THE YOUNGEST GEOLOGIC TERRAINS ON MERCURY. Zhiyong Xiao[1,2 *], Robert G. Strom[1], David T. Blewett[3], Clark R. Chapman[4], Brett W. Denevi[3], James W. Head[5], Caleb I. Fassett[5], Sarah E. Braden[6], Klaus Gwinner[7], Sean C. Solomon[8], Scott L. Murchie[3], Thomas R. Watters[9], Maria E. Banks[9].
[1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85719, USA. [2]China University of Geosciences (Wuhan), Wuhan, Hubei 430074, P. R. China. [3]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA. [4]Department of Space Sciences, Southwest Research Institute, Boulder, CO 80302, USA. [5]Department of Geological Sciences, Brown University, Providence, RI 20912, USA. [6]School of Earth and Space Exploration, Arizona State University, AZ 85281, USA. [7]Institute of Planetary Research, German Aerospace Center, D-12489 Berlin, Germany. [8]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA. [9]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560,USA. xiaobear@lpl.arizona.edu

Introduction: Before the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission, Mercury had generally been considered as having a Moon-like surface without recent volcanic or tectonic activity [1]. During the three MESSENGER flybys, lava-flooded plains as young as ~1 Ga were found [2, 3]. After MESSENGER was inserted into orbit about Mercury in March 2011, high-resolution imaging revealed a large population of bright-haloed hollows that formed geologically recently [4]. With orbital data, we have identified bright-haloed hollows, dark spots, and volcanic vents that appear to be younger than rayed craters. We have also documented lobate scarps [5] and lava-flooded plains that are younger than impact craters of the youngest morphological class (the so-called Class 1 craters [6]).

Methodology and materials: Rayed craters are among the youngest geologic features on Mercury and the Moon. We have catalogued rayed craters on 98.35% of Mercury's surface, and we have sought examples of features younger than the rayed craters, including hollows, dark spots, volcanic vents, lava-flooded plains, and lobate scarps. Monochrome (250 m/pixel) and color (500 m/pixel) global mosaics from MESSENGER's Mercury Dual Imaging System (MDIS) were used for the analysis. The rayed craters are divided into two age groups on the basis of the reflectance and apparent freshness of the rays. A total of 205 fresh-rayed craters and 284 faint-rayed craters are included in the catalog. We applied crater production functions to the rayed craters to constrain model ages for the two crater populations. The model ages (Table 1) are the maximum ages for terrains younger than the rayed craters. Those derived from the most recent production functions [7, 8] are deemed more reliable.

The youngest geologic terrains: Bright-haloed hollows are widely distributed on Mercury [4]. More than 12 rayed craters have hollows. These hollows are usually surrounded by low-reflectance material termed "dark spots." The dark spots appear to differ in origin from impact-excavated low-reflectance material (LRM) [9]. Fig. 1 shows an example of bright-haloed hollows and dark spots on the floor of Kuiper crater, which has well-defined rays but no associated LRM (Fig. 1A). Bright-haloed hollows are located at the border of the crater floor and crater wall/central peak and are accompanied by dark spots (Fig. 1B). The hollows and dark spots are younger than the crater. Globally, dark spots nearly always occur in association with hollows; the few exceptions may be the result of presently limited image resolution. Some hollows, especially those without bright haloes, do not have surrounding dark spots, suggesting that dark spots may have formed before or during hollow formation and fade faster than the bright haloes.

Some irregularly shaped, rimless depressions on Mercury were interpreted to be volcanic pits on the basis of flyby images [10]. They differ from the hollows in scale, morphology, and color. Pit craters and their surroundings are mostly comparatively reddish in color and are interpreted to be volcanic vents with reddish pyroclastic deposits [2,10,11,12]. Pits less reddish in color may be older vents at which pyroclastic material has been modified or removed by space weathering [10]. We have found several volcanic pits on Mercury at which the most recent eruptions appear to postdate rays from nearby craters. If this association is correct, these pits are among the youngest volcanic centers on Mercury. Most of the pits as seen in color images have a black interior and reddish exterior deposits. The pyroclastic materials are dark or bright in monochrome images. Fig. 2 shows an example of such young pyroclastic deposit in a fresh impact crater. A diffuse dark deposit interpreted as pyroclastics appears to superpose rays from a nearby crater. An irregularly shaped rimless depression is located on the crater wall, but it is not fresh in appearance (Fig. 2B). In general, no lava flows are associated with these young deposits, indicating that the most recent interpreted eruptions were probably explosive.

Several lobate scarps are seen to transect Class 1 craters as large as 50 km in diameter on Mercury [5]. However, no lobate scarps that transect rayed craters or their rays have yet been identifided. Features on Mercury that resemble small-scale, relatively young (Copernican-age) lunar lobate scarps [13] are interpreted to be tectonic in origin. Impact craters with diameters of a few kilometers or smaller may have been crosscut by small-scale scarps. If confirmed by future targeted MDIS images, such features may have accommodated recent contraction on Mercury. We also found two small patches of lava-flooded plains embaying nearby Class 1 craters, indicating that lava-flooding events occurred on Mercury well after the late heavy bombardment, a finding that confirms previous results [2,3]. However, no lava-flooded plains have been found that embay crater rays.

