Research in Progress

Inside Information

PROBING THE INTERIOR of the earth to figure out the processes that determine its surface configuration has been a daunting problem for modern technology. But a recently developed technique combining seismology and computer modeling techniques has enabled scientists to construct images of the earth's crust and mantle down to the core-mantle boundary and to begin to understand the convection mechanisms in the mantle that drive the moving plates of the crust.

Seismic tomography was adapted from medical technology — computerized axial tomography, better known as the CAT scan — that has allowed the three-dimensional imaging of the inside of the human body. Robert Clayton, assistant professor of exploration geophysics, pioneered the application of tomographic techniques to the earth. A CAT scan uses x-rays, which are variously absorbed by the different densities they pass through, to image, say, the brain. The computer is used to reconstruct a three- dimensional picture of the density by creating a composite of the information measured from many ray paths onto a grid of cells. High-resolution pictures can be achieved if the experiment contains many crisscrossing ray paths.

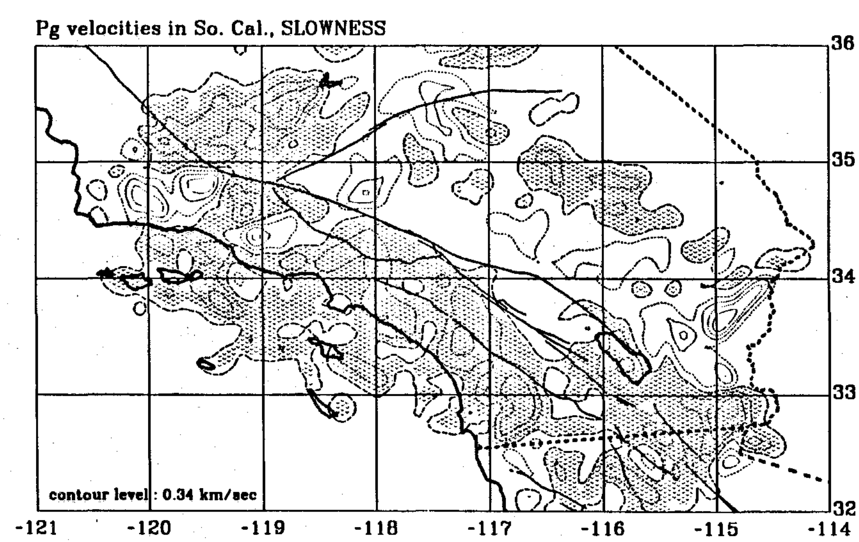
Instead of x-rays, seismic tomography measures the velocity of the waves generated by earthquakes that travel through the earth; the rate at which these waves propagate is affected by the rigidity and compressibility of the material they are traveling through. They travel faster through denser, or colder, rock. Signals recorded from various earthquake sources at arrays of seismographic stations, both local and worldwide, provide the crisscrossing network of rays necessary for a three-dimensional image of the intervening space.

Using seismic data from local earthquakes recorded on Caltech's southern California seismic array, Clayton and his colleagues have mapped the crust below southern California to 30 km; teleseismic, or more distant, events, recorded on the southern California array provide clues to the underlying mantle (to 500 km); and a worldwide network of seismic instruments is providing a picture of the earth's mantle down to the core boundary at 2900 km. The cells determining the resolution of the crustal study are 5 by 5 by 15 km; the upper mantle was imaged with a resolution of 50 by 50 by 50 km, and the global study at 500 by 500 by 100 km.

Clayton and Thomas Hearn (PhD 1984) delivered a paper on the first seismic tomography crustal maps of southern California at the December meeting of the American Geophysical Union. They used two types of waves to obtain images of the crust at two depths: Pg waves, which dive down into the mid-crust at 10-15 km and back up, and Pn waves, which dive 30 km to the edge of the mantle (the Moho discontinuity) and travel along it before returning to the surface. Travel times of approximately 300,000 waves were measured from earthquake sources within the southern California array (an area about 400 by 500 km) to their recording at the array's more than 200 seismographic stations.

The middle of the crust, according to Clayton and Hearn's findings, is intimately related to the surface tectonics, and, in fact, the tomographic maps show features recognizable to anyone reasonably familiar with southern California's surface geology. The San Andreas fault shows up as a sharp boundary with rocks on the eastern side characteristic of the less dense American plate, while that on the western side exhibits its origin in the Pacific plate. The Garlock and San Jacinto faults are also clear at this depth, but, surprisingly, the Transverse Ranges, including the San Gabriel and San Bernardino Mountains, are not visible as deep as 10 km below the surface and probably consist of rock that has migrated from elsewhere.

