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A geologically supervised spectral analysis of 121 globally distributed impact craters as a tool for identifying vertical and horizontal heterogeneities in the composition of the shallow crust of Mercury

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ABSTRACT

In the present work, we expose procedures and results from a global scale geologically supervised spectral analysis of 121 impact craters on Mercury, selected on the basis of specific morphologic criteria. Using the capabilities of DFTs developed by PEL researchers at DLR, we combined MASCS spectra from the DLR database with MDIS high-resolution images. We use impact structures as a window for identifying vertical and horizontal compositional heterogeneities in the shallow crust of Mercury. Using specific GIS queries on a global scale, we defined five morphologic classes of units for each of the 121 impact craters, moving outward from the central peak to deposits at ten radii distance from the crater rim. We also used an external reference area as a term of comparison to represent intercrater plains. We then retrieved all the available MASCS spectra contained within each of those units. We analyzed the spectral slopes in the 350–450 nm and 450–650 nm ranges and reflectances in the 700–750 nm range using two different approaches, the first one being more conservative than the second one. The results indicate that the central peaks class is spectrally the most heterogeneous compared to all the other defined classes. As we move outward from the central peaks to external deposits, the other morphologic classes tend to get more and more spectrally and compositionally homogenous and more similar to intercrater plains. We identified a dependency of the spectral slopes from latitude. The spectral slopes of the analyzed deposits tend to decrease at increasing latitudes. This result might indicate the presence of a global N-S dichotomy in the composition of the shallow crust of Mercury. The detailed analysis of three impact craters with distinctive spectral characteristics revealed as well the occurrence of short-range horizontal heterogeneities in the composition of the shallow crust of Mercury.

1. Introduction

This study is focused on the global spectral analysis of the surface and subsurface of Mercury by simultaneously selecting all the available spectral observations contained within a number of previously defined morphologic units. The Planetary Emissivity Laboratory (PEL) group at DLR has been working in the last years on the development of techniques which allow the fusion of different planetary datasets in order to improve the ratio between quality of results and data processing time for both local and global scale supervised classifications. We name these procedures (here for the first time) as "Datasets Fusion Techniques" (DFTs) (D'Incecco et al., 2015).

Building on the results obtained through the global scale unsupervised clustering (D'Amore et al. 2012, 2013a,b; Helbert et al., 2013) and local scale geologically supervised studies performed by the D'Incecco et al. (2012, 2013, 2015), we used DFTs to perform a global scale geologically supervised spectral study of Mercury. In this study, we combine Mercury Atmospheric and Surface Composition Spectrometer (MASCS) Visible and Infrared Spectrograph (VIRS) data with Mercury Dual Imaging System (MDIS) images, both acquired from orbit by the Mercury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft. This global scale analysis is the direct continuation of the local scale geologically supervised spectral study of Waters and Kuiper craters by D'Incecco et al. (2012, 2013, 2015). The morphologic units we have defined for our global scale analysis follow the same approach used for the nomenclature of the units in the local scale study of Waters crater and Kuiper crater by D'Incecco et al. (2012,

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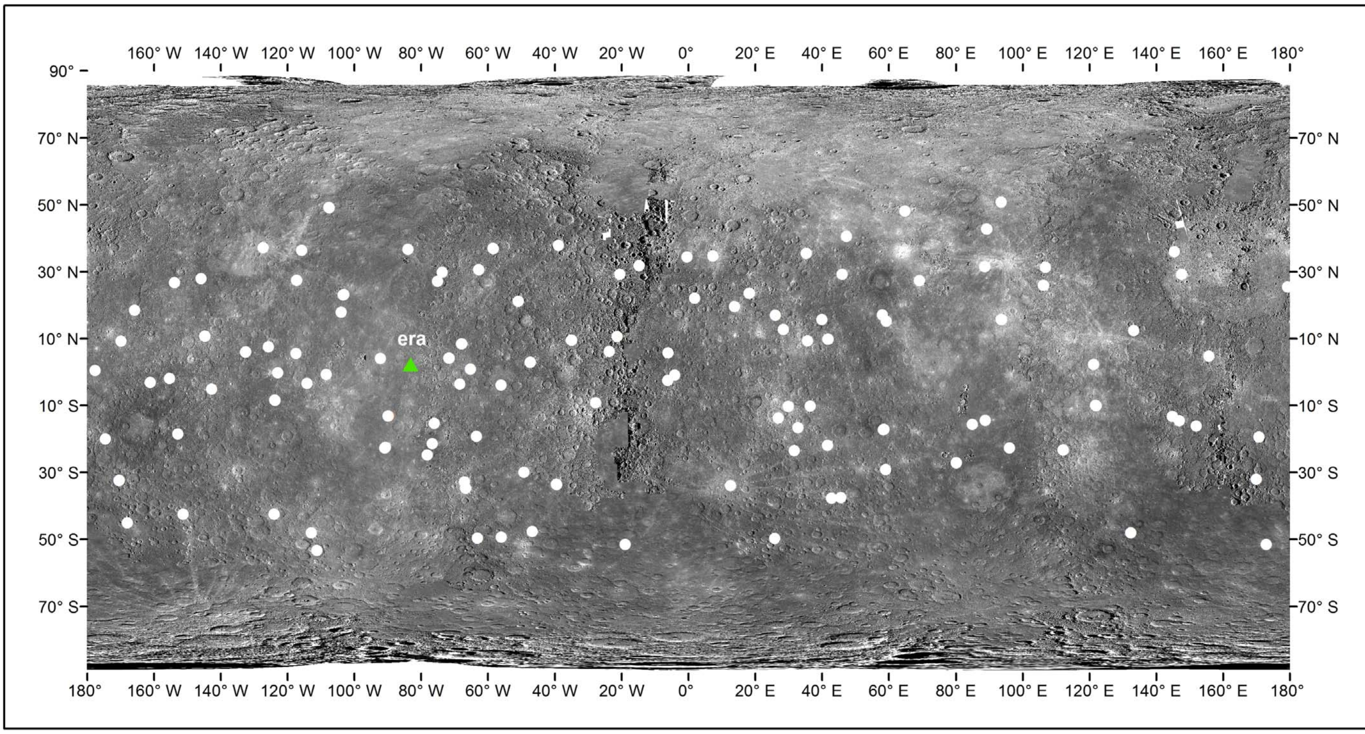

