MAPPING DATA FUSION: A GEOSTRATIGRAPHIC MAP FOR THE LUNAR TSIOLKOVSKIY CRATER.

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Introduction: Despite being the most studied and explored body in the Solar System (after the Earth), geologic maps of the Moon do not consistently integrate multispectral and hyperspectral data reflecting the surface composition.

Following a contextual mapping approach [1], [2] produced two distinct mapping products, namely a morpho-stratigraphic and a Clementine color-based map, for the lunar Tsiolkovskiy crater (20.4°S, 129.1°E). The study allowed a first correlation between geology and compositional differences as derived from the multispectral Clementine UVVIS Color Ratio mosaic [3]. The floor of Tsiolkovskiy is characterized by the presence of a large smooth mare infilling, formed by at least three different effusive events taking place between 3.6 and 2.9 Ga, surrounded by norites and anorthosites spread out over the mature lunar highland soil and correlated with the hummocky floor and slope materials.

In order to further investigate the compositional properties of the area, we used hyperspectral data acquired by the Moon Mineralogy Mapper (M^3) onboard the Chandrayaan-1 mission [4] to derive a spectral units map returning the information encased by a set of spectral parameters using the method applied by [5] on the H5-Hokusai quandrangle on Mercury. We then integrated and updated the previously published morpho-stratigraphic map by digitalizing new contacts indicating spectral variations within a pre-defined geologic unit. As a result, we obtained a geostratigraphic map, namely an in-series mapping product [1] derived by integrating spectral information to enhance a morpho-stratigraphic map.

Data and methods: To obtain a map of spectral units, we used hyperspectral M^3 data acquired in global mode and considered the following spectral parameters: a) the reflectance at 540 nm, b) the band depth at 1000 and 2000 nm, and c) the spectral slope between 540 nm and the maximum of the first and second shoulder of the band depth at 1000 nm.

The method of extrapolation and extraction of the spectral units follows the work by [5]. In the end, we obtained a 10-units spectral units map.

To produce a geostratigraphic map, we then used the contacts digitalized for the morpho-stratigraphic and Clementine color-based maps [2], which are publicly available as GIS shapefile data, to integrate geology with the spectroscopic information summarized in the spectral units map.

As a final step, we investigated the compositional properties of Tsiolkovskiy crater. We thus retrieved the reflectance spectra of each spectral unit and compared them with laboratory spectra of synthetic pyroxenes [6,7], which are among the most common minerals on the Moon [e.g. 8]. To estimate the relative abundance of olivine and pyroxene, finally, we calculated the Band Area Ratio between the 2000 and 1000 nm absorption bands and conveniently compared our results to the olivine-pyroxene mixtures trend by [9].

Results: The final mapping product is a 34-units geostratigraphic map coupling morpho-stratigraphic and compositional information (**Fig. 1**).

Below, we summarize for each geologic unit its most relevant compositional observations.

Crater floor, smooth material. Similarly to the Clementine color-based map [2], on the smooth infilling of Tsiolkovskiy we can discriminate three distinct units, which seem pretty well correlated with a respective Clementine color unit. This unit is characterized by a pigeonitic composition shifting to a more Ca-rich composition during the intermediate effusive event, also associated with a relative enrichment in titanium content, indicating a change in the magmatic source then gradually returned to the initial conditions during the last volcanic infilling.

Crater floor, hummocky material. This unit shows a strong contribution of glasses and Fe-bearing minerals which well correlate with the impact melt material representing this geologic unit.

Crater floor, central peak. The well-preserved central peak of Tsiolkovskiy is characterized by a plagioclase-dominated composition, although partly masked by opaque mineralogical phases and glasses. This unit, moreover, reflects the presence of small amounts of olivine that, together with plagioclase, supports a troctolitic composition.

Crater wall, smooth ponds. This unit reflects the presence of mature highland soil characterized by a strong contribution of glasses due to the prolonged exposure to space weathering.

