ALPHONSUS CRATER: COMPOSITIONAL CLUES TO ERUPTION STYLES OF LUNAR SMALL VOLCANOES. Lisa R. Gaddis[1], Briony Horgan[2], Marie McBride[2], Kristen Bennett[3], Julie Stopar[3] and J. Olaf Gustafson[4], [1]Astrogeology Science Center, U. S. Geological Survey, 2255 North Gemini Drive, Flagstaff, AZ 86001; [2]Earth, Atmospheric & Planetary Sciences, Purdue University, W. Lafayette, IN, 47907; [3]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85282; [4]Dept. Earth & Atmospheric Sciences, Cornell University, Ithaca, NY (lgaddis@usgs.gov).

Introduction: Small volcanic craters in the floor of Alphonsus crater (108 km diameter; ~13°S/357°E) are considered type localities of small lunar pyroclastic deposits, based on the observed association of dark mantling material with floor fractures, non-circular craters, and positive-relief features marking source vents [1]. Here we analyze hyperspectral data for Alphonsus from the NASA Moon Mineralogy Mapper (M^3) instrument on the ISRO Chandrayaan-1 spacecraft [2]. Using M^3 global imaging mode data (140 m/pixel spatial resolution, OP1B/2A) with spectral resolution of 20-40 nm in 85 channels between 460 and 3000 nm, the data allow us to identify and map soil and rock mineralogies that are related directly to their volcanic eruption and emplacement styles.

Head and Wilson [1] studied the geomorphology of Alphonsus volcanic deposits, and they concluded that juvenile materials likely were present in many of them, representing magmatic components added to the deposits from the source dike. Such pyroclastic materials may include the best examples of primitive components (i.e., mantle xenoliths) on the Moon and thus are important for characterizing the lunar interior and constraining the origin and evolution of lunar basaltic magmatism. Earth-based spectral data indicate that the Alphonsus pyroclastic deposits are compositionally diverse and that olivine may be present in several of the pyroclastic deposits [3-6]. The iron-rich glasses observed at Alphonsus crater may provide an invaluable feedstock for lunar oxygen production [7].

Geologic Setting: Alphonsus is a pre-Imbrian aged crater located in the highlands east of Mare Nubium. Alphonsus has a broad, low rim, a flat cratered floor dissected into eastern and western sections by a ~N-S ridge (likely comprised of Imbrium basin ejecta), and a central peak. The crater floor is covered with a light plains unit that is dissected by numerous floor fractures. The 12 pyroclastic deposits of Alphonsus [8] are located within or adjacent to several floor fractures, indicating that fractures likely provided conduits for volatile accumulation and subsequent pyroclastic eruption. The vents are characterized by non-circular rims <3 km across and dark halos that extend up to 11 km from the crater center [8]. Head and Wilson [1] modeled the eruption of these small pyroclastic deposits as Vulcanian, occurring via the accumulation and explosive decompression of volatiles that collected beneath a caprock above a rising magma body.

Compositional Analysis: We characterize the position and shape of the 1 and 2 μm iron absorption bands in M^3 data to identify and map mineralogy of Alphonsus crater floor (***Figure 1***). We first smooth the data and then remove the continuum using a linear convex hull and finding local band maxima near 0.7, 1.5 and 2.6 microns. The "glass band depth" spectral parameter is calculated as the average band depth below the continuum at 1.15, 1.18, and 1.20 μm, and the "orthopyroxene (OPX) band depth" spectral parameter is calculated as the average band depth below the continuum at 0.88, 0.90, and 0.92 μm. The band analysis methods of Horgan et al. [9] are then used to parameterize the centers and depths of the 1 and 2 μm iron absorption bands. Maps of these parameters are used to distinguish between orthopyroxene (OPX; band centers between 0.9-0.94 and 1.8-1.95 μm), clinopyroxene (CPX; 0.98-1.06 and 2.05-2.4 μm), and iron-bearing glass (1.06-1.2 and 1.9-2.05 μm). Mixtures of these minerals have band centers that fall between the endmembers [9]. Other iron-bearing minerals, including olivine and plagioclase feldspars, can be identified using similar methods. Olivine has an asymmetric 1 μm band centered near 1.05-1.08 μm and plagioclase have broad, shallow bands centered between 1.25-1.35 μm (neither has a 2 μm band).

Observations: Band parameter maps (***Figure 1b, 1e***) with red as glass band depth, green as the OPX band depth, and blue as the 2 μm band center (1.9-2.07 μm) highlight all 12 known pyroclastic deposits in the crater floor. In this view, green colors indicate strong OPX absorptions, blue indicates weak OPX absorptions, pink indicates the presence of a mixture of Glass + OPX, and yellow indicates the presence of a mixture of Glass + CPX. Fresh craters with strong OPX bands are green (band centers = 0.93-0.95, 1.97-2.0 μm) with radial rays, while some older craters have less prominent rays but circular outlines. The pyroclastic deposits are largely pink, indicating Glass + OPX, and the clustered vents in the western crater floor (***Figure 1e***) also show areas of yellow and white units; these are units of

mixed Glass + CPX. In the three largest pyroclastic deposits (western cluster, Ravi, Soraya) there is a halo of CPX nearest the vent, an overall signature of OPX within the deposit, and a glass signature that decreases in magnitude away from the vents. There is a greenish annulus of OPX around the margins of each of the pyroclastic deposits.

