UNSAMPLED MARE BASALTS AND THE EVOLUTION OF THE MOON


Models for the evolution of mare basalts (1,2) have been constrained by the composition of returned mare samples. It has been estimated, however, that over half the mare surface is covered with unsampled material, whose composition may be inconsistent with these evolutionary models (3).

Samples of mare basalts recovered from the lunar surface fall into three categories (4): high Titanium basalts (10-12 wt% TiO₂), low Ti basalts (1-3 wt% TiO₂) and very low Ti basalts (0.1-1 wt% TiO₂). The hi-Ti basalts have ages 3.7-3.8 b.y., are found primarily in western mare (e.g. Apollo 11 and 17 sites), and are believed by many workers to come from a Ti-rich cumulate region at a depth of roughly 150 km (5). The low-Ti basalts, found in central and eastern mare regions, may have a deeper origin; most recent work has suggested they originate from the boundary at 400 km depth, between the magma ocean cumulate and undifferentiated mantle regions (6,7). They appear to be significantly younger, 3.2-3.5 b.y. old. The origin of the VLT basalts is still unclear.

Photogeologic mapping of the moon, including stratigraphic relationships, crater densities, and crater degradation studies, has been used extensively to study the unsampled lunar mare (8). Given the radiometric ages of rocks from the sampled regions, flows can be compared and the relative ages for these regions can be determined. By this method it has been estimated that much of western Oceanus Procellarum may be as young as 2.5 b.y. old.

Likewise, various remote sensing techniques have been employed to determine the Ti content of these unsampled regions. Both the UV/VIS slope ratio technique (9) and γ-ray spectroscopy (10), used by many workers, give consistent results for many areas; however, Metzger et al. (11) have catalogued areas of discrepancy between results given by the two methods. The most serious disagreements seem to be found at Mare Crisium and in the western regions of Procellarum.

A possible explanation for the conflicting results found by the two methods in these areas may be related to the contribution of very low Ti glasses to the optical spectra of these regions. Work by Dyar and Burns (12) has shown that laboratory spectra of low Ti glasses feature a strong absorption edge due to ferric iron in the region where the UV/VIS ratios are measured. Thus regions which have been interpreted by the UV/VIS ratio as hi-Ti may in fact be areas of soil with a large content of low Ti glass.

A widely-accepted hypothesis for the evolution of mare basalts involves the remelting of a cumulate region formed by the freezing of a large "magma ocean"(1). By this hypothesis the region of melting started with the shallower, Ti-rich regions and progressed downward, making lower-Ti basalts at a later time. While this is consistent with the ages and Ti contents of returned samples, it would be strongly contradicted if western Procellarum were both young and Ti-rich. If, however, the low Ti glass hypothesis is correct, this objection would be removed.

Nonetheless, problems still exist with the cumulate remelting hypothesis. A simple downward progression of melting is inconsistent with the moderate Ti contents seen by both γ-ray and UV/VIS techniques in regions of Procellarum and Imbrium of relatively young age. It is also inconsistent with thermal models constrained by surface tectonism.

An example of such a thermal model (from Solomon and Head [13]) is shown in figure 1. Note that the presumed source region of hi-Ti basalts does not
coincide with any region of partial melting during the formation time of these basalts. At the time of lunar remelting, the first melting appears to occur at a depth of 400 km, not 150 km. A likely scenario might be that rising magma from this deep, presumably moderate-to-low Ti source, would intersect the Ti-rich cumulate region. If Ti is concentrated in the last-freezing parts of the magma ocean, this region would have a low melting point. Thus production of hi-Ti basalts may result from the melting and subsequent mixing of this region by and with the magma of deeper origin. In effect, this is the "dynamic assimilation" model of Ringwood and Kesson (2), run in reverse.

One might reasonably question how, given such a scenario, any deep-origin low Ti basalts can survive to the surface without always becoming hi-Ti basalts in the process. We postulate that the Ti-bearing cumulate region is melted, and exhausted, in areas where low-Ti magmas are later to traverse. This is consistent with the stratigraphy of a basin like Serenetatis, which was filled primarily with hi-Ti basalts, covered later by low-Ti flows (13). A mass balance analysis of the Serenetatis basin suggests that the volume of hi-Ti (unit I) basalt is more than $6 \times 10^5$ cubic kilometers. If this basalt came from 10% partial melting$^1$ of a source region 5 km thick, it would exhaust an area of 4.6 times the area of Serenetatis; thus a neighboring region like Imbrium could be filled with low-Ti basalts without having to generate hi-Ti basalts first. Regions further away from Serenetatis (e.g. Procellarum) might have a higher Ti content in their later basalts.

This work was supported by NASA grants NSG-7604 and NSG-7081.