RELATIONSHIP BETWEEN EFFUSIVE AND EXPLOSIVE VOLCANISM IN THE MONTES APENNINUS REGION OF THE MOON. L.M. Pigue[1], K.A. Bennett[1], B.H.N Horgan[2], L.R. Gaddis[3]
[1]U.S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ 86001 (lpigue@usgs.edu), [2]Earth Atmospheric and Planetary Sciences, Purdue University, West Lafayette, IN, [3]USRA - Lunar and Planetary Institute, Houston, TX.

Introduction: The lunar surface is covered with a wide variety of volcanic features including mare flows, lava channels, pyroclastic deposits, and irregular mare patches. Here we evaluate the relationship between three specific explosive eruptions (i.e., pyroclastic deposits) and associated effusive features (e.g., co-located rilles) to characterize eruption dynamics during their emplacement.

Lunar Pyroclastic Deposits (LPDs) are the surface materials left from explosive volcanic eruptions on the Moon. They typically have a low relative albedo and mantle (i.e., blanket) the underlying surface, smoothing the texture of the pre-existing topography [1, 2]. A sinuous rille is thought to have been placed by surface lava flows or left by collapsed lava tubes. On Earth, it has been observed that most volcanoes erupt both effusively and explosively [3]. On the Moon these two eruption styles can be correlated spatially, but most explosive eruptions are over 3 billion years old, leading to an inability to directly observe the relationship between these eruption styles.

Studies have shown that magma storage conditions (e.g., storage temperatures, dissolved water, and crystallinity) can affect the explosivity of eruptions on Earth [3]. Lunar water content likely has an observable relationship with gas content of the erupting magma, which has implications for eruptive behaviors [4]. This is supported by the work presented by [3], who determined that there is a defined range of water content and crystallinity under which eruptions will be explosive in nature in eruptions on Earth.

Regions of Interest: For this analysis, we compare three areas of explosive volcanism in the Montes Apenninus region that are closely spatially associated with sinuous rilles as defined by [5] and [7]: Mozart, Rimae Bode, and Rimae Fresnel (Figure 1). Rima Hadley is also an LPD in this region that is closely associated with a sinuous rille, but this LPD and its geologic context have been heavily studied and was omitted for this study [6]. It should be noted that the LPD associated with Rimae Bode is also known historically as "Rima Bode," however we use the formal name as assigned by the IAU.

Study Goals: For this work, we will discuss the question: what genetic relationship, if any, exists between the explosive and effusive volcanism? We will examine compositional data for the LPDs and nearby rilles to assess whether there is a genetic relationship between rille materials and pyroclastic materials. We will also compare the composition of the effusive and explosive features to nearby volcanic areas (e.g., any lava flows or mare ponds) to characterize their geologic context.

We will refine the boundary extents of the pyroclastic deposits in the three study regions and delineate all associated rille or vent features.

We will construct detailed stratigraphic and geologic history of the three regions to better examine the possible genetic relationships (if any) between the observed effusive and explosive volcanic features.

Methods: We used data from the hyperspectral Moon Mineralogy Mapper (M^3, 85 bands in global mode, [9]) to map the lunar surface and evaluate spectra to compare the composition of the features in each study set. The calibrated M^3 products downloaded from the Planetary Data System were processed following the methods of [10] to remove continuum contribution due to space weathering effects, continuum smoothing to better isolate spectral changes, and for spectral characterization. We created spectral parameter maps of targeted minerals (e.g., clinopyroxene and iron-bearing glass) and specific regions of the spectrum where iron has characteristic absorption features (i.e., 1µm and 2µm). These parameter maps included band depth, band center, area under the curve at a band location, and band asymmetry.

We then used ENVI to analyze spectra from Regions of Interest covering explosive and effusive features within each region. Spectral parameter maps of targeted minerals were created individually and overlaid on a LRO WAC base map in ArcMap (Fig. 1 for glass band parameter map). Further characterization of spectra of the LPDs, rilles, and locally associated features are reported here. The glass band parameter also identified olivine where present, and we, therefore, used spectra to confirm whether iron-bearing glass or olivine was being detected.

Results: All three pyroclastic deposits have a strong iron-bearing glass signature relative to background terrain and mare lavas (Fig. 1). This glass signature is further confirmed by the broad band shape of the 1-µm band shifted to longer wavelengths for the pyroclastic regions (Fig. 2), contrasted against various other materials in each image (e.g., mare, highland).

The Rimae Fresnel LPD [~307 km^2; center lat/lon: 28°N, 4.3°E] is a small pyroclastic deposit on the western wall of Montes Apenninus (near Promontorium Fresnel), east of Rimae Fresnel (Fig. 1a). Rimae Fresnel is not identified in [5] but has been named as a fissure by the IAU [7]. Rimae Fresnel LPD does not have a well-defined vent depression; therefore, a source vent for the LPD is unknown. The LPD appears to blanket the Rimae Fresnel rille, indicating an eruptive history in which the rille was emplaced prior to the explosive volcanism (Fig. 1a). The Rimae Fresnel LPD also does not demonstrate the characteristic low albedo that most LPDs do, making the boundary of the LPD difficult to delineate.

The Mozart LPD region [central lat/lon: 24.7°N, 0.5°E] has an isolated mare deposit (the informally named Lacus Mozart) that lies between the second and third rings of the Imbrium basin (Fig. 1c, [8]). Northwest of Lacus Mozart is a rille (Rima Mozart) with four along-rille depressions, some identified as volcanic vents and others as collapsed features (identified in Fig. 1c; [8]). The source vent of Rima Mozart is hypothesized to be Kathleen, flowing to the west towards Ann, Michael, and terminating at Patricia [8]. The LPDs along Rima Mozart do not demonstrate the strong characteristic low albedo that most pyroclastic deposits do (relative to the mare lavas of Lacus Mozart), despite their association with Mozart rille and strong glass signature. The spectral shape of the 1-µm and 2-µm features of LPD2 and Lacus Mozart potentially indicate the pyroclastic deposits are mantling this part of the lava lake, rather than that the composition of the lava lake is similar to the LPDs.

The Rimae Bode LPD is a regional LPD [~6,620 km^2, center lat/lon: ~11.6°N, ~3.5°W] along the eastern margin of Sinus Aestuum (Fig. 1b). Southeast of the Rimae Bode LPD is the rille Rimae Bode [8], and there are two small unnamed rilles – one to the northwest and one to the southeast of the LPD [5].

Rimae Bode LPD does not have a well-defined vent depression, however the shape of the regional deposit suggests that a vent may be present in Sinus Aestuum, likely buried under younger maria [11]. The Rimae Bode LPD mantles a large area north of the Rimae Bode sinuous rille and is embayed by and overlain by the higher-albedo lava flows from the Rimae Bode rille (Fig. 1b). Spectrally, areas in this region have similar spectral shape with a well-defined 1-µm band depth and broad, shallow 2-µm band. The two LPD spectra have stronger asymmetry of this region than the mare and rille spectra, indicating a stronger glassy signature of the pyroclastic materials than the mare and rille.

Future Work: We will continue addressing the study goals outlined above to fully characterize genetic relationship between explosive and effusive volcanism at these locations.

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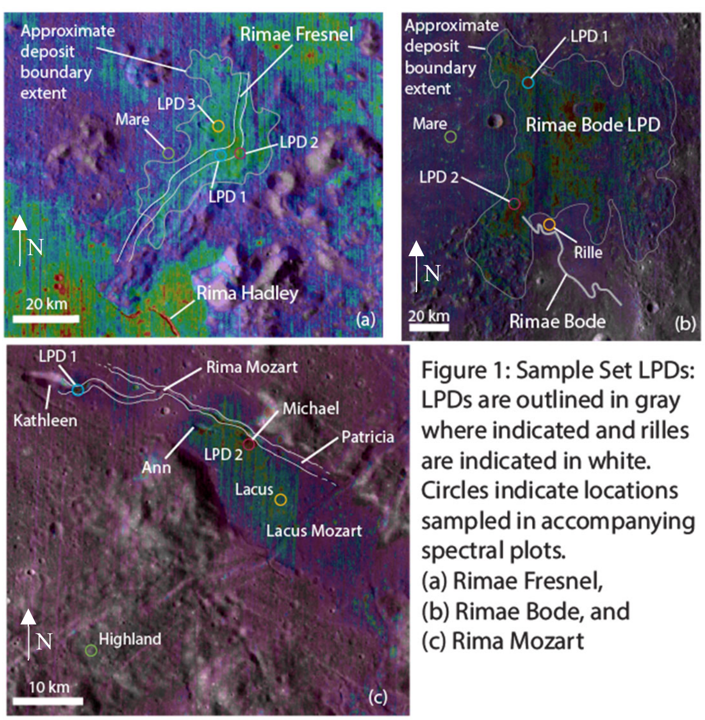

Figure 1: Sample Set LPDs: LPDs are outlined in gray where indicated and rilles are indicated in white. Circles indicate locations sampled in accompanying spectral plots.
(a) Rimae Fresnel,
(b) Rimae Bode, and
(c) Rima Mozart

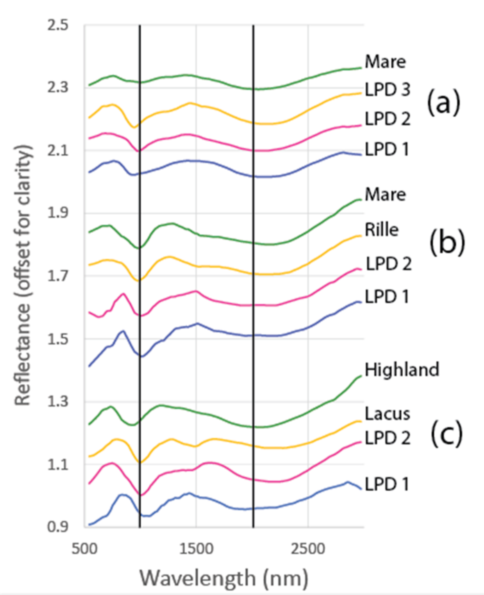

Figure 2: Spectra taken from regions identified in Fig. 1; (a) from Fig. 1a (Rimae Fresnel), (b) from Fig. 1b (Rimae Bode), and (c) from Fig. 1c (Rima Mozart). Spectra are offset for clarity.