earth scope

EARTHSCOPE EDUCATION AND OUTREACH

Seismic Tomography

WHEN SCIENTISTS WANT TO KNOW MORE about the rocks in a mountain range, they go there. They peer at the minerals that make up the rocks, they examine the weights, colors, and textures of the rocks, and sometimes they even taste the rocks. When scientists want to know more about the rocks deep inside the Earth, they must use other methods because they can't observe the rocks directly with their senses.

Then, how can we explore the rocks that make up the deep Earth? Scientists have drilled holes into Earth's crust, but so far, the drill bit has not penetrated the mantle. Buses can't take us on a field trip through Earth's layers to scout the rock, so we must *infer* its composition. Scientists can infer what types of rocks make up the deep Earth from earthquake recordings.

View an animation of seismic tomography at http://www.iris.edu/about/ENO/aotw/archive/7

Using a technique called seismic tomography, scientists decode the information contained in seismograms' squiggles to develop images of individual slices through the deep Earth. These images are used to understand not only the composition of Earth's interior, but also to help explain geologic mysteries, like how the Sierra Nevada mountains formed and why there has been so much volcanism in eastern Oregon.

> A TECTONIC PLATE SINKING UNDER THE UNITED STATES

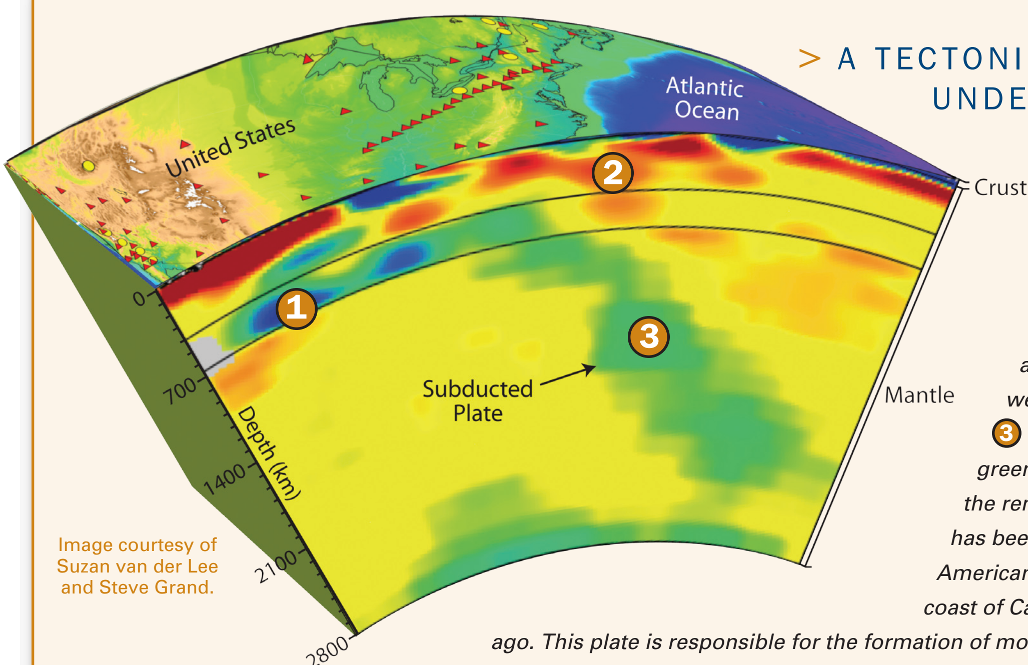


Image courtesy of Suzan van der Lee and Steve Grand.

This actual seismic tomography image shows a cross section of the crust and mantle underneath North America. (1) *Blue and green shades mean colder and stiffer rock and* (2) *red shades mean warmer and weaker regions. Scientists think that* (3) *the green diagonal shape and the green and blue above it and to the west are the remnants of an old tectonic plate that has been subducted underneath the North American plate. It was ocean seafloor off the coast of California more than 30 million years ago. This plate is responsible for the formation of mountains and ancient volcanoes across much of the western United States. The image shows that now the remnants of the plate are still sliding to the east and sinking further into the mantle. Currently, the bottom of the plate is deep under the East Coast and the Atlantic Ocean.*

