Ocean Bumps and Dips

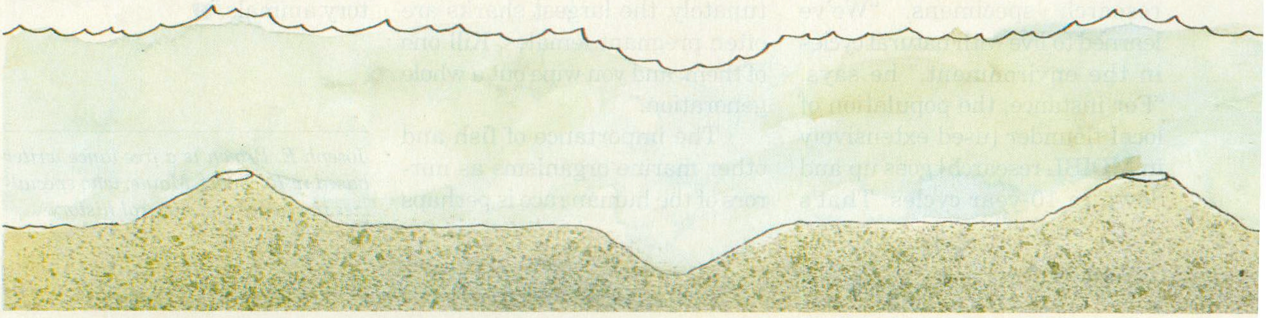
David T. Sandwell

The surface of the ocean bulges outward and inward, mimicking the topography of the ocean floor. The bumps, too small to be detected by the naked eye, can be measured by satellite.

The surface of our planet consists of about 30 percent land and 70 percent ocean. Many of us could sketch the outlines of the continents and perhaps label the major mountain ranges and river basins. Yet most people are unfamiliar with the large topographic features beneath the deep oceans. For example, the Pacific-Antarctic Rise, which has an area about equal to South America, is a broad rise of the ocean floor caused by seafloor spreading between two major tectonic plates. To the west of the rise lies the Louisville Ridge, which is a chain of large undersea volcanoes having a length equal to the distance between New York and Los Angeles. The Louisville Ridge was first detected in 1972 and charted in greater detail in 1986, although many of the 4,000-meter-tall seamounts along this ridge remain uncharted. In an age when we are mapping the surfaces of Venus and Mars in great detail, it is difficult to believe that so little is known about our own planet.

The basic problem is that the seafloor is masked by 3,000–5,000 meters of salty water. Electromagnetic waves cannot penetrate to this depth, so a satellite carrying a radar or laser equipment cannot be used to directly measure the seafloor topography. Prior to World War II, ocean depths were measured using a lead weight attached to a very long wire. Clearly, this is an inefficient and inaccurate method of mapping large areas. It takes hours to deploy and retrieve the wire, and during that time the ship can drift so that the wire is no longer vertical. Using this tedious method, explorers and scientists were able to establish the broad-scale variations in ocean depth. Most details were completely unknown, however, and most maps portrayed the ocean floor as a featureless plain.

While the ocean is impenetrable to electromagnetic waves, acoustic waves propagate quite efficiently in seawater. In the late 1940s echo sounders were developed to rapidly measure ocean depth. The apparatus consists of a transponder (underwater speaker) and a hydrophone installed on the hull of a ship. An acoustic pulse, emitted by the transponder, travels through the ocean and reflects from the closest rock surface on the ocean floor. The two-way travel time (about



long-range planning committee. In the Harpswell days, the lab subsisted entirely on private grants and donations. Beginning in the 1950s, much of its work relied on federal grants. "Now we've reduced our reliance on federal money," says Schmidt-Nielsen, "and we've been fortunate to receive substantial private grants once again."

The second major refocusing has been MDIBL's increasing interest in marine pollution, specifically how it affects humans. 'The effect of heavy metals on the functioning of biological membranes is the subject of one intensive study here," notes director Evans. "That's a personal interest as well. I want to know: 'What's the effect of heavy metals on smooth muscle contractibility that can lead to hypertension [high blood pressure]?' What I use to look for answers is a blood vessel from a shark." In related studies, MDIBL is also looking into how pesticides, industrial wastes, petroleum, and drilling fluids are affecting marine organisms and pelagic birds.

