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Week 4 Discussion Summary
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Lava Flows in Mare Imbrium

Bugiolacchi, R. and Guest, J. (2008):

Imbrium Basin is a large impact basin, which was formed about 3.85 Ga and later filled with several basalts of varying Ti composition. Mare Imbrium is the second largest basaltic region on the Moon after Oceanus Procellarum. Providing a background for Mare Imbrium begins with a brief history of the Moon, from the time of the magma ocean. As the magma ocean cooled, experienced extensive differentiation and bottom up fractional crystallization. Mafic materials settled first, followed by settling ferriferous and titaniferous ultramafic cumulates. KREEP was the last to crystallize. Later remelting of the KREEP layer and late production of picritic and ultramafic liquids could have been the source for some of the volacanism in Mare Imbrium.

Bugiolacchi and Guest (2008) study the history of the lava flows in Mare Imbrium. They visually and spectrally mapped about 102 individual flows in the region. However, not all these flows are unrelated. Some have similar FeO and TiO_2 compositions. FeO is important because it is fundamental to our understanding and classification of igneous rock types. TiO_2 reflects the abundance of ilmenite ($FeTiO_3$), which can reveal the composition and state of the partial melt at depth. In the Imbrium flows, a relationship between FeO and TiO_2 becomes apparent, especially at higher wt% abundances. As the abundance of FeO increases, so does TiO_2. Bugiolacchi and Guest (2008) mapped the units with comparable FeO and TiO_2 contents.

In addition to chemical composition, Bugiolacchi and Guest (2008) also determined a crater density distribution for Mare Imbrium. They counted craters with diameters greater than 500 m, taking special care to avoid regions (especially those around Copernicus crater) that could contain a large amount of secondary craters. Crater density revealed a relationship between FeO wt%, TiO_2 wt% and crater density—namely compositional units appeared to cluster about three density ranges, aging approximately 2300 Ma, 3000 Ma, and 3300 Ma.

With both the chemical composition and crater density data, Bugiolacchi and Guest (2008) were able to create a geomorphological map of the Mare Imbrium region. Mare of the oldest age have very low Ti and Fe wt%, and are classified as Period I. The middle aged flows are Period II, and the youngest flows, distinct because of their high Ti and Fe, are Period III. Period III flows were the focus of the Schaber (1973) paper.

Schaber, G. (1973)

Schaber (1973) mapped the flows in Mare Imbrium, and determined the probable extent of Phase I, II, and III flows (1200 km, 600 km, and 400km, respectively). The flows appear to be emanating from a single region around Euler β. This source may be associated with the locus of one active lunar seismic region, and may be controlled by the intersection of the Imbrian and "Copernican" ring structures.

To understand the lava emplacement in Mare Imbrium, Schaber (1973) studied some Earth analogs, including the Colombia River Basalts and Hawaiian basalts. Compared to these analogs, lunar basalts have a lower viscosity. The viscosity difference could be from the FeO and TiO_2 enrichment, in correlation to reduced SiO_2. Or, more likely, simply a reduction in SiO_2 and alkalis due to volatilization may be the cause.

Velocity proved an interesting study, because within the laminar regime, lunar mare basalts had a greater flow velocity than Earth basalts, but they were slower than Earth basalts in the turbulent regime. Specific studies using Danes (1972) flow thickness calculation show that a magma erupting at 1250°C seems to match the low length (~300 m) and height (30-35 m) of Period III flows. The relationship with velocity and viscosity, as well as a thicker flow on the Moon, led Schaber (1973) to the conclusion that rate of extrusion is likely more significant than viscosity. Also, the extrusion rate on the Moon must have been large to for lavas to flow to such extents.

In summary, multiple authors agree that there were three primary phases of eruption in Mare Imbrium. The large flow lengths of Imbrium lavas indicate a high extrusion rate that gradually decreased over time. Finally, Ti and Fe content appear to have increased over time, based on crater density calculations in relation to chemical composition of individual flows.

Discussion

During the class we discussed several topics related to Mare Imbrium lava flows:

- How does eruption in a vacuum affect the flow features we are used to seeing?
- What evidence do we have of magma storage beneath the surface?
    - What kind of structure do we expect?
    - What does the scope and composition of the lavas say about the storage of magma beneath the surface?
- What evidence do we see for lava produced by vents/fissures/volcanoes?
    - How does flow thickness and extrusion rate change for these features?
- How does the evidence for lava flows and magma storage change in other regions of the Moon?
- Why might basin infilling have commenced after basin formation?

We talked a little about each of these topics; however our most in-depth discussion focused on what evidence we have of magma storage beneath the surface. We concluded earlier in the class that magma chambers are not likely to form within the Moon’s thick, low-density crust—instead chambers probably form deep at the base of the crust (or perhaps at a rheological boundary). So, magma propagation to the surface takes the form of dikes. The ring structures of Imbrium and Copernicus likely do not actually control magma ascent to the surface, because crustal fracture and from these events may not penetrate the entire crust. However, such a fractured crust may facilitate lateral motion of dikes, as we see evidence for it in other regions. We also discussed the composition of the lavas, and how they may be related to crustal overturn. Alternatively, KREEP heating could be a source of melting.