

## Listening Closely to 'See' Into the Earth

### A new national facility of cutting-edge seafloor seismographs probes Earth's interior

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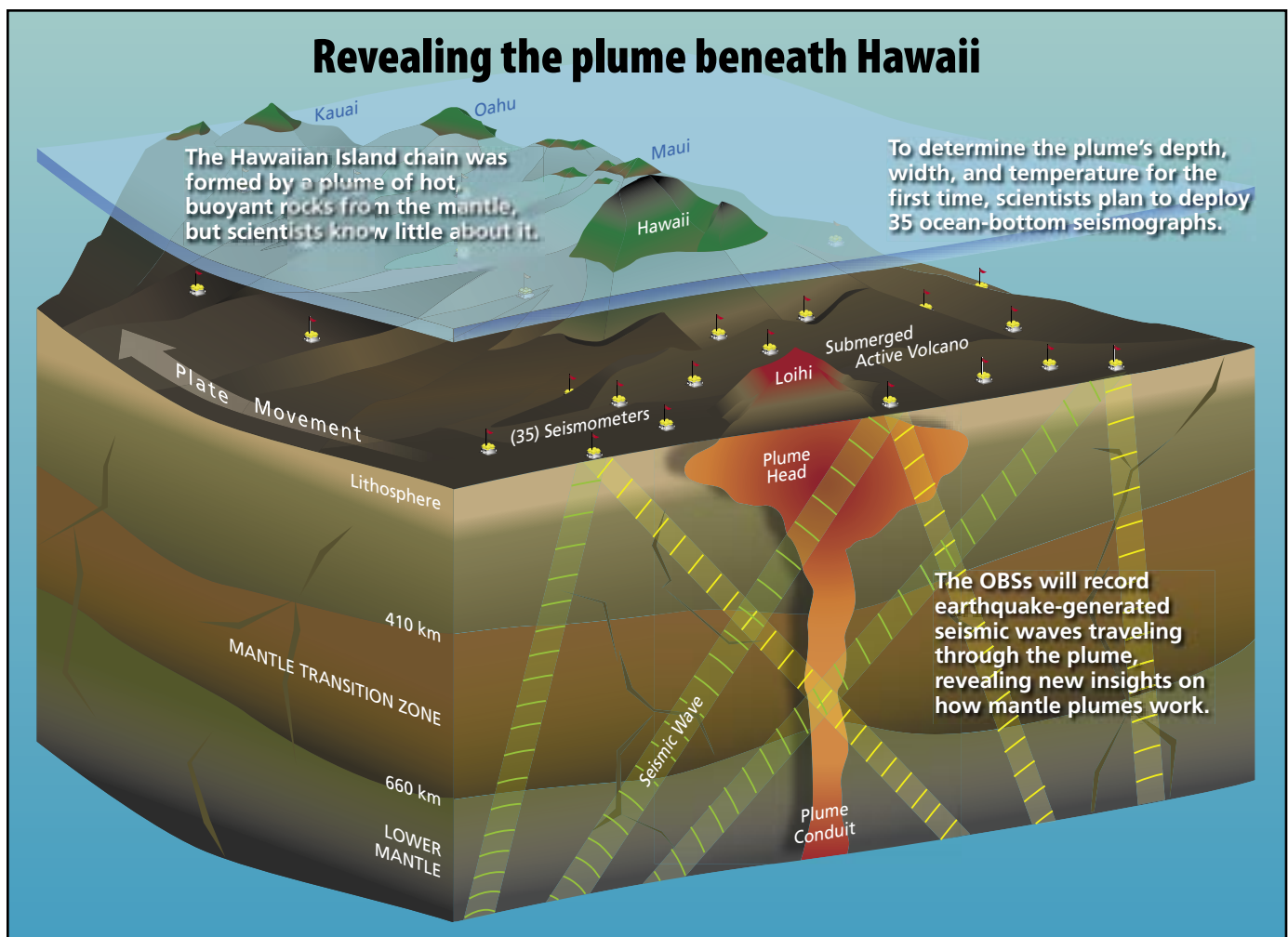
Chemists can monitor reactions in test tubes in their labs. Ecologists can go into the field to make observations. But earth scientists interested in the structure of Earth's deep interior don't have the luxury of seeing their subject close at hand. Without a way to travel through the

earth, we have had to rely on ways to "see" Earth's structure from a great distance.

To accomplish that, our method employs sound, rather than sight. Whenever an earthquake occurs, scientists can tune in and "listen" to it. We use seismometers and seismographs that measure and record earthquake-generated seismic waves that travel along Earth's surface and through its interior. By analyzing these waves, we can

infer a great deal about the characteristics of the materials the waves are traveling through (see "Earthquakes and Seismic Waves" on page 3).