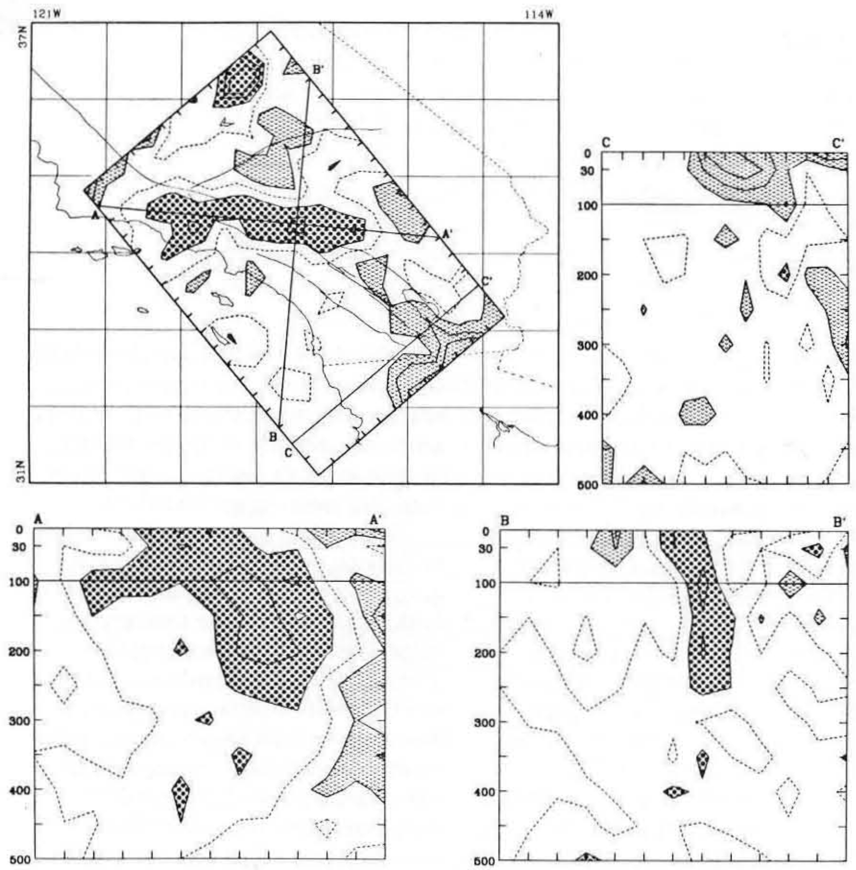
The lower part of the crust seems to have no immediately recognizable



Velocities of Pg waves under southern California show a clear relationship between the mid-crust (at 10-15 km) and the surface features. The San Andreas fault marks a sharp boundary at the denser (shaded) rock of the Pacific plate.

