interface. When these seismograms are used as the input to the spatial model incorporating the original velocity structure, the wavefronts concentrate with increasing extrapolation to give a sharp image of the source that generated them. It is also possible to distinguish multiple sources occurring at different times and so, in principle, detect the propagation speed of a source.

Improved estimates of seismic source locations would be particularly useful in several problems. Following a major earthquake there is normally a sequence of smaller 'aftershocks', and the spatial distribution of these events often provides the best indicator for the region of the fault ruptured in the original earthquake. Also, the changing location of seismic events beneath a volcano can give information on the movement of magma and the likelihood of an eruption.

How far, then, is a scheme such as McMechan's able to help with improving source parameters? With a scattered network of stations it is clear that no improvement is likely over existing methods. A tightly distributed network of digital stations would give good results, provided the seismic properties of the region are well established. Imperfections in structural information would be reflected in smearing of the source images and the generation of 'ghost' sources. A potential advantage of the approach is that no specific interpretation needs to be made of the various arrivals on the seismograms, since their interrelation is unravelled during the backward extrapolation. But, when both compressional waves and transverse waves are recorded at the same station for a particular event, it will require recordings of all three components of displacement and the use of the full elastic wave equation to get the best image of the source.

The new method is likely to stimulate much further work but offers no panacea for painless seismic source extraction. □

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Earth science

A new look at the inner core of the Earth

from Don L. Anderson

THE inner core is slightly smaller than the Moon but is more than three times denser. It represents less than two per cent of the mass of the Earth but nevertheless has had important effects on the Earth's magnetic field and on the thermal history of the core.

The change in physical properties at a radius of about 1,215 km that defines the inner core has usually been interpreted as stemming from a melting phenomenon related to crystrallization of the inner core. A recent high-resolution study by Choy and Cormier[1] of the outer part of the inner core indicates that this may actually be an oversimplification. The rigidity and viscosity of the outer core are known to be very low and convection is presumed to take place with ease, as this is required by dynamo theories of the Earth's magnetic field. The new study suggests that the rigidity at the top of the inner core is also very low, perhaps zero, and increases gradually with depth.

The inner core was discovered in 1936 by the Danish seismologist Inge Lehmann[2]. Birch[3] and Bullen[4] concluded that it was solid, and later work showed that its density was consistent with that of solid iron with, perhaps, some nickel. Thus, the inner core appeared to be a small dense solid body suspended in a fluid outer core.

More recently it has been shown that at least part of the inner core–outer core boundary is sharp, that its Poisson's ratio is very high and that it attenuates seismic energy more rapidly than the outer core. Oscillation and precession of the inner core may be important in maintaining and modifying the dynamo. It is not clear whether the inner core shares the same rotation axis as the mantle, whether it spins at the same rate, or if it follows the polar wanderings of the mantle.

It is usually assumed that the inner core–outer core boundary represents the zone where the melting point of the iron-rich alloy making up the outer core is passed. Although the inner core may simply represent frozen outer-core material, no light element is required in its makeup. If the inner core has crystallized over time, it may have excluded the lighter elements to the outer core. The inner core may also represent a glassy-type transition[6,7] and simply have a higher shear viscosity than the outer core rather than have the rigidity of lattice. If this is the case, the increase of 'rigidity' with depth would be gradual, since pressure can be expected to increase viscosity. The 'boundary' between the outer and inner cores would be the depth at which the viscous relaxation time is the same as the frequency of the seismic wave which is interrogating it. The location of the boundary would be frequency dependent. The inner core would be much smaller at free oscillation periods than for 1-s body waves, and perhaps would not exist at tidal and longer periods.

Analysis of seismic waves by Choy and Cormier allowed them to conclude that there are strong gradients in the velocities of P and S waves and anelasticity in the upper 200–300 km of the inner core. The compressional velocity jump is about 5 per cent, substantially less than previous estimates, and the shear velocity may be nearly zero at the top of the inner core. Another recent study[5] presents models with high gradients in shear velocity over the outer half of the inner core. These results plus the high gradient in bulk modulus and anelasticity are suggestive of a broad transition region.

The pressure interval of the anomalous gradient is 0.1–0.3 megabars, much greater than the pressure interval of transition regions in the mantle. It is hard to imagine how a fluffy or partially molten or two-phase inner core could exist over such a large pressure interval. Turbulent convection could keep solid particles in suspension, but this would require a high temperature gradient. The temperature gradient at the center of the Earth, of course, should be zero. It is also hard to reconcile the high attenuation of the outer part of the inner core with a slurry. In this case the Q should initially decrease with depth, starting at the high values appropriate for the fluid outer core.

If the inner core is a viscous fluid, with the relaxation time increasing with pressure, then the shear velocity, for a given frequency seismic wave, increases from zero to a finite value controlled by the viscosity. The absorption is very high where the velocity is low and increases as the velocity increases. If this is true, the transition depth would depend on frequency and the boundary would have little to do with the melting point of iron. A viscous fluid can transmit shear waves but would still be able to flow in response to longer-term stresses. The interesting possibility would then exist that there is no inner core at all on time scales relevant to convection in the core.

The concepts of a solid and crystallizing inner core are important in calculations of the geometry and energy sources of the dynamo. If the inner core is a viscous fluid, rather than a crystalline solid, then the anomalously low shear velocity and high Poisson's ratio would have a simple explanation. A critical experiment now is to determine whether the radius of the inner core varies with frequency. □

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