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Unsupervised clustering analysis of normalized spectral reflectance data for the Rudaki/Kuiper area on Mercury

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Abstract

We present a study of spectral reflectance data from Mercury focused on an area that encompasses the craters Kuiper-Murasaki, Rudaki, and Waters. The goal is to identify different spectral units and analyze potential relations among them.

The study region is geologically and spectrally classified as heavily cratered intermediate terrain (IT) with mixed patches of high-reflectance red plains (HRP) and intermediate plains (IP), on the basis of multispectral images taken by the Mercury Dual Imaging System (MDIS) [1].

Recent analysis of observations by the Mercury Atmospheric and Surface Composition Spectrometer (MASCS) instrument on the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft with an unsupervised hierarchical clustering method shows a comparable number of units at global scales [2,3]. Analyses on the local scale reveal a larger number of spectral units with a substantially more complex relationship among units.

1. Introduction

The MESSENGER spacecraft has provided the most complete spectral dataset from Mercury available to date. To handle and extract information from this extensive dataset we developed new approaches based on a relational database.

We start from the hypothesis that surface compositional information can be efficiently separated from other contributions by the use of statistical techniques. We apply an unsupervised hierarchical clustering technique on MASCS data for a given study region. A similar approach applied to the global MASCS dataset has proven to be effective even in the absence of a final photometric correction [2].

2. The MASCS instrument

The MASCS instrument [4] consists of a small Cassegrain telescope with an aperture that simultaneously feeds an Ultraviolet and Visible Spectrometer (UVVS) and a Visible and Infrared Spectrograph (VIRS).

VIRS is a fixed concave-grating spectrograph with a beam splitter that disperses the spectrum onto a 512-element silicon visible photodiode array and a 256-element indium-gallium-arsenide infrared photodiode array with spectral resolution of 5 nm.

VIRS has a circular field of view with a circular diameter of 0.023°. The visible (VIS) detector of VIRS covers the wavelength range from 300 to 1050 nm, and the near-infrared (NIR) detector covers the range 850–1450 nm. The study of Mercury's surface presented here made use only of the VIRS channel of MASCS.

3. Data Analysis

MDIS observations characterize [1] the study area essentially as a background of heavily cratered IT admixed with patches of likely younger HRP and IP.

From the results of global-scale unsupervised hierarchical clustering [2], the area is primarily classified as a homogeneous expanse of the equatorial region (ER) global spectral unit. Finer partitioning shows that the study area belongs to the core ER, with some smaller patches of a sub-unit that is transitional between the ER global unit and the polar region (PR) global spectral unit. To investigate this result further in a regional context we focus on MASCS data for the study area extracted from the Berlin MASCS database [3].

We apply the approach described earlier [2] to a region between 250° and 340°E and between 0° and 20°S. The reflectance data are normalized at 700 nm wavelength as a first-order photometric correction and then averaged on a grid with a resolution of 1 pixel/degree.

The results show that the area exhibits two main cluster units: a unit of low normalized reflectance (concentrated on the western side) interleaved with a unit exhibiting intermediate to high normalized reflectance (Fig. 1). The latter unit is concentrated on the eastern side but includes Waters ejecta and Snorri crater surroundings, which are clearly distinct from background material in MDIS images as well. The western unit shows a slightly lower spectral slope then the eastern unit and a higher absolute reflectance at 700 nm. The ring around Waters is a separate unit, but two longitudinal sides of the ring are associated with some small areas on the eastern side of the study area. This behavior could imply that the eastern unit is superimposed on the western unit. The idea of adopting exposure of spectrally distinct material by impact crater excavation on Mercury as a proxy for vertical stratigraphy has been successfully applied to MDIS camera data [5].

Strict filtering of the data allows us to add the absolute reflectance at 700 nm to the analyzed data, without introducing strong geometrical effects. We limited the data to spectra acquired at an emission angle less than 40˚ and a detector temperature lower than 30˚ C. The absolute reflectance data exhibit a separate high-reflectance region, mainly concentrated on Waters and Kuiper-Murasaki and on some other high-reflectance features. It is interesting to note that the Kuiper-Murasaki spectra show a lower normalized reflectance than Waters spectra, possibly resulting from different exposure to the Mercury environment. In fact, laboratory studies confirmed how exposure to high temperature could increase spectral slope and decrease spectral contrast [6].

Clustering results obtained with the inclusion of absolute reflectance at 700 nm show essentially the same surface units as those obtained from normalized reflectance, but distributions differ in detail.

4. Conclusion

This example analysis of a portion of the MASCS data shows that the spectral characteristics of local areas can be studied in considerable detail with this dataset. The study area provides an interesting test case for exploring our approach on a regional scale. The area has been geologically classified from MDIS color data as intermediate plains but has patches of smooth high-reflectance and intermediate plains. The spectral characteristics of the area derived from MASCS data with this approach indicate a more complex inter-relation among the different units. These interconnections can be used to understand better the complex vertical and lateral heterogeneity of near-surface crustal composition. Combining the geological interpretation derived from MDIS with the spectral information from MASCS and geochemical information from the Gamma-Ray Spectrometer and X-Ray Spectrometer can provide deeper insights into the structure and compositional heterogeneity of Mercury's crust.

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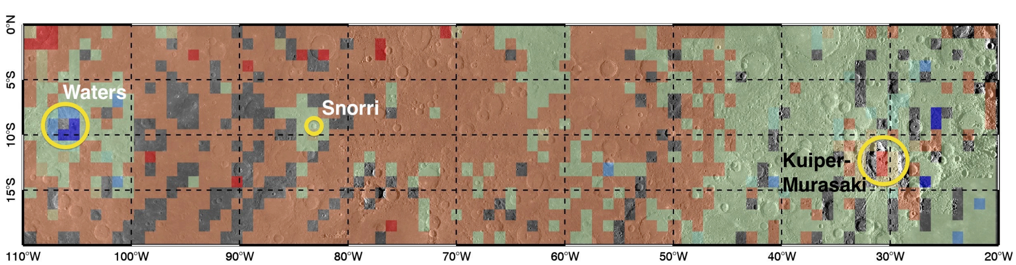

Fig. 1. Distribution of spectral clusters in the study area. The western unit (see text) is shown in green, and the eastern unit in orange.