Evans worries that pollution and other human pressures on local and offshore marine animal populations could adversely affect MDIBL's supply of healthy research specimens. "We've learned to live with natural cycles in the environment," he says. "For instance, the population of local flounder [used extensively in MDIBL research] goes up and down in 10-year cycles. That's

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Originally welcomed, then banned, summer students are once again accepted at MDIBL.

expected. A couple of years ago, we had to stop some research because there weren't enough flounders available."

Man's intervention, however, is another matter. "Sharks have become scarcer and scarcer since humans discovered the shark as a dinner table item. One large shark fishery off Boston has impacted our population severely." The problem with the "shark harvest," he notes, is that most fishermen want the largest ones they can find. "And, unfortunately, the largest sharks are often pregnant females. Kill one of them, and you wipe out a whole generation."

The importance of fish and other marine organisms as mirrors of the human race is perhaps best summed up in a statement issued not long ago by MDIBL President Franklin Epstein.

"The sea is the mother of us all," he wrote. "In the sea, long ago, life was formed. The patterns of basic chemical reactions that sustain life were fixed in that prehistoric ocean and have persisted with little change through eons of time. Because of the diversity of life in the oceans—the variety of nature's experiments—it is often possible to unravel the ways in which the cells in our own bodies work."

Study fish, Epstein concludes, and man can be understood "in a way that might be impossible using typical laboratory animals."■

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GUY MOTIL / WEST LIGHT

■ ***Above:*** **In general, the ocean's surface seems to be fairly uniform, except for the usual waves and swells.** ***Below:*** **However, with the help of satellites scientists have been able to determine that this seemingly uniform surface actually possesses bumps and dips that mimic the ocean floor beneath.**

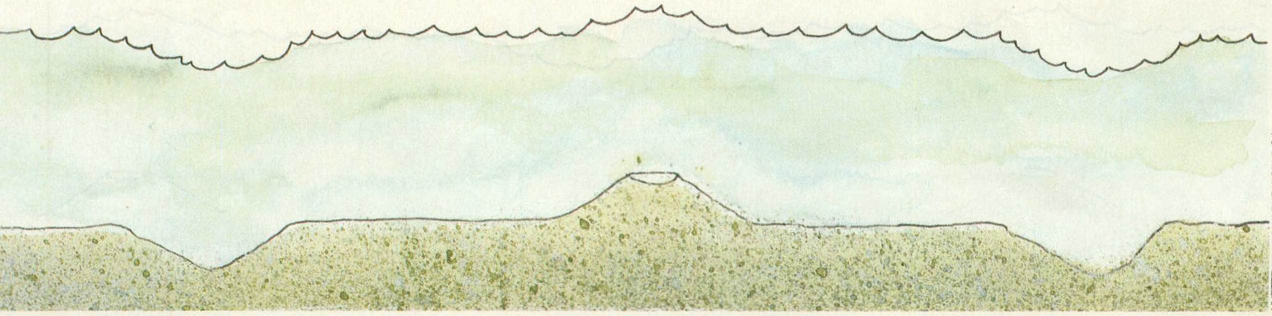
3–6 seconds) provides a measure of the ocean depth. With such rapid measurements, scientists could collect continuous profiles while steaming at full speed.

The installation of echo sounders on several research vessels dramatically increased the number of depth soundings and proved that the ocean floor was not featureless. Indeed, compilation of these soundings into topographic charts revealed the highly structured nature of the ocean floor topography. These topographic measurements, along with the measurements of magnetic stripes on the seafloor, led to the plate tectonic revolution in the 1960s.

