EXPLOSIVE VOLCANISM ON THE MOON; C.R. Coombs, B.R. Hawke, L.R. Gaddis, Planetary Geosciences Division, Hawaii Institute of Geophysics, Univ. of Hawaii, Honolulu, HI, 96822

INTRODUCTION: In recent years the aquisition of a variety of remote sensing and geologic data for pyroclastic mantling units has increased our understanding of the important role of lunar explosive volcanism in the formation and resurfacing of the lunar surface. Two genetically distinct types of pyroclastic deposits have been recognized on the lunar surface: regional and localized. Eruption mechanisms and emplacement styles for both the regional and localized lunar pyroclastic materials have been inferred from their distribution, source vent morphology and the composition and geometry of their mantling deposits. Various data sets used in this study include: Apollo photographs, near-IR reflectance spectra, 3.8 cm radar, and returned lunar samples. This paper summarizes our studies of lunar explosive volcanism to date, and presents new compositional information which enables us to place localized lunar pyroclastic mantling deposits into context with regional lunar pyroclastic mantling deposits to create an overall picture of lunar explosive volcanism.

REGIONAL PYROCLASTICS: Regional lunar pyroclastic deposits (RDMD) formed as products of fire-fountaining which occur in association with basaltic eruptions.[1] Commonly recognized as "dark mantle deposits" in lunar highland areas adjacent to many of the major maria, RDMD may have been associated with some of the early mare-filling volcanic episodes.[2] Depressions at the head of associated sinuous rilles and other related irregular depressions are the probable source vents for this RDMD. Characteristically, these deposits are low-albedo (0.079-0.096) units[3] which appear to cover and subdue the features of the underlying terrain. Visual observations and photographs obtained during the Apollo missions indicated that the surface of lunar pyroclastic materials is relatively fine textured with a smooth, velvety appearance.[4,5,6] These regional pyroclastic deposits exhibit very weak to nonexistent echoes on the depolarized 3.8-cm radar maps of Zisk *et. al.*.[7] These low returns are attributed to the lack of surface scatterers (rocks, boulders, etc.; 1-50 cm in size) on the smooth surfaces of pyroclastic mantling deposits.[8,9]

Spectral reflectance data (0.6-2.5 μm) for several RDMD (i.e. Taurus Littrow, Aristarchus regions) indicate that these mantling units contain a significant Fe^{2+}-bearing glass component[9,10] further supporting what was found in the returned samples. Volcanic (orange) glass spherules returned by Apollo 17 are believed to be relatively unfractionated samples of the deep lunar interior (>300 km). These glasses, collected from regional pyroclastic deposits, have a volatile-rich coating. Presumably condensed from gases involved in an explosive eruption, these glass coatings strongly suggest the existence of a volatile gas phase in their source magmas. The fire-fountain origin of the volatile-coated pyroclastic glass stands in striking contrast to the massive outpouring of volatile-depleted, low-viscosity magma which formed the lunar maria. Thus, regional pyroclastic mantling deposits are unique among lunar volcanic materials.[9]

Head and Wilson[11,12] and Wilson and Head[13] have suggested that RDMD are more likely related to conditions characterized by strombolian or continuous eruption activity and, that it is unlikely that the extensive dark mantle deposits are the result of coalescing deposits of localized pyroclastics (i.e. Alphonsus-type dark-halo craters). Their calculations indicate that the lunar equivalent of strombolian activity is likely to lead to the dispersal of pyroclastics over a wide area, with extreme sorting of particles: clasts greater than a few cm will remain within several tens of m of the vent while clasts much smaller than 1m may be projected to tens of km. Thus, unless a very restricted size range of fragments is erupted, it is unlikely that a well defined boundary (within 4 km of vent) will be produced.

