must be taken in interpreting the statistics. Although he basically agrees with Bailar and Smith, Marvin Zelen of Harvard University offers a few cautionary notes. For example, Zelen says, "if you really cure people, you only know about it if they live a long time. The vital statistics of today might reflect the therapies of 10 to 15 years ago."

There also is the problem of interpreting mortality data. These data are usually taken from death certificates. But, Zelen notes, "there are many patients who die of cancer but do not have cancer listed as the cause of death on their death certificates."

Still another caveat is that the data on cancer may be skewed by the changes in heart disease mortality. "Mortality associated with cardiovascular diseases is going down and so more people are at risk for other diseases. They may then die of cancer," Zelen remarks.

A final difficulty, according to Zelen, is in the very age-adjusted rate concept itself. Eleven to 12% of the population is older than age 65, but 60% of those who die from cancer are older than age 65. "When you quote age-adjusted figures, all the action is in those over age 65. If anything is going on [in the mortality data], it gets modulated." In other words, to make a big difference in the age-adjusted rates, you have to concentrate on the very oldest members of the population, who may be least likely to live significantly longer with better treatments.

Yet despite the difficulties in interpreting data, analyses such as Bailar and Smith's do raise important policy questions. Where should the emphasis be in combatting cancer? Bailar and Smith argue that there should be more emphasis on prevention, specifically on smoking cessation. "The major conclusion we draw is that some 35 years of intense effort focused largely on improving treatments must be judged a qualified failure," they write in their *New England Journal* article.

Others, while not denying that cancer prevention is a major goal, are not yet ready to throw in the towel on treatments. Edward Sondik, who is chief of surveillance and operations research at the NCI, notes that in order to assess current treatments, researchers must predict how recent apparent advances will affect survival statistics and how long it will take for the effect to show up in mortality data. Then they must look for their predicted effect. Sondik and his colleagues are doing such analyses now.

With all these complications in interpreting the data, there is no simple answer to the question of whether the war on cancer is being won. "It gets very political," says Zelen. "Unfortunately, people have all sorts of axes to grind." ■ GINA KOLATA

The Continental Plates Are Getting Thicker

Petrologists and seismologists now agree that the old cores of the continents have deep roots extending well below the thickest ocean plates

A continent and an ocean basin, so different that one is usually high and dry and the other is forever filled with water, were assumed to be structured much the same beneath the surface. Each seemed to be composed of slabs of rigid rock as much as 100 kilometers thick, the tectonic plates that together cover the globe and drift about it on a layer of viscous rock.

There is now a consensus among earth scientists that continental and ocean plates differ in more than their height with respect to sea level. To judge from the rock recovered from beneath the oldest crust of at least one continent, long-lived continental roots extend downward as much as 190 kilometers into the 650-kilometer-deep upper mantle. But to judge from the way seismic waves pass beneath the continents, the roots extend 250 or even 400 kilometers beneath the surface. Reconciling this difference is the next task for seismologists and petrologists, but it is clear that somehow, perhaps through the collisions of plate tectonics, continents have stabilized part of the mobile mantle rock beneath them to form deep roots.

The first telling evidence of the existence of continental roots came from observations of the waves passing beneath continents from large earthquakes. In the mid 1970's, Stuart Sipkin, now at the U.S. Geological Survey in Golden, Colorado, and Thomas Jordan, now at the Massachusetts Institute of Technology (MIT), found that seismic waves passing beneath continents traveled faster than those passing beneath ocean basins.

They probed these two types of regions by comparing the speed of waves reflected off the core directly to a seismometer with those that bounced between the core and the surface twice rather than once. The primary difference between the two paths is the passage of the waves through the upper mantle near the surface reflection of the longer path. When the surface reflection occurred in an ocean basin, the difference in the time required to traverse each path was considerably greater than when the reflection point was in a continent. Thus, the waves traveled much faster than expected through the upper mantle and crust beneath the continent than beneath the ocean basin.

