DIVERSITY OF LUNAR VOLCANIC ERUPTIONS AT THE MARIUS HILLS COMPLEX. C. M. Weitz and J. W. Head III, Department of Geological Sciences, Brown University, Box 1846, Providence, RI 02912 (Catherine_Weitz@Brown.edu; James_Head@brown.edu).

Introduction: The 35,000 km^2 Marius Hills volcanic complex has a concentration of volcanic features that are rare elsewhere on the Moon [1, 2, 3]. It has been suggested that the morphologic variations seen in the volcanic features of Marius Hills could be due to changes in the effusion rates [3]. Recent Galileo spectral data of the region indicate complex variations in volcanic activity, including variability in the composition of the basalts and pyroclastic deposits [4]. In this study, we have used Clementine UVVIS data to examine the various volcanic features of the Marius Hills region. The Clementine data were calibrated using procedures described in [5]. Our goal was to document the range of volcanic landforms possible on the Moon and understand the eruption styles that produced them.

Mare Units: Color ratio images produced by combining the 415/750 nm ratio in the red channel, the 750/950 nm ratio in the green channel, and the 750 nm in the blue channel were used to identify mare units in the region. The color ratio image shows several mare units in the area, although the mare can best be divided into those that appear red and others that appear green in color. To quantitatively compare the mare units, we have plotted their 415/750 ratio against their 750/950 ratio (Figure 1). All spectra were taken from orbits with 22-26° phase angle to avoid calibration errors associated with the orbits taken at angles below 10°. The MS-2 symbol (taken at 30° phase) corresponds to the low-Ti mare unit in southern Mare Serenitatis used as a standard for spectral reference.

The 415/750 value is both a measure of the Ti content and maturity level for lunar soils. Since we are only dealing with mature mare soils, the color of the mare in the color ratio image is mainly a function of the titanium content, with lower Ti contents having redder colors and green indicating higher contents [6]. The 750/950 value indicates the strength of the high-Ca pyroxene absorption in the mare. The 415/750 nm values for the mare units range from 0.617 to 0.680 while the 750/950 nm values vary between 0.957 and 0.989. Some of the spectral variations appear to reflect small heterogeneities (possibly calibration errors) in the same flow units rather than indicating distinct mare units. All the mare in Marius Hills have higher 415/750 nm ratios compared to the MS-2 site, supporting the conclusion that the mare of Marius Hills are relatively high in titanium compared to other lunar mare [4].

Several sinuous rilles are visible traversing through the mare units in the region. Those that are large enough to be resolved in Clementine data have strong high-Ca pyroxene absorptions, indicating exposure of fresh mare along their walls. The rilles occur in both the low- and high-Ti mare units and several show evidence of embayment by younger mare.

Volcanic Constructs: In addition to the mare units, there are numerous volcanic domes and cones in the complex, which are less common elsewhere on the Moon [1]. In the Clementine data, the domes are spectrally indistinguishable from the surrounding mare and they have the same color of both the red and green mare units in the color ratio image. All the domes appear to have been embayed by younger mare indicating that they represent an older stage of volcanism in the region.

The volcanic cones in the complex are <3 km in diameter and <300 m in height [2]. High-resolution Lunar Orbiter V images of portions of the Marius Hills region show the cones as generally having a horse-shoe appearance. Morphologically, these cones are very similar to terrestrial cinder cones, such as those in Hawaii and the Snake River Plain. The horse-shoe appearance indicates that the cones were breached on one side where lava flowed out. In the Clementine color ratio image, the volcanic cones are readily visible as black spots in both the red and green mare units. In a few cases, these black spots are surrounded by red circles. Lunar Orbiter images show that the black spots correspond to the interior of the cones while the red circles are the cone flanks.

Figure 1 shows the spectral ratios for the volcanic cones. The black spots associated with the volcanic cones have the bluest color and weakest mafic band of all the units. To account for the spectra of the black spots requires a material that will darken the soil and remove any mafic signature, similar to the effect that agglutinates produce in lunar soils. On Earth, the flanks of basaltic volcanic cones are composed of scoria, including spatter and cinder, and we assume that the lunar cones are formed of similar scoria in order to build up a cone. Hawaiian spatter has a microcrystalline structure due to a cooling rate that allows nucleation of crystals but inhibits their growth. Glasses are also unstable over time and can devitrify to form microliths, a process thought to have occurred in the Apollo 17 volcanic beads [7]. Assuming that lunar spatter has similar microliths then, during regolith formation, they would be crushed to a fine-grained size and could act as darkening agent to explain the spectra for the black spots.