Still uncharted

Today, arrays of echo sounders can be used to map a swath of seafloor up to 10 kilometers wide. Yet despite these major improvements in technology, the oceans remain largely uncharted because ships travel so slowly. Consider a research vessel steaming at 15 miles per hour. At this rate it would take approximately 300 years to chart the ocean basins using the latest swath-mapping tools. Of course, if 30 ships were commissioned the oceans could be mapped in just 10 years, but in addition to the high cost of such an effort, many countries restrict scientific exploration in their territorial waters. Fortunately, such a major mapping program is largely unnecessary because the ocean surface has broad bumps and dips that mimic the topography of the ocean floor. Remarkably, this ocean-surface topography can be mapped with satellites.

Everyone is familiar with the ocean swells generated by storms at sea. However, in addition to these small-scale transient features, there are much broader scale bumps on the ocean surface



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that persist for millions of years. What causes the surface of the ocean to bulge outward and inward, mimicking the topography of the ocean floor? How big are these bumps? How can they be measured?

According to the laws of physics, the surface of the ocean is an "equipotential surface" of the earth's gravity field. (Let's ignore waves, winds, tides, and currents for the moment.) Basically, this means that if one could place balls everywhere on the surface of the ocean, none of the balls would roll downhill because they are all on the same "level." To a first approximation, this equipotential surface of the earth is a sphere. Because the earth is rotating, however, the ocean surface bulges around the equator. In fact, the polar diameter is 43 kilometers less than the equatorial diameter.

While this ellipsoidal shape fits the earth remarkably well, the actual ocean surface deviates by up to 100 meters from this ideal ellipsoid. These bumps and dips in the ocean surface are caused by minute variations in the earth's gravitational field. For example, the gravitational field of a massive mountain on the ocean floor attracts water toward it, causing a local bump in the ocean surface. Similarly, an ocean trench is a local mass deficit that repels the water, resulting in a dip in the ocean surface. It is these small bumps that scientists are now using to infer the topography of the ocean floor.

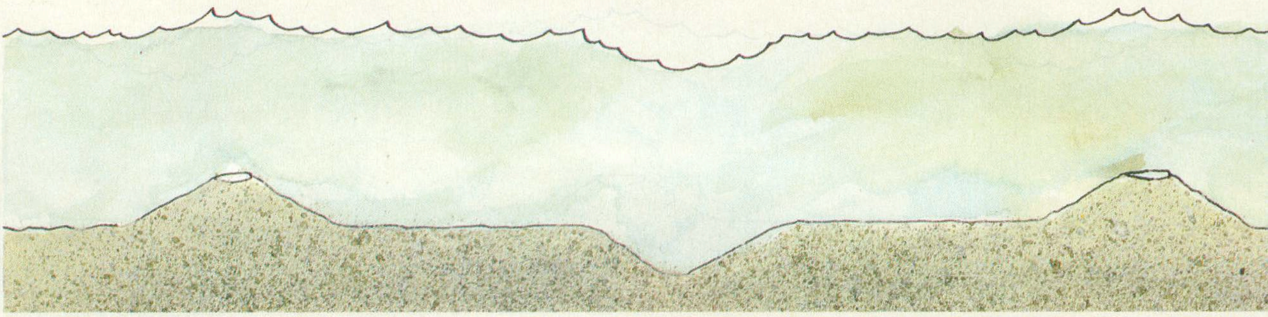
A typical undersea volcano, which is 2,000 meters tall and has a radius of about 20 kilometers, produces a bump on the ocean surface that is 1,000 times shorter, or only 2 meters high. While a 2-meter-tall bump seems quite large, it cannot be seen with the naked eye, because the slope of the ocean surface is very low; in this case, the slope is only a 2-meter change in height over a 20-kilometer change in distance.