Sipkin and Jordan attributed the differences among the pairs of mantlewide paths to differences in the rock that extend at least 200 and perhaps more than 400 kilometers below the surface. Jordan took these and other seismic observations, combined them with geochemical, petrological, and geophysical data supporting such deep-seated differences, and proposed that the drifting continents carry with them at least several hundred kilometers of chemically distinctive mantle rock.

In the last few years, several seismological studies based on the use of different analytical techniques and different kinds of seismic waves that follow various paths through the mantle have supported Jordan's contention that the first few hundred kilometers of mantle beneath continents are somehow different. In 1984, John Woodhouse and Adam Dziewonski of Harvard University mathematically combined observations of waves that travel near the surface and within the upper mantle. They used the same type of analysis developed for the medical x-ray technique called computerized axial tomography or CAT scanning. The resulting three-dimensional map showed zones of relatively high seismic velocity extending 250 to 350 kilometers beneath the continents. New analyses including more than three times the number of initial observations produce similar results, says Woodhouse.

Arthur Lerner-Lam of Lamont-Doherty Geological Observatory and Jordan have recently used surface seismic waves particularly suited to mapping changes in seismic properties with depth to probe the western Pacific and the Eurasian continent. By building mathematical models of the mantle to reproduce the seismic wave shapes that they found, Lerner-Lam and Jordan tried to find some structure of the mantle that could reproduce their results while keeping differences in mantle structure at minimal depths. Confining the differences to depths shallower than 220 kilometers does not work, says Lerner-Lam, although the differences probably do not extend deeper than 400 kilometers.

Stephen Grand of the California Institute of Technology has recently applied tomographic analysis to the travel times of seismic waves that pass through the mantle beneath North America without reflecting off the core. He found a high-velocity root extending as deep as 400 kilometers beneath the Canadian shield, the old, stable part of North America. The deepest, highest velocity part of the root lies below the Superior craton, the central core and the oldest part of North America.

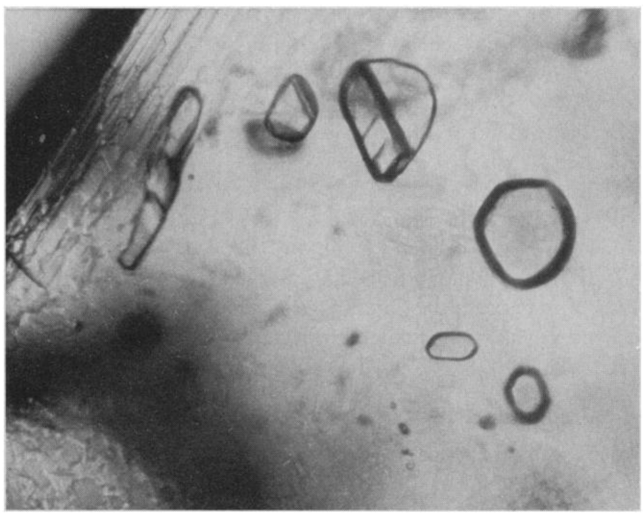
Jordan's claim that permanent continental roots produced such seismic anomalies created controversy during the late 1970's in part because the current theory of plate formation required thin plates. In 1978, Barry Parsons of MIT and Dan McKenzie of the University of Cambridge proposed that oceanic plates, no matter how long they lost heat from their upper surfaces, could grow no thicker than about 90 kilometers. Cool mantle might extend below the rigid plate to about 120 kilometers, according to the theory, but before this subplate region could cool enough to "freeze" to the plate and thicken it, the cooling mantle layer would become unstable, fall away, and be replaced by hotter mantle flowing in to replace it. This theory of the thermal boundary layer has provided a good explanation for the thickness of oceanic plates, and seemed likely to work as well for the continents. It has not.

