Table 2
Magmatic abundances, in ppm, of selected volatiles required to emplace pyroclastic material to the maximum radial extent of each deposit. Abundances for some of the volatiles suggested as likely by Zolotov (2011) can be expressed in a similar way by scaling the calculated CO value by the ratio of the molecular weight of each volatile to that of CO, as follows: N_2=CO (identical molecular weights), S_2=2.3 (CO), CS=2.7 (CO), SCl=3.6 (CO), Cl=1.3 (CO), Cl=2.5 (CO), COS=2.1 (CO). Most of these abundances would therefore be high, near values for SO_2 at 2.4 (CO).

Site	CO	H_2O	CO_2	SO_2	H_2S
Rachmaninoff NE	16,000	11,000	26,000	37,000	21,000
RS-05	12,000	8000	20,000	29,000	16,000
Hemingway	12,000	8000	19,000	28,000	16,000
Lermontov NE	7600	4900	12,000	17,000	9800
Lermontov SE	7200	4700	11,000	17,000	9300
Raphael	7000	4500	11,000	16,000	9000
Hesiod	7000	4500	11,000	16,000	8900
Praxiteles NE	6000	3800	9400	14,000	7700
RS-03	5600	3600	8700	13,000	7000
RS-02	5300	3400	8400	12,000	6800
To Ngoc Van	5100	3300	8000	12,000	6600
Gibran	5100	3300	8000	12,000	6600
Scarlatti	5100	3300	8000	12,000	6500
Geddes	5000	3200	7800	11,000	6400
Hesiod c	4900	3100	7700	11,000	6300
Rachmaninoff SW	4700	3000	7300	11,000	6000
RS-04b	4600	3000	7200	10,000	5900
Hesiod b	4500	2900	7000	10,000	5700
Mistral SE	4300	2800	6800	9900	5600
RS-04a	4300	2800	6800	9900	5500
RS-04c	4300	2800	6700	9800	5500
RS-03 SW	4300	2800	6700	9800	5500
RS-01	4200	2700	6600	9600	5400
Praxiteles SW	4100	2700	6500	9400	5300
Melville	4000	2600	6300	9200	5200
Unnamed crater 1	4000	2600	6300	9200	5100
RS-04d	3800	2400	6000	8800	4900
Glinka	3800	2400	6000	8700	4900
NE Derzhavin	3500	2200	5400	7900	4400
Hesiod e	3200	2100	5000	7400	4200
Mistral NW	2600	1700	4100	6000	3300
Beckett	2200	1400	3500	5000	2800
Hesiod d	2000	1300	3200	4700	2600
RS-03 SE	1600	1000	2400	3600	2000

features into different volcanological regimes (Wilson and Head, 1981) that depend on the availability of magma, the abundance of volatiles, and the stress state of the lithosphere (Head and Wilson, 1992). Similar analyses have begun on Mercury (Wilson and Head, 2008) and will be greatly facilitated by the high-resolution image data to be collected by MESSENGER and BepiColombo.

In addition to morphological analysis, MESSENGER's multi-spectral MDIS WAC and hyper-spectral Mercury Atmospheric and Surface Composition Spectrometer (MASCS) instrument (McClintock and Lankton, 2007) make compositional analysis of pyroclastic deposits possible. The BepiColombo Mercury Planetary Orbiter (MPO) will be equipped with the Spectrometers and Imagers for MPO BepiColombo Integrated Observatory System (SIMBIO-SYS) and the Mercury Thermal Infrared Spectrometer (MERTIS) instruments that will view the planet in visible, infrared, and thermal wavelengths (Flamini et al., 2010; Hiesinger et al., 2010). For the Moon, the Apollo samples have enabled in-depth characterization of pyroclastic bead composition and distribution, which, combined with Clementine multi-spectral imagery, has allowed for the classification of pyroclastic deposits by bead color, iron content, and titanium content (Delano, 1986; Gaddis et al., 2003). Newly acquired spectral and imaging data (e.g., from Chandrayaan 1, Kaguya, and Lunar Reconnaissance Orbiter instruments) will enable even more detailed classification of pyroclastic deposits in order to determine the key parameters that lead to the differences between them, including source magma and style of volcanologic emplacement.

Table 3
Anticipated data sets that will further the understanding of pyroclastic deposits on Mercury.

Instruments	Mission	Possible insights
MDIS NAC	MESSENGER	Morphology, albedo, geological context
MDIS WAC	MESSENGER	Fe, Ti, and opaque mineral characterization, estimates of crystallization extent
MASCS	MESSENGER	Mineral identification
SIMBIO-SYS	BepiColombo	Morphology, albedo
MERTIS	BepiColombo	Mineral identification, thermal properties
XRS	MESSENGER	Al/Si ratio, Al/Mg ratio, Fe and Ca detections during solar flares
MIXS	BepiColombo	Al/Si ratio, Al/Mg ratio

Ages are not currently available for the pyroclastic deposits on Mercury. Whereas samples of lunar pyroclastic deposits have been returned to the Earth where they can be dated with laboratory techniques, mercurian deposits must be dated using a combination of crater-retention age dating (better for larger, thicker, and more coherent deposits), spectral maturity, and stratigraphic relationships. In the areas where Caloris impact-related features are visible, mapping conducted after the Mariner 10 flybys placed many of the craters hosting pyroclastic deposits at ages concurrent with or directly after the Caloris impact event (e.g., Guest and Greeley, 1983; Spudis and Prosser, 1984). Further dating of associated host craters and nearby volcanic units during the orbital phase of MESSENGER will help constrain the ages of the deposits to the several recognized periods in Mercury's history.

X-ray fluorescence instruments flown on the Apollo 15 and 16 missions documented the correlation between lunar dark mantling deposits and very high Mg/Al ratios (Schonfeld and Bielefeld, 1978). The later European Space Agency mission Small Missions for Advanced Research in Technology (SMART-1) continued mapping the Moon in X-rays, specifically targeting lunar pyroclastic deposits as a possible source of oxygen for future industrial use (Dunkin et al., 2003). The MESSENGER X-Ray Spectrometer (XRS) instrument will be able to search for correlations between high Mg/Al ratios and the mercurian pyroclastic deposits (Schlemm et al., 2007). During solar flares, the XRS will also be able to measure the distribution of Fe, Ti, and Ca (Schlemm et al., 2007). These XRS measurements, together with those taken by MASCS and MDIS, will serve to better characterize the petrological evolution of Mercury's source magmas, especially in comparison with those of the Moon (Dunkin et al., 2003). The best XRS resolution, over Mercury's northern hemisphere (~40 km per pixel), will be sufficiently high to resolve the larger pyroclastic deposits (Schlemm et al., 2007). BepiColombo's Mercury Imaging X-ray Spectrometer (MIXS) will gather X-ray data complementary to those of MESSENGER given that MPO will fly in a different orbit from that of MESSENGER and during a time of different levels of solar X-ray activity (Fraser et al., 2010). A summary of anticipated data resources is shown in Table 3.

5. Discussion and conclusions

The discovery of pyroclastic deposits on the surface of Mercury (Rava and Hapke, 1987; Head et al., 2008, 2009; Murchie et al., 2008; Robinson et al., 2008; Blewett et al., 2009a; Kerber et al., 2009) yielded several important insights. Pyroclastic deposits on Mercury were found to be similar to those on the Moon in that both are mantling deposits with diffuse edges often distributed around an approximately central, irregularly shaped depression (Fig. 3).