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COMMENTARY
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Key Points:

- The geologically supervised spectral investigation has been used to analyze three volcanic structures of Venus
- The authors conclude that some lava flows at Maat Mons may be as recent as ∼25 Ma
- In future missions, these techniques can be used to provide new elements in the debate on the style of resurfacing on Venus

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The Geologically Supervised Spectral Investigation as a Key Methodology for Identifying Volcanically Active Areas on Venus

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Abstract Combining geologic mapping and stratigraphic reconstruction of lava flows at Sapas, Maat and Ozza Montes, three potentially young volcanic structures of Atla Regio on Venus, with analysis of the spectral signature (radar emissivity anomalies) characterizing each mapped flow, Brossier et al. (2021, https://doi.org/10.1029/2020je006722), conclude that some of the lava flows at Maat Mons may be geologically recent (∼25 Ma) (Smrekar et al., 2010, https://doi.org/10.1126/science.1186785; D'Incecco et al., 2017, https://doi.org/10.1016/j.pss.2016.12.002; Zolotov, 2018, https://doi.org/10.1515/rmg.2018.84.10; Brossier et al., 2020, https://doi.org/10.1016/j.icarus.2020.113693, 2021, https://doi.org/10.1029/2020je006722). The lava flows of Sapas and Ozza Montes are consistent with weathered lava flows forming chlorapatite and some perovskite oxides. We discuss the reasons why, besides the importance of the results they obtained, the methodology they used can be very valuable for future investigations with higher resolution datasets.

Plain Language Summary Combining geologic mapping and stratigraphic reconstruction of lava flows at Sapas, Maat and Ozza Montes, three potentially young volcanic structures of Atla Regio on Venus, with analysis of the spectral signature (radar emissivity anomalies) characterizing each mapped flow, Brossier et al. (2021), https://doi.org/10.1029/2020je006722 conclude that some of the lava flows at Maat Mons may be geologically recent (∼25 Ma). The lava flows of Sapas and Ozza Montes are more consistent with weathered lava flows forming chlorapatite and some perovskite oxides. We discuss the reasons why, besides the importance of the results they obtained, the methodology they used can be very valuable for future investigations with higher resolution datasets.

1. The Importance of Combining Geologic Interpretation With Spectral Analysis in the Reconstruction of the Volcanic History of Venus

Considering its size, gravity and the presence of an atmosphere, Venus is typically considered as the twin sister of the Earth, but despite the apparent similarities with our planet, Venus is notably different because it is characterized by its extreme surface environment. With 90 bars and 475°C, its surface is a very inhospitable place for life as we know it. Venus does not show evidence for a present plate tectonics-like activity, as the major part of its surface consists of volcanic deposits younger than 300 Ma (McKinnon et al., 1997). In fact, it has been hypothesized that Venus underwent a catastrophic event of global resurfacing about 300 Ma ago, which may have almost entirely rejuvenated its surface (Nimmo & McKenzie, 1998; Romeo & Turcotte, 2010; Schaber et al., 1992; Strom et al., 1994; Turcotte et al., 1999). Some other studies instead favor a more equilibrium resurfacing model of the surface (Bjonnes et al., 2012; O'Rourke & Korenaga, 2015; Phillips & Hansen, 1994; Phillips et al., 1992). It is also possible that the past volcanic history of Venus somehow reflected an intermediate situation between these two end-member scenarios. Related to this topic, it has been debated whether or not the volcanism on Venus is currently evolving toward an equilibrium stage, with occurrences of smaller and more frequent localized eruptions. In this regard, it is vital to identify areas with current or recent volcanism, to measure the actual rate and volume of the most recent volcanic eruptions. The geologic interpretation and analysis of spectral signatures (both in radar