How Seismic Tomography Works

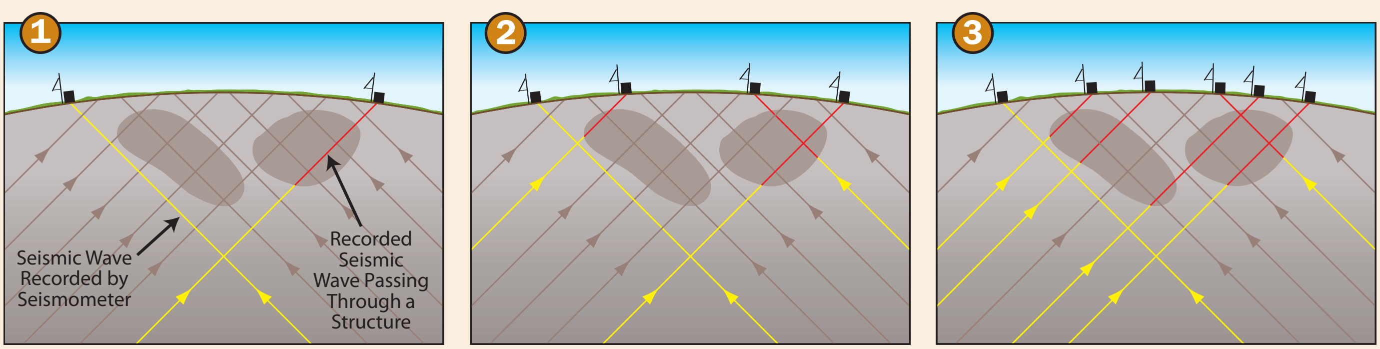
Seismic tomography is like taking a CT scan (or CAT scan) of the Earth. Doctors use CT scans to look at organs and bones inside the body without surgery. CT scan machines shoot X-rays through a patient's body in all directions. Instead of making just one black-and-white image, CT scans make many images, all showing the patient's internal structures from different directions. Computers then combine these images into a three-dimensional picture of the body.

In a method similar to CT scans, scientists instead use seismic waves to make images of Earth's interior. When the ground jolts at the start of an earthquake, seismic waves race outwards from it. These seismic waves travel through the Earth up to the surface, and when they reach the surface, they shake the ground. Seismometers record these up-and-down and side-to-side motions in the form of squiggly lines known as seismograms.

Modern seismometers, which can detect ground motion about 1000 times smaller than the width of a human hair, can record even small earthquakes from anywhere on the planet. After an earthquake, scientists compile digital earthquake records from hundreds of seismometers all over the world. When they've gathered records from many earthquakes at each station, they can start creating high-resolution images of Earth's interior using seismic tomography.

There are many ways to do seismic tomography, just as there are many ways to image the human body, such as through CT scans, ultrasounds, and MRIs. One way starts by marking the arrival time of the first seismic wave, known as the P wave, on each record. Using the distance the wave traveled to the seismometer and the time it took to get there, scientists can calculate the average speed of the seismic waves. They then map out large regions where the seismic waves traveled slower or faster than average. How fast the waves travel depends on the type of material they travel through. Waves travel faster through cold, stiff materials, like a plate subducting into the mantle, and slower through warmer materials, like hot rock rising to the surface.

> IMAGING THE EARTH WITH SEISMIC WAVES



1 Two seismometers on the surface record incoming seismic waves. Only one recorded wave passes through part of one of the structures with different properties than the surrounding material. Scientists examining the recorded seismograms would infer that only one structure is present instead of two.

2 As more seismometers are added, scientists can detect two structures from the recorded seismograms, but they can't determine the size and shape of each.

3 Six seismometers catch enough recorded waves for scientists to start determining the borders of the structures. With dozens of seismometers, scientists can produce an image of a slice of the Earth.

> INSTALLING SEISMOMETERS AROUND THE WORLD

Seismologists work inside at computers most of the year, but part of their job can require traveling to places far away from the background noise of human civilization to install seismometers. Engineers who work for EarthScope get to travel to a new spot everyday to install and maintain seismometers. (1) *Many places are so remote that no electricity supply is nearby, so crews install solar panels to power the equipment. Seismometers are not like the drum and pen recording systems you might see at a museum.* (2) *Modern seismometers instead contain delicate moving parts inside a metallic case that is the size of a gallon paint can.* (3) *The seismometer and its electronics are placed in an insulated plastic tube. Also inside the tube is a computer connected to the Internet, which transmits the recorded seismic waves to a data processing center in California. Once the tube is sealed, the seismometer is ready to record earthquakes from around the world.*

A fast wave tells you the wave may have passed through cold material, but you cannot determine where the wave encountered the material or the material's shape and size from just one earthquake recording. The situation would be as if a normally "exactly on-time" friend arrived late to a party. You know her car was likely stopped in traffic along her route, but without talking with her you can't know the location of the traffic jam or how large it was.

If you then start writing down when other friends arrive at the party, and if you know the routes from their houses to yours, you might be able to map out what streets had traffic and how big the jam was. The more information you record about the arrival times of your friends, the more accurate your map of the traffic will be. Scientists have to solve the same sort of puzzle to figure out the location and size of structures deep below the surface. After processing data from huge numbers of seismic waves (sometimes millions!), scientists can produce an image of a slice through the deep Earth. The image shows areas where seismic waves travel faster or slower than average, thus, scientists can infer structures, such as sinking tectonic plates and magma beneath a volcano.