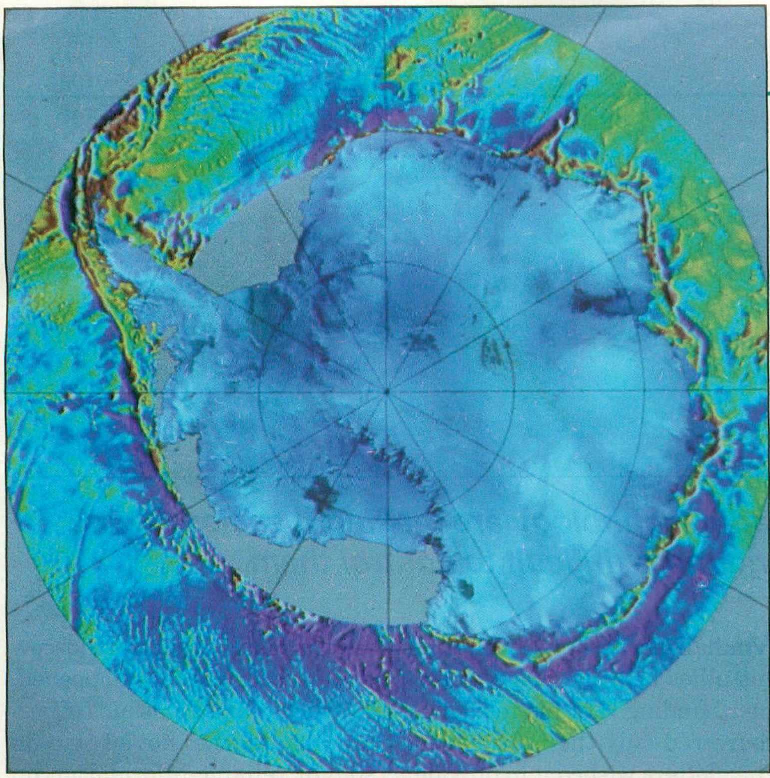
Long linear troughs in the ocean surface (up to 40 meters deep) occur above the deep-ocean trenches, where the tectonic plates are plunging back into the interior of the earth. The largest ocean surface slopes occur above the walls of these trenches, but the slopes are still only 40 meters change in height over a 200-kilometer change in distance; typical sea surface slopes are only 1 meter per 100 kilometers. Such subtle features are impossible to see and difficult to measure, especially while aboard a ship at sea.

Satellite measurements

The breakthrough came 20 years ago when scientists and engineers began to measure the topography of the ocean surface using a radar altimeter mounted on a satellite. The measurement is actually quite simple. The radar emits a microwave pulse that travels from the satellite and reflects from the closest ocean surface. The pulse travels at the speed of light, so the two-way travel time (about 5 milliseconds) is a measure of the altitude of the satellite. To determine the topography of the ocean surface, the height of the satellite above the center of the earth must also be measured. This is accomplished by tracking the satellite with ground-based laser and by modeling the trajectory of the satellite during its orbit through the earth's gravity field. Using this method, the topography of the ocean surface can be measured to a precision of about 2 centimeters. The microwave pulse, which reflects from an area approximately 3 kilometers in diameter, effectively averages out the ocean roughness associated with swells and waves.

Most of the high-resolution satellite altimeter data are clas-





■ **This image of ocean surface around Antarctica was constructed from satellite altimetry. The ridges and troughs on the ocean surface reflect fracture zones on the ocean floor. Small circular bumps on the ocean surface reflect large volcanoes on the ocean floor.**

sified by the Department of Defense because they are used to plot the paths of submarines and missiles. However, data from the ocean areas around Antarctica were recently declassified (see image below). In these remote waters, the details of the structure of the ocean floor were almost completely unknown. Now the altimeter onboard the GEOSAT spacecraft (launched in 1985 by the U.S. Navy) has revealed a variety of geologic structures. The undersea volcanoes appear as symmetrical bumps on the ocean surface; the faults and fractures appear as linear ridges and troughs. The submerged shelf of the Antarctic continent appears as a linear ridge seaward of the coastline.

In the next few years, as more satellite altimeter measurements become available, scientists will obtain the first detailed view of the ocean floor on a global basis. These data will be used along with shipboard measurements of ocean depth to map the seafloor at a horizontal resolution of 10 kilometers. Based on the currently available data, scientists expect to discover many 2,000-meter-tall seamounts and numerous fracture zones. The most important and interesting discoveries, however, will be those that are completely unexpected.