"The evidence is now against us for applying thermal boundary theory to the continents," says Parsons. The best evidence in support of thicker continental plates, he says, comes from recent studies of strange volcanoes called kimberlite pipes that tapped so far into the mantle and delivered debris so quickly to the surface that they provide geologists with the deepest rock samples available, including diamonds. These upper mantle samples reveal that at least beneath southern Africa a continental root extends 170 to 190 kilometers, well beyond the theoretically predicted depth.

Last year, Francis Boyd of the Carnegie Institution of Washington's Geophysical Laboratory, John Gurney of the University of Cape Town, and Stephen Richardson of the Institute of Physics of the Globe in Paris reported on studies of diamonds and diamond-bearing rocks found in South African kimberlite pipes. They analyzed tiny mineral crystals encased in diamonds and mantle rocks that held diamonds for some time before eruption for elements whose abundances depend in known ways on temperature and pressure. Results from three different mineral systems placed the formation of the diamonds at depths between 150 and 200 kilometers.

A petrologist's best friend

The composition of these clinopyroxene crystals embedded in a diamond from the Premier Mine in South Africa can help determine the temperature at which the diamond crystallized. These analyses of diamond inclusions and others have shown that such diamonds formed near the tip of a deep continental root extending almost 200 kilometers into the mantle.



R. Moore

Perhaps even more surprising were the temperatures of 900° to 1200°C at which the diamonds formed. That range encompasses the temperatures expected at those depths today. But, as shown in 1984 by Richardson, Gurney, and their colleagues using the neodymium-samarium isotope technique, these diamonds formed 3.2 to 3.3 billion years ago in the Archean eon, a time when twice as much heat was flowing from the interior of the earth as today. Somehow, a deep, cold root formed beneath the Kaapvaal craton, where the diamond-bearing kimberlite pipes occur, despite the greater heating that was expected to keep Archean plates even thinner than the present 100-kilometer maximum.

Jordan has explained the stability of such deep roots in terms of their chemical composition. A cold root having the same composition as the surrounding mantle would be dense enough to break away and sink, but if the root were made of slightly less dense rock than its surroundings, the effect of temperature on density could be counteracted. Boyd and Gurney note that the rocks of the root beneath the Kaapvaal craton are slightly richer in magnesium than those in oceanic plates, which would indeed tend to make the root lighter.

The enrichment in magnesium, they say, could have occurred during the Archean when more magnesium was left behind in the mantle by the greater volumes of basaltic magmas extracted from the mantle to form new crust. Henry Pollack of the University of Michigan adds that the accompanying loss of volatile compounds such as water would have tended to stiffen the remaining mantle rock as well. Simple squeezing of an existing plate into a thicker one, as is now happening beneath the Himalayas in the collision of the Indian and Eurasian plates, could actually be the basic process that forms roots, says Jordan.

Pushing continental roots down to almost 200 kilometers now seems acceptable to all, but there remains the question of how much deeper they can go. Seismologists see 200 kilometers as a bare minimum for whatever it is that creates the anomalies that they see. On the other hand, petrologists and geochemists see good reason to stop just short of 200 kilometers. When the kimberlite pipes of southern Africa erupted about 100 million years ago, they broke mantle rock off the walls of their conduits up to 190 kilometers down.

One group of these xenoliths, according to work by Boyd and Gurney, came from a zone having about the same high temperature, near their melting point. But the zone had varying depths, 170 to 190 kilometers beneath the craton but only 140 kilometers outside of it. Boyd and Gurney suggest that this zone lay at the base of the rigid plate 100 million years ago, just within the viscous athenosphere on which the plates move. Below that, the mantle would have been decoupled from the continent. Certain types of seismic waves do in some places detect a moderate change in mantle properties at depths of around 200 kilometers, but, as several seismologists point out, that does not explain away the pervasive deeper anomalies. Resolution of the question might come from thorough seismic experiments coincident with the kind of geochemistry and petrology available from southern Africa. ■ RICHARD A. KERR

ADDITIONAL READING

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