The comparison of 1- and 2-µm band center positions (***Figure 1c, d***) for the western clustered deposits shows several notable trends: the 1-µm band center position decreases radially away from the vents, consistent with a decrease in glass abundance relative to OPX, but the 2-µm band center shows a radial change away from the vent, with higher band centers nearer the vents and lower 2-µm band centers farther away, consistent with CPX near the vent and OPX or glass farther away. This is shown in Figure 1d, where the 1 µm band shifts up and becomes more asymmetrical in spectra closer to the vent (blue/green spectra). Similar trends are observed for the other larger pyroclastic deposits at Ravi and Soraya, except that at Ravi very little CPX is observed.

Interpretation: These observations support an origin for these deposits as Vulcanian. The wide distribution of crater-floor-like OPX away from the vent is consistent with an energetic initial explosion, followed by fire-fountaining to form glass-rich deposits. The near-vent CPX signatures could be especially thick, possibly coherent pyroclastic deposits, thin flows, or fragmented basalt from within the source dike. These observations contrast with those at Oppenheimer crater on the lunar far side, which exhibit little to no evidence for a country rock component within the deposits. At Oppenheimer, both Vulcanian and fire-fountain eruption styles are inferred for several of the small pyroclastic deposits [10, 11]. Taken together, the constrasting but similarly complex mineralogies of Alphonsus and Oppenheimer attest to the complex nature of eruptions of small lunar volcanoes.

References: [1] Head & Wilson (1979) PLPSC 10th, 2861. [2] Goswami & Annadurai, 2009, Curr. Sci., 96(4), 486-491. [3] Hawke et al. (1989) PLPSC 19th, 255. [4] Coombs et al. (1990) PLPSC. 20th, 339. [5] Besse et al. (2014) J. Geophys. Res. Planets 119, 355–372, doi:10.1002/2013JE004537. [6] Jawin et al. (2015) J. Geophys. Res. Planets 120, doi:10.1002/2014JE004759. [7] Allen (2015) 46th LPSC, abs. 1140. [8] Gaddis et al. (2011) LPSC 42, abs 2691. [9] Horgan et al., 2014, *Icarus*, *234*(C), 132–154, doi:10.1016/j.icarus.2014.02.031. [10] Bennett et al., in review, Icarus. [11] Horgan et al. (2015) AGU abstract P31H-03.

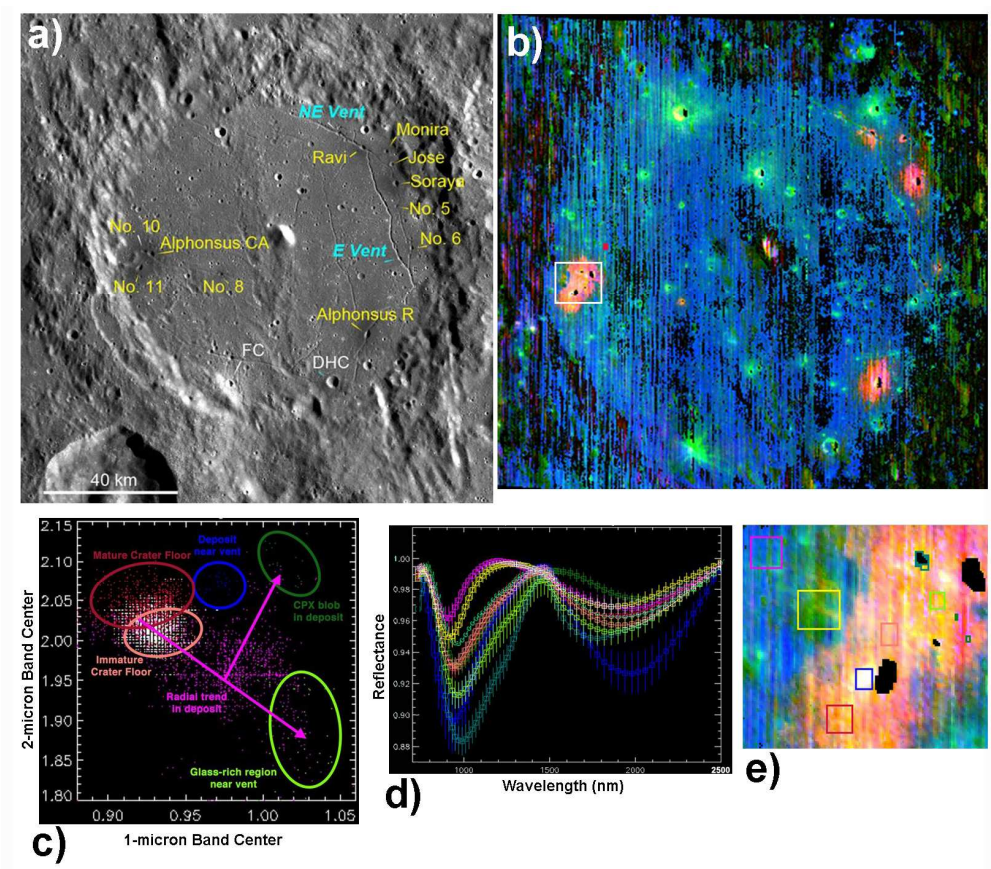

Figure 1. *Alphonsus crater data: a) Kaguya Terrain Camera mosaic showing 12 dark pyroclastic deposits (including very small northeast (NE) and east (E) vents), a mantled older impact crater (José), a central peak, a fresh crater (FC), and an impact-related dark-halo crater (DHC). b) M³ color mosaic, with R=Glass band depth (0-2%), G=OPX band depth (0-6%), B=2 µm band center (1.9-2.07%). c) Band center histogram comparing 1- and 2-µm band center positions. d)Continuum-removed reflectance spectra of units highlighted in e), colors correspond to colored boxes in e). e) Close-up view of three clustered pyroclastic vents in the western crater floor.*