Within the last decade, two factors have helped make seismology the pre-eminent tool for determining Earth's hidden interior structure. First, more permanent and temporary seismographs to record seismic waves have been distributed



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around the globe. Second, international policies have made archives of seismic data freely and widely available on the Internet to any investigator.

Today, excitement and anticipation is growing because of new generations of seismographs designed for use in the oceans. These new instruments are being built at Woods Hole and two other oceanographic institutions, and they will comprise a new national pool of instruments for use by the scientific community. This new national facility will let us monitor more of the planet with the precision we've long wished for, and thus enhance our ability to answer fundamental questions about our planet.

### Mapping Hawaii's plume

Until now, almost all seismic observatories have been located on land, which accounts for only 30 percent of Earth's surface. The lack of evenly distributed seismograph coverage in the oceans has limited our understanding of Earth's structure at both regional and global scales.

On a regional scale, consider the task of understanding the structure of the upper mantle beneath the small geographic region of Hawaii. Hawaii is thought to be the surface expression of a buoyant plume of hot rock in the upper mantle, possibly originating at the core-mantle boundary at a depth of about 2,900 kilometers (1,800 miles). We don't know the width, temperature, or depth of the plume.

To find out, we will need to record seismic waves that travel from a known source, through the plume, to receiving seismographs. But the waves must travel through as little as possible of the rest of the earth, so that we can attribute any anomalies or alterations in the waves entirely to their passing through the plume.

Hawaii's landmass is so small, however, that land seismic stations cannot be positioned in places to intercept waves that travel through the plume at depth—so that we can measure how deep the plume is. Nor are the islands close enough together to let us accurately measure the



Victor Bender

A vanload of new WHOI "D2" ocean-bottom seismographs is readied for field testing. The D2s are small and light, for easy deployment and recovery. With a six-month battery capacity, they are designed for relatively short-term experiments. The D2s are available to scientists through the newly created National Ocean-Bottom Seismograph Instrumentation Pool. WHOI Senior Engineer Ken Peal, who helped design the D2, is in the background.

plume's diameter. The only way to determine the plume's structure is by placing seismographs in appropriate locations to intercept waves that have traveled only through the plume—and those locations are on the seafloor.

### Seismic waves through the earth

To probe Earth's interior on a more global scale, the most useful earthquakes to study are large and deep. But such earthquakes do not occur uniformly over the planet. They happen only in specific geographic areas called subduction zones, where tectonic plates plunge back into the mantle.



Victor Bender

The D2's electronic data logger (above), which records seismic wave measurements, resides in a glass ball in one half of the peanut-shaped D2. Batteries are in the other half.

Seismic waves from these earthquakes radiate through Earth's deep interior to the other side of the globe. But because existing land-based seismic stations aren't distributed uniformly on Earth's surface, we don't receive any information from many areas. That leaves us with large gaps in our knowledge about some parts of Earth's deep interior.

Very large earthquakes can actually set the whole planet vibrating in a series of oscillations, commonly likened to the ringing of a bell, which affect the entire surface of the earth. But we can't measure them over large areas where there are no seismographs, once again leaving us with an incomplete picture of Earth's interior. In fact, the optimum location to observe and measure seismic waves that pass through Earth's core lies in the central Atlantic Ocean—where there are few seismographic stations!

### Seismic data gaps in the ocean

The oceanographic community has long recognized the need for seafloor seismic stations. Since the 1970s, several oceanographic institutions—including Woods Hole, Scripps Institute of Oceanography, and the University of Texas

