ONE-AND-A-HALF LAYER CONVECTION?...

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Recycling at convergence zones is very much dependent upon the fate of the subducting lithosphere in a convecting mantle. Hot spots also play a key role in the understanding of the circulation in the mantle.

In the present contribution, I review some of the seismological and geodynamical constraints on the layering of convection and on the origin of hot spots. This leads me to propose a speculative model in which convection is layered (upper mantle/lower mantle), but where narrow intense density anomalies (such as hot spots or slabs) can partly pass across the interface.

THE LAYERING OF CONVECTION IN THE MANTLE

The debate is an old one: is the circulation associated with the motion of the plates mantle-wide or restricted to the upper mantle?

Many of the arguments against layered mantle convection come from the ideas one has concerning the interface between the two layers. In particular, if heat can be carried only by conduction across the interface, one expects boundary layers to form above and below the interface. This yields a temperature increase across the boundary. Arguments have been developed to prove that this was in contradiction with observations. Davies (1983) proposed that this would reduce the viscosity of the lower mantle down to an unacceptable value. Spohn & Schubert (1982) have argued that the deduced temperature in the lower mantle would be too high. Dziewonski & Woodhouse (1987) have found that there was no evidence for boundary layers in the models of lateral heterogeneities of the transition zone obtained from seismic tomography.

I will challenge these arguments, using a revised value for the temperature increase expected across the interface. Indeed, recent progress in the understanding of convection with a temperature- and pressure-dependent viscosity (Richter et al., 1983; Morris & Canright, 1984; Christensen, 1984, 1985; Nataf, 1986) lead me to propose that the

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temperature should increase by no more than 300 K above the interface and 150 K below it.

However, convincing evidence has been found by Creager & Jordan (1984, 1986) that the lower mantle was anomalously fast under several subducting slabs. If the mantle is layered, this would imply that downwelling convection currents systematically form under subducting slabs. This is not unexpected since laboratory experiments on layered convection show that "thermal coupling" is the preferred mode of coupling (Moreno & Nataf, 1985). Nevertheless, even in that case one does not expect the coupling to be systematic. Therefore, we will follow Creager & Jordan in assuming that their observations imply that some slabs do penetrate into the lower mantle. I will, however, argue that other observations suggest that this is not always the case, or else that slabs can rise up back into the upper mantle after they have warmed up. Indeed large scale heterogeneities are detected at the base of the upper mantle (Masters et al., 1982; Nataf et al., 1984; Woodhouse & Dziewonski, 1984): they are best explained as remnants of cold subducted lithosphere. In my view, the 2% (300K) anomalies observed are difficult to explain if convection is whole mantle.

THE ORIGIN OF HOT SPOTS

The fact that hot spots do not seem to move with respect to each other indicate that their origin is, at least, deeper than the base of the lithosphere. However, seismic surveys fail to detect anomalous mantle under most hot spots, except in the lithosphere. These two observations put together indicate that the "pipe" that feeds a hot spot is narrow (<100 km).

In turn, that and the fact that hot spots last for more than 100 Ma indicate that their feeding is regulated. This excludes, for example, that they form from large chunks of buoyant material, as proposed by Davies (1984), since these would tend to rise as a whole. Only in a thermal boundary layer can regulation occur: while material that has become unstable is rising up, new material replaces it that will also become unstable, and so on.

Which boundary layer do hot spots come from?

Let's suppose that they come from the lower boundary layer of the upper mantle. One needs then to explain how they can tap the lower mantle, in order to explain their "primitive" isotopic component. Laboratory experiments show that material of the lower layer can indeed be entrained by uprising currents in the upper layer (Moreno & Nataf, 1985). Quantification of this phenomenon shows that the contamination of the material could be large enough to explain the observations. It remains difficult, however, to explain why hot spots move so little. Indeed, the return flow in the upper mantle should make them move at a speed of at least 5mm/year, in contradiction to the observations.

Probably higher large-scale horizontal velocities are, in fact, needed in order to explain the relative homogeneity of MORB (Richter et al., 1982). Finally, hot spots do not seem to be associated with hot regions of the upper mantle as revealed by seismic tomography, while the lower mantle is hot where hot spots are found.

I will therefore consider that hot spots come from the thermal boundary layer at the core-mantle interface. The major problem is then to explain how they can rise across the interface between the upper and the lower mantles.

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The two major problems we are left with are of the same kind: how can buoyant material (hot: hot spots; cold: slabs) get across the interface between the two layers of the mantle while not disrupting the overall layering?

Our laboratory experiments indicate that when the density contrasts due to convection become as large as the intrinsic density contrast that makes the layering, the deformation of the interface becomes huge and overturn occurs. This is because large cushions of hot (cold) material get stuck below (above) the interface. In the case of narrow intense density anomalies, it is, however, possible that they could rise across the interface, if they do not pile up at the interface, or if they do so only after they have lost most of their buoyancy. Thermals in a Newtonian fluid might never fulfill that condition, but I find it conceivable that the somewhat rigid slabs, and the hot spots that burn their way up, would.

Finally, I note that in such a model some material gets across the interface. Therefore, part of the heat can be advected through the interface, and the temperature increase across it is lowered.

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