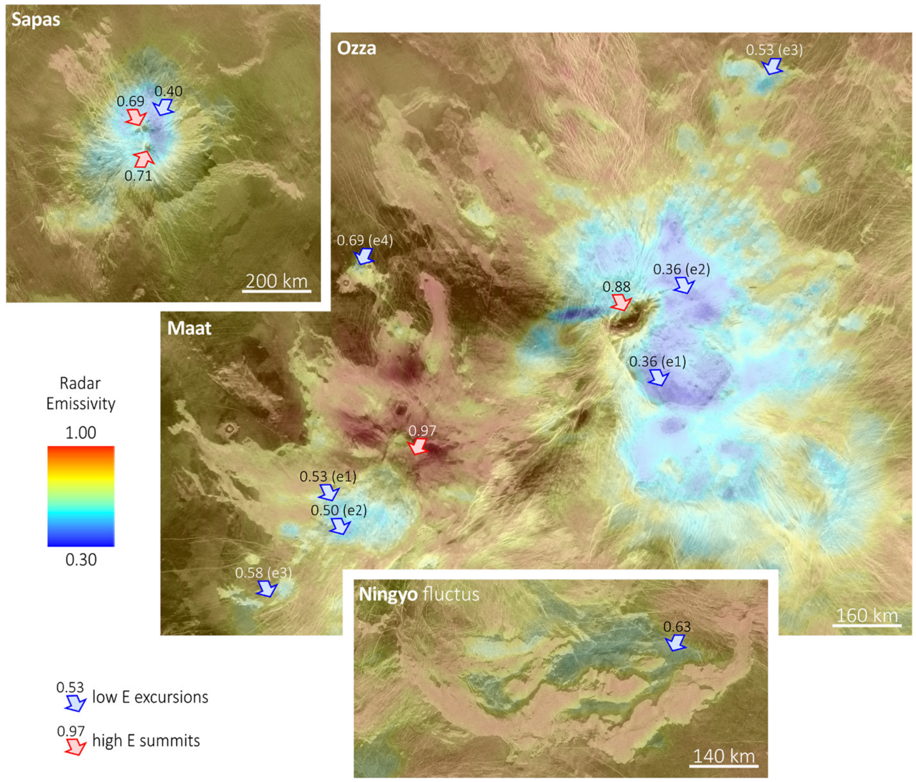

Figure 1. Magellan SAR images overlapped by emissivity maps of Atla Regio: Sapas (188°E, 8°N), Maat and Ozza (198°E, 4°N) and Ningyo Fluctus (206°E, 5°S), a flow field located near Atla Regio and Parga Chasma. From Brossier et al. (2021).

and infrared wavelengths) can help us constraining the age of surface volcanic deposits on Venus (Shalygin et al, 2012, 2015; Smrekar et al., 2010).

In geology, the so called "cross-cutting interrelationships" can constrain the relative age of two lava flows as it has been applied to young, possibly very recent lava flows and tectonic features on Venus (i.e., Figure 6 in D'Incecco et al., 2020). Spectral analysis can provide some additional constraints on the ages of surface volcanic materials. We know that on Venus recently erupted lava flows become rapidly altered when they come in contact with the thick and chemically active atmosphere (Brossier et al., 2020, 2021; Cutler et al., 2020; Filiberto et al., 2020; Smrekar et al., 2010). This process is called chemical weathering. In general, unweathered materials are characterized by high 1 μm emissivity anomalies in the infrared band (Cutler et al., 2020; Filiberto et al., 2020; Smrekar et al., 2010) and high emissivity anomalies in the radar S-band (12 cm) at certain altitudes (Brossier et al., 2020, 2021) and such materials can be considered as geologically recent. Recent laboratory analyses on the oxidation rate of igneous minerals showed that such chemical weathering on Venus may act on the order of weeks or months (Cutler et al., 2020; Berger et al., 2019; Fegley et al., 1995; Filiberto et al., 2020; Treiman et al., 2021). This implies that areas on Venus with high infrared emissivity anomalies (and high radar emissivity) may be volcanically active at the present day.

The present manuscript presented by Brossier et al. (2021) combines geologic interpretation and consequent stratigraphic reconstruction with spectral analysis of radar emissivity anomalies observed at a number of lava flows, using a peculiar technique which may be defined as a geologically supervised spectral investigation. The authors find spatial correlations between many lava flow units and radar emissivity excursions at different altitudes, over three volcanic structures of Atla Regio; Sapas, Maat and Ozza Montes (Figure 1). At the three volcanic structures, for a given altitude and temperature, low emissivity excursions do not occur uniformly over all the mapped units and surface materials. This implies that the observed low emissivity excursions are strongly controlled by the presence of distinct ferroelectric minerals with high dielectric constant.

The authors assume that a group of ferroelectric minerals can explain the observed low emissivity excursions. In particular, chlorapatite and four perovskites can account for any of the emissivity excursions observed at the three volcanoes. They indicate that ferroelectric (high dielectric) minerals can be intrinsic of a lava flow in the form of direct crystallization or, alternatively, can be produced by the surface-atmosphere chemical interactions over the time. Furthermore, the authors assume that—for a given composition and atmospheric condition—the low radar emissivity excursions can be then used as a chronometer for estimating the relative ages of the lava flow units. Sharp low emissivity excursions (high dielectric constants) will indicate older (more weathered) surface materials. Building on the degradation model of dark haloes surrounding some impact craters on Venus (Izenberg et al., 1994), the authors also provide further constraints in terms of absolute ages of the volcano-tectonic activity in the study area.

The investigation conducted with this work, which correlates morphologic mapping with radar properties of surface materials on Venus is elegant and innovative. The methodology used could provide a significant contribution to the key debate regarding the style of resurfacing on Venus. Their results demonstrate what can be still achieved using the (relatively low resolution) Magellan radar data set but it also shows what could be potentially obtained by higher resolution radar data which are going to be provided from future missions to Venus, such as the European Space Agency's EnVision mission (Ghail et al., 2012, 2020) or the NASA's Venus Emissivity, Radio Science, InSAR, Topography & Spectroscopy mission (i.e., Smrekar et al., 2020). The Deep Atmosphere of Venus Investigation of Noble gases, Chemistry and Imaging, Plus (DAVINCI+) (Garvin et al., 2020; Glaze et al., 2017, 2018) and Venera-D (Senske et al., 2017; Zasova et al., 2019) missions will instead provide more detailed data on the structure and thermal profiles of the Venusian atmosphere. DAVINCI+ will also image the surface below the cloud deck, while Venera-D will obtain and analyze a sample of the surface material at the landing site. In this regard, new experimental data obtained in the laboratory will help interpret the data observed through remote sensing. In addition to those mentioned above, a Venus Flagship mission concept is currently being developed, with the main goal of unveiling new clues about the geologic history of Venus (Bullock et al., 2009; Gilmore et al., 2019).

Data Availability Statement

For this commentary article, no new data were used. The data we commented in this article come from the previously published research by Brossier et al. (2021), on this journal.

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