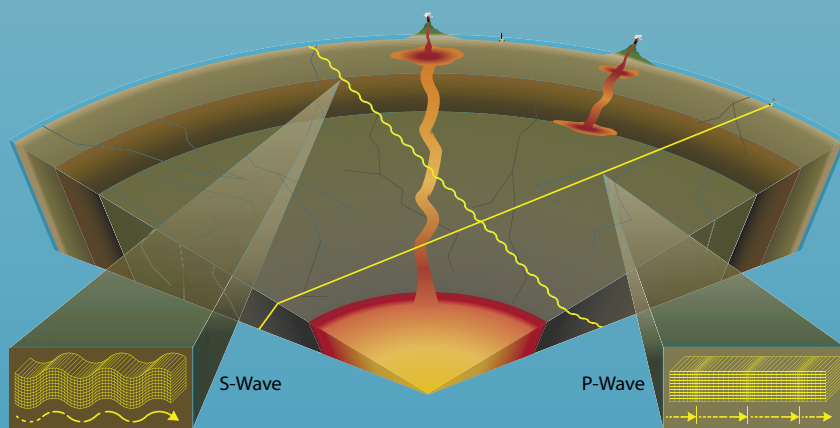
## Earthquakes and seismic waves

When an earthquake occurs, rocks at a fault line slip or rupture, and a portion of Earth's crust physically moves. That releases energy, and two types of seismic waves radiate outward from the earthquake through Earth's interior and along its surface. Compression waves alternately compress and release rocks in the direction the waves are moving (similar to the air compression we hear as sound). Shear waves move rocks perpendicularly to the direction the waves are moving.

Seismographs (seismometers and associated recording systems) detect and measure these waves. Compression and shear waves travel through the earth at different speeds. By measuring the speed of the waves as they travel

through different positions within the earth, we can draw inferences about the temperature, composition, and degree of deformation of the material that the waves travel through. In turn, better estimates of these characteristics improve our understanding of hidden processes that occur in the earth's core, mantle, and crust.

With seismic measurements we can also locate an earthquake's source. The characteristics of an earthquake itself, such as its location, magnitude, fault orientation, and fault slip, are important for understanding tectonic processes at global and regional scales, and seismology is essential for understanding the physics of earthquake initiation and rupture.



**1**—Shear waves (S-waves) move rocks perpendicularly to the direction the waves are moving (similar to waves at the beach).

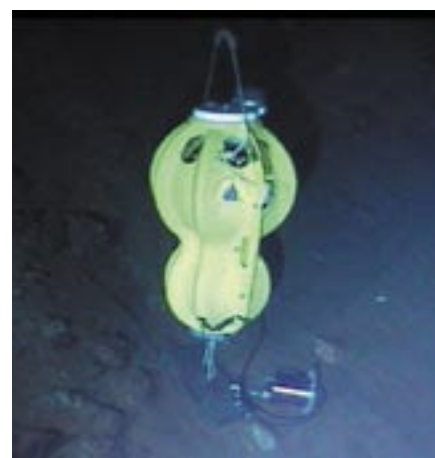
**2**—Compression waves (P-waves) alternately compress and release rocks in the direction the waves are moving (similar to the air compression that we hear as sound).

Institute of Geophysics—have designed, built, and operated ocean floor seismic-monitoring instruments, known as ocean bottom seismographs (OBSs) and ocean bottom hydrophones (OBHs). The research was funded primarily by the Office of Naval Research.

For several reasons, these first-generation OBS and OBH instruments didn't

give us a clear picture of Earth's structure. They required a lot of power, had limited storage capacity, and used inexact clocks that couldn't determine (with enough accuracy) the times when waves from an earthquake arrived.

But today's seafloor seismic instruments are being built with low-power digital electronics, very large storage ca-



Rob Reves-Sohn

A D2 is field-tested on the seafloor near the TAG hydrothermal vent site in the North Atlantic. A weight anchors it to the bottom. The seismometer is housed in the silver canister at right.

pacities, and high-precision clocks that drift only a millisecond a day or less. The older instruments measured earth movements with periods of a second or so, but new seafloor seismometers are sensitive to motions with periods of hundreds to tenths of seconds, which can tell us much more about the earth's deep structure. And new high dynamic range analog-to-digital converters improve upon older converters, which tended to distort both small signals (such as from a distant moderate earthquake) and large signals (such as from a large local earthquake).

### A new national seismic facility

Another obstacle in the early days was a limited availability of OBSs. Most early instruments were available only to investigators at institutions that built the instruments, and these investigators didn't necessarily pursue scientific questions of interest to a broader earth science community. In addition, early seismic data were stored in scattered sites and in a variety of formats, so much of the data remained inaccessible because it was hard to find and use.

Now, with National Science Foundation funding, three institutions—Woods Hole Oceanographic Institution (WHOI), the Institute of Geophysics and Planetary

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Physics at Scripps Institution of Oceanography (SIO), and the Lamont-Doherty Earth Observatory of Columbia University—will form the National OBS Instrumentation Pool.

Each institution will design, build, and operate instruments, and provide engineering and technical support to deploy the instruments on the seafloor. Investigators can request to use OBSs from the national facility as a part of the standard NSF proposal process, and other private and public organizations can use them as availability permits. All data collected with these new instruments will be centrally archived at the same national data repository used by the US land seismological community. After two years' proprietary access for investigators, the data will be available to all.

