ON THE EVOLUTION OF THE LUNAR DENSITY PROFILE. Floyd Herbert (Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona 85721)

The thermal and chemical evolution of the moon appears to have been dominated by a short-lived (about 10^8 yr) phenomenon which is usually referred to as the lunar magma ocean, though the term is generally understood to include melt events in which only a small fraction of the ultimately melted material is molten at any given time. Many attempts have been made to model this event from several points of view. The work reported here is an extension of one of these attempts (1, hereafter called Paper I) which approached the subject from the point of view of the interaction between the geochemical and geophysical evolution of the moon.

In Paper I it was noted that cumulate density increases with degree of crystallization in fractional crystallization of magmas likely to be derived from the lunar composition. The significance of this compositional density variation is that it is likely to have dominated subsequent subsolidus convection. Modelling heat flow in the lunar interior as subsolidus convection in a homogeneous medium is thus highly unrealistic if an appreciable fraction of the lunar interior has been fractionated. In fact, detailed modelling led to the view that compositional rather than thermal variation controlled the lunar convective history. In those models the gravitationally unstable density profile left by fractional crystallization of a magma ocean (Fig. 1) overturned itself into a sufficiently centrally dense configuration (Fig. 2) such that the observed lunar moment of inertia coefficient was reproduced without any metallic iron core at all. Also, since the last-crystalizing minerals contain most of the long-lived radionuclides present in the original melt and are also the densest, the long-term migration of this material is likely to have carried it to much greater depths. Downward redistribution of much of the original complement of long-lived radionuclides is also likely to have significantly modified subsequent lunar evolution.

A different criticism of the lunar magma ocean picture has also been made by Stevenson (2) and others. The production of melt in large quantities is made difficult by the ability of subsolidus convection to dissipate high temperatures and the difficulty of segregation of small quantities of melt. Pressure-release melting in rising columns of plastically deforming rock thus becomes the favored means of magma production. Magma ocean evolution as influenced by these considerations would likely involve a smaller magma body representing the sequential processing of a larger quantity of parental source rock. Most of the chemistry would therefore tend to be characterized by lower pressures than would be expected from solidification at the base of a large magma ocean resulting from melting all the involved rock at one time.

The present work is intended as an extension of Paper I with the intent of remedying some of its deficiencies. The principal improvement is the starting of the calculation from the epoch before any part of the moon has melted, so that melt production and segregation can be followed as it occurs, rather than assuming a magma ocean as a starting condition. Another refinement is to use a more accurate characterization of the melt chemistry (3) to replace the simple approximation used in Paper I. This more accurate chemistry has already been applied in a global approach (4); the present work seeks to apply it on a local basis. Another important effect in lunar evolution is the process whereby migrating magma interacts with surrounding rock. The present work attempts to model the equilibration of percolating magma with its matrix and the fractionation of this magma as it separates and crystallizes. Convective transport of both heat and mass is modelled as in the previous work.

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Although calculations are still incomplete, the expected scenario includes a rapid initial convective overturn in response to a primordial heat source with the generation of magma near the surface. This magma should rise to the surface as it is generated and fractionate into a floating anorthositic crust and a subcrustal magma enriched in silica and iron silicates and depleted in anorthosite. Detailed density considerations should then determine whether the source rock of the magma is more or less dense than the unmodified lunar material, and thus whether the magma ocean's source rock sinks with the thermal overturn or remains atop the convecting region. This dichotomy strongly affects the later chemical evolution via the pressure dependence of the phase boundaries. This short evolutionary epoch and its impact on the long-term evolution of the moon are to be discussed.

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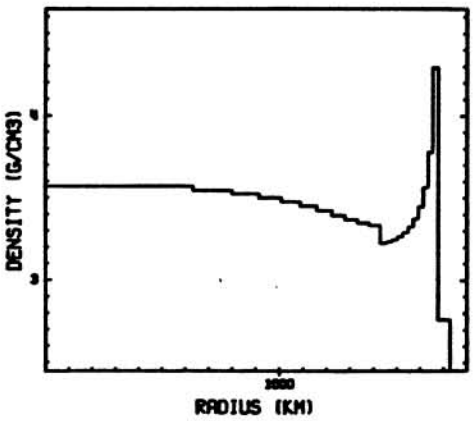

Fig. 1

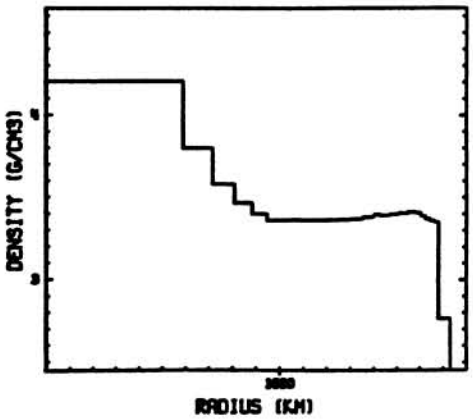

Fig. 2

Model lunar density profiles produced by fractional crystallization of a 300 km deep magma ocean. Fig. 1 precedes, Fig. 2 follows the subsequent rearrangement (by layers) of the lunar interior via subsolidus convection. Subsolidus convection is driven by bouyancy forces arising from variation of density with depth largely due to compositional inhomogeneity. Layers change thickness in response to mass conservation as they change depth.