yielding (for an angle of 45°, chosen to determine the minimum energy needed to emplace the particles)

$$X = \frac{2v_0^2 \sin\theta\cos\theta}{g} = \frac{v_0^2 \sin 2\theta}{g} = \frac{v_0^2}{g} \propto \frac{1}{g}.$$

In this way we may scale a deposit radius measured on Mercury to what it would be on the Moon for the same initial ejection velocity

$$\frac{X_{Moon}}{X_{Mercury}} = \frac{g_{Mercury}}{g_{Moon}} = \frac{3.7\,\mathrm{m/s^2}}{1.6\,\mathrm{m/s^2}} \Rightarrow X_{Moon} = 2.3X_{Mercury}.$$

From this scaling, it can be seen that the candidate pyroclastic deposits thus far identified on Mercury required markedly higher eruption velocities (and hence more energy) to achieve their observed radial extents than their lunar counterparts (Fig. 5b). If mercurian deposit radii calculated from area measurements are used instead of directly measured radii, this difference is enhanced.

The surface area of Mercury is approximately two times greater than that of the Moon, suggesting that, all else being equal, two times as many pyroclastic deposits would be expected on Mercury. Only about half as many pyroclastic deposits have been identified on Mercury to date, however, as have been identified on the Moon. This difference may mean that pyroclastic volcanism was less common on Mercury or that pyroclastic deposits were more commonly buried by other types of deposits on Mercury than on the Moon. However, many of the deposits documented on the Moon are "small" or "very small" deposits. No "small" or "very small" deposits have yet been found on Mercury (shown in Fig. 4, where the deposits are displayed with symbols corresponding to the same size classes). This absence of small pyroclastic deposits on Mercury could be an effect of resolution, and as the resolution of data for Mercury improves it is expected that additional smaller pyroclastic deposits may be discovered. Milkovich et al. (2002) estimated from analysis of lunar volcanic features at different resolutions that small volcanic domes required both low Sun and resolutions between 100 and 500 m/pixel in order to be identifiable in images. The current NAC mosaic has a spatial resolution of approximately 500 m/pixel, and that for the WAC mosaic is closer to ~5 km/pixel (Becker et al., 2009). The orbital phase of the MESSENGER mission will generate higher-resolution data, including NAC image mosaics with an average resolution of better than 250 m/pixel and targeted images with resolutions of 25 m/pixel. WAC color data will be available with resolutions of 1.1 km/pixel, and targeted images will have resolutions of approximately 300 m/pixel, meaning that smaller volcanic features on Mercury should be resolvable (Milkovich et al., 2002).

2.5. Color and albedo

Multi-band spectral reflectance data from the MDIS WAC instrument obtained during the MESSENGER flybys allow for broad correlations between spectrally similar units. However, limited data taken at a variety of phase angles and viewing geometries make detailed compositional analysis of individual spectra difficult, especially for smaller pyroclastic deposits and those located at high latitudes or along the limb of the planet. Pyroclastic deposits on Mercury generally appear to be brighter and redder (that is, displaying higher reflectance and a more steeply inclined visible to infrared reflectance slope) than average background terrain (Robinson et al., 2008; Blewett et al., 2009a; Kerber et al., 2009). On Mercury, volcanic fire fountains are expected to have a greater optical density than fire fountains on the Moon. Together with shorter flight times due to the greater gravitational acceleration of Mercury, this effect would result in a larger percentage of pyroclasts falling to the surface warm on Mercury than on the Moon (Kerber et al., 2009). Pyroclasts deposited in this way would be more likely to crystallize as opposed to being quenched as glasses.

On the Moon, crystallized pyroclastic beads are darker than quenched glasses because of the crystallization of opaque minerals such as ilmenite, which also tends to make the deposit relatively "blue" (Pieters et al., 1974). Lunar pyroclastic deposits that are relatively bright and red relative to other lunar pyroclastic deposits appear to be lower in iron (Lucey et al., 1995). The bright and red character of the pyroclastic deposits on Mercury may thus indicate that they are relatively low in iron compared with surrounding terrain (which may already be low in iron). Although pyroclastic deposits on Mercury may be more likely to have crystallized than their lunar counterparts, they apparently did not crystallize a large amount of opaque minerals. The lack of a 1000-nm ferrous iron band in any of the pyroclast spectra supports the conclusion that the deposits are low in ferrous iron and is consistent with the general paucity of iron in silicates at the surface of Mercury (Blewett et al., 2002, 2009a; Warell and Blewett, 2004; Robinson et al., 2008; Denevi et al., 2009). An absence of opaque minerals could reflect a paucity of titanium, if the most common opaque mineral was ilmenite.

Reflectance spectra of mercurian pyroclastic deposits can be broadly compared with reflectance spectra derived from five-band Clementine data for lunar pyroclasts (Gaddis et al., 2003) by removing the WAC bands that are not shared between the two instruments (the 415 nm Clementine and 430 nm WAC bands are left to illustrate the visible continuum; Fig. 6). The reflectance values of the mercurian pyroclastic deposits fall within the general range reported for the lunar deposits (Fig. 6). Thus, whereas mercurian pyroclastic deposits appear brighter than surrounding terrain, and lunar deposits appear dark compared with their surroundings, this difference in contrasts appears to have more to do with the relative albedos of the surrounding terrain than with the pyroclastic deposits themselves. Further compositional analysis of pyroclastic deposits will be possible following the detailed photometric and scattered-light calibration of the WAC multi-spectral image data (e.g., Domingue et al., 2010). Deposits of particular interest are those that appear to resemble other pyroclastic deposits but are located in the areas for which the spectral data are uncertain (e.g., NE Rachmaninoff, Rachmaninoff SE, Beckett, unnamed crater 4, and Gibran).

3. Implications of deposit dimensions for interior volatile contents

The presence of volatile elements deep within the interior of Mercury sufficient to drive pyroclastic eruptions has implications for the planet's mode of formation and subsequent evolution (e.g., Kerber et al., 2009). It had long been thought that Mercury's interior would be volatile-poor, since it is likely to have accreted in a hot part of the solar nebula (Wetherill, 1994). In addition, the large core-to-mantle ratio of Mercury has been hypothesized to be due to some type of later heating episode, either by the nebula (Cameron, 1985; Fegley and Cameron, 1987) or by a giant impact (Wetherill, 1988; Benz et al., 1988, 2007). Both types of heating event would have further devolatilized the planet's interior. However, the presence of pyroclastic volcanism on Mercury suggests that the devolatilization of the planet was not complete, or that the initial volatile budget of the planet was greater than previously hypothesized, perhaps due to the incorporation during accretion of planetesimals formed over a large range of solar distances, excursions of the semi-major axis of Mercury's orbit in the early stages of accretion (Wetherill, 1988), or bombardment by volatile-rich embryos from the outer solar system (Morbidelli et al., 2000).