MARE BASALT PETROGENESIS
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We have approached the problems of mare basalt petrogenesis using similar methods to those applied successfully to terrestrial basalts (1, 2). In the latter case, the existence of a homogeneous mantle source region (pyrolite) is assumed, and the observed spectrum of basalt magmas is interpreted in terms of factors such as the degree of partial melting, depth of magma segregation, water content of magma, etc. The nature of the partial melting equilibria and the composition of the source region are established by determining the compositions of near-liquidus phases from a variety of primary basalt magmas over a wide range of P and T conditions and relating these to the source material via a self-consistent model which assumes the occurrence of bulk-equilibrium during partial melting.

This approach, when applied to mare basalts, led to the conclusion that they had formed by varying degrees of partial melting of a homogeneous source material ($Mg/Mg+Fe = 0.75-0.80$, CaO, $Al_2O_3 = 4$ to $5\%$) composed dominantly of subcalcic pyroxenes plus olivine at pressures between 10 and 20 kb (3, 4). However, this model encountered difficulties in explaining the europium anomalies and titanium abundances in mare basalts. A more complicated model involving partial melting of a disequilibrium mineral assemblage under conditions of surface or local equilibrium was therefore devised (5). Although this model appears feasible in principle, its complexity and the introduction of additional assumptions lessen its plausibility.

An alternative model of mare basalt genesis is currently receiving widespread attention. This maintains that mare basalts formed by partial melting of mafic cumulates underlying and complementary to the anorthositic highlands (6, 7). Apollo 11 and 17 hi-Ti basalts are interpreted as partial melts of a pyroxene-olivine-ilmenite assemblage derived from a residual liquid resulting from advanced crystallization differentiation, which accumulated between the highland crust and a deeper zone of olivine-pyroxene cumulates, from which Apollo 12 and 15 low-Ti basalts were formed. The essence of this model is that hi and low Ti basalts were formed from different source materials at different depths (8, 9). This model has several appealing features, including an apparent simplicity as well as explanations of the 4.5 b.y. model Sr-Rb ages and the Eu anomalies in mare basalts. However it encounters some serious problems:

1. In order to explain the titanium abundances and other
trace element characteristics of Apollo 11 and 17 basalts, the residual liquid must result from more than 90% fractional crystallization of the parent magma of the lunar highlands. Such a residual liquid would be strongly depleted in chromium and enriched in iron and sodium. High titanium basalts are supposed to result from remelting of this residual system (which crystallizes to an olivine-pyroxene-ilmenite assemblage) whereas low titanium basalts result from the remelting of early cumulates necessarily high in Cr, Mg, and low in Fe, Ti and Na. Thus the model would predict that hi-Ti basalts would be strongly depleted in Cr and strongly enriched in Fe and Na, relatively to low-Ti basalt. This prediction is not fulfilled. The general similarity in Mg/Mg+Fe ratios and in Cr and Na contents of the most primitive hi-Ti and low Ti basalts (e.g., 74275 (11), 12009) implies to the contrary that both types have formed by partial melting of source materials possessing generally similar abundances of these components.

(2) The residual, high-Ti liquid resulting from advanced (> 90%) fractional crystallization would necessarily accumulate immediately beneath the highland crust at depths of 60-80 km and above the complementary cumulate zone of olivine and pyroxenes. Yet phase equilibrium studies indicate that hi-Ti basalts are derived from depths of 120-180 km (8, 10, 11). It is improbable that the small volume of residual ilmenite-saturated liquid would accumulate at such a great depth, among the early cumulates.

(3) The continued existence of mascons for up to 3.8 b.y. implies the existence of a strong, cool and thick (> 150 km) lithosphere at the time of mare volcanism. The derivation of mare basalts from a source region immediately underlying the crust (60-80 km) requires high temperatures (~ 1200°C) and partial melting in this region. This would imply a thin and weak lithosphere which would be incapable of supporting the loads represented by mascons.

(4) It is extremely difficult to provide heat sources for partial melting of mafic cumulates at depths of 60-150 km, some 0.7 to 1.3 b.y. after the presumed major differentiation event during which the highlands were formed. On this time scale, the outer 150 km of the moon will have cooled deeply below the solidus by thermal conduction.

(5) Additional problems encountered by this hypothesis are detailed in ref. (11).

The answers so far provided to these problems are unconvincing. Walker et al. (8) do not address the problem of iron-enrichment explicitly. They make an apparent implicit attempt to avoid it by postulating reversible crystallization paths.
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when their model necessarily involves fractional crystallization. The same authors claim that chromium is unlikely to be substantially depleted during fractional crystallization of the parental lunar residual magma, prior to crystallization of ilmenite. A study of the fractional crystallization of Apollo 12 magma shows to the contrary that Cr is continuously depleted throughout the entire crystallization sequence, prior to the entry of ilmenite (12).

If the difficulties confronting the cumulate melting hypothesis could be rigorously overcome, it would merit widespread support. Whilst they remain, however, there is a strong incentive to explore alternative hypotheses (5) even if they invoke specialized and unfamiliar melting relationships.

11. Green, D.H., A.E. Ringwood, N. Ware and W. Hibberson (1975) This volume