MARE LAVAS AND MASCONS — A TALE OF TWO BASINS.

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Introduction: The compositions and timing of mare basalts flows vary among lunar impact basins and are likely influenced by the presence or absence of mascons. This study addresses these interactions for the Tranquillitatis and Serenitatis basins.

In the decade after the Apollo missions, detailed studies addressed questions of mare basalt interactions with mascons [1]. Modern datasets, geographic information systems, and hydrocode modeling allow study of these interactions in ways that were not previously possible.

Serenitatis and Tranquillitatis: The two adjacent impact basins (Fig. 1), each ~ 700 km across, were formed ~ 4 Gy ago and subsequently were filled by flows of basalt. The outline of Serenitatis is nearly circular, while the outline of Tranquillitatis is irregular. The Tranquillitatis basin may be the result of two separate impacts [2]. Nearby basins include Imbrium and Crisium. Apollo 11 landed in the southwest quadrant of Tranquillitatis and Apollo 17 landed near the southeast edge of Serenitatis.

Data Sets: *Mare Units and Crater Ages.* Hiesinger et al. [3] mapped multiple units, interpreted as individual lava flows, within the Tranquillitatis, Serenitatis, and Imbrium basins, based on multispectral Galileo Earth/Moon encounter images. They derived model ages for each unit, based on crater counts in areas within the units. The outline for each flow unit and count area can be displayed in the Geographic Information System LROC QuickMap [4].

TiO_2 Abundances in Lava Flows. Fig. 2 maps TiO_2 abundances, derived from WAC 321/415 nm band ratios [5]. Regolith TiO_2 is directly correlated with TiO_2 in the underlying mare basalt [6]. Sato et al. [5] used these data in their analyses of TiO_2 in mare flows.

Gravity. The GRAIL mission [7] provided high-resolution maps of the lunar gravity field. Mascons [8] underlie the Serenitatis and Crisium basins as well as a portion of the Imbrium basin (Fig. 3).

Observations: *Tranquillitatis Lavas.* Regolith of exposed flows in the northern sector of this basin are mainly composed of high-Ti basalt (Fig. 2), while

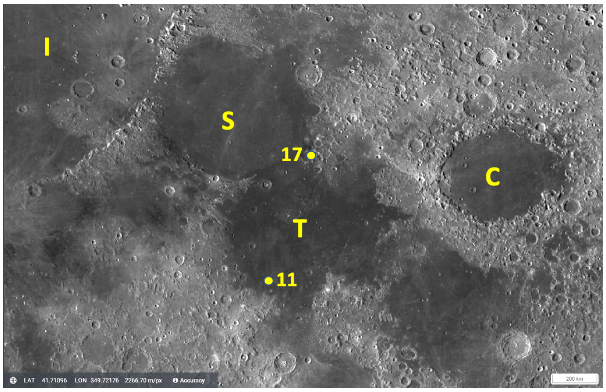

Fig. 1. Imbrium (I), Serenitatis (S), Tranquillitatis (T), and Crisium (C), and Apollo landing sites; LRO WAC

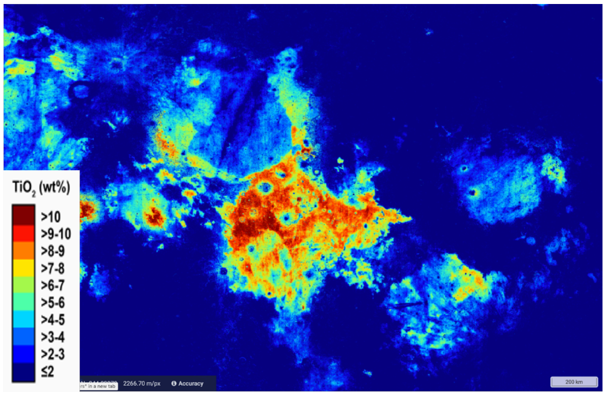

Fig. 2. TiO_2 abundances [5]; LROC QuickMap

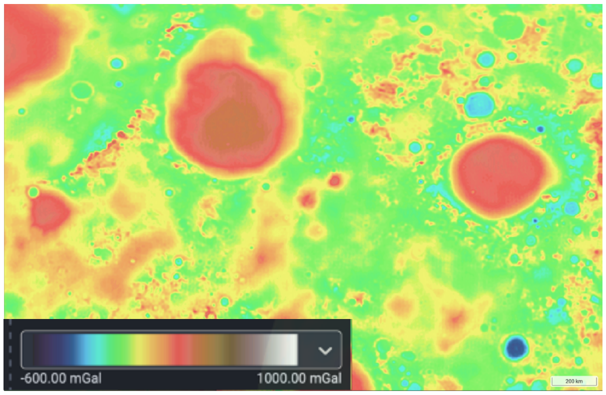

Fig. 3. GRAIL free-air gravity [7]; LROC QuickMap

flows in the southern sector exhibit slightly lower TiO_2 abundances [5]. Apollo 11 (Fig. 1) sampled ilmenite basalts with TiO_2 abundance of 8.5 - 11.9 wt.% and Sm-Nd ages of 3.6 - 3.9 Ga [9]. Crater counting across the basin gives a range of ages from 3.4 - 3.8 Ga [5]. Flows exhibit considerable variation in TiO_2 abundances but no compositional trends with age [5].