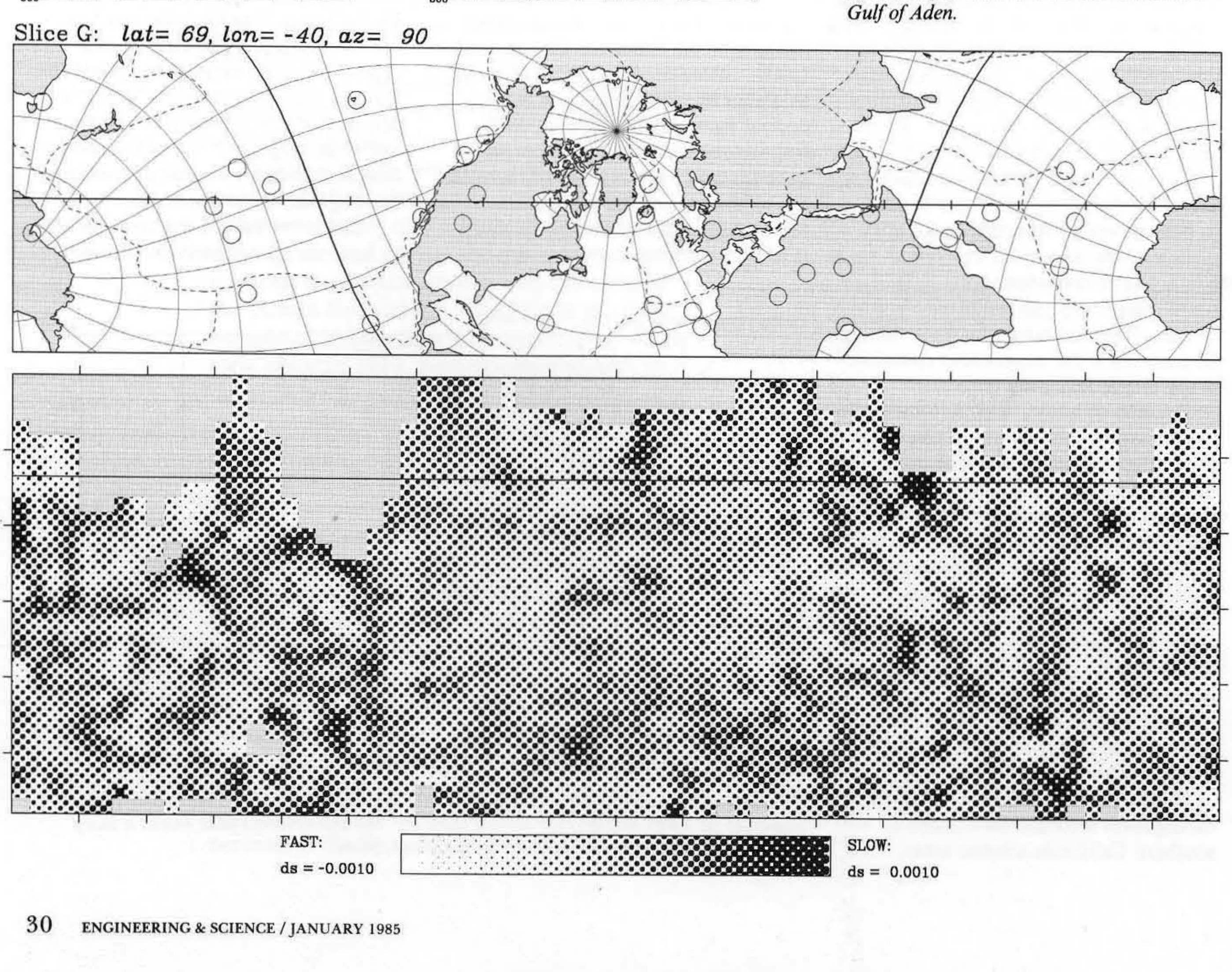
relationship to surface features. Clayton and Hearn determined from their data that the crust of southern California is of varying thickness, that under the Los Angeles and Ventura basins lies a 10-km-thick layer of sediment (a fact that may have been responsible for the unexpectedly great damage from the 1971 San Fernando Valley earthquake), and that the Moho boundary is deformed below the San Bernardino Mountains.

The Transverse Ranges were also involved in the most prominent feature found in a study (using teleseismic data) of the mantle underlying



*(**Left**) In the top left panel the mantle structure at a depth of 100 km indicates the presence of a small convection cell with cold downward convection under the Transverse Ranges related to the warmer upwelling in the Salton Trough. Cross sections to a depth of 500 km are shown in the other panels.*

*(**Below**) A slice through the mantle to 2900 km shows evidence of known hot spots in the upper mantle under Iceland and the Afar triangle, where the Red Sea meets the Gulf of Aden.*



the same region by Clayton, Bradford Hager, assistant professor of geophysics, and grad student Eugene Humphreys. This was a high-velocity anomaly beneath the mountains — a vertical slab extending downward to approximately 250 km on the deepest (eastern) side. The three scientists speculate that the Transverse Ranges are the site of a cold downward convection in the "viscous" mantle, related to the active geothermal "hot" area observed in the Imperial Valley, possible an upwelling in the mantle. This may be an example of a small convection cell under southern California, causing compression under the mountain ranges and locking the Big Bend of the San Andreas fault.

In their global seismic tomography mapping Clayton and Hager found significant variations in the mantle that appear to be related to a much broader scale of convection. Creating maps of the entire mantle down to the core boundary at 2900 km required data from 25,000 earthquakes recorded at a worldwide network of 1500 seismographic stations. More than 2 million rays were analyzed (this originally took many days' worth of computer time). Although there is evidence of such known hot spots as exist under Iceland, Hawaii, and the Afar triangle, the larger anomalies occur toward the bottom of the mantle. Few obvious patterns emerge immediately from the data, which should keep geophysicists busy for quite a while. Hager is currently using the densities to compute the earth's gravitational response, to corroborate the theory that variations in the earth's gravity are due to convection. And ultimately these first pictures of the dynamic processes going on inside the earth may be the key to understanding how our planet works. □ — *JD*