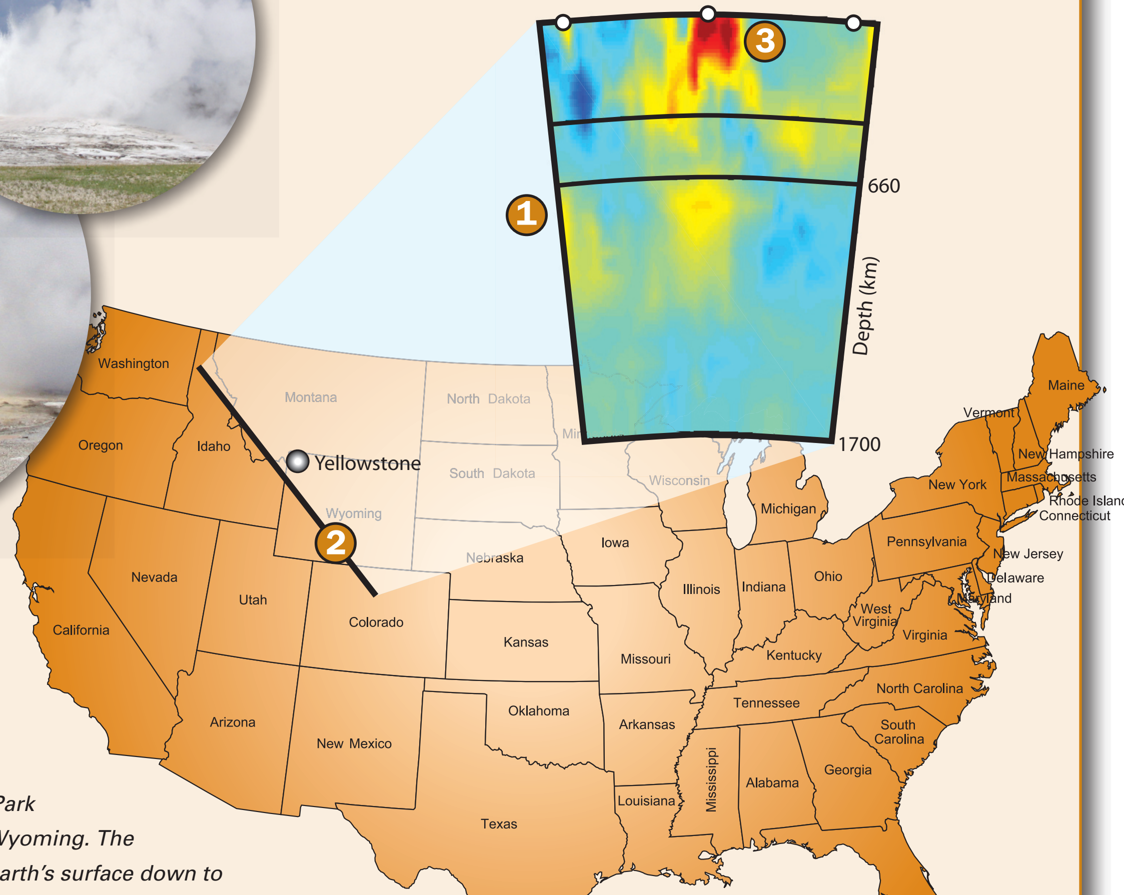
So far, seismic tomography has taught scientists that Earth structure is more complicated than a simple layered sphere divided into a crust, mantle, and core, as depicted in many textbooks. The mantle, for example, contains materials of different compositions and temperatures. It holds plumes of rising hot rock and warped pieces of old oceanic crust and mantle that have been subducted beneath other tectonic plates. The images we have now of Earth's interior are like blown-up pictures taken from early models of digital cameras. As more seismometers are placed on the surface to catch more seismic waves, the pictures are becoming sharper and scientists are seeing more details. With these details, scientists are making new discoveries about structures in Earth's interior, and with each new set of images, they are changing the ways we think about how the Earth works.

EarthScope and Seismic Tomography

OVER THE NEXT TEN YEARS, scientists are going to be able to upgrade their knowledge of Earth's interior through an exciting project called EarthScope. One part of EarthScope involves blanketing the entire United States with seismometers. EarthScope field crews install 20 new seismometers every month. They started by placing stations in the west and are now working their way east. If you live in the Northeast, your seismometers will not be installed until 2013.

Data recorded by all these seismometers will allow scientists to develop the sharpest images yet of Earth's interior. From these images, scientists can devise new ideas about how the North American continent formed and evolved.

> IMAGING YELLOWSTONE



Tomographic image courtesy of Scott Burdick et al.

1 This tomographic image shows a cross section of Earth's crust and upper mantle along 2 the line on the map. The center of the line passes through Yellowstone National Park in the northwestern corner of Wyoming. The image shows structures from Earth's surface down to a depth of 1700 kilometers (that's 1050 miles).

3 Guess what the dark red shape is? That's the hotspot beneath the Yellowstone supervolcano. It is warmer than the surrounding rock. The underground heat causes 4 the famous geysers and bubbling mudpots at Yellowstone. The most recent volcanic eruption from the Yellowstone hotspot volcano was 70,000 years ago, but the tomographic image shows that magma still exists beneath the caldera (a wide depression that can form as a volcano collapses). One day in the future, Yellowstone will explode again, but we cannot predict when.