in assessing the amount and distribution of volatile and heat-producing elements within the interior (e.g., Solomon and Chaiken, 1976; Wilson, 2009).

The discovery of pyroclastic deposits on the surface of Mercury has already provided an important constraint on the interior volatile budget of the planet (Kerber et al., 2009), which had previously been hypothesized to be extremely volatile poor (e.g., Boynton et al., 2007). The presence of pyroclastic and other volcanic deposits has also revealed that the stress state of the crust of Mercury has not, on a global basis, been sufficiently compressive throughout its history to prohibit the propagation of dikes to the surface (Wilson and Head, 2008). In this work we provide a detailed documentation of what we interpret to be pyroclastic deposits identified in the course of the three MESSENGER flybys of Mercury and an analysis of their morphologies, physical properties, and distribution. This analysis is used to provide a framework for future study of pyroclastic deposits by MESSENGER after its insertion into orbit about Mercury (scheduled for March 18, 2011) and by the later BepiColombo mission, which is expected to begin data collection in 2020 (Benkhoff et al., 2010), by identifying key areas for targeting, outlining major science questions and objectives, and summarizing techniques and analyses successfully used to study lunar pyroclastic deposits. Given the recent and projected influx of data from both Mercury and the Moon, the extremely rich opportunity to study pyroclastic deposits on the two bodies in concert is also discussed.

2. Characteristics of pyroclastic deposits on Mercury

Possible pyroclastic deposits on Mercury were first identified in Mariner 10 data. Rava and Hapke (1987) identified, on the floor of the crater Lermontov, a candidate pyroclastic deposit characterized by diffuse borders, high reflectance, and relatively red color (i.e., displaying a more steeply sloped reflectance spectrum from visible to near-infrared wavelengths). MESSENGER has provided additional evidence to support the inference that this deposit is indeed pyroclastic in nature. Several other diffuse, low-albedo, relatively blue deposits were suggested to be either ballistically emplaced ejecta deposits or pyroclastic deposits (Robinson and Lucey, 1997). New, higher-resolution data and multi-band color information acquired by the Mercury Dual Imaging System (MDIS) narrow-angle camera (NAC) and wide-angle camera (WAC) (Hawkins et al., 2007) have suggested that several of these low-albedo, relatively blue deposits (northwest of Lermontov crater and within Homer basin) are most likely of impact origin (Blewett et al., 2009b).

During the first MESSENGER flyby, five additional candidate pyroclastic deposits were identified, mostly immediately inside the southern rim of the 1550-km-diameter Caloris impact basin (Head et al., 2008; Murchie et al., 2008; Robinson et al., 2008; Blewett et al., 2009a; Kerber et al., 2009). These deposits have diffuse boundaries and are generally bright and red with respect to nearby units (Robinson et al., 2008; Blewett et al., 2009a; Kerber et al., 2009). Many of the deposits are associated with irregularly shaped vent-like depressions (Head et al., 2008, 2009; Murchie et al., 2008; Robinson et al., 2008; Kerber et al., 2009).

Subsequent flybys provided many more observations from which additional pyroclastic deposits could be identified. From images obtained during the second flyby, Blewett et al. (2009b) identified two additional pyroclastic deposits, one within the crater Mistral and another within a crater modified by Antoniadi Dorsum, and Denevi et al. (2009) mentioned a possible pyroclastic deposit in Praxiteles crater. With the completion of the third flyby, it is possible now to identify, describe, and map pyroclastic deposits on a global basis.

2.1. Identification of pyroclastic deposits

We have identified candidate pyroclastic deposits globally on Mercury on the basis of spectral character, morphology, and surface texture inferred from a combination of WAC 11-band color image mosaics (with bands centered at 430, 480, 560, 630, 700, 750, 830, 900, 950, 1000, and 1020 nm wavelength, and a resolution of ~5 km/pixel), and NAC high-resolution image mosaics (centered at 750 nm, with a resolution of 500 m/pixel) (Hawkins et al., 2007; Robinson et al., 2008; Becker et al., 2009; Domingue et al., 2010). The image mosaics were calibrated to irradiance/solar flux (I/F), photometrically adjusted to the standard bidirectional geometry of 30° solar incidence and 0° emission angle (Robinson et al., 2008; Domingue et al., 2010), and analyzed using ENVI, an image visualization software package. Representative spectra were selected from the pyroclastic deposit studied in detail by Kerber et al. (2009), here termed RS-03 (after Red Spot 3, the designation given to the feature by Blewett et al., 2009a); Caloris interior plains material; bright crater-fill material; dark crater material; and plains materials exterior to Caloris. A linear spectral unmixing (end-members summing to unity using a weight of 4) was then performed to highlight the units that had spectra that are most similar to the spectrum of RS-03. One representation of the result of the spectral unmixing is shown in Fig. 1a and b, for which red (R) is pyroclastic material, green (G) is bright crater-fill material, and blue (B) exterior Caloris plains. The locations of the end-member spectra are indicated in Fig. 1a.

Several other spectral unmixing procedures were performed with other types of deposits chosen as the end-members. These results were compared to RGB color composite images obtained with several combinations of WAC bands (e.g., 430, 750, and 1000 nm). The areas consistently identified as similar to RS-03 were targeted for further analysis. For regions where Mariner 10 images had a resolution or viewing angle that was preferable to that provided by MESSENGER NAC data, these images provided supplementary information for morphological identification. Areas with high incidence angles or non-ideal viewing geometry appear around the edges of the spectral classification composite

Fig. 1. (a) Spectral classification results (resolution ~5 km/pixel), based on the calibrated WAC color mosaic (Hawkins et al., 2007; Robinson et al., 2008; Becker et al., 2009; Domingue et al., 2010). Representative end-member spectra were selected from (1) RS-03 (the pyroclastic deposit studied by Kerber et al., 2009), (2) plains material interior to the Caloris basin, (3) bright crater-fill material, (4) dark crater material, and (5) plains material exterior to Caloris (end-member locations indicated). A linear spectral unmixing was performed to identify the units that had spectra most similar to that of RS-03. Three end-member abundance images are presented here as an R–G–B composite (R: pyroclastic material; G: bright crater-fill material; B: plains exterior to Caloris). (b) Locations of candidate pyroclastic deposits. The deposits are generally named after the crater in which they are found. In cases where there is more than one deposit in a crater, the location of the deposit in the crater is added at the end (e.g., Praxiteles NE is a deposit in the northeastern part of Praxiteles crater). In cases where the deposit is not within a crater but there was a named crater nearby, the deposit name indicates the named crater, with the direction of the deposit from the crater added at the beginning (e.g., NE Rachmaninoff is a deposit located to the northeast of Rachmaninoff basin). Deposits associated with an unnamed crater are designated as such and numbered. (c) Composite image showing the maximum incidence angles for areas imaged by MESSENGER. Areas in red were imaged at high Sun (low incidence angle), and areas in blue at low Sun (high incidence angle). Most of the pyroclastic deposits that were identified appear in the areas between these two extremes, because sufficient color and morphologic indicators were both present. Future searches should be directed toward the reddest and bluest areas shown here, as these are the areas where deposits were most likely to have been missed.