Serenitatis Lavas. Flows in this basin are mainly composed of low to mid-Ti basalt (Fig. 2). The central portion is crossed by several prominent crater rays, making calculated TiO_2 abundances in those areas unreliable. A narrow arc of high-Ti flows covers the southern and eastern margins of the basin (Fig. 2). Apollo 17, landing in this high-Ti arc (Fig. 1), sampled basalts with 13.9 - 18.3 wt.% TiO_2 and ages of 3.7 - 3.8 Ga [9]. Regolith over exposed Serenitatis flows in the basin range in age from 2.4 - 3.8 Ga [5]. Flows exhibit considerable variation in TiO_2 abundances but no compositional trends with age [5].

Mascons. Roughly circular gravity highs, reflecting basin-forming impacts followed by mantle uplift and - in some cases - mare infilling, are known as mascons [7]. Hydrocode modeling indicates that mascon formation is dependent on impact parameters, as well as crustal thickness and temperature [8]. The Serenitatis, Crisium, and Imbrium mascons (Fig. 3) are similar in size, and have free-air gravity maxima of 389, 346, and 354 mGal, respectively [7]. No mascon underlies the Tranquillitatis basin.

Interpretation: *Possible Effects of a Mascon on Lava Flow Compositions.* Significantly after the formation of the Tranquillitatis and Serenitatis basins, they were filled by multiple flows of basalt. Below the Tranquillitatis basin the source magma was high-Ti and included abundant ilmenite. Localized high-Ti flows outside of Tranquillitatis (Fig. 2) indicate that the high-Ti source region, or similar regions, extended hundreds of km past the basin boundaries.

Flows in Serenitatis generally have significantly lower TiO_2 abundances than those in Tranquillitatis (Fig. 2). The basin-forming Serenitatis impact could have produced fracture systems that tapped a body of low-Ti magma. Alternatively, the mascon formed by that impact could have introduced low-Ti melt that significantly diluted existing high-Ti magma.

The correlation between mascons and lower Ti lavas is not restricted to Serenitatis. A similar correlation is seen in the Imbrium and Crisium basins (Figs. 2 and 3). In those basins the lavas vary locally between low-Ti and medium-Ti compositions, suggesting mixing at depth among several magma bodies.

High-Ti flows erupted along the southern and eastern margins of the Serenitatis basin. Hydrocode modeling from GRAIL data [8] predicts a strongly fractured ring of rock around a mascon. Such fracturing around the Serenitatis mascon could have tapped Ti-rich magma and led to formation of the high-Ti circumferential arc.

Possible Effects of a Mascon on Eruption Durations. Apollo samples and exposed mare units in Tranquillitatis show that eruptions started approximately 3.8 Ga ago and ceased after ~ 400 My. Eruptions in the Serenitatis basin commenced at around the same time and continued for ~ 1.4 Ga. In the Imbrium basin, flow unit ages span ~ 2 Ga [3], though some of the youngest flows may have originated outside of the basin [10].

In the case of Tranquillitatis, the eruption duration depended on the temperature of the high-Ti source region, the impact energy, and the fracture paths to the surface created by the impact(s). If the basin was actually formed as a result of two smaller impacts [2], total heat and fracture paths might be smaller than would be the case for a single larger impact. This combination could lead to the observed limited eruption duration.

In the case of Serenitatis and other mascon basins, the gravity high reflects significant mantle uplift below the impact point [8]. This factor would result in additional high temperature material, which could heat the magma source material and increase eruption duration.

Conclusions: The Tranquillitatis and Serenitatis basins are located in the same section of the lunar surface, are approximately the same size, and are of similar age. They were both flooded with basalt. The basalts in Tranquillitatis, generally high-Ti, erupted over ~ 400 My. The basalts in Serenitatis, generally low- to mid-Ti, erupted over ~ 1.4 Ga. The presence of a mascon beneath Serenitatis and the absence of a mascon beneath Tranquillitatis resulted in significantly different amounts of subsurface heat and fracturing. These effects may be responsible for the different elemental compositions and eruption durations in these two basins.

References: [1] Solomon, S. (1980) doi.org/10.1029/RG018i001p00107. [2] DeHon, R. (2017) LPSC Abs. 2769. [3] Hiesinger H. et al. (2000) *JGR*, *105*, 29,239–29,275. [4] https://quickmap.lroc.asu.edu. [5] Sato H. et al. (2017) *Icarus*, *296*, 216-238. [6] Giguere, T et al. (2000), *MAPS, 35*, 193-200. [7] Lemoine, F. et al. (2014) doi.org/10.1002/2014GL060027. [8] Melosh, H. et al (2013) doi: 10.1126/science.1235768. [9] Lunar Sourcebook (1991), Heiken, G. et al. eds, Cambridge, 736 pp. [10] Zheng N. et al. (2013) *JGR, 118*, 1789 — 1804.