Fig. 1. The 121 selected impact craters (white circles) and the external reference area (*era*) unit (green triangle) defined by D'Incecco et al. (2015) are plotted on the MDIS monochrome global mosaic at 250 m/pixel resolution. The selection considered only complex and morphologically fresh impact craters between 60°N and 60°S. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2013, 2015), with some adaptations due to special needs for the global scale approach. After the results from the local scale analysis by D'Incecco et al. (2015), this study highlights again the potential of using DFTs as a tool for both local and global scale studies in many different contexts.

2. Background studies

2.1. Geology of Mercury after the Mariner 10 mission

In the mid-1970s, the Mariner 10 science team divided Mercury's surface into three morphologic units: intercrater plains, heavily cratered terrain and smooth plains (e.g., Trask and Guest, 1975; Gault et al. 1975; Trask and Strom, 1976; Strom, 1977; Kiefer and Murray, 1987; Spudis and Guest, 1988). Intercrater plains and heavily cratered terrain represent the oldest units of Mercury (e.g., Strom, 1977; Trask and Guest, 1975; Trask and Strom, 1976), and their origins and chronostratigraphic relations have been debated by various authors.

Compared to heavily cratered terrain and intercrater plains, the smooth plains are characterized by lower density of impact craters and smoother surface morphology. Hence, smooth plains were interpreted to be stratigraphically younger than intercrater plains (i.e., Schaber and McCauley, 1980; De Hon et al., 1981; Guest and Greeley, 1983; Grolier and Boyce, 1984; King and Scott, 1990).

Since no relevant geologic activity has been recorded on the surface of Mercury during the last 3 Ga, intercrater plains, heavily cratered terrains and smooth plains were all plausibly emplaced during a very early phase of Mercury's geologic history.

2.2. MESSENGER's studies

Using MDIS images with enhanced colors, Denevi et al. (2009) subdivided the former Mariner 10 units into the following units: the smooth plains, the intermediate terrain (IT) and the low-reflectance material (LRM). These authors also divided the smooth plains into three color subunits: the high-reflectance red plains (HRP), the intermediate plains (IP) and the low-reflectance blue plains (LBP). More recently, Whitten et al. (2014) suggested that intermediate plains by Denevi et al. (2009) can be completely remapped either as intercrater plains or as smooth plains units.

Izenberg et al. (2014) used MASCS VIRS data for analyzing the spectral variations on the surface of Mercury. They selected three spectral parameters: (a) The reflectance at 575 nm wavelength (R575, red), (b) the spectral slope at visible and infrared wavelengths, represented by the ratio of reflectance at 415 nm to that at 750 nm (VISr, green), (c) the spectral slope at ultraviolet (UV) and visible wavelengths, represented by the ratio of reflectance at 310 nm to that at 390 nm (UVr, blue). On the basis of these three spectral parameters, Izenberg et al. (2014) divided Mercury's surface into four VIRS spectral units: average, dark blue, red and bright. The average unit includes the plains as defined by MDIS color units (e.g., Robinson et al. 2008; Denevi et al. 2009, 2013). The dark blue spectral unit is characterized by spectra both darker than the planetary mean spectrum and less sloped or bluer (Izenberg et al., 2014). All areas identified as LRM and some areas defined as LBP from the MDIS dataset (i.e., Robinson et al., 2008; Denevi et al., 2009; Denevi et al. 2013) fall within this unit. The Red VIRS spectral unit is characterized by higher in reflectances and redder spectra than the planetary average (Izenberg et al., 2014). This unit includes pyroclastic deposits formed through explosive volcanism (i.e., Head et al., 2008; Kerber et al., 2011; Goudge et al., 2014). The bright spectral unit is characterized by higher VISr value and reflectances compared to the average unit (Izenberg et al., 2014). This unit includes hollows (Blewett et al., 2011, 2013; Helbert et al., 2013).

Using the same normalization approach we describe in this manuscript (Section 3.3), Helbert et al. (2013) performed a global scale unsupervised classification on MASCS VIRS spectra. They divided the surface of Mercury into two mega-regions: an

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