FeO AND TiO_2 VARIATIONS IN MARE IMBRIUM;

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We are investigating regional variations in mare basalts to determine whether there are changes in the magma sources over time or evolution of lava during the course of emplacement. Mare Imbrium, with its multiple high-volume Eratosthenian flows [1], is a prime location for examining magma compositions in three spatial and temporal contexts: along lengthy flows, between major eruptive events (represented by at least three phases of lava flows), and between younger (Eratosthenian) and older (Late Imbrium) mare filling lavas. We have used Clementine and Galileo spectral reflectance data, calibrated to determine FeO [2] and TiO_2 [3] contents to high accuracy. These data show significant differences between older and younger Imbrium mare, which suggest distinctly different geochemical provinces: one like Apollo 15 basalts [4] and one like yellow glass 15010,3189 and richer in TiO_2 and Th [5]. The flows from three eruptive events, attributed to the same source but spread over 0.5 Gy [1], show minor variations in composition, suggesting modest evolution through time of the magma source due to the repeated high volume melting events. Two long (400-600 km) Eratosthenian flows show no consistent variation downstream, indicating little fractional crystallization took place during flow emplacement.

Mare basalt compositional variations

Apollo samples [e.g. 6] and remote FeO and TiO_2 data [e.g. 2, 7, 8] show a wide range in compositions of mare basalts. Large scale variations are most likely attributable to different geochemical provinces [4]. At a different scale, many of the Apollo basalt samples show elemental trends indicative of a history of fractional crystallization [9, 10], but where and how this differentiation occurred is still unclear. Magma evolution could occur within surface flows, within the conduit, deep in a magma chamber [11] or at the magma source in the mantle. Examining the context of any compositional variations could give clues to the evolution of the magma, from source to final emplacement.

Mare Imbrium

Mare Imbrium gives us a great opportunity to examine variations in basalts from various stages, and at various scales, of mare-filling events. The mare underlying the western portion of the basin is considered Late Imbrium (3.2-3.5 Ga) [12], while the overlying Eratosthenian flows are dated by crater counts as 3.0 ± 0.4 Gy, 2.7 ± 0.3 Gy, and 2.5 ± 0.3 Gy [1]. The young flows are unusual for lunar basalt flows in being well-delineated units displaying visible margins and terminating lobes, making it possible to distinguish lava from different eruptive events. In addition, it is possible to trace the flows back to a common vent area [1], linking them to a common magma source. All three flows are also impressively long (phase I = 1200 km, II = 600 km, and III = 400 km) and make up a total volume of at least 4×10^4 km^3. This interesting stratigraphic set-up lets us compare compositions of two distinct epochs of mare fill and of three superposed lava flows, each of which also presents an opportunity to test the feasibility of differentiation by crystal settling during emplacement.

Clementine and Galileo spectral reflectance data have been calibrated to give FeO and TiO_2 wt% [2, 3] with errors of less than 0.5%. Galileo images, with resolution of ~1 km, was used for a preliminary study of the Imbrium flows. Clementine data with resolution of 100-200 m will be used for a closer examination of the region.

Preliminary results

At the largest scale we see distinct composition differences between the young Eratosthenian flows ($TiO_2 \approx 3.2$ wt%, FeO ≈ 17.9 wt%) and the surrounding mare to the north and east ($TiO_2 \approx 0.7$ wt%, FeO ≈ 15.9 wt%) and to the south ($TiO_2 \approx 1.4$ wt%, FeO ≈ 15.5 wt%). Variations between large mare units of different ages would be best explained tapping of nearby, but distinct, mantle sources. Two geochemical provinces have been identified previously for Mare Imbrium basalts: one like the Apollo 15 basalts [4] and one like the Eratosthenian flows as identified using sample 15010,3189 [5] with higher FeO, TiO_2 and Th. Our data support the existence of these provinces and suggest there may be another province to the south of Timocharis.

Between the large volume flows we see minor but probably real differences in TiO2. Using boundaries defined in Schaber's flow phase map[1], the further (exposed) half of phase I (2.72 wt%) is most distinctive, while phases II and III are only slightly different from each other: 3.37 wt% and 3.17 wt%, respectively. These compositional variations, if real, could be indicative of evolution of a single magma source that supplied the vast amounts of lava for these events by repeated melting episodes. Alternatively, the slight variations in TiO_2 could be due to fractional crystallization somewhere at depth. However, the paucity of phenocrysts in most basalts may suggest that lunar magma chambers are not common.

The evidence of fractionation in many Apollo basalts suggested to us we might see an increase in FeO and TiO2 down the individual lava flows due to lava evolution by crystal settling during emplacement. However, within the error of these data, we see no consistent trends downstream in any of the flows. This fact has some interesting implications for the magma source and emplacement mechanism for these flood basalt-sized flows.

Two mechanisms for emplacing such vast, and long, flows as these have been suggested: rapid, a'a-like transport [e.g. 13] and slow, tube-fed pahoehoe-like emplacement [e.g. 14]. A rapidly moving a'a-like emplacement would be turbulent enough to prevent any crystal settling, and the short duration of the event (≈ 1 week) would prevent changes in the magma composition. But the large eruption flux would require a subsurface chamber, large enough to supply plenty of chemically homogeneous magma and deep enough to leave no caldera-like surface feature after the eruption. Alternatively, a gradually emplaced tube-fed flow field could reach sufficient length by long lived ($\approx 10^2$ yr), medium-sized lava tubes (5-10 m diam.) and a moderate effusion rate (<20 m^3/s) [15]. If this gradual emplacement were the case, the magma composition generated at depth did not change drastically during the century that each eruption lasted.

References

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