Crater wall, steep scarps. Similarly to the central peak unit, the crater scarps reflect a significant contribution of plagioclase indicating the exposure of anorthositic bedrock. Also for this unit, the

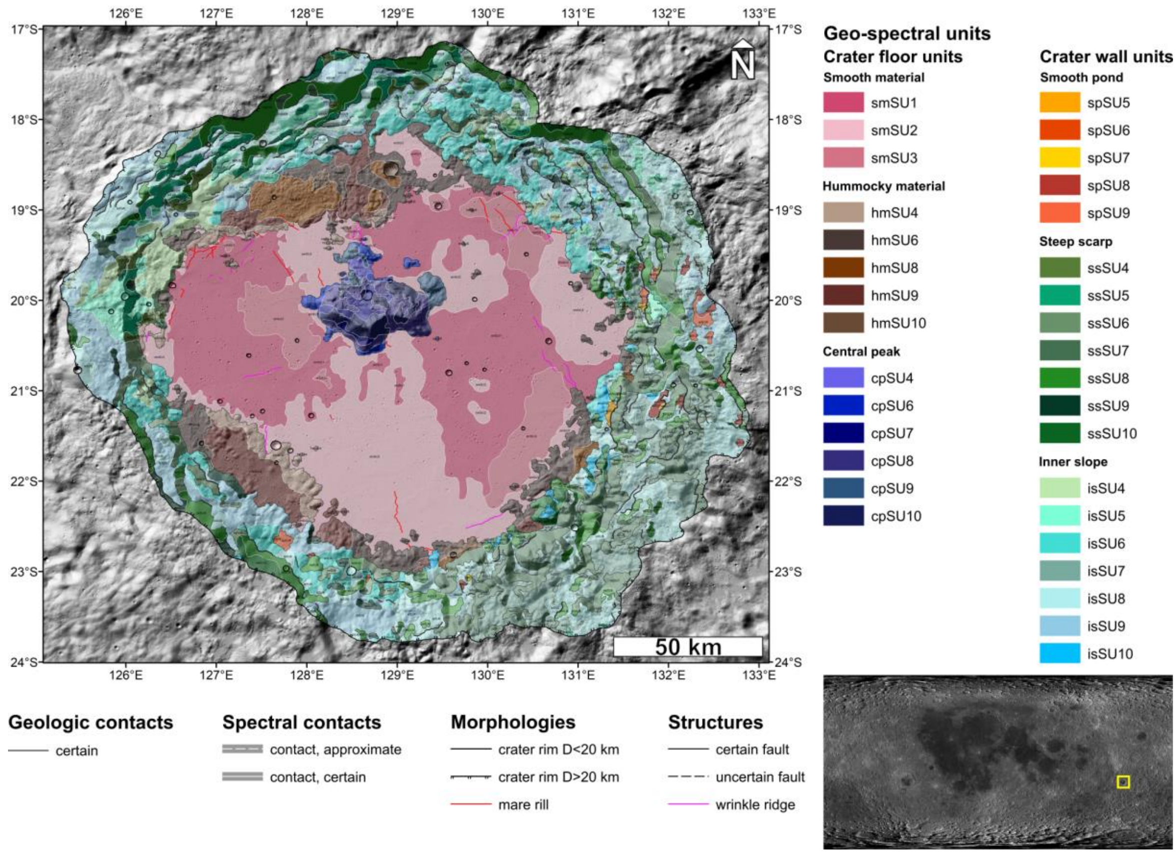

Figure 1. Geostratigraphic map of Tsiolkovskiy crater visualized on top of a DEM-derived hillshade with 50% of transparency.

strong presence of glasses and opaque mineral phases might reflect the contamination of more mature material due to secondary events.

Crater wall, inner slope. As for the hummocky floor and smooth ponds units, the inner slope of the crater is characterized by the presence of abundant opaque mineral phases and glasses reflecting the presence of melted and shocked materials exposed for a long time to space weathering.

Conclusions: By integrating the previously published morpho-stratigraphic map of Tsiolkovskiy crater with the multispectral information derived through RGB basemaps (i.e. Clementine UVVIS Color Ratio mosaic and spectral units map) and the comparison with laboratory data, we obtained a new mapping product comprehensive of both morphologic, stratigraphic and compositional information. A similar product takes one step further towards the level of information provided by Earth's geologic maps and helps in better understanding the evolution of a planetary surface, in this case the Moon, and focusing the strategy of exploration.

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