PYROCLASTIC DEPOSITS IN FLOOR-FRACTURED CRATERS – A UNIQUE STYLE OF LUNAR BASALTIC VOLCANISM ?

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Do pyroclastic deposits in floor-fractured craters represent a unique style of lunar basaltic volcanism? The lunar maria were formed by effusive fissure flows of low-viscosity basalt. Regional pyroclastic deposits were formed by deep-sourced fire-fountain eruptions dominated by basaltic glass. Basaltic material is also erupted from small vents within floor-fractured impact craters. These craters are characterized by shallow, flat floors cut by radial, concentric and/or polygonal fractures. Schultz [1] identified and classified over 200 examples. Low-albedo pyroclastic deposits originate from depressions along the fractures in many of these craters.

Alphonsus: This 118 km diameter early Nectarian floor-fractured crater is centered near 13^{o} S, 357^{o} E (Fig. 1). The crater was formed in highland material, and is located immediately east of Mare Nubium.

Eleven pyroclastic deposits, with associated depressions thought to be their vents, have been identified on the floor of Alphonsus. These vents are non-circular, 1 – 3 km across, and located on fractures approximately 1 km wide [2]. The interiors of the vents are brighter than the surrounding low-albedo deposits [3]. These deposits range from 3.5 to 10 km across, and superpose other geologic units [2]. Radar images show that the largest deposits are smooth, meters thick and rock-free, particularly the large west deposit [2; Fig. 1]. Telescopic spectra indicate that the Alphonsus floor is noritic, and that the pyroclastic deposits contain mixtures of floor material and a juvenile component including basaltic glass and possibly olivine [2].

Head and Wilson [3] contend that Mare Nubium lavas intruded the breccia zone beneath Alphonsus, forming dikes and fractures on the crater floor. In this model, the magma ascended to the level of the mare but cooled underground, and a portion broke thru to the surface in vulcanian (explosive) eruptions without associated lava flows. Alternatively, the erupted material could be from a source unrelated to the mare, in the style of regional pyroclastic deposits.

High-resolution images and spectroscopy from the Lunar Reconnaissance Orbiter (LRO) and Chandrayaan-1 spacecraft provide data to assess the mineralogy, major element composition and vent characteristics of the pyroclastic deposits. These data allow a test of formation models, and an assessment of the uniqueness of this eruption style.

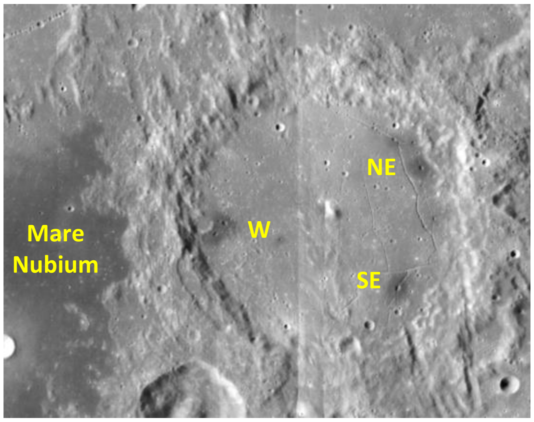

Figure 1. LROC WAC mosaic of Alphonsus crater and eastern Mare Nubium; the largest pyroclastic deposits (W, NE, SE) are seen as low albedo units on the crater floor.

Methods: Lunar Reconnaissance Orbiter Cameras (LROC) Regional mapping utilized the 100 m/pixel mosaic produced from wide-angle camera (WAC) images. Detailed analyses used narrow-angle camera (NAC) frames, with resolutions of 0.5 m/pixel [4].

Moon Mineralogy Mapper (M^3) A high spatial (140 m/pixel) and spectral (83 bands) resolution mosaic was made for Alphonsus and eastern Mare Nubium, using data (corrected for the thermal emission contribution to the reflectance spectra) from the M^3 instrument on Chandrayaan-1 [5]. Spectral measurements in the visible- to near-infrared (VIS-NIR) wavelengths are sensitive to Fe-bearing minerals such as pyroxene, plagioclase and olivine as well as Fe-bearing glass.

Diviner Lunar Radiometer Experiment Diviner is a near- and thermal-IR mapping radiometer on LRO, with a 320 m (in track) by 160 m (cross track) detector field of view at an altitude of 50 km. Three channels centered near 8 µm are used to measure the emissivity maximum known as the Christiansen feature (CF) [6]. The wavelength of this feature is particularly sensitive to silica polymerization in minerals including plagioclase, pyroxene and olivine. These values were plotted against published FeO abundances for Apollo soil samples, along with Apollo 17 pyroclastic glass. The CF and FeO values closely correlate across the full range of Apollo soil and glass compositions, providing a basis for estimating the FeO concentrations of other lunar soils and pyroclastic deposits [7].

