Comparison Between Pyroclastic Deposits on the Moon and Mercury

Fig. 6. Comparison of reflectance spectra of pyroclastic deposits on Mercury and the Moon. The spectrum of each deposit represents an average of ~5 individually selected pixels taken from outside each candidate vent. All MDIS spectra (collected during the first and second Mercury flybys) were corrected for phase angle and calibrated to absolute reflectance. The Hillier et al. (1999) correction was applied to the Clementine lunar spectra. Bands that were not shared between the two data sets were not included, except for the 415-nm band of Clementine and the 430-nm band of MDIS in order to illustrate the visible continuum. Although detailed spectral and albedo comparisons must await further collection and calibration of instrument data, it appears from current information that the albedos of mercurian pyroclastic deposits fall within the range of albedos for lunar pyroclastic deposits. The ferrous iron absorption near 1000 nm seen in the spectra of lunar pyroclastic deposits is absent in spectra of the deposits on Mercury, consistent with the overall paucity of ferrous iron in silicate minerals on Mercury compared with the Moon (Blewett et al., 2002, 2009a; Warell and Blewett, 2004; Robinson et al., 2008).

The recent documentation of water and other volatiles in lunar pyroclastic glasses (Saal et al., 2008) and water in lunar minerals (McCubbin et al., 2010) suggest that lunar formation models predicting near-complete devolatilization may bear revisiting. These findings need not imply, however, that water incorporated during accretion was the only, or even the major, volatile responsible for explosive volcanism on the Moon. It has been suggested, for instance, that lunar pyroclastic deposits could have been fueled by an oxidation reaction producing CO from elemental carbon through the reduction of Cr_2O_3, TiO_2, or FeO (e.g., Sato, 1976; Fogel and Rutherford, 1995; Nicholis and Rutherford, 2005).

Zolotov (2011) explored this process for Mercury and suggested that several other species (S, Cl, and N) could survive devolatilization events because they are stable in their solid, reduced forms. The inferred dry, reducing conditions of the mantle of Mercury would result in volatile species that are distinct from those commonly encountered on Earth, perhaps including N_2, CO, S_2, CS_2, S_2Cl, Cl, Cl_2, and COS, rather than H_2O, CO_2, SO_2, H_2S, and HCl (Zolotov, 2011). The dominant volatiles expected to drive pyroclastic eruptions would depend on the initial composition of the accreted planet (e.g., elemental carbon may not be as abundant in planetesimals that formed in the inner parts of the solar nebula), the redox state of the mantle, and the temperature and pressure conditions encountered during the rise of the erupting magma (which affect how the volatile components partition into the gas phase) (Zolotov, 2011).

Analysis following the first MESSENGER flyby (Kerber et al., 2009) indicated that in order to produce a deposit the size of RS-03 (the fifth largest in Table 1; Fig. 2a), approximately 5550 parts per million (ppm) of CO (or an equivalent amount of another volatile) would be required. This calculation can be made because the horizontal range, X, of any ballistic particle is directly proportional

to v_0^2/g, as described above, and thus is also directly proportional to the kinetic energy of the particle at the time of eruption, $(1/2)mv_0^2$, where m is particle mass. The kinetic energy at the time of eruption is, to a good approximation, directly proportional to the released magma gas fraction by mass, f (Wilson, 1980), so f/g is proportional to X. Wilson and Head (1981) determined that approximately 500 ppm of CO (equivalent to an eruption speed of 90 m/s) would be needed to emplace pyroclasts to a distance of 5 km on the Moon. From the relationship above, it would take 2.3 times the amount of a particular volatile species to emplace pyroclasts to the same distance on Mercury.

In this way, we converted each measured deposit radius into the equivalent proportion of volatiles needed to eject a pyroclastic particle to this distance on Mercury. The results, displayed in Fig. 7 and Table 2, are shown in ppm CO because CO is a volatile species that could be produced on Mercury under a variety of conditions, and the values can be easily compared with values discussed for the Moon, where CO is considered a likely volatile (Nicholis and Rutherford, 2005). It is more likely in practice that an eruption on Mercury would be driven by a combination of volatile species. The required amount of different volatile species can be readily calculated, as the energy available from the expansion of a gas is inversely proportional to its molecular weight. These calculations hold for any type of explosive eruption, as they address only the amount of energy imparted to the entrained pyroclasts as they exit the vent and are not dependent on the manner or timing of degassing. However, depending on the type of eruption, volatiles could have passively degassed from the magma, causing a depletion in volatiles needed for an explosive eruption, or they could have become concentrated during the dike propagation and eruption processes, yielding calculated abundances that are greater than their original abundances in the melt.