### Two new kinds of OBSs

WHOI and SIO each will build and operate two distinct types of OBSs. One will be used for short deployments to record predominantly short-period (i.e. high-frequency) Earth motions. The other can be deployed for a year or more to record Earth motions over a much broader range of periods.

Short-period OBSs are usually used in closely spaced arrays for durations of days. They typically record seismic waves from artificial sources, such as those used by the oil-exploration industry, which use compressed air to produce a brief wave pulse. These instruments are used to determine the structure of the outer tens of kilometers of the seafloor.

The WHOI short-period OBSs, called "D2," have a six-month battery capacity and are equipped with a seismometer and a hydrophone. They can detect Earth motions in both vertical and horizontal directions, and can even record small, short-period earthquakes, such as those associated with hydrothermal vent activity.

In typical experiments using short-period OBSs, large numbers of instruments must be deployed repeatedly during 30-day cruises. So the D2s were designed to

be small and light, for easy recovery. They don't need to be opened at sea; instead recorded data can be offloaded easily onto a shipboard data-storage system over an Internet connection.

### A long-awaited experiment

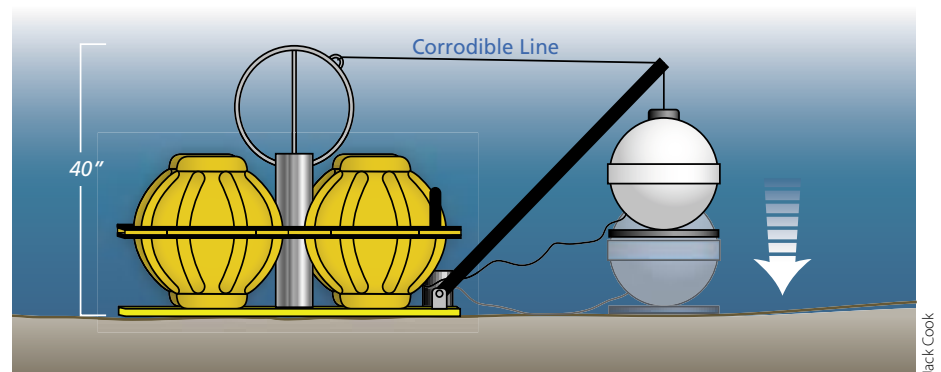
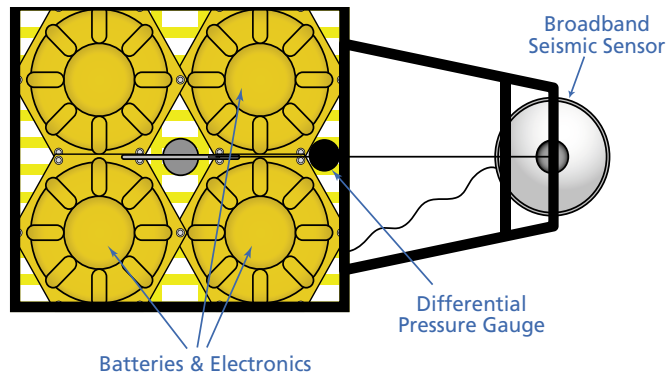
The first short-deployment experiments using D2s were completed in the summer of 2002. In April of 2004, we will undertake our first really challenging experiment, deploying and recovering some 150 D2s during a 35-day cruise.

All three institutions are building long-deployment OBSs. These carry long-period pressure sensors and seismometers capable of recording Earth motions with periods ranging from about 40 seconds to 0.1 seconds. The WHOI long-deployment OBS will have the same data logger used in the D2 OBS, but will be equipped

with a WHOI-designed acoustic modem that will let investigators on research vessels remotely retrieve data from the OBS sitting on the seafloor. This capability will allow investigators to check that the OBS is performing adequately before the ship leaves the area for a year.

The first long-term deployment is scheduled to take place in November/December 2004 off Hawaii in the Plume Lithosphere Undersea Melt Experiment (PLUME). The goal of this two-year long experiment—a collaboration between WHOI, SIO, the University of Hawaii, and the Carnegie Institution of Washington—is to image the Hawaiian plume. This one experiment has the potential to revolutionize our understanding of how Earth's mantle convects.

For earth scientists, the future looks bright, and will sound even better.



WHOI is designing and building new-generation ocean-bottom seismographs (OBSs) for long-term deployments of more than a year. The four orange fiberglass "hardhats," mounted on a plastic grillwork, contain batteries and electronics. A differential pressure gauge measures earthquake-generated waves in the water. The seismometer is housed in a metal sphere at right. When the OBS is deployed, a line corrodes, positioning the seismometer on the seafloor.

Jack Cook