MECHANISMS OF EARLY PLANETARY DIFFERENTIATION, Donald L. Turcotte and Steven H. Emerman, Department of Geological Sciences, Cornell University, Ithaca, New York 14853

Most studies of planetary accretion favor homogeneous or near homogeneous accretion of the earth. If this is true then the earth's iron core must have formed by differentiation early in the earth's evolution. It is easy to show that the energy release associated with core formation would be sufficient to melt the entire earth if the energy was uniformly distributed (Flasar and Birch, 1973). Core formation can be easily explained if the entire earth was molten early in its evolution. The immiscible liquid iron would have fallen through the silicate to the center. However, the generally accepted chemical models for the evolution of the earth preclude total melting. It is presumed that total melting would have expelled the volatiles which are now found at areas of surface volcanism. It is also presumed that total melting would have resulted in a strongly differentiated earth with near surface rocks similar to those found in the lunar highlands.

The possibility of an entirely liquid earth cannot be dismissed, however. As the liquid earth solidified, solid-state thermal convection could have homogenized the mantle. Thus the crucial question is whether the volatiles could have remained in solution during the melting and solidification processes.

Assuming, for the moment, that the earth was not totally molten, is it possible to propose a mechanism for core formation that does not lead to a uniform distribution of the energy of differentiation? A number of authors have considered this problem (Elsasser, 1963; Solomon, 1979; Stevenson, 1981; Andrews, 1982). But no detailed studies of the relevent flow processes have been carried out.

Since our understanding of magma migration is incomplete (Turcotte, 1982), it is not surprising that we do not understand the differentiation processes leading to core formation. One mechanism for the migration of liquid iron through solid silicates is by migration along grain boundary intersections. Porous flow models for this type of flow have been derived and show that the energy of differentiation is uniformly distributed by viscous dissipation (Ahern and Turcotte, 1979).

An alternative approach to iron separation is by diapirism. A liquid iron diapir could fall through a solid silicate without solidification due to the heating caused by viscous dissipation. In order to study this problem we have obtained solutions for a number of simplified models. A spherical body can melt its way through a solid if its radius is greater than the critical value

$$R_c = \frac{3}{4}\left(\frac{\rho_s}{\rho_b - \rho_s}\right)\frac{L}{g}$$

where ρ_b is the density of the body, ρ_s and L are the density and latent heat of the solid, and g the acceleration of gravity. For an iron body melting its way through silicates the critical radius is 20 km.

For a liquid iron diapir, the assumption of a spherical shape is clearly arbitrary. The shape of the diapir is a result of a solution to the problem that matches pressure, shear stress, and velocity between the liquid iron and liquid silicate. A solution has been obtained if the viscosity of the iron is assumed to be small compared with the viscosity of the liquid silicate. An infinite family of solutions is obtained with any aspect ratio smaller than a critical value. Thin, very long diapirs are most efficient for the transport of mass.

REFERENCES

1. Ahern, J.L., and Turcotte, D.L. (1979), Magma migration beneath an ocean ridge, Earth Planet. Sci. Let. 45, 115-122.
2. Andrews, D.J. (1982), Could the earth's core and moon have formed at the same time?, Geophys. Res. Let. 9, 1259-1262.
3. Elsasser, W.M. (1963), Early History of the Earth, in Earth Science and Meteoritics (North Holland, Amsterdam), pp. 1-30.
4. Flasar, F.M., and Birch, F. (1973), Energetics of core formation: A correction, J. Geophys. Res. 78, 6101-6103.
5. Solomon, S.C. (1979), Formation, history and energetics of cores of the terrestrial planets, Phys. Earth Planet. Interiors 19, 168-182.
6. Stevenson, D.J. (1981), Models of the earth's core, Science 214, 611-619.
7. Turcotte, D.L. (1982), Magma migration, Ann. Rev. Earth Planet Sci. 10, 397-408.