LOCALIZED PYROCLASTICS: Localized lunar dark mantle deposits (LDMD) are small, low-albedo units of pyroclastic origin which are concentrated around the perimeters of the major lunar maria and are commonly located in the floors of large Imbrian and pre-Imbrian (or >3.4 by) aged impact structures .[11] These deposits are generally associated with endogenic dark halo craters. Characteristically, dark-halo craters (DHC) are small in size (<3 km), aligned along crater floor-fractures, have a non-circular shape, lack obvious rays.[11], and are smooth and generally block free (i.e. Alphonsus-type dark-halo craters,). Morphometric analyses of these "haloes" have led investigators to suggest an eruption mechanism analogous to that of terrestrial vulcanian explosive eruptions.[11] In this style of eruption, the accumulation of gas in a capped magma chamber leads to explosive decompression, and the subsequent emplacement of a pyroclastic deposit around an endogenic source crater. It has been shown that for these types of eruptions the maximum range of all pyroclasts much larger than 1 cm is up to 4 km, while smaller clasts may be thrown up to tens of km, leaving a well-defined division between the localized deposits of coarse clasts and the widely dispersed deposit of small clasts.[11,12,13]

Although an eruption mechanism has been proposed for the Alphonsus-type LDMD the question remains as to how these deposits fit into the big picture of lunar explosive volcanism. Several related questions that may help answer this are: 1) Do intra- and inter- compositional variations exist? 2) Do all localized dark mantle deposits have basaltic compositions? 3) How do compositions of localized dark mantle deposits compare to those of the large regional dark mantle deposits such as Taurus Littrow, Aristarchus and Rima Bode? and, 4) Do localized dark mantle deposits also contain volcanic glass? Analyses of near-infrared spectra (0.6-2.5 μm) of 12 LDMD have helped answer the previous questions. The spectra collected for these LDMD exhibit marked compositional variations. Dominant in these data is the Fe^{2+} absorption band in the 1.0μm wavelength region. To emphasize the differences in the characteristics of this absorption band, a straight-line continuum has been removed from these spectra. Three distinct spectral groups have been discerned on the basis of the depth and shape of the 1.0μm absorption band.

Group 1 includes spectra of pyroclastics from Grimaldi, Franklin floor, Atlas DHC 1, and Archimedes S. rim. Centered at 0.93-0.95μm, the absorption band for this group has a depth of 4-5 % and a check-like shape. These bands are similar to those obtained for mature highland areas, but may have an additional Fe-Ti rich glass component present, as suggested by their low-albedoes and unusual 0.40/0.56μm ratios. These deposits are possibly composed of highlands-rich wall rock and glass-rich juvenile material with much lesser amounts of basaltic cap rock material. Localized pyroclastic deposits represented in group 2 include: 2 deposits east of Aristoteles, Rima Fresnel, and Atlas DHC 2. Band centers near 0.96μm, are deeper at 7%, and more symmetrical than group 1. These spectra most closely resemble mature mare spectra with the presence of Ca-rich pyroxene as indicated by the 0.96μm band. This group is spectrally and geologically consistent with a vulcanian eruption origin, the products of which are dominated by fragmented basaltic rock material with much lesser amounts of highlands debris and juvenile material. The spectra collected from the J. Herschel pyroclastic deposit are representative of group 3. The broad and moderately deep bands in the 1.0μm region indicate the presence of a mixture of olivine and pyroxene in the soils of this region.[14] Other members of this group may also contain material rich in olivine and pyroxene as well as pryoclastic glass. Lesser amounts of fragmental basaltic plug rock and highlands-rich wall rock may also be present.

CONCLUSION: Eruption mechanisms and emplacement styles for both the regional and localized lunar pyroclastic materials inferred from their distribution, source vent morphology, and composition and geometry of their mantling deposits have shown that though they are genetically different, regional and localized dark mantle deposits may be compositionally similar. Both exhibit a low-radar return (3.8 cm), have a smooth surface and low albedoes, and contain varying amounts of Fe^{2+}-bearing glass. The strombolian eruption origin of RDMD is consistent with the unfractionated, volatile-coated glass samples returned by Apollo 17 and the idea that these originated deep in the lunar interior (<300 km). The lack of associated lava flows and the small radial extent of the dark-halos (3-5 km) around the LDMD suggests that they were formed during a short-lived (vulcanian) explosive eruption. The explosive origin of these volatile-rich pyroclastic materials stands in striking contrast to the massive outpouring of volatile-depleted low-viscosity magma which formed the lunar maria. Thus, lunar pyroclastic mantling deposits are unique among lunar volcanic materials.

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