Results: Spectra from M[3] confirm that the floor of Alphonsus is composed of noritic material, with spectra dominated by low-Ca pyroxene absorptions with band centers near 0.945 – 0.960 μm and 1.97 – 2.00 μm. Fresh exposed small craters in Mare Nubium show high-Ca pyroxene absorptions with band centers near 0.985 – 1.0 μm and 2.05 – 2.15 μm (Fig. 2).

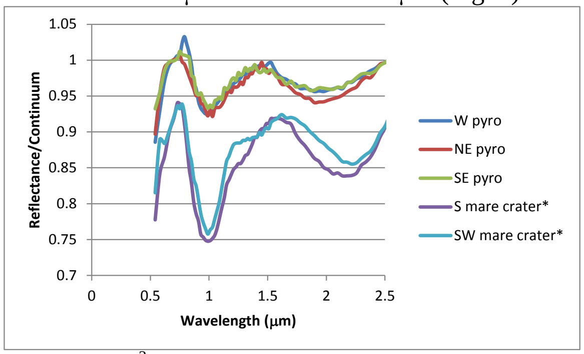

Figure 2. M[3] spectra of pyroclastic deposits compared to Mare Nubium craters; *mare crater spectra are vertically offset by - 0.08.

The three largest pyroclastic deposits on the floor of Alphonsus (W, NE, SE) were also analyzed (Fig. 2). The 1 μm absorption bands for these deposits are broad, with band centers near 0.98 – 1.02 μm, and the 2 μm absorption bands have centers near 1.95 – 2.00 μm. This is consistent with a minor low-Ca pyroxene component in a glass-rich matrix with or without minor olivine. The 2 μm absorption bands have centers too short to be of the same origin as the Nubium basalts.

Diviner CF values were used to calculate FeO abundances for the Alphonsus crater floor, Mare Nubium soil and the largest pyroclastic deposits [7]. The calculated FeO abundance for the crater floor (7.5 +/- 1.4 wt.%) is within the range of values for norite samples [8], supporting the interpretation of the floor material as noritic. However, the calculated FeO abundance for Nubium soil (13.4 +/- 1.4 wt.%) is lower than those for most mare samples [8] and lower than the value of 17.5 wt.% derived from Clementine data for eastern Nubium [9]. The difference may reflect contamination of the mare soil by ejecta from craters into highland material.

The Diviner-derived FeO abundance for the west (thickest) pyroclastic deposit is 13.8 +/- 3.3 wt.%. This is lower than the FeO abundance for mare soil samples, but within the FeO range of pyroclastic glasses [8].

The NAC images of the largest pyroclastic vents highlight their high-albedo wall materials and lack of lava flows (Fig. 3). The M[3] spectra of the southeast vent indicate that this bright material is noritic, and is interpreted as crater floor material exposed by explosive eruption.

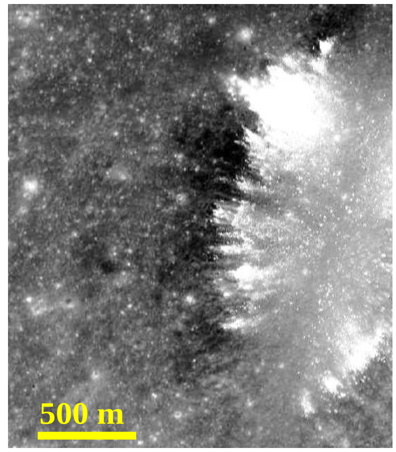

Figure 3. LROC NAC image of the southeast vent in the Alphonsus floor; image M155247161R.

Discussion: These observations directly address the hypothesis [3] that Mare Nubium lavas intruded the deep fracture network beneath Alphonsus, leading to localized vulcanian-style eruptions. This model predicts that the juvenile eruption products would be dominated by crystalline basalt fragments similar in elemental composition and mineralogy to mare lavas.

The bright noritic material exposed in the vent walls, without apparent coating by lava flows, is consistent with explosive eruptions. Diviner-derived FeO abundances for the pyroclastic deposits are too low for mare basalts, but are within the compositional range of pyroclastic glass samples. The M[3] VIS-NIR spectra of the pyroclastic deposits and Mare Nubium soils are significantly different. The pyroclastic spectra are consistent with Fe-bearing glass with or without olivine, and containing a small amount of noritic wall rock. Similar Fe-bearing glass materials dominate regional pyroclastic deposits, including the Taurus-Littrow deposit sampled on Apollo 17 [10].

These results suggest that the small pyroclastic deposits in Alphonsus are chemically and mineralogically distinct from mare basalts, but are similar to regional pyroclastic deposits. The deposits in this crater thus represent a unique combination of composition and eruption style.

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