more turbulence as they flow over more rough seafloor topography, thereby tying the large scales back to the small scales.

Ultimately, the ocean's circulation moves heat and chemicals such as carbon dioxide around the planet to determine its climate. So by understanding where and how mixing and energy transformation happens on the ocean floor, we edge our way closer to understanding the vast ocean's effects on our climate and our planet.

In the ocean, as in life, everything is connected. So maybe feeling philosophical while studying the sea is not so surprising.

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REBECCA **WALSH DELL**

Growing up, Rebecca Walsh Dell lived on both the Atlantic and Pacific Oceans, first in New Hampshire then in California. Though she always liked the beach, she never thought too much about the ocean until she learned as an undergraduate physics student that we still don't really understand how the ocean works and that hanging out on boats and trying to figure it out was actually a job. She has pursued the research in this article with her Ph.D. advisor, Lawrence Pratt. When she's not trying to solve the Navier-Stokes Equations, she loves sailing, reading widely, and writing her representatives in Congress. She also has a black belt in Taekwon Do. Her mentor for this article was Ken Kostel, Web writer/editor at WHOI.