While the satellite altimeter method of inferring seafloor depth by mapping the bumps and dips on the ocean surface will certainly lead to a revolutionary new view of the earth, it is interesting to note that this method has a fundamental limitation. Features on the ocean floor that are narrower than the average ocean depth of 3–5 kilometers do not produce measurable bumps on the ocean surface. Thus higher-resolution maps of the ocean basins will depend on yet another technological breakthrough.■

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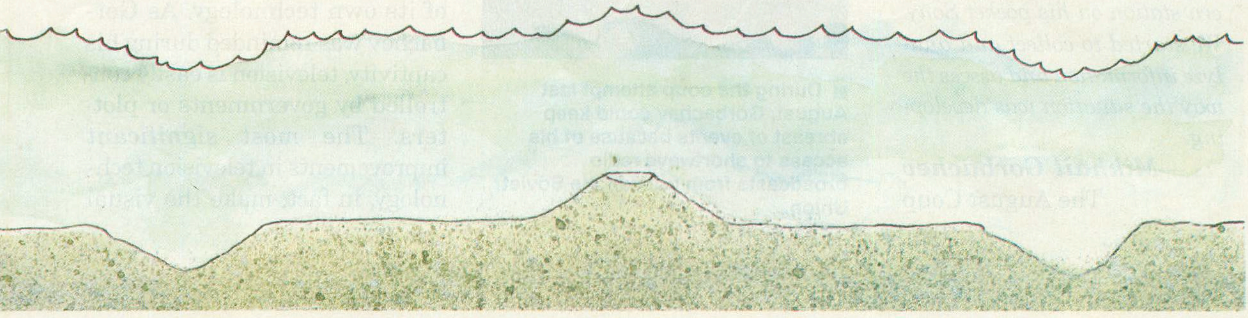


Listening to the World

Stephen K. Thompson

Advances in shortwave radio technology are making it easier to tune into the world airwaves and more difficult to control them.

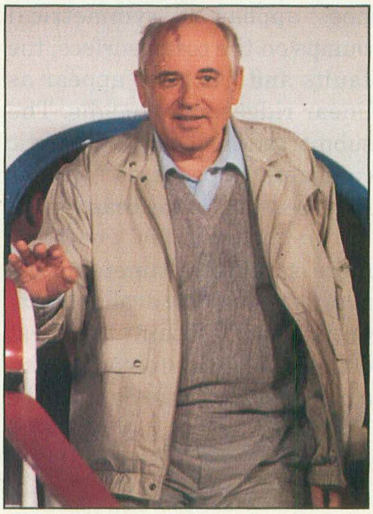
The plotters isolated me completely from the outside world, both from the sea and the land, creating what was essentially psychological pressure. I was totally isolated.

The most difficult aspect of the situation was the lack of information. Everything was cut off except the television, on which statements by the State Committee for the Emergency alternated with feature films and orchestral concerts. But the security officers from the bodyguard, very smart boys, found some old radio receivers in the service areas [of the dacha], fixed up aerials and started to pick up foreign broadcasts. The best reception was from the BBC and Radio Liberty. Later we managed to pick up the Voice of America. My son-in-law Anatoli managed to listen to a Western station on his pocket Sony. We started to collect and analyze information and assess the way the situation was developing.

—***Mikhail Gorbachev***
The August Coup

Mikhail Gorbachev, cut off from his allies and, like his countrymen, finding that his television delivered only the information the plotters wished it to provide, thus turned to an older, more reliable source of news: international shortwave radio.

At the same time viewers around the world were watching the dramatic events in Moscow on television, as they happened, Gorbachev and thousands of people inside the Soviet Union sought reliable information on the radio—and received it quite effectively. Shortwave broadcasting, as on countless previous occasions, demonstrated during the abortive Soviet coup that it remains the single source of information that oppressive governments are unable to deny to their captive populations.



AP

During the coup attempt last August, Gorbachev could keep abreast of events because of his access to shortwave radio broadcasts from outside the Soviet Union.

New radio technology has left governments essentially impotent, unable to stem the flood of uncensored news and information that crosses their frontiers hourly, reaching anyone who wants to hear it.

Television easily controlled

Television, however, is a prisoner of its own technology. As Gorbachev was reminded during his captivity, television is easily controlled by governments or plotters. The most significant improvements in television technology, in fact, make the visual