Implications for the evolution of Mercury: Compared with the Moon, where internal geologic activity ceased long ago, Mercury experienced recent geologic activity of several types. Several bright-haloed hollows, dark spots, and possible volcanic vents formed more recently than some bright crater rays on Mercury, as recently as about 40 Ma according to the Le Feuvre and Wieczorek [8] timescale (Table 1). These findings thus indicate volatile-related and perhaps volcanic activity within the last few tens of millions of years.

No lava-flooded plains or lobate scarps younger than crater rays have yet been confirmed on Mercury. Some examples of both types of feature, however, are younger than Class 1 craters. This result indicates that Mercury experienced global contraction and plains volcanism well after the end of late heavy bombardment 3.8 Ga [15].

Acknowledgements: We thank the MESSENGER engineering and science teams. Simone Marchi helped us to apply his model [7].

References: [1] Head, J. W. et al. (2007), *Space. Sci. Rev.* 131, 41. [2] Prockter, L. M. et al. (2010), *Science* 329, 668. [3] Marchi, S. et al. (2011), *Planet. Space Sci.* 59, 1968. [4] Blewett, D. T. et al. (2011), *Science* 333, 1856. [5] Banks, M. E. et al. (2012), *LPS* 43, this mtg. [6] Wood, C. A. and L. Andersson (1978), *Proc. Lunar Planet. Sci. Conf. 9th*, 3669. [7] Marchi, S. et al. (2009), *Astron. Astrophys.* 431, 1123. [8] Le Feuvre, M. and M. Wieczorek (2011), *Icarus* 214, 1. [9] Denevi, B. W. et al. (2010), *Science* 324, 613. [10] Blewett, D. T. et al. (2009), *EPSL* 285, 272–282. [11] Gillis-Davis, J. J. et al. (2009), *EPSL* 285, 243. [12] Kerber, L. et al. (2011), *Planet. Space Sci*. 59, 1895. [13] Watters, T. R. et al. (2010), *Science* 329, 936. [14] Neukum, G. et al. (2001), *Planet. Space Sci.* 49, 1507. [15] Strom, R. G. et al. (2005), *Science* 309, 1847.

Table 1. Model ages for rayed craters obtained with different crater production and chronology functions.

Crater counting method	Age for all rayed craters (Ma)	Age for fresh-rayed craters (Ma)
[14]	689±57	271±36
[7]	159±19	64±6
[8]	110±4	42±4.3

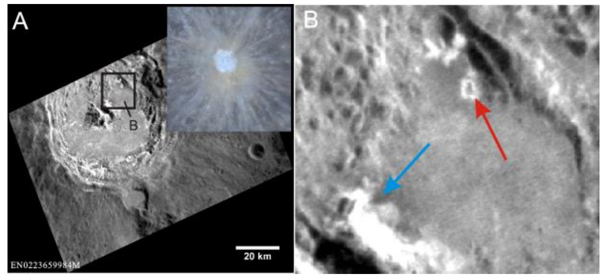

Fig. 1. Hollows and dark spots on the floor of Kuiper crater. (A) Monochrome image showing bright-haloed hollows and dark spots in the crater floor; the base image is EN0223659984M. (Inset) Color image (1000-750-430 nm mapped to Red-Green-Blue) shows no LRM around Kuiper, indicating that dark spots are not material excavated by the impact. (B) Detailed view of examples of hollows (red arrow) and dark spots (blue arrow). Up is to the north in both panels.

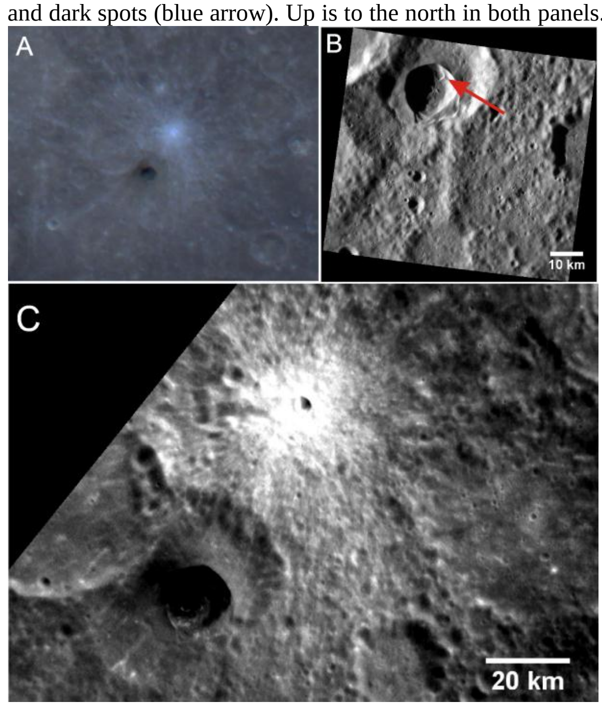

Fig. 2. A relatively young dark impact crater (black interior and ejecta) is interpreted to host a volcanic vent and associated pyroclastic deposits younger than the nearby rayed crater. (A) 1000-750-430 nm color image mapped to Red-Green-Blue shows that dark materials appear to superpose rays from the nearby crater. (B) An irregularly shaped rimless depression (red arrow) on the crater wall of the dark impact crater shown in (A). The pit is about 4 km long and 2 km wide, and the rim of the pit is not fresh. The base image is EN0220635705M. (C) Apparent overlap relation between the crater rays and dark materials. The eastern portion of the dark deposits has a deeper color and appears to superpose the rays. The source for the dark deposits interpreted to be pyroclastic is not determined. The base image is EW0230964748G. Up is to the north in all panels.