The annular deposits that appear red and correspond to the cone flanks have a very strong mafic absorption and similar 415/750 nm ratios to the red mare units. The high 415/750 and 750/950 nm ratios are similar to those of volcanic glasses found in lunar dark mantle deposits [8]. Both strombolian and hawaiian eruptions produce some achneliths that are glass-rich and can be deposited further away from the vents than the spatter. Hence, the red spots could represent glassy deposits on the cone flanks that had higher cooling rates to prevent microliths from developing. Since most of the cones do not have these glassy deposits on their flanks, it indicates that most eruptions had slower cooling rates, perhaps due to slightly higher optical densities.

Comparison to Rima Parry V cones: Because of the unusual spectra for the volcanic cones of Marius Hills, we have also studied cones associated with the rille Rima Parry V in Fra Mauro crater [9, 10, 11]. Just offset from the 50 km long rille is a row of volcanic cones to the west and two cones to the east. The cones are thought to be composed of spatter produced from strombolian eruptions from a near-surface dike [10]. Spectra of the cones from Clementine data show that they are higher in reflectance than those at Marius Hills, up to 3% higher for similar phase angles. The Rima Parry cones also have a lower 415/750 value of 0.602 while the 750/950 value of 0.975 is similar to the ratios for the mare at Marius Hills. Surrounding the Rima Parry V cones is a dark veneer of debris. The debris has a spectra that closely matches that for dark mantle deposits composed of volcanic glasses [8]. The presence of volcanic glasses indicates that the eruptions were gas-rich with minor amounts of magma that cooled rapidly to form either spatter (cones) or small glass beads (dark mantle deposit).

Discussion: The Marius Hills complex illustrates the variety of volcanic features that can form on the Moon. The morphology of these features is a function of both their accumulation rate and the temperature of the pyroclasts. At one extreme where the accumulation rates and temperatures are high, clasts can land hot to coalesce and form lava flows, in some cases producing sinuous rilles if there is thermal erosion [12]. Domes form when lower effusion rate eruptions, similar to those that formed Mauna Ulu in Hawaii [13], build up a low shield volcano, probably accompanied by some pyroclastic activity. Volcanic cones result from cooler clasts and lower accumulation rates where spatter and cinder are produced. While the cones at Rima Parry V and other cones like Isis and Osiris are aligned linearly, no alignment is recognizable for the cones in Marius Hills. This observation suggests that the domes and cones may represent the terminal stages of earlier eruptions due to decreasing mass fluxes.

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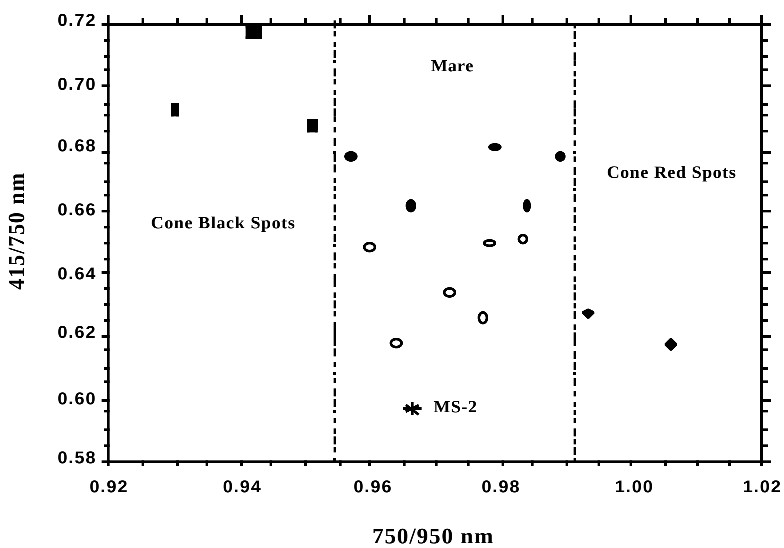

Figure 1. Open circles for mare correspond to units that appear red in the color ratio image while closed circles indicate a green color. MS-2 is the low-Ti mare